rosetta

→ LIVING WITH A COMET

European Space Agency

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Using powerful mirrors to help solve mysteries of the violent X-ray Universe, from enigmatic black holes to the formation of galaxies.

An ESA Communications Production
BR-321 July 2015

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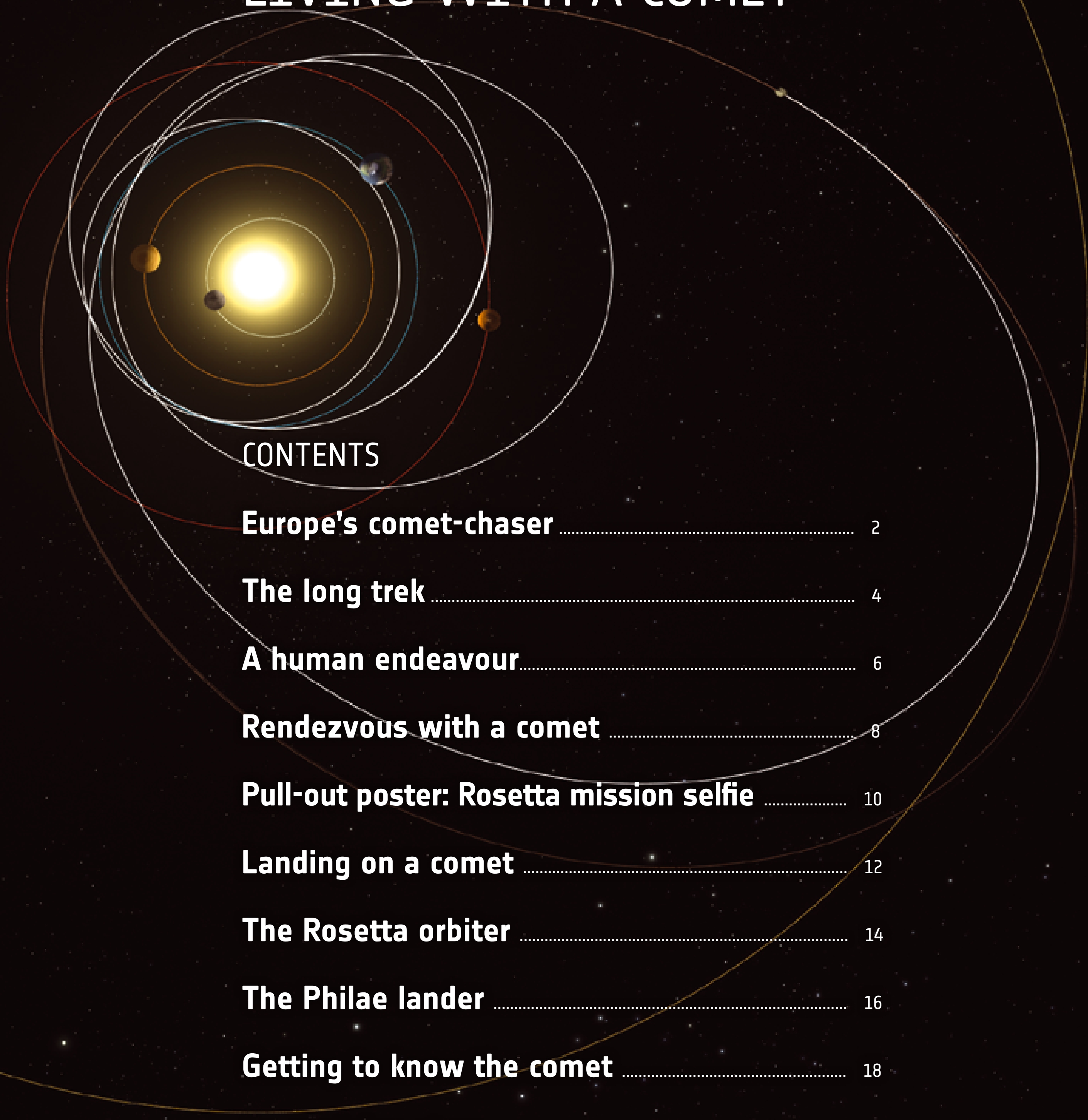
Production Editor	K. Fletcher
Designer	E. Damato
ISBN	978-92-9221-084-7
ISSN	0250-1589

ROSETTA

LIVING WITH A COMET



CONTENTS

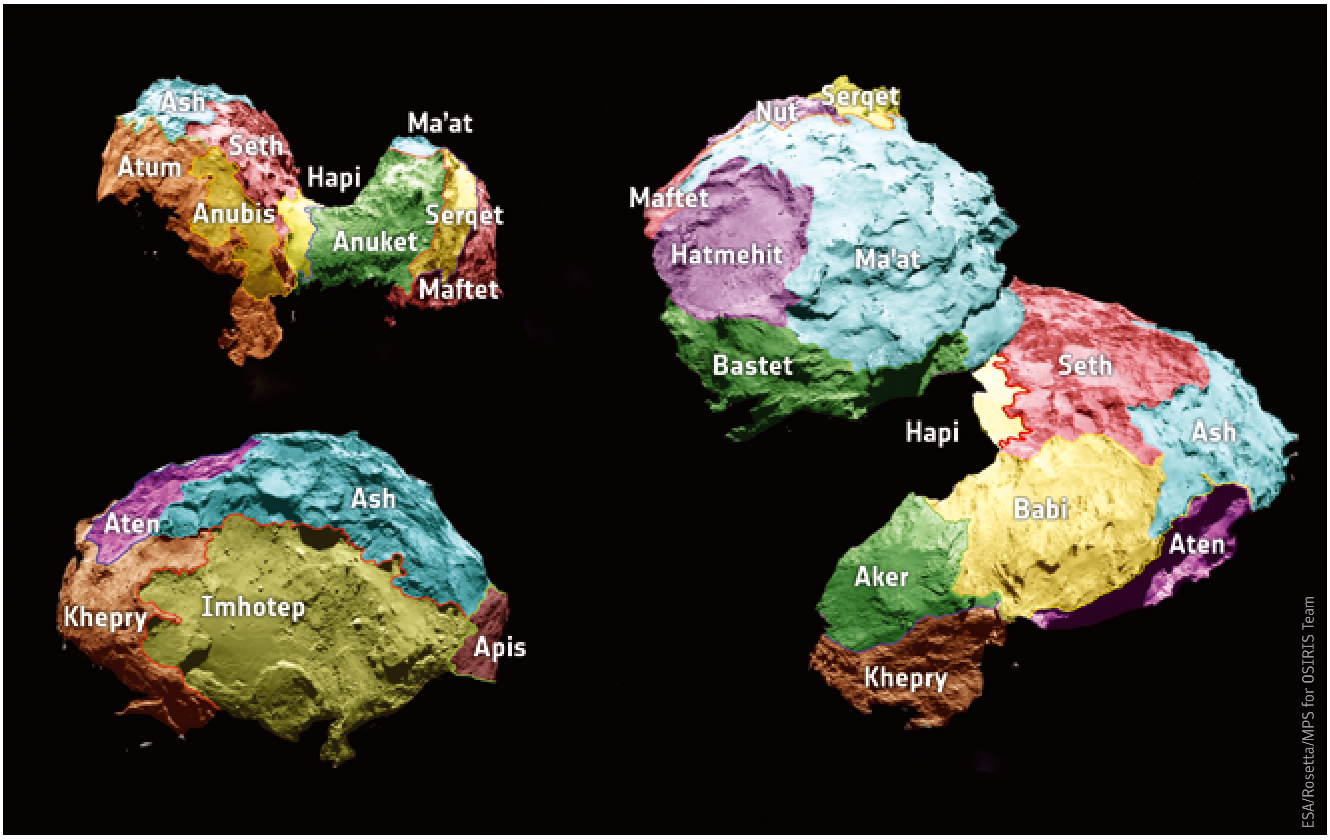
→ EUROPE'S COMET-CHASER

Rosetta is ESA's comet-chasing mission to 67P/Churyumov–Gerasimenko. Launched on 2 March 2004, the spacecraft travelled for 10 years and required three gravity-assist flybys at Earth and one at Mars before homing in on its target.

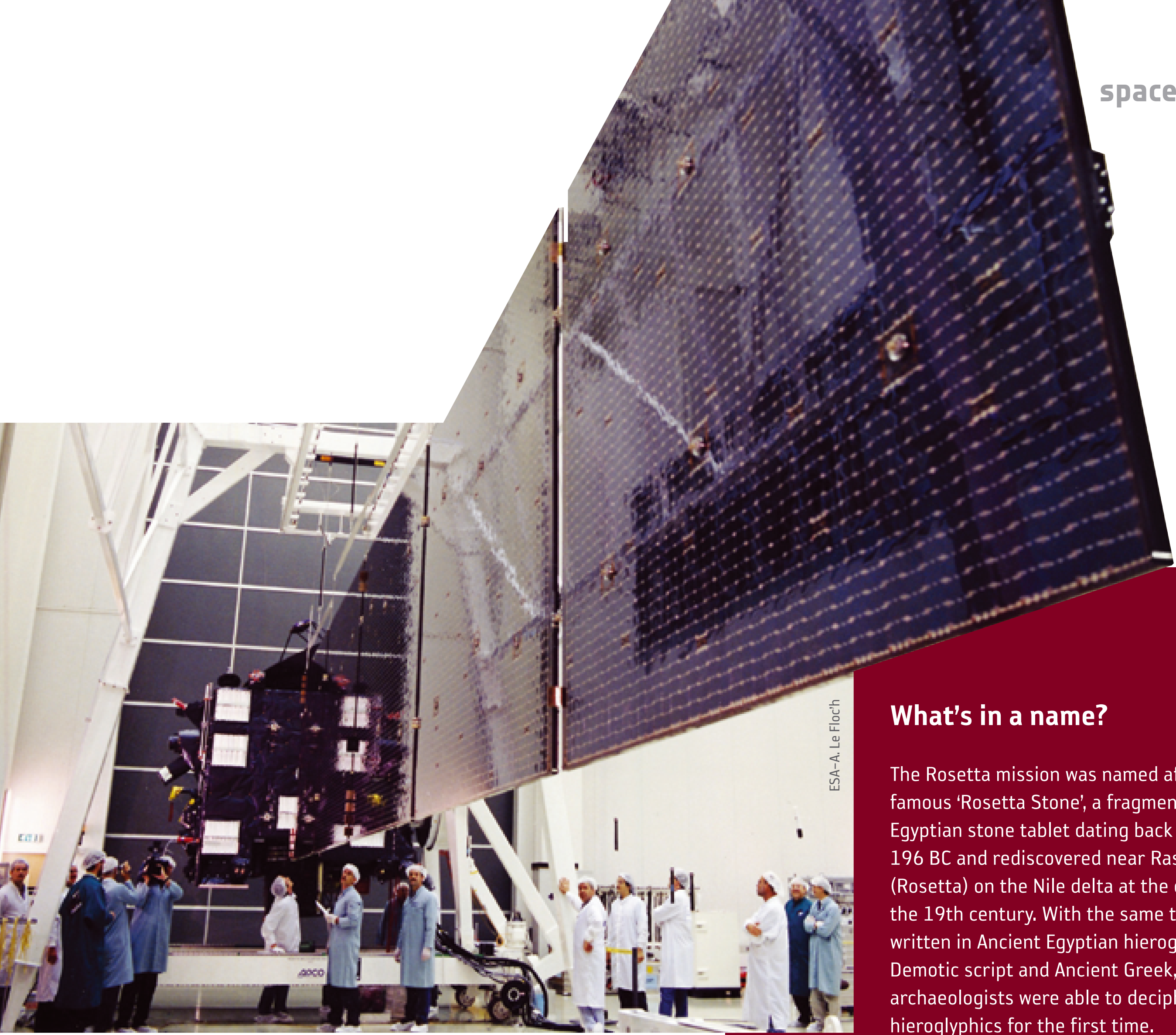
Comets are time capsules containing primitive material left over from the epoch when the Sun and its planets formed. By studying the gas, dust and structure of the nucleus and organic materials associated with the comet, via both remote and *in situ* observations, the Rosetta mission could be the key to unlocking the history and evolution of our Solar System.

Spacecraft vital statistics

Rosetta orbiter size: 2.8 x 2.1 x 2.0 m with two 14 m-long solar wings
Orbiter solar array output: Up to 1500 W (650 W was measured at hibernation exit, 675 million km from the Sun)
Orbiter propulsion: 24 bipropellant 10 N thrusters
Philae lander size: 1 × 1 × 0.8 m (before deployment of its landing gear)
Launch mass: Rosetta: 2900 kg (including 1670 kg propellant and 165 kg science payload); Philae: 100 kg (including nearly 30 kg science payload)
Orbiter experiments: 11
Lander experiments: 10



The regions on the comet have been named for Egyptian deities.



ESA-A. Le Floc'h

Testing the opening of one of Rosetta's massive solar wings, May 2002.

A mission of firsts

Rosetta is a mission of many historic firsts. It is the first spacecraft to have journeyed beyond the asteroid belt relying only on solar cells for power. Special cells developed for the orbiter's two 14 m-long solar wings allow them to generate power efficiently more than 800 million kilometres from the Sun, where sunlight levels are only 4% of those at Earth and operating temperatures are about –150°C.

In August 2014, Rosetta became the first mission ever to rendezvous with and subsequently orbit a comet, and in November 2014, with the world watching breathlessly, it became the first to soft-land a probe – Philae – on a comet nucleus.

Rosetta followed in the footsteps of ESA's first deep-space mission, Giotto, which sent back the first close images of a comet nucleus as it flew past Comet Halley at a distance of about 600 km in 1986. While Giotto and other missions have spent only fleeting moments flying past their targets at high speed, Rosetta is the first to fly alongside a comet as it heads towards the inner Solar System and away again, allowing it to watch how the comet is transformed by the Sun's warmth.

What's in a name?

The Rosetta mission was named after the famous 'Rosetta Stone', a fragment of an Egyptian stone tablet dating back to 196 BC and rediscovered near Rashid (Rosetta) on the Nile delta at the end of the 19th century. With the same text written in Ancient Egyptian hieroglyphics, Demotic script and Ancient Greek, archaeologists were able to decipher hieroglyphics for the first time.

Rosetta's lander, Philae, is named for the island in the River Nile on which an obelisk was found that also had a Greek and hieroglyphic bilingual inscription that helped in deciphering the Rosetta Stone.

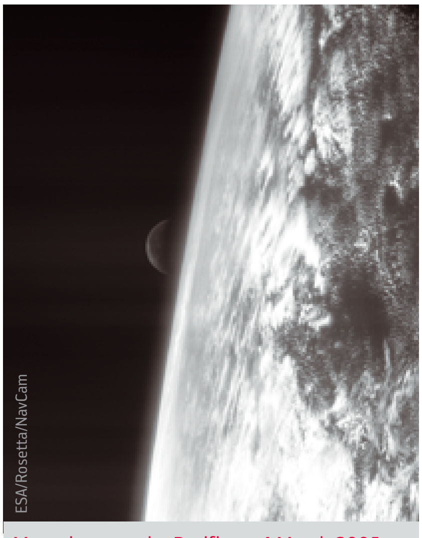
The Ancient Egyptian naming theme continued once the mission arrived at the comet: Philae's first touchdown site is named Agilkia, after another island on the River Nile, to where several famous temples were moved from Philae when the latter was flooded. The final touchdown site is named Abydos, after the sacred city that hosted many ancient temples. In addition, the comet's surface has been divided into regions according to terrain types, with each region given the name of an Egyptian deity.

Comet 67P/Churyumov–Gerasimenko is named after its discoverers. Klim Churyumov discovered it in 1969 in a photograph taken by Svetlana Gerasimenko. The 67P indicates that it was the 67th periodic (P) comet discovered.

→ THE LONG TREK

1


Rosetta lifted off from Europe's Spaceport at 07:17 GMT on 2 March 2004.

2


Moonrise over the Pacific on 4 March 2005.

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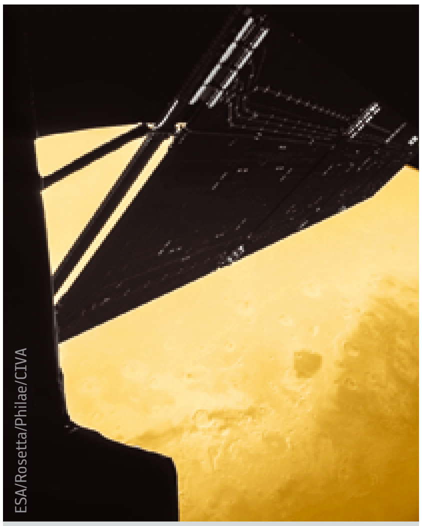


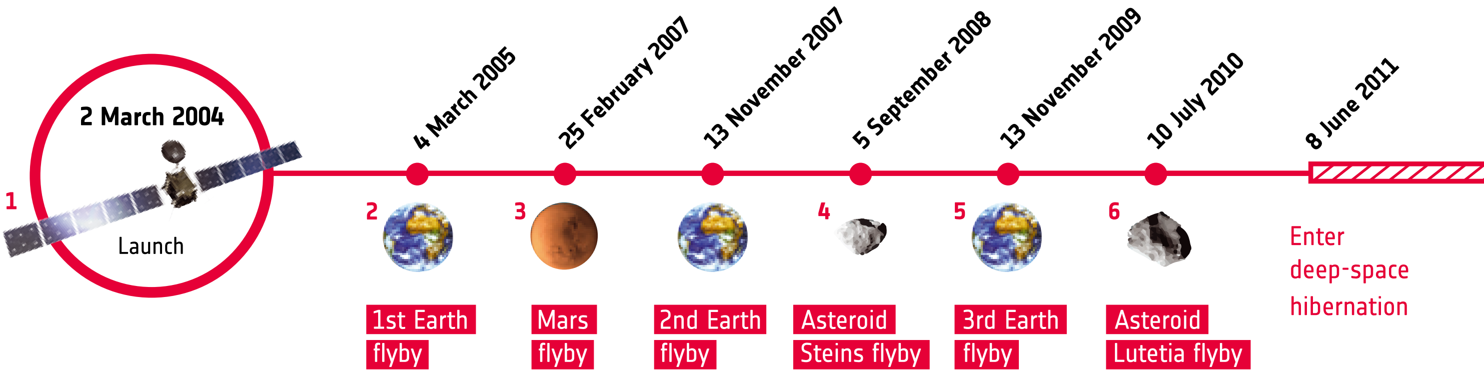
Self-portrait 1000 km above the surface of Mars.

A 14-month delay to Rosetta's departure following an unrelated launch failure in late 2002 meant that the original target, Comet 46P/Wirtanen, could no longer be reached. When Rosetta was finally launched on 2 March 2004 on an Ariane 5 from Europe's Spaceport in Kourou, French Guiana, it was towards Comet 67P/Churyumov–Gerasimenko. The comet has a 6.45-year elliptical orbit that takes it from between the orbits of Earth and Mars at its closest to the Sun, to out beyond Jupiter at its furthest. Rosetta had to play a game of cosmic pinball to match the comet's trajectory, picking up gravity boosts from Earth three times and Mars once to set it on course. Along the way, Rosetta twice passed through the Solar System's asteroid belt, taking the opportunity to return spectacular close-up images and perform scientific analysis of two previously uncharted asteroids: 2867 Steins on 5 September 2008 and 21 Lutetia on 10 July 2010.

Hibernation

Even though Rosetta was equipped with newly developed low-intensity, low-temperature solar cells to work efficiently in both the relatively warm conditions of the inner Solar System and the cold further out, the solar panels could not generate enough power to operate the spacecraft safely during the most distant part of its journey through the Solar System. Thus, on 8 June 2011, Rosetta was put into hibernation to save power.

Apart from the thermal control system and onboard computer, all systems were turned off, including Rosetta's attitude control system. Before hibernation, the spacecraft was oriented so that its solar wings were facing the Sun at the furthest point along its orbit, and placed in a slow spin, rotating once every 90 seconds, to maintain stability.



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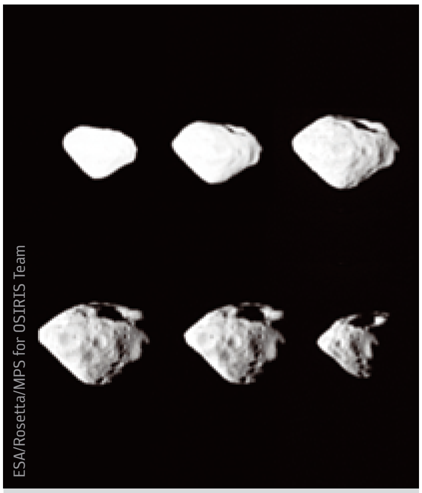
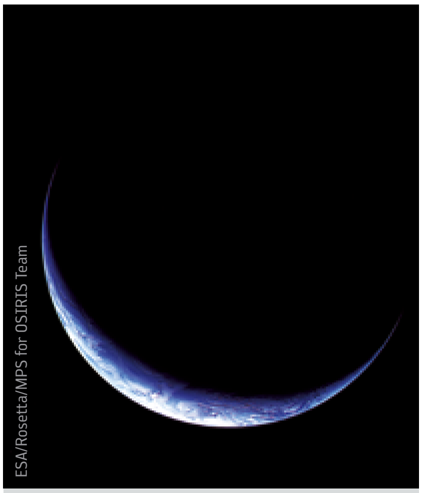


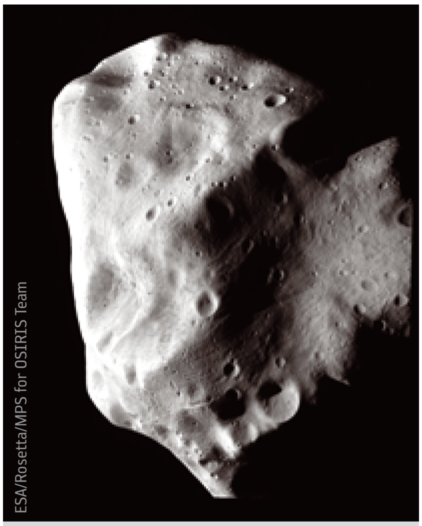
Asteroid Steins, a diamond-shaped world measuring 6.67 × 5.81 × 4.47 km.

5



Earth from a distance of 633 000 km on 12 November 2009.

6



100 km-wide asteroid Lutetia.

Critically, this meant that Rosetta's main antenna was no longer pointing towards Earth: the spacecraft was on its own.

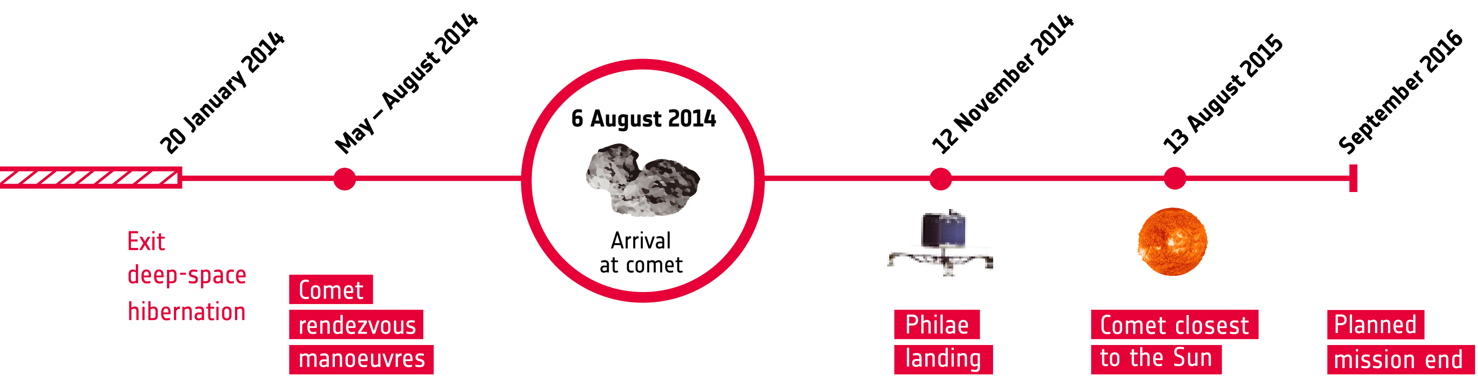
After 957 days, with Rosetta returning to the inner Solar System where more power is available, its computers autonomously woke the spacecraft from hibernation on 20 January 2014. This process included warming up the startrackers, despinning and then reorienting itself before transmitting its signal back to Earth.

Long-distance operations

ESA's European Space Operations Centre, ESOC, in Darmstadt, Germany is responsible for overall control of the spacecraft, while lander operations are coordinated through the DLR German Aerospace Center control centre in Cologne and the scientific control centre of CNES, the French space agency, in Toulouse.

Reliable radio communications with Earth are an essential part of Rosetta's long interplanetary expedition, both to control the spacecraft and to return the precious scientific data collected by the instruments for analysis.

Radio communications between Rosetta and Earth use the 35 m-diameter deep-space antennas of ESA's Estrack network in New Norcia in Western Australia, Cebreros in Spain, and Malargüe in Argentina. Travelling at the speed of light, the radio signals take a varying time to cover the distance between the spacecraft and Earth that depends on their ever-changing separation. This reached 52 minutes each way at their greatest separation.



→ A HUMAN ENDEAVOUR

The hard work pays off

Rosetta wakes up (ESA–J. Mai)

Comet-arrival operations team (ESA–J. Mai)

ESA–J. Mai

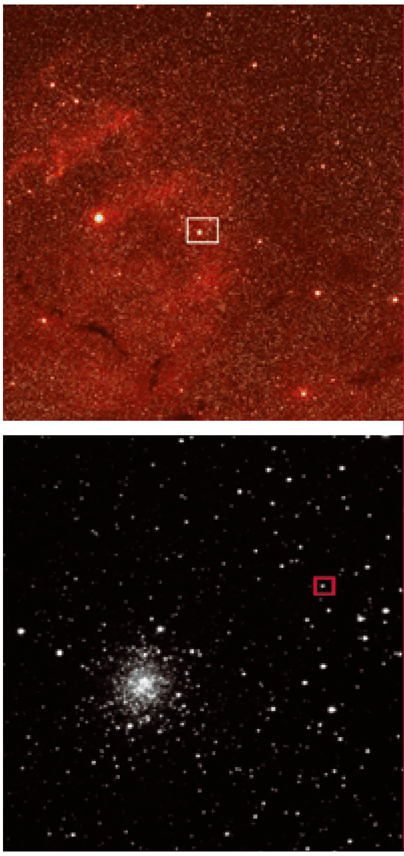
Years and years of planning and development, a decade of navigating the Solar System, hundreds and hundreds of people – and finally a series of euphoric moments in the control rooms.

Rosetta team members and friends at the European Space Operations Centre on 12 November 2014.

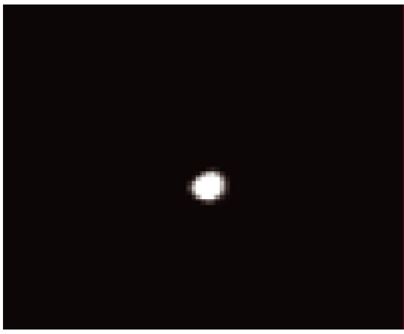

Separation of Philae (ESA–S. Bierwald)


Philae has landed… relief (ESA–J. Mai)

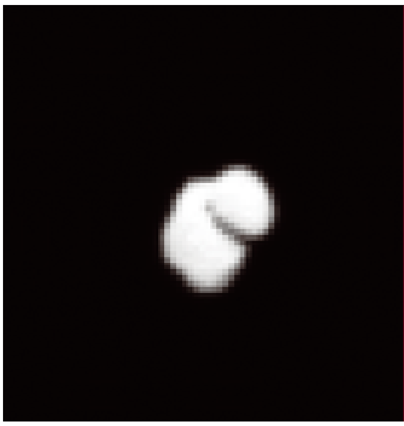
→ RENDEZVOUS WITH A COMET



Rosetta's first views of the comet after waking up from deep-space hibernation, taken on **20/21 March 2014** by the OSIRIS wide-angle camera (top) and narrow-angle camera (bottom, as outlined in the wide-angle view) from a distance of about 5 million km. The comet is indicated in the narrow-angle view; the globular star cluster M107 can also be seen.



28 June 2014:
86 000 km to go.



14 July 2014:
12 000 km to go.

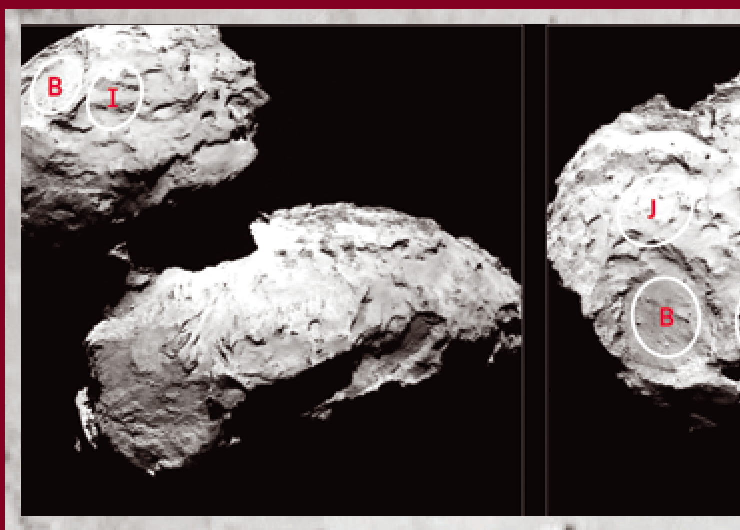
When Rosetta woke up from deep-space hibernation in early 2014, there was still a nine million kilometre gap to close before meeting its target. By early May, this had been reduced to two million kilometres. A series of critical 'braking' manoeuvres carried out by Rosetta's thrusters between May and August reduced the speed of the spacecraft relative to its target to walking pace, and images of the distant comet against the background of stars were taken by Rosetta to refine the approach trajectory.

Shortly before arriving, the comet's shape was resolved, revealing a curious dual-lobed comet that many likened to the shape of a rubber duck. Scientists had been expecting an irregular-shaped world – Hubble Space Telescope observations made in 2003 had provided an estimate of roughly 3 x 4 x 5 km – but no one was expecting the duck shape.

Choosing a landing site

Using information collected after rendezvous, five 1 km-diameter landing ellipses were identified as candidate sites for the Philae lander. In choosing the final site and a backup, important questions were considered:

Would the lander be able to maintain regular communications with Rosetta? How common were surface hazards such as large boulders, deep crevasses and steep slopes? Would there be sufficient illumination for scientific operations and enough sunlight to recharge the lander's batteries beyond its initial 64-hour lifetime, but not so much as to cause overheating?

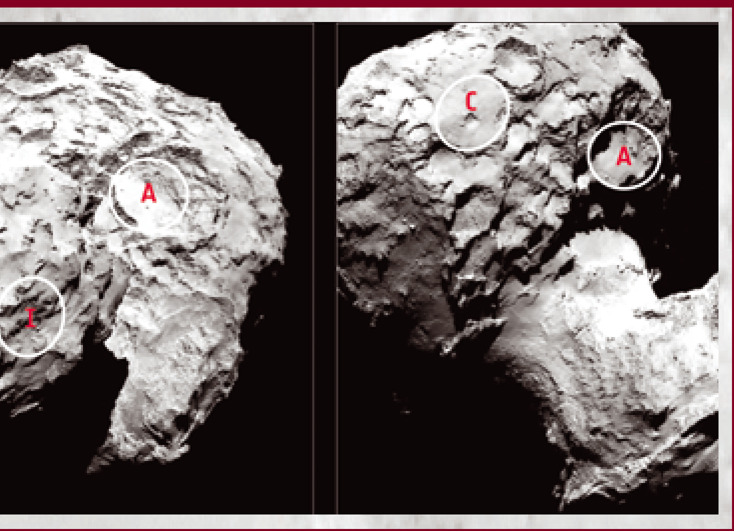


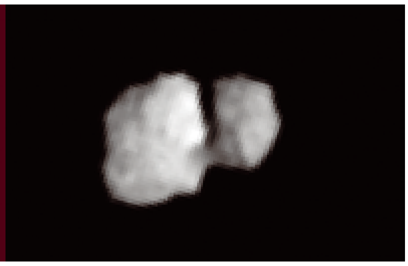
Pictures taken on arrival on 6 August, at a distance of just 100 km, showed the comet in spectacular close-up detail. Following rendezvous, the spacecraft was manoeuvred to follow a series of triangular paths in front of the comet, bringing it down from 100 km to 50 km altitude and then to an orbit just 30–10 km above the surface.

While Rosetta's extensive suite of multiwavelength cameras, spectrographs, mass spectrometers and other scientific instruments began collecting data on the characteristics of the comet, its composition and environment, the race was on to map the surface in high resolution to identify a landing site for Philae: the landing had to be in November, before activity on the comet reached levels that might jeopardise the safe and accurate deployment of Philae to the comet's surface, but the mapping could only be done after rendezvous.

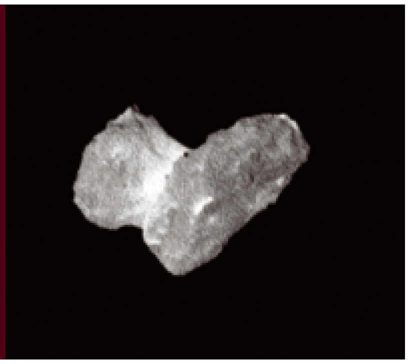
The final site had to balance the technical needs of the orbiter and lander during all phases (separation, descent and landing, and surface operations) with the scientific requirements of Philae's 10 instruments.

Over the following three weeks the spacecraft moved to within 30 km of the comet, affording more detailed scientific measurements of the candidate sites. In parallel, the operations and flight dynamics teams explored options for delivering the lander to the candidate landing sites. Finally, a decision was made: Philae would target Site J – which would later become known as Agilkia after a public naming competition – with Site C as backup.

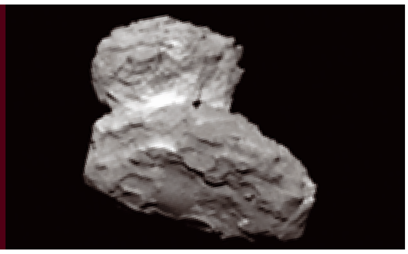




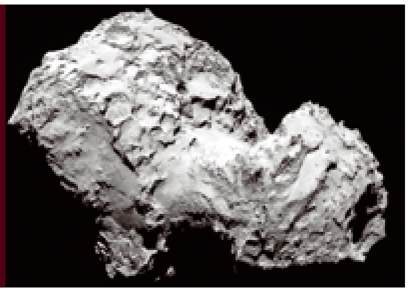
20 July 2014: 5500 km to go.



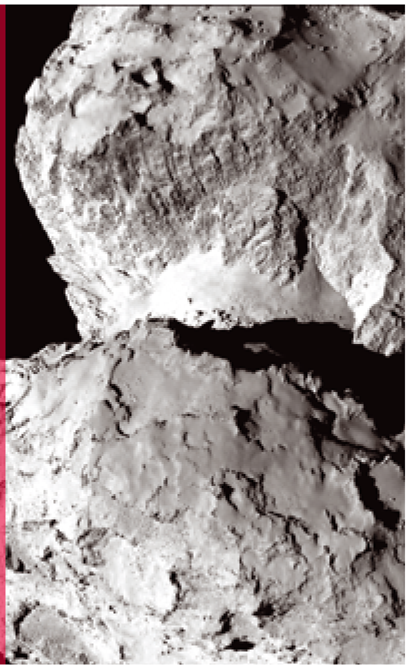
29 July 2014: 1950 km to go.



1 August 2014: 1000 km to go.



3 August 2014: 285 km to go.



After arriving at the comet on **6 August 2014**, Rosetta returned close-up images, with the body now over-filling the narrow-angle camera field of view. This image, taken on 7 August, shows the smaller lobe in the top half of the image, revealing parallel linear features connecting with a smooth 'neck' scattered with boulders. The comet's larger lobe occupies the lower half of the image.

All images: ESA/Rosetta/MPS for OSIRIS Team

Rosetta mission 'selfie'

Using the CIVA camera on Rosetta's Philae lander, the spacecraft snapped a 'selfie' at comet 67P/Churyumov–Gerasimenko from a distance of about 16 km from the surface of the comet. The image was taken on 7 October 2014 and captures the side of the Rosetta spacecraft and one of its 14 m-long solar wings, with the comet in the background.

Two images with different exposure times were combined to bring out the faint details in this very high contrast situation. The comet's active 'neck' region is clearly visible, with streams of dust and gas extending away from the surface.

On the day the image was taken, Rosetta was 469 million km from Earth and 483 million km from the Sun.

The comet's small lobe is towards the bottom and the large lobe towards the top.

ESA/Rosetta/Philae/CIVA

→ LANDING ON A COMET

OSIRIS wide-angle camera view on 12 November 2014 at 17:18 GMT. The small dot above the limb of the comet is believed to be Philae.

On 12 November 2014, at 08:35 GMT by the spacecraft clock, Rosetta released Philae from an altitude of about 22.5 km, letting it fall slowly without propulsion or guidance towards the surface. The signal confirming separation arrived on Earth at 09:03 GMT and a tense seven-hour wait began. Prior to separation a problem with the small thruster on top of the lander had been identified, meaning that there would be no force to counteract the impulse of the harpoon that was designed to secure the lander to the surface.

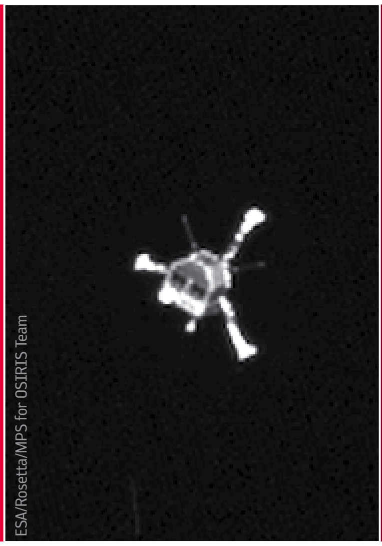
Finally, the signal confirming landing at Agilkia arrived on Earth at 16:03 GMT. But it soon transpired that Philae had rebounded from the surface – not only had the thruster failed as expected, but so had the harpoons. Furthermore, the ice screws in the lander's feet did not attach the lander to the surface. Subsequent analysis found that the lander made contact with the comet's surface three times before bouncing to its final landing place in a different area, around two hours after the initial touchdown. As of mid-July 2015, the exact location of the lander has yet to be found in high-resolution images.

Nevertheless, Philae completed its planned initial 2.5 days of science operations, with most of the instruments providing results. It sent back panoramic images of its surroundings and high-resolution images of the surface immediately beneath. It performed on-the-spot analysis of the composition of the surface materials and the gases that entered its onboard laboratory. Radio signals were also beamed from Philae through the nucleus to Rosetta, in order to probe the internal structure.

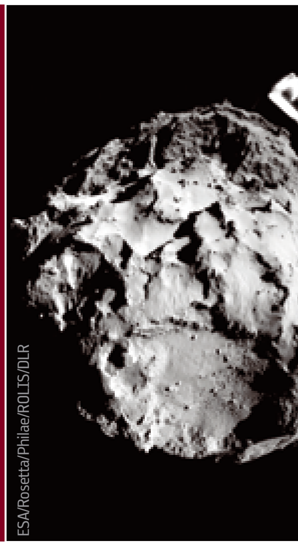
With its data safely transmitted back to Earth via Rosetta, Philae fell into hibernation as its battery ran down. The final landing site offered just 1.3 hours of illumination per comet day, insufficient to recharge the battery, whereas the original site would have given 6.5 hours and the possibility to continue the mission for several months. Philae remained in hibernation until 13 June 2015 when Rosetta first picked up its signal again, after the region started receiving more sunlight. Several short, intermittent periods of communications were confirmed in the weeks that followed, and the mission team are working on improving the communication link in hope of continued operations on the surface.

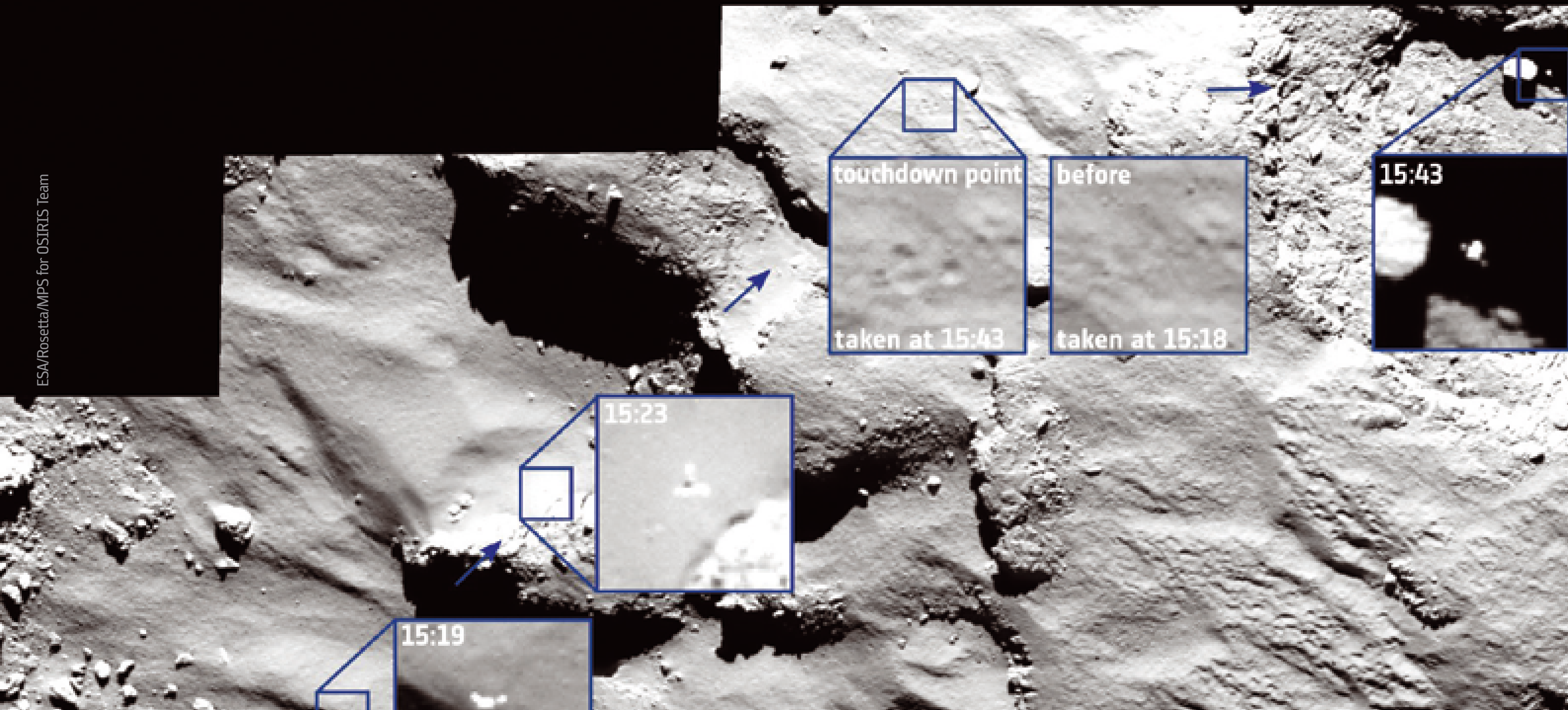
The *in situ* surface measurements made by Philae are being used to complement and calibrate the extensive remote observations being made by Rosetta, which is covering the whole comet as the mission continues.

Philae took this parting shot of its mothership shortly after separation, after more than 10 years' travelling through space together. The image was taken with the CIVA-P cameras and captures one of Rosetta's 14 m-long solar wings.

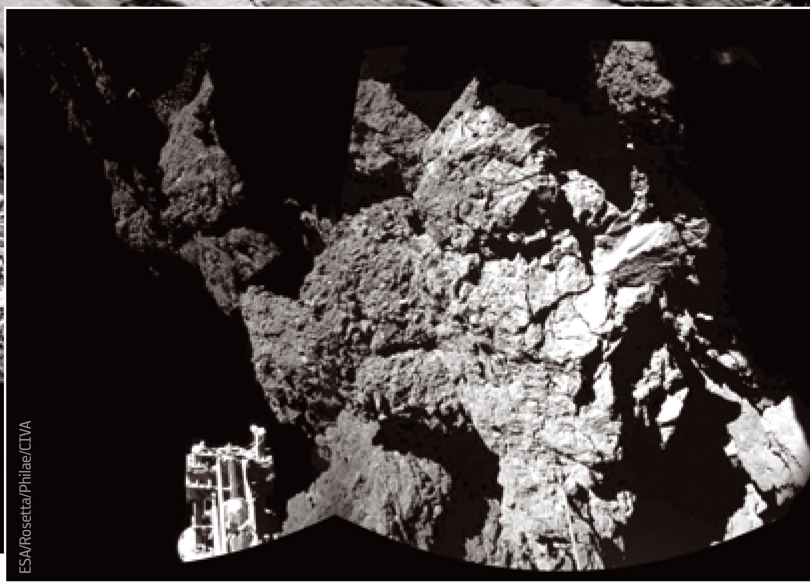


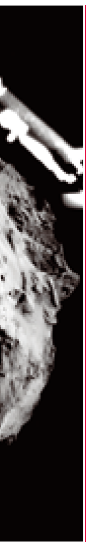
This image, taken by the OSIRIS narrow-angle camera, shows Philae falling away from Rosetta nearly two hours after separation, at 10:23 GMT. The image shows details of the lander, including the deployment of the three legs and of the antennas.





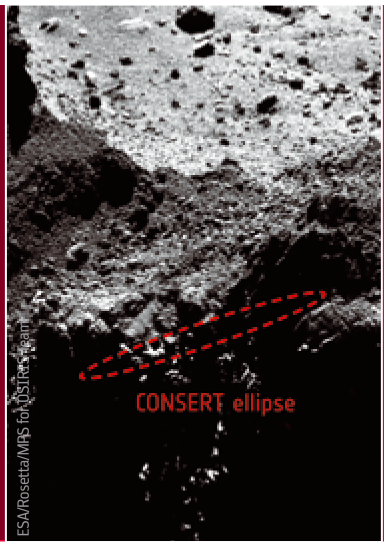
Top images: Philae's breathtaking journey as it approached and then rebounded from its first touchdown on 12 November 2014. The time of each of image is marked on the corresponding insets in GMT.
Right image: Welcome to a comet! Two-image mosaic of Philae's view at its final landing site. One of the lander's three feet and one of the CONSERT antennas can be seen in the foreground.





A view of the first landing site from Philae's downward-looking camera ROLIS, with 3 km to go. The comet is imaged with a resolution of about 3 m per pixel.

This image of the first landing site was taken just 40 m above the surface by ROLIS. It shows that the comet is covered with dust and debris ranging from centimetre to metre sizes. The large block in the top right corner is 5 m in size. In the same corner, the structure of Philae's landing gear is visible.



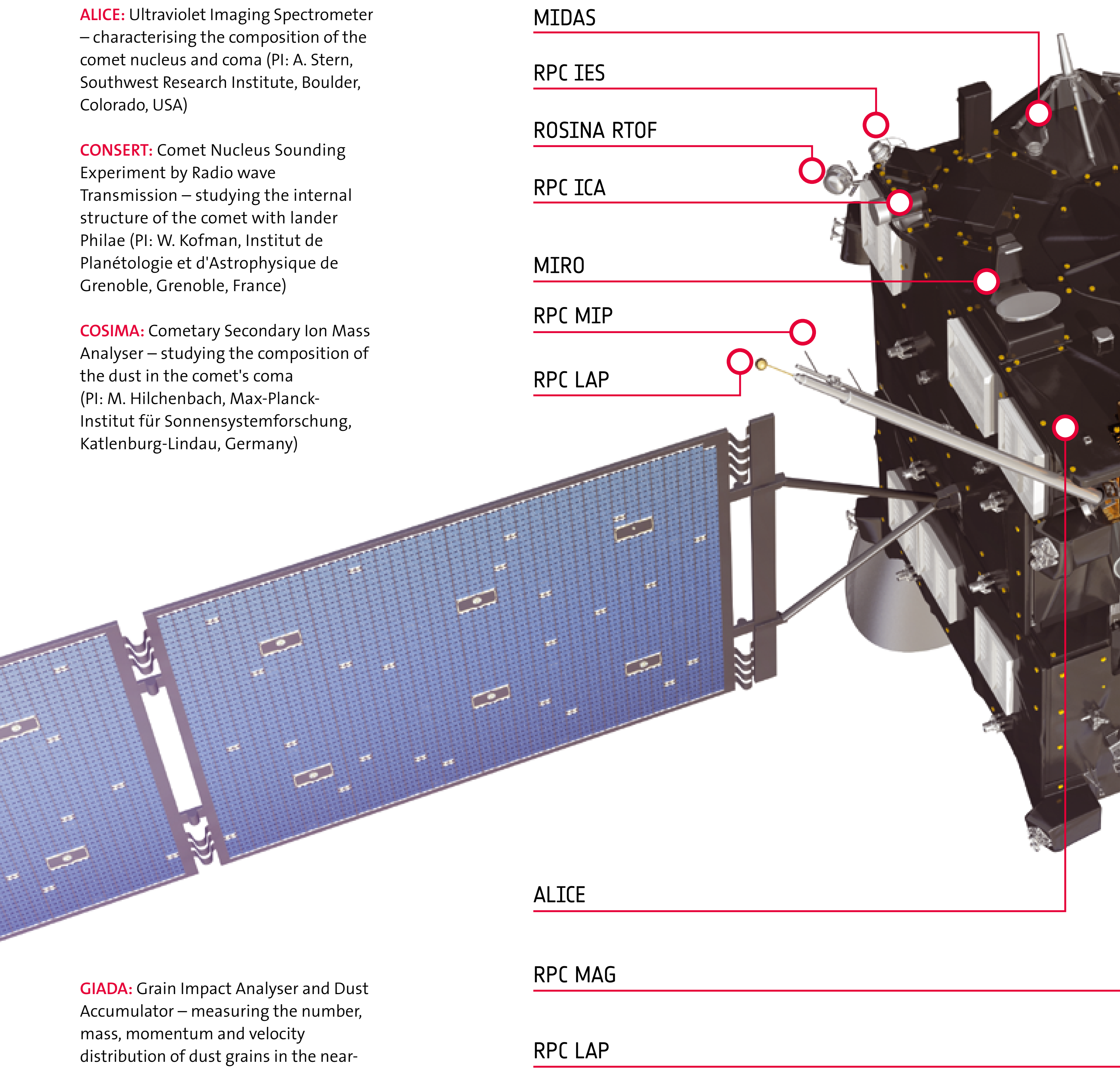
Philae's final landing site is thought to be within the red ellipse as defined by data from the CONSERT experiment, but the lander has yet to be visually identified.

→ THE ROSETTA ORBITER

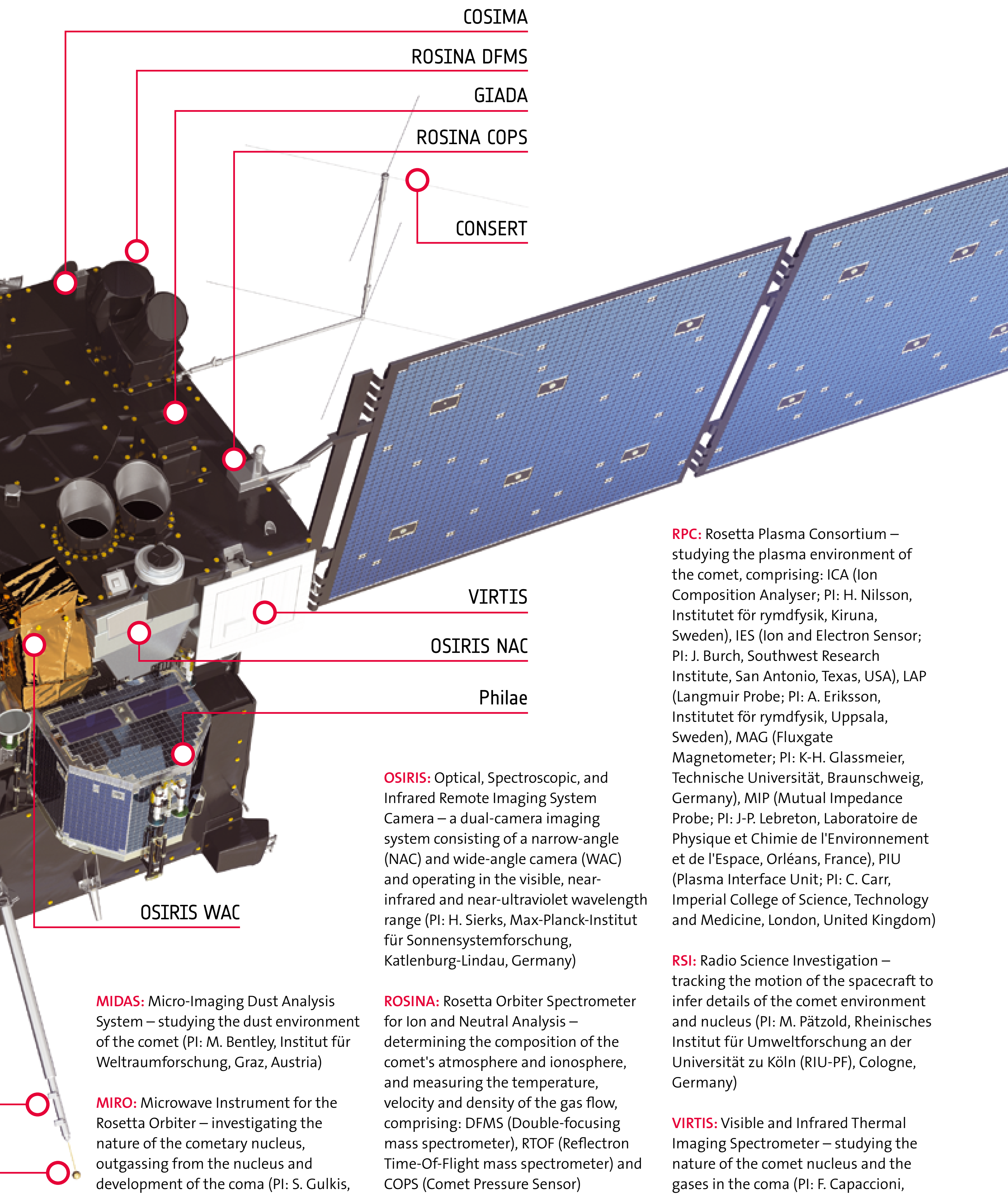
ALICE: Ultraviolet Imaging Spectrometer – characterising the composition of the comet nucleus and coma (PI: A. Stern, Southwest Research Institute, Boulder, Colorado, USA)

CONSERT: Comet Nucleus Sounding Experiment by Radio wave Transmission – studying the internal structure of the comet with lander Philae (PI: W. Kofman, Institut de Planétologie et d'Astrophysique de Grenoble, Grenoble, France)

COSIMA: Cometary Secondary Ion Mass Analyser – studying the composition of the dust in the comet's coma (PI: M. Hilchenbach, Max-Planck-Institut für Sonnensystemforschung, Katlenburg-Lindau, Germany)



GIADA: Grain Impact Analyser and Dust Accumulator – measuring the number, mass, momentum and velocity distribution of dust grains in the near-comet environment (PI: A. Rotundi, Università degli Studi di Napoli "Parthenope", Naples, Italy)



RPC: Rosetta Plasma Consortium – studying the plasma environment of the comet, comprising: ICA (Ion Composition Analyser; PI: H. Nilsson, Institutet för rymdfysik, Kiruna, Sweden), IES (Ion and Electron Sensor; PI: J. Burch, Southwest Research Institute, San Antonio, Texas, USA), LAP (Langmuir Probe; PI: A. Eriksson, Institutet för rymdfysik, Uppsala, Sweden), MAG (Fluxgate Magnetometer; PI: K-H. Glassmeier, Technische Universität, Braunschweig, Germany), MIP (Mutual Impedance Probe; PI: J-P. Lebreton, Laboratoire de Physique et Chimie de l'Environnement et de l'Espace, Orléans, France), PIU (Plasma Interface Unit; PI: C. Carr, Imperial College of Science, Technology and Medicine, London, United Kingdom)

OSIRIS: Optical, Spectroscopic, and Infrared Remote Imaging System Camera – a dual-camera imaging system consisting of a narrow-angle (NAC) and wide-angle camera (WAC) and operating in the visible, near-infrared and near-ultraviolet wavelength range (PI: H. Sierks, Max-Planck-Institut für Sonnensystemforschung, Katlenburg-Lindau, Germany)

MIDAS: Micro-Imaging Dust Analysis System – studying the dust environment of the comet (PI: M. Bentley, Institut für Weltraumforschung, Graz, Austria)

MIRO: Microwave Instrument for the Rosetta Orbiter – investigating the nature of the cometary nucleus, outgassing from the nucleus and development of the coma (PI: S. Gulkis, Jet Propulsion Laboratory, Pasadena, California, USA)

ROSINA: Rosetta Orbiter Spectrometer for Ion and Neutral Analysis – determining the composition of the comet's atmosphere and ionosphere, and measuring the temperature, velocity and density of the gas flow, comprising: DFMS (Double-focusing mass spectrometer), RTOF (Reflectron Time-Of-Flight mass spectrometer) and COPS (Comet Pressure Sensor) (PI: K. Altwegg, Universität Bern, Switzerland)

RSI: Radio Science Investigation – tracking the motion of the spacecraft to infer details of the comet environment and nucleus (PI: M. Pätzold, Rheinisches Institut für Umweltforschung an der Universität zu Köln (RIU-PF), Cologne, Germany)

VIRTIS: Visible and Infrared Thermal Imaging Spectrometer – studying the nature of the comet nucleus and the gases in the coma (PI: F. Capaccioni, Istituto di Astrofisica e Planetologia Spaziali, Rome, Italy)

→ THE PHILAE LANDER

Rosetta deployed the Philae lander to the surface of comet 67P/Churyumov–Gerasimenko for *in situ* analysis with its 10 experiments:

APXS: Alpha Proton X-ray Spectrometer – studying the chemical composition of the landing site and its potential alteration during the comet's approach to the Sun (PI: G. Klingelhöfer, Johannes Gutenberg-Universität, Mainz, Germany)

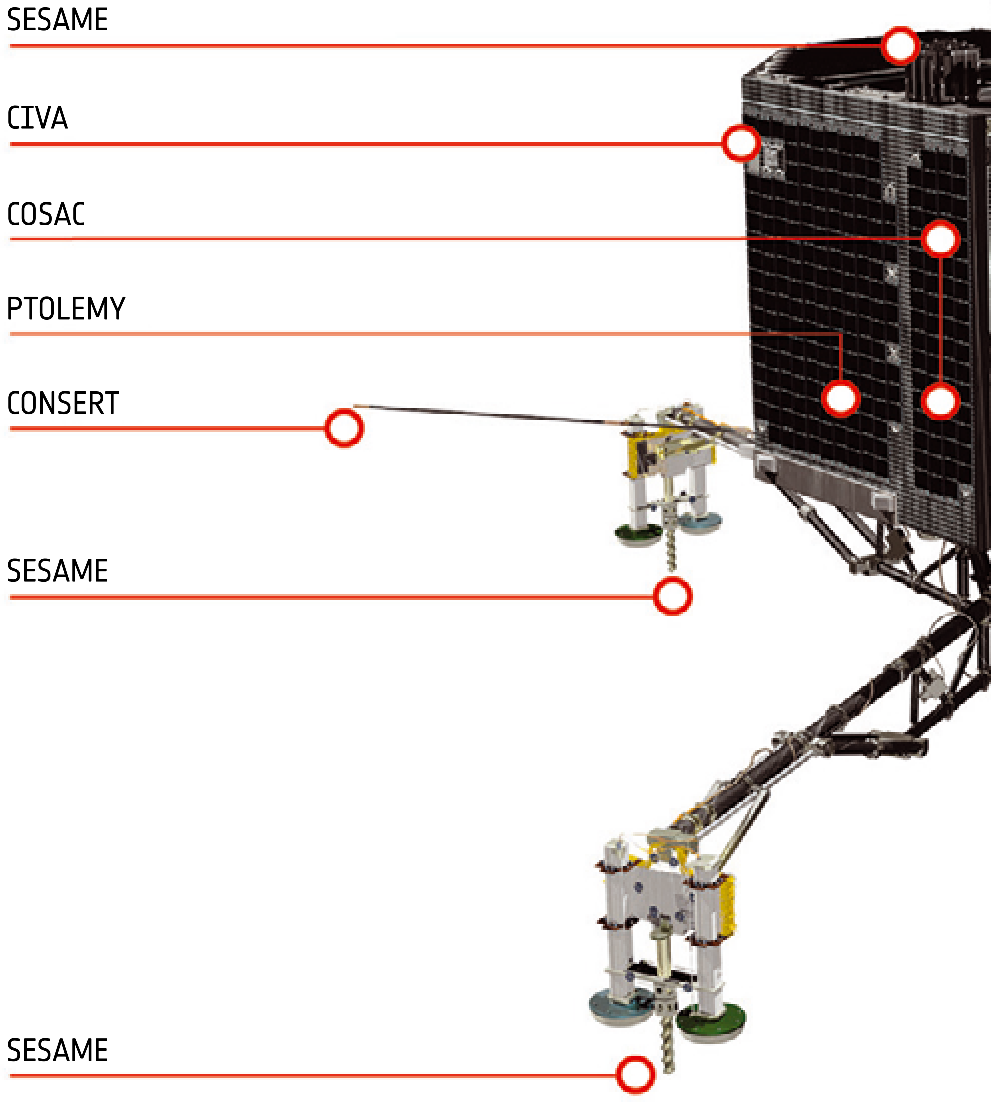
CIVA: Comet Nucleus Infrared and Visible Analyser – six cameras to take panoramic pictures of the comet surface (PI: J-P. Bibring, Institut d'Astrophysique Spatiale, Université Paris Sud, Orsay, France)

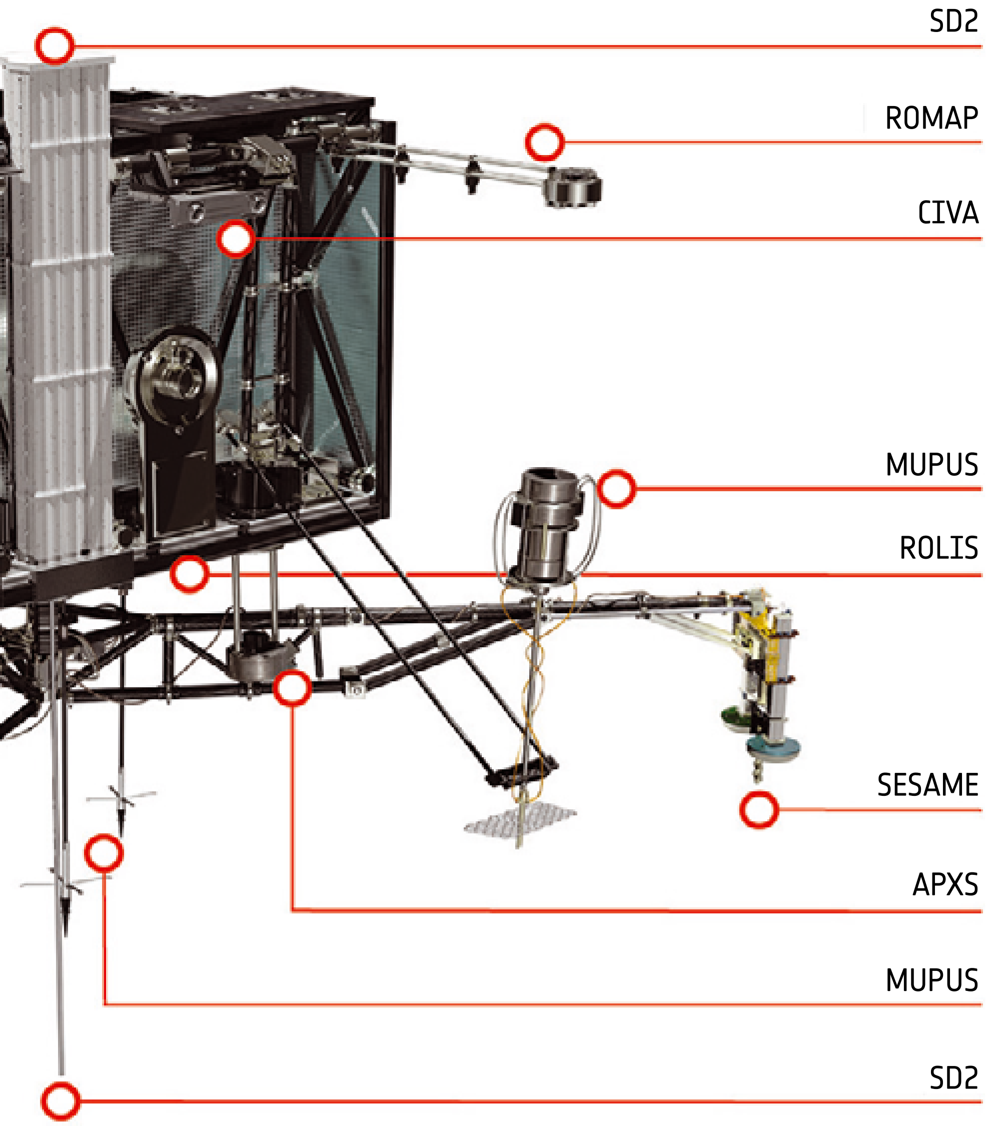
CONSERT: COmet Nucleus Sounding Experiment by Radiowave Transmission – studying the internal structure of the comet nucleus with Rosetta orbiter (PI: W. Kofman, Institut de Planétologie et d'Astrophysique de Grenoble, Grenoble, France)

COSAC: The COmetary SAmpling and Composition Experiment – detecting and identifying complex organic molecules (PI: F. Goesmann, Max-Planck-Institut für Sonnensystemforschung, Katlenburg-Lindau, Germany)

PTOLEMY: an evolved gas analyser, which obtains accurate measurements of isotopic ratios of light elements (PI: I. Wright, Open University, Milton Keynes, UK)

MUPUS: MUlti-PUrpose Sensors for Surface and Subsurface Science – studying the properties of the comet surface and immediate sub-surface (PI: T. Spohn, Institut für Planetenforschung, Deutsches Zentrum für Luft- und Raumfahrt, Berlin, Germany)





ROLIS: Rosetta Lander Imaging System – providing the first close-up images of the landing site (PI: S. Mottola, Deutsches Zentrum für Luft- und Raumfahrt, Berlin, Germany)

ROMAP: Rosetta Lander Magnetometer and Plasma Monitor – studying the magnetic field and plasma environment of the comet (PI: H-U. Auster, Technische Universität, Braunschweig, Germany & I. Apáthy, KFKI, Budapest, Hungary)

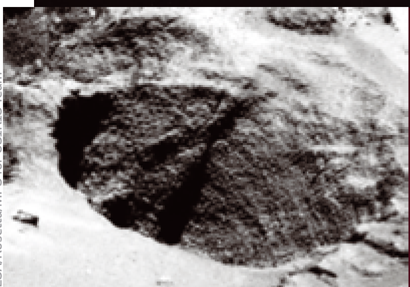
SD2: Sampling, drilling and distribution subsystem – drilling up to 23 cm depth and delivering material to onboard instruments for analysis (PI: A. Ercoli-Finzi, Politecnico di Milano, Milan, Italy)

SESAME: Surface Electric Sounding and Acoustic Monitoring Experiments – three instruments to measure properties of the comet's outer layers. The Cometary Acoustic Sounding Surface Experiment (CASSE, PI: K. Seidensticker, German Aerospace Center, Institute of Planetary Research, Asteroids and Comets, Berlin, Germany) measures the way in which sound travels through the surface. The Permittivity Probe (PP, PI: W. Schmidt, Finnish Meteorological Institute, Helsinki, Finland) investigates its electrical characteristics, and the Dust Impact Monitor (DIM; PI: H. Krueger, Max-Planck-Institute for Solar System Research, Göttingen, Germany) measures dust falling back to the surface.

→ GETTING TO KNOW A COMET

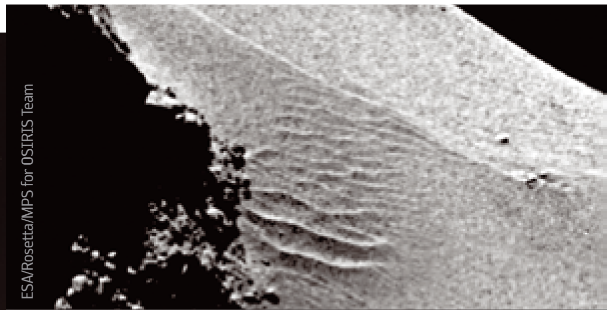
Comet 67P/Churyumov–Gerasimenko is a regular visitor to the inner Solar System and has been observed many times by ground-based telescopes on its 6.45 year commute between the orbits of Jupiter and Earth. At its closest – perihelion – it comes within 186 million kilometres of the Sun, between the orbits of Earth and Mars. However, it used to orbit further out: it turns out that encounters in 1840 and 1959 both shifted the comet's perihelion closer to the Sun, meaning that it is only recently experiencing greater heating, making it an excellent target for scientific investigation. Indeed, Rosetta is revealing that its host comet has a remarkable array of surface features with many processes contributing to its activity, pointing to a complex evolution.

The origin of the double-lobed shape remains a mystery, with one of two ideas most likely: either it is one body that has been eroded into this shape over time, or it comprises two separate comets that merged together at some point in its early history.



ESA/Rosetta/MPS for OSIRIS Team

Close-up of a curious surface texture nicknamed 'goosebumps'. The characteristic scale of all the bumps seen on the comet is about 3 m, extending over regions greater than 100 m. They are seen on pit walls, steep slopes and exposed cliff faces, but how they formed has yet to be explained.



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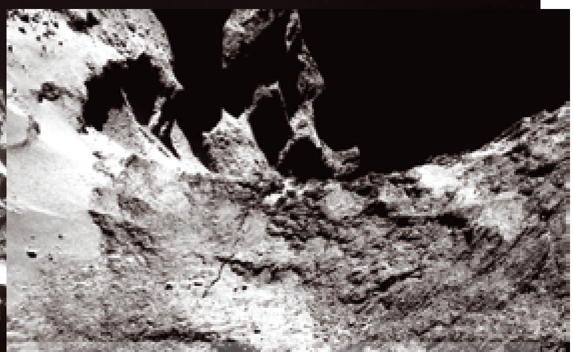
Features in the Hapi region show evidence of local gas-driven movement producing dune-like ripples.



This image shows part of a large fracture running across the neck where it leaves Hapi and extends into Anuket.

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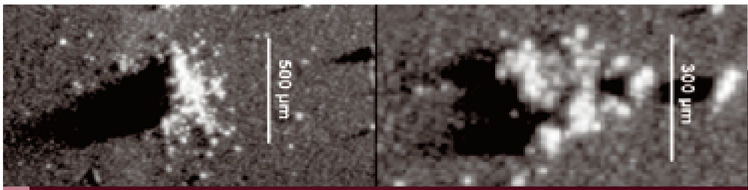
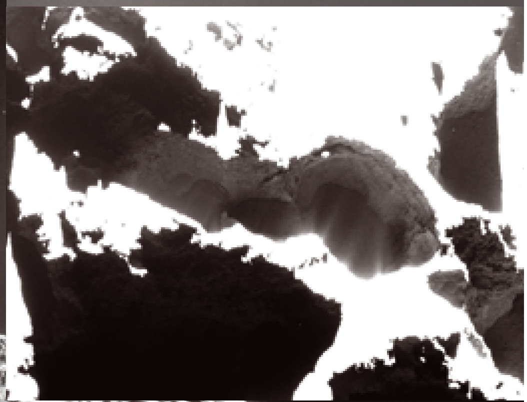


ESA/Rosetta/MPS for COSIMA Team

Rosetta is also collecting dust that is ejected from the comet, in order to study its structure and composition. These grains were collected by the COSIMA instrument.

Active pit detected in Seth region. This image was acquired from a distance of 60 km. Enhancing the contrast reveals fine structures in the shadow of the pit, interpreted as jet-like features rising from the pit.



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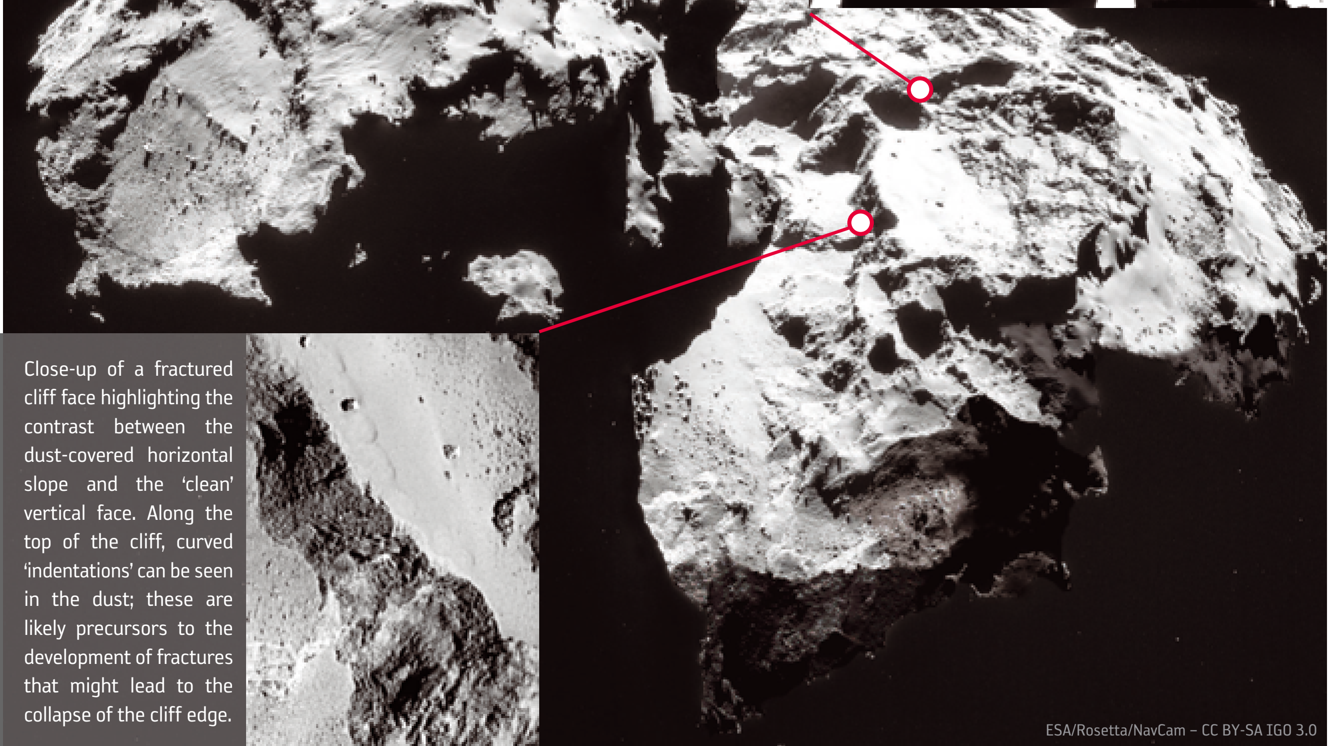


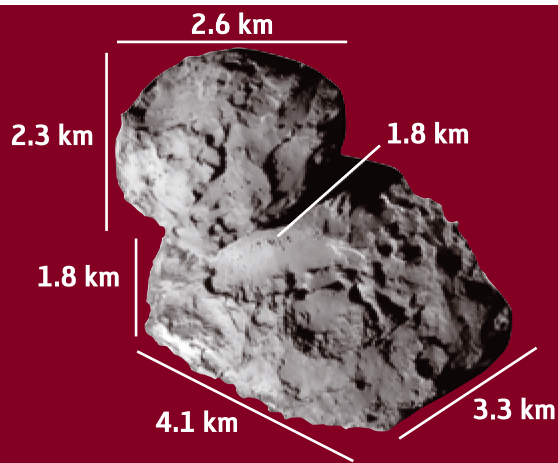
Close-up of a fractured cliff face highlighting the contrast between the dust-covered horizontal slope and the 'clean' vertical face. Along the top of the cliff, curved 'indentations' can be seen in the dust; these are likely precursors to the development of fractures that might lead to the collapse of the cliff edge.

ESA/Rosetta/MPS for OSIRIS Team

Comet vital statistics

Volume: 21.4 km^3
Mass: 1 x 10^{13} kg
Density: 470 kg/m^3
Porosity: 70–80%
Average albedo: 6%
Surface temperature: –93°C to –43°C
Subsurface temperature: –243°C to –83°C
Rotation period: 12.4 hours
Angle between equator and orbital plane: 52°

Credits: Shape model, rotation properties, volume and porosity: OSIRIS; mass: RSI; density: RSI/OSIRIS; surface temperature: VIRTIS; subsurface temperature: MIRO; albedo: OSIRIS and VIRTIS. Image: NavCam.



These measurements are based on data collected in the first few months at the comet; measurements are subject to change as the comet evolves and as more data are collected.

→ AN EVOLVING STORY

Rosetta is watching carefully as the comet moves ever closer to the Sun along its orbit, observing how the activity increases towards perihelion on 13 August 2015, and how it subsides again towards the end of 2015 and beyond. These close-up observations by Rosetta provide vital context to the ground-based images that show the much wider view of the comet's dust–gas 'atmosphere', or coma, and its tail extending for tens of thousands of kilometres into space. Scientists are keen to study the relationship between the gas and dust seen rising from pits on the surface of the comet to this vast coma, and how the amount and composition change throughout the mission.

MIRO has already found a general rise in the comet's global water vapour production rate, from 0.3 litres per second in early June 2014 to 1.2 litres per second by late August 2014. It also found that a substantial portion of the water seen during this phase originated from the comet's neck. Water is accompanied by other outgassing species, including carbon monoxide and carbon dioxide. ROSINA is finding large fluctuations in the composition of the coma, representing daily and perhaps seasonal variations in

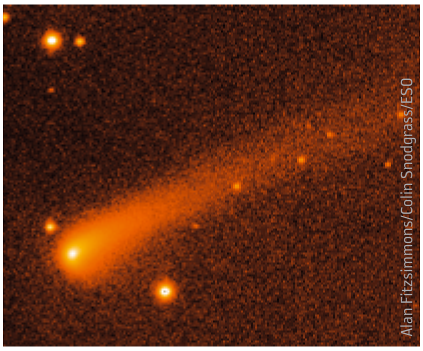
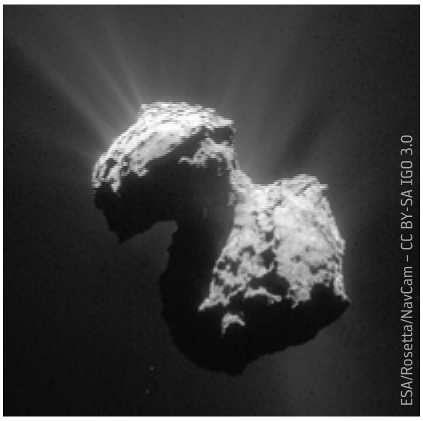


Image taken on 8 July 2015 using the European Southern Observatory's Very Large Telescope in Chile. At this time, the tail extended at least 120 000 km from the nucleus.



Rosetta's view of the comet's activity on 7 July 2015, from a distance of 154 km.

the major outgassing species. The instrument has detected a range of gases, including molecular nitrogen for the first time, along with methanol, methane, ammonia, formaldehyde, hydrogen sulphide, hydrogen cyanide and more.

Meanwhile Rosetta's dust instruments COSIMA, GIADA and MIDAS have been analysing the properties of the dust being ejected from the comet. For example, by looking at how the dust grains break apart when they strike the instrument's detectors their composition can be determined. While the first population of dust grains were devoid of ice, more ice-rich detections are expected as activity increases.

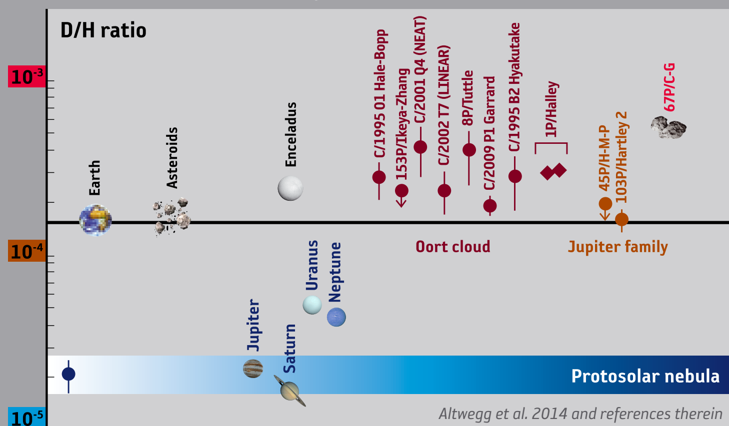
As the gas–dust coma continues to grow, it will interact with charged particles of the solar wind and with the Sun's ultraviolet light. RPC instruments are studying this evolution and the comet's plasma environment. Together with Philae's ROMAP instrument, RPC has helped to show the comet's nucleus is non-magnetic at scales of greater than one metre, suggesting that magnetic forces are unlikely to have played a role in the accumulation of planetary building blocks in the early Solar System.

Did Earth's oceans hail from comets?

One of the most eagerly awaited early results from Rosetta revealed that the comet's water composition is significantly different from that of Earth's oceans.

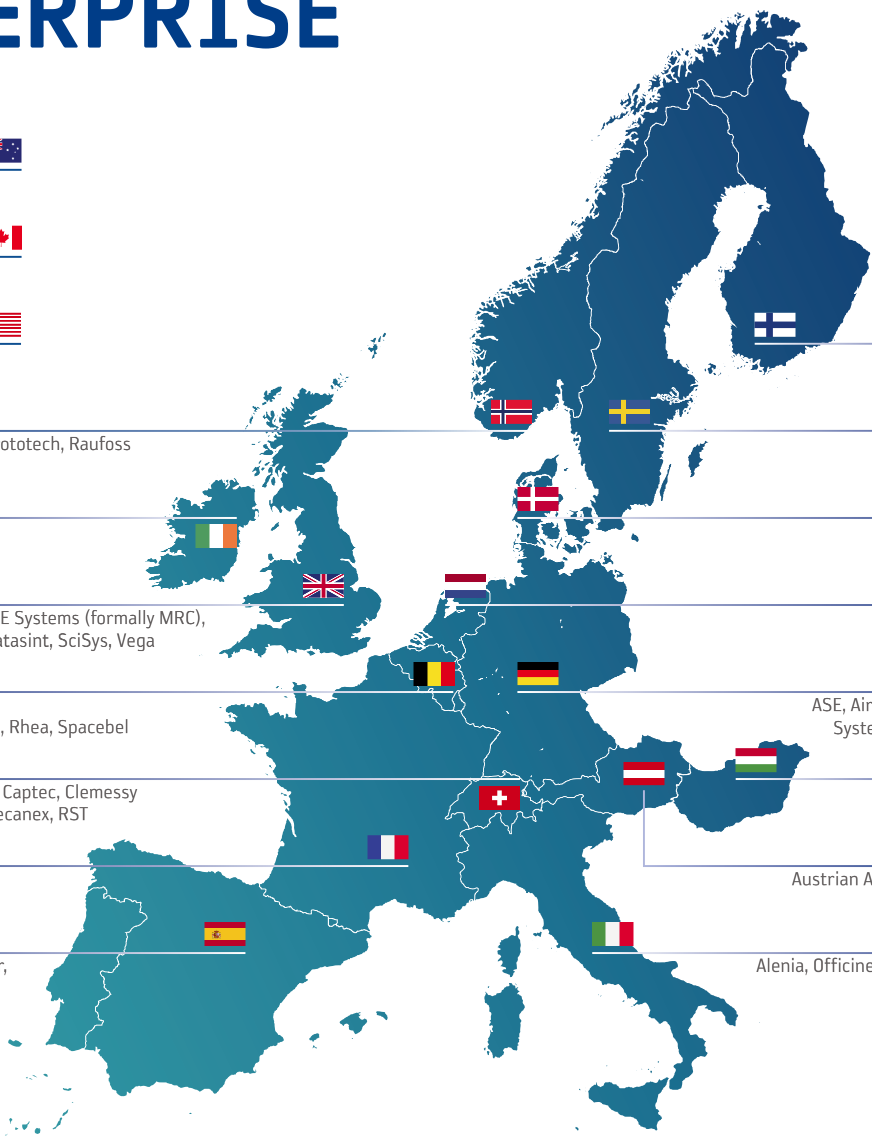
A leading hypothesis on Earth's formation is that it was so hot when it formed 4.6 billion years ago that any original water content would have boiled off. The idea is that water was delivered after our planet had cooled, most likely from collisions with comets and asteroids, but the relative contribution of each class of object to our planet's water supply is much debated.

The key to determining where the water originated is in the proportion of deuterium – a form of hydrogen with an additional neutron – to normal hydrogen. Most comets have more deuterium than Earth's ocean water, and Rosetta's ROSINA instrument found it to be three times higher on the comet than in Earth's oceans. Strangely, 67P is a Jupiter-family comet, much like Comet 103P/ Hartley 2, whose water is the same as in Earth's oceans. These findings add weight to models that place more emphasis on asteroids as the main delivery mechanism of water to the Earth.



The different values of the deuterium-to-hydrogen ratio (D/H) in water observed in various bodies in the Solar System.

→ AN INTERNATIONAL ENTERPRISE



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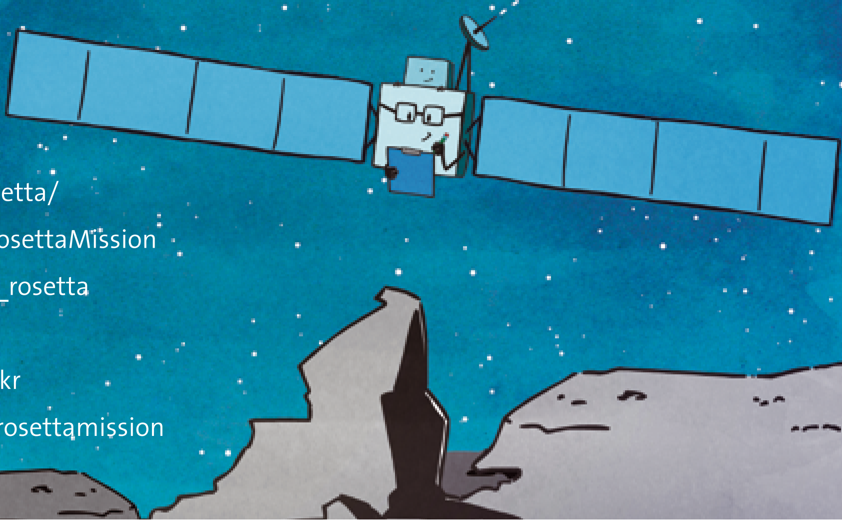

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