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→ RENDEZVOUS WITH A COMET

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ROSETTA
RENDEZVOUS WITH A COMET

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→ ROSETTA: EUROPE'S COMET-CHASER

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Why 'Rosetta'?

The Rosetta mission was named after the famous 'Rosetta Stone', a fragment of an Egyptian stone tablet dating back to 196BC 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. Scientists hope that by studying a comet close up and for an extended period of time, the mission will unlock the mysteries of how the Solar System evolved.

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 considered to be the most primitive building blocks of our cosmic neighbourhood, surviving the Solar System's chaotic 4.6 billion-year history more or less intact. Laced with ice and organic materials, comets likely helped to 'seed' Earth with water, and perhaps even the ingredients for life. By studying one of these icy treasure chests in great detail, ESA's Rosetta is set to unlock the secrets of the Solar System.

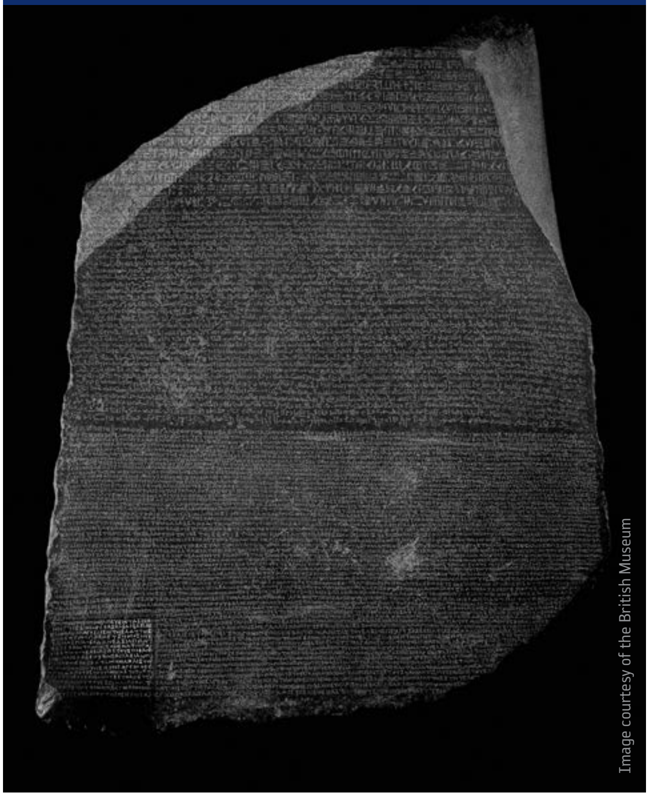
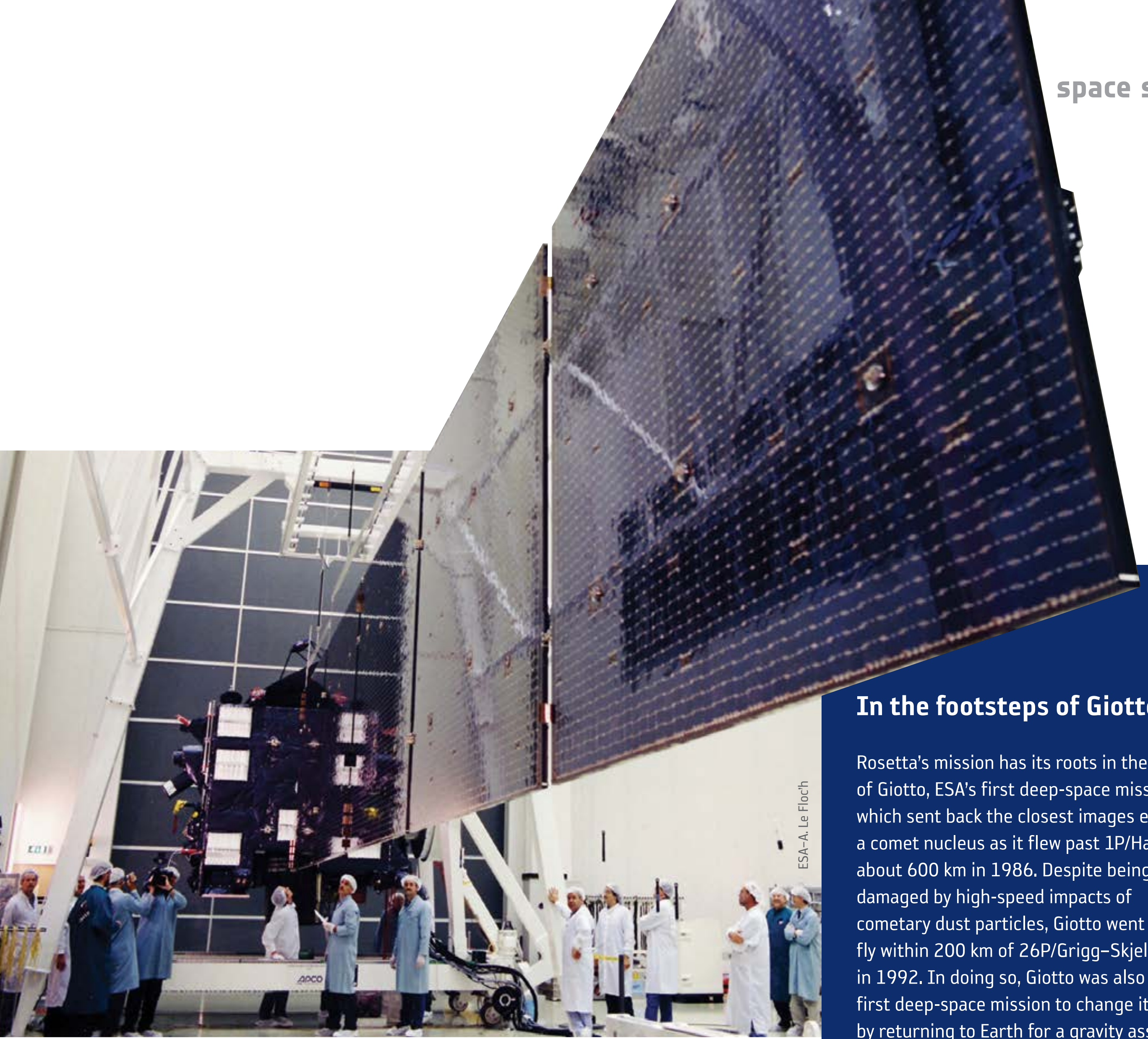


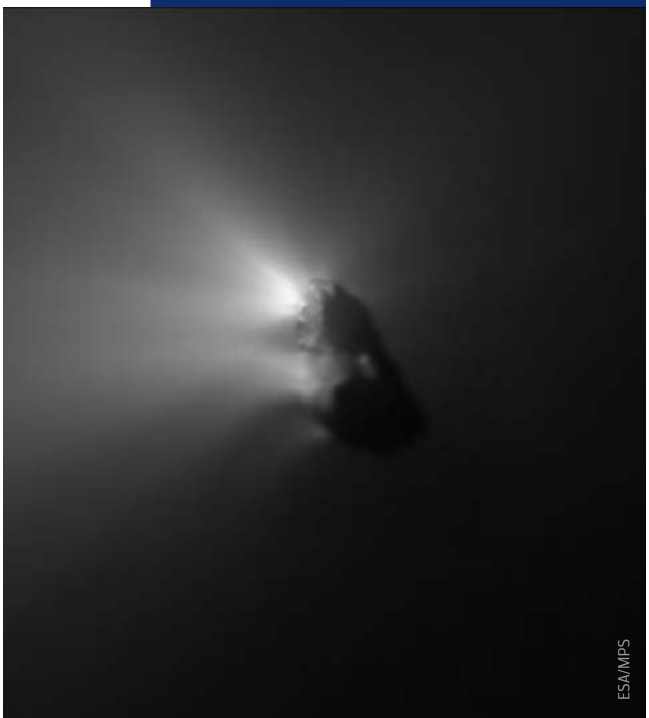
Image courtesy of the British Museum



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

In the footsteps of Giotto

Rosetta's mission has its roots in the legacy of Giotto, ESA's first deep-space mission, which sent back the closest images ever of a comet nucleus as it flew past 1P/Halley at about 600 km in 1986. Despite being damaged by high-speed impacts of cometary dust particles, Giotto went on to fly within 200 km of 26P/Grigg–Skjellerup in 1992. In doing so, Giotto was also the first deep-space mission to change its orbit, by returning to Earth for a gravity assist.



The nucleus of Halley's comet as seen by Giotto

A mission of firsts

Rosetta is claiming many historic firsts. It is the first spacecraft to have journeyed beyond the main asteroid belt relying solely on solar cells for power. Special solar 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 the second half of 2014, Rosetta will be the first mission ever to orbit a comet and the first to attempt to soft-land a probe on its nucleus. While previous missions have spent only fleeting moments flying past their targets at high speed, Rosetta will be the first to fly alongside a comet heading towards the inner Solar System, watching how its ices are transformed by the Sun's warmth. Rosetta will continue to follow the comet for several months beyond its closest approach to the Sun in August 2015, watching how the comet's activity subsides again.

→ THE LONG TREK

Rosetta's journey through the Solar System

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 67P/Churyumov–Gerasimenko.

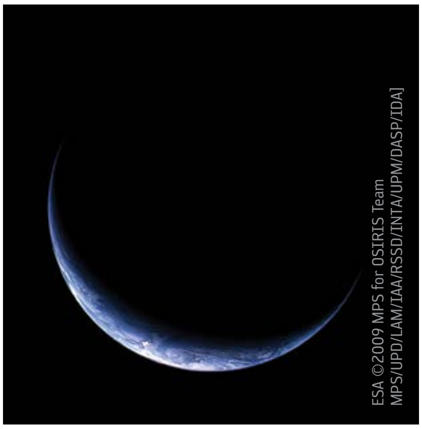
Cosmic pinball

Comet Churyumov–Gerasimenko has a 6.5-year, elliptical orbit that takes it from between the orbits of Earth and Mars at its closest to the Sun, near to Jupiter's orbit at its furthest. Thus, for the first half of its journey, Rosetta played a game of cosmic pinball to match the comet's trajectory, first getting a boost from Earth's gravity on 4 March 2005, then Mars on 25 February 2007, before returning back to Earth on 13 November 2007 and again on 13 November 2009.

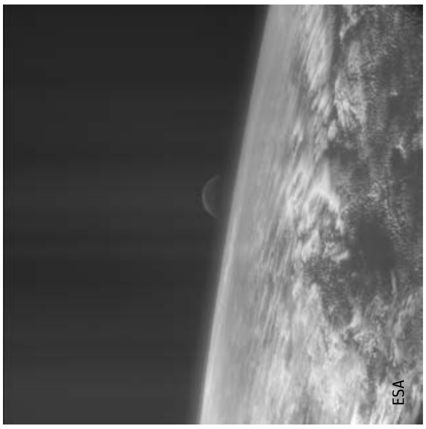
Rosetta lifted off from Europe's Spaceport in Kourou, French Guiana, at 07:17 GMT on 2 March 2004

The CIVA instrument on Philae took this portrait of Rosetta at Mars on 25 February 2007

Earth from a distance of 633 000 km on 12 November 2009 by Rosetta's OSIRIS narrow-angle camera



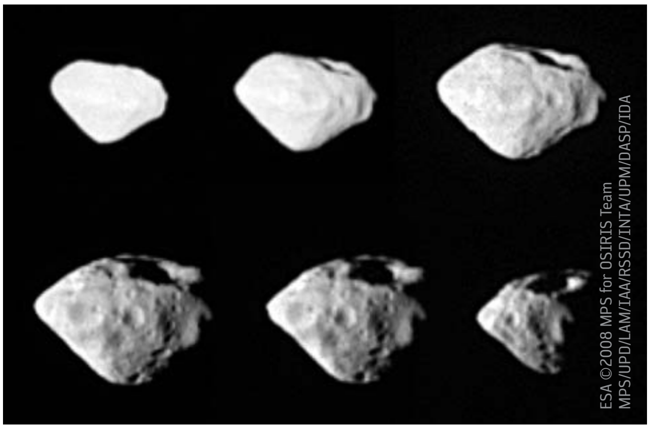
Moonrise over the Pacific at 22:06 GMT on 4 March 2005, just three minutes before the point of closest approach of 1955 km. The image was taken by Rosetta's navigation camera



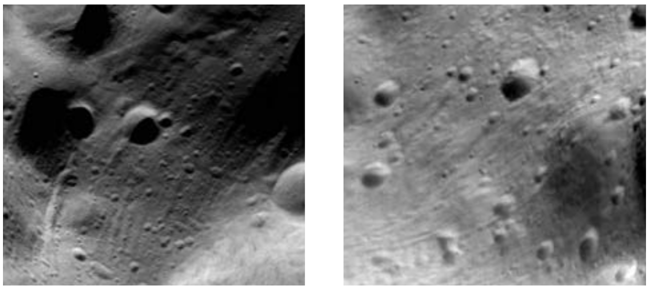
→ FLEETING FLYBYS OF BATTERED ASTEROIDS

Along the way, Rosetta passed twice 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, namely Steins on 5 September 2008 and Lutetia on 10 July 2010.

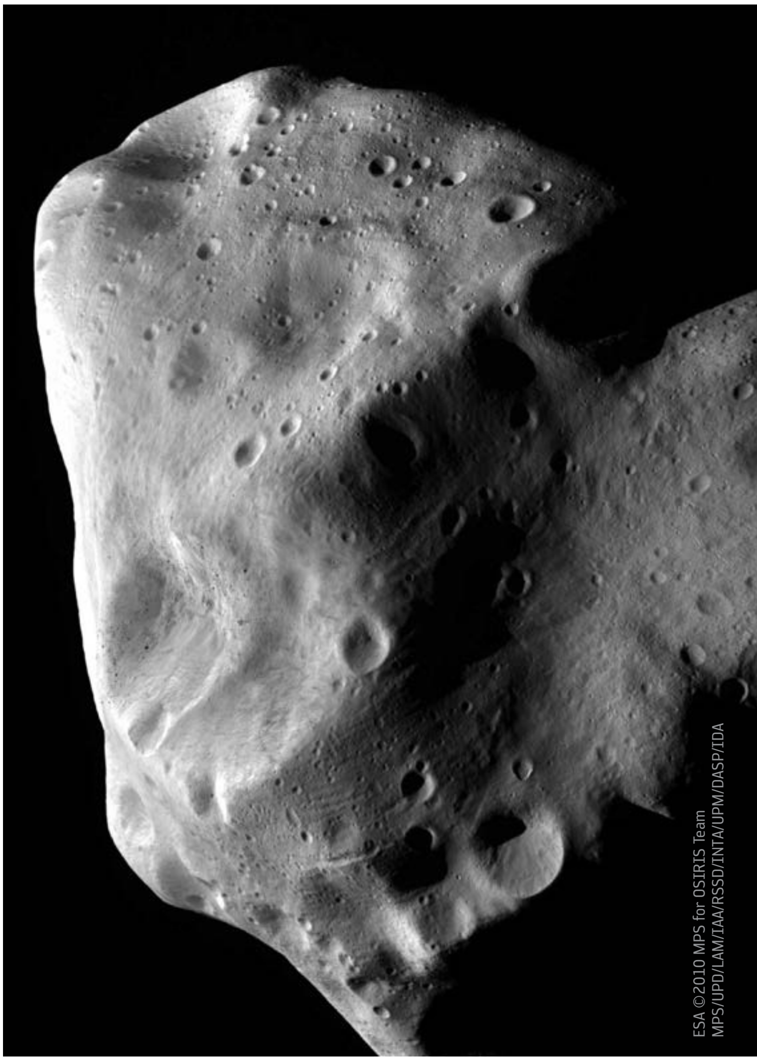
Asteroid Steins seen from a distance of 800 km from two different perspectives. Rosetta provided accurate measurements of its dimensions: 6.67 × 5.81 × 4.47 km. A large crater, about 1.5 km across, can be seen at the 'top' of this diamond-shaped asteroid



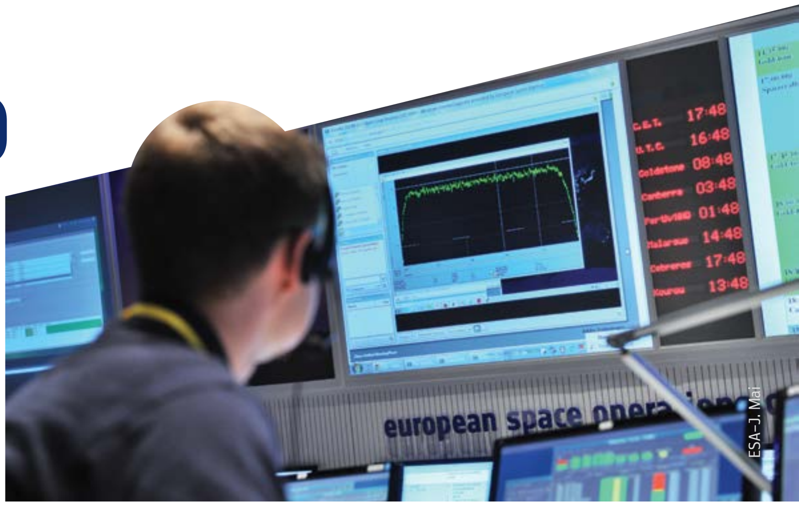
A last look back at Lutetia before journeying on to the comet



These images of the 100 km-diameter asteroid Lutetia were acquired during Rosetta's flyby at 3162 km. Detailed views of craters and grooves are seen on Lutetia's surface



→ HOT AND COLD



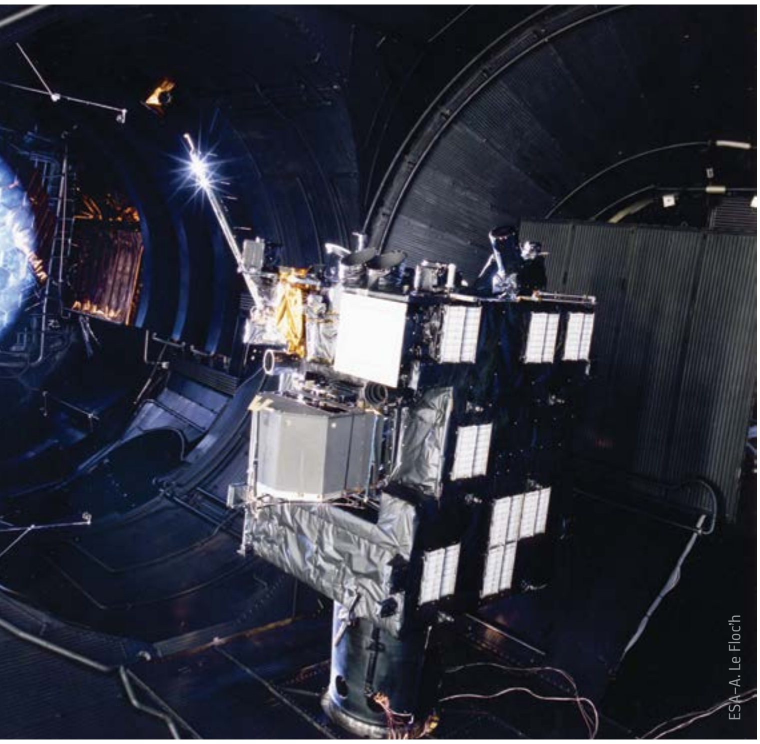
Waiting for the signal

At launch, Rosetta was about 150 million kilometres from the Sun, but at its furthest point it was close to the orbit of Jupiter, nearly 800 million kilometres away. In August 2015, the spacecraft will return to within 185 million kilometres when the comet is between the orbits of Earth and Mars. This greatly changing distance translates into wide ranges in solar intensity and heating, and has required special planning.

In the inner Solar System, radiators dissipate surplus heat and prevent overheating. Conversely, in the cold outer Solar System, key hardware such as fuel tanks, pipework, thrusters and the scientific instruments are kept warm with heaters at strategic points. Multilayered insulation blankets wrapped around the spacecraft also help to maintain a comfortable operating temperature.

A key development for the mission was special low-intensity, low-temperature solar cells to work efficiently in both the warm, bright conditions of the inner Solar System and the relative dark and cold further out. Nearly 25 000 non-reflective silicon cells generated up to 8700 W in the inner Solar System; when Rosetta reaches its rendezvous with the comet in August 2014, the solar cells will be generating about 1000 W.

Rosetta's wake-up signal on 20 January 2014 was greeted with much relief



Rosetta Structural and Thermal Model under testing in 2002 in the Large Space Simulator, Europe's largest thermal vacuum chamber, in ESA's Technical Centre, ESTEC

Hibernation

Even with this new technology, Rosetta's solar panels could not generate enough power to operate the spacecraft safely during the most distant part of its journey through the Solar System, as far as 800 million kilometres from the Sun. Instead, on 8 June 2011, Rosetta was put into hibernation.

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 with its solar wings facing the Sun and placed in a slow spin, rotating once every 90 seconds, to maintain stability. Critically, this meant that Rosetta's main antenna was no longer pointing towards Earth: the spacecraft was on its own.

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

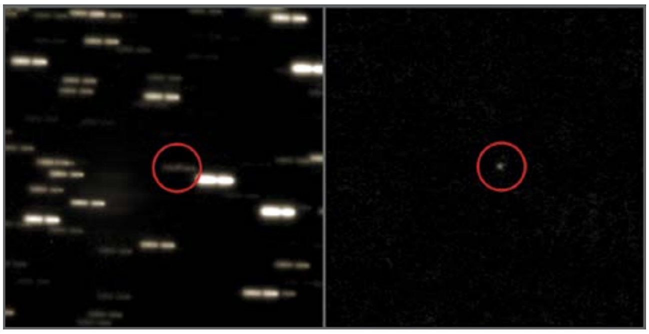
→ WHAT DO WE KNOW ABOUT COMET 67P/CHURYUMOV–GERASIMENKO?

The comet is a regular visitor to the inner Solar System. It orbits the Sun once every 6.5 years, commuting between the orbits of Jupiter and Earth. At its closest, it comes within 185 million kilometres of the Sun; by comparison, Earth is about 150 million kilometres from the Sun.

The comet was first observed from Earth in 1969 by Klim Churyumov, who discovered it in a photograph taken by Svetlana Gerasimenko, giving rise to its name. 67P indicates that it was the 67th periodic (= P) comet discovered.

It was later realised that an encounter with Jupiter in 1959 had moved the comet's perihelion closer to the Sun and it is thought that another encounter with Jupiter in 1840 had had the same effect. Thus, although the comet now comes relatively close to the Sun, it has only recently started doing so, which means that it is relatively unaltered by the Sun's heat and an excellent target for Rosetta.

In 2003, the Hubble Space Telescope took images of the comet. Although it was too far away to be directly resolved, observations of changes in the brightness of the comet as it rotated allowed estimates of its size and shape to be made. It appears to be an irregular object roughly 3 x 4 x 5 km across, with a rotation period of about 12 hours.

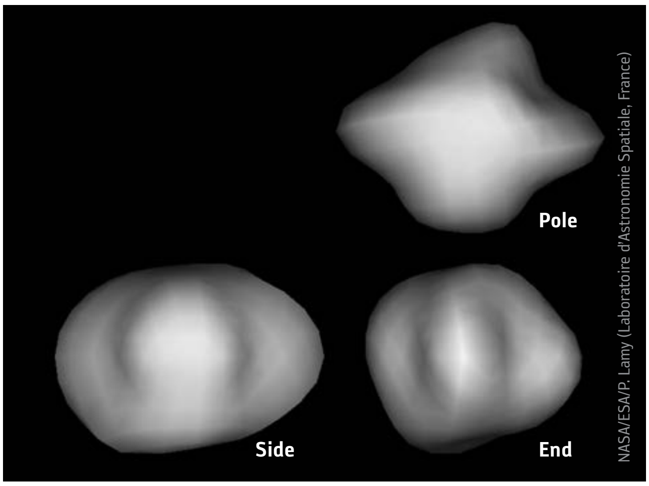


ESO/C. Snodgrass (Max Planck Institute for Solar System Research, Germany)/O. Hainaut (ESO)

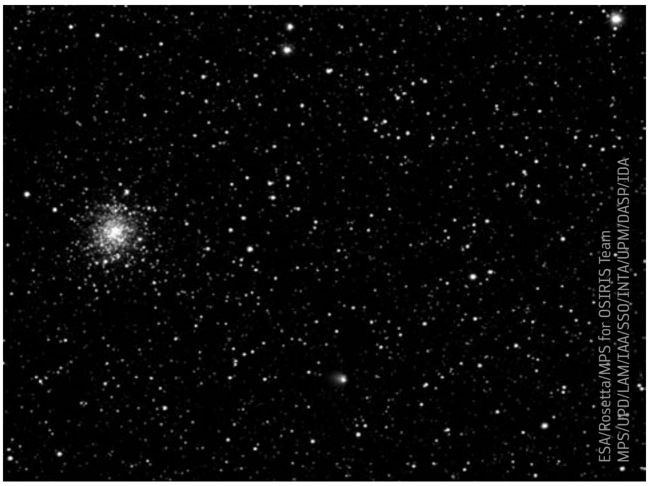
The European Southern Observatory's Very Large Telescope in Chile was used to observe the comet on 28 February 2014, just after it became visible again to ground observers. Ground-based observations will play a key role in gathering information about the comet and its coma during Rosetta's mission

Observations by ground-based telescopes have also provided insight into the nature of the comet, again by noting changes in the brightness of the comet and its coma. For example, during the 2009 perihelion passage, astronomers inferred that much of its activity was coming from three particular surface regions.

But only when Rosetta is close to its target will we be able to see in clear detail exactly what the surface looks like, and how the behaviour of the comet varies on its orbit around the Sun.



The Hubble Space Telescope was used in March 2003 to provide estimates of the size, shape and rotational period of the nucleus



Comet 67P/Churyumov-Gerasimenko on 30 April 2014, by the OSIRIS Narrow Angle Camera. The comet displays a coma, which extends over 1300 km from the nucleus

→ RENDEZVOUS WITH A COMET

Rosetta performs a series of complex manoeuvres to arrive at the comet

When Rosetta woke up from deep-space hibernation in early 2014, there was still a 9 million kilometre gap to close before meeting its target. By early May, this had been reduced to 2 million kilometres. A series of critical ‘braking’ manoeuvres with Rosetta’s thrusters between May and August reduced the speed of the spacecraft relative to its target, and images of the distant comet against the background of stars were taken by Rosetta to refine the approach trajectory.

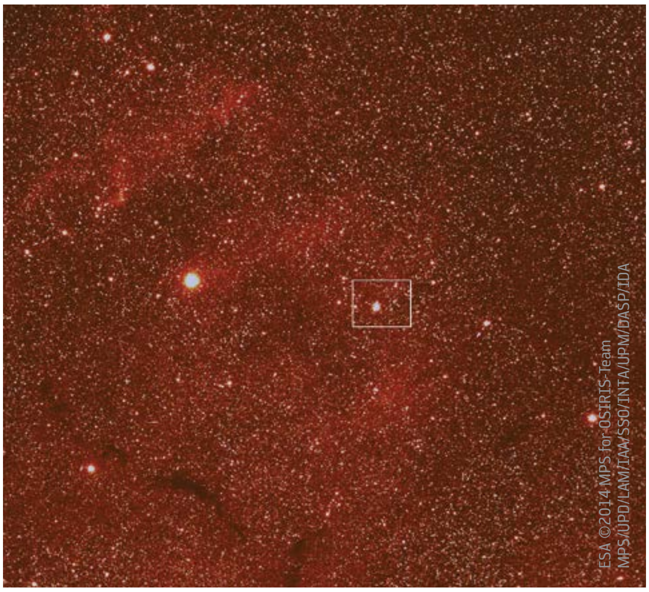
The aim is to ensure arrival in early August at walking pace and at a distance of around 100 km. At that point, Rosetta will become the first mission to rendezvous with a comet.

Once at the comet, the spacecraft will be manoeuvred to follow a series of triangular paths in front of the comet, bringing it down from 100 km to 50 km altitude. Eventually, Rosetta will be orbiting at an altitude of 30–10 km above the comet, allowing detailed mapping of its nucleus with resolution of 20–50 cm on the surface. A key aim of this phase is to identify five possible landing sites for the mission’s Philae probe in November 2014.

But this intense mapping period will provide much more than just target sites for the lander. Rosetta’s extensive suite of multi-wavelength cameras, spectrographs, mass spectrometers and other scientific instruments will provide a comprehensive understanding of the characteristics of the comet, its composition and environment, both by studying the nucleus itself remotely and by measuring the properties of the gas, dust and plasma in the coma around the comet. This initial ‘close-in’ phase, before the comet becomes more active and Rosetta needs to move further away, will be particularly critical.

One of the unique aspects of the mission is that it will ride along with the comet for more than year, in tandem as they pass through the closest approach to the Sun in August 2015 and beyond. The observations made in 2014 will provide initial activity measurements and a detailed characterisation of the nucleus that will be fundamental in following the evolution of the comet during the entire escort phase.

Rosetta’s first view of the comet since 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 kilometres. The comet is circled in the narrow-angle view; the globular star cluster M107 can also be seen



→ LANDING ON A COMET

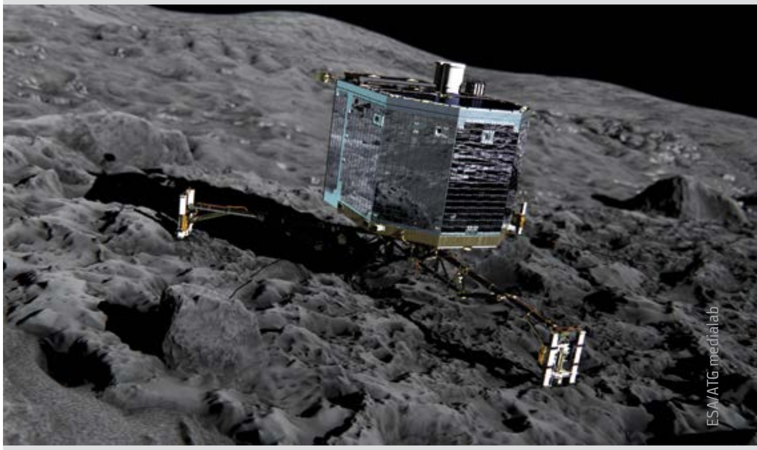
Beyond the significant first rendezvous with a comet, Rosetta will attempt to go one step further: landing on it.

In November 2014, after a safe but scientifically interesting landing site has been identified and studied, Rosetta will skim a few kilometres above the surface and release the 100 kg Philae lander towards it. Philae will fall slowly without propulsion or guidance, gathering speed under the comet's weak gravity. Meanwhile, the orbiter will continue on its path away from the nucleus, looking back to monitor Philae's descent with its cameras and via radio tracking.

After several hours, Philae will reach the surface at roughly walking pace. Its momentum will ensure that it lands with appreciable force, but as the surface gravity is only a few tens of millionths of that on Earth, a sophisticated system will 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, a harpoon will fire to lock the probe onto the surface, and a small thruster on top will counteract the impulse of the harpoon.

Once anchored to the nucleus, Philae will begin its primary science mission, based on its 64-hour initial battery lifetime. The lander also has solar panels and it is hoped that it will be able to recharge its batteries to extend the lifetime, but 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 onboard laboratory for analysis. The data will be relayed to the orbiter, ready for transmission back to Earth at the next period of contact with a ground station. These in situ surface measurements at one location will be used to complement and calibrate the extensive remote observations made by the orbiter covering the whole comet. Low-frequency radio signals will be beamed between Philae and the orbiter through the nucleus, to probe its internal structure.



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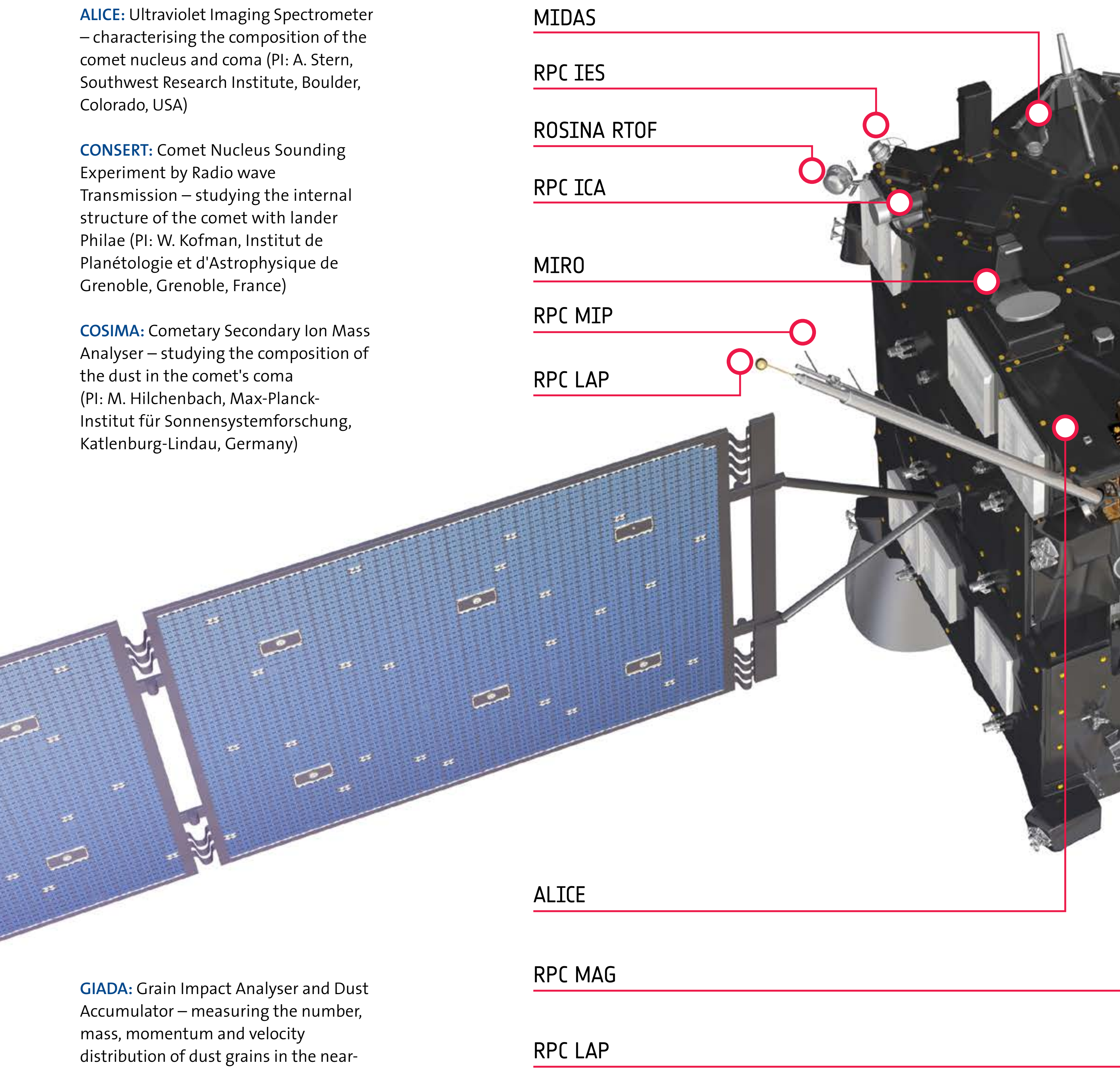
→ THE ROSETTA ORBITER

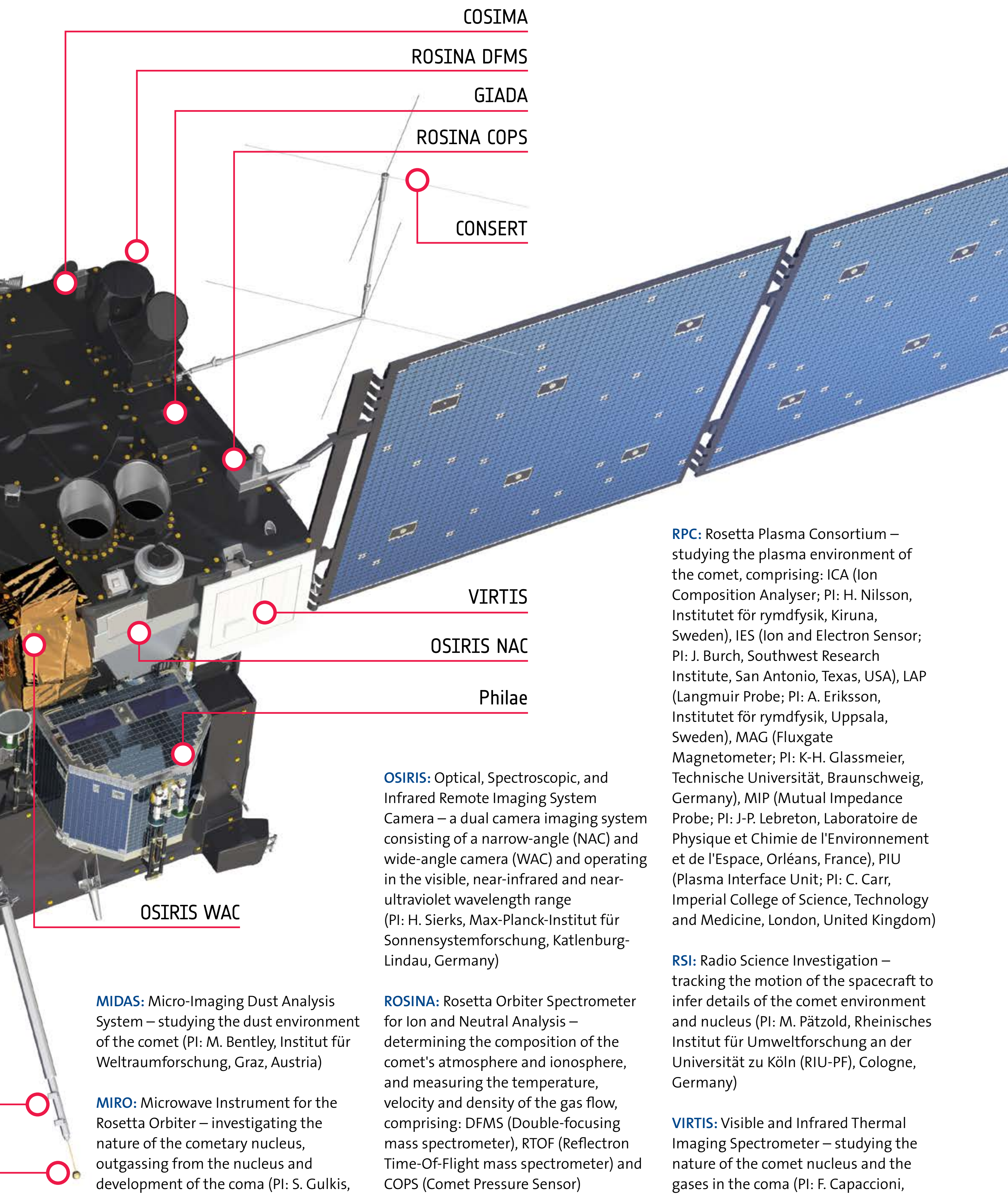
ALICE: Ultraviolet Imaging Spectrometer – characterising the composition of the comet nucleus and coma (PI: A. Stern, Southwest Research Institute, Boulder, Colorado, USA)

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)



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)

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)

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)

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)

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 will deploy the Philae lander to the surface of comet 67P/Churyumov–Gerisamenko for in situ analysis with its 10 instruments:

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)

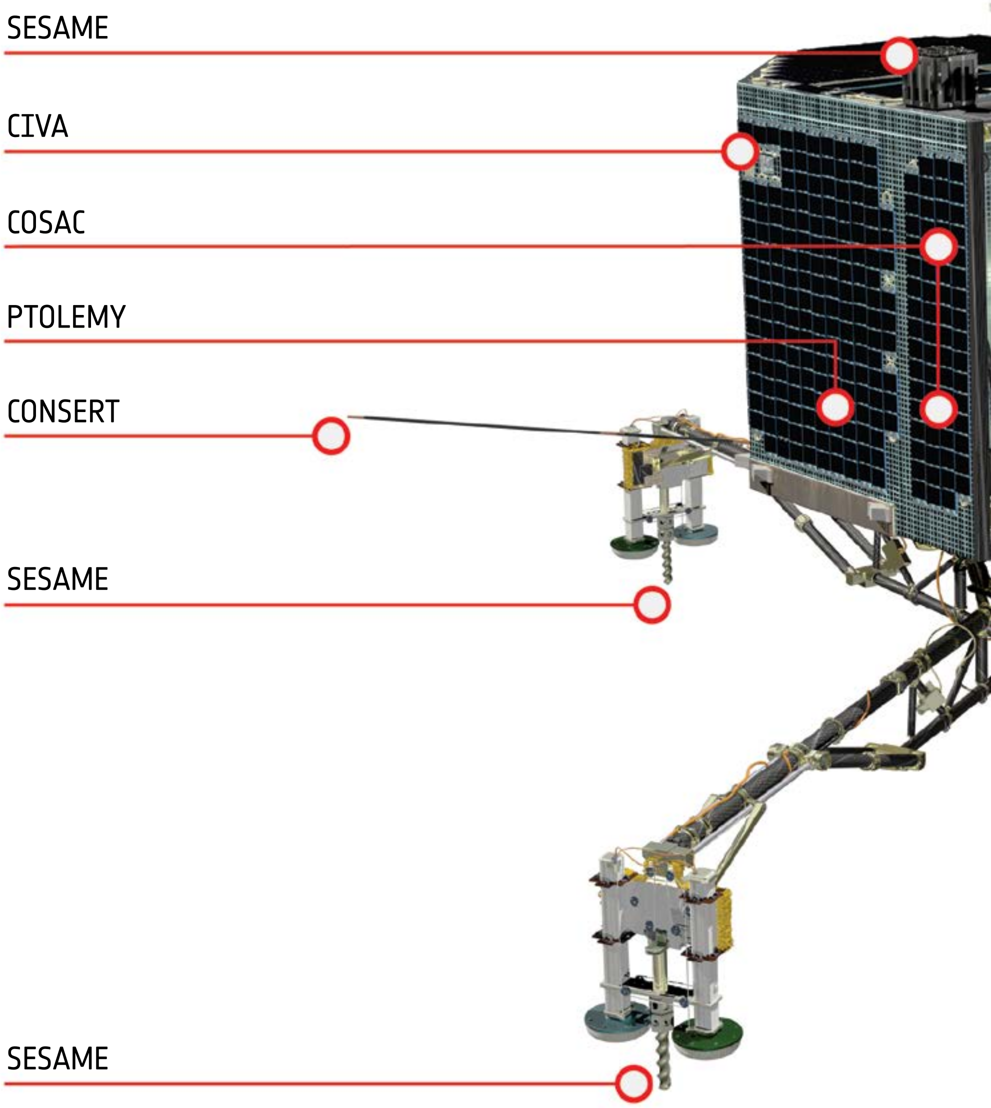
CIVA: Comet Nucleus Infrared and Visible Analyser – six cameras to take panoramic pictures of the comet surface (PI: J-P. Bibring, Institut d'Astrophysique Spatiale, Université Paris Sud, Orsay, France)

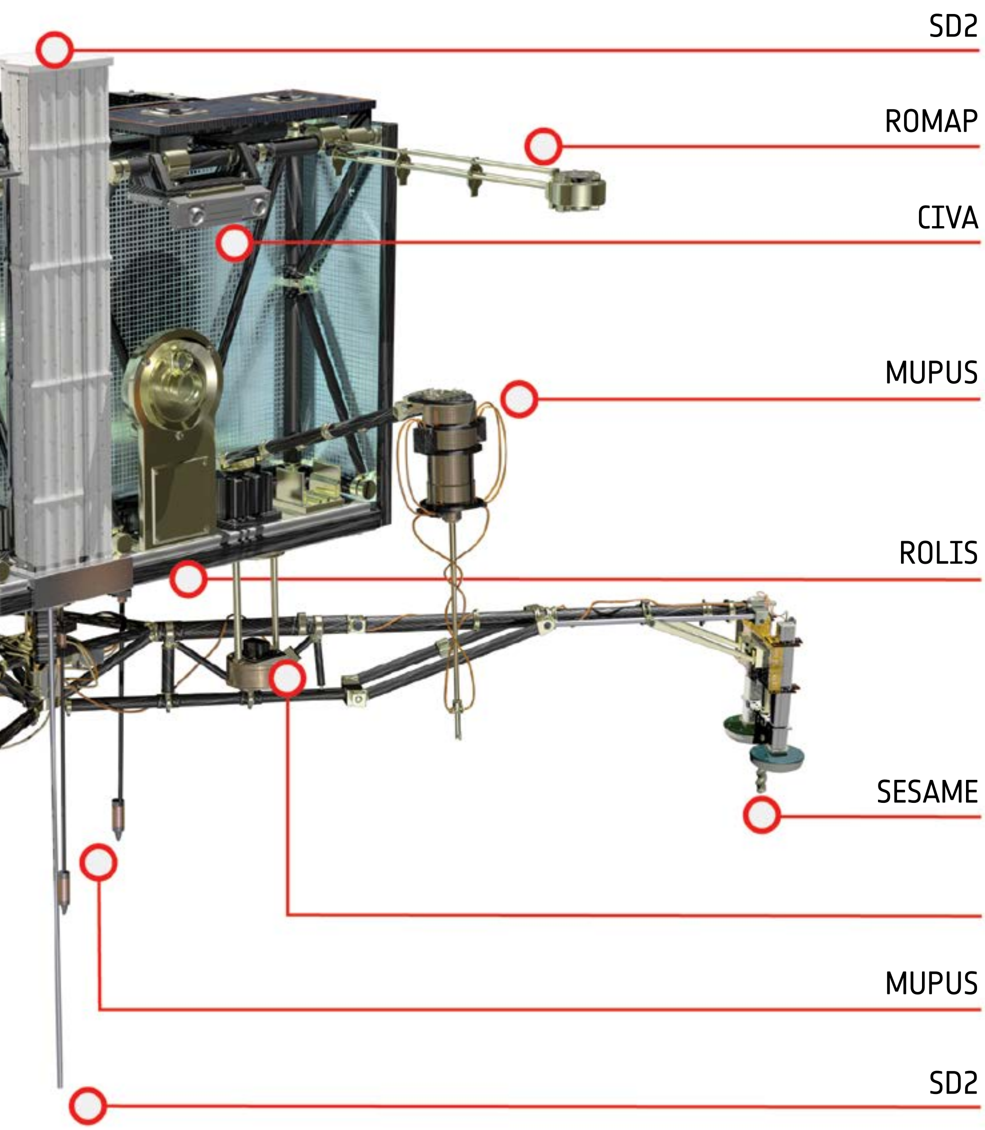
CONSERT: COmet Nucleus Sounding Experiment by Radiowave Transmission – studying the internal structure of the comet nucleus with Rosetta orbiter (PI: W. Kofman, Institut de Planétologie et d'Astrophysique de Grenoble, Grenoble, France)

COSAC: The COmetary SAmpling and Composition – 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)

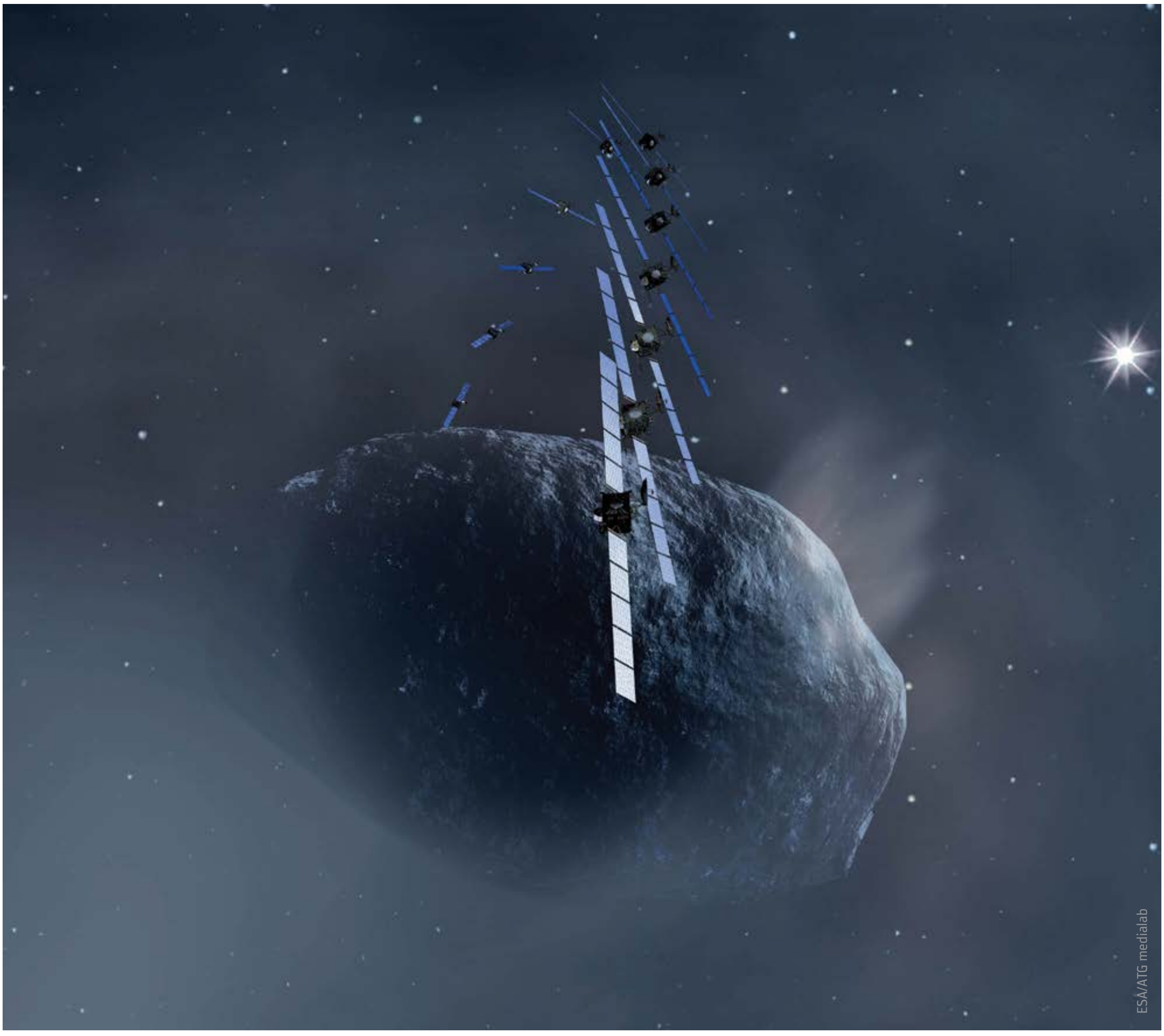
SESAME: Surface Electric Sounding and Acoustic Monitoring Experiments – three instruments to measure properties of the comet's outer layers. The Cometary Acoustic Sounding Surface Experiment (CASSE, PI: K. Seidensticker, German Aerospace Center, Institute of Planetary Research, Asteroids and Comets, 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.

→ ESCORTING A COMET

After the rendezvous and landing, Rosetta will move on to the escort phase. As the comet moves closer to the Sun during 2015, it will heat up and become more active, throwing out increasing quantities of gas and dust. Combined with the low gravity, this ever-changing activity will make for hugely challenging operations, trying to keep the spacecraft close enough to the comet to do good science, while ensuring that it remains safe.

Rushing together towards the inner Solar System at over 100 000 km/h, Rosetta will stay nearby, manoeuvring around the comet at walking pace, collecting dust and gas samples while monitoring the evolving conditions on the surface as the comet warms up.

At their closest approach on 13 August 2015, they will be 185 million kilometres from the Sun, between the orbits of Earth and Mars. Rosetta will continue to escort the comet throughout the remainder of 2015, as they head back away from the Sun again and as activity begins to subside. The escort phase will thus provide unique results on the dynamic waxing and waning of a cometary nucleus on a daily basis, the first time that this will have been achieved from close by.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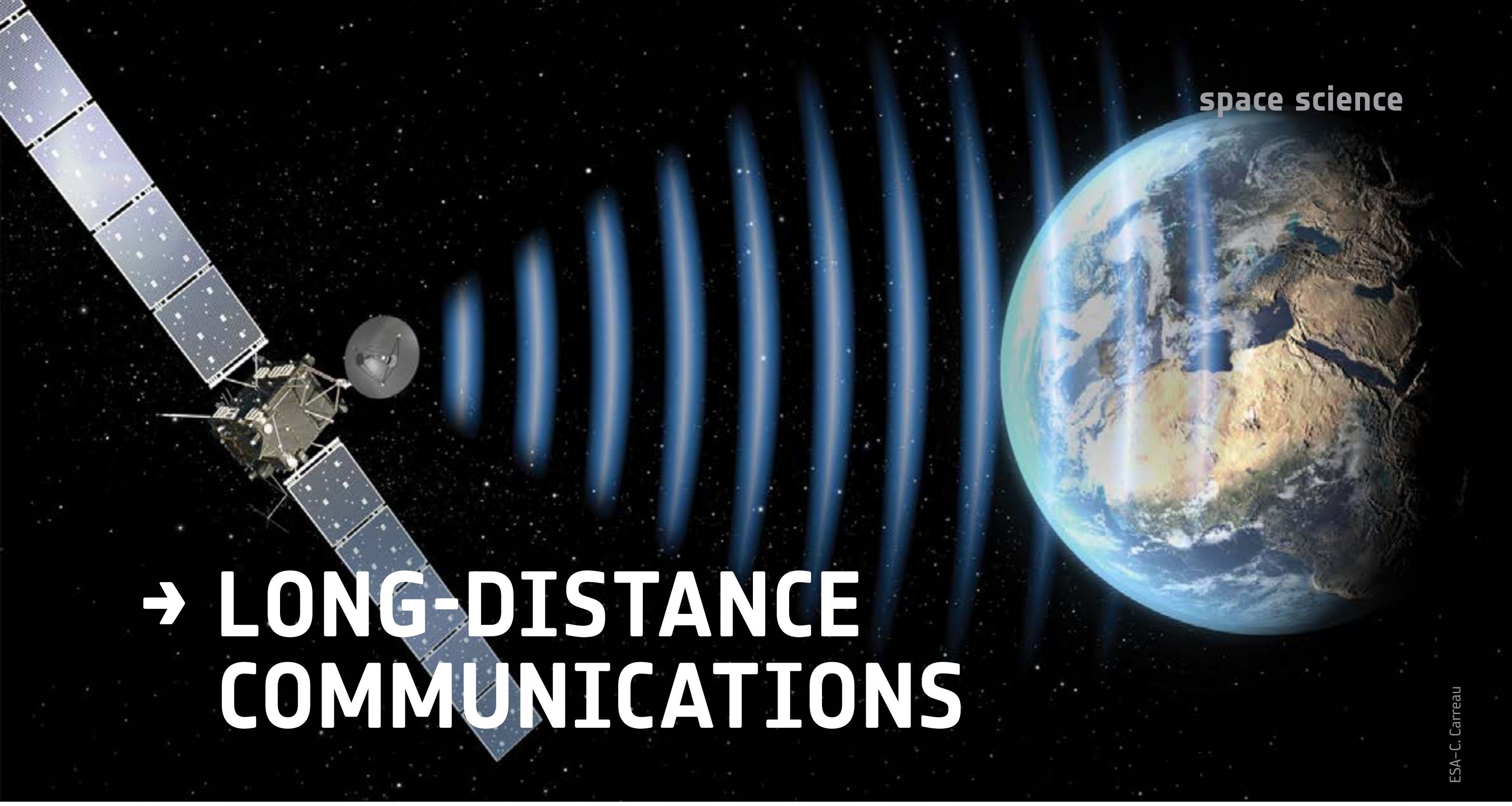


→ LONG-DISTANCE COMMUNICATIONS

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. ESA's European Space Operations Centre (ESOC) in Darmstadt, Germany is responsible for overall control of the mission and its instruments, 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.

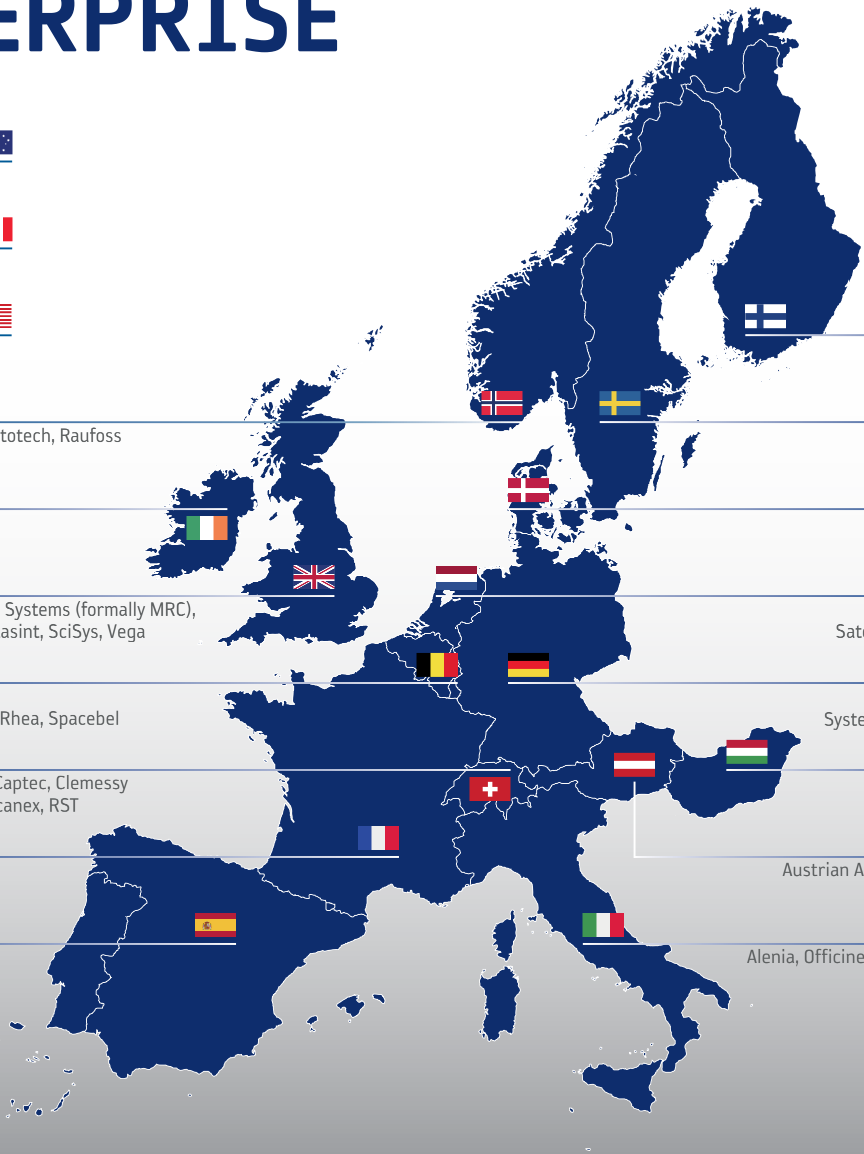
Radio communications between Rosetta and the ground use the 35 m-diameter deep-space antennas of ESA's Estrack network in New Norcia in Western Australia, Cebreros in Spain, and Malargüe in Argentina. Travelling at the speed of light, the time the radio signals take to cover the distance between Rosetta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

There will also be periods when communications are interrupted, either because none of the deep-space dishes on Earth is visible to the spacecraft or Rosetta is unable to turn its main antenna towards one. During these times, scientific data will be stored in Rosetta's solid-state memory for transmission at the next opportunity. Again depending on the distance during the mission, the rate at which data can be sent from Rosetta to Earth varies between 10–91 000 bits per second.

ESA's 35 m-diameter deep-space dish antenna at Cebreros, Spain

Rosetta mission control team at ESOC

→ AN INTERNATIONAL ENTERPRISE



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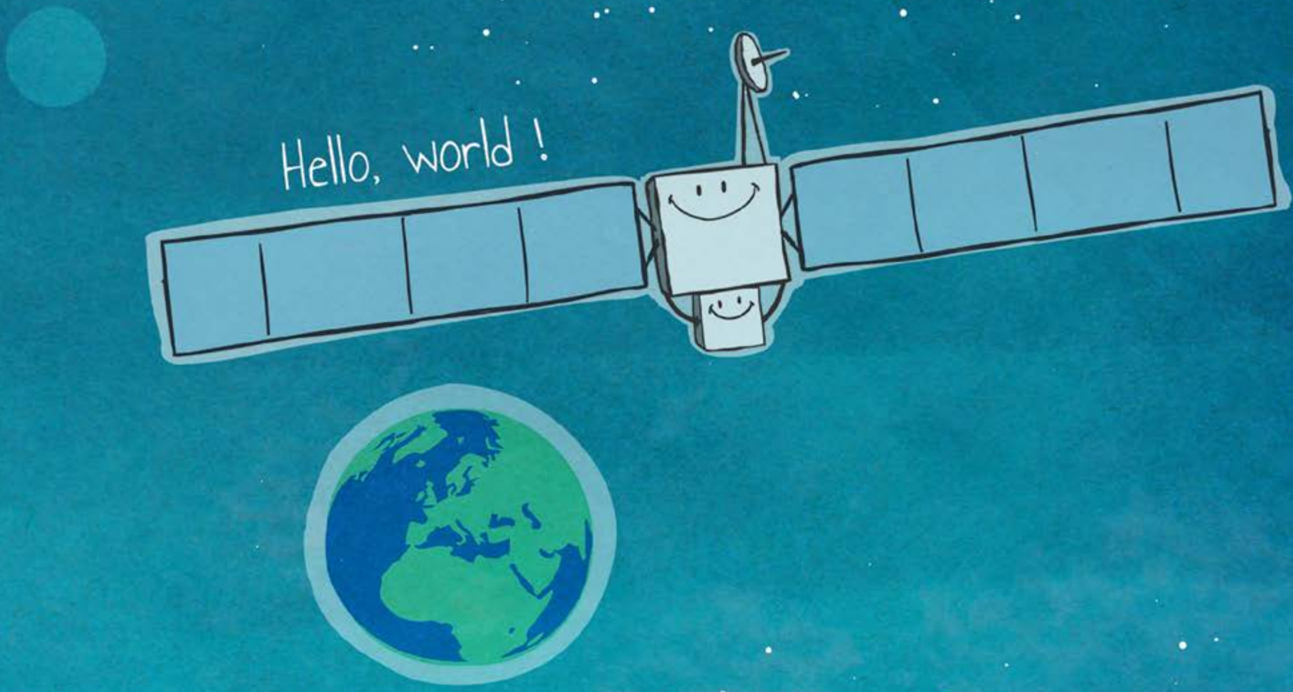
The industrial team that built Rosetta involved more than 50 companies from 14 European countries and the US. The prime spacecraft contractor was Astrium Germany, with major subcontractors Astrium UK (responsible for the spacecraft platform), Astrium France (spacecraft avionics) and Alenia Spazio (assembly, integration and verification).

Scientific teams from institutes across Europe and the US provided the orbiter's scientific instruments, while a European consortium of agencies and institutes headed by the DLR German Aerospace Center provided the lander and its instruments.

Spacecraft vital statistics

Size	2.8 x 2.1 x 2.0 m with two 14 m-long solar wings
Launch mass	Orbiter: 2900 kg (including 1670 kg propellant and 165 kg science payload); Lander (Philae): 100 kg
Launcher	Ariane 5 G+
Solar array output	1100 W at 3.4 AU, 440 W at 5.29 AU
Propulsion	24 bipropellant 10 N thrusters

➔ JOIN THE ADVENTURE



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