CNES MAG

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ROSETTA-PHILAE

THE ADVENTURE CONTINUES

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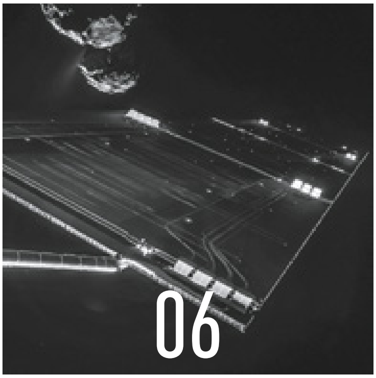
INSIDE



PARTNERS

Mentioned in this issue: p.15 - IAS space astrophysics institute, Paris; p.23 IPAG planetology and astrophysics institute, Grenoble; p.26 CDPP plasma physics data centre; p.32 LESIA space and astrophysics instrumentation research laboratory (CNRS); p.34 IRAP astrophysics and planetology research institute.

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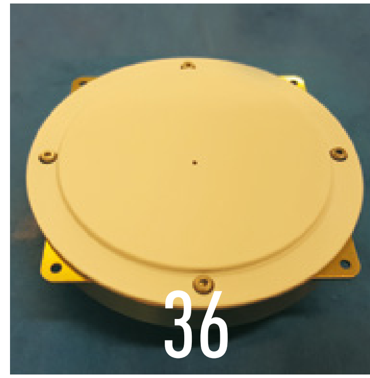

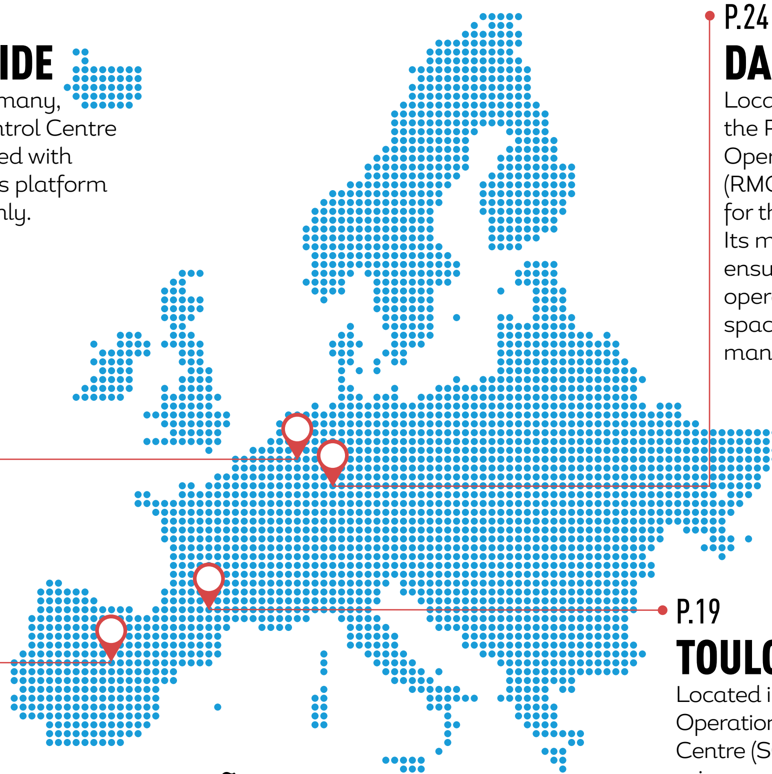

P.20

WAHNHEIDE

Located in Germany, the Lander Control Centre (LCC) was tasked with keeping Philae's platform running smoothly.

P.24

DARMSTADT

Located in Germany, the Rosetta Mission Operations Centre (RMOC) is the main centre for the Rosetta orbiter. Its missions included ensuring the smooth operation of the Rosetta spacecraft bus and orbital manoeuvres.

P.19

TOULOUSE

Located in France, the Science Operations and Navigation Centre (SONC) is where Philae science operations were planned. Its missions included monitoring the lander's 10 experiments, processing data, selecting the landing site, optimizing the landing trajectory and locating Philae after landing.

VILLANUEVA DE LA CAÑADA

Located in Spain, the Rosetta Science Ground Segment (RSGS) is where science operations for the Rosetta orbiter's 11 experiments were planned. It also houses the mission's long-term data archive.

CONTRIBUTORS

FRANCIS ROCARD

An astrophysicist and CNES's expert for solar system programmes, Francis Rocard was involved in every step of the Rosetta mission, from the obstacles it had to overcome at the outset to its rich harvest of science data. Working in permanent contact with science and engineering teams, he was the objective eye watching over this out-of-the-ordinary mission.

JOËLLE DURAND

Joëlle Durand has taken over from Philippe Gaudon as CNES's Rosetta mission project leader. Previously behind the controls at the Science Operations & Navigation Centre (SONC), she was there during Philae's nail-biting descent to the comet and when it returned its first data. She has now left the SONC to focus on preserving the mission's precious data.

THIERRY GENTET

This former CNES engineer today pursues his two passions—the space adventure and film—at Mira Productions. He makes documentaries for television and corporate films for CNES, like the one put together with Steve Balestreri about the Rosetta programme viewable on line in the digital version of CNESMAG.

JEAN-MICHEL MARTINUZZI

Jean-Michel Martinuzzi is in charge of science education projects at CNES's Youth Education department. Philea, the educational replica of Philae, was his brainchild. After rallying education authorities in the Paris region around this project led by the Ministry of Education, he helped to get it up and running in a little over a year. Although now engaged on other projects, he is still helping to manage Philea operations.

CNESMAG

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EDITORIAL

1994: The member states of the European Space Agency decide, at France's initiative, to study a comet's nucleus in situ and search for the origins of life.
2004: Ariane 5 lifts off from the Guiana Space Centre and Rosetta and Philae begin a 10-year game of cosmic billiards.
2014: On 6 August, Rosetta goes into orbit around the nucleus of comet Churyumov-Gerasimenko and on 12 November Philae lands on its surface.
These three dates have secured Europe's place in the annals of space science and shown just what our continent can achieve when it sets its mind to the task. It took genuine political vision to engage a €1.5-billion programme that would not deliver its expected results for another 20 years. It also took remarkable industrial prowess to build and launch Rosetta and Philae. And it took extraordinary scientific expertise to rendezvous with a comet and land on its nucleus.
CNES of course played a pivotal role in each of these three steps along the road to success. And today, 55 years after our agency's inception, its scientists and engineers are inventing the future of space and pursuing Rosetta and Philae's fabulous adventure—because at the end of the day, we are all in a way the children of the comet…

JEAN-YVES LE GALL
CNES PRESIDENT

Selfie of Rosetta approaching comet Churyumov-Gerasimenko taken by its CIVA camera on 7 October 2014, 16 km from the surface.

VIDEO

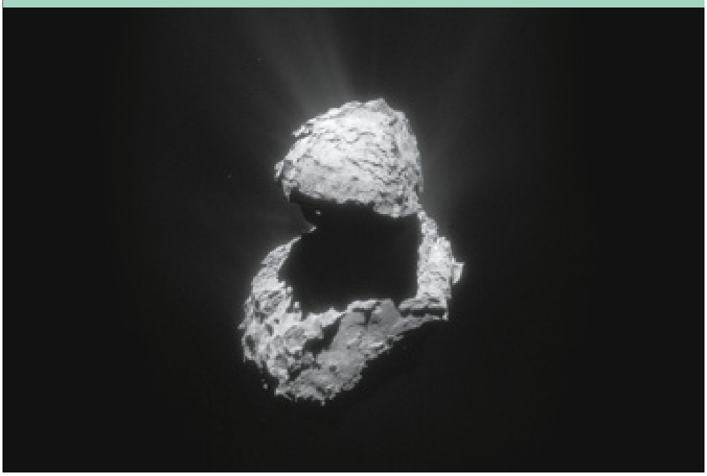
Rosetta mission finale live

MISSION FINALE

Goodbye to a comet

For certain, the Rosetta mission that ended last September with the orbiter impacting the nucleus of comet 67P/Churyumov-Gerasimenko after a controlled descent will mark the history of space exploration. Having achieved numerous firsts, collected a wealth of data and made major discoveries, this ambitious mission–a veritable space odyssey, given the length of its journey and the operational obstacles it had to overcome–has indisputably been a huge success. The first results hold out the tantalizing prospect of unlocking some of the secrets of the origin of life in the not-too-distant future.

MORE INFORMATION:
CNES.FR/CNESMAG71-ROSETTA-FIN-MISSION



DISCOVERY
TWO HEARTS AS ONE

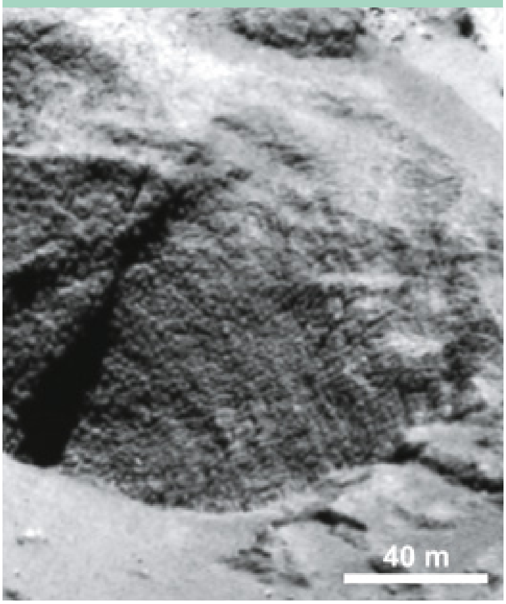
The first discovery of the mission came in the summer of 2014 when pictures revealed the comet's double-lobed nucleus. Was this the result of erosion of an initially larger nucleus, or of a low-speed collision between two separate nuclei that subsequently merged? The second hypothesis is now thought the most likely explanation. Scientists looked at how layers sloped away from the vertical to see if there was any continuity between them. Their very exhaustive study clearly leans towards two separately formed nuclei and strongly constrains current comet formation models. As comets are very fragile objects, the non-destructive collisions like the one that probably gave 67P its form must have occurred at speeds much lower than anything previously imagined.

500

No fewer than 500 scientists and engineers worked on Rosetta in Europe, 150 in France, across 17 research laboratories and science institutes.

MAGNETIC ATTRACTION
A COMET FULL OF SURPRISES

Another surprise discovery came from Philae's ROMAP magnetometer. Many models assume the presence of a magnetic field to more accurately reflect the process of comet formation and cohesion, but ROMAP's results leave no room for doubt: there is not the slightest trace of remanent surface magnetism on 67P and therefore in its inner core. This fundamental finding means theorists will have to completely re-examine their comet nuclei and planet growth scenarios, only this time taking magnetic fields out of the equation. But the comet is still affected by the magnetic field of the solar wind and a complex mechanism of interactions between the solar wind and the comet's coma forms a 'magnetic cavity' where the field is cancelled out, a phenomenon observed for the first time on 67P.



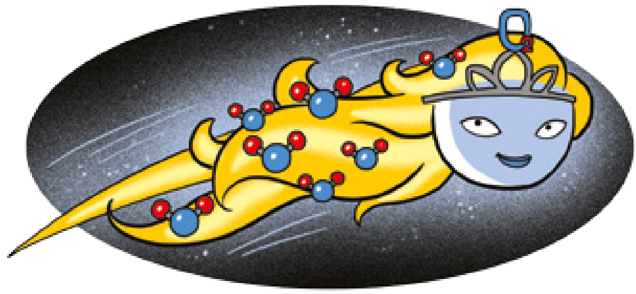
TEXTURE

A COMET WITH GOOSEBUMPS

It certainly gets very cold on 67P (as cold as –230°C), but that's not why it has 'goosebumps', the name mission scientists have given to the lumpy structures on a scale of three metres the Rosetta orbiter's OSIRIS camera spotted on the steep walls of collapsed pits on the comet's surface. These structures are in fact thought to be 'cometesimals', the result of agglomeration of dust, ice, silicate and organic particles up to a size of one metre from which the comet formed. This would agree with solar system formation models, the only difference being that the 'lumps' on Churyumov-Gerasimenko are a little larger than expected. The findings do not therefore fundamentally controvert these models, but rather call for further research to complement them.

OUTGASSING

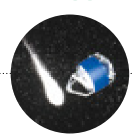
AN OXYGEN-BREATHING COMET



Undoubtedly one of the most surprising discoveries made by Rosetta and Philae is the unexpectedly large amounts of oxygen in comet 67P's coma, forming up to 10% of measured water vapour. This is a big surprise for scientists, as oxygen is an extremely volatile molecule that reacts easily with other compounds, for example to form water or ozone. All of this oxygen around Churyumov-Gerasimenko points to the comet having formed at very low temperature, a long way from the sun, and suggests it has evolved very little since. The finding confirms the comet was an excellent choice for the Rosetta mission, whose aim was to probe the secrets of the most primitive celestial bodies in the solar system.

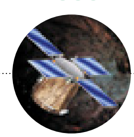
30 YEARS EXPLORING SMALL BODIES

1986



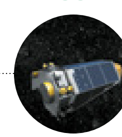
The Soviet Vega 1 and Vega 2 probes and Europe's Giotto probe fly by Halley's Comet. Giotto changes how we see comets forever.

2000

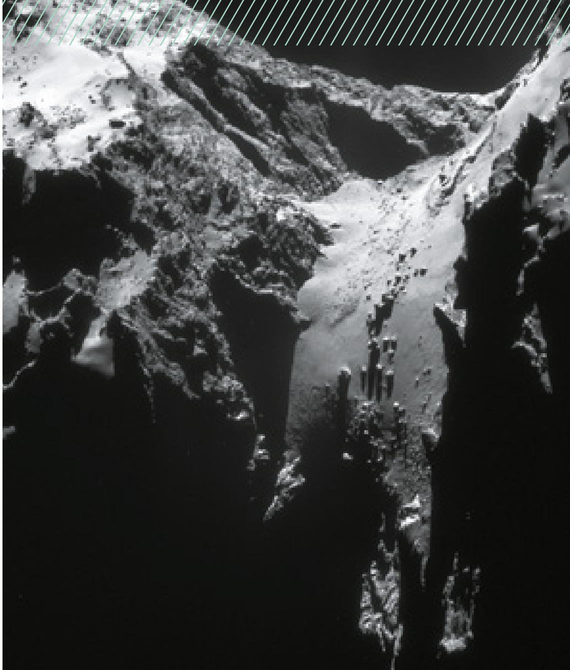


The NEAR probe encounters asteroid Eros.

2001



The Deep Space 1 probe flies by Comets Wilson-Harrington and Borrelly.



INFOG

Active infographic: mission results

RECORD-SETTER
A TREASURE TROVE OF MOLECULES

The previous record for the number of molecules discovered in the vicinity of a comet was 40, held until now by Hale-Bopp, a bright comet observed in detail from Earth in 1997. Thanks to Rosetta and Philae, Churyumov-Gerasimenko has now smashed this record with more than 60 molecules catalogued. The jewel in the crown is glycine, an amino acid found in the comet's coma and one of the basic building blocks of proteins that is involved in cell processes. Its unambiguous detection lends extra weight to the hypothesis that comets could have seeded our planet with the ingredients for life.

10 BILLION TONNES

Previously unknown, comet 67P has revealed some of its secrets. Its nucleus is about 4.1 x 5.4 kilometres, the size of the first six arrondissements of Paris. Its mass is estimated at 10 billion tonnes and its nucleus spins on itself in 12 hours and 24 minutes.

€250 MILLION

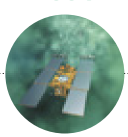
Funding for the Rosetta mission was spread over 20 years. In all, France contributed €250 million, equivalent to 20 cents per year for every French citizen. The total cost of the mission to Europe was €1.3 billion, the price of four Airbus A380 aircraft.

70 EXPERTS

The choice of Philae's landing site was CNES's responsibility. To this end, the agency's Toulouse Space Centre brought together 70 experts from Europe and the United States to select the best site. Early in August 2014, the experts analysed ten candidate sites and downselected them to five. Each site was reviewed in detail in pictures from the OSIRIS camera, closely enough to count boulders more than one metre across. Three weeks later, two sites were chosen and Agilkia was validated by ESA as the primary landing site.

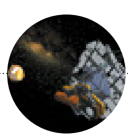
IN THE SOLAR SYSTEM

2004



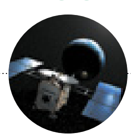
Stardust flies by comet Wild 2 and collects dust samples that it returns to Earth in 2006 / Launch of Rosetta.

2005



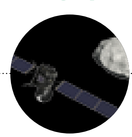
Deep Impact sends an impactor crashing into the surface of Comet Tempel 1 to excavate a crater and debris for analysis during its flyby.

2010



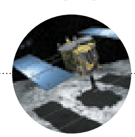
The Hayabusa probe returns samples from asteroid Itokawa to Earth.

2014



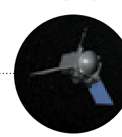
Rosetta arrives at its destination and Philae lands on the comet, beginning a two-year mission. 2016: Rosetta ends its mission with a landing on the comet.

2020



Hayabusa 2 to return samples from asteroid Ryugu.

2023



OSIRIS-REx to return samples from asteroid Bennu.

COMETARY BEHAVIOUR
COMPLEX PROCESSES REVEALED

Churyumov-Gerasimenko caught in a burst of activity.

An area where in-situ analysis of comet 67P has proved most instructive is in understanding the processes that occur as comets approach the sun. One of the mysteries still surrounding comets is why they are more active after passing perihelion—their closest point to the sun—than during their approach, despite being the same distance away, possibly due to thermal inertia and an accumulation of heat. In the case of 67P, heat was indeed seen to accumulate over a much shorter period, with temperatures rising sharply by several tens of degrees in a same region in sunlight for a little over six hours. Once this wave of heat reaches an icy zone, the ice evaporates and generates an overpressure, but as night falls, the surface freezes instantaneously and the temperature drops 50 degrees down to a depth of 10 centimetres. However, the large amounts of heat built up during the day continue to propagate to the comet's interior and gas escapes through cracks, condensing on the underside of the now very cold surface crust. Ice thus accumulates under the surface every night and escapes in the form of vapour jets as soon as temperatures rise at daybreak. Reaching speeds of 1,000 to 2,000 km/h, these jets contain more or less large grains of organic matter, the smallest and fastest of which are dispersed in the comet's tail, while the largest fall back to the surface where they form a layer of dust found mainly in the northern hemisphere.

CAPTURING A COMET OUTBURST

Of all the objects in the solar system, comets are without doubt the most unpredictable, sometimes exhibiting strange outbursts of activity that rarely bear any relation to their proximity to the sun. Such an event was caught by Rosetta on comet 67P in February 2016, when it was in an ideal position to study the outburst close up. Numerous clues observed throughout the mission seem to suggest that landslides originating from steep slopes located at the boundary between two layers are the cause of these outbursts. When one of them collapses as a result of the slow process of day-night variations, it exposes fresh water ice to direct solar illumination. The ice then immediately turns to gas, dragging surrounding dust with it to produce a debris cloud. Although no landslide has been observed directly, all signs point towards this scenario. Not all outbursts are caused by such landslides, however, and other factors may be at play.

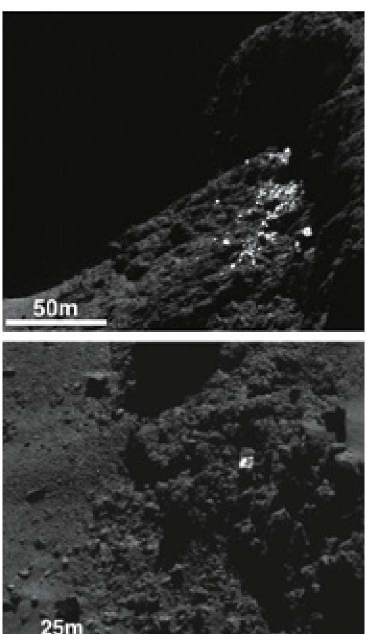
ACTIVITY

A RICH VARIETY OF JETS

A comet's activity is visible chiefly in the form of jets, which are usually narrow and rectilinear, but not always. Scientists have built a 3D model of comet 67P to reveal where its jets are coming from. They are emerging from circular pits or 'sinkholes' and cavities that are abundant in its northern hemisphere and sometimes span 100 metres and are just as deep. However, in a specific region that has been named Imhotep, the comet's activity is not forming pits but round features that grow day by day for several weeks. The process forming these features is not clear, but is likely related to the nature of the subsurface of the very flat terrain in this region.

100 **METRES**

Jets outgassing from the comet are emerging from circular pits or 'sinkholes' sometimes spanning 100 metres and just as deep.



ISOTOPE

HEAVY WATER HINTS AT COMETARY ORIGINS

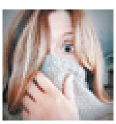
Another clue suggesting the comet formed at very low temperatures is the proportion of deuterium—an isotope of hydrogen—in its water vapour. As the amount of deuterium in the water molecules of cometary ice is inversely proportional to the temperature at which they formed, comet 67P/Churyumov-Gerasimenko's constituents clearly came together as the result of grains condensing in a very cold region of space when the solar system was formed. These grains may themselves have formed in the interstellar medium before the primordial solar cloud collapsed.In fact, comet 67P has proved to be the richest in deuterium ever observed. Does this mean Earth's water could not have come from comets? It's not quite as simple as that. Comets are classed in two main families with different proportions of deuterium, but this ratio of deuterium to ordinary hydrogen (or D/H ratio) can also vary greatly between comets of the same family, depending on where exactly they formed. In the final analysis, the water on Earth probably comes from a mix of sources, chiefly asteroids and comets, but also remnants of water from the primitive planet.

#COMMUNITY

Every day, CNES engages with you on social networks and you share your thoughts and questions with us. Join the conversation!

@ NAJAT BELKACEM
Minister of Education, Higher Education and Research

Congratulations to all the researchers @CNES @ESA_Rosetta on this extraordinary scientific success #Philae #PoseToiPhilae #Rosetta !



@ ZE_B__ÉA
Full-time Mum, part-time pianist (Liszt, Rachmaninov) and photographer, but above all a nutritionist from Marseille!

@CNES #FF_Special_Philae pulling out all the stops to communicate with Rosetta! Well done the CNES Team! You made a dream come true! #RepondsPhilae

@ MYLLOU
All my (re)tweets are in my/your/his humble opinion.

Well done @CNES @ESA_Rosetta @esaoperations and of course @Philae2014! So exciting, captivating, breathtaking, awesome... #Philae

VINCENT DUPONT
30 September 2016

It's kind of weird it's all over now after following the mission for many months. Well, not quite over, as we're bound to learn loads of new things from all the data Rosetta sent back. Well done everyone who worked on this fine project and shared it with us.

XAVIER BAR
30 September 2016

All I can say is well done, what an amazing feat, you landed a speck of dust on a grain of sand in the middle of the Pacific Ocean...

SETIA BLISS
30 September 2016

It's hard to imagine all the years of work that went into it... And to have watched it from cradle to grave. But it's not the end, just the beginning of a new adventure. Well done everyone.

CNESfrance @CNES YouTube CNES

VIDEO

A giant leap in understanding comets

Q & A

JEAN-PIERRE BIBRING

ASTROPHYSICIST AND PHILAE LEAD SCIENTIST Jean-Pierre Bibring believes Rosetta marks a turning point in our understanding of comets, revealing new insights into how the solar system formed. He is also fully conscious of CNES's key role in the mission's success.

Q & A

NOW THE ROSETTA-PHILAE MISSION IS OVER, WHAT IS YOUR INITIAL ASSESSMENT?

Jean-Pierre Bibring: This mission has marked a major step forward, not only in cometary science but also in solar system exploration, by revealing the role comets could have played in its evolution. There's a world of difference between what we knew about the solar system in the late 1980s and what we now know from space exploration missions. We've discovered the amazing diversity of planetary worlds and how they formed from the same primordial cloud. We're only just beginning to understand how that diversity came about, and Rosetta and Philae are making a big contribution to that quest. They are piercing the secrets behind what drove the formation of the young solar system and the primitive ingredients that were present, as we seek to solve the mystery of how life emerged and evolved on Earth.

"THERE'S A WORLD OF DIFFERENCE BETWEEN WHAT WE KNEW ABOUT THE SOLAR SYSTEM IN THE LATE 1980S AND WHAT WE NOW KNOW FROM SPACE EXPLORATION MISSIONS."

DID THE MISSION LIVE UP TO ITS PROMISES IN THIS RESPECT?

J.-P. B.: Yes, absolutely. It's transformed how we see comets and the role they could have played in the process of planetary evolution. Seeing that Rosetta and Philae were conceived more than 25 years ago, when key questions about planetary evolution weren't even being addressed yet by scientists, it was far from certain they would advance science in this area. But they have, and in the most brilliant fashion! For example, Rosetta and Philae have shown that comet nuclei aren't the 'dirty ice balls' we once thought. They are in fact made chiefly of organic matter, with molecular grains that are rich in carbon, hydrogen, oxygen and nitrogen, with ice and mineral grains trapped inside. These organic grains, up to several millimetres in size, are mainly what we see in images taken by Philae's CIVA camera, a remarkable record of the pristine matter from which they formed.

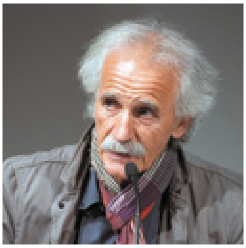
WHAT CAN WE DEDUCE FROM THAT?

J.-P. B.: We're witnessing a fundamental paradigm shift concerning how life emerged from inert matter. The appearance of life has long been viewed from the perspective of the ability to synthesize specific molecules. Rosetta has completely changed that perspective and we now suspect most of the ingredients for life were already there before planets even started to coalesce out of the same collapsing cloud and then from the protosolar disk. These component elements are thought to have accreted at the very cold outer edges of the disk into objects similar to comet 67P. So the molecules aren't 'living matter'; rather, life is the process through which these ingredients, in a particular type of environment, likely evolved as a result of auto-catalytic chemical reactions to build the insulating membranes needed to sustain life.

WHY WAS IT SO IMPORTANT TO LAND PHILAE ON THE COMET'S NUCLEUS?

J.-P. B.: Together, Rosetta and Philae have changed how we see comets, their activity, structure, properties and composition. There are big differences in the results acquired by Philae in situ on the comet's surface and those recorded by Rosetta remotely in its **coma[1].** The fact that Philae bounced on the surface, the nature of the location where it finally came to rest and all of the measurements it was able

"WITHOUT CNES, ROSETTA AND PHILAE COULD NOT HAVE MARKED THE HISTORY OF SOLAR SYSTEM EXPLORATION AS THEY DID."



JEAN-PIERRE BIBRING

ASTROPHYSICIST AT THE IAS SPACE ASTROPHYSICS INSTITUTE IN ORSAY, PHILAE LEAD SCIENTIST.

"WE'RE WITNESSING A FUNDAMENTAL PARADIGM SHIFT CONCERNING HOW LIFE EMERGED FROM INERT MATTER."

to acquire revealed unique and mostly unexpected properties. The lander bounced because there is a hard surface crust that contrasts with the porous and fragile material underneath. This crust would appear to be the result of a purely thermal sintering effect that could have acted as a protective shield if similar objects bombarded the atmosphere of the primordial Earth and seeded its oceans. The compositions measured with Philae reveal some molecules that are not quite the same as those measured in the comet's coma. These measurements were obtained from grains in the dust cloud kicked up by Philae when it touched the surface before bouncing. These grains came into contact with our instruments, which had been heated during the seven-hour descent, and released molecules at much higher temperatures than those fuelling the coma. The measurements show some complex and very interesting molecules. For now, in accordance with the usual procedure for scientific publications, only 16 molecules have been discovered by Philae, but more will follow once the results have been checked and confirmed, in particular by ground simulations. Obviously, we would have liked to switch Philae back on to heat the samples to 250°C and complete our analysis, but we have all the more reason now to pursue our research and exploration.

HOW DO YOU ENVISION THIS NEXT PHASE OF EXPLORATION?

J.-P. B.: Bringing back a sample of this organic comet 'binder' to Earth to analyse it in closer detail in the lab would be the ultimate dream. In the meantime, there are plenty of other easier steps that will be of great value. We have every reason to believe the organic material in comets is also present in other small celestial bodies, particularly asteroids that have evolved little since they were formed. The Japanese Hayabusa 2 mission is set to return samples from a carbonaceous asteroid in 2021, which will first be analysed in situ in 2018 with the MASCOT lander developed with CNES's support, and by the MicrOmega infrared microscope developed by the IAS space astrophysics institute.

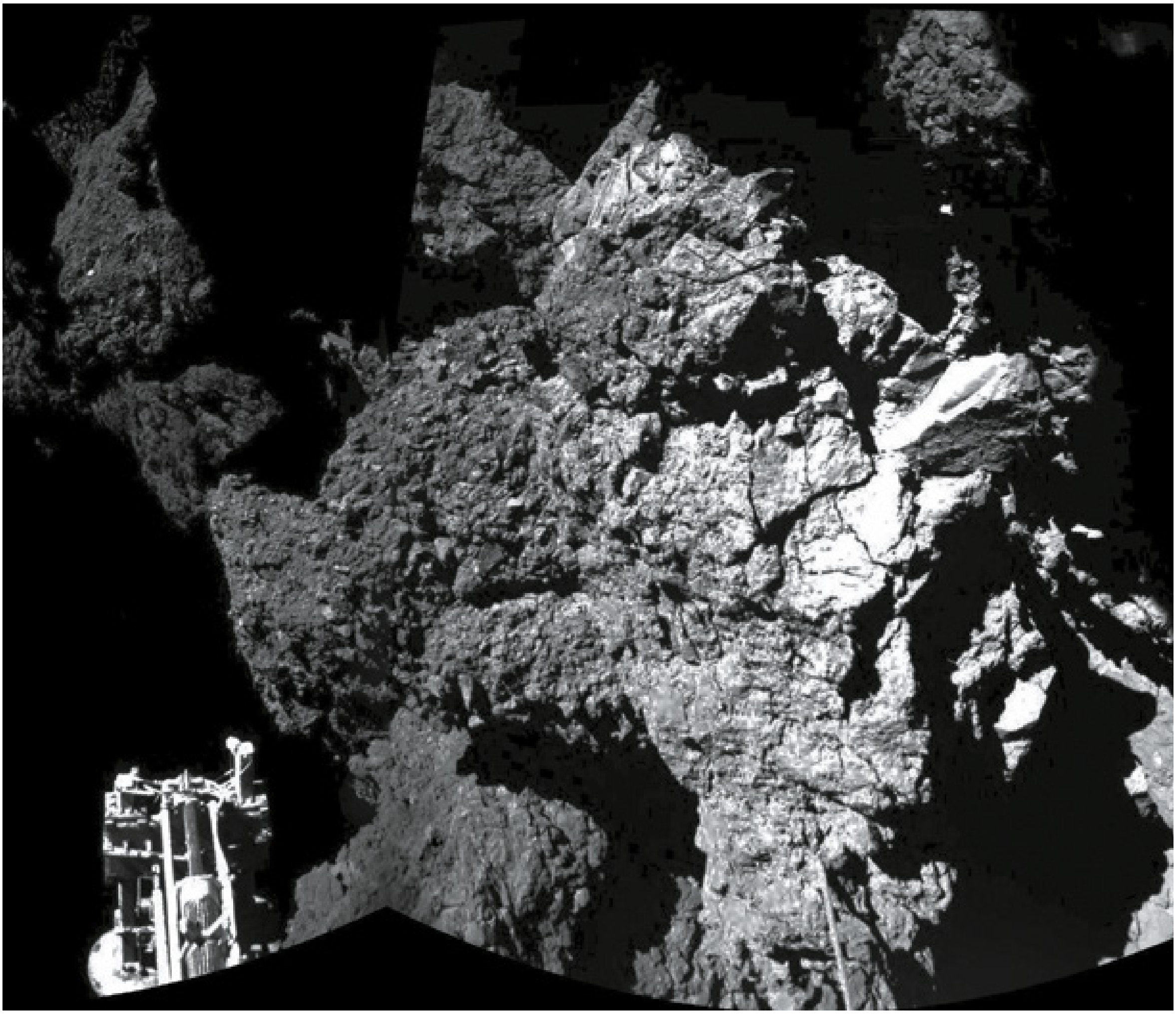
HOW DO YOU VIEW CNES'S ROLE IN THE ROSETTA MISSION?

J.-P. B.: CNES's most visible contribution to Rosetta was the Philae Science Operations & Navigation Centre (SONC) in Toulouse, which proved instrumental in the mission's success. But the agency's role didn't stop there. French science teams were closely involved, largely thanks to CNES's programmatic, technical and funding support, particularly in building the mission's instruments and systems, where its expertise was vital. Without CNES, Rosetta and Philae could not have marked the history of solar system exploration as they did.

1. As a comet gets closer to the sun, a fuzzy 'halo' or coma forms around the nucleus, which kicks up gas and dust as it warms. Two bright long tails several million kilometres long often trail behind the coma.

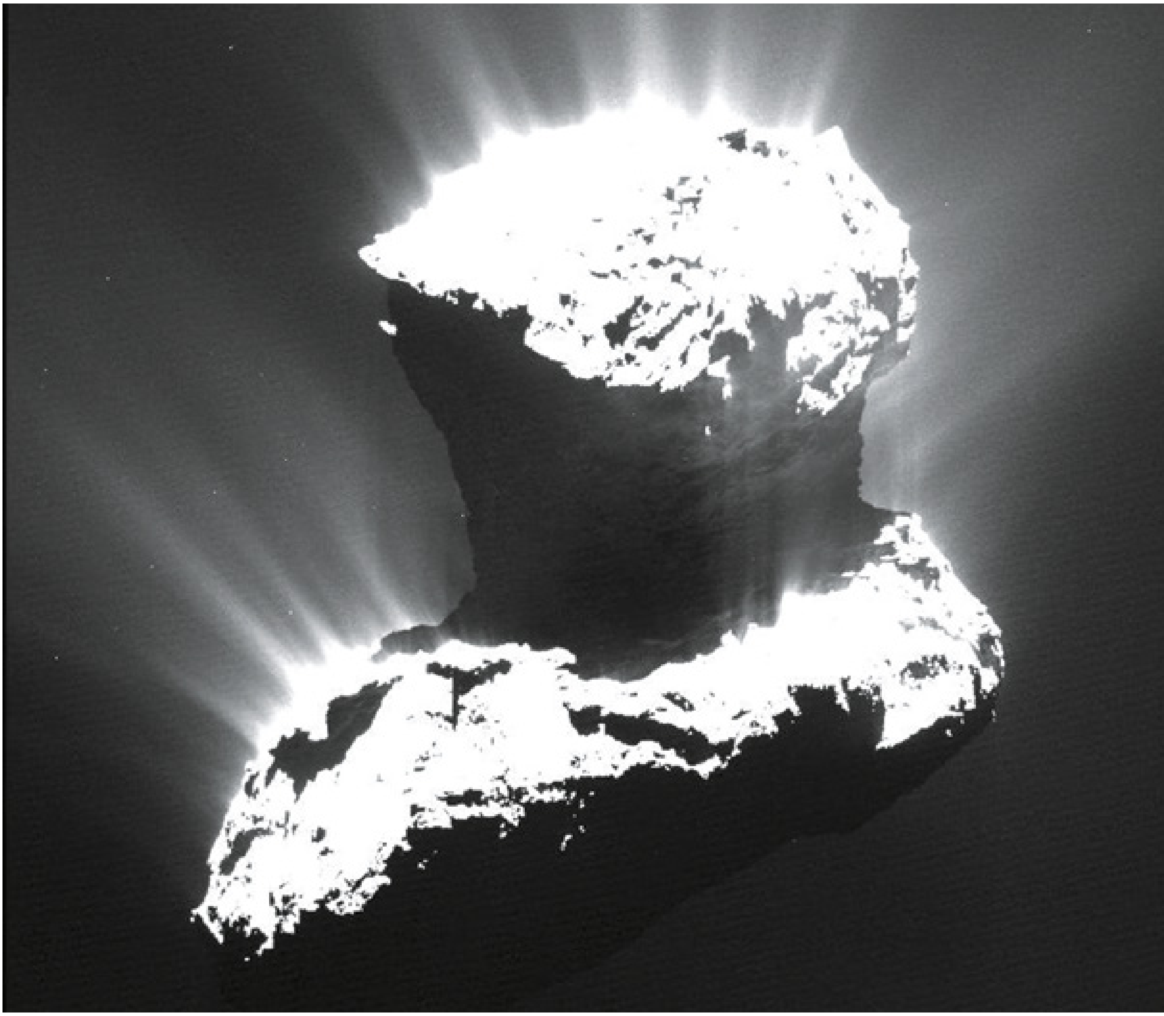
Profile

1978
Obtained PhD is astrophysics from Paris-Sud University
2003
Lead scientist for the OMEGA instrument on Mars Express
2015
Corresponding member of the French air and space academy



HISTORIC CRACKS

Philae's panoramic cameras sent back the first-ever landscape shot from the surface of a comet. The CIVA cameras were developed by the IAS space astrophysics institute. In the picture, we can clearly see one of Philae's legs touching the ground. It appears not to have suffered any damage despite bouncing hard on landing, and the CONSERT radar's antenna is fully deployed. The scene here is one to two metres from the cameras and shows cracks in the carbon-rich crust on a scale of one centimetre.



DUST TRACKS

In April 2015, the comet is still 270 million kilometres[1] from the sun, four months from its closest point of approach to Earth. Activity on its nucleus is already really intense and it is generating some 5,000 tonnes of water a day. This can be seen from the high number of gas and dust jets in the picture taken by Rosetta. The gas jets can reach velocities of up to 2,000 km/h, dragging with them dust initially ejected at very low speed. The gas is invisible but the light scattered by the dust grains shows up the jets in the picture.

1. ~ 1.8 astronomical units

IN FIGURES

INFOG

See the full infographic

25,000

Rosetta's journey took it out to 800 million kilometres from the sun, **so its solar array was designed to allow for the faint sunlight at such distances. Its solar panels were 32 metres long and offered a total surface area of 64 sq.m., composed of no fewer than 25,000 solar cells made of silicon.**

1 GRAM

ALREADY A LIGHTWEIGHT ON EARTH at 100 kilograms, Philae was as light as a feather on the comet, tipping the scales at just 1 gram due to the very weak surface gravity.

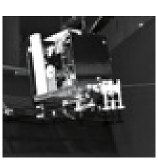
Gravitational assists

NO LAUNCHER COULD HAVE IMPARTED ENOUGH INITIAL VELOCITY TO GET ROSETTA TO ITS TARGET. The spacecraft had to overcome a serious energy handicap during its 10-year odyssey. It did so by seeking gravity 'assists', three from Earth and one from Mars. Rosetta then conserved power by going into 'hibernation' mode for 31 months, shutting down all communications with Earth. During its journey, it also flew by two asteroids.

14/10/2016

The Rosetta mission came to an end with the orbiter's controlled descent into the comet surface. Ukrainian astrophysicist Klim Churyumov passed away shortly afterwards on 14 October. In 1969, with astronomer Svetlana Gerasimenko, he discovered comet 67P to which they gave their names. On 12 November 2014, Klim Churyumov watched as Philae landed on 'his' comet from the European Space Operations Centre (ESOC) in Darmstadt, Germany.

PHILEA VS PHILAE



A lesser-known fact is that Philae has a terrestrial analogue called Philea. In 2013 and 2014, vocational baccalaureate and BTS diploma students at 15 French high schools built a replica of the lander. Cleverly dubbed Philea as a nod to the original, the replica was the result of a collaborative project undertaken in the education districts of Créteil, Versailles, Paris and Limoges in partnership with CNES, which funded the project and drafted specifications. Delivered on 6 November 2014 to the Le Bourget air and space museum, the full-scale replica of Philae features the latest technologies—more innovative and capable than those conceived 20 years ago for the original.

ROSETTA

A MISSION LIKE NO OTHER

FOR 12 YEARS, THE ROSETTA MISSION KEPT THE WORLD'S SCIENTIFIC COMMUNITY ON THE EDGE OF ITS SEATS. BUT THE ADVENTURE DIDN'T END WITH PHILAE'S LANDING ON COMET 67P/CHURYUMOV-GERASIMENKO. A KEY PLAYER IN THE MISSION ALONGSIDE ESA, CNES IS NOW HELPING TO MINE THE RICH HARVEST OF DATA RECORDED BY THE LANDER, OPENING UP NEW PERSPECTIVES FOR OUR UNDERSTANDING OF HOW THE SOLAR SYSTEM WAS BORN.

On the night of 13-14 March 1986, ESA's Giotto space probe completed a successful flyby of Comet Halley to the delight of the international scientific community. In so doing, it did much more than just take a symbolic picture of the comet, revealing new clues to how the solar system formed. But Giotto left several stones unturned.

BOLD DECISION

In 1987, ESA and NASA drew up a scenario for a new mission called Comet Nucleus Sample Return (CNSR) that would go one step further to actually land on a comet's nucleus, collect samples and bring them back to Earth. But NASA had to drop this ambitious mission in 1993 as part of a refocusing of its efforts. ESA's Science Programme Committee decided to press on alone and in 1994 selected Rosetta as the third cornerstone mission of its Horizon 2000 programme. Rosetta originally planned to take two small landers: RoLand, a long-duration lander built by the German space agency DLR, and Champollion, a French-US short-duration lander built jointly with the Jet Propulsion Laboratory (JPL) and CNES. Ten years after Giotto, in 1996, Rosetta seemed all set to get the go-ahead, but on 20 September of that year budget choices forced NASA to forgo its contribution to Champollion in favour of another comet mission dubbed DS4-Champollion. CNES worked on this new project for three years before it was also abandoned in 1999. ESA then took the bold decision to invite France and Germany to work together on a big 100-kilogram lander. After a redesign, RoLand was renamed Philae and a consortium of eight countries and their space agencies and 10 research institutes was formed to build it.

50

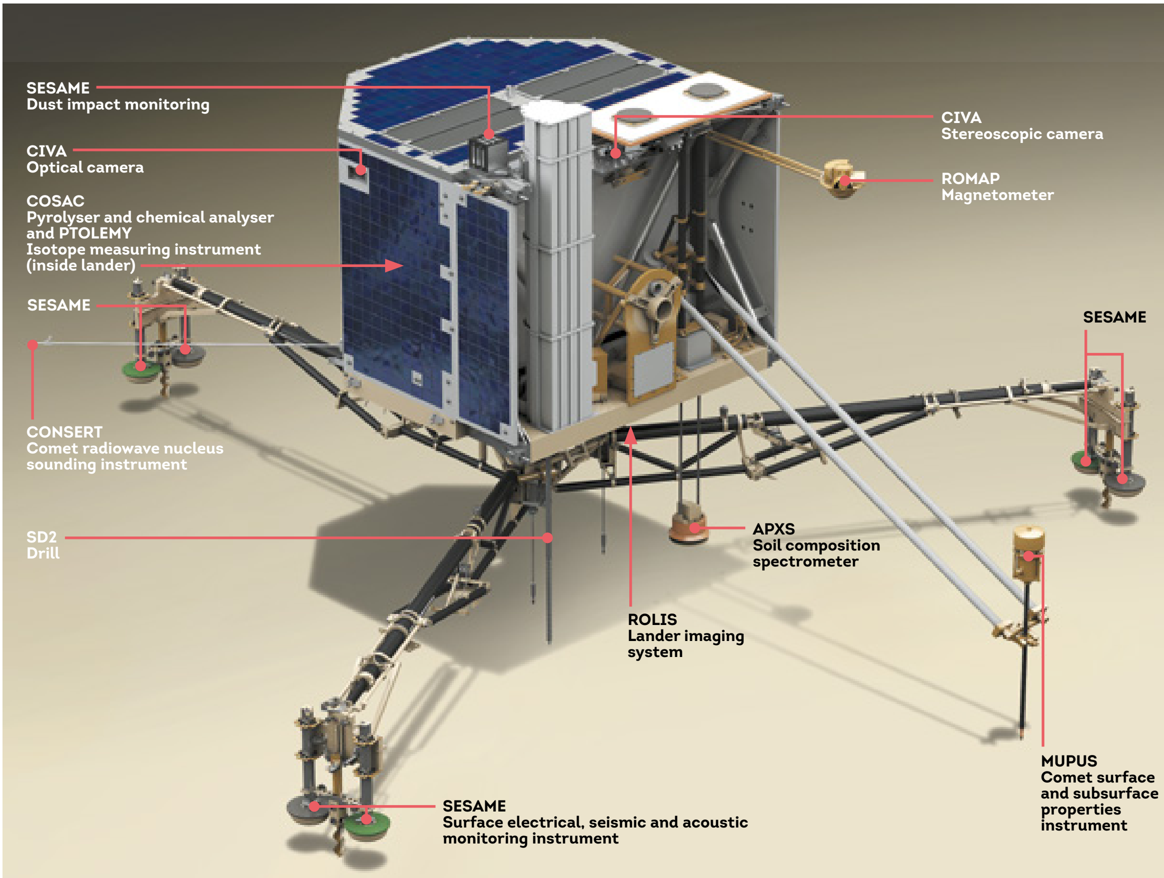
Firms

from 14 EU member countries and from the United States, Norway, Switzerland, Australia and Canada contributed to the Rosetta programme, 10 from France.

The Rosetta orbiter and Philae lander are integrated at the Guiana Space Centre before their launch by Ariane 5 on 2 March 2004 (flight 158).

LEAP INTO THE UNKNOWN

The mission's profile and technological complexity would require a long period of research and development, Rosetta and Philae totalling 21 instruments between them. The payloads would be supplied by ESA member states, with DLR given oversight responsibility for developing Philae and the mission's Lander Control Centre (LCC) in Cologne. German industry would also play a key role building the orbiter, while CNES would be instrumental in calculating the lander trajectory during its descent to the comet's surface. The Science Operations & Navigation Centre (SONC) conceived to coordinate lander science operations would be staffed by a team at CNES in Toulouse throughout the adventure. With Rosetta poised for departure in 2003, things took a final and unexpected turn when a last-minute hitch sidelined the Ariane 5 launcher for a year. As a result, Rosetta would be unable to reach its target comet Wirtanen and a new destination had to be found: it would be 67P/Churyumov-Gerasimenko, a leap into the unknown.



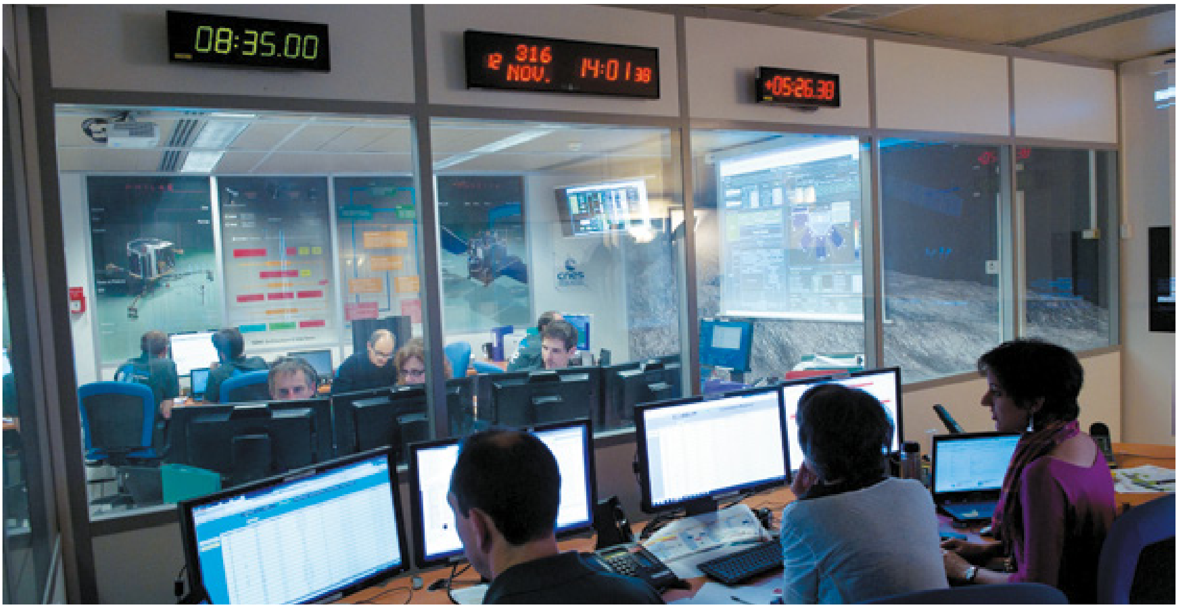
Philae's instruments and their functions. With its legs folded, the lander is one cubic metre in size.

MISSION ACCOMPLISHED

At 7:27 on 2 March 2004, Rosetta finally left the launch pad to begin a mission that would advance comet and cosmic science (see Roundup p.7-11). On 30 September 2016, its 'kiss of death' with the comet brought the mission to a happy end. "*We couldn't have dreamed of a more successful mission,*" says Jean-Pierre Bibring, Philae lead scientist. While the descent to the comet marked the point of no return for Rosetta, the rich data return is set to keep scientists busy for years to come.
And as science is always looking ahead to the next discovery, all eyes are now on MASCOT (see Q&A p.13-15), a small lander developed by DLR with CNES that is on the Japanese Hayabusa 2 probe launched in December 2014. MASCOT is scheduled to be released in October 2018 onto the surface not of a comet, but an asteroid called Ryugu. As such small celestial bodies have remained relatively preserved since they were formed, analysis of their pristine mineral composition in situ or in samples returned to Earth is also expected to tell us more about what conditions were like in the primordial solar system.

VIDEO

Rosetta
A space odyssey of more than 12 years



12 November 2014, the SONC teams waits to hear from Philae to confirm its landing.

OPERATIONS PLANNING

NO TIME TO LOSE, NO ROOM FOR ERROR

Before Europe, no space agency had ever landed a spacecraft on the active nucleus of a comet. CNES provided the know-how and human resources to track Philae every step of the way and deliver the mission's science data.

VIDEO

Inside CNES's Toulouse operations centre

Through CNES, the European Rosetta mission's pioneering Philae comet lander is close to France's heart and it didn't take long for it to become the nation's favourite robotic probe. Never before had a space science endeavour attracted such a keen following, much to the delight of the team at the mission's Science Operations & Navigation Centre (SONC) at CNES, although science remained the prime focus at all times. *"If we've helped to fuel the media buzz around the mission by engaging with the public, that's great. But our chief concern was Philae's engineering and science activities. The mission entailed lots of unknowns and risks that we had to be ready to deal with,"* explains Philippe Gaudon, then team leader at the SONC.

TEAM EFFORT

France's space agency supplied key lander components including the power system (see Materials p.27) and communications system

(see Spinoff p.36). The SONC was in charge of operating the lander's 10 scientific instruments. It also chose the landing site and studied the attendant descent trajectories. This programme occupied a core team of 10 people after mission launch and during its cruise phase, but at CNES other teams were also engaged in electrical engineering, antenna design, spaceflight dynamics, data processing and operations. And in 2014, the year the spacecraft reached its destination, the core team grew to about 40 people at crucial times like the comet approach phase, Philae's landing and operations on the comet surface.
"Operational tasks at the SONC were just the tip of the iceberg," says Philippe Gaudon. Behind the scenes, mission teams were engaged at each phase of its development throughout a 20-year effort. From Philae's conception in 1997 to post-launch operations, CNES played a pivotal role, but it was not alone. For this first-of-a-kind programme, the agency succeeded in federating a closely knit team of French and European SMEs and research laboratories. The CIVA panoramic landing site imaging and sample analysis system led by the IAS space astrophysics institute and the CONSERT nucleus sounding instrument by the IPAG planetology and astrophysics institute in Grenoble are just two examples of this fruitful collaboration.

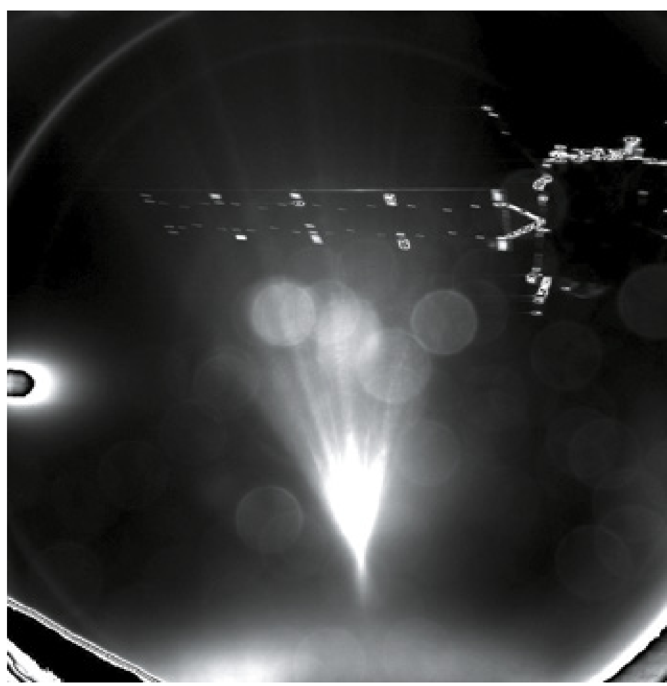
35,000 km/h

That was Rosetta's mean cruising velocity while in hibernation. In 'barbecue' mode it was able to stabilize its temperature despite being a long way from the sun. On awaking from its slumber, the probe pointed its antenna to Earth and radioed back to mission control.

MORE WITH LESS

Aside from the science mission, the SONC faced several technological challenges. The orbiter and lander were designed in the 1990s using then-innovative technologies, but by the time science operations got underway 10 years later, they were pushing their limits: Philae, for example, was handicapped by a serious lack of memory and power (see Timeline p.28-29). The SONC therefore had to invent work-around strategies like its MOST scheduling tool to do more with what little capacity it had, working in close collaboration with its German counterpart the LCC, in charge of Philae's platform and of uplinking telecommands to the lander. While this interdependent and time-consuming interface was another constraint to be reckoned with, it was also key to the smooth conduct of science operations, the mission's prime goal. Above all, the mission team had to prepare for every eventuality. Philae's mission was short and intense, failure not an option: there would be no second chances and from the outset until just after Philae had landed, each operation would be 'one shot'. The SONC handled this uncomfortable situation by imagining the worst possible scenarios and most improbable hitches, and devising the best countermeasures for what turned out to be a fantastic, albeit high-stress, high-wire act.

MORE INFORMATION: CNES.FR/CNESMAG71-ROSETTA-SONC



15:34 UTC, a first picture of Philae separating from Rosetta.

LANDING PULLING OFF THE GAMBLE

Rosetta was a bold and courageous mission, and Philae's landing on comet 67P an extraordinary feat. During the course of the adventure, CNES reaffirmed its expertise in spaceflight dynamics.

Mission planners didn't have a lot to go on and landing Philae on comet 67P/Churyumov-Gerasimenko was something of a leap in the dark. "*We know how to land on a planet of known mass and density*," notes Philippe Gaudon. "*But what did we know about 67P's density, shape, mass and composition? We had a rough idea of its diameter and rotation, about four kilometres and 12 hours, but that's all.*" Unsurprisingly, science was therefore the chief focus throughout the mission.

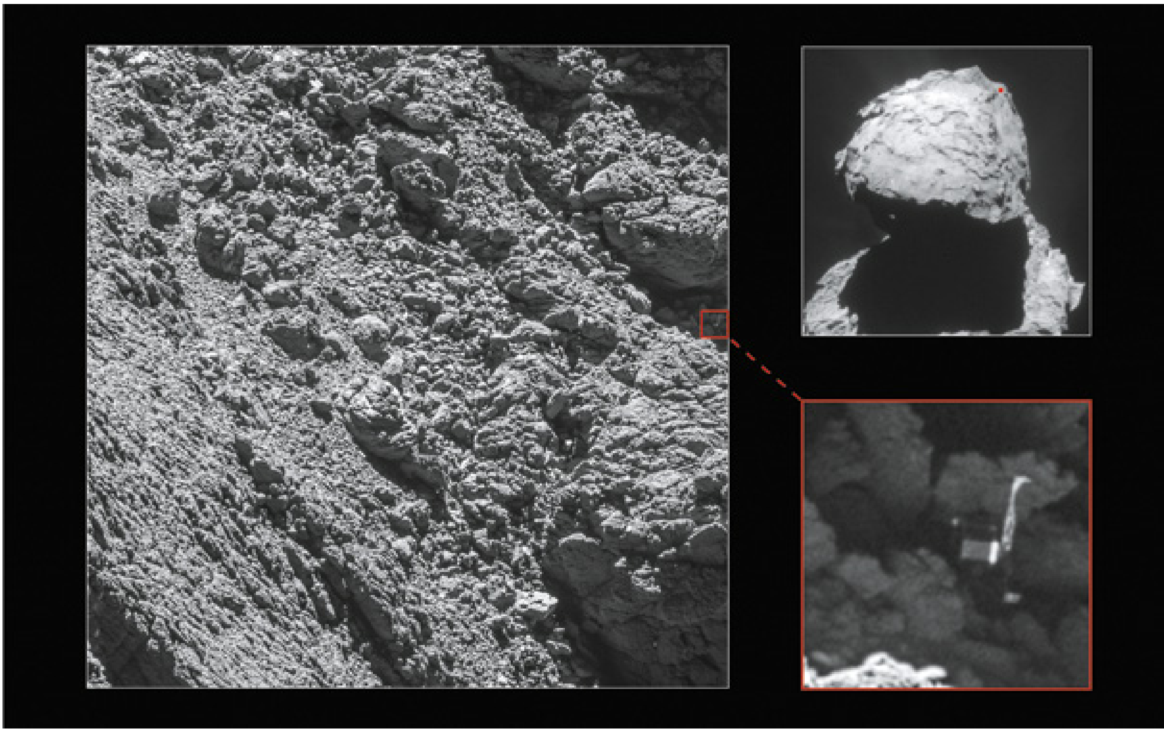
PREPARING FOR LANDING

It wasn't until 2014 that the mission team began to see things more clearly, after an eventful 10-year ride through the inner solar system during which Rosetta and Philae completed three gravitational assist phases and spent 31 months in hibernation. On 21 January 2014, Rosetta was the first to wake up from its slumber and all 11 experiments designed to characterize the comet were nominal. On 28 March it was Philae's turn and all systems checked out OK. Then on 6 August, ESA performed a series of tricky manoeuvres to bring Rosetta within the comet's zone of influence and begin acquiring measurements for the mission scientists to model its shape, motion, composition, temperature, outgassing and gravity. The models were then delivered to the SONC, leaving just three months to pore over the data, refine the results and choose the site where Philae would land on 12 November.

AGILKIA, THE COMPROMISE CHOICE

The primary landing site was the result of a compromise between the sometimes diverging wishes of the science teams and the operational and safety constraints imposed by ESA's European Space Operations Centre (ESOC). Over three and a half months, the models were tweaked with new data. As the spacecraft approached the comet, the field of candidate sites was narrowed down from ten to five, and then to just two. During this period, the SONC's spaceflight dynamics team calculated millions of descent trajectories to determine where Philae could land and generated vast amounts of statistics on landing ellipses and the risk of encountering a boulder. The choice of the Agilkia landing site was a trade-off between the length of the lander's descent, safety on landing, solar illumina-

12 November 2014 - SONC teams are ecstatic after a tense day.



2 September 2016 - After a search lasting several months, Rosetta's OSIRIS camera finds Philae lying on the comet's surface (bottom right) in an image taken just 2.7 km from the nucleus, exactly where CNES's spaceflight dynamics engineers had predicted.

tion and science value. This option and a back-up site were confirmed by ESA.

ACTION STATIONS AT SONC

On 12 November, the teams in Toulouse waited with bated breath as Philae plunged towards the comet. The public will never forget the tiny craft's landing and two unplanned bounces on the surface. The acquisition sequence programmed at the SONC collected a wealth of valuable science data and the First Science Sequence, planned in close detail by the operations teams after the lander came to a halt on the surface, was almost nominal. Over these few days, the SONC and everyone involved proved exceptionally responsive. The ROMAP instrument measured the comet's surface magnetism and CONSERT measured the distance from the ground, while CIVA and ROLIS acquired imagery, with the orbiter and lander in continuous contact. Science operations planning was guided by Philae's supposed position and orientation, and all instruments were successfully activated. The only regret is that the lander's drill was deployed but couldn't reach the surface.

8,000

The number of responses

received by ESA from all over the world to the naming competition for Philae's landing site. More than 150 respondents proposed the name Agilkia, finally preselected by CNES.

MINING MISSION DATA FOR SCIENCE

Besides informing immediate planning of science operations during the mission, the data returned by Philae were also stored for future investigation—two different phases driven by two different approaches.

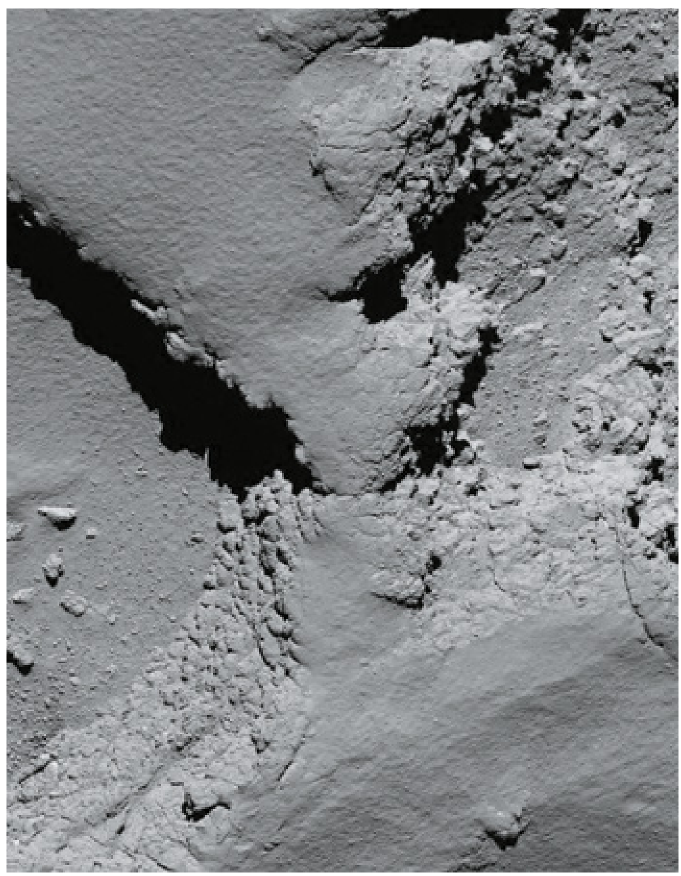
Mission teams needed immediate data from the science instruments to optimize operations on the comet's surface. The SONC was tasked with retrieving data collected from Philae by ground stations and ESA. These data were quickly processed and timestamped, and then posted on a Web server for the science and operations teams in Toulouse, Cologne and Darmstadt.

FAILURE NOT AN OPTION

The slightest anomaly in the million or so lines of code, a network bottleneck or a server failure could have caused part of the science mission to be lost. That's why a strict 'failsafe' service level agreement was signed with the SONC's data centre, and why it tested the whole chain of systems for several years. When the first image from Philae, acquired three kilometres from the comet, appeared on the SONC's screens, a loud cheer went up in the control room. This meant all systems were working perfectly, as they would throughout the mission.

FUELLING FUTURE SCIENCE

Analysis of Rosetta's science data was only just beginning. These data remained the property of the science teams for six months, then were made public as required under international agreements. They will be stored in ESA's Planetary Science Archive (PSA) in a format meeting NASA's Planetary Data System (PDS) standards, along with all records from the mission, its instruments, the measurement environment and processing. Some of the data will also be held at CDPP, the French plasma physics data centre. These records will be a precious archive for the mission's scientists, but above all "*it's a heritage to be handed down to future research scientists who may one day reinterpret the data in the light of new theories,*" concludes Joëlle Durand, CNES's current Rosetta project manager.



Just before its demise, Rosetta took this image 5.8 km from its point of impact. The last signal from the orbiter was received on Earth on 30 September at 13:21.

VIDEO

Packing maximum power into a shoe box

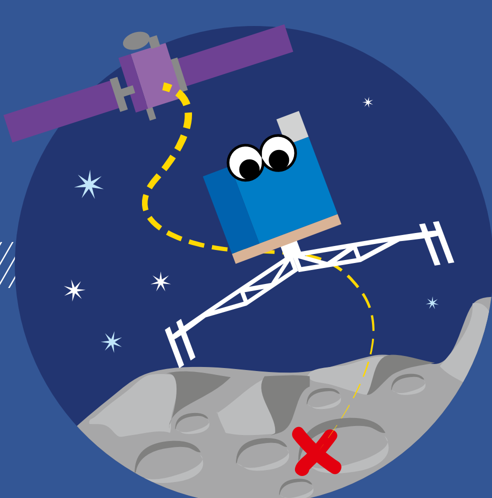
SOLAR CHARGER

THE 1,350 WATTS PER HOUR FROM PHILAE'S PRIMARY LITHIUM BATTERY only covered its first 60 hours of investigations. CNES therefore designed a secondary battery rechargeable from the lander's solar panels to cut in and pursue the mission once the primary battery ran out. Composed of two packs of 14 electrochemical cells and rechargeable every two days, this secondary battery provided an additional 100 watts per hour. Tests during the cruise phase of the mission showed it was working well, confirming the utility of these solar-rechargeable cells. The battery has since been used on several satellites including Demeter and Pleiades, for which its power capacity, size, mass and ability to withstand ageing suited mission requirements. It will also equip future missions such as Taranis in 2018.

MORE INFORMATION: CNES.FR/CNESMAG71-ROSETTA-20ANS

TIMELINE

60 HRS



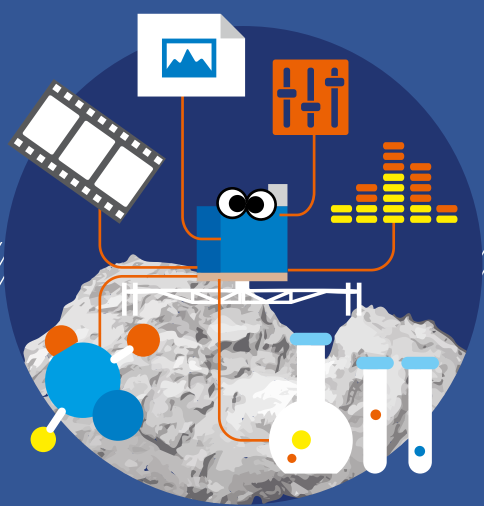
LANDING
EARTH
HOLDS ITS BREATH

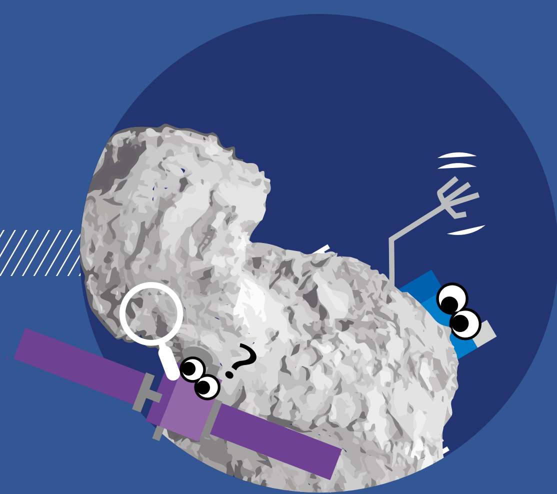
Philae calling Earth... all communications to ground passed through Rosetta. On 12 November 2014 at 9:35 CET, Philae was released and over the next seven hours operations teams and the scientific community held their breath for what felt like an eternity as all contact with the lander was temporarily lost during its 20-kilometre descent. At 16:34 CET, Philae radioed back that it had arrived and the good news was confirmed by ESOC in Darmstadt. It had followed a nominal trajectory, making its historic touchdown at a speed of around 1 metre per second, 118 metres from the planned landing point.

POWER
CONSERVING
AVAILABLE POWER

Philae had the capacity to generate 1,350 watts per hour, enough to power a 100-watt light bulb for 13 hours, but not to operate a platform, its electronics, memory, transponder and 10 instruments. To factor in these constraints, the SONC therefore had to make trade-offs between the instruments, data acquisition and transfer to the central processor and data readout to Rosetta. For this it used MOST (Mission Operations Scheduling Tool), a piece of software with highly sophisticated algorithms capable of handling more than a thousand constraints.

“TOUCHDOWN! MY NEW ADDRESS: 67P.” WITH THAT TWEET, PHILAE ANNOUNCED ITS ARRIVAL ON COMET 67P TO ITS FOLLOWERS. WHILE WEDGED IN THE SHADOW OF A CAVITY IN THE RUGGED TERRAIN OF ABYDOS, THE LANDER STILL MANAGED TO OPERATE FOR TWO DAYS AND ONE NIGHT. HERE’S WHAT WENT DOWN IN THOSE 60 HOURS.





DATA

OVERCOMING MEMORY SHORTAGE

Philae only had 32 megabytes of capacity to store data before uplinking them to Rosetta, so the SONC had its work cut out, starting even before Philae separated from Rosetta and continuing throughout the lander’s descent. The CIVA and ROLIS cameras acquired images of Rosetta and the comet’s surface. Philae then recorded more data on the magnetic field, solar wind direction, distance from Rosetta and gases and dust ‘sniffed’ during its bounces. In all, this task extended well beyond the 60 hours for which the lander operated on the surface.

STATUS

DESPERATELY SEEKING PHILAE

After bouncing unexpectedly twice, Philae stayed on the comet’s surface but vanished from view. It took two years to find it. From the outset, the SONC had solid clues to go on from the lander’s instruments. It pursued these clues, matched positions with illumination conditions and defined the lander’s orientation from pictures of its environment. It then deduced Philae’s status from these theoretical calculations. Confirmation came from Rosetta’s OSIRIS-NAC camera on 2 September 2016 when it found the lander wedged in a cavity, putting all the data Philae had acquired over 60 hours in their true context, much to the relief of mission scientists.

FATIMA HAMANI

Coordinator of the Philea lander model project.

"Even when Rosetta went dead, pupils were as awestruck as ever..."

"All pupils who worked on the Philea project have gone on to engineering school and placements in industry!" Fatima Hamani, now deputy head of the Lycée Jean Perrin high school in Paris, is clearly delighted. **In 2013–14, she was one of the four coordinators of the inter-schools project inspired by the Rosetta mission.** CNES's Philea project involved building a full-scale model of the Philae lander, complete with instruments. On 12 November 2014, Rosetta released Philae onto the comet. As it did so, teachers and pupils at the Le Bourget air and space museum in Paris lowered the Philea model by winch onto a reconstructed comet surface. ***"Everything worked except the active descent system and harpoons—just like the actual lander,"*** she says.

"For pupils, the project gave meaning to their learning. But it took teachers out of their comfort zone. They had to be willing to say: I don't know! It changed the whole teacher-pupil dynamic, with pupils taking initiatives, listening to each other and working as a team. The entire school got caught up in the Rosetta adventure. It was an unforgettable experience!" Three years on, pupils are still passionate about Philea. *"When the lander was found on the comet and when Rosetta went dead, they were as awestruck as ever."* So where does this young deputy head get her energy? *"I'm a pure product of the French state school system. I received a lot and now I want to put something back."* **She encourages girls to be ambitious and keenly supports technology-related streams.** *"Technology education is a great way to get ahead in life. Many pupils will do better in STIDD[1] subjects than in a typical science baccalaureate stream,"* she explains. Fatima Hamani has two passions: family and work. And to cap it all, her son is currently doing his 11th-grade supervised practical project on... Rosetta!

1. Industrial science and technology and sustainable development

PHILIPPE GAUDON

Rosetta mission project leader at CNES.

"I know how lucky we were to be part of this historic endeavour."

Philippe Gaudon lived the Rosetta mission on the inside. From 2004, as team leader at the Science Operations & Navigation Centre (SONC) in Toulouse, he experienced highlights, adrenaline, anxiousness, but not a moment of monotony. *"There was no such thing as 'business as usual'. The mission was complex and its targets uncharted. In 10 years, our enthusiasm never waned, and few quit the project before the end,"* he says. The mission had its challenges, from developing the SONC and finding the best in-house organization to working efficiently with partners, engineers and scientists in France and beyond. ***"We only had one shot at the comet, so failure was not an option. It was a bit daunting—but so exciting!"*** There was no magic wand to ensure success: *"We planned everything to the detail: systems, teams, every last operation".* On 12 November 2014, when Philae landed on Comet 67P, Philippe was nervous but confident: *"We'd done everything we could. Everyone was at their station and knew what they had to do."* The team was unfazed by Philae's bumpy landing. The SONC *"made every effort to extend the battery"* to allow as much data as possible to be gathered for science. And not only that. With Rosetta now at the comet, **Philippe Gaudon found himself in a new role as media spokesperson**. More at home in the shadows of a vast European organization than in the limelight, it was a step into the unknown. *"I know how lucky we were to be part of this historic endeavour. During operations, few people were allowed into the SONC. But after each crucial stage, it was important to share it with the world. It was also a chance to promote science and learning,"* he notes. And after 20 years of effort, the mission deserved a bit of publicity—up to a point, anyway: on the day Philae touched down, traffic on the Rosetta website peaked at over 1 million visitors. *"We had to take the site off line so we could process the science data."* Well, science did come first after all!

DOMINIQUE BOCKELÉE-MORVAN

Research scientist at the CNRS/LESIA laboratory[1].

"What these instruments have revealed is hugely significant."

Dominique Bockelée-Morvan is passionate about dance. And if she hadn't stepped up to the urgent demands of Rosetta, she'd probably be dancing today. She's also a research scientist at the Paris Observatory, specializing in gases, and won the CNRS silver medal in 2014 for her work. **For Dominique, the Rosetta adventure began in 1992,** when she helped define the VIRTIS spectrometer and MIRO microwave instrument, selected to further our knowledge of the surface and atmosphere of comet 67P/Churyumov-Gerasimenko. Over 20 years later, the results are hugely significant. ***"These instruments have revealed new molecules, complex materials and much more.*** *We now have a complete map of water distribution on the comet, based on two years of observations. It's a considerable discovery spanning the whole cycle, from the location of water, stored under the surface as ice, to its sublimation and evaporation,"* she says. **Nonetheless, the comet still holds some of its secrets.** *"I'm currently investigating the bursts of activity we observe. What causes the jets of dust flowing out of the comet as it nears the sun? Avalanches? Pockets of gas under the surface? Our data tell us the comet's two lobes are structured like the layers of an onion. Why's that? It's intriguing, isn't it?"* She admits workloads during the two-year mission were demanding. Planning observations in three-hour slots over a month took extensive coordination and an inordinate amount of time. Today, while data analysis is complex, requiring the development of new models and painstaking calibration, the pressure is largely off. So, will she start running her dance classes again at the lab? Some staff at least are patiently hoping so!

1. LESIA space and astrophysics instrumentation research laboratory, part of CNRS, the French national scientific research centre

Jacques Arnould,
science historian
and theologian,
CNES ethics officer.

J.A.

JACQUES **ARNOULD**

THE DRAMA OF THE COMETS

The Rosetta mission's success, the knowledge gained and the excitement generated shouldn't make us forget the important place that comets occupy in the human imagination, reflecting our innermost hopes and fears.

Let's not be too quick to think we've cracked all their secrets! Amid the enthusiasm for Rosetta in the media and public opinion, we shouldn't overlook the legacy of centuries past and the collective panic and hysteria each time one of these spectacular 'long-haired stars' appeared in the sky. While they've captured the public's imagination beyond all expectation, the scholarly articles, humorous depictions, factual accounts and live reports have only added to the sense of drama that so characterizes humanity's time-honoured relationship with comets. Ever since we emerged from the raging river of life, from the rich and balmy lands of ancient Africa, humans have sought comfort in the cold calmness of the heavens—perhaps as a way to deal with the tragedies of our existence. A purely cosmetic exercise since, as we now know, the universe itself is the scene of dramas on a scale beyond human comprehension. But knowing that changes nothing: we're still *Homo sapiens*, the fellow creatures of those who believed that the death of Julius Caesar and others of such illustrious repute was caused by the passage of a comet. More recently, the approach of Halley's Comet in 1910 also brought its unfortunate share of suicides. As late as the 1980s, Fred Hoyle attempted to find a cometary cause for the frequency and spread of certain epidemics.

A DOUBLED-EDGED DESIRE

So, let's not get too excited. The great strides we're making in the field of knowledge and education will never prevent the rise of such fears: *Homo sapiens* loves to frighten his fellow creatures, and indeed himself, far too much to ever strike these 'celestial bearers of bad omens' from his imagination, or any of the other more down-to-earth forms of disaster. The 'comet pills' sold by quacks in 1910 are no less a part of our drug-making history: each return of a long-haired visitor reminds us of their existence and vital necessity. It's the task of the learned to judiciously modify the content, rather than the packaging. An inseparable mix of tragedy and comedy, the drama of the comets seems very much intertwined with the drama of humanity. So, let's congratulate ourselves on the friendly 'tweets' between Rosetta and Philae that so enthralled earthlings at the start of the 21st century. But let's also be wise, cautious and keenly attentive: comets will continue to reflect that double-edged desire we've always had to know where we came from and where we're headed.

PODCAST

Talking about Rosetta over coffee

BOOKS
THE REAL STORY OF THE SOLAR SYSTEM

How could the planets have come from such minute grains of interstellar dust? Have they ever changed place, like balls in a cosmic billiard game? And do other systems like ours exist elsewhere in the cosmos? Two CNES experts shed light on the birth of the Universe.

Quelle est la véritable histoire du Système solaire? by Francis Rocard and Florence Chiavassa – Published by Le Pommier – Petites Pommes du Savoir collection – 2014 – 128 pages – €7.90

COMETS IN VIEW – FROM HALLEY TO ROSETTA

After Rosetta's exploration of comet 67P, this book brings readers up to speed with what we know about these mythical bodies. The authors tell the story from an original perspective, complete with anecdotes.

À la rencontre des comètes – De Halley à Rosetta, by James Lequeux and Thérèse Encrenaz – Published by Belin – Pour la Science collection – 2015 – 144 pages – €22.90

WHAT'S ON
Philea on display

Philea, the full-scale replica of the Philae lander, is on display at the Le Bourget air and space museum in Paris, accompanied by an exhibition on comets and a video retracing the schools project. Entry is free.

CINEMA OUTING
Space Oditty

CNES's partnership with the Toulouse film archive and the Cité de l'espace space theme park continues with a new season of Space Odyssey, inviting movie lovers in 2017 on a voyage to Mars. On the programme: 18 January, *A Trip to Mars* – silent film directed by Holger-Madsen (Denmark, 1918), 22 February, *Robinson Crusoe on Mars* by Byron Haskin (USA, 1964), and 29 March, *Total Recall* by Paul Verhoeven (USA, 1990). Each screening starts at 8 p.m. and is followed by a debate mediated by subject matter experts.

www.lacinemathequedetoulouse.com

SYMPOSIUM
COMETS: THE ULTIMATE RENDEZVOUS

Toulouse, the nerve centre of Philae operations throughout the Rosetta mission, brought together the cometary science community for the Comets symposium. Organized by CNES, ESA and the IRAP institute[1], the event was held at the Les Abattoirs Museum, 14 to 18 November 2016, and was attended by a record 200 participants from 21 countries. *"All 21 experiments on Rosetta worked, so we have a huge amount of data. So far, only 5% of it has been analysed,"* says Joëlle Durand, Rosetta mission project leader at CNES. The potential for new insights into the solar system's origins is generating real enthusiasm within the science community. A gauge of this success is the impressive number of papers, 150 annually in the last three years, and young researchers who have joined their elders.

1. IRAP astrophysics and planetology research institute, part of CNRS, the French national scientific research centre

DOCTORAL RESEARCH
FROM ROSETTA TO THE ANTARCTIC

Rosetta has provided a wealth of subject matter for PhD students and postdocs, with some writing their theses on aspects of the mission. One such student is Anaïs Bardyn[1], who defended her thesis on spectrometry analysis of cometary dust grains by the COSIMA instrument in late 2016. Her goal was to determine the composition of particles. What she discovered was unexpected: *"The organic matter in meteorites and comets could have a common origin, even though comets contain more primitive materials."* Her findings have been published in the journal Nature[2]. Anaïs wants to pursue her investigation by studying extraterrestrial particles collected in Antarctica, working with American researchers. But why this passion for cometary particles? *"She's part of the Rosetta generation and was just five when the mission was selected by ESA,"* says Michel Viso of CNES, who has followed her work with admiration.

1. Doctoral student at CNES and LISA/LPC2E environmental and space physics and chemistry laboratory
2. *Nature*, October 2016, vol. 538, p.72

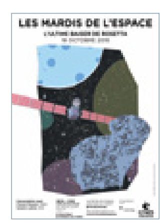
DIARY

23–28 APRIL
European Geophysical Union
Vienna, Austria

18–22 SEPTEMBER
Cospar 2017
South Korea

15–20 OCTOBER
Division Planetary Science
49th Annual Meeting of the American Astronomical Society
Utah Valley, United States

TUESDAY SPACE TALKS
Rosetta at the Science Bar



The new season of Tuesday space lectures kicked off on 18 October with "Rosetta's last kiss goodbye". Francis Rocard reviewed the initial haul of science results from the Rosetta mission. Then, Sylvain Lodiot talked visitors through the spacecraft's long voyage—which was not without incident—to the comet. Listen to the podcast on the CNES website > cnes.fr/podcast.

Café du Pont Neuf, Paris. Every third Tuesday of the month. Entry free.

MORE INFORMATION: CNES.FR/CNESMAG71-ROSETTA-MARDIS

ANTENNAS
STAYING ONE STEP AHEAD

The Eye-Sat astronomy nanosatellite to be launched in 2017 prefigures a new generation of antennas made in France and unique in Europe. It also drew on lessons learned from Rosetta.

This new concept is the result of recent research at CNES's Antennas department designed to follow the current trend of technologies anticipating growth in the market for nanosatellites. Miniaturization is the watchword to shave off size, volume, weight, cost and everything else that can be reduced. The department therefore downsized its flight antennas while retaining the same level of performance and has obtained conclusive results by designing a smaller radiating element. They also favour a 'two-in-one' design, with transmit and receive functions co-located on the same device. Tests underway on Eye-Sat are expected to confirm their excellent performance.

LEARNING FROM PHILAE

Meanwhile, at CNES's Instrumentation, Telemetry and Propagation department, lessons learned from the Rosetta mission have been applied to locating a lander. The mission's Space Operations & Navigation Centre (SONC) and German space agency DLR spent months trying to find Philae on comet 67P. Simply by enabling a higher-data-rate transmit-receive system with a range-finding capability, the lander would have been found within days. This capability could be built into several landers to create a multipoint communication network with an orbiter—a plus that could become a standard feature of future space exploration missions.

The MASCOT lander
launched in 2014 is already equipped with an intermediate miniaturized antenna. Future generations will further reduce antenna size by two-thirds.