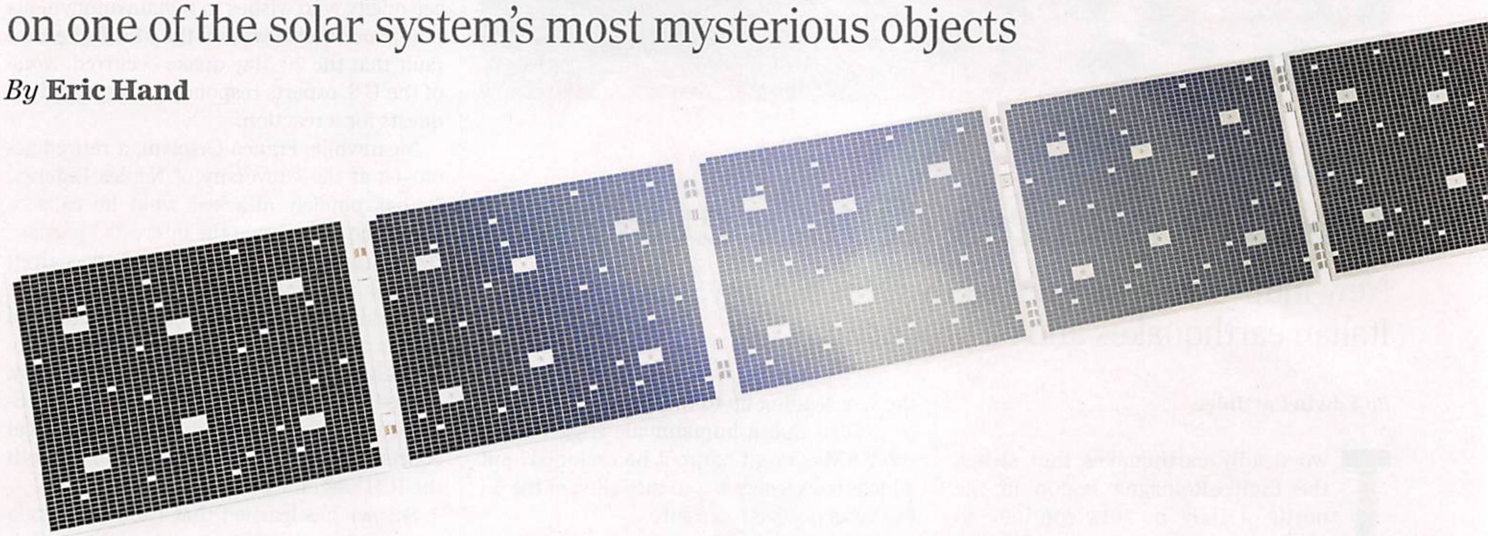
FEATURES

Comet catcher

Europe's Rosetta spacecraft is about to orbit and then land on one of the solar system's most mysterious objects

By **Eric Hand**

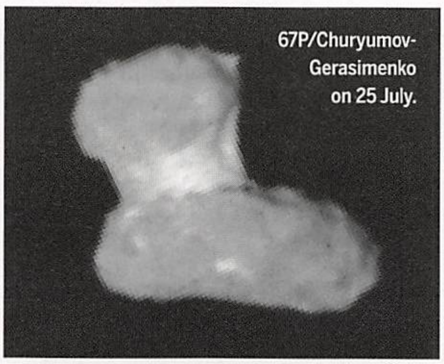


The lump of ice and dust tumbled into view as little more than a dot. Then it grew to a smudge. It was sputtering fitfully in a halo of expelled gas and dust, a sign that its internal engine was revving up but had not yet been stoked by the sun to full throttle.

As the spacecraft drew closer, the dot became a pixelated blob. A few weeks ago, its true shape began to emerge: The object is 4 kilometers long and lopsided, with two lobes. From certain angles, it looks like a rubber duck. It rotates, languidly, every 12 hours. Now, the spacecraft is just 1000 kilometers away from the object, called 67P/Churyumov-Gerasimenko, and closing in. Each day brings new terrain into focus, all encrusted in organic dust blacker than asphalt.

67P is a comet: that most eccentric of solar system species, in orbit and behavior. The great amateur comet hunter David Levy once said: "Comets are like cats. They have tails, and they do precisely what they want." Yet comets are also time capsules. Formed in the cold of the outer solar system 4.5 billion years ago, they have stayed cold—and, the thinking goes, chemically inert—but for their occasional dalliances with the sun. For this reason, researchers think they hold valuable information about the solar system's formation and about their own possible role in delivering water and organics to Earth early in its history.

67P's pursuer is Rosetta, a €1.3 billion flagship mission of the European Space Agency. Launched in 2004, the spacecraft spent a decade chasing down the comet, looping once around Mars and three times around Earth in gravity slingshots. On 6 August, Rosetta will finally intercept the comet at a point 3.5 times Earth's distance from the sun—between the orbits of Mars and Jupiter—and the entwined couple will begin a dance around the sun, one that should get ever hotter and more intimate. There have been just a handful of comet missions, beginning in 1985 with Giotto's voyage to Halley's Comet, and each achieved its 15 minutes of fame through whipsaw flybys that lasted about that long. Rosetta, by contrast, will be the first to orbit a comet—no mean feat, given 67P's jumpy behavior and feeble, irregular gravity field.



67P/Churyumov-Gerasimenko on 25 July.

Rosetta is also the first spacecraft to accompany a comet during a full trip around the sun. Below the thin, dirty skin of 67P are stores of ice—predominantly water ice, but also ices of carbon dioxide, methane, and ammonia. As the heat of the sun penetrates the surface, the ices will thaw and sublimate, creating diffuse jets of gas that also blow out dust. The comet's coma, or atmosphere, will expand to thousands or even millions of times the size of its nucleus. In August 2015, 67P will make its closest approach to the sun, between the orbits of Earth and Mars, and the comet's dual tails—one of dust, one of

CREDITS: (TOP TO BOTTOM) ESA/ATG MEDIALAB; ESA/ROSETTA/MPS FOR OSIRIS TEAM MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA

Aftermath of a 29 May 2012 earthquake in the town of Concordia sulla Secchia.

ITALY

Deadly quakes divide experts

New industry-sponsored study rules out any link between Italian earthquakes and oil production

By **Edwin Cartlidge**

Two deadly earthquakes that struck the Emilia-Romagna region in the north of Italy in 2012 continue to generate political aftershocks. According to the Italian government, a report by six U.S. scientists puts to rest the suggestion that the quakes, which killed 27 people, could have been triggered by increasing production at a nearby oil field, known as Cavone. But some researchers are unconvinced, while experts and the public alike question the origins of the study, which the government requested from the oil field's owner.

The possibility that activities at Cavone might have triggered the two quakes, a magnitude-5.9 event on 20 May 2012 and a magnitude-5.8 event 9 days later, was raised earlier this year in a different report, from a panel known as ICHESE. That panel was set up in December 2012 at the request of the Emilia-Romagna regional government, following local rumors that exploratory drilling for a gas storage facility had set off the tremors.

In its report, ICHESE—made up of two Italian and three foreign geoscientists as well as engineer Franco Terlizzese, director of mineral and energetic resources at Italy's Ministry of Economic Development—dismissed that link. The panel did, however, find that increased petroleum extraction and wastewater injection at nearby Cavone correlated with a rise in seismic activity in the year leading up to the quakes. The panel concluded that a humanmade triggering of the 20 May event "cannot be excluded" but added that physics-based modeling of the oil field was needed to be sure.

ICHESE's report generated controversy, in part because the regional government received it in mid-February but only made it public on 15 April, just 4 days after *Science* reported the study's main conclusions (11 April, p. 141). Regional President Vasco Errani explained that he needed time to carry out "further studies" in order "not to cause alarm." His administration also suspended all new hydrocarbon exploration in the region.

Both the Ministry of Economic Development and the regional government say that the latest report, written by leading U.S. geoscientists, resolves the controversy. The U.S. researchers developed a mathematical model to simulate the mechanical effects of fluid flow on the rocks in and around the Cavone oil field. The model also draws on measurements of fluid pressure at the bottom of the wastewater injection well carried out by the field's operator, Padana Energia, in May and June this year. The experts conclude that activities at Cavone could not have altered pressure and stress within the crust enough to have triggered the two quakes.

In a press release, the ministry cites an analysis by Italy's National Institute of Geophysics and Volcanology (INGV) that "attests to the validity" of the new report. Some scientists also give the American report the thumbs up. Marco Mucciarelli, a seismologist at Italy's National Institute of Oceanography and Experimental Geophysics in Trieste, says the study provides an "unequivocal" response to the uncertainties surrounding Cavone.

Others, however, challenge the work. In their model, the American researchers simulated how the changing output at Cavone would have affected the fault nearest the oil field—the Mirandola fault—but not the more distant Middle Ferrara fault, which lies about 20 km away. But one expert in induced seismicity who wishes to remain anonymous points out that it was on the Middle Ferrara fault that the 20 May quake occurred. None of the U.S. experts responded to repeated requests for a reaction.

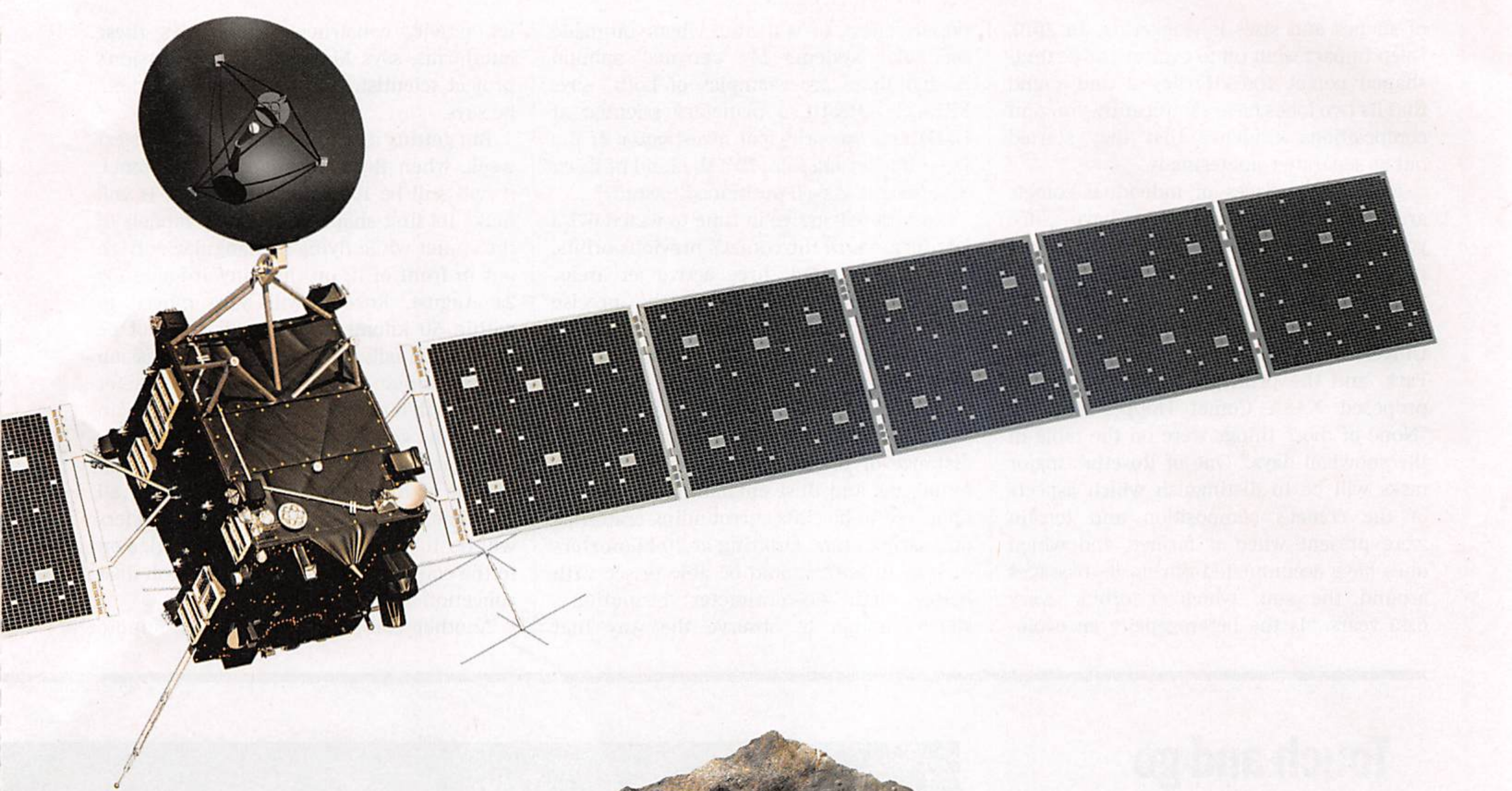
Meanwhile, Franco Ortolani, a retired geologist at the University of Naples Federico II, has publicly attacked what he calls "a game played between the interested parties," complaining that Padana Energia was given the task of commissioning the new research and taking the pressure measurements. He argues that only the judiciary has the independence to shed light on the controversy. Indeed, last week a number of environmental groups filed a complaint in several local courts calling for an investigation of both the ICHESE and U.S. studies.

Science has learned that Padana Energia entrusted the commissioning of the modeling research to energy and mineral trade body Assomineraria, which worked on the task together with the ministry. But instead of commissioning a brand new study, the trade body and the ministry simply released an expanded version of the American group's research, which had been commissioned and funded by ENI in late 2012 or early 2013. (ENI sold Padana Energia to the company Gas Plus in 2010.) One of the study's authors, James Dieterich of the University of California, Riverside, told *Science* that the modeling and pressure tests "confirmed our initial conclusions concerning the origins of the 2012 earthquakes."

Terlizzese defends the decision to use the American research, arguing that the six scientists are internationally renowned and were already well-versed in the subject matter, adding that "we also needed the study done quickly." He acknowledges that commissioning the report via Padana Energia "seems like a conflict of interest" but says that the review by INGV "attenuated" that conflict. The modeling required oil field data that only the ministry, the regional government, and Padana Energia possessed, he adds. ■

Edwin Cartlidge is a science writer in Rome.

PHOTO: ASSOCIATED PRESS



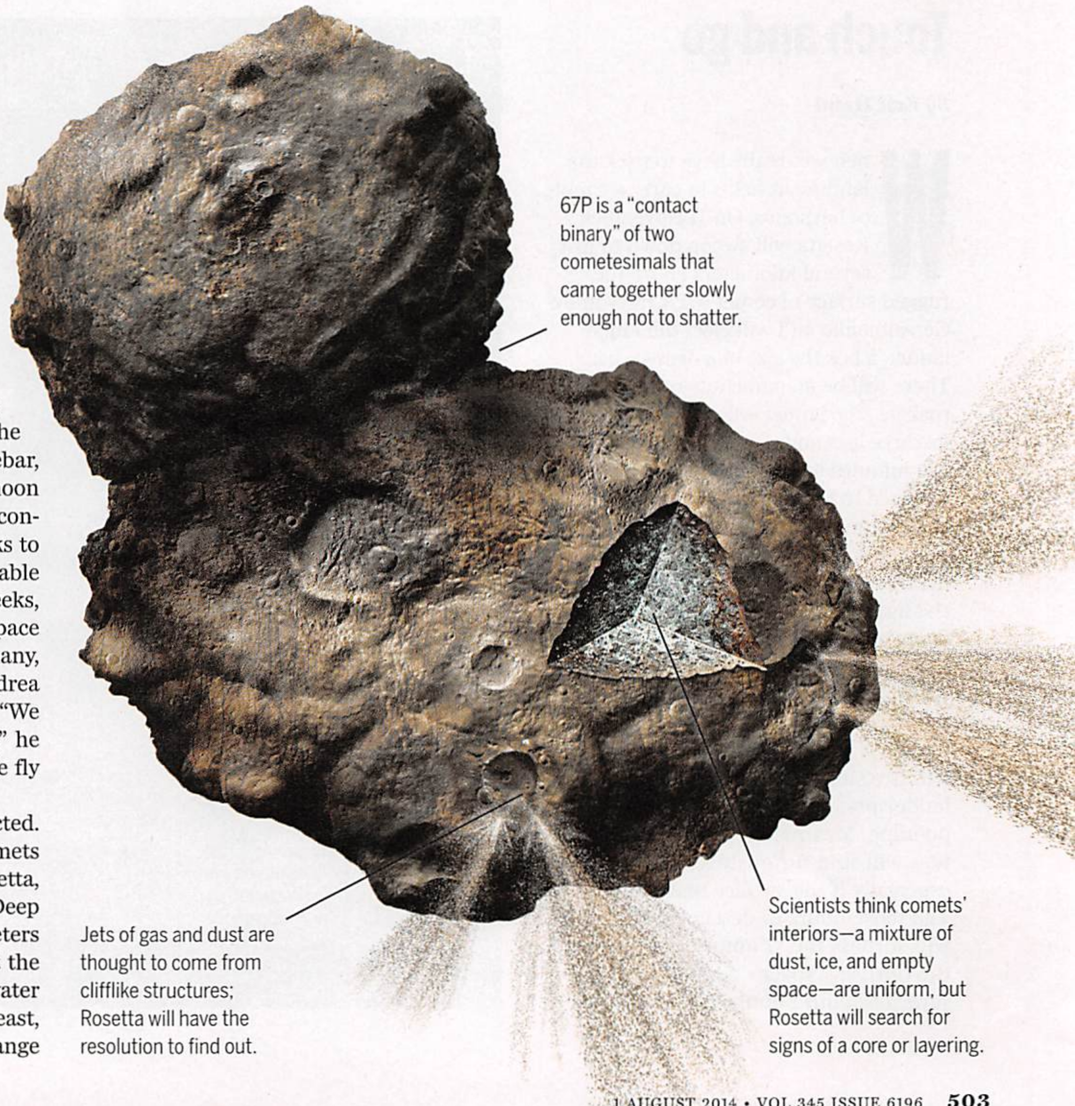


ILLUSTRATION: NICOLLE R. FULLER

ionized gas, both pointing away from the sun like windsocks—will reach their peak.

Perhaps the most daring moment of the mission will come on 11 November, when mission leaders plan to drop the Philae lander to the surface (see sidebar, p. 504). Whereas landings on the moon or Mars are preceded by years of reconnaissance, Rosetta will have just 6 weeks to map the comet's surface and find a suitable landing site for Philae. During those weeks, the atmosphere at the European Space Operations Centre in Darmstadt, Germany, will be frenzied and intense, says Andrea Accomazzo, Rosetta's flight director. "We know everything when we fly to Mars," he says. "We don't know anything when we fly to the comet."

Scientists are expecting the unexpected. Contrary to what they used to think, comets are not simply dirty snowballs. Rosetta, watching from afar in 2005 as the Deep Impact mission sent a penetrator 25 meters into the comet 9P/Tempel 1, found that the explosion kicked up more dust than water vapor—proof that, in some cases at least, comets are icy dirtballs. And their range of shapes and sizes is staggering. In 2010, Deep Impact went on to explore the peanut-shaped comet 103P/Hartley 2 and found that its two lobes have significantly different compositions—evidence that they started out as separate cometesimals.

Even the surfaces of individual comets are surprisingly varied. "You have cliffs, you have smooth flows, you have material moving from one side of the comet to the other and redepositing," says Jessica Sunshine, a planetary scientist at the University of Maryland (UMD), College Park, and the principal investigator for a proposed NASA Comet Hopper mission. "None of those things were on the table in the snowball days." One of Rosetta's major tasks will be to distinguish which aspects of the comet's composition and terrain were present when it formed and which ones have accumulated during its passages around the sun, which it orbits every 6.45 years. "Is the heterogeneity an evolutionary effect, or is it from when you made the solar system? My personal opinion is that there are examples of both," says Michael A'Hearn, a planetary scientist at UMD and the principal investigator of the Deep Impact mission. "It's the kind of thing that Rosetta is well positioned to study."

Rosetta will arrive in time to watch 67P's jets turn on. In the comet's previous orbits, telescopes spotted three active jet areas. Scientists don't understand the precise nature of those jets or how they might be shaping cometary surface features, but they found valuable clues when NASA's Stardust-NExT mission flew past Tempel 1 in 2011. Viewing that comet's active areas from a distance of 181 kilometers, Stardust-NExT found gas and dust emanating from what appeared to be cliffs surrounding craterlike outgassing scars. Orbiting at 30 kilometers or less, Rosetta should be able to see with better than 60-centimeter resolution—sharp enough to observe the way that jet activity constructs or destroys these landforms, says Matt Taylor, the mission's project scientist. "We'll see that evolution," he says.

But getting into orbit is no easy task. Next week, when Rosetta arrives at the comet, it will still be 100 kilometers away. It will make its first shape and gravity models of the comet while flying a triangular pattern out in front of it, on the sunward side. By 24 August, Rosetta will have moved to within 50 kilometers but will still not be in orbit. Finally, on 10 September, mission managers plan to put it into a 30-kilometer orbit. At that point, the spacecraft will begin to feel the gentle pressure of the jets on its 64 square meters of solar panels, which will act like giant sails. "It's pushing us away all the time," Taylor says. Mission controllers will try to keep the panels pointed edge-on to the comet surface to minimize both dust collection and gas pressure.

Another complication is the 40-minute

Touch and go

By **Eric Hand**

When you really have to stick the landing, it helps to carry a couple of harpoons. On 11 November, Rosetta will swoop down to just several kilometers above the rugged surface of comet 67P/Churyumov-Gerasimenko and will eject the Philae lander, a box the size of a dishwasher. There will be no parachute or retro-rockets. The lander will simply unfold its three legs and, over anywhere from 100 minutes to several hours, drift unpowered to the surface at walking speeds. That is the benefit of a gravitational field hundreds of thousands of times weaker than Earth's. But the weak field also carries a risk: A bounce could send the lander flying into the abyss.

Sensors in the toes of each lander leg will signal touchdown. Seconds later, the harpoons will burst from the belly of Philae. A thruster on the lander's back will fire simultaneously, keeping the lander pressed down during the harpooning. Meanwhile, screws in the three toes will spin furiously to find purchase, especially if the surface material is soft. The tense hours of descent and landing will surpass the "7 minutes of terror" of the Curiosity rover's descent to Mars, says Hermann Böhnhardt, one of the

Landing on a comet

In November, Philae will use an arsenal of tools to dock with 67P.

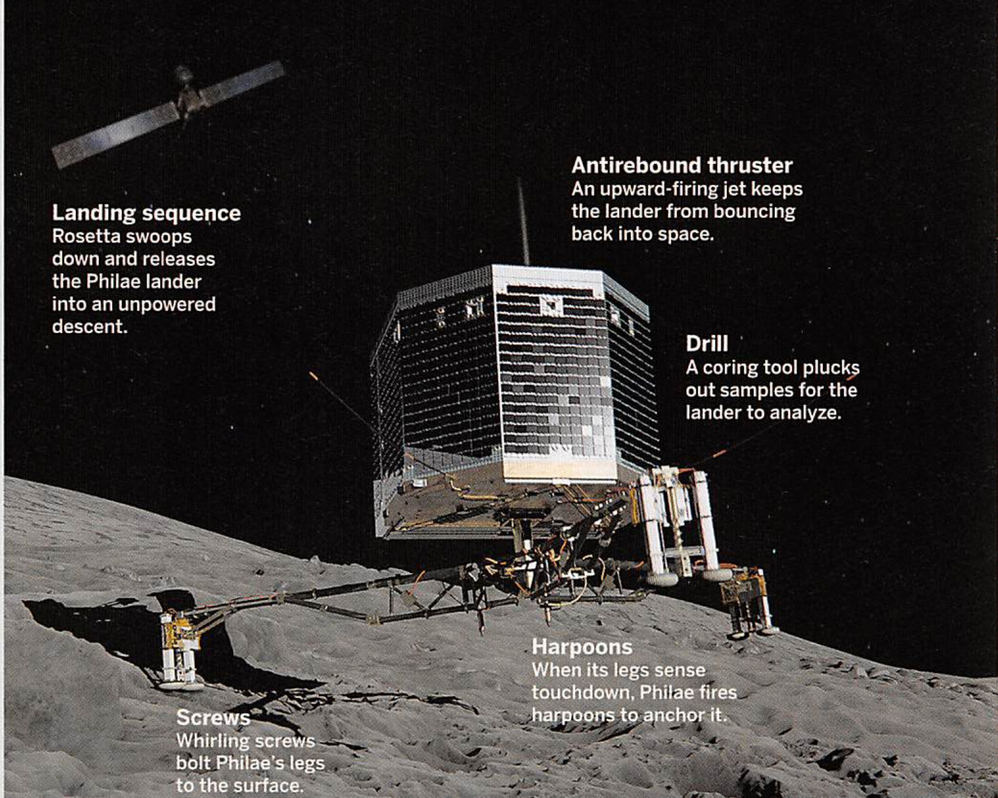
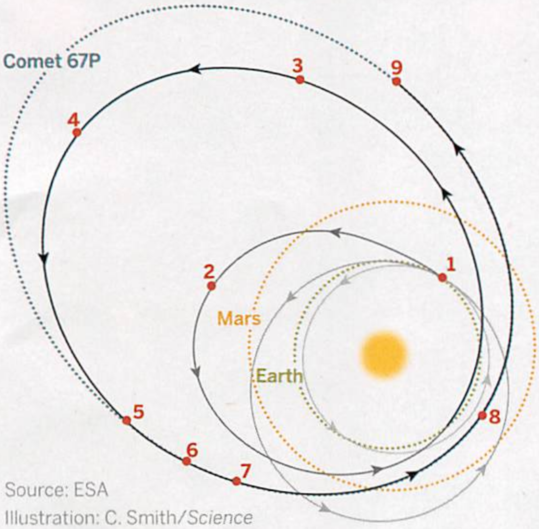


ILLUSTRATION: ADAPTED FROM ESA/ATG MEDIALAB

A long, looping chase

Rosetta used Earth and Mars flybys to catch its quarry.



Source: ESA
Illustration: C. Smith/*Science*

1. **2 March 2004**
   Launch
2. **5 September 2008**
   Asteroid Steins flyby
3. **10 July 2010**
   Asteroid Lutetia flyby
4. **8 June 2011**
   Enter deep space hibernation
5. **20 January 2014**
   Exit deep space hibernation
6. **August 2014**
   Arrive at comet
7. **November 2014**
   Lander delivery
8. **13 August 2015**
   Closest approach to sun
9. **31 December 2015**
   Nominal end of mission

travel time for commands to arrive from Earth. Except for twice-a-week course corrections, the spacecraft will operate autonomously, keeping its camera pointed at 67P and backing off to a higher orbit to regain its bearings anytime the comet slips out of the viewfinder. The team will not attempt to lower the spacecraft into a 20- or 10-kilometer orbit until it gauges the stability of the orbit.

Still, after a journey of a decade and more than 6 billion kilometers, mission scientists are happy that they are no longer chasing a will-o'-the-wisp. Holger Sierks, principal investigator for the OSIRIS camera at the Max Planck Institute for Solar System Research in Göttingen, Germany, was overjoyed when he saw some of his first multipixel images a few weeks ago. "It's overwhelming to see it has a shape," he said. Now, the team faces a tougher, more thrilling job, as the distant shape gives way to an intimate encounter. ■

two lead scientists for Philae. "It is for us a very stressful and dramatic period of time," says Böhnhardt, a comet scientist at the Max Planck Institute for Solar System Research in Göttingen, Germany.

Mission scientists hope to improve the odds by identifying a safe landing site. When Philae was designed and built in the 1990s, little was known about the surface strength of comets. So the lander is designed to handle all manner of terrains, from a surface as tough as solid ice to one as soft as cigarette ash, Böhnhardt says. "Something in between would be good," he says. Some scientists want to land near the plumes of gas and dust erupting from the comet—assumed to come from ice-rich regions—in order to sample them. Others say it would be safer to avoid the jets; they would target a pristine area that may harbor organic dust that has been unaltered by outgassing. The emerging picture of 67P as a contact binary—with two lobes barely attached to each other—adds to the challenge: Some areas may be dangerously unstable. And with a landing footprint nearly a kilometer across—on a comet with just 50 square kilometers of area—mission scientists may not get to be so choosy.

Assuming Philae lands safely—and mission manager Fred Jansen can be coaxed only into a gut estimate of 70% landing success—it will launch into a preprogrammed science routine that could last months. One key experiment is CONSERT, which will detect radio waves beamed from the mother spacecraft when it is on the opposite side of the comet. By measuring their travel time, researchers will build a 3D model of the nucleus. "We have no idea if anything is concentrated at the center," says Michael A'Hearn, a planetary scientist at the University of Maryland, College Park. Some theorists speculate that at the birth of the solar system, the comet-forming region could have harbored enough of the short-lived and hot radioactive isotope aluminum-26 to melt ice. If Philae finds evidence for hydrated minerals, or increasing concentrations of ice with depth, it would support the notion that a hot, watery chemistry altered comets soon after their formation—and that maybe comets aren't as pristine as thought.

Philae will also sample the comet with a coring tool that will drill to depths of about 20 centimeters and supply thimblefuls of material to a carousel of 26 ovens that can vaporize dust at temperatures up to 800°C. Gas from the ovens will be routed to gas chromatographs and mass spectrometers for analysis. One experiment, Ptolemy, will assess the abundance of lightweight molecules such as water and heavy water, which contains an atom of hydrogen that has an extra neutron. In 2011, researchers using the Herschel space telescope found that comet 103P/Hartley 2 contained almost the same fraction of heavy hydrogen as Earth's oceans—a result that revived the long-standing debate over whether a rain of comets, rather than icy asteroids, delivered Earth's water.

Another experiment, COSAC, will look for heavier molecules—in particular long-chain organic ones. Ground-based telescopes have identified many rudimentary organic molecules in comets, but they are hampered by atmospheric interference and are limited to studying molecules that end up suspended in a comet's halolike coma. The Stardust probe, which swept through the coma of comet Wild 2 (*Science*, 9 January 2004, p. 151) collecting dust and gas, also found organic molecules, including the amino acid glycine. COSAC, by sampling the nucleus itself, will compile a much longer list of organics that may include many more amino acids. The longer the list delivered to Earth, the easier it is to explain how life could have begun, says Scott Sandford, a planetary scientist at NASA Ames Research Center in Moffett Field, California, and a principal investigator on a proposed comet sample return mission. "It wouldn't hurt to start with as wide a mix of chemicals as possible so you can play with your Lego blocks," he says.

COSAC will also be able to detect the chirality, or handedness, of these molecules. On Earth, all amino acids used in biology are left-handed, even though life based on right-handed molecules would have worked just fine. If COSAC finds any left-handed bias in comets, it would be a clue that life didn't need to select for left-handedness—it could have simply picked up what asteroids and comets dropped off. ■

Nucleoli (raised, orange ovals) stand out in these colon cancer cells.

Central command

More capable than once thought, the cellular structure known as the nucleolus may be a target for treating diseases

By **Mitch Leslie**

Hit cancer cells where they're unique: the mutated genes and deranged molecular pathways that drive rampant growth. That's the strategy most researchers have adopted to kill cancer cells without massacring healthy ones, but it's backward, says cell biologist Ross Hannan of the Peter MacCallum Cancer Centre in East Melbourne, Australia. The way to take down tumor cells, he says, is to disturb the normal cellular "housekeeping processes," which are even more crucial to fast-growing cancer cells. And a focal point of those mundane processes is a dark spot in the cell nucleus called the nucleolus.

Hannan and his colleagues, who are running a clinical trial of an experimental cancer drug targeting the nucleolus, are capitalizing on a new understanding of this obscure organelle. For more than 30 years, researchers thought that the nucleolus performed a vital but circumscribed role in the nucleus—manufacturing a specific type of RNA, dubbed rRNA, that assembles into ribosomes, the organelles that make proteins. But scientists have come to realize that, as molecular cell biologist Robert Tsai of the Texas A&M Health Science Center in Houston puts it, "the nucleolus is much more complex than rRNA synthesis."

Besides serving as a ribosome factory, the organelle also functions as a command center that monitors a cell's condition and orchestrates responses when it's under stress. By storing certain proteins and doling them out when they are required, the nucleolus "endows cells with an accurate way to regulate distribution of proteins," says Michal Hetman, a molecular and cellular neurobiologist at the University of Louisville in Kentucky. Ultimately, the nucleolus helps determine whether cells reproduce and when they die.

All of that makes it a tempting target for treating diseases, starting with cancer. Researchers have known for more than 200 years that cancer cells often sport extra nucleoli, which balloon as they attempt to help the rapidly dividing cells meet their insatiable need for proteins. In recent years, hints have emerged that the nucleolus's activities also contribute to heart disease, neurological illnesses, and other diseases.

PHOTO: STEVE GSCHMEISSNER/SCIENCE SOURCE