Corrected 12 January 2015; see full text.

# Comet rendezvous

## Rosetta's short-lived lander grabbed the headlines, but the ongoing orbital mission is the real news for science

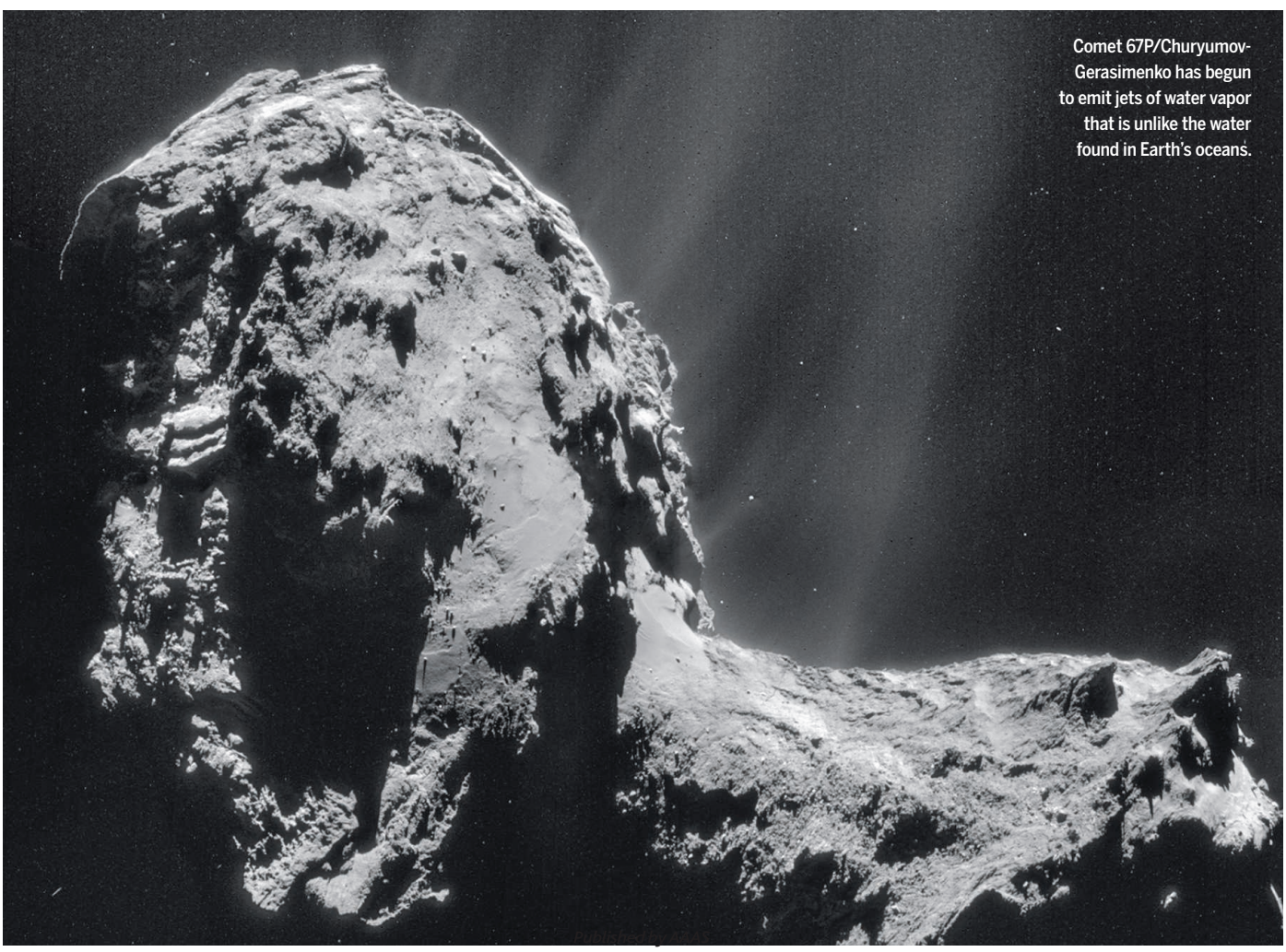
*By* **Eric Hand**

This year's breakthrough captured the public's imagination with a series of hard-won pictures, beamed to Earth from a place beyond Mars. First: an image of a spindly, three-legged thing, framed against the blackness of space, falling toward a comet nearly as black. Would the little Philae lander survive its descent to 67P/Churyumov-Gerasimenko?

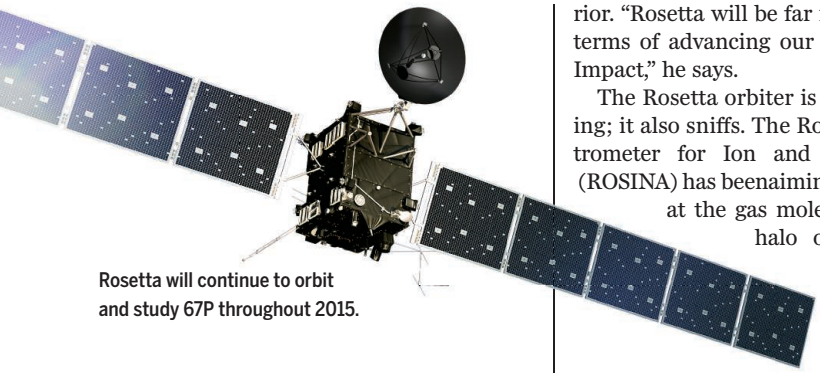
Soon, other pictures arrived. One revealed the dusty surface where Philae initially, and briefly, touched down. The lander, equipped with harpoons, screws, and reverse thrusters that didn't work, failed to gain purchase in the surprisingly hard comet crust, and so it rebounded in the barely-there gravity. Then came some disorienting, ominous images. Philae appeared to have come to rest on its side, far from its intended landing spot, in the shadows of a cliff.

Comets are sintered lumps of dust, ice, and organic molecules and do not contain rocks per se. Nevertheless, Philae was caught in a hard place, next to something that looked very much like a rock. With too little sunlight to recharge its batteries, the lander had a feverish 57 hours to gather data before it expired. Philae's anthropomorphized Twitter account mawkishly narrated its final moments. "I'm feeling a bit tired, did you get all my data? I might take a nap," it said.

Whatever data Philae did manage to return will be significant, not least because 67P is just the seventh place beyond Earth explored by a lander. (Venus, Mars, the moon, Saturn's moon Titan, and two asteroids are the others.) Yet the importance of the landing was largely emotional and symbolic. Mission managers have suggested that 80% of the overall science return would come from Philae's mother ship, Rosetta, which reached the comet in August and has been orbiting it ever since, scrutinizing it from as close as 10 kilometers away. That broader achievement, and the cornucopia of information it is yielding, are what



Comet 67P/Churyumov-Gerasimenko has begun to emit jets of water vapor that is unlike the water found in Earth's oceans.



Rosetta will continue to orbit and study 67P throughout 2015.

*Science* is celebrating as 2014's Breakthrough of the Year.

Merely getting the €1.4 billion mission to the comet was a massive undertaking for the European Space Agency. After launch in 2004, flight engineers put Rosetta through a decade of orbital tricks: Mars and Earth were used as gravitational slingshots to bring the spacecraft in line with the comet's elliptical 6.5-year orbit. When Rosetta caught up with 67P, the comet was still far from the sun and cold. As it plunges sunward, its subsurface ice deposits have begun to sublimate, powering jets of gas and dust. Peak activity should come in August 2015 at perihelion, when the comet is halfway between the orbits of Earth and Mars. By watching the jets develop and change, scientists can learn how comets are altered each time they approach the sun. Then, by subtracting those processes, they can turn back the clock and understand how comets formed some 4.5 billion years ago.

Much of Rosetta's power comes from its ability to inspect the comet at close range for months on end. The half-dozen or so previous missions to comets were all flybys that were over in hours. Another ballyhooed flyby of an icy body—NASA's New Horizons mission to Pluto—will whiz past the dwarf planet on 14 July 2015. At its closest, New Horizons will pass Pluto at a distance of 10,000 kilometers, close enough to make out building-sized features (with a camera resolution of between 70 and 90 meters per pixel). By contrast, Rosetta's camera can discriminate between objects just centimeters apart. Already, Rosetta has tracked arcs of dust emerging from active jets.

"The breakthrough is yet to come, and it will come from having the orbiter stay with the comet," says Michael A'Hearn, a planetary scientist at the University of Maryland, College Park. A scientist on two of Rosetta's instruments, A'Hearn was also the principal investigator for Deep Impact, a NASA comet flyby that in 2005 lobbed a projectile into the comet Tempel 1 to probe its interior. "Rosetta will be far more impressive in terms of advancing our science than Deep Impact," he says.

The Rosetta orbiter is not just about seeing; it also sniffs. The Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA) has beenaiming its spectrometers at the gas molecules in 67P's thin halo of an atmosphere, called the coma. In addition to detecting expected gases such as water, methane, and hydrogen, it has started to find rarer species, including formaldehyde and hydrogen cyanide. Getting the list of comets' primordial ingredients is important because many scientists think comets helped jump-start life on early Earth with an infusion of water and organic molecules.

ROSINA has the sensitivity to detect isotopes, too. In one of the most important mission results so far, published online on 10 December in *Science*, the ROSINA team found an exceptionally high ratio of heavy hydrogen (deuterium) to regular hydrogen. Because this D-to-H ratio is so much higher than that found in Earth water, it suggests that comets like 67P—part of a group that hails from the Kuiper belt, a region beyond Neptune—could not have played a major role in delivering water to Earth. The high ratio also buttresses the classical view of where the two main groups of comets formed. In this view, Kuiper belt comets like 67P formed beyond Neptune before being flung farther out into the Kuiper belt by the gravitational influence of Jupiter. Other comets, with lower D-to-H ratios, formed closer to the sun. There, solar system dynamics gave them an even bigger push, strong enough to scatter them out to an even more distant solar suburb known as the Oort cloud.

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For more on the Breakthrough of the Year, including a video and a podcast, go to http://scim.ag/breakthru14.

Rosetta has its limitations. It struggles to detect complex chains of organic molecules, such as amino acids, especially on the comet's solid surface. As a result, it is unlikely to tell scientists conclusively whether the organics at the comet's surface are the pristine ingredients that 67P started with, or products of chemical reactions sparked by earlier close encounters with the sun. That's why mission scientists are disappointed that Philae was unable to perform its most ambitious experiment: drilling a sample from below the comet's surface and baking it in an oven for analysis.

Mission managers haven't completely ruled out trying again. As 67P approaches the sun, more light will fall on Philae's solar panels. In its last tweet, the lander raised the possibility of a resurrection. "My #lifeonacomet has just begun @ESA_Rosetta. I'll tell you more about my new home, comet #67P soon… zzzzz." Regardless of whether Philae wakes up, Rosetta's life at comet 67P has indeed just begun—and it heralds a new age of comet science. ■

## People's choice

Visitors to *Science*'s website picked their top breakthroughs of 2014. The results:

1. Giving life a bigger genetic alphabet **34%**
2. Young blood fixes old **32%**
3. Comet rendezvous **17%**
4. Cells that might cure diabetes **11%**
5. An easy cure for hepatitis C **6%**

Since 1996, *Science*'s writers and editors have assembled the Breakthrough of the Year section by holding meetings, revising lists, and even installing a suggestion jar in the office kitchen. This year, we decided to give the public a say. In November, we posted our "long list" of 19 breakthrough candidates online at www.sciencemag.org and let visitors vote on them for 2 weeks. In December, we took the top five semifinalists and posted them for a second, weeklong round of voting.

A science-themed horserace ensued. The Rosetta comet mission—which was making headlines worldwide as the voting began—finished the first round with a healthy lead, garnering more than 16% of the 24,947 votes cast. Next came "Young blood fixes old" with 11% of the votes, followed by "Cells that might cure diabetes" with 10%.

In the second round, things got interesting. "Young blood" took an early lead and looked like a shoo-in. But in a late surge, "Giving life a bigger genetic alphabet" pulled even with the rejuvenated mice. The two results ran neck and neck in the final stages of voting, but the expanded genetic alphabet pulled ahead and won by a nose. The Rosetta mission—*Science*'s own choice—finished third. Kudos to all contestants, and thanks to everyone who cast a vote.

PHOTO: ESA/ATG MEDIALAB

# Comet Breakthrough of the Year + People's choice

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