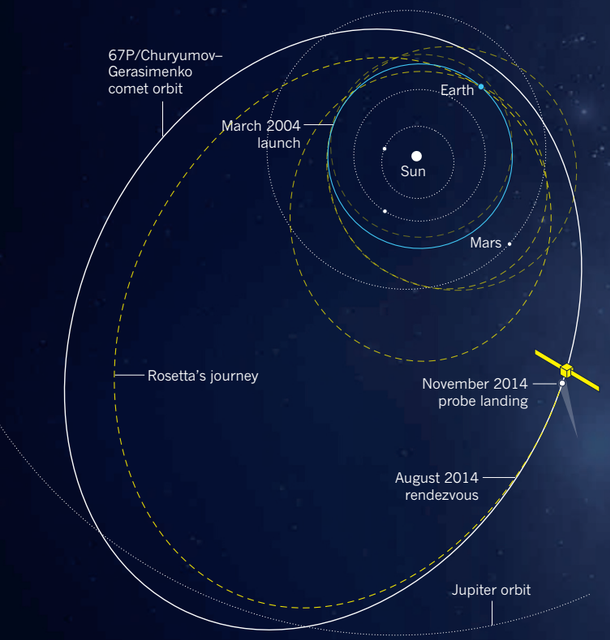
LANDING ON A COMET

A STEP-BY-STEP GUIDE TO A PERILOUS DESCENT



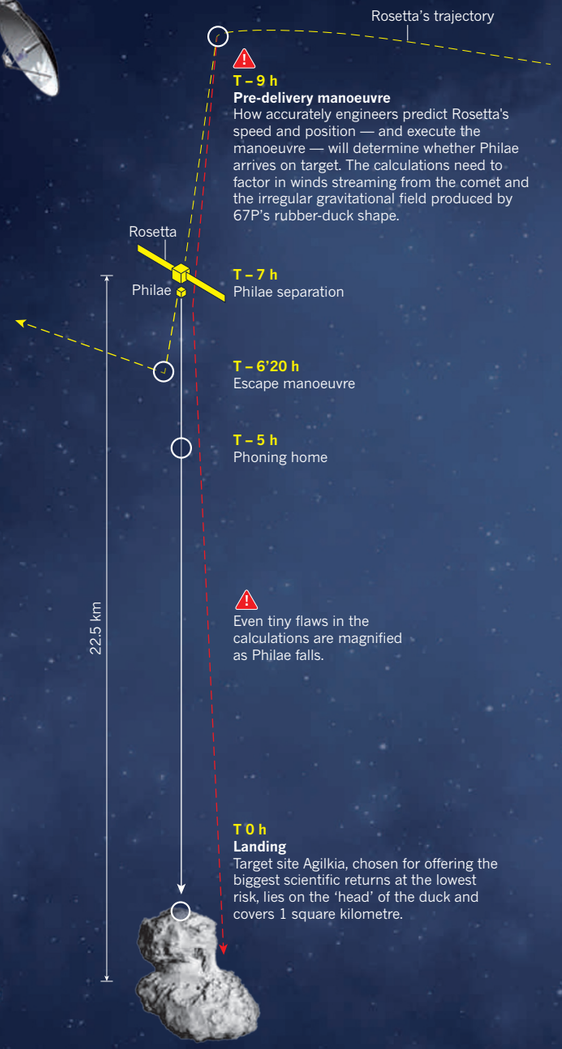
Never before has a space mission put a lander on a comet. But as *Nature* went to press, the European Space Agency (ESA) was poised to change that. Its Rosetta craft had been orbiting comet 67P/Churyumov–Gerasimenko since August and was set to release the washing-machine-sized lander, Philae, on 12 November. This would set in motion a nail-biting seven-hour fall that would deliver Philae to a landing site called Agilkia on the comet's surface. Philae is programmed to beam data and images back to Earth to help scientists to understand comets, including whether these conglomerations of ice, rock and dust supplied our planet with water and other building blocks of life when they smashed into it billions of years ago. But even if the landing fails, it will go down as one of the most ambitious feats attempted in space. Our guide illustrates why.

NATURE.COM
Visit **www.nature.com/philae** to find out what happened

BYE-BYE MISSION CONTROL

T – 9 h

Rosetta is steered by infrequent thruster burns, directed from mission control in Darmstadt, Germany. The last burn before landing comes when Rosetta turns towards the comet.



T – 9 h
Pre-delivery manoeuvre
How accurately engineers predict Rosetta's speed and position — and execute the manoeuvre — will determine whether Philae arrives on target. The calculations need to factor in winds streaming from the comet and the irregular gravitational field produced by 67P's rubber-duck shape.

T – 7 h
Philae separation

T – 6'20 h
Escape manoeuvre

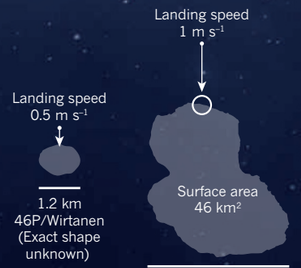
T – 5 h
Phoning home

Even tiny flaws in the calculations are magnified as Philae falls.

T 0 h
Landing
Target site Agilkia, chosen for offering the biggest scientific returns at the lowest risk, lies on the 'head' of the duck and covers 1 square kilometre.

COMET SWITCHEROO

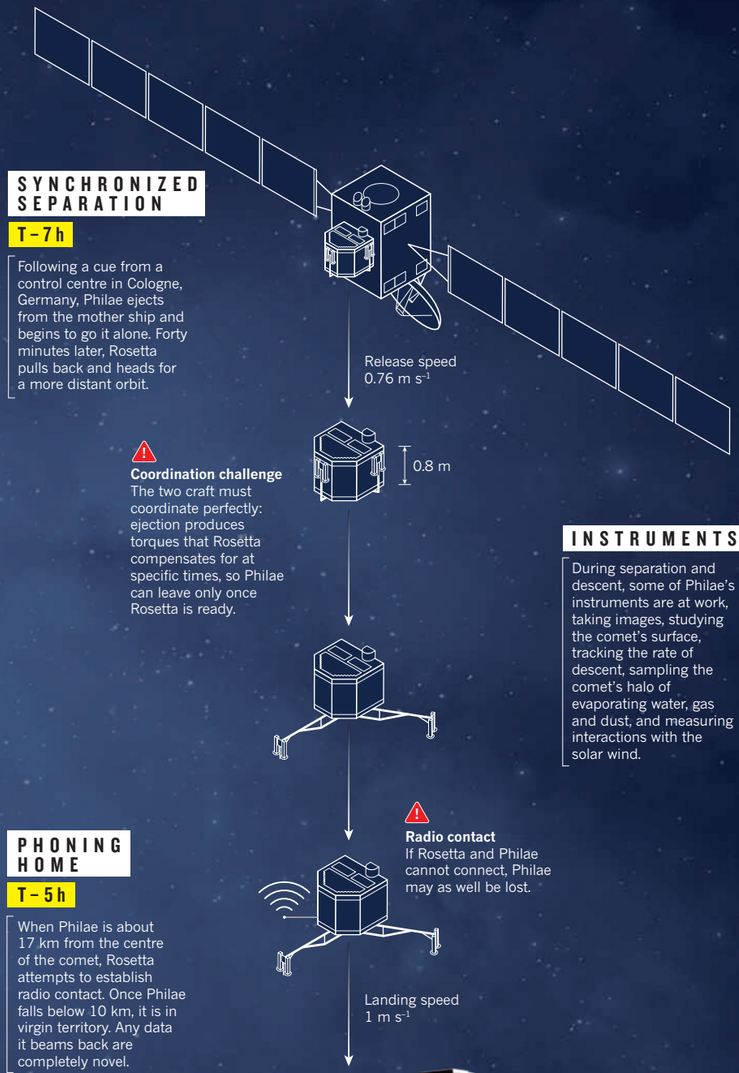
ESA originally planned for Rosetta to visit a smaller comet, 46P/Wirtanen, but a postponed launch forced the agency to choose a replacement. The bigger comet increases the distance at which separation must occur, decreasing Philae's landing precision. It also has a stronger gravitational pull, making the landing heavier.



SYNCHRONIZED SEPARATION

T – 7 h

Following a cue from a control centre in Cologne, Germany, Philae ejects from the mother ship and begins to go it alone. Forty minutes later, Rosetta pulls back and heads for a more distant orbit.



Coordination challenge
The two craft must coordinate perfectly: ejection produces torques that Rosetta compensates for at specific times, so Philae can leave only once Rosetta is ready.

Radio contact
If Rosetta and Philae cannot connect, Philae may as well be lost.

Landing speed 1 m s⁻¹

PHONING HOME

T – 5 h

When Philae is about 17 km from the centre of the comet, Rosetta attempts to establish radio contact. Once Philae falls below 10 km, it is in virgin territory. Any data it beams back are completely novel.

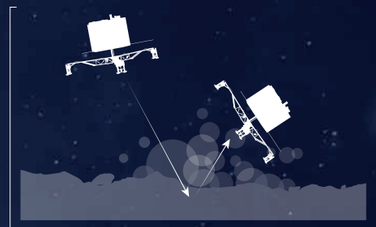
INSTRUMENTS

During separation and descent, some of Philae's instruments are at work, taking images, studying the comet's surface, tracking the rate of descent, sampling the comet's halo of evaporating water, gas and dust, and measuring interactions with the solar wind.

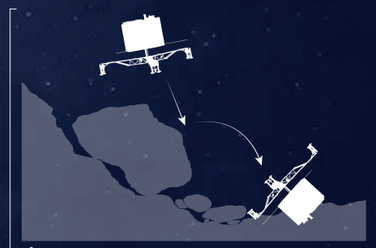
TOUCHDOWN

T 0 h

Assuming that mission control got the sums right for the final manoeuvre (see T – 9 h), Philae hits somewhere within Agilkia. But much can still go wrong.



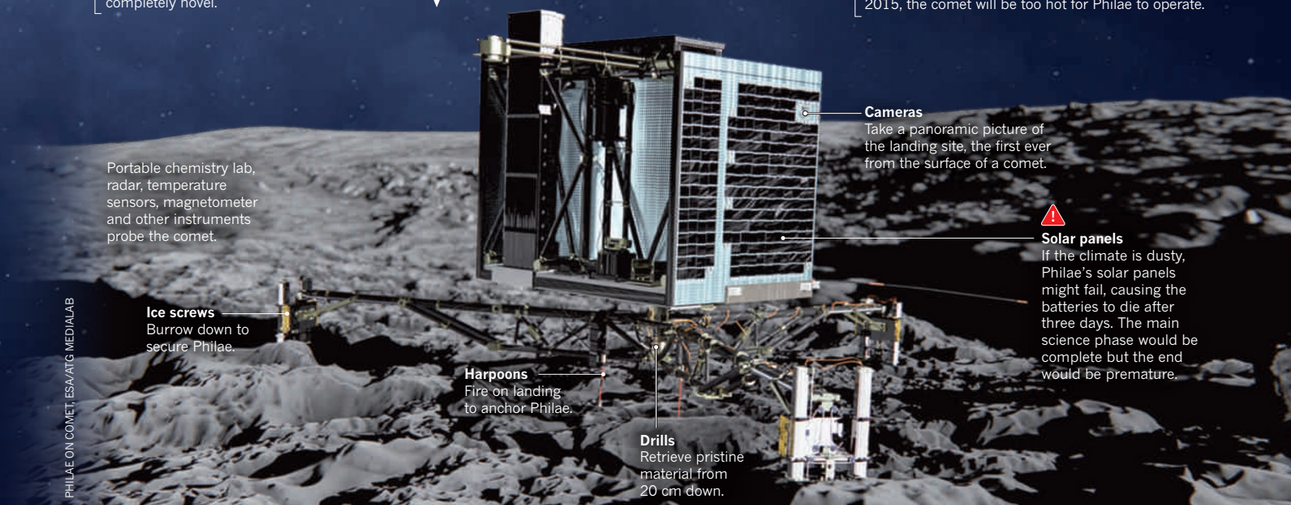
The surface is too hard and Philae bounces. The surface is too soft and the lander struggles to secure itself with harpoons and screws. Low gravity makes drilling difficult.



A steep slope or a boulder as small as a chair flips the lander. Philae's legs can cope with a slight tilt, but the lander has no way to fully right itself.

EXPLORATION

Philae's main science phase lasts for three days and includes drilling into the comet's surface and analysing what it finds. But if its solar panels work, Philae can keep going after that, studying how conditions change as the comet gets closer to the Sun and looking for evidence of amino acids. By March 2015, the comet will be too hot for Philae to operate.



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