a similar mission planned by NASA, see reference 5.

Known unknowns

Despite its wildly different climate, Venus is sometimes known as Earth's twin. The two are similar in size, mass, bulk composition, and proximity to the Sun. And although radar maps have revealed Venus to be covered in volcanic and tectonic features, no one knows whether volcanism and tectonic activity continue today. Establishing the current geological state would help scientists address a fundamental question about Venus that they are still struggling to answer about Mars—whether the planet ever had a habitable environment with liquid-water oceans. (See the article by Ashwin Vasavada on page 34 of this issue.)

Unlike Mars's surface, whose study has benefited enormously from a succession of rovers crawling around the planet for the past decade, the surface of Venus remains almost completely unexplored. If roving on Venus's rugged terrain turns out to be too challenging or otherwise impractical, the high atmospheric density near its surface—50 times that on Earth—enables another possible way to get around: using metal Chinese-lantern-like balloons whose bellows can expand or contract to control buoyancy.[6]

The concept of planetary ballooning is less outlandish than one might think. Back in 1985 the Soviet Union successfully deployed two balloons in the clouds of Venus, 55 km above the surface. Too high up to image the ground, the balloons and their payloads were carried more than 10 000 km by fast winds and enjoyed balmy temperatures around 20 °C. Today's research into robust SiC circuitry could lead to high-temperature balloon missions that travel far closer to the ground—even touching down in spots—so that instruments can photograph passing terrain or sample its broiling soil and rock.

Mark Wilson

References

1. See, for example, C.-M. Zetterling, *Mater. Res. Soc. Bull.* **40**, 431 (2015).
2. D. J. Spry et al., *IEEE Electron Device Lett.* **37**, 625 (2016), and references therein.
3. P. G. Neudeck et al., *AIP Adv.* **6**, 125119 (2016).
4. C. F. Wilson, C.-M Zetterling, W. T. Pike, https://arXiv.org/abs/1611.03365; for more on the feasibility of investigating Venus's interior with seismological techniques, see D. Stevenson et al., *Probing the Interior Structure of Venus*, Keck Institute for Space Studies (2015).
5. T. Kremic, "Long-Lived In-Situ Solar System Explorer (LLISSE)," presented at the 14th Meeting of the Venus Exploration and Analysis Group, 29 November–1 December 2016.
6. L. S. Glaze et al., *Venus Mobile Explorer: Mission Concept Report to the NRC Decadal Survey Inner Planets Panel*, NASA–GSFC, JPL–Caltech, NASA–ARC (18 December 2009).
7. C. M. Pieters et al., *Science* **234**, 1379 (1986).

PHYSICS UPDATE

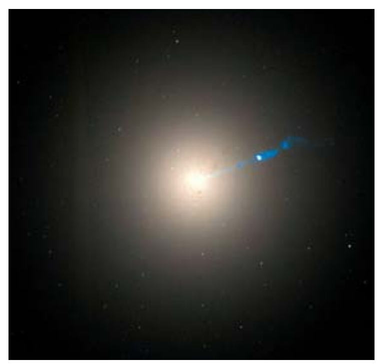
These items, with supplementary material, first appeared at www.physicstoday.org.

TESTING THEORIES OF MODIFIED GRAVITY

The accelerated expansion of the universe is usually attributed to a mysterious dark energy, but there's another conceivable explanation: modified gravity. Unmodified gravity—that is, Einstein's general relativity—satisfactorily accounts for the dynamics of the solar system, where precision measurements can be made without the confounding influence of dark matter. Nor have any violations been detected in one of general relativity's principal ingredients, the strong equivalence principle, which posits that inertial mass and gravitational mass are identical.

But those observational constraints are not ineluctable. In particular, a class of gravitational theories called Galileon models can also pass them. In 2012 Lam Hui and Alberto Nicolis of Columbia University devised a cosmic test that could refute or confirm the models. Their test hinges on the models' central feature: an additional scalar field that couples to mass. The coupling can be characterized by a charge-like parameter, Q. For most cosmic objects, Q has the same value as the inertial mass. But for a black hole, whose mass arises entirely from its gravitational binding energy, Q is zero; the strong equivalence principle is violated.

Galaxies fall through space away from low concentrations of mass and toward high concentrations. The supermassive black holes at the centers of some galaxies are carried along with the flow. But if gravity has a Galileon component, the black hole feels less of a tug than do the galaxy's stars, interstellar medium, and dark-matter particles. The upshot, Hui and Nicolis realized, is that the black hole will lag the rest of the galaxy and slip away from its center. The displacement is arrested when the black hole reaches the point where the lag is offset by the presence of more of the galaxy's gravitational mass on one side of the black hole than on the other. Given the right circumstances, the displacement can be measured.



Hui and Nicolis's proposal has now itself been put to the test. Asha Asvathaman and Jeremy Heyl of the University of British Columbia, together with Hui, have applied it to two galaxies: M32, which is being pulled toward its larger neighbor, the Andromeda galaxy, and M87 (shown here), which is being pulled through the Virgo cluster of galaxies. Both M32 and M87 are elliptical galaxies. Because of their simple shapes, their centroids can be determined from optical observations. The locations of their respective black holes can be determined from radio observations. Although the limit on Galileon gravity that Asvathaman, Heyl, and Hui derived was too loose to refute or confirm the theory, they nevertheless validated the test itself. More precise astrometric observations could make it decisive. (A. Asvathaman, J. S. Heyl, L. Hui, *Mon. Not. R. Astron. Soc.* **465**, 3261, 2017.)

—CD

WATCHING PEROVSKITE PHOTOEXCITATIONS, ATOM BY ATOM

Certain members of the class of crystalline materials known as perovskites have recently shown great promise for optoelectronic applications. Perovskites have the chemical formula ABX_3, where A and B are cations and X is an anion, arranged as shown on page 22. Crystals that combine an organic cation, lead as the