PHYSICS TODAY

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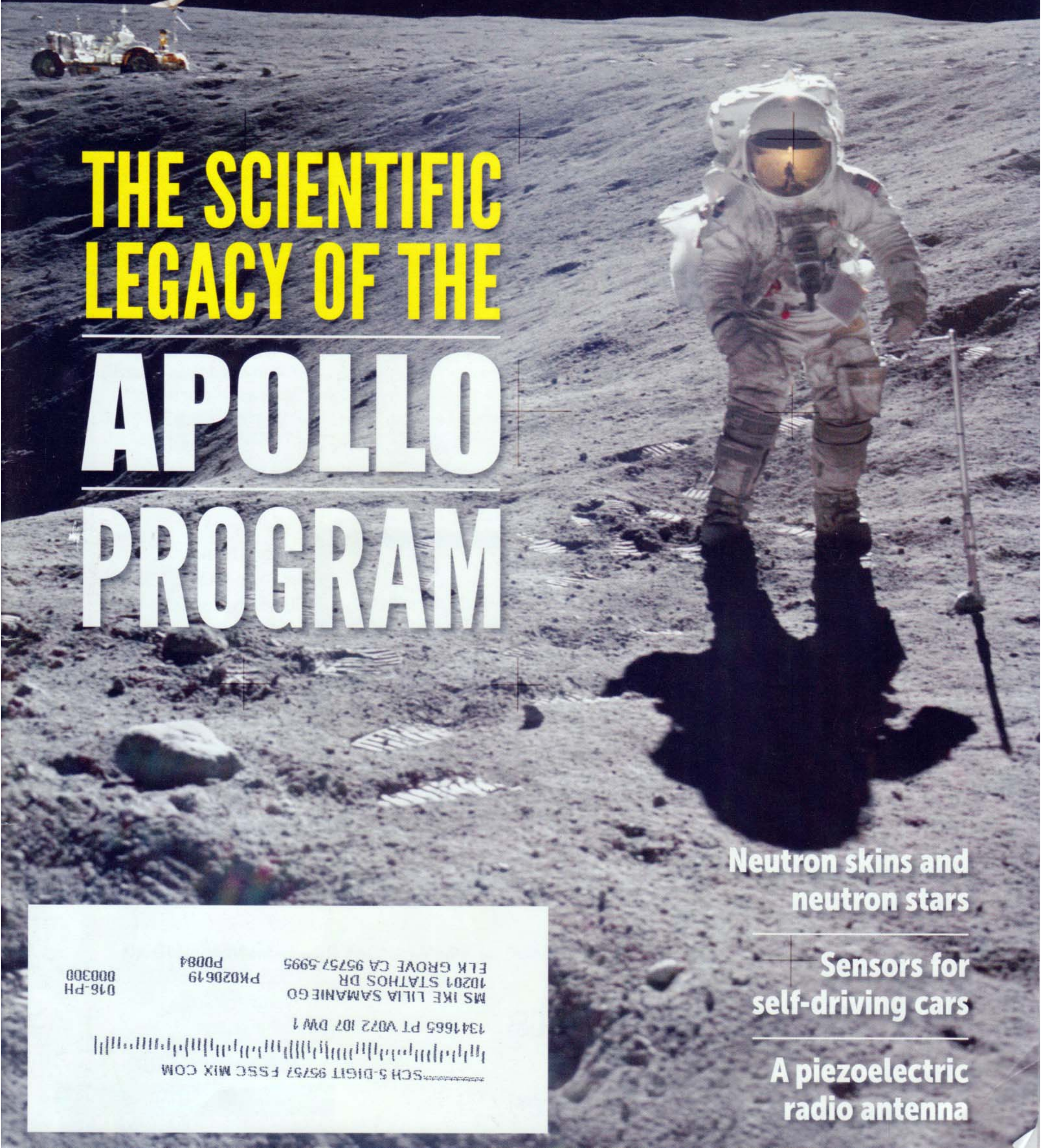

THE SCIENTIFIC LEGACY OF THE APOLLO PROGRAM

Neutron skins and neutron stars

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A piezoelectric radio antenna

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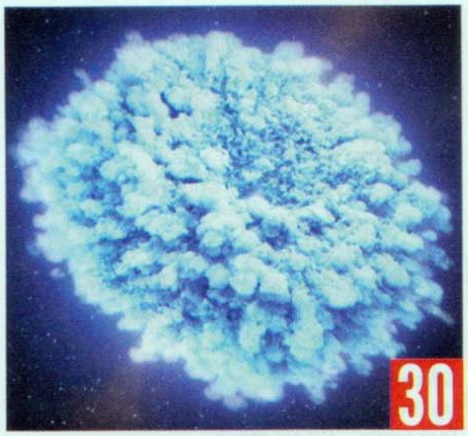

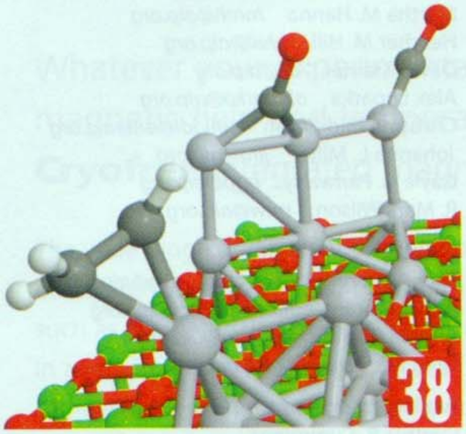

ON THE COVER: Astronaut Charles M. Duke Jr collects lunar samples next to the rim of Plum Crater during the first *Apollo 16* extravehicular activity on 21 April 1972. The parked lunar rover sits in the background. On **page 44**, Brad Jolliff and Mark Robinson discuss the achievements and scientific legacy of the Apollo program. (Photo taken by astronaut John W. Young. Courtesy of NASA.)

Recently on PHYSICS TODAY ONLINE

www.physicstoday.org

TERRY THRELFALL

▸ Melt mystery

In 1896 chemist Emil Fischer produced a crystal that sometimes melts at 65 °C and sometimes at 100 °C. It took 123 years to learn how that could happen. David Adam explains how researchers determined that identical crystalline solids can melt into structurally distinct liquids.
physicstoday.org/Jul2019a

ADEM ALTAN/AFP/GETTY IMAGES

▸ Serkan Golge

On 29 May physicist and dual US–Turkish citizen Serkan Golge was released from prison in Turkey after a nearly three-year incarceration on charges that the US government and human rights organizations called unsubstantiated. Golge talks to Physics Today about his experience and his desire to return to physics research.
physicstoday.org/Jul2019b

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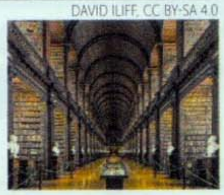

▸ Plan S

If implemented, Plan S would require recipients of research grants from a dozen European national funding agencies to publish work in open-access journals. Dalmeet Singh Chawla details recently announced revisions to the controversial policy, including a delay in adoption until 2021.
physicstoday.org/Jul2019c

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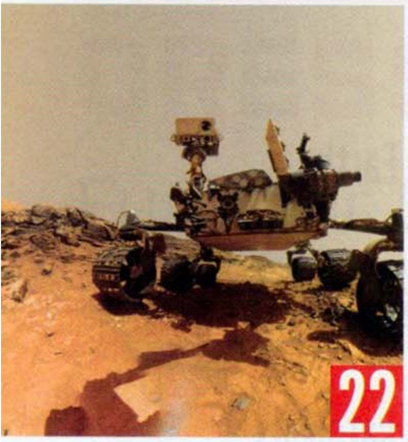
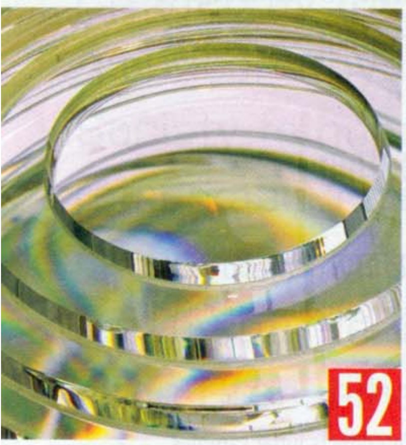
DEPARTMENTS





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Commentary

The universe and the university: Physics preparation for academic leadership

No school or degree specifically prepares a person for becoming a university president, provost, dean, or other academic administrator. Institutions of higher learning instead seek people with demonstrated management talent in their specific disciplines and count on them to translate those skills to administration. The institutions often find that physicists have developed a powerful skill set for leadership.

My physics background equipped me for roles as dean, vice president, and president. I acquired the mind-set and skills to manage the major topics of concern in those positions: complexity management, data-driven decision making, design and long-range planning, communication, globalization, and diversity and inclusion. In academic administration, I depend every day on the lessons I learned in physics. Following are ways that a physicist's knowledge and skills can help in addressing the six topics of concern.

What physics taught me

▶ **Managing complexity.** A university is a very elaborate organization with widely diverse elements—faculty, students, staff, departments, curricula, laboratories, and so on. Physicists are taught to deal with extremely complex ideas and processes—as small as a subatomic particle or as big as the universe. I was drawn to physics by the interconnectedness of nature and the apparently simple laws that govern it. As my research career broadened, I studied ever more intricate systems—soft-matter materials, the underlying principles of thermodynamics, statistical physics, and often-unexpected responses to constraints, external forces, and stimuli. I explored how systems adapt, evolve, self-organize, and reveal complex patterns.

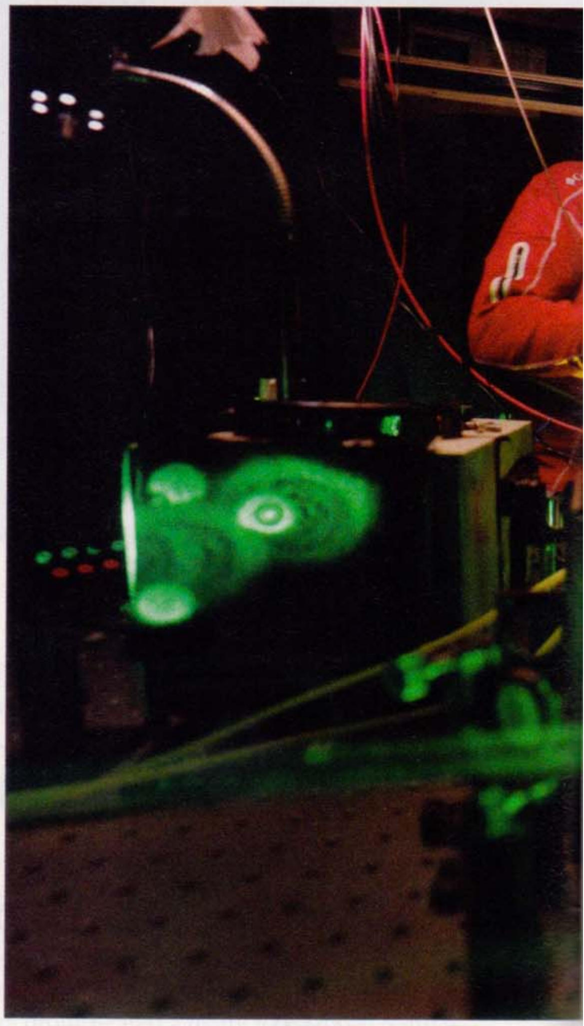
Academic leadership likewise involves both attention to detail and breadth of vision. A university community is organized, at least in theory, to align individual interests with the institution's vision. Fostering such a unifying vision for a complex organization is necessary for academic leadership today, and it is analogous to a physicist's understanding complex systems in nature.

▶ **Driving with data.** The accelerated dependence on data analytics in higher education means that quantitative skills are needed more than ever. Physicists are adept at comprehending data, identifying trends, and discovering patterns. From those data, they imagine things that have never been seen. They are equipped to recognize problematic data, misinterpretations, and hypotheses drawn from incorrect information. They must translate data into a story, starting with the question and narrating the path to the solution. Physicists tend to be great storytellers.

In academic oversight, much is driven by data, from devising financial models to leveraging artificial intelligence for student success. The capacity to analyze whether data are accurate and reliable and the skill to communicate the analysis with a compelling story are vital contributions physicists can bring to university administration.

▶ **Transcending barriers.** Today's global challenges are bigger than any single a cademic discipline can address. Universities need leaders who can break down silos and unite disparate expertise into powerful collaborations.

Physics touches many other disciplines, and it inspired me to be a perpetual student. My education first crossed boundaries from theoretical to computational to experimental physics, reached across different subdisciplines, and then



moved from pure to applied physics. Collaborations broadened; I worked with chemists and mathematicians, then with various engineers, and even with medical doctors. We reached the best solutions by presenting and discussing disagreements with humility and openness. My physics background enabled me to cross all those boundaries.

Universities by definition embrace a broad range of disciplines, departments, colleges, and programs. The capacity to unify faculty and staff across them all and forge a shared vision and mission is a skill that physicists can bring to higher education.

▶ **Designing with purpose.** In the fast-moving modern environment, universities can no longer expect to create and execute long-term plans without constant attention to unexpected events. To physicists, a "problem" is not an obstacle but a question not yet answered, and we tend to be confident in the progress made using the scientific method. I designed experiments that could fail or succeed or that could cause the research team to pivot when we saw an anomaly more ex-

Dark-matter detector observes a rare nuclear decay

The result shows that the exquisitely sensitive apparatus's potential extends beyond the purpose for which it was built.

Dark matter must exist. Gravitational phenomena such as the rotation of galaxies (see PHYSICS TODAY, December 2006, page 8) and lensing of light from distant stars (see PHYSICS TODAY, June 2015, page 18) consistently show signs of far more mass than ordinary protons, neutrons, and electrons can account for. Unless there's some large but subtle gap in the theory of general relativity, the universe must be swarming with some mysterious particles that feel the force of gravity but can't be seen or touched.

What those particles are is anyone's guess. One possibility—that dark matter is made of weakly interacting massive particles, or WIMPs—is appealing because it arises theoretically out of solutions to unrelated problems in particle physics. WIMPs, if they exist, could interact with ordinary matter not just gravitationally but also via a force on the scale of the weak interaction that neutrinos experience. So in principle, they can be detected the same way neutrinos are: Gather a large quantity of some material that's expected to produce a distinct scattering signature, put it deep underground to shield it from cosmic rays, surround it with sensors, and wait.

Dozens of would-be WIMP detectors have been built and operated over the years in underground labs around the world. With the exception of disputed results from one group (see PHYSICS TODAY, July 2016, page 28), they've all come up empty so far. But even if WIMPs aren't the solution to the dark-matter puzzle, the effort to observe them needn't be all for naught. The extraordinarily sensitive detectors, painstakingly rid of almost all background, are in a position to make measurements that no other experiments can, and they potentially can uncover new physics in quarters unrelated to dark matter.

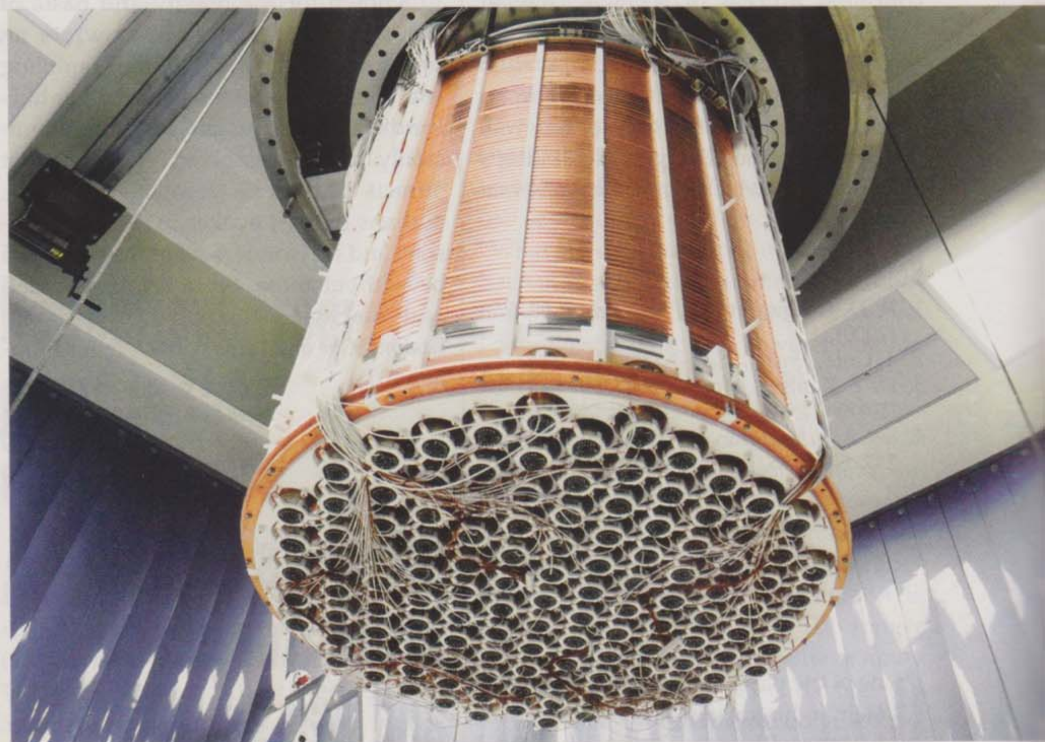


FIGURE 1. THE XENON1T DETECTOR before it was installed in 2016. The cylindrical vessel, roughly 1 m across and 1 m high, contained 3.2 tons of mostly liquid xenon at an operating temperature of −96 °C. The top and bottom faces were lined with photomultiplier tubes to detect and measure the energies of scattering events and radioactive decays. (Courtesy of the XENON collaboration.)

The XENON collaboration, founded in 2002 by Elena Aprile of Columbia University, has just made that potential look a lot more like a reality.[1] With its detector—which unsurprisingly uses chilled xenon as its target material—at Gran Sasso National Laboratory in Italy, the group has observed a rare form of nuclear decay, two-neutrino double-electron capture (2νECEC), in the neutron-poor isotope ^{124}Xe.

The result itself is not terribly startling. Nuclear theory predicts that ^{124}Xe should undergo 2νECEC, and the measured half-life is in line with expectations. But it's an experimental tour de force. Less than 0.1% of natural Xe is ^{124}Xe, and its half-life, $(1.8 \pm 0.6) \times 10^{22}$ yr, is the longest ever measured directly. As WIMP detectors continue to improve, they'll be ready to observe even rarer events. One much-discussed possibility is the neutrinoless version of the same decay, 0νECEC. If detected, 0νECEC would establish that neutrinos are their own antiparticles and that lepton number is not conserved.

Slow decay

A cousin of two-neutrino double-beta decay (2$\nu\beta\beta$; see PHYSICS TODAY, December 1987, page 19), 2νECEC is also related to single-beta decay and single-electron capture. All are based on the same fundamental weak interaction: Either a neutron decays into a proton, an electron, and an antineutrino, or a proton and electron combine to yield a neutron and a neutrino. (Nuclear-physics parlance isn't always fussy about distinguishing neutrinos and antineutrinos, but to conserve lepton number, they need to be counted as different particles.)

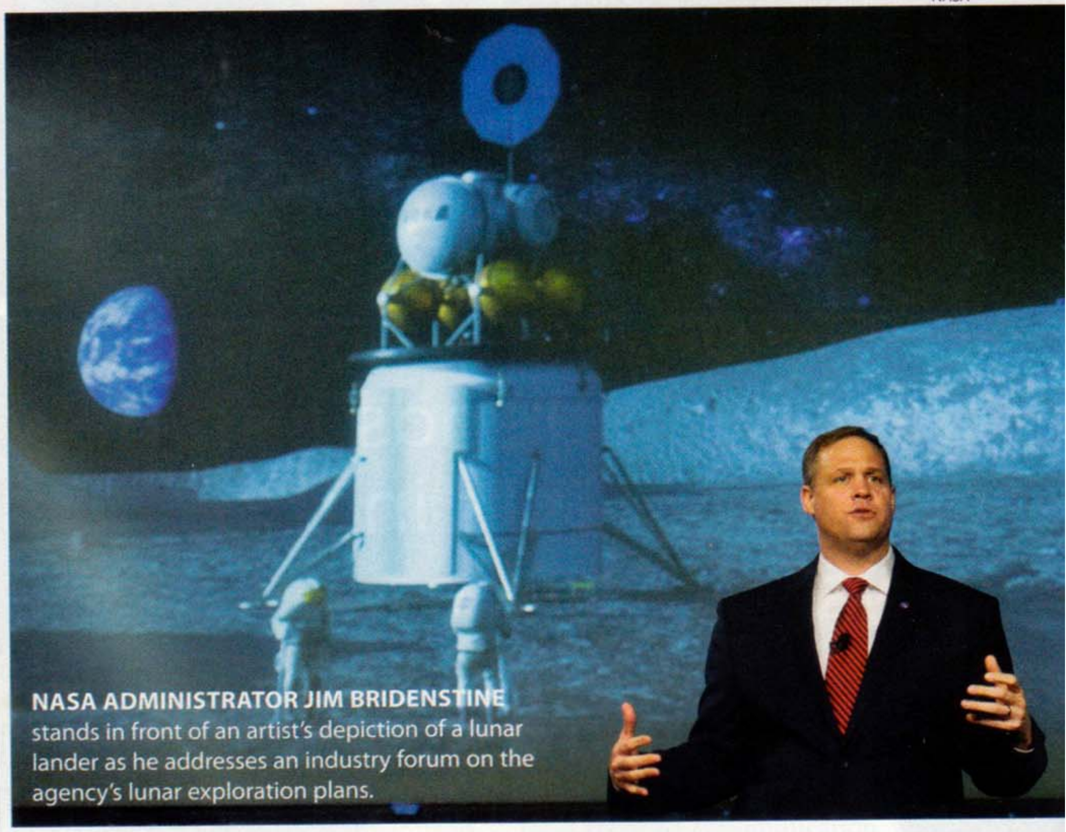
Nuclides that undergo beta decay include tritium and carbon-14, with half-lives of 12 yr and 5700 yr, respectively. But 2$\nu\beta\beta$, which requires the weak process to happen twice simultaneously, is correspondingly more infrequent: All known half-lives are greater than 10^{18} yr, so it's detectable only in nuclides for which single-beta decay is forbidden or strongly suppressed.

In general, 2νECEC is rarer still, be-

Quo vadis, NASA: The Moon, Mars, or both?

Fifty years after *Apollo 11*, the US spaceflight program is juggling political and technological factors as it moves toward the red planet, its ultimate destination.

NASA



NASA ADMINISTRATOR JIM BRIDENSTINE stands in front of an artist's depiction of a lunar lander as he addresses an industry forum on the agency's lunar exploration plans.

President Trump, NASA's leadership, Congress, and advocates for human space exploration agree that Mars should be the ultimate destination for the US spaceflight program. But will the administration's plan to send astronauts back to the Moon advance a Mars mission, or could the lunar program draw resources away from Mars and thus delay an excursion to the red planet?

In March of this year, Vice President Pence announced the administration's decision to move up by four years, to 2024, its target date for sending astronauts, including the first woman, to the Moon. But congressional appropriators' rejection of the administration's request to add $1.6 billion to NASA's fiscal year 2020 budget to accelerate the Moon landing program casts doubt on the 2024 goal.

Trump's December 2017 executive order, Space Policy Directive 1, acknowledged the goal of getting to Mars even as it ordered a return to the Moon. The 2017 NASA authorization act—which does not provide funding—also confirmed Mars as the ultimate destination for human exploration.

Regardless of exactly when it may happen, is putting humans back on the lunar surface truly a prerequisite for going to Mars? "I wish I could give you a really crisp, black and white answer, but it is a bit nuanced," says Scott Hubbard, who was director of NASA's Ames Research Center and NASA's first Mars program manager.

"This debate has been going on for decades," says Hubbard. "You can make a solid case that you can send people to Mars with only minimal testing at the Moon." As far back as 1991, aerospace engineer Robert Zubrin and colleagues at Martin Marietta (now Lockheed Martin) floated a Mars Direct plan, which eschewed a return to the Moon and the associated components of NASA's proposed lunar and Martian flight architecture.

Hubbard points to another proposal by three scientists at NASA's Jet Propulsion Laboratory (JPL) in 2015. It relied heavily on a set of elements already built or planned by NASA, such as the Space Launch System (SLS) heavy-lift rocket, the four-person Orion capsule, a deep-space habitat, and a 100 kW solar-electric-propelled "tug" for transporting supplies ahead of a human landing. The plan entailed few if any operations on the lunar surface and avoided complicated development programs such as nuclear-thermal propulsion. The JPL proposal envisioned an initial human mission landing on Phobos, the larger of Mars's two moons, in 2033, with a Mars touchdown in 2039.

More recently, SpaceX has proposed flying humans directly to Mars aboard its planned "starship." Paul Wooster, SpaceX's principal Mars engineer, told the Humans to Mars Summit (H2M) in May, "It's not unreasonable" that the company will put people on the planet by the mid 2020s.

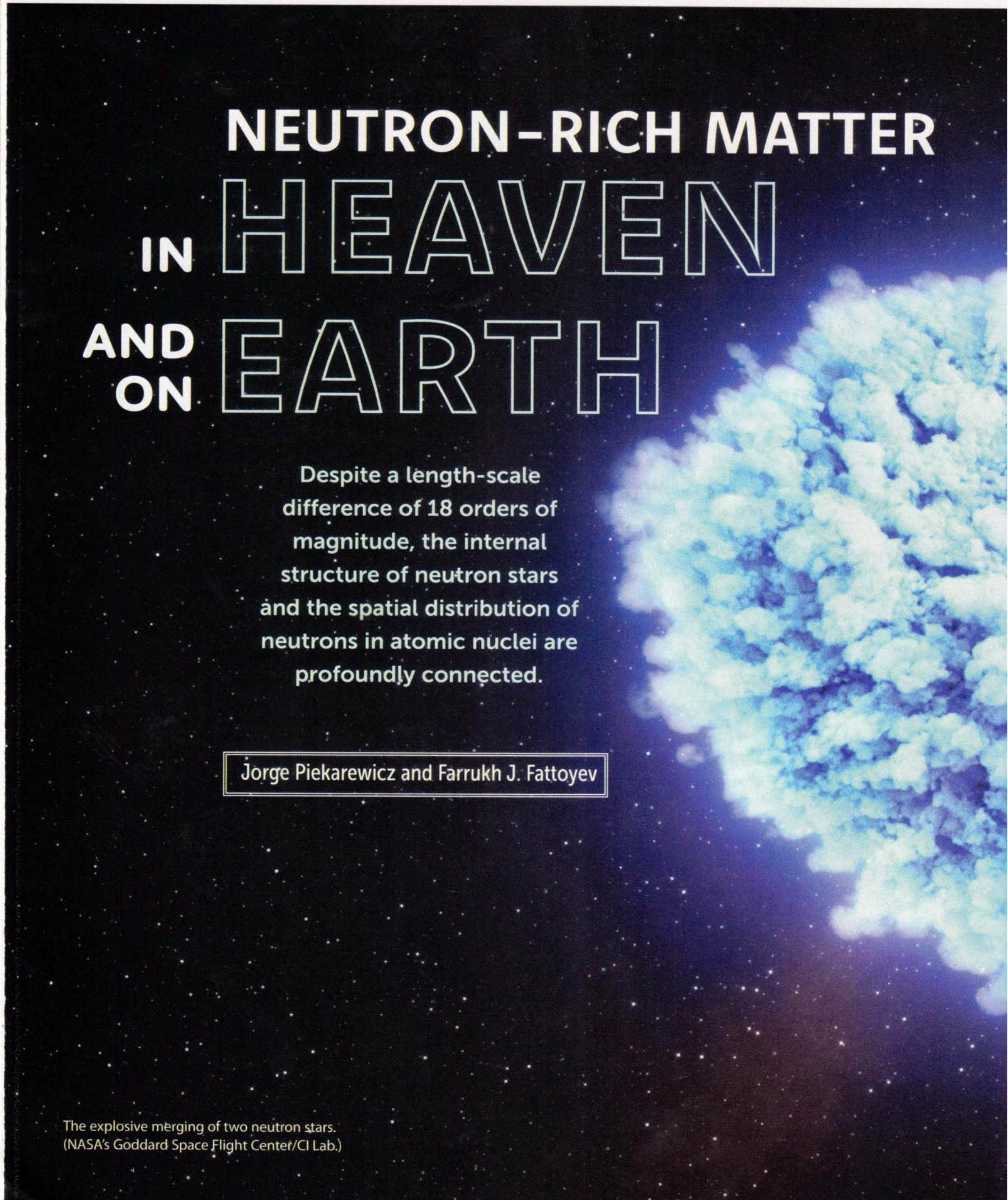
Jonathan Lunine, a Cornell University astronomer who cochaired a National Academy of Sciences (NAS) review of NASA's human spaceflight program in 2014, says that "from a strictly engineering point of view," a direct-to-Mars approach is feasible. "But you increase the risk tremendously, from two points of view: One, you're not going to be testing a lot of technologies until you actually get to Mars; and two, politically, because you don't have an intermediate goal in a program that is going to stretch significantly in time beyond what Apollo was."

Returning to the Moon would build momentum in a human spaceflight program that hasn't ventured beyond low-Earth orbit since the Apollo program ended in 1972. "If we wait until Mars, the whole government spaceflight program will collapse of its own weight," says John Logsdon, emeritus professor of space policy at George Washington University. "There's a pretty convincing case

NEUTRON-RICH MATTER IN HEAVEN AND ON EARTH

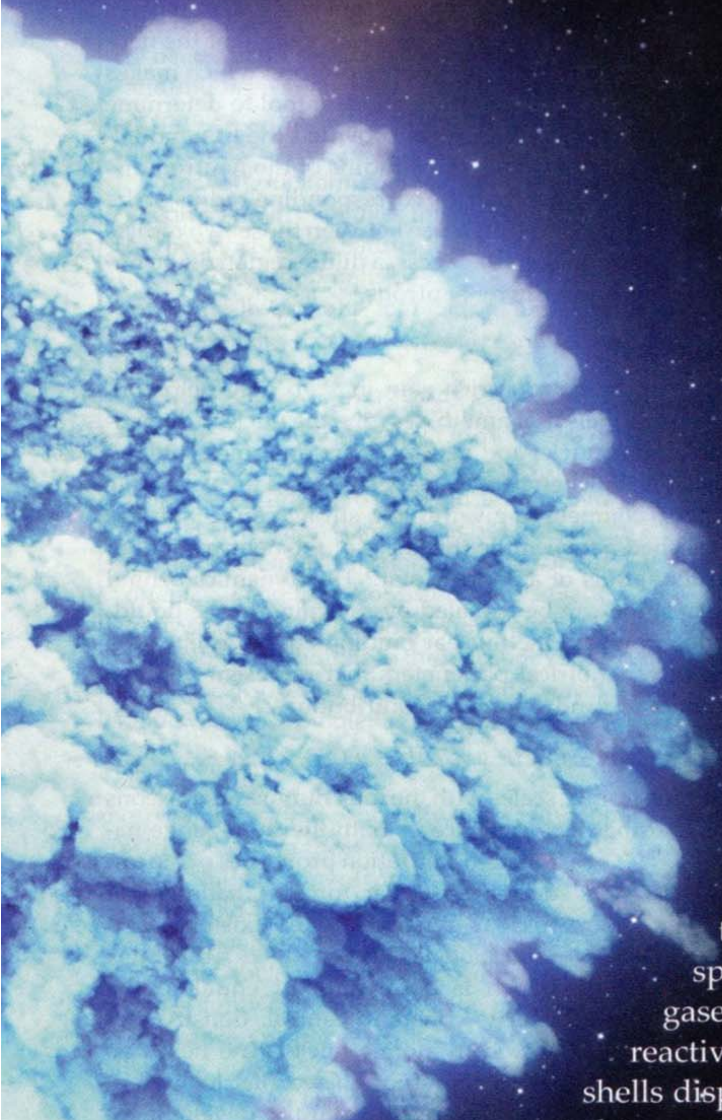
Despite a length-scale difference of 18 orders of magnitude, the internal structure of neutron stars and the spatial distribution of neutrons in atomic nuclei are profoundly connected.

Jorge Piekarewicz and Farrukh J. Fattoyev



The explosive merging of two neutron stars. (NASA's Goddard Space Flight Center/CI Lab.)

Jorge Piekarewicz is a professor in the department of physics at Florida State University in Tallahassee, and **Farrukh Fattoyev** is an assistant professor in the department of physics at Manhattan College in New York City.



Where do neutrons go? The elusive answer to such a seemingly simple question provides fundamental new insights into the structure of both atomic nuclei and neutron stars. To place the question in the proper context, consider lead-208, the element's most abundant isotope, which contains 82 protons and 126 neutrons. As the heaviest known doubly magic nucleus, ^{208}Pb holds a special place in the nuclear-physics community. Just as noble gases with filled electronic shells exhibit low levels of chemical reactivity, doubly magic nuclei with filled proton and neutron shells display great stability. Because ^{208}Pb is heavy, the Coulomb repulsion among its protons leads to a large neutron excess. The Lead Radius Experiment, or PREX, at the Thomas Jefferson National Accelerator Facility in Virginia was built to measure the location of ^{208}Pb's 44 excess neutrons.[1] In turn, a detailed knowledge of the neutron distribution in ^{208}Pb illuminates the structure of a neutron star.

Elisa Jimenez-Izal is an Ikerbasque research fellow at the University of the Basque Country and the Donostia International Physics Center, both in Donostia, Spain. **Bruce Gates** is a professor of chemical engineering at the University of California, Davis. **Anastassia Alexandrova** is a professor of chemistry and biochemistry at UCLA and the California NanoSystems Institute there.

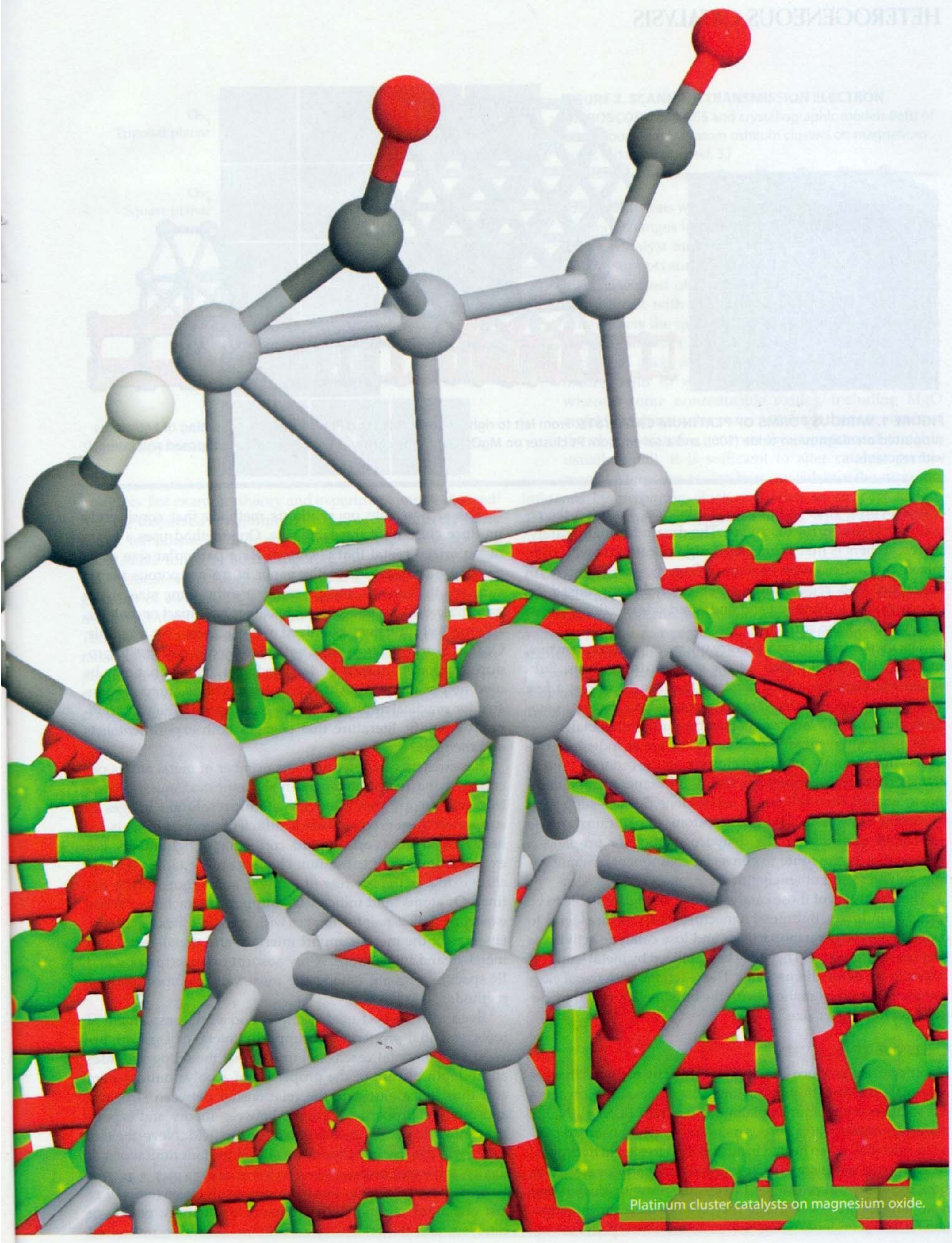
Designing clusters for HETEROGENEOUS CATALYSIS

Elisa Jimenez-Izal,
Bruce C. Gates, and
Anastassia N. Alexandrova

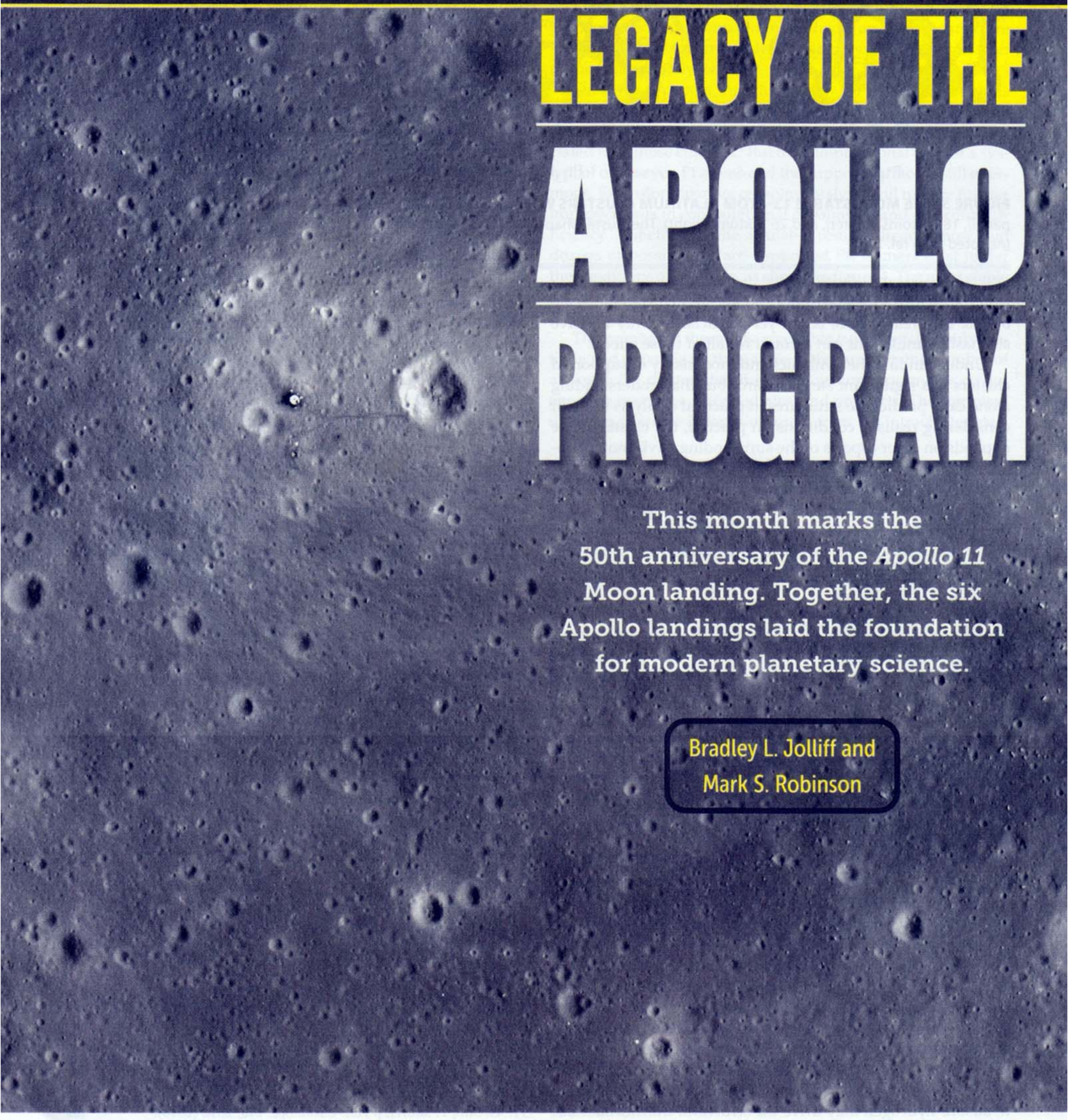
Subnanometer metal clusters offer catalytic properties not possible on bulk or nanoparticle metals.

In 1987 Masatake Haruta and his colleagues at the Osaka National Research Institute in Japan reported on catalytic behavior of gold nanoclusters.[1] Theirs was not the first work to demonstrate metal nanoclusters as catalysts, but that discovery was striking given bulk gold's well-known chemical inertness. The startling change in the behavior of gold when its size was reduced drew renewed attention to the study of metal nanocluster catalysts.

Today catalysis is involved at some point in more than 90% of all chemical manufacturing processes. Most catalysts used for those and other large-scale processes—including fuel conversion and abatement of waste from vehicles and power plants—are porous, high-area solids with nanoparticles dispersed on the internal surfaces. Such catalysis is complex because it occurs on surfaces that are heterogeneous in both composition



Platinum cluster catalysts on magnesium oxide.



THE SCIENTIFIC LEGACY OF THE APOLLO PROGRAM

This month marks the 50th anniversary of the *Apollo 11* Moon landing. Together, the six Apollo landings laid the foundation for modern planetary science.

Bradley L. Jolliff and Mark S. Robinson

Brad Jolliff is the Scott Rudolph Professor of Earth and Planetary Sciences at Washington University in St Louis, in Missouri. **Mark Robinson** is a professor in the School of Earth and Space Exploration at Arizona State University in Tempe and the principal investigator of the NASA Lunar Reconnaissance Orbiter Camera.

NASA/GSFC/ASU

On 20 July 1969, *Apollo 11* astronauts Neil Armstrong and Edwin "Buzz" Aldrin landed on the Moon while Michael Collins orbited in the command module *Columbia*. "Tranquility Base here. The *Eagle* has landed" became one of the most iconic statements of the Apollo experience and set the stage for five additional Apollo landings.

Each of the Apollo missions explored carefully selected landing sites and conducted a variety of experiments to probe the lunar interior and measure the solar wind. Well-trained astronauts made geologic observations and collected samples of rock and regolith, the impact-generated layer of debris that composes the lunar surface. Over a half century of study, the samples have revealed abundant information not only about the Moon's origin and history but also about the workings of our solar system.

Apollo 11

Results from the *Apollo 11* mission established key paradigms of lunar and planetary science. After a harrowing descent to the surface, Armstrong set the *Eagle* down on the cratered basaltic plains of *Mare Tranquillitatis*. Extravehicular activity was brief—just two and a half hours during that first mission—and included setting up surface experiments and exploring a small cluster of craters near the lunar module and Little West Crater some 60 meters away, as shown in figure 1. Aldrin's iconic *Apollo 11* bootprint photo revealed much about the lunar soil, including its fine-grained nature, its cohesiveness, and its ability to pack tightly together.

The Early Apollo Scientific Experiment Package contained, among other instruments, a passive seismometer and a laser-ranging retroreflector. Although designed to work for only three weeks, the seismometer provided a first key look at lunar seismic data. The seismometers brought to the Moon during the *Apollo 12*, *14*, *15*, and *16* missions were used as a larger network