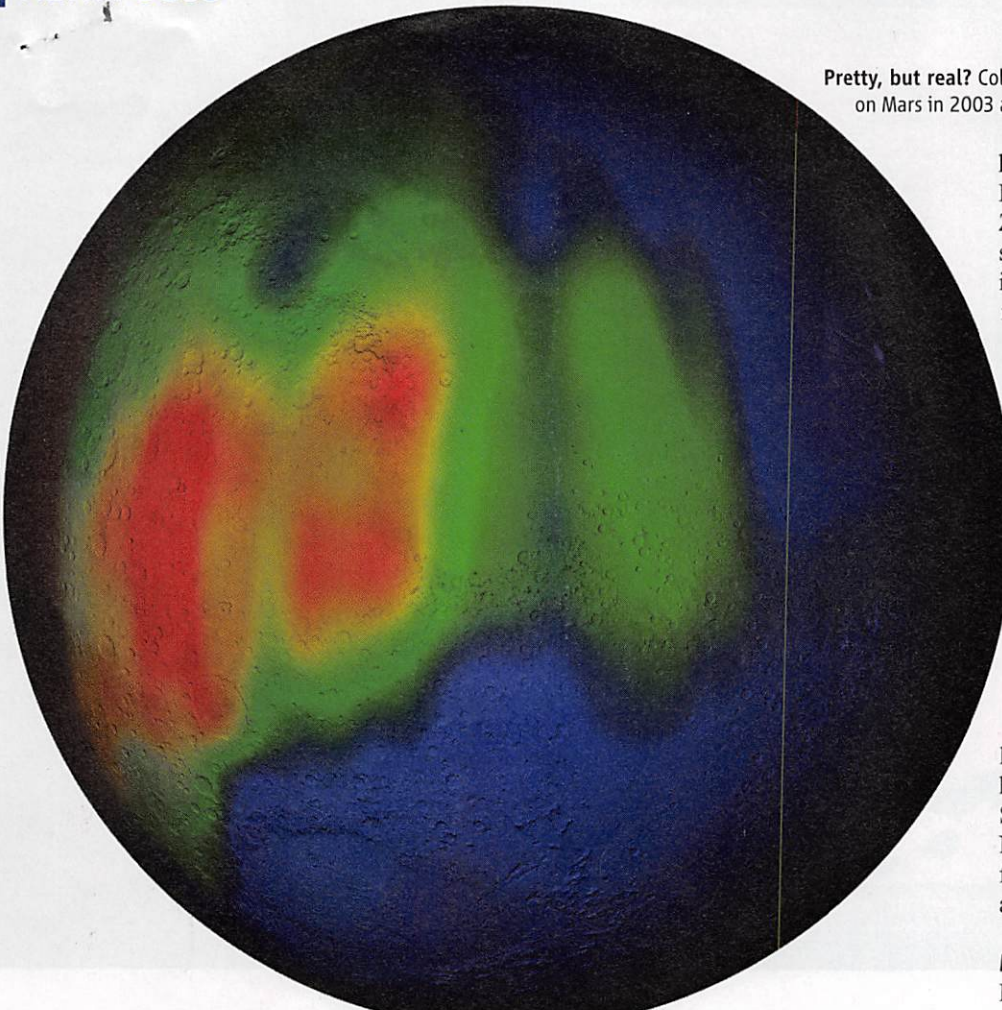


Pretty, but real? Colors denote concentrations of atmospheric methane on Mars in 2003 as reported by Mumma and colleagues.

PLANETARY SCIENCE

Could a Whiff of Methane Revive The Exploration of Mars?

The controversy over claimed detections of martian methane—a possible product of life on Mars—could be settled come August once the Curiosity rover arrives at the Red Planet

How many cows are there on Mars? That depends on which planetary scientist you're asking. Some would say there have been thousands of head of cattle, judging by how much methane three independent groups reported detecting in the atmosphere of Mars in 2003. Earthly cows belch the digestive gas all day long, so a bovine equivalent for Mars is a convenient, if playful, way to quantify martian methane. Whether the reported methane is from microbes eking out a living beneath the surface or from deep stirrings of the geologically moribund planet, no one can say. Either would excite scientists, but only martian biology could rejuvenate a troubled NASA Mars program.

Despite the playful units, planetary researchers are quite serious about their methane on Mars. "I'm shocked by these results," said planetary scientist Michael Mumma of NASA's Goddard Space Flight Center in Greenbelt, Maryland, when he first announced his team's methane detection at a meeting in 2004, but "our results are certain." The researchers reported that they had detected a few tens of parts per billion (ppb) by volume of martian methane. They found it by reading the squiggly lines of infrared spectra recorded by ground-based telescopes. Two other independent groups backed up Mumma with their own reported spectroscopic detections.

But some planetary scientists now see no credible signs that there ever was any methane on Mars. Last October, planetary scientist Kevin Zahnle of NASA's Ames Research Center at Moffett Field in California called his invited seminar on the subject "Lack of Evidence for Animal Husbandry on Mars." Zahnle has never done spectroscopy of any sort. But he and more spectroscopically inclined colleagues have scrutinized Mumma's results, noting that the reported parts-per-billion detection relied on instruments looking through the 2000-times-more-abundant methane of Earth's atmosphere. Correcting for that earthly methane "is just really, really hard," Zahnle says. "I don't think they can possibly do it."

The right head count of martian livestock could have multibillion-dollar implications for the exploration of Mars. NASA's Mars science program took a severe hit in President Barack Obama's 2013 budget request this past February (*Science*, 24 February, p. 900). But once before, in the 1990s, hints of ancient martian life—that time in a meteorite from Mars—helped resuscitate NASA's Mars program. So within weeks after its arrival this August, NASA's rover Curiosity could again fan the flames of life on Mars if it detects uncontestable martian methane.

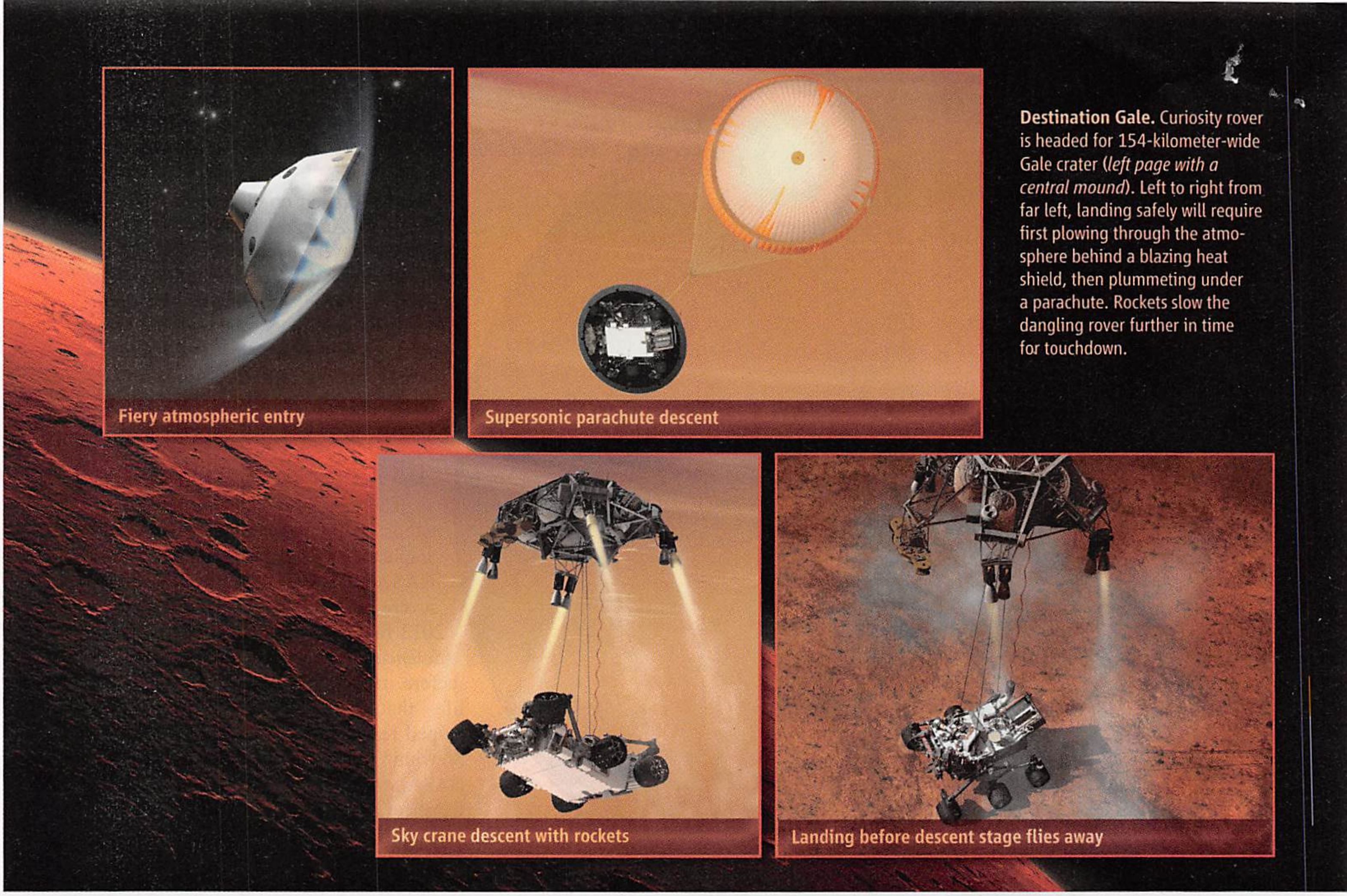
Methane, methane everywhere?

Martian methane burst on the scene in March 2004 at a press conference in Paris (*Science*, 26 March 2004, p. 1953), and was soon followed by two more independent claims in a meeting and its press conference. All three research groups reported at least 10 ppb of methane in the atmosphere of Mars in 2003. That's just 10 cubic centimeters of methane dispersed in the thousand cubic meters of a 10-meter cube of thin martian air. The three claimed detections—all since published in leading peer-reviewed journals—are still often cited as reinforcing one another, implying some measure of consensus. But they have not fared equally well among experts.

All three reported detections rely on recognizing methane's signature in the sun's infrared radiation reflected from the surface of Mars. As solar radiation passes through the martian atmosphere, methane molecules—carbon atoms studded with four hydrogen atoms—absorb infrared energy at specific wavelengths. A spectrometer's optics break the reflected radiation into a rainbowlike spectrum in which scientists can recognize the narrow "lines" of absorption unique to methane.

First to announce the detection of methane was Vittorio Formisano of the Institute of Physics and Interplanetary Space in Rome and the orbiting Mars Express spectrometer

CREDIT: TRENT SCHINDLER/NASA



Destination Gale. Curiosity rover is headed for 154-kilometer-wide Gale crater (*left page with a central mound*). Left to right from far left, landing safely will require first plowing through the atmosphere behind a blazing heat shield, then plummeting under a parachute. Rockets slow the dangling rover further in time for touchdown.

CREDIT (TOP TO BOTTOM): NASA/JPL-CALTECH

in the "sky crane" phase of descent (lower left panel). Once the rover eases onto the surface (lower right), the control system will sense the drop in tension on the cables and the descent stage will fly out of harm's way.

Less innovative was the engineers' solution to the problem of shrinking the rover's landing zone from an ellipse 100 kilometers long to one just 20 kilometers long. Planners wanted to be able to land their bigger, better rover near the most interesting geology, whether or not there was a broad swath of forgiving terrain there. So Curiosity engineers borrowed the concept of "guided entry" from the system used for returning Apollo astronauts to Earth.

All previous Mars landers had entered the atmosphere like bullets; they could hit their targets no more accurately than they were aimed. Throw in the vagaries of entry vehicle performance and martian winds, and they arrived a good deal less accurately than that. The limited targeting accuracy of the previous generation of rovers kept them out of Gale crater, whose central mound boasts a Grand Canyon–like exposure of early Mars history.

With guided entry, Curiosity's 3.3-ton bullet becomes more like a guided missile. Tilted slightly up so it can "surf" the martian atmosphere, the entry vehicle will sense departures from its intended entry track. Then it will fire side thrusters to get back on track. The promised accuracy of guided entry let the Curiosity team, with community guidance, target the flat Gale crater floor within driving distance of the mound (*Science*, 29 July 2011, p. 508).

Testing, testing, testing

"That's a lot of parts that have to work together," as one scientist observed after watching the EDL video. So with 30 or 40 other engineers, the Curiosity EDL team "analyzed, peer-reviewed, and tested the hell out of" the EDL system, as Curiosity project manager Peter Theisinger of JPL put it during a press teleconference last week. The problem is that "you cannot test as you fly," he noted. "It is impossible to replicate the EDL conditions of Mars."

Instead, engineers first tested each EDL component as realistically as they could. They checked the strength of a full-size, 21-meter-diameter Curiosity parachute in the world's largest wind tunnel, tested a scaled-down version for aerodynamic stability in another wind tunnel at realistic supersonic speeds, and investigated aerodynamic regimes inaccessible in wind tunnels in computer simulations. Then they tweaked their design and tested again.

Entry-to-touchdown testing came in a computer simulation of "the entire spacecraft built in a computer," Sell says. That let them "fly EDL over and over and over again. We do that with thousands of variables and run the system millions of times." Such testing makes the EDL system "as robust as possible to variations at Mars," he says, from a gust of wind to an underperforming retrorocket. "We're still doing it," Sell says, and "we'll keep doing it until landing day."

"We're confident we've done everything we know how to do," Theisinger said. "You do the best testing you can on Earth, but it's not the same. That's where the trepidation is. It's really the unknown unknowns we'll be worried about on the 5th." That's what stung engineers in 1999 during Mars Polar Lander's Viking-style EDL. Investigators suspect that the onboard control system mistook the jolt of the lander's legs snapping into place for touchdown and cut the retrorockets while the lander was still 40 meters off the ground, ending the mission. Phoenix later landed using the same EDL system (with a software fix), but unknown unknowns are likely still in any EDL. As Sell puts it, "good or bad, August 5th we're on Mars." **–RICHARD A. KERR** team. After the announcement at that Paris press conference, Formisano told *Science* that he and his team "have seen methane on Mars. A very little amount, but the result is clear." The group's paper appeared in the 3 December 2004 issue of *Science* (p. 1758), but its reported detection of 10 ppb averaged across Mars has fared the worst of the three claims.

Sushil Atreya, an atmospheric chemist at the University of Michigan, Ann Arbor, and second author on the Mars Express paper in *Science*, says the Mars Express result was not a true "detection." The spectrometer's ability to separate methane's absorption lines from interfering lines, its spectral resolution, was not up to snuff, he says, adding, "I would put more stock in ground-based" results.

The two ground-based claims of martian methane in fact look somewhat better. At times working with colleagues, planetary astronomer Vladimir Krasnopolsky of the Catholic University of America in Washington, D.C., has used spectrometers mounted on large telescopes to search for methane. In three papers in *Icarus*, the first in 2004, Krasnopolsky reported methane detections.

But Mumma, who has published with Krasnopolsky and supervised him at Goddard, has his doubts. Krasnopolsky's first two reported detections suffered from technical problems in processing the data, Mumma says. In a third paper, in the January 2012 issue of *Icarus*, Krasnopolsky reports detecting 10 ppb of methane over the Valles Marineris canyon region of Mars in 2006. Mumma calls the result "interesting," although his own group's observations a few weeks before and after Krasnopolsky's found no detectable methane over Valles Marineris.

The Cadillac of data reductions

By all accounts, Mumma's observations have fared the best. For one thing, Mumma is highly regarded in the planetary observing community. He has measured 10 different volatile compounds, including methane, spewing from 30 active comets. Mumma and his group are also seen as having most thoroughly accounted for the bugaboo of ground-based observers: Earth's own methane. An absorption line from Earth's methane should be 2000 times as strong as a line from 20 ppb of methane on Mars would be. (After all, Earth has actual belching cows.)

Mumma first reported detection of martian methane at the annual meeting of the Division for Planetary Science (DPS) in November 2004. In his talk, Mumma reported finding 86 ppb of methane using one absorption line and 66 ppb using another line. That rough agreement from two independent absorption lines remains the backbone of the Goddard group's defense of their numbers. "The methane is secure," he said. At a press briefing later the same day, however, he mentioned a methane concentration of 250 ppb. Over the next year or two, Mumma continued to report readings as high as 700 ppb, Atreya recalls. But none of the numbers appeared in DPS abstracts because Mumma considered them still preliminary.

After almost 4 years of increasingly thorough processing of the raw data, including accounting for terrestrial methane, Mumma and colleagues published their 2003 observations in the 20 February 2009 issue of *Science* (p. 1041). The group reported much lower final values for the 2003 methane detections—20 to 45 ppb—along with a detection of 5 ppb from 2006. Methane was concentrated in the vicinity of Syrtis Major and Nili Fossae near the equator and varied in abundance from season to season and year to year.

To Mumma's group, that evanescent, plume-like behavior of methane suggested that shortly before the 2003 observations—and perhaps at other times—the planet had been spewing a couple of tons of methane an hour from the ground. The methane might have been microbial, trapped kilometers beneath the frozen crust and released occasionally through crustal cracks. Or it could have been geological, escaping from volcanic or geothermal vents. No one can say what the source would have been, and no one has reported detecting any methane since 2006.

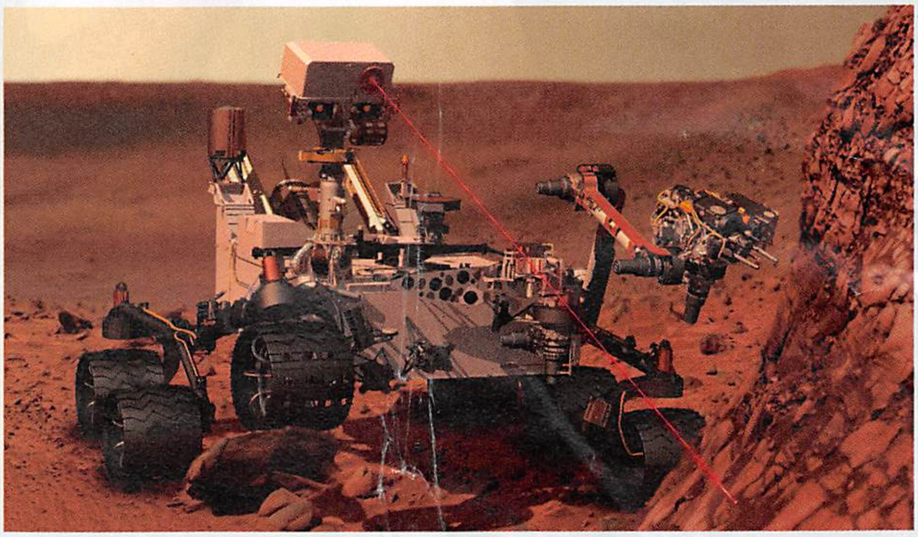
Key to determining whether the martian methane plumes were real is the procedure for removing the spectral signal of Earth's methane. Ground-based observers avoid most of the interference by observing Mars when it is moving toward or away from Earth. That's when the Doppler effect shifts a given martian methane absorption line away from the same line created by terrestrial absorption, making the two lines distinguishable.

Mumma thinks that he and his co-authors—most of whom are at Goddard—have reliably accounted for any remaining methane interference using a sophisticated model of Earth's atmosphere. The 20-person spectroscopy group he directs at Goddard is "a powerhouse in the world community," he says. That view is widely shared. "Mumma has given [his data] about as good a look as can be," says atmospheric chemist Paul Wennberg of the California Institute of Technology (Caltech) in Pasadena.

Not so fast

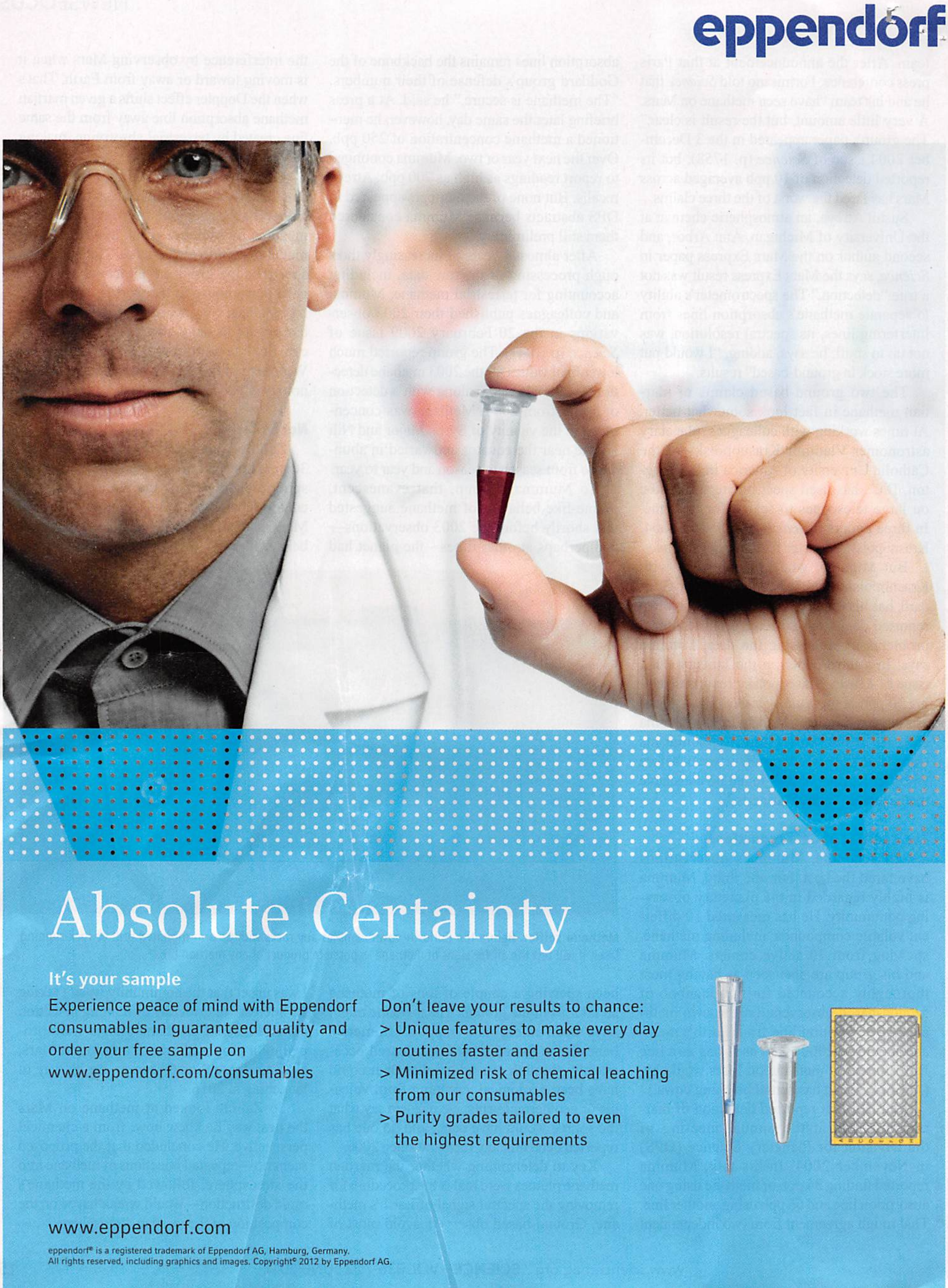
Zahnle wasn't having any of it. With 30 years of experience modeling the atmospheric chemistry of the planets, he "just couldn't imagine anyone taking [methane on Mars] seriously," he says. "Methane doesn't behave like this. It was such an obvious joke. I was upset that the community wasn't taking an interest" in critically evaluating detection claims. Instead, methane claims were propelling a proposed orbital mission to Mars, NASA's Trace Gas Observer, on its way to launching in 2016.

So Zahnle looked at methane on Mars the best way he knew how: from a chemical perspective. He concluded that the proposed scenario—repeated injections of methane into the atmosphere, followed by the methane's rapid destruction—would wreak havoc on the composition of the martian atmosphere.



Methane sniffer. Before the Curiosity rover samples any rocks with its arm-mounted drill or rock-zapping laser, it will test the air for signs of methane, a possible product of any martian life.

CREDIT: NASA/JPL-CALTECH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As Zahnle lays out in an April 2011 *Icarus* paper, destroying that much methane that quickly would consume the atmosphere's meager endowment of oxygen in 7000 years. That might not happen if exotic processes had been overlooked—say, chemical oxidizing agents generated on the dust of self-electrifying dust devils.

But that doesn't seem to be the case, Zahnle says. The standard model of how solar energy creates and destroys chemical compounds already neatly explains the trace gas composition of the martian atmosphere without invoking any such hidden methane-busters. And nonphotochemical means of removing methane, such as adsorbing it onto soil, don't work either if theory, lab experimentation, and the trace gas composition of Mars are any indication, he says. Even microbes feeding on the methane probably couldn't cause the proposed disappearing plumes, Zahnle says. That's because the martian atmosphere abounds in carbon monoxide—a molecule that microorganisms with anything like earthly metabolisms would finish off before starting to consume methane.

Zahnle concludes that there is no support for claims that martian methane plumes were popping up repeatedly almost a decade ago. However, he can't exclude the possibility that a single plume appeared in 2003. "If it's one time in 100 years, it's not a problem," he says. That relieves atmospheric chemists' great unease with the idea of methane coming and going on Mars. "The photochemical argument Kevin made seems to be pretty solid," Atreya says.

About that spectroscopy

Next, Zahnle looked for possible problems in Mumma's spectroscopic methane detection. As an atmospheric chemist, he needed lots of help. So he brought in Richard Freedman of Ames, an astrophysicist and stellar spectroscopist, and David Catling of the University of Washington, Seattle, "somebody who knows something about Mars."

The trio found several possible problems with both the space- and ground-based spectroscopy, as they reported in the *Icarus* paper. But the focus of their criticism became the two absorption lines at the core of Mumma and colleagues' reported detections. Mumma, they note, is relying on only two methane lines and can see only one of them on any given observing night.

More worrisome, they say, is their suspicion that the same Doppler shift that conveniently brings Mars methane lines into view, by moving them away from Earth's methane lines, also moves a Mars line to where a minor Earth methane line can impersonate the Mars line. The Mumma group has never seen methane when Mars is moving away from Earth; it is only seen when Mars is moving toward Earth, and the lines are shifted toward the blue end of the spectrum. Zahnle and colleagues suggest that in such a blue shift, the line of methane that contains the heavy carbon-13 isotope comes into coincidence with the martian line of normal methane. The heavy-carbon methane line is about 25 times as strong as the line of martian methane at 20 ppb would be. So the Earth line, the group contends, could appear to signify abundant methane on Mars.

"I'm no spectroscopist, but it's going to be challenging to correct for that," Zahnle says. "The point is not to slam Mike Mumma. This is just really, really hard; it's ridiculously difficult."

Mumma disagrees. "I respect Kevin as a colleague," he says, but "there are so many errors" in the Zahnle *et al.* paper, some of which "were egregious." He points to three sorts of consistent behavior in the spectroscopic data that support martian methane. One involves the nonappearance of the terrestrial carbon-13 methane line when, as he sees it, Zahnle's reasoning would have it there. "We've got carbon-13 methane modeled correctly," Mumma says.

All this debate, which has not gotten much of a public airing, has left the larger planetary community a bit adrift. With 50 years working in the Mars community, geologist Michael Carr of the U.S. Geological Survey in Menlo Park, California, finds methane on Mars "such an iffy thing." John Mustard of Brown University does spectroscopy of the martian surface from orbiters. "It looks really problematic for Mumma's [detections]," he says. All the variability "just doesn't make sense. I'm thinking it's not there."

David Crisp of NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, does atmospheric spectroscopy. "My intuition is there's methane there," he says, "but it's not clear [Mumma] is seeing time and spatial variations." Interfering atmospheric dust is just too variable on Mars, he says. "If anything, I would trust the detection of methane more than the [reported] absolute amount," says Mark Allen of Caltech, who was the principal investigator of the now-canceled Trace Gas Orbiter mission. Mumma "is really doing differences of [two] large numbers to get a small number," Allen says, always a tricky bit of arithmetic.

Last chance?

Confirming such contentious claims will require getting up close and personal with Mars. The Trace Gas Orbiter was going to carry a capable spectrometer that "could detect three cows on Mars," Allen says. But NASA killed the mission when it restarted its Mars program in the wake of the Obama Administration's lowered budget request. Next up is NASA's Curiosity rover, arriving at Mars on 6 August. It carries a different sort of spectrometer, the Tunable Laser Spectrometer (TLS). It has two lasers whose beams bounce back and forth 81 times through a sample cell filled with martian atmosphere. The lasers scan across infrared wavelengths in which methane has not one or two but three absorption lines that form a distinctive fingerprint for methane. "It's a very simple, direct, and unambiguous measurement," says TLS developer Christopher Webster of JPL.

TLS will also be extremely sensitive. Its first quick measurement, scheduled for the first few weeks of the mission, should be able to detect as little as 1 ppb of methane. Mumma calculated that the 2003 release of methane would have amounted to 6 ppb once it spread around the planet. Although Mumma sees his observations as suggesting that methane on Mars has a lifetime of a few years, atmospheric chemists still think martian methane would last several centuries. If they are right, almost all of 6-ppb methane should still be there. And even if it is destroyed faster, when TLS takes a longer look at atmospheric samples, it will be able to detect 50 to 100 parts per *trillion* of methane, according to Webster. If methane really is long-lived on Mars, Zahnle says, Curiosity "is going to crush this."

–RICHARD A. KERR

Methanogenic? Water-altered Nili Fossae (color-coded by mineral) may have gushed methane in 2003.

CREDIT: NASA/JPL/JHUAPL/BROWN UNIVERSITY

LETTERS

edited by Jennifer Sills

Community Colleges: Veterans' Best Bet

AS J. C. MINER POINTS OUT IN HER EDITORIAL "AMERICA'S COMMUNITY COLLEGES" (23 MARCH, p. 1409), community colleges offer outstanding training opportunities in science, technology, engineering, and mathematics (STEM) for underrepresented populations. They also provide an important STEM training opportunity for veterans returning from Iraq and Afghanistan, a population that unfortunately has been preyed upon by for-profit universities.

The Post-9/11 G.I. Bill provides veterans and their families generous educational benefits but, as the U.S. Senate's HELP Committee's ongoing investigation reported (*1*), 37% of the $4.4 billion spent between 2009 and 2011 went to for-profit educational institutions, which trained only 25% of the veterans. In these schools, the cost per veteran averaged $10,875, compared with $4,874 in public colleges. Moreover, the withdrawal rate for bachelor's students in the eight most generously funded for-profit schools averaged a disappointing 53.3%, compared with 19.8% in public schools. The investigation reported that "[t]he majority of students enrolling in for-profit schools emerge with debt but without a diploma." President Obama sought to end these abuses through an Executive Order signed at Fort Stewart on 27 April (*2*).

Supporting the troops. President Obama signs an Executive Order to protect veterans from deceptive marketing by for-profit schools.

Community colleges offer broad-based curricula, quality teaching, flexible class schedules, and (unlike many for-profit schools) college credits transferable to 4-year institutions, all at an affordable price. Yet cuts in state funding are diminishing our community colleges. For example, California's outstanding system will endure a 5% budget cut in 2013, forcing a 20% decrease in course offerings (*3*); California's state college system is planning to freeze admissions, which will clog community colleges and curtail opportunities for new students, including veterans.

Many young people opt for military service specifically to qualify for educational benefits, and some are primed for STEM training because of the positions they filled in the service. We owe these students quality STEM educational opportunities. Community colleges offer a superior product and value; they are veterans' best bet.

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An Eye Toward Iodine in China

I WAS GLAD TO SEE THE NEWS & ANALYSIS story calling attention to China's continuing problem of rural malnutrition and resultant developmental stunting of children ("Despite gains, malnutrition among China's rural poor sparks concern," R. Stone, 27 April, p. 402). Two specific aspects of the problem bear emphasis.

First, iodine deficiency has historically played a dominant role in both mental and physical stunting in Chinese rural populations. Children born after the introduction of iodine supplementation (without other nutritional intervention) have lower infant mortality and improved development, activity, and stature (*1*, *2*). Second, micronutrient supplementation, particularly iodine, should be administered during early pregnancy. Studies carried out in Xinjiang Province and in Inner Mongolia by our joint Chinese-American team demonstrated that iodine supplementation alone to pregnant women in areas of severe iodine deficiency, before the end of the second trimester, resulted in decreased infant mortality and in significantly improved development and stature in the offspring at 2 and 6 years of age (*3*, *4*). Iodine supplementation at later times was progressively less effective.

Iodine deficiency continues to be severe in Chinese soils in many areas. In addition to other nutritional interventions, careful monitoring of iodine availability to the population, especially to women of childbearing age and to young children, will need to be carried out indefinitely and with a high priority. A trial program of iodization

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