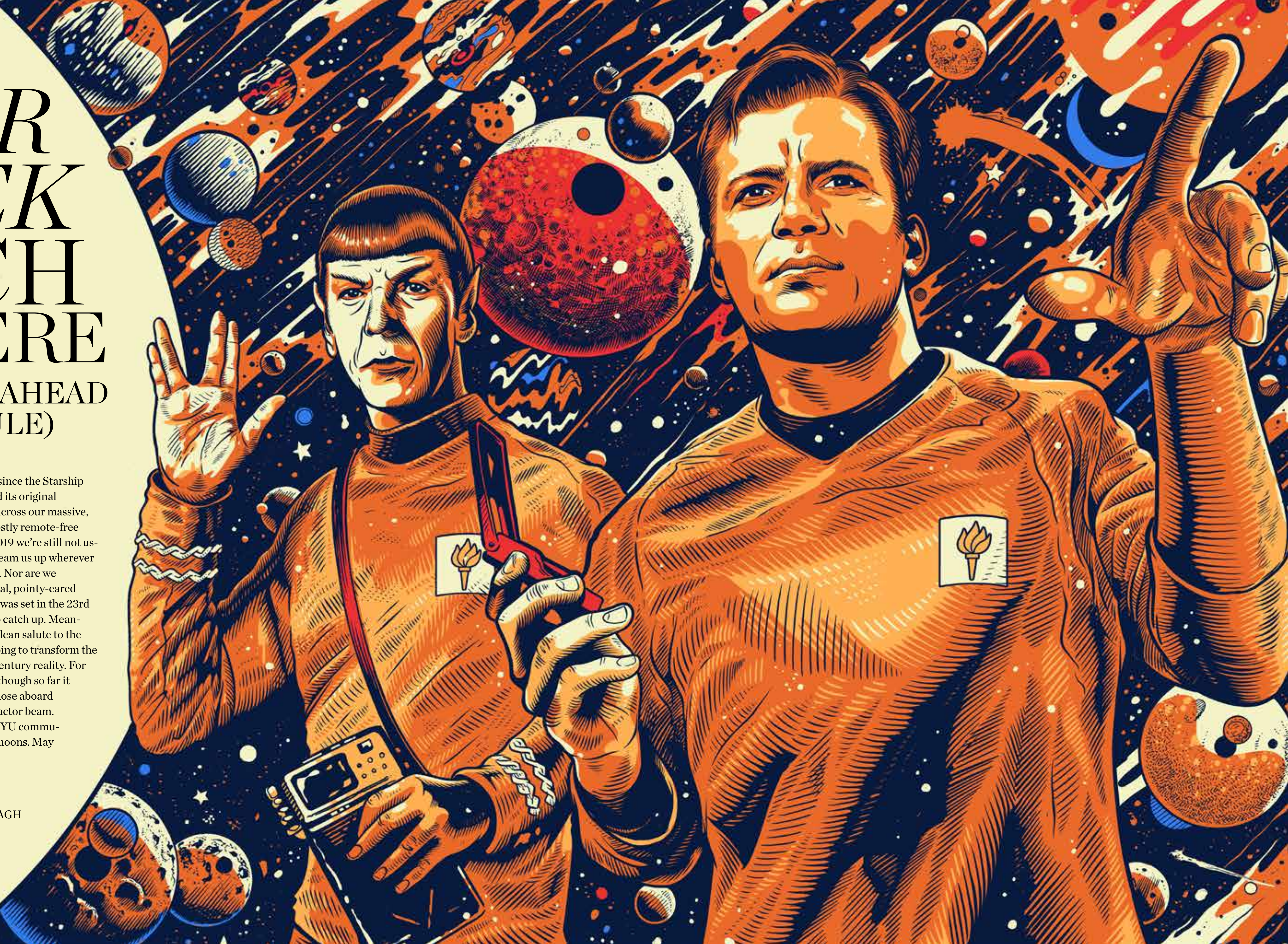
STAR TREK TECH IS HERE

(250 YEARS AHEAD OF SCHEDULE)

It's been 50 years since the Starship *Enterprise* ended its original 79-episode run across our massive, rounded, and mostly remote-free TVs. And yet, in 2019 we're still not using transporters to beam us up wherever we want to go. No warp speed, either. Nor are we gleaning wisdom from any ultralogical, pointy-eared extraterrestrials. Granted, *Star Trek* was set in the 23rd century—so we do have some time to catch up. Meanwhile, we can raise our hands in a Vulcan salute to the many NYU researchers who are helping to transform the science fiction of the past into 21st-century reality. For instance, there's an NYU Holodeck, though so far it bears only passing resemblance to those aboard Starfleet ships. There is a working tractor beam. (Ditto). And other members of the NYU community are reaching for the stars—and moons. May they live long and prosper.

BY LINDSY VAN GELDER
ILLUSTRATION BY TIM McDONAGH



"BEAM ME UP, SCOTTY"

HOW A FAILED EXPERIMENT IN THE LAB LED TO A SCI-FI-INSPIRED PHYSICS BREAKTHROUGH

David Grier didn't set out to invent a *Star Trek* tractor beam, that famous graviton carpet of light that can reel in a giant spaceship as if it were a fish on the end of a line.

Back in the early '90s, Grier, professor of physics and director of the Center for Soft Matter Research, did postgraduate work at Bell Labs in New Jersey, where he met Nobel Prize winner Arthur Ashkin, inventor of optical tweezers, a technique that uses the power of a laser beam to pick up a microscopic object. (The approach held promise for data processing and signal processing—of particular interest to AT&T, which owned Bell Labs.)

Grier continued to work with optical tweezers after leaving Bell Labs, but as his research interests expanded, he realized he needed to trap more than one micro-scopic particle at a time. Studying the concepts of attraction and repulsion, he says, "I needed dozens, maybe hundreds, of traps to assemble lots of things into interesting structures that hopefully would reveal some of nature's organizing principles."

He and his graduate student, Eric Dufresne (now at Yale), came up with the idea of using a computer-generated hologram rather than a single beam of light. Their initial attempts entailed some decidedly humble supplies: "We started out with a plastic hologram that we bought for five bucks from the back of the American Science & Surplus catalogue. It was one of those things where you shine your laser pointer through it, and you get *Your Company Logo Here*. And hey, presto, it worked." Hoping that they were onto a technique that could have applications in medical diagnostics and other commercial areas, they continued to experiment with different shapes of holograms and their effect on groups of microscopic particles.

But then a crucial experiment failed. "Instead of drifting nicely along the line [of the beam] like they were supposed to, the particles ended off in one corner," Grier recalls. "We were bummed, because our experiment wasn't working, and so we sat down and tried to understand these forces." But beyond being bummed out, he and his colleagues also realized that they'd stumbled upon something interesting—even something they'd seen before, if only on TV. "One of the reasons we were inspired to follow up is that the first time the particle moved the wrong way up the beam and we were perplexed, the first thing we said to each other is, 'It's a tractor beam, just like *Star Trek*,' " says Grier. "*Star Trek* had primed our minds to be ready for it."

It ultimately dawned on them that if particles were going off in the "wrong" direction, their motion could be manipulated by changing the shape of the hologram into a curlicue instead of a straight line. "Our first one looked like a Fritos corn chip," Grier admits, but eventually a Slinky-like helix shape emerged as the winner. "It doesn't look like any beam of light you've ever seen. It's like a twisted coil of brightness," he says. "In theory, the beam goes on forever, and that means that [anything that is trapped in it] will be pulled upstream in the wrong direction forever. And that's a tractor beam."

The beauty—and the irony—is that the concept marries two very simple things, he adds: consumer electronics and "a basic principle that's taught in every high school physics class," Newton's third law of motion, that every action has an equal and opposite reaction. "We use holograms to create bizarre-looking beams of light whose intricate structure ensures that objects always scatter the light's momentum into the downstream direction," Grier explains. "Because momentum is conserved—Newton's third law—the object recoils in the upstream direction so that its 'backward' momentum cancels the extra 'forward' momentum imparted to the light.... We were lucky enough to have gone through the right sequence of mistakes that this revealed itself to us."

Today the tractor beam physically exists on an optical table several feet away from the person who is controlling it with points and clicks, and it can pick up micrometer-scale objects. Even though it's still far from ready to slurp up a spacecraft, Captain Kirk–style, NASA is interested in its potential to gather up comet dust, ice crystals, and other particles in space.

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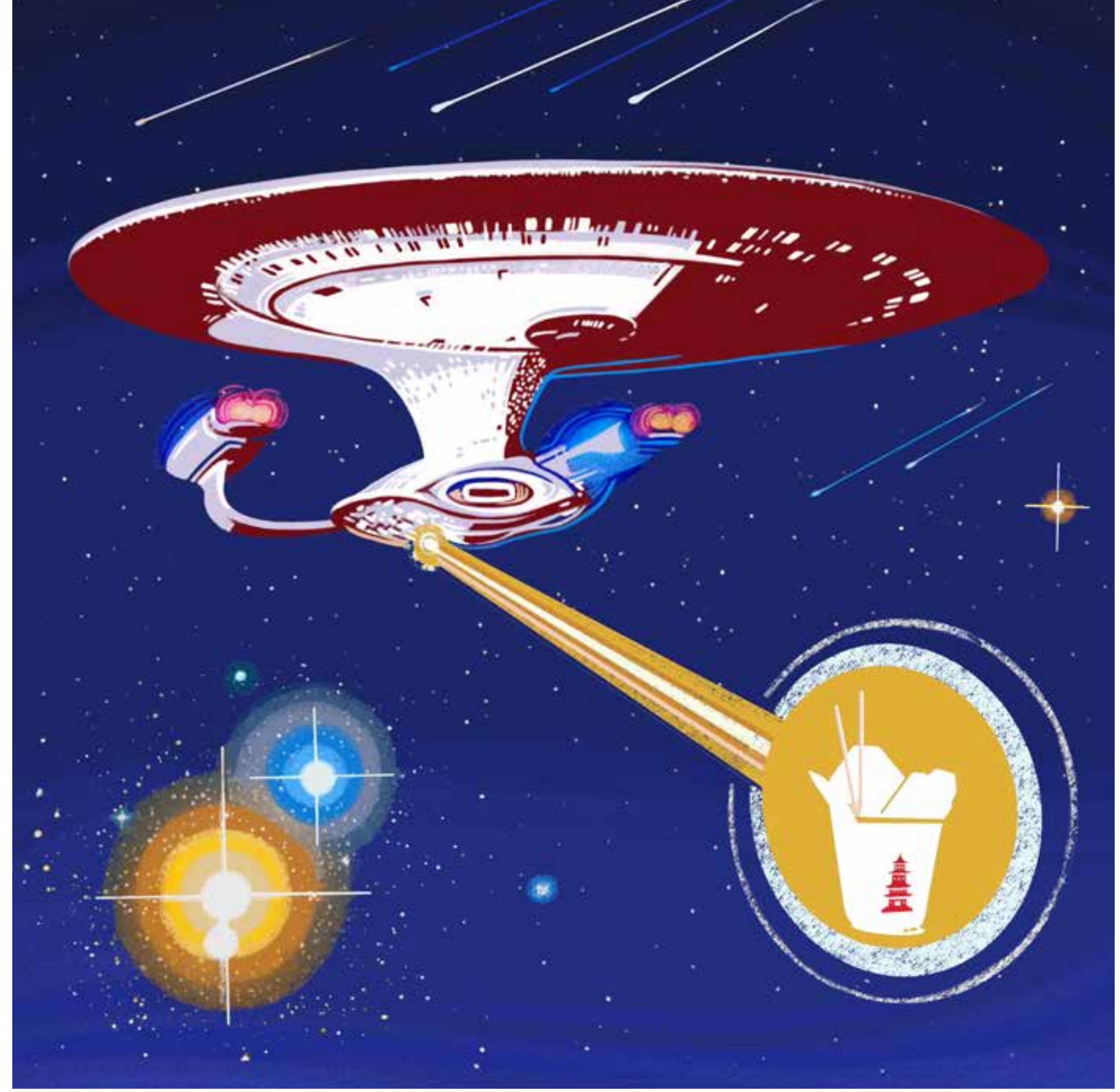

Illustration by Ivan Canu

Grier, meanwhile, is continuing his research into beams that can haul things—although he has expanded his focus. "Sound travels slower than light, which means that it packs a million times more punch per watt. That means bigger objects, more force," he says. For the layperson, he likens it to music: "When you go to a club, you can feel the sound—*boom! boom!*—in your chest. But you don't feel the light show. So the idea is to develop new techniques of acoustic holography and imaging so that we can shape sound fields to take advantage of everything we've learned about light fields." He envisions devices that could assemble components, do environmental sampling, or handle dangerous materials at a distance. It might sound like the stuff of sci-fi, but in the immortal words of Captain Jean-Luc Picard: "Things are only impossible until they're not."

MORE ON THE WEB | Take a look inside the lab with a real-life tractor beam at **nyu.edu/scope/star-trek**

“MAKE IT SO”

IF YOU CAN IMAGINE IT, THE HOLODECK CAN TURN IT INTO A (VIRTUAL) REALITY

On *Star Trek*, the Holodeck was an R&R playpen where the *Enterprise* crew went to unwind in virtual reality worlds, from sports to travel. The NYU Holodeck experience—developed through an interdisciplinary collaboration—usually involves goggles and headsets that connect to augmented or virtual reality, and it often includes fun and games. But unlike its eponym’s inspiration, the NYU Holodeck is primarily educational. In fact, Winslow Burleson, associate professor of nursing, has called it “the classroom of the future.”

For instance, Jan Plass, the Paulette Goddard Professor in Digital Media and Learning Sciences, used motion capture technology to create a set of four VR Magic Bongo drums designed to teach kids the rewards of impulse control: When kids correctly follow instructions about a drumming sequence, the trees in the forest around them light up; when they don’t, the forest darkens. Plass also collaborated with Ken Perlin, professor of computer science, to create an augmented reality learning simulation for middle school science students who work together to assemble the nucleus, mitochondria, and other components of plant and animal cells. These and other Holodeck educational games “not only measure learning outcomes,” says Plass; they also use sensors to gauge “learners’ emotional response to virtual and augmented reality.” The immediate result? The kids’ educators get real-time feedback on how to teach better.

Now in the third year of a five-year project funded by a $2.9 million grant from the National Science Foundation (with another $1.2 million from NYU), the physical Holodeck is spread around three different locations (two in Manhattan and one in Brooklyn). It also operates under the auspices of four NYU schools: the Courant Institute of Mathematical Sciences; the Rory Meyers College of Nursing; the Steinhardt School of Culture, Education, and Human Development; and the Tandon School of Engineering.

Each Holodeck faculty member “brings a different flavor,” says Perlin, and collaborations are common. His group’s focus at the NYU Future Reality Lab “is asking what extended reality will be in the future, when it’s just reality. [Music associate professor of music technology] Agnieszka Roginska’s group is focused on spatial audio. Jan Plass’s group is interested in how to assess these things, because they’re cognitive scientists. R. Luke DuBois [associate professor of integrated digital media] is interested in assistive technologies and artistic performance. Win Burleson is interested in health applications and education. Claudio Silva [professor of computer science and engineering] is interested in applying these future technologies to urban planning. What we have in common is that we are building together an instrument—a combination of hardware and software—that allows us to look into the future.”

The most Holodecky projects (that is, the most authentically like *Star Trek*) are those that plunge participants into full-on immersive VR. “We can be in *The Lord of the Rings*’ Shire, we can be on Tatooine, we can be in Hogwarts, we can be robots on the moon, or we can be shrunk down to the size of a cell and doing microsurgery, whatever the application is,” says Perlin. One project had audiences following a rabbit down an *Alice in Wonderland* hole and then shrinking to mushroom size. (Roginska’s group orchestrated all the sounds—like raindrops and cricket chirps—to resize accordingly, and to sound the way they would in “real” reality, depending on one’s distance from the noise source.)

Last year, Perlin’s group put on another VR production about a young woman in 10,000 BC. As she tells her spirit ancestors—that is, the audience—about her journey to become a shaman, animated drawings dance on the cave walls and a woolly mammoth lumbers by. In addition to screenings at academic computer graphics venues, *Cave* hit the art circuit, including the Tribeca Film Festival. A new augmented reality production from Perlin’s team, *Mary and the Monster*, debuted this past summer. It transports participants into the year 1816, when Mary Wollstonecraft Godwin, her fiancé Percy Shelley, Lord Byron, and others were trapped indoors by horrible weather caused by the previous year’s eruption of the Tambora volcano, half a world away. To pass the time, the group competed at writing ghost stories, and Godwin’s tale of a mad scientist named Frankenstein blew the rest of them out of the frozen ash cloud. The AR production has a cast of five and brings the audience into Lord Byron’s literary drawing room as well as Dr. Frankenstein’s lab.

But Holodeck projects don’t necessarily involve every bell and whistle in the toolkit, says Burleson. The group’s expertise in sensor usage recently attracted the attention of Yale’s School of Medicine, and the two universities are now jointly training Yale medical students in a project with no augmented or virtual reality. Instead, students perform emergency care on a lifelike robot, who, for instance, has supposedly been bitten by a black widow spider. The trainers can then introduce challenging complications into the patient care scenario, according to NYU-X Lab senior research scientist Jeremy Rowe. “Say, they’re trying to call the doctor and the phone system is out, or they’re trying to see the results of a test and it’s not available,” he says. Sensors measure the heart rate and other stress indicators of the test-takers, to determine which scenarios are most exciting or most nerve-racking.

“The Holodeck is a telescope into the future,” says Perlin. As such, staying ahead of the present curve is essentially part of the job description. In 2014, when the group had not yet received its grant, he and DuBois bought a $50,000 motion-capture lab in order to create what were then cutting-edge wireless VR headsets, which allowed users to walk around freely and see each other as accurately positioned avatars on the Holodeck. “Now flash forward five years and the Oculus Quest [$399 on Amazon] is out,” he says, “and with the right software, it does a lot of what we did five years ago.” The question now, he adds, is what the Holodeck team should be inventing in 2020: “Because it’s going to be the thing you can order online in 2025. That’s the way we think about things.”

Illustration by Frank Stockton

"SPACE: THE FINAL FRONTIER"

ENGINEERING A SUBMARINE CAPABLE OF EXPLORING EXTRATERRESTRIAL SEAS FOR THE FIRST TIME

S*tar Trek*'s original three-season run coincided with the peak of the space race: show creator Gene Roddenberry wrote the treatment for the show in 1964, a year after NASA's last Mercury mission. It premiered just after the Gemini 10 flight. And the original series finale aired less than two months before the Apollo 11 moon landing 50 years ago. More recently, NYU research has been involved with yet another moon shot, of Titan, Saturn's largest moon: Iskender Sahin, industry professor of mechanical engineering at the Tandon School of Engineering, helped design an autonomous submarine that is a candidate to navigate two primordial seas there. Launched from a spacecraft, it would be the first planetary probe in history to land in extraterrestrial liquid.

Titan has long intrigued scientists because its chemical composition and its topography seem to resemble early Earth—and therefore may offer tantalizing clues to our own origins. "It's one of the very few planetary bodies where there's a liquid surface," says Sahin. "And we're not talking about drops of water. These lakes, or seas, are huge." Connected by a narrow waterway that the submarine would negotiate, the two seas, Ligeia Mare and Kraken Mare, are larger respectively than Lake Superior and the Caspian Sea. They are also deep. But their resemblance to any sea that has ever hosted whales, lobsters, and surfers pretty much ends there. The waves "are liquid carbon, not water, mixed with cooled, compressed methane," Sahin explains. "There is no oxygen in the atmosphere at all, above the seas or under it."

Sahin's design work was part of an ongoing research collaboration between Tandon's Space and Fluids Group and NASA's Glenn Research Center in Cleveland. Sahin, who has a background as a Naval architect/ship designer and academic specialties in fluid mechanics, heat transfer, and marine hydrodynamics, headed the NYU team. "We did the computational work for the hydrodynamics and power requirements and drag," he says.

One of the challenges of their calculations, Sahin explains, is the temperature on Titan. "This is nothing like Earth, because it's extremely cold," he says. "We are talking minus hundreds." And yet, nothing freezes because the chemical composition is so different from our own planet.

These unearthly super-frigid-but-not-frozen temperatures posed a number of logistical problems to Sahin and his collaborators: they needed to find a way to protect the sensitive electronics equipment and other devices inside the vehicle. (The solution, says Sahin, is that "the heat coming from the power supply keeps it warm enough so that you can get the equipment to work.") They also needed to figure out how to maneuver to and from the surface in an extreme environment. Traditionally submarines hover, go up, and go down by taking in or purging seawater as ballast to adjust their weight. "But this is very difficult to do in liquid that's very cold," says Sahin. Instead, the 20-foot-long submarine would be equipped with a complex system of neon-powered external ballast tanks that would be brought from Earth.

Granted, the proposed project would literally not get off the ground until 2047—to coincide with Titan's next summer period, when lighting conditions will be optimal for scientific observation. (Seasons are long, since it takes Saturn more than 29 Earth years to orbit the sun.) "The engineers are all saying we probably won't be alive," says Sahin. "This is for the future."

The experience of working on the project was nonetheless a career high for Sahin. "What was amazing was they invited me and my PhD student to Cleveland, where all these brains at NASA—all these little Jules Vernes—were throwing ideas at us. We were able to throw ideas back at them. *What if we did this, what if we did that*? We were basically just brainstorming, and that was fascinating to me," he says. When people in his life express dazzlement at his opportunity, he remains dazzled himself: "I had the same reaction. I feel privileged to have worked on this. This was supercool."

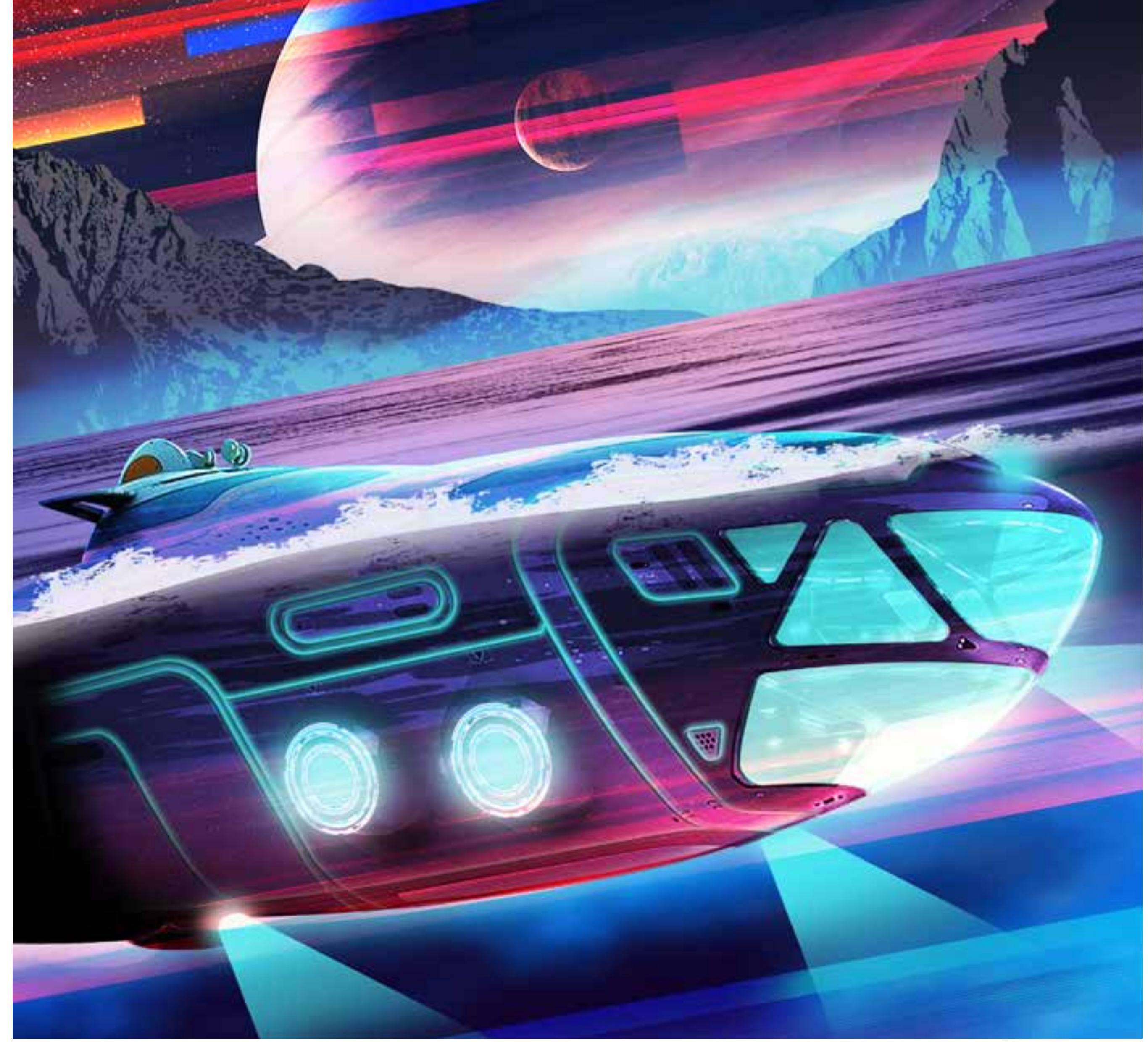

Illustration by Taylor Callery

STARFLEET: THE NEXT GENERATION

NYU RESEARCHERS BREAKING NEW GROUND ELSEWHERE IN THE SKY

● Benjamin Pope, NASA Sagan Fellow at the Center for Cosmology and Particle Physics, was part of an international team that discovered a new binary star system 8,000 light years away. Named Apep—after the ancient Egyptian god of destruction—the pair of massive Wolf-Rayet stars are among the hottest and brightest stars in the universe. When the rapid winds produced by the two stars collide, which Pope likens to "two dragons fighting," it creates rare pinwheeling clouds of dust as the stars orbit each other. The rate of expansion of the pinwheel is a predictor that when one of the stars eventually explodes, it will produce a gamma ray burst—a phenomenon that has never yet been observed in the Milky Way. "It's almost certainly one of the most exotic star systems in the galaxy," Pope says.

● Researchers at the NYU Abu Dhabi Center for Space Science have found a new way to calculate the rotation of sunlike stars. Led by research associate Othman Benomar, the team learned that while the equator of our sun rotates about 10 percent faster than its midlatitudes, those of stars similar in size and age to our sun rotate up to two and a half times faster. Their findings have implications for the study of magnetic fields.

● An international team of scientists—led by Laurent Gizon, coprincipal investigator of the Center for Space Science at NYU Abu Dhabi—has discovered that gigantic planetary waves of vorticity similar to those that influence weather on Earth also exist on the sun. While these Rossby waves are close relatives of those in the Earth's atmosphere and oceans, they are extremely difficult to detect on the sun because they have such small flow amplitudes. But the waves are an essential part of the sun's internal dynamics, as they contribute half of its large-scale kinetic energy. Their discovery was published in the journal *Nature Astronomy*.