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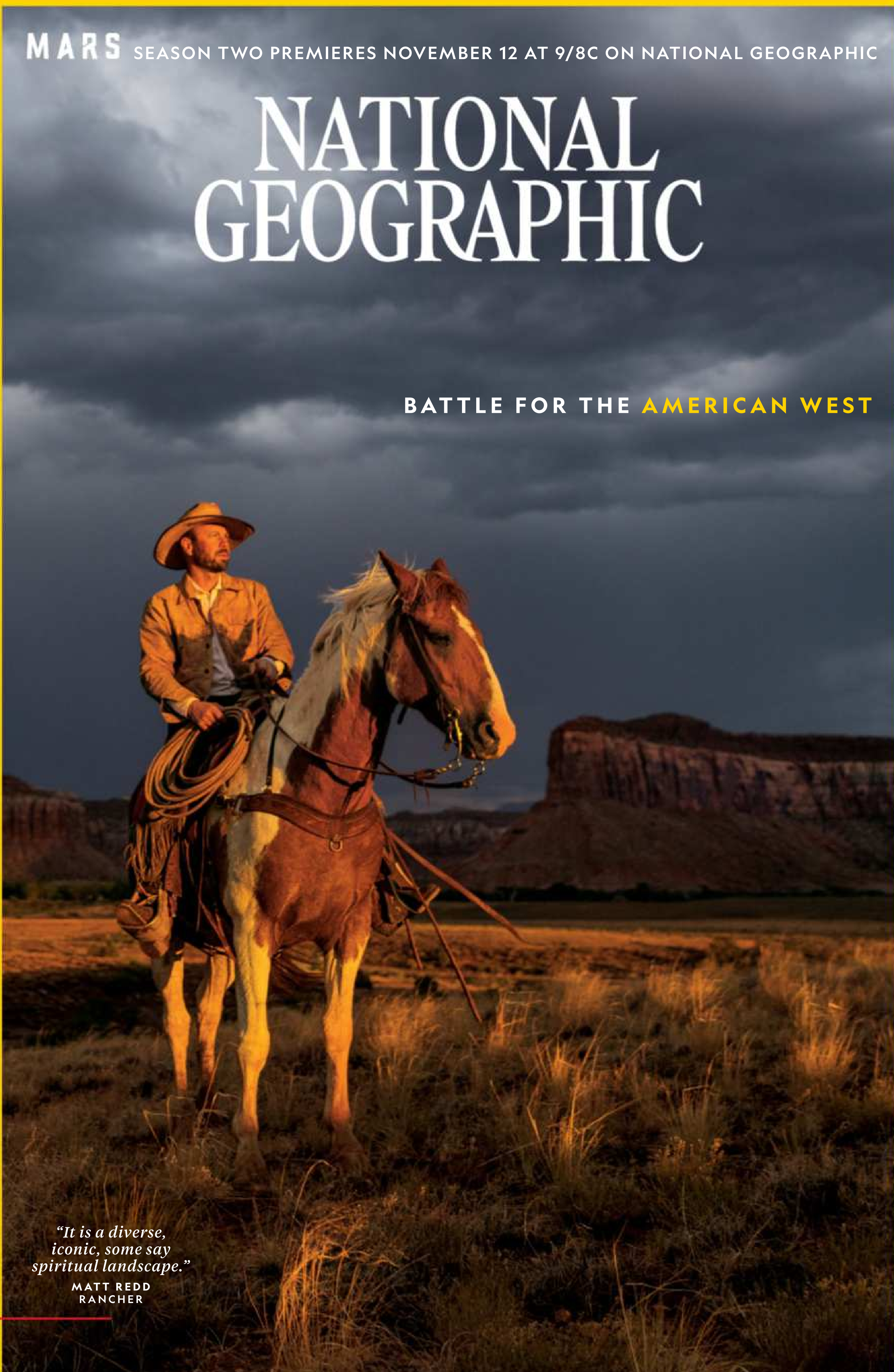
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THE DISCOVERIES OF TODAY THAT WILL DEFINE THE WORLD OF TOMORROW
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A Sun-Powered Sail Into Space

IMAGINED BY ASTRONOMERS FROM JOHANNES KEPLER TO CARL SAGAN, A SOLAR-SAILING SPACECRAFT IS POISED FOR LAUNCH.

BY **BILL NYE**

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DO YOU KNOW THE CURRENT phase of the moon? Most of us don't have any idea; nowadays we hardly need to know. But before there were streetlamps and electric lights everywhere, people watched the night sky diligently. So when a very bright comet appeared in 1607, people were frightened and fascinated.

German astronomer Johannes Kepler thought deeply about what he saw that year. He reasoned that the spectacular tail of what we now call Halley's comet (named after English scientist Edmond Halley, who computed its orbit) was probably caused by the sun's warmth somehow evaporating or liberating material from the comet's surface. Kepler imagined exploring those star scapes: "Given ships or sails adapted to the breezes of heaven, there will be those who will not shrink from even that vast expanse," he wrote.

Ships, after all, were common enough in the 16th and 17th centuries, and they were driven by

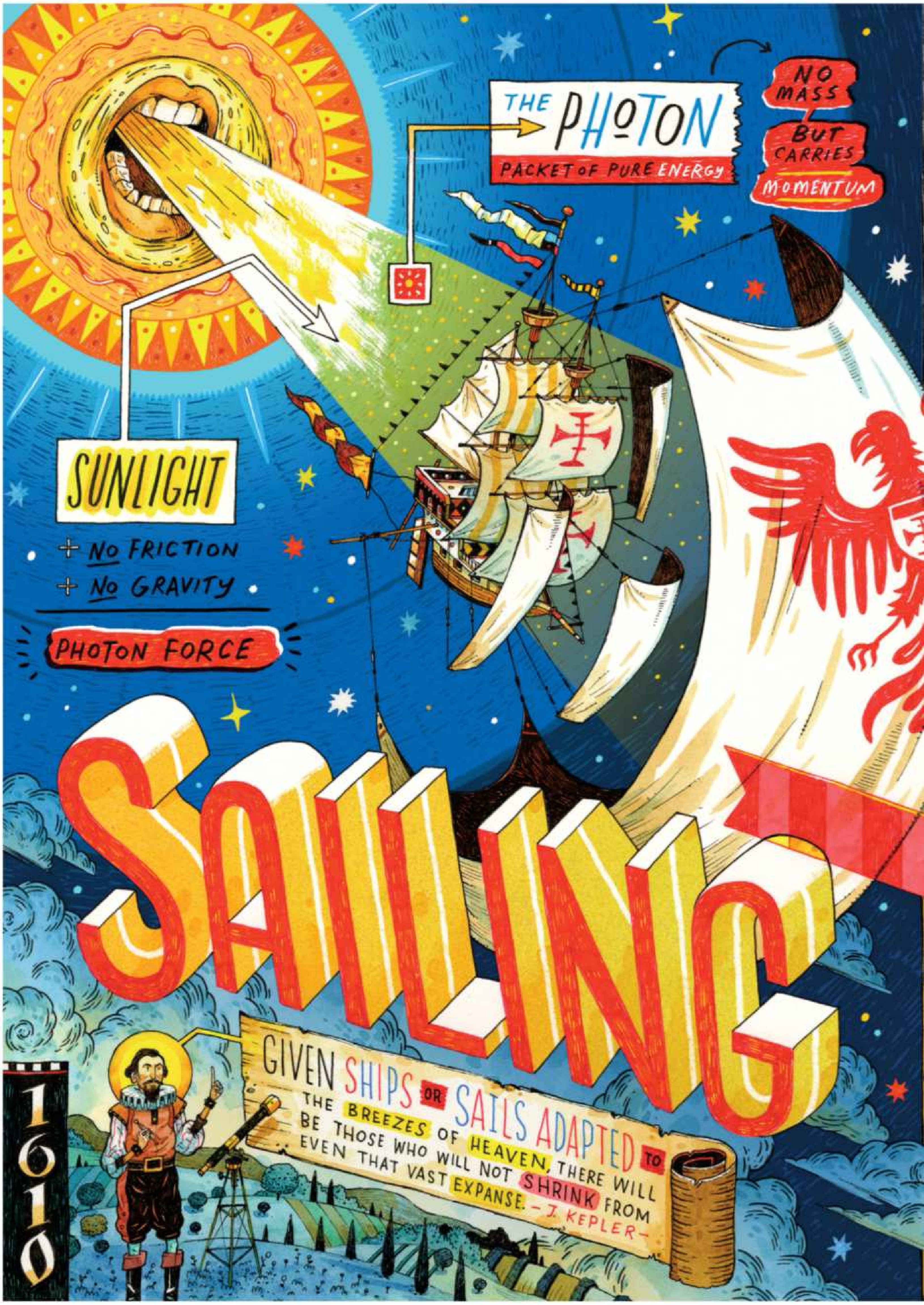


ILLUSTRATION: JOHN HENDRIX

the winds, which are themselves created in part by the sun's warmth. Kepler lived during a moment in history when, thanks to Nicolaus Copernicus, we came to understand that we're aboard a planet orbiting a star. Perhaps it was natural, then, for Kepler to envision humankind sailing the starry heavens.

As I sat in Carl Sagan's astronomy classes at Cornell University in 1977, sailing through space certainly seemed natural to me. Sagan vividly described his vision of a craft that could operate within the constraints of gravity and the mechanics of orbits, yet glide among the stars. It would sail the cosmic ocean, driven by the force of starlight in the vastness of space.

The dream that our professor outlined is now being realized by the Planetary Society, the world's largest nongovernmental space organization, which Sagan co-founded in 1980 (and I now lead). In June 2015 the society tested its own crowdfunded, flight-by-light spacecraft, LightSail 1. As this article goes to press, we're preparing for the scheduled autumn launch from Cape Canaveral of its successor, LightSail 2, to be vaulted into Earth orbit on the SpaceX Falcon Heavy rocket.

SOME THREE CENTURIES after Kepler first wrote about stellar sailing, scientists discovered that light is pure energy—that property in nature that makes things go, run, or happen. These days we know just how much energy is in each packet of light, or photon. Although photons have absolutely no mass, they nevertheless carry momentum.

We probably all recognize that a rolling bowling ball has momentum, which it transfers to bowling pins. When the ball strikes, the pins go down and the points rack up. Furthermore, if you were to experience a bowling ball rolling into your rib cage (as I did while appearing on a kids TV show), you'd notice its momentum quite strongly.

In contrast, the momentum of light is a concept outside our ordinary experience: When you're out in the sun, you don't feel that sunlight can push you around. The force of light, a single photon in particular, is tiny—so on Earth the sunlight pressure, as it's called, is overwhelmed by the other forces and pressures you encounter, such as friction and gravity.

What if we could harness the energy of a tremendous number of photons and we had nothing holding us back? There's only one place we know of to get away from all the friction and gravity: outer space.

Since the 1920s, people have imagined spacecraft that would be so low mass and so big that the pressure of photons would push them through space the same way molecules of gas—air—push sailing ships across the sea.

Solar sailing is elegant not only in concept but also in its efficiency. Once in orbit, there's no fuel needed. Although the propulsive force is quite small—barely nine micro-newtons (two-millionths of a pound) per square meter (or yard) of shiny sail—unlike a conventional rocket engine, it never runs out of fuel.

Because the sun shines around the clock, the small bit of energy imparted every second builds and builds.

Here's how LightSail 2 will fly. Our spacecraft starts no bigger than a loaf of bread: 4 x 4 x 12 inches, a standard size and shape for today's cubical satellites, or CubeSats. It's fun to realize that since there's hardly any air in Earth orbit, there's no need for spacecraft to have sleek, aerodynamic shapes.

Small compartments in the spacecraft hold very shiny sails; in orbit, they'll be unfurled to a square more than 18 feet on each side. As sunlight pushes the sails, ground control can cue the craft's very small electric motors to make it twist in space. As we orbit Earth, we will fly edge-on toward the sun, then twist or tack the spacecraft to present its sails right across the sunbeams, then tack again edge-on with each orbit.

It's just like a sailing ship except it's in space, driven directly by sunlight. And instead of being built in an enormous shipyard by the sea, the LightSail is built in small labs on land in California (albeit with access to some pretty good surfing).

DURING OUR LIGHTSAIL 2 mission, we anticipate building orbital energy so that our noble little craft will climb to a higher and higher orbit. We hope it will send back beautiful pictures of itself and the Earth below. And we believe it will fundamentally advance the technology of spaceflight. These LightSail missions are part of a global effort to lower the cost of space exploration, so missions could be flown that would otherwise be cost prohibitive or impossible.

For example: Now and then, the sun ejects an enormous amount of energy called a coronal mass ejection, or CME. These streams of charged particles, which can ruin the electronics aboard satellites, move very rapidly through space—but not nearly as rapidly as photons of light.

As Kepler himself pointed out, an object that is in close orbit to the sun goes faster than an object that's in orbit farther out, because of the sun's gravitational pull. If we were to attempt to put a satellite in an orbit at about the same distance from the sun as, say, Venus is, and we planned to have our spacecraft keep pace with the Earth—well, it wouldn't. Instead, it would literally fall into the sun. To stay in such an orbit, a spacecraft would need another constant outward force. A solar sail could provide that continuous push, and the instruments on board could detect a CME and

WE HOPE LIGHTSAIL 2 WILL SEND BACK BEAUTIFUL PICTURES. AND WE BELIEVE IT WILL FUNDAMENTALLY ADVANCE THE TECHNOLOGY OF SPACEFLIGHT.

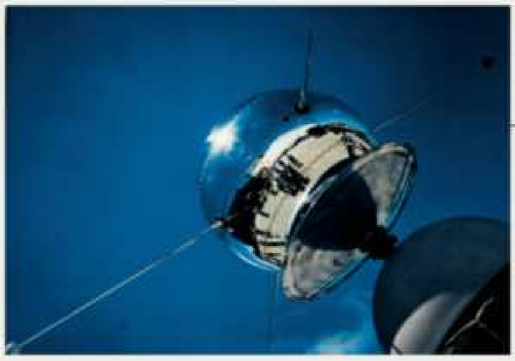
send us a warning signal. We could maneuver nearby Earth-orbiting satellites so that they essentially turn their backs to the stream of particles—and our vital spacecraft would suffer little damage.

With this same feature of solar sailing, we could send a spacecraft outfitted with infrared telescopes to orbit in step with Earth. The craft could point its heat-sensing telescope away from the sun, scan the icy blackness of space, and perhaps detect the glow of a dangerous asteroid on a collision course with Earth. Or a solar-sail spacecraft could be placed in orbit almost permanently above Earth's North or South Pole to monitor weather and climate. Solar sailing is a fantastic technology that is just in its infancy.

Think about the modern world we inhabit and the vast influence of exploration. The electronics or paper you're reading, the car you drive, the plane or train you ride, the food you eat, and the clothes you're wearing are all available to you because our ancestors figured out how to navigate the trackless ocean... the uncharted continents...the infinitude of space.

At the Planetary Society, our mission is to advance space science and exploration. Most people on Earth live day to day and night to night without thinking too much about space—but when we do, we can accomplish great things. By inviting the world's citizens to play a role in LightSail missions—to advocate for science funding, attend Planetary Society events, subscribe to launch updates—we give them a chance to be part of the future, to democratize space, and to help us all gain an important new perspective of the cosmos and our place within it. To the stars!

Mechanical engineer **Bill Nye** is CEO of the Planetary Society and an on-air expert on National Geographic's series *MARS* (season two premieres November 12). He is host of *Bill Nye Saves the World* on Netflix and a best-selling author whose book *Everything All at Once* is out in paperback this month. His Emmy Award–winning program *Bill Nye the Science Guy* helped introduce the millennial generation to science and engineering.



It Keeps Going...

As LightSail 2 prepares to go into Earth orbit, here's an update on a veteran of that circuit. Vanguard 1 (left) was the first solar-powered satellite when the U.S. vaulted it into orbit on March 17, 1958. It stopped transmitting in 1964—but more than 60 years after launch, it's still orbiting. That makes Vanguard 1 the oldest artificial satellite in space. So far it has circled Earth roughly 239,000 times, says NASA's David Williams, and "most estimates have the orbit lasting for hundreds of years."

PHOTO: NASA GLENN RESEARCH CENTER