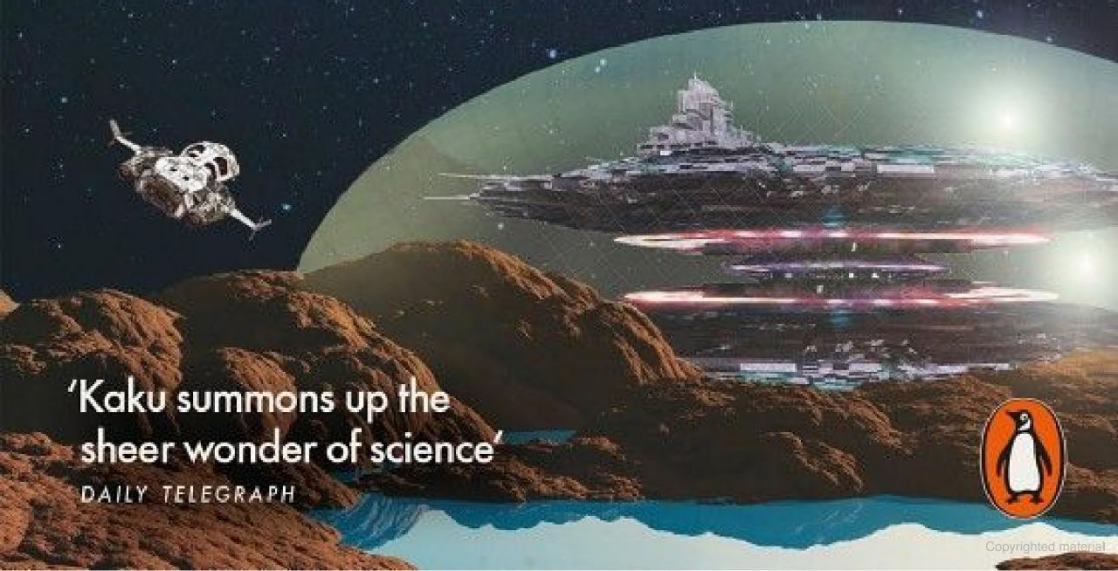
THE INTERNATIONAL BESTSELLER

MICHIO KAKU

The Future of Humanity

Terraforming Mars, Interstellar Travel, Immortality and Our Destiny Beyond Earth



'Kaku summons up the sheer wonder of science'
DAILY TELEGRAPH

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ABOUT THE AUTHOR

Michio Kaku is a professor of physics at the City University of New York, cofounder of string field theory, and the author of several widely acclaimed science books, including *Hyperspace, Beyond Einstein, Physics of the Impossible*, and *Physics of the Future*.

PENGUIN BOOKS

THE FUTURE OF HUMANITY

'Kaku argues passionately that our future lies not on Earth, but in the stars' *National Geographic*

'He marshals fresh advances in artificial intelligence, nanotechnology and bioengineering for his vision, segueing from lunar stations and Martian colonies to interstellar travel and human genetic engineering. There's plenty of hypothetical innovation too' Barbara Kiser, *Nature*

'Kaku is a practiced and very effective popularizer of science for a general audience; he's unfailingly interesting, with an unerring instinct for the most thought-provoking aspects of his various subjects. The sheer amount of technical scientific speculation in *The Future of Humanity* is amazing, and yet Kaku is in smooth, perfect control of it the entire time' Steve Donoghue, *Christian Science Monitor*

'An exhilarating look at the future' *Kirkus Reviews*

'Kaku thinks with great breadth, and the vistas he presents us are worth the trip' *The New York Times Book Review*

BY THE SAME AUTHOR

The Future of the Mind
Physics of the Future
Physics of the Impossible
Parallel Worlds
Hyperspace
Visions
Einstein's Cosmos
Beyond Einstein

To my loving wife Shizue,

and my daughters Michelle and Alyson

I then imagined a civilization on that planet, aware that their mother sun was dying, working urgently to assemble a huge armada of spaceships that might transport them to another star system. There would have been utter chaos on the planet as people, in panic and desperation, tried to scramble and secure the last few seats on the departing vessels. I imagined the horror felt by those who were left behind to meet their fate as their sun exploded.

It is as inescapable as the laws of physics that humanity will one day confront some type of extinction-level event. But will we, like our ancestors, have the drive and determination to survive and even flourish?

If we scan all the life-forms that have ever existed on the Earth, from microscopic bacteria to towering forests, lumbering dinosaurs, and enterprising humans, we find that more than 99.9 percent of them eventually became extinct. This means that extinction is the norm, that the odds are already stacked heavily against us. When we dig beneath our feet into the soil to unearth the fossil record, we see evidence of many ancient life-forms. Yet only the smallest handful survive today. Millions of species have appeared before us; they had their day in the sun, and then they withered and died. That is the story of life.

No matter how much we may treasure the sight of dramatic, romantic sunsets, the smell of fresh ocean breezes, and the warmth of a summer's day, one day it will all end, and the planet will become inhospitable to human life. Nature will eventually turn on us, as it did to all those extinct life-forms.

The grand history of life on Earth shows that, faced with a hostile environment, organisms inevitably meet one of three fates. They can leave that environment, they can adapt to it,

or they will die. But if we look far enough into the future, we will eventually face a disaster so great that adaptation will be virtually impossible. Either we must leave the Earth or we will perish. There is no other way.

These disasters have happened repeatedly in the past, and they will inevitably happen in the future. The Earth has already sustained five major extinction cycles, in which up to 90 percent of all life-forms vanished from the Earth. As sure as day follows night, there will be more to come.

On a scale of decades, we face threats that are not natural but are largely self-inflicted, due to our own folly and shortsightedness. We face the danger of global warming, when the atmosphere of the Earth itself turns against us. We face the danger of modern warfare, as nuclear weapons proliferate in some of the most unstable regions of the globe. We face the danger of weaponized microbes, such as airborne AIDS or Ebola, which can be transmitted by a simple cough or sneeze. This could wipe out upward of 98 percent of the human race. Furthermore, we face an expanding population that consumes resources at a furious rate. We may exceed the carrying capacity of Earth at some point and find ourselves in an ecological Armageddon, vying for the planet's last remaining supplies.

In addition to calamities that we create ourselves, there are also natural disasters over which we have little control. On a scale of thousands of years, we face the onset of another ice age. For the past one hundred thousand years, much of Earth's surface was blanketed by up to a half mile of solid ice. The bleak frozen landscape drove many animals to extinction. Then, ten thousand years ago, there was a thaw in the weather. This brief warming spell led to the sudden rise

of modern civilization, and humans have taken advantage of it to spread and thrive. But this flowering has occurred during an interglacial period, meaning we will likely meet another ice age within the next ten thousand years. When it comes, our cities will disappear under mountains of snow and civilization will be crushed under the ice.

We also face the possibility that the supervolcano under Yellowstone National Park may awaken from its long slumber, tearing the United States apart and engulfing the Earth in a choking, poisonous cloud of soot and debris. Previous eruptions took place 630,000, 1.3 million, and 2.1 million years ago. Each event was separated by roughly 700,000 years; therefore, we may be due for another colossal eruption in the next 100,000 years.

On a scale of millions of years, we face the threat of another meteor or cometary impact, similar to the one that helped to destroy the dinosaurs 65 million years ago. Back then, a rock about six miles across plunged into the Yucatán peninsula of Mexico, sending into the sky fiery debris that rained back on Earth. As with the explosion at Toba, only much larger, the ash clouds eventually darkened the sun and led temperatures to plunge globally. With the withering of vegetation, the food chain collapsed. Plant-eating dinosaurs starved to death, followed soon by their carnivorous cousins. In the end, 90 percent of all life-forms on Earth perished in the wake of this catastrophic event.

For millennia, we have been blissfully ignorant of the reality that the Earth is floating in a swarm of potentially deadly rocks. Only within the last decade have scientists begun to quantify the real risk of a major impact. We now know that there are several thousand NEOs (near-Earth

objects) that cross the orbit of the Earth and pose a danger to life on our planet. As of June 2017, 16,294 of these objects have been catalogued. But these are just the ones we've found. Astronomers estimate that there are perhaps several million uncharted objects in the solar system that pass by the Earth.

I once interviewed the late astronomer Carl Sagan about this threat. He stressed to me that "we live in a cosmic shooting gallery," surrounded by potential hazards. It is only a matter of time, he told me, before a large asteroid hits the Earth. If we could somehow illuminate these asteroids, we would see the night sky filled with thousands of menacing points of light.

Even assuming we avoid all these dangers, there is another that dwarfs all the others. Five billion years from now, the sun will expand into a giant red star that fills the entire sky. The sun will be so gigantic that the orbit of the Earth will be inside its blazing atmosphere, and the blistering heat will make life impossible within this inferno.

Unlike all other life-forms on this planet, which must passively await their fate, we humans are masters of our own destiny. Fortunately, we are now creating the tools that will defy the odds given to us by nature, so that we don't become one of the 99.9 percent of life-forms destined for extinction. In this book, we will encounter the pioneers who have the energy, the vision, and the resources to change the fate of humanity. We will meet the dreamers who believe that humanity can live and thrive in outer space. We will analyze the revolutionary advances in technology that will make it possible to leave the Earth and to settle elsewhere in the solar system, and even beyond.

But if there is one lesson we can learn from our history, it is that humanity, when faced with life-threatening crises, has risen to the challenge and has reached for even higher goals. In some sense, the spirit of exploration is in our genes and hardwired into our soul.

But now we face perhaps the greatest challenge of all: to leave the confines of the Earth and soar into outer space. The laws of physics are clear; sooner or later we will face global crises that threaten our very existence.

Life is too precious to be placed on a single planet, to be at the mercy of these planetary threats.

We need an insurance policy, Sagan told me. He concluded that we should become a "two planet species." In other words, we need a backup plan.

In this book, we will explore the history, the challenges, and the possible solutions that lie before us. The path will not be easy, and there will be setbacks, but we have no choice.

From near extinction approximately seventy-five thousand years ago, our ancestors ventured forth and began the colonization of the entire Earth. This book will, I hope, lay out the steps necessary to conquer these obstacles that we will inevitably face in the future. Perhaps our fate is to become a multiplanet species that lives among the stars.

a secret from lower civilizations, to prevent accidentally contaminating them with advanced technology. This concept is similar to the Prime Directive, one of the guiding principles of the Federation in the *Star Trek* series.

Our hero also comes across a civilization so sophisticated that its members enclose their mother sun in a gigantic sphere to utilize all its energy. This concept, which would later be called the Dyson sphere, is now a staple of science fiction.

He meets a race of individuals who are in constant telepathic contact with one another. Every individual knows the intimate thoughts of the others. This idea predates the Borg of *Star Trek,* where individuals are connected mentally and are subordinate to the will of the Hive.

And at the end of the novel, he encounters the Star Maker himself, a celestial being who creates and tinkers with entire universes, each with its own laws of physics. Our universe is just one in a multiverse. In total awe, our hero witnesses the Star Maker at work as he conjures up new and exciting realms, discarding those not pleasing to him.

Stapledon's trailblazing novel came as quite a shock in a world where the radio was still considered a miracle of technology. In the 1930s, the idea of achieving a space-faring civilization seemed preposterous. Back then, propeller-driven airplanes were state-of-the-art and had hardly managed to venture above the clouds, so the possibility of traveling to the stars seemed hopelessly remote.

Star Maker was an instant success. Arthur C. Clarke called it one of the finest works of science fiction ever published. It fired up the imagination of a whole generation of postwar science fiction writers. But among the general public, the

novel was soon forgotten amidst the chaos and savagery of World War II.

FINDING NEW PLANETS IN SPACE

Now that the Kepler spacecraft and teams of Earth-bound astronomers have discovered about four thousand planets orbiting other stars in the Milky Way galaxy, one begins to wonder if the civilizations described by Stapledon actually exist.

In 2017, NASA scientists identified not one but seven Earth-sized planets orbiting a nearby star, a mere thirty-nine light-years from Earth. Of these seven planets, three of them are close enough to their mother star to support liquid water. Very soon, astronomers will be able to confirm whether or not these and other planets have atmospheres containing water vapor. Since water is the "universal solvent" capable of being the mixing bowl for the organic chemicals that make up the DNA molecule, scientists may be able to show that the conditions for life are common in the universe. We may be on the verge of finding the Holy Grail of planetary astronomy, a twin of the Earth in outer space.

Around the same time, astronomers made another game-changing discovery, an Earth-sized planet named Proxima Centauri b, which orbits the star closest to our sun, Proxima Centauri, which is just 4.2 light-years away from us. Scientists have long conjectured that this star would be one of the first to be explored.

These planets are just a few of the recent entries in the huge Extrasolar Planets Encyclopaedia, which has to be updated practically every week. It contains strange, unusual star systems that Stapledon could only have dreamt of—

including systems where four or more stars rotate among one another. Many astronomers believe that if you can imagine any bizarre formation of planets, then it probably exists somewhere in the galaxy, as long as it doesn't violate some law of physics.

This means that we can roughly calculate how many Earth-sized planets there are in the galaxy. Since it has about one hundred billion stars, there might be twenty billion Earth-sized planets orbiting a sun-like star in our galaxy alone. And since there are one hundred billion galaxies that can be seen with our instruments, we can estimate how many Earth-sized planets there are in the visible universe: a staggering two billion trillion.

Realizing that the galaxy could be teeming with habitable planets, you will never see the night sky in the same way again.

Once astronomers have identified these Earth-sized planets, the next goal will be to analyze their atmospheres for oxygen and water vapor, a sign of life, and listen for radio waves, which would signal the existence of an intelligent civilization. Such a discovery would be one of the great turning points in human history, comparable to the taming of fire. Not only would it redefine our relationship to the rest of the universe, it would also change our destiny.

THE NEW GOLDEN AGE OF SPACE EXPLORATION

All these exciting discoveries of exoplanets, along with the novel ideas brought about by a fresh new generation of visionaries, are rekindling the public's interest in space travel. Originally, what drove the space program was the Cold War and superpower rivalry. The public did not mind

spending a staggering 5.5 percent of the nation's federal budget on the Apollo space program because our national prestige was at stake. However, this feverish competition could not be sustained forever, and the funding eventually collapsed.

U.S. astronauts last walked on the surface of the moon about forty-five years ago. Now, the Saturn V rocket and the space shuttle are dismantled and rusting in pieces in museums and junkyards, their stories languishing in dusty history books. In the years that followed, NASA was criticized as the "agency to nowhere." It has been spinning its wheels for decades, boldly going where everyone has gone before.

But the economic situation has begun to change. The price of space travel, once so high it could cripple a nation's budget, has been dropping steadily, in large part because of the influx of energy, money, and enthusiasm from a rising cohort of entrepreneurs. Impatient with NASA's sometimes glacial pace, billionaires like Elon Musk, Richard Branson, and Jeff Bezos have been opening up their checkbooks to build new rockets. Not only do they want to turn a profit, they also want to fulfill their childhood dreams of going to the stars.

Now there is a rejuvenated national will. The question is no longer whether the U.S. will send astronauts to the Red Planet, but when. Former president Barack Obama stated that astronauts would walk on the surface of Mars sometime after 2030, and President Donald Trump has asked NASA to accelerate that timetable.

A fleet of rockets and space modules capable of an interplanetary journey—like NASA's Space Launch System (SLS) booster rocket with the Orion capsule and Elon Musk's Falcon Heavy booster rocket with the Dragon capsule—are in

the early testing phase. They will do the heavy lifting, taking our astronauts to the moon, asteroids, Mars, and even beyond. In fact, so much publicity and enthusiasm have been generated by this mission that there is rivalry building up around it. Perhaps there will be a traffic jam over Mars as different groups compete to plant the first flag on Martian soil.

Some have written that we are entering a new golden age of space travel, when exploring the universe will once again become an exciting part of the national agenda after decades of neglect.

As we look to the future, we can see the outlines of how science will transform space exploration. Because of revolutionary advances in a wide range of modern technologies, we can now speculate how our civilization may one day move into outer space, terraforming planets and traveling among the stars. Although this is a long-term goal, it is now possible to give a reasonable time frame and estimate when certain cosmic milestones will be met.

In this book, I will investigate the steps necessary to accomplish this ambitious goal. But the key to discovering how our future may unfold is to understand the science behind all of these miraculous developments.

REVOLUTIONARY WAVES OF TECHNOLOGY

Given the vast frontiers of science that lie before us, it may help to put the broad panorama of human history into perspective. If our ancestors could see us today, what would they think? For most of human history, we lived wretched lives, struggling in a hostile, uncaring world where life expectancy was between twenty and thirty years of age. We

Furthermore, we may have to genetically engineer our bodies to flourish on distant planets with different gravity, atmospheric composition, and ecology.

Thanks to the Human Connectome Project, which will map every neuron in the human brain, one day we may be able to send our connectomes into outer space on giant laser beams, eliminating a number of problems in interstellar travel. I call this laser porting, and it may free our consciousness to explore the galaxy or even the universe at the speed of light, so we don't have to worry about the obvious dangers of interstellar travel.

If our ancestors in the last century would think of us today as magicians and sorcerers, then how might we view our descendants a century from now?

More than likely, we would consider our descendants to be like Greek gods. Like Mercury, they would be able to soar into space to visit nearby planets. Like Venus, they would have perfect immortal bodies. Like Apollo, they would have unlimited access to the sun's energy. Like Zeus, they would be able to issue mental commands and have their wishes come true. And they would be able to conjure up mythical animals like Pegasus using genetic engineering.

In other words, our destiny is to become the gods that we once feared and worshipped. Science will give us the means by which we can shape the universe in our image. The question is whether we will have the wisdom of Solomon to accompany this vast celestial power.

There is also the possibility that we will make contact with extraterrestrial life. We will discuss what might happen were we to encounter a civilization that's a million years more advanced than ours, that has the capability to roam across

the galaxy and alter the fabric of space and time. They might be able to play with black holes and use wormholes for faster-than-light travel.

In 2016, speculation about advanced civilizations in space reached a fever pitch among astronomers and the media, with the announcement that astronomers had found evidence of some sort of colossal "megastructure," perhaps as big as a Dyson sphere, orbiting around a distant star many light-years away. While the evidence is far from conclusive, for the first time, scientists were confronted with evidence that an advanced civilization may actually exist in outer space.

Lastly, we explore the possibility that we will face not just the death of the Earth but the death of the universe itself. Although our universe is still young, we can foresee the day in the distant future when we might approach the Big Freeze as temperatures plunge to near absolute zero and all life as we know it will likely cease to exist. At that point, our technology might be advanced enough to leave the universe and venture through hyperspace to a new, younger universe.

Theoretical physics (my own specialization) opens up the notion that our universe could be just a single bubble floating in a multiverse of other bubble universes. Perhaps among the other universes in the multiverse, there is a new home for us. Gazing upon the multitude of universes, perhaps we will be able to reveal the grand designs of a Star Maker.

So the fantastic feats of science fiction, once considered the byproduct of the overheated imagination of dreamers, may one day become reality.

Humanity is about to embark on perhaps its greatest adventure. And the gap that separates the speculations of Asimov and Stapledon from reality may be bridged by the

astonishing and rapid advancements being made in science. And the first step we take in our long journey to the stars begins when we leave the Earth. As the old Chinese proverb says, the journey of a thousand miles begins with the first step. The journey to the stars begins with the very first rocket.

Part I

LEAVING THE EARTH

1 Preparing for Liftoff

> Anyone who sits on top of the largest hydrogen-oxygen fueled system in the world, knowing they're going to light the bottom, and doesn't get a little worried, does not fully understand the situation.
>
> —ASTRONAUT JOHN YOUNG

On October 19, 1899, a seventeen-year-old boy climbed a cherry tree and had an epiphany. He had just read H. G. Wells's *War of the Worlds* and was excited by the idea that rockets could allow us to explore the universe. He imagined how wonderful it would be to make some device that had even the *possibility* of traveling to Mars and had a vision that it was our destiny to explore the Red Planet. By the time he came down from that tree, his life had been forever changed. That boy would dedicate his life to the dream of perfecting a rocket that would make this vision a reality. He would celebrate October 19 for the rest of his life.

His name was Robert Goddard, and he went on to perfect the first liquid fueled multistage rocket, setting into motion events that changed the course of human history.

TSIOLKOVSKY—A LONELY VISIONARY

Goddard was one of a handful of pioneers who, despite isolation, poverty, and ridicule from their peers, forged ahead against all odds and laid the foundation for space travel. One

powdered fuel with liquid fuel, which could be precisely controlled so that it burned cleanly and steadily. He built a rocket with two tanks, one containing a fuel, such as alcohol, and the other tank containing an oxidizer, such as liquid oxygen. These liquids were fed by a series of pipes and valves into the firing chamber, creating a carefully controlled explosion that could propel a rocket.

Goddard realized that as the rocket rose into the sky, its fuel tanks were gradually depleted. His next innovation was to introduce multistage rockets that discarded spent fuel tanks and therefore could shed some dead weight along the way, vastly increasing their range and efficiency.

And third, he introduced gyroscopes. Once a gyroscope is sent spinning, its axis always points in the same direction, even if you rotate it. For example, if the axis points toward the North Star, it will continue to point in that direction if you turn it upside down. This means that a spaceship, if it were to wander in its trajectory, can alter its rockets to compensate for this motion and return to its original course. Goddard realized he could use gyroscopes to help keep his rockets on target.

In 1926, he made history with the first successful launch of a liquid fueled rocket. It rose 41 feet into the air, flew for 2.5 seconds, and landed 184 feet away in a cabbage patch. (The exact site is now hallowed ground to every rocket scientist, and it has been declared a National Historic Landmark.)

In his laboratory at Clark College he established the basic architecture for all chemical rockets. The thundering behemoths we see blasting off from launchpads today are direct descendants of the prototypes he built.

FACING RIDICULE

Despite his successes, Goddard proved to be an ideal whipping boy for the media. When word leaked out in 1920 that he was giving serious thought to space travel, the *New York Times* published scathing criticism that would have crushed any lesser scientist. "That Professor Goddard," the *Times* snickered, "with his 'chair' in Clark College ... does not know the relation of action and reaction, and of the need to have something better than a vacuum against which to react —to say that would be absurd. Of course he only seems to lack the knowledge ladled out daily in high school." And in 1929, after he launched one of his rockets, the local Worcester newspaper ran a degrading headline: "Moon Rocket Misses Target by 238,799 1/2 Miles." Clearly the *Times* and others did not understand Newton's laws of motion and incorrectly believed that rockets could not move in the vacuum of outer space.

Newton's third law, which states that for every action, there is an equal and opposite reaction, governs space travel. This law is known to any child who has ever blown up a balloon, released it, and watched the balloon fly in all directions. The action is the air that suddenly rushes out of the balloon, and the reaction is the forward motion of the balloon itself. Similarly, in a rocket, the action is the hot gas ejected out of one end, while the reaction is the forward motion of the rocket that propels it, even in the vacuum of space.

Goddard died in 1945 and did not live long enough to see the apology written by the editors of the *New York Times* after the Apollo moon landing in 1969. They wrote, "It is now

definitely established that a rocket can function in a vacuum as well as in an atmosphere. The *Times* regrets the error."

ROCKETS FOR WAR AND PEACE

In the first phase of rocketry, we had the dreamers, like Tsiolkovsky, who worked out the physics and mathematics of space travel. In the second phase, we had people like Goddard, who actually built the first prototypes of these rockets. In the third phase, rocket scientists caught the eye of major governments. Wernher von Braun would take the sketches, dreams, and models of his predecessors and with the support of the German government—and later the United States—would create gargantuan rockets that would successfully take us to the moon.

The most celebrated of all rocket scientists was born an aristocrat. Baron Wernher von Braun's father was the German minister of agriculture during the Weimar Republic, and his mother could trace her ancestry to the royal houses of France, Denmark, Scotland, and England. Von Braun was an accomplished pianist as a child and even wrote original works of music. At one point, he might have become a renowned musician or composer. But his destiny changed when his mother bought him a telescope. He became fascinated by space. He devoured science fiction and was inspired by the speed records set by rocket-propelled cars. One day, when he was twelve, he unleashed chaos in the crowded streets of Berlin by attaching a series of fireworks to a toy wagon. He was delighted that it took off like, well, a rocket. However, the police were less impressed. Von Braun was taken into custody but released because of his father's influence. As he recalled fondly years later, "It performed

beyond my wildest dreams. The wagon careened crazily about, trailing fire like a comet. When the rockets burned out, ending their sparkling performance with a magnificent thunderclap, the wagon rolled majestically to a halt."

Von Braun confessed that he was never good with mathematics. But his drive to perfect rocketry led him to master calculus, Newton's laws, and the mechanics of space travel. As he once told his professor, "I plan on traveling to the Moon."

He became a graduate student in physics and earned his Ph.D. in 1934. But he spent much of his time with the amateur Berlin Rocket Society, an organization that used spare parts to build and test rockets on a deserted three-hundred-acre piece of land outside of the city. That year, the society successfully tested a rocket that rose two miles into the air.

Von Braun might have become a professor of physics at some German university, writing learned articles about astronomy and astronautics. But war was in the air, and all of German society, including the universities, was being militarized. Unlike his predecessor, Robert Goddard, who had requested funding from the U.S. military but was turned down, von Braun got an entirely different reception from the Nazi government. The German Army Ordnance Department, always searching for new weapons of war, noticed von Braun and offered him generous funding. His work was so sensitive that his Ph.D. thesis was classified by the army and wasn't published until 1960.

Von Braun, by all accounts, was apolitical. Rocketry was his passion, and if the government would fund his research, he would accept it. The Nazi Party offered him the dream of a lifetime: directorship of a massive project to build the rocket

of the future, with a nearly unlimited budget, employing the cream of German science. Von Braun claimed that being offered membership in the Nazi Party and even the SS was a rite of passage for government workers rather than a reflection of his politics. But when you make a deal with the devil, the devil always asks for more.

RISE OF THE V-2

Under von Braun's leadership, the scribblings and sketches of Tsiolkovsky and the prototypes of Goddard became the Vengeance Weapon 2 rocket, an advanced weapon of war that terrorized London and Antwerp, blowing up entire city blocks. The V-2 was unbelievably powerful. It dwarfed Goddard's rockets, making them look like toys. The V-2 stood forty-six feet tall and weighed 27,600 pounds. It could travel at a blazing speed of 3,580 miles per hour and it achieved a maximum altitude of about sixty miles. It hit its targets at three times the speed of sound, giving no warning apart from a double cracking noise as it broke the sound barrier. And it had an operational range of two hundred miles. Countermeasures were futile since no human could track it and no airplane could catch it.

The V-2 set a number of world records, shattering all past achievements in terms of speed and range for a rocket. It was the first long-range guided ballistic missile. It was the first rocket to break the sound barrier. And most impressively, it was the first rocket ever to leave the boundary of the atmosphere and enter outer space.

The British government was so flummoxed by this advanced weapon that they had no words for it. They invented the story that all these explosions were caused by

words, "Once the rockets are up, who cares where they come down? That's not my department."

ROCKETRY AND SUPERPOWER RIVALRY

In the 1920s and 1930s, U.S. government officials missed a strategic opportunity when they did not recognize the prophetic work being done in their own backyard by Goddard. They missed a second strategic opportunity after the war, with the arrival of von Braun. In the 1950s, they left von Braun and his assistants in limbo, without giving them any real focus. Eventually, interservice rivalry took over. The army, under von Braun, created the Redstone rocket, while the navy had the Vanguard missile and the air force the Atlas.

Without any immediate obligations for the army, von Braun began to take an interest in science education. He created a series of animated TV specials with Walt Disney that captured the imagination of future rocket scientists. In the series, von Braun painted the broad outlines of a massive scientific effort to land on the moon as well as to develop a fleet of ships that would reach Mars.

While the U.S. rocketry program proceeded by fits and starts, the Russians moved ahead rapidly with theirs. Joseph Stalin and Nikita Khrushchev grasped the strategic importance of the space program and made it a top priority. The Soviet program was put under the direction of Sergei Korolev, whose very identity was kept top secret. For years he was only referred to mysteriously as "Chief Designer" or "the Engineer." The Russians had also captured a number of V-2 engineers and moved them to the Soviet Union. With their guidance, the Soviets took the basic V-2 design and quickly built a series of rockets based on it. Essentially, the entire U.S.

and USSR arsenals were based on modifying or lashing together the V-2 rockets, which in turn were based on Goddard's pioneering prototypes.

One of the major goals of both the United States and USSR was launching the first artificial satellite. It was Isaac Newton himself who first proposed the concept. In a now-famous diagram, Newton noted that if you fire a cannonball from a mountaintop, it will fall near the base of the mountain. Following his equations of motion, however, the faster the cannonball travels, the farther it will go. If you fire the cannonball fast enough, it will circle completely around the Earth and become a satellite. Newton made a historic breakthrough: if you replace this cannonball with the moon, then his equations of motion should be able to predict the precise nature of the moon's orbit.

In his cannonball thought experiment, he asked a key question: If an apple falls, does the moon also fall? Since the cannonball is in free fall as it goes around the Earth, the moon must also be in free fall. Newton's insight set into motion one of the greatest revolutions in all of history. Newton could now calculate the motion of cannonballs, moons, planets—almost everything. For example, using his laws of motion, you can easily show that you must fire the cannonball at eighteen thousand miles per hour in order to have it orbit the Earth.

Newton's vision became a reality when the Soviets launched the world's first artificial satellite, Sputnik, in October 1957.

SPUTNIK AGE

The immense shock to the American psyche upon learning of Sputnik cannot be underestimated. Americans quickly realized that the Soviets led the world in rocket science. The humiliation was made worse when, two months later, the navy's Vanguard missile suffered a catastrophic failure on international TV. I vividly remember, as a child, asking my mother if I could stay up and watch the missile launch. She reluctantly agreed. I was horrified to witness the Vanguard missile rise four feet into the air, then drop back down four feet, tip over, and destroy its own launchpad in a huge, blinding explosion. I could clearly see the nose cone at the top of the missile, which contained the satellite, topple over and disappear in a ball of flames.

The humiliation continued when the second Vanguard launch a few months later also failed. The press had a field day, calling the missile "Flopnik" and "Kaputnik." The Soviet U.N. delegate even joked that Russia should give aid to the United States.

Trying to recover from this huge media blow to our national prestige, von Braun was ordered to quickly launch a satellite, Explorer I, using the Juno I missile. The Juno I was based on the Redstone rocket, which in turn was based on the V-2.

But the Soviets had a series of aces up their sleeve. A sequence of historic "firsts" dominated the headlines for the next several years:

1957: Sputnik 2 carried the first animal, a dog named Laika, into orbit
1957: Lunik 1 was the first rocket to fly past the moon
1959: Lunik 2 was the first to hit the moon

1959: Lunik 3 was the first rocket to photograph the back side of the moon

1960: Sputnik 5 had the first animals returned safely from space

1961: Venera 1 was the first probe to fly past Venus

The Russian space program reached its crowning achievement when Yuri Gagarin safely orbited the Earth in 1961.

I distinctly remember those years, when Sputnik spread panic throughout the United States. How could a seemingly backward nation, the Soviet Union, suddenly leapfrog ahead of us?

Commentators concluded that the root cause of this fiasco was the U.S. education system. American students were falling behind the Soviets. A crash campaign had to be mounted so that money, resources, and media attention could be devoted to producing a new generation of American scientists who could compete with the Russians. Articles at the time declared that "Ivan can read, but Johnny cannot."

Out of this troubled time came the Sputnik generation, a cohort of students who considered it their national duty to become physicists, chemists, or rocket scientists.

Under enormous pressure to let the military wrest control over the U.S. space program from seemingly hapless civilian scientists, President Dwight Eisenhower bravely insisted on continued civilian oversight and created NASA. Then President John F. Kennedy, responding to Gagarin's orbital trip, called for an expedited program to put humans on the moon by the end of the decade.

This call galvanized the nation. By 1966, an astounding 5.5 percent of the U.S. federal budget was going into the lunar

program. As always NASA moved cautiously, perfecting the technology needed to bring a moon landing about in a series of launches. First, there was the one-manned craft called Mercury, and then the two-manned Gemini, and finally the three-manned Apollo. NASA also carefully mastered each step in space travel. First, astronauts left the safety of their spaceships and made the first spacewalks. Then astronauts mastered the complex art of docking their spaceship with another ship. Next, astronauts orbited completely around the moon but did not land on the surface. Then, finally, NASA was ready to launch astronauts directly to the moon.

Von Braun was called in to help build the Saturn V, which was to be the biggest rocket ever built. This rocket was a truly marvelous engineering masterpiece. It stood sixty feet taller than the Statue of Liberty. It could lift a payload of 310,000 pounds into orbit around the Earth. Most important, it could send large payloads past twenty-five thousand miles per hour, which is the escape velocity of the Earth.

The possibility of a fatal disaster was ever on the minds of NASA. President Richard Nixon had two speeches prepared for his TV announcement of the results of the Apollo 11 mission. One speech was to report that the effort was a failure and that American astronauts had died on the moon. This scenario actually came very close to happening. In the final seconds before the Lunar Module was to land, computer alarms went off inside the capsule. Neil Armstrong manually took control of the spacecraft and gently landed it on the moon. Analysis later showed that they had only fifty seconds of fuel left; the capsule might have crashed.

Fortunately, on July 20, 1969, President Nixon was able to deliver the other speech, congratulating our astronauts for

Over time, problems emerged with the space shuttle. For one, although the shuttle was designed to save money, costs nevertheless began to soar, so that each launch consumed about $1 billion. Sending anything into near-Earth orbit on the shuttle cost roughly $40,000 per pound, which was about four times the cost of other delivery systems. Companies complained that it was much cheaper to send their satellites using conventional rockets. Secondly, flights took place infrequently, with many months between launches. Even the U.S. Air Force was frustrated by these limitations and eventually canceled some of its space shuttle launches in favor of using other options.

Physicist Freeman Dyson of the Institute for Advanced Study in Princeton, New Jersey, has his own thoughts on why the space shuttle failed to live up to expectations. When we look at the history of the railroad, we see that it initially started as a carrier for all goods, including humans and commercial products. The commercial side and consumer side of the industry each had their own distinct priorities and concerns, and they eventually split apart, increasing efficiency and lowering costs. The space shuttle, however, never made this split and remained a cross between commercial and consumer interests. Instead of being "everything to everyone," it became "nothing to nobody," especially with its cost overruns and flight delays.

And matters worsened after the *Challenger* and *Columbia* tragedies, which cost the lives of fourteen brave astronauts. These disasters weakened public, private, and government support for the space program. As physicists James and Gregory Benford wrote, "Congress came to see NASA primarily as a jobs program, not an exploratory agency."

They also observed that "very little useful science got done in the space station ... The station was about camping in space, not living in space."

Without the wind of the Cold War in its sails, the space program rapidly lost funding and momentum. Back in the heyday of the Apollo space program, the joke was that NASA could go to Congress asking for funds and say just one word: "Russia!" Then Congress would whip out its checkbook and reply, "How much?" But those days were long gone. As Isaac Asimov said, we scored a touchdown—and then we took our football and went home.

Things finally came to a head in 2011, when former President Barack Obama ordered a new "Valentine's Day massacre." In one sweeping gesture, he canceled the Constellation program (the replacement for the shuttle), the moon program, and the Mars program. To relieve the tax burden on the public, he defunded these programs in hope that the private sector would make up the difference. Twenty thousand veterans of the space program were suddenly laid off, throwing away the collective wisdom of NASA's best and brightest. The greatest humiliation was that American astronauts, after going toe-to-toe with Russian astronauts for decades, would now be forced to hitchhike on Russian booster rockets. The heyday of space exploration, it seemed, was over; things had reached rock bottom.

The problem could be summed up in one four-letter word, *c-o-s-t.* It takes $10,000 to put a pound of anything in near-Earth orbit. Imagine your body made of solid gold. That's roughly what it would take to put you into orbit. To put something on the moon can easily cost $100,000 per pound. And to put things on Mars costs upward of a million dollars

per pound. Estimates of putting an astronaut on Mars are often between $400 and $500 billion in total.

I live in New York City. For me it was a sad day when the space shuttle came to town. Although curious tourists lined up and cheered as the shuttle came rolling down the street, it represented the end of an era. The ship was put on display, eventually resting off the pier on Forty-Second Street. With no replacement in sight, it felt as if we were giving up on science, and hence our future.

Looking back at those dark days, I am sometimes reminded of what happened to the great Chinese imperial fleet in the fifteenth century. Back then, the Chinese were the undisputed leaders in science and exploration. They invented gunpowder, the compass, and the printing press. They were unparalleled in military power and technology. Meanwhile, medieval Europe was wracked by religious wars and mired in inquisitions, witch trials, and superstition, and great scientists and visionaries like Giordano Bruno and Galileo were often either burned alive or placed under house arrest, their works banned. Europe, at the time, was a net importer of technology, not a source of innovation.

The Chinese emperor launched, under the command of Admiral Zheng He, the most ambitious naval expedition of all time, with twenty-eight thousand sailors on a fleet of 317 huge ships, each one five times longer than the ships of Columbus. The world would not see anything like it for another four hundred years. Not once, but seven times, from 1405 to 1433, Admiral Zheng He sailed across the known world, around Southeast Asia and past the Middle East, eventually ending up in East Africa. There are ancient woodcuts of the strange animals, like giraffes, that he

brought back from his voyages of discovery being paraded before the court.

But when the emperor passed away, the new rulers decided that they had no use for exploration and discovery. They even decreed that a Chinese citizen could not own a boat. The fleet itself was left to rot or allowed to burn, and records of Admiral Zheng He's great accomplishments were suppressed. Succeeding emperors effectively cut off contact between China and the rest of the world. China turned inward, with disastrous results, eventually leading to decay, total collapse, chaos, civil war, and revolution.

I sometimes think about how easy it is for a nation to slip into complacency and ruin after decades of basking in the sun. Since science is the engine of prosperity, nations that turn their backs on science and technology eventually enter a downward spiral.

The U.S. space program similarly fell into decline. But now the political and economic circumstances are changing. A new cast of characters is taking center stage. Daring astronauts are being replaced by dashing billionaire entrepreneurs. New ideas, new energy, and new funding are driving this renaissance. But can this combination of private funds and government financing pave the way to the heavens?

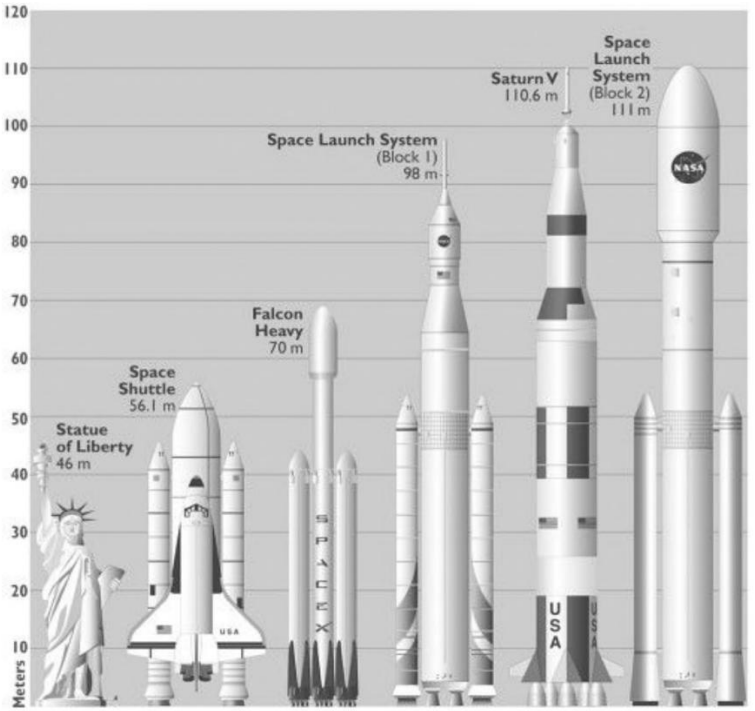
2 New Golden Age of Space Travel

> Yours is the light by which my spirit's born. You are my sun, my moon, and all my stars.
>
> —E. E. CUMMINGS

Unlike the decline of China's naval fleet, which lasted for centuries, the U.S. manned space program is experiencing a revival after only a few decades of neglect. A variety of factors is turning the tide.

One is the influx of resources from Silicon Valley entrepreneurs. A rare combination of private funding and governmental financing is making possible a new generation of rockets. At the same time, the falling cost of space travel allows a range of projects to become feasible. Public support for space travel is also reaching a tipping point, as Americans again warm up to Hollywood movies and TV specials about space exploration.

And most important, NASA has finally regained its focus. On October 8, 2015, after years of muddle, vacillation, and indecision, NASA finally declared its long-term goal: to send astronauts to Mars. NASA even sketched out a rough set of goals for itself, beginning with returning to the moon. Rather than a final destination, though, the moon would be a stepping-stone for the more ambitious goal of reaching Mars. The once rudderless agency suddenly had a direction.



This lineup compares the original Saturn V rocket, which took our astronauts to the moon and the Space Shuttle, with other booster rockets being tested.

Defenders of NASA claim that its cautious pace is due to NASA's safety concerns. In the wake of the two space shuttle disasters, congressional hearings almost caused the space program to shut down entirely amid strong public disapproval. Another disaster of that scope could put an end to the program. Also, they point out that in the 1990s, NASA tried adopting the mantra "Faster, Better, Cheaper." However, when the Mars Observer was lost in 1993 due to a ruptured fuel tank just as it was about to orbit Mars, many thought that NASA might have rushed the mission, and the "Faster, Better, Cheaper" slogan was quietly dropped.

So one has to strike a delicate balance between the hotheads who want an accelerated pace and the bureaucrats who are gun-shy about safety and the cost of failure.

Nevertheless, two billionaires have taken the lead in fast-tracking the space program: Jeff Bezos, founder of Amazon and owner of the *Washington Post,* and Elon Musk, founder of PayPal, Tesla, and SpaceX.

The press is already dubbing it the "battle of the billionaires."

Both Bezos and Musk would like to shift humanity into outer space. While Musk is taking the long view and setting his sights on Mars, Bezos has a more immediate vision of going to the moon.

TO THE MOON

People from all over have flocked to Florida, hoping to catch a glimpse of the first capsule that will take our astronauts to the moon. The lunar capsule will carry three astronauts on a voyage unprecedented in human history, an encounter with another celestial body. The journey to the moon will take about three days, and the astronauts will experience things never felt before, such as weightlessness. After a heroic voyage, the ship will splash down safely in the Pacific Ocean, and its passengers will be celebrated as heroes, opening up a new chapter in world history.

All the calculations have been done using Newton's laws, ensuring a precise voyage. But there is one problem. It's actually a tale written by Jules Verne, in his prophetic novel *From the Earth to the Moon,* published in 1865, just after the end of the Civil War. The organizers of the moon shot are not NASA scientists but members of the Baltimore Gun Club.

What is truly remarkable is that Jules Verne, writing more than one hundred years before the first lunar landing, was able to predict so many features of the actual moon shot. He was able to correctly portray the size of the capsule, the location of the launch, and the method of landing back on Earth.

The only major flaw in his book was the use of a gigantic cannon to send the astronauts to the moon. The sudden acceleration of the gunshot would be about twenty thousand times the force of gravity, which would certainly kill anyone aboard the ship. However, before the coming of liquid fueled rockets, Verne had no other way to envision the journey.

Verne also postulated that the astronauts would become weightless, but only at one point, midway between the moon and the Earth. He did not realize that the astronauts would become weightless throughout their voyage. (Even today, commentators make mistakes about weightlessness, sometimes stating that it is caused by the absence of gravity in space. Actually, there is plenty of gravity in space, enough to whip giant planets like Jupiter around the sun. The experience of weightlessness is caused by the fact that everything falls at the same rate. So an astronaut inside the spaceship would fall at the same rate as his ship and experience the illusion that gravity has been turned off.)

Today, it is not the private fortunes of the members of the Baltimore Gun Club fueling this new space race but the checkbooks of moguls like Jeff Bezos. Instead of waiting for NASA to give him permission to build rockets and a launchpad with taxpayer dollars, he founded his own company, Blue Origin, and is building them himself, with his own pocket money.

Already, the project has gone beyond the planning stage. Blue Origin has produced its own rocket system, called New Shepard (named after Alan Shepard, the first American to go into space via a suborbital rocket). In fact, the New Shepard rocket was the first suborbital rocket in the world to successfully land back on its original launchpad, just beating out Elon Musk's Falcon rocket (which was the first reusable rocket to actually send a payload into Earth orbit).

Bezos's New Shepard rocket is only suborbital, meaning that it cannot reach a speed of eighteen thousand miles per hour and go into near-Earth orbit. It won't take us to the moon, but it may be the first American rocket to routinely offer tourists a view of space. Blue Origin recently released a video of a hypothetical journey on the New Shepard, and it looked like you were riding first class on a luxury ship. When you enter the space capsule, you are immediately impressed with how roomy it is. Far from the cramped quarters often seen in science fiction movies, there is ample room for you and five other tourists to be strapped into your lush reclining seats, where you immediately sink into black leather. You can look out of huge windows that are approximately 2.4 feet wide and 3.5 feet tall. "Every seat is a window seat, the largest windows ever in space," Bezos claims. Space travel has never been so gorgeous.

Because you are about to enter outer space, there are some precautions you must take. Two days before the trip, you fly into Van Horn, Texas, where Blue Origin has its launch facility. There you meet your fellow tourists and hear short talks by the crew. Since the voyage is completely automated, the crew members do not ride along with the tourists.

Your instructor explains that the entire trip will take eleven minutes as you soar vertically, sixty-two miles straight up, reaching the boundary between the atmosphere and outer space. Outside, the sky will turn dark purple and then inky black. Once the capsule reaches outer space, you can unbuckle your seat and experience four minutes of weightlessness. You will then float like an acrobat, free of the earthly constraints of gravity.

Some people get sick and vomit while experiencing weightlessness, but this won't be a problem, the instructor claims, since the trip is so short.

(For training astronauts, NASA employs the "vomit comet," which is a KC-135 airplane that can simulate weightlessness. The vomit comet rises steeply, suddenly shuts off its engines for about thirty seconds, and then falls back down. The astronauts are now like a rock thrown in the air—they are in free fall. When the airplane turns on its engines, the astronauts fall back to the floor. This process is repeated for several hours.)

At the end of the New Shepard trip, the capsule releases parachutes and then gently lands back on the ground using its own rockets. There is no need for a splashdown in the ocean. And unlike the space shuttle, it has a safety system so that you can be ejected from the rocket if there is a misfire during launch. (The space shuttle *Challenger* did not have such an ejection system, and seven astronauts died.)

Blue Origin has not yet released the price tag for this suborbital trip into space, but analysts think initially it could be in the neighborhood of $200,000 per passenger. This is the price of a trip on a rival suborbital rocket being developed by Richard Branson, another billionaire who has made his mark

In the 1990s, an unexpected discovery caught scientists by surprise: the presence of large quantities of ice in the southern hemisphere of the moon. There, in the shadows of large mountain ranges and craters, is a perpetual darkness that is below freezing. The origin of this ice is probably cometary impacts in the early history of the solar system. Comets are mainly made of ice, dust, and rock, so any comet that strikes the moon in one of these shadows might leave a deposit of water and ice. The water, in turn, can be turned into oxygen and hydrogen (which happen to be the principal components of rocket fuel). This could turn the moon into a cosmic gas station. The water could also be purified for drinking purposes or used to create small-scale agricultural farms.

In fact, another group of Silicon Valley entrepreneurs has created a company called Moon Express to begin the process of mining ice from the moon. It is the first company ever to get permission from the government to begin this commercial enterprise. The preliminary target for Moon Express is, however, more modest. The company will begin by putting a lunar rover on the moon that will systematically search for the presence of ice deposits. The company has already raised enough money through private funding to proceed with this mission. With the financing in place, all systems are go.

Scientists have analyzed the moon rocks brought back by the Apollo astronauts and believe there may be other economically significant elements on the moon. Rare earth elements are crucial for the electronics industry but are mostly found in China. (Rare earths are located everywhere in small quantities, but the Chinese rare earth industry makes

up 97 percent of the world trade. China has roughly 30 percent of the world's reserves.) A few years ago, an international trade war almost erupted when Chinese suppliers abruptly raised prices on these key elements, and the world suddenly realized that China had a near monopoly. It is estimated that the supply will begin to be depleted in the coming decades, making it urgent to find alternate sources. Rare earths have been found in moon rocks, so one day it may be cost-effective to extract them from the moon. Platinum is another important element for the electronics industry, and the presence of platinum-like minerals, perhaps left over from ancient asteroid impacts, has also been detected on the moon.

Finally, there is the possibility of finding helium-3, which is useful in fusion reactions. When hydrogen atoms are combined at the extremely high temperatures found in these reactions, the hydrogen nuclei fuse, creating helium, plus large amounts of energy and heat. This excess energy is useful to power machines. However, this process also produces copious quantities of neutrons, which are dangerous. The advantage of the fusion process involving helium-3 is that it instead releases an excess proton, which can be handled more easily and deflected by electromagnetic fields. Fusion reactors are still highly experimental, and so far, none exist on Earth. But if they are successfully developed, helium-3 could be mined from the moon to supply fuel for the fusion reactors of the future.

But this also raises a tricky point: Is it legal to mine the moon? Or to stake a claim there?

In 1967, the United States, Soviet Union, and many other nations signed the Outer Space Treaty, which banned nations

from claiming ownership of celestial bodies like the moon. It banned nuclear weapons from Earth orbit and from being placed on the moon or elsewhere in space. The testing of these weapons was also prohibited. The Outer Space Treaty, the first and only one of its kind, holds to this day.

However, the treaty said nothing about private ownership of land or the use of the moon for commercial activities, probably because those who drafted it didn't believe private individuals would ever be able to reach the moon. But these matters must be addressed soon, especially now that the price of space travel is dropping and billionaires want to commercialize outer space.

The Chinese have announced that they will put their astronauts on the moon by 2025. If they plant their flag, it will largely be symbolic. But what happens if some private developer stakes a claim to the moon after arriving on his or her private spaceship?

Once these technical and political issues are settled, the next question is, What will it be like to actually live on the moon?

LIVING ON THE MOON

Our original astronauts only spent brief periods of time on the moon, usually a few days. To create the first manned outposts, future astronauts would have to spend extended time there. They would need to adjust to lunar conditions, which, as you can imagine, are quite different from the Earth's.

One factor that limits how long our astronauts can stay on the moon is the availability of food, water, and air, since they would exhaust the supplies that they carry with them within

a matter of weeks. In the beginning, everything would have to be shipped from the Earth. Unmanned lunar probes would have to be sent every few weeks to resupply the station. These shipments would become a lifeline for the astronauts, so any accident involving them could present an emergency. Once a moon base is constructed, even a temporary one, one of the first endeavors for the astronauts might be to create oxygen for breathing and for growing their own food. There are a number of chemical reactions that can produce oxygen, and the presence of water creates a ready supply. And this water could also be used in hydroponic gardens to grow crops.

Fortunately, communication with the Earth would not pose much of a problem, since it only takes a little more than a second for a radio signal to reach the Earth from the moon. Apart from a slight delay, astronauts would be able to use their cell phones and the internet like they do on Earth, so they could be in constant contact with their loved ones and receive the latest news.

Initially, our astronauts would have to live inside the space capsule. When they venture out, the first order of business would be to unfurl large solar panels to harvest energy. Since one lunar day corresponds to one Earth month, any site on the moon has two weeks of daylight followed by two weeks of darkness. So they would need large banks of batteries to store the electrical energy harvested during the two-week "day" for use during the long "night" that follows.

Once on the moon, the astronauts might want to travel to the poles for several reasons. There are peaks in the polar regions where the sun never sets, so a solar farm with thousands of solar panels could create a steady supply of