SPACEFARERS

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How Humans Will Settle the Moon, Mars, and Beyond

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For my daughter Lin, because hers will be the first generation
to see this stuff happen. And for my wife, Suzumi,
a boundless source of insight and inspiration.

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Introduction

Pre-Launch

Living on a planet or moon far beyond the safe confines of Earth seems a cinch when you have a good animator on your team. Parachutes open and engines fire flawlessly, allowing your spacecraft to sweetly kiss the soft alien regolith, pleasantly free from menacing boulders, cliffs, and canyons. A ground shuttle is available to whisk you to the newly established base a few kilometers from the spaceport with efficiency rivaling a Japanese train. There, the scene is abuzz with able workers busily doing their part—digging, probing, pointing, building, transporting—all as happy as whistling dwarfs. You pass alongside massive, golden-lit domes housing a veritable Garden of Eden, where vegetables grow lush and blight-free. You then step lightly over the threshold into the pressurized habitat, with hardly a thought for the months-long treacherous voyage you took through a soup of cosmic radiation in bone-whittling microgravity. And, when you finally make it to your stylish living quarters, you lie back on your bed and think, gee, if only everything worked this well back home.

Most plans for space settlements look this good on paper and in the animated videos. But the devil is in the details. Mars, should

that be your destination, is as frigid and lifeless as the Earth's South Pole, only without the luxury of breathable air. Despite claims that we could go to Mars today with current technology, much still needs to be worked out to ensure this wouldn't be a suicide mission. The formidable solar and cosmic radiation exposure that travelers would encounter during the nine-month flight to Mars (as well as during the return) is considered by some scientists to be a showstopper. Landing safely on the red planet remains a dicey proposition; the majority of landers we have sent have failed. Converting carbon dioxide in the Martian atmosphere to oxygen—robotically, in advance of our arrival—and storing it in pressurized tanks for astronauts when they get there is an untested technology. The same goes for extracting water and fuel in situ for the return trip—feasible, but difficult to pull off even on Earth. And growing potatoes? Alas, the Martian "soil" likely contains toxic levels of perchlorate that would need to be removed—again, by a technology still under development.

The Moon, although much closer to Earth than Mars, is no tiptoe through the tulips. The radical temperature fluctuation—from minus to positive 120 degrees Celsius (250 degrees Fahrenheit) between the two-week-long night and day on the lunar surface—makes for a challenging long-term stay. And then there's all that solar and cosmic radiation showering down on the surface. Plans to deal with these challenges include sending a robot to build protective domes for shelter made from the lunar regolith, an unproven technology. And then? Well, as they say, Rome wasn't built in a day.

Thinking big is important. I began writing this book in the early spring, when my small garden plot was weed-free and redolent with the smell of rich, dark-brown dirt, evenly spread in neat squares. With a dozen or so packets of seeds in my hands, a ver-

dant future lay before me. Much like the astronomy animators, I had it all mapped out. The sunchokes will go there, I said, in the back on the north side, because they are the tallest. I'll plant the beans just in front of them so that they can use the sunchokes as a natural trellis. So clever. I'll plant fava beans, too, because they are so tasty yet so expensive in the stores. In the front I'll plant leafy greens in succession, week by week, which will produce a daily salad straight through to the fall. Tomatoes. You gotta have tomatoes. And big winter squash, like one of those massive blue Hubbards that taste great and store so well. Perfect.

Then came an unusually cold April, colder than March, that killed half of what I had planted, followed by an unusually wet May that washed out nearly the rest. And you know what's funny about winter squash? Apparently, there's this little creature called the squash vine borer, *Melittia cucurbitae,* a species of moth that lays its eggs on the base of a well-developed squash vine in early July so that its larvae can feed safely inside the vine and reach maturity as they kill the entire plant before it can bear fruit. They seem to violate a basic tenet of biology by wiping out the very food source that they will need to rely on during the next season. Who knew?

I relay my garden woes partly as catharsis, yes, but mostly as an example of how often things don't go as planned, despite research and preparations. The unexpected occurs reliably, be it unusual weather, such as a month-long dust storm on Mars kicking up during crucial assembly of habitats, or a fly in the ointment, such as an undetected chemical blocking an essential biological reaction from taking place. NASA had its share of the unexpected in the eight-year rush to place humans on the Moon. The Apollo 1 mission ended tragically for astronauts Gus Grissom, Ed White, and Roger Chaffee when a tiny spark in a high-pressure, pure oxygen capsule environment grew instantly into an unescapable

fireball—a design flaw that no one had realized was there. NASA administrators later confessed to being lucky that Apollo 11 ever succeeded; Neil Armstrong had to unexpectedly manually steer the *Eagle* lander away from boulders to a smooth landing site with less than thirty seconds of fuel left.

Apollo 13 astronauts never landed on the Moon as intended. An oxygen tank exploded en route, an accident that would have proved fatal if not for the quick thinking and skilled actions of both crew and mission control. Yet another group of Apollo astronauts just missed a large solar flare that could have poisoned them with radiation. Many space enthusiasts are on NASA's case about not getting us to Mars, as if that were the space agency's sole raison d'être. But despite the agency's flaws, which I don't shy away from enumerating in this book, NASA isn't rushing to place humans on Mars because, reasonably enough, it doesn't want anyone dying out there. You can't launch humans to Mars on a tank of hope. We can and should go to Mars only when the risks and costs are minimized, for there is no imperative demanding immediate action. Right now, the voyage is dangerous, and the cost is exorbitant.

The monumental accomplishment of placing humans on the Moon in 1969 set, for some, unrealistic expectations of what would follow. Pick up any popular space book from the 1970s, and you'll conclude that we should have been to Mars a long time ago. Mars was to be the natural, next step after NASA astronaut Alan Shepard played golf on the lunar surface in 1971, cocky as that was. After all, the Americans and Soviets were sending probes to Mercury, Venus, and Mars by this point, and there was a US space shuttle project in the works with planned twice-monthly flights into orbit. Thomas Paine, who led NASA from March 1969 to September 1970, put a date for Mars on the table: a human spaceflight to Mars with a crew of twelve, to depart Earth on November 12, 1981, powered by a nuclear rocket.[1] Meanwhile, physicists, engineers,

and members of the US Congress were holding serious conversations about massive, orbiting spheres to be built in the 1980s that could house more than 10,000 people apiece. The orbiting space residents' primary occupation would be harvesting solar energy to beam down to Earth, weaning the world of its oil dependency. We'd be mining asteroids and living on Mars by the 1990s. The moons of Jupiter and Saturn would be explored by humans by the year 2000.

So, a half century after the first moon landing, why aren't we living "out there" or making entry into space safe and affordable? Many factors are at play, which this book will elaborate on. First, some grounding is needed.

The Kennedy You Never Knew

Some place the blame for our lack of a sizeable presence in space on US president Richard Nixon, who requested a slash in NASA's budget, which at its peak during the Johnson administration in 1966 was an extraordinary 4.3 percent of the federal budget. The NASA allotment had fallen to about 1 percent of the federal budget by the time Nixon left office and has continued to fall, to below a half percent in 2019.[2] It was as if we had invested in the railroad and Nixon tore up the tracks. There's some kernel of truth to this. Historians have documented how landing on the Moon was John F. Kennedy's legacy, carried through by Lyndon Johnson, and that Nixon didn't want to extend that legacy. Scouring through Nixon's archival materials related to NASA, John Logsdon, the director of the Space Policy Institute at George Washington University from 1987 to 2008, neatly summarized Nixon's space strategy as (1) demoting NASA from the sacred position it held in the 1960s to just another domestic program required to compete for funds; (2) reining in human spaceflight to low-earth orbit, within 200

miles of Earth's surface; and (3) focusing on a space shuttle program with no specific goal, forgoing development of large rockets capable of sending humans to the Moon and beyond.[3] Logsdon, in his book *After Apollo?: Richard Nixon and the American Space Program,* noted that Nixon was deeply shaken by the near-fatal events of Apollo 13 caused by a ruptured oxygen tank—so much so that he attempted (in vain) to cancel the Apollo 16 and 17 missions ahead of the 1972 presidential election, fearing that tragedy was inevitable and the criticism would doom his reelection bid.[4]

One should not castigate Nixon, though, whose primary concern was fiscal responsibility. Moreover, focusing on near-Earth activities, as opposed to shooting off to Mars, isn't a poor strategy if the goal is to learn how to more efficiently leave and return to Earth. It was Kennedy, actually, who told NASA administrator James Webb in the Oval Office in November 1962, just two months after his famous Moon speech at Rice University calling for a human Moon landing by the end of the decade, "I'm not that interested in space." This statement lays bare how he and other leaders really viewed the Moon missions back then, and it hints at why there are no Moon villages today. We could have been in a race to the center of the Earth, for all Kennedy cared, because apparently the race to the Moon, in his mind, had no other purpose than "to beat [the Soviet Union] and demonstrate that starting behind it, as we did by a couple of years, by God we passed them," as he said to Webb. "I think it would be a helluva thing for us."[5] This helluva revelation by the man we thought was gung ho about the Moon was not made fully public until 2009, part of 260 hours of secret recordings that Kennedy made in the Oval Office and Cabinet Room, unbeknownst to even his aides.

The Soviets felt the same way as Kennedy did. For Soviet leadership, space exploration needed to serve a purpose to justify the enormous cost and danger. The purpose for the Soviets was pri-

marily militaristic: rockets that could carry cargo into space could also carry nuclear warheads across the globe.[6] The space race was an extension of the missile-based nuclear arms race between the Soviets and Americans that began after World War II; and, metaphorically, the space race was about establishing the higher ground. With the United States beating the Soviets to a *human* Moon landing, and with no intention by the United States of setting up a military base on the Moon, the Soviets no longer had any reason to pursue the Moon—nor did the United States, by extension.* No leader during the heyday of the space race—not Kennedy, Johnson, Nixon, Khrushchev, or Brezhnev—cared so much about human space exploration as to advocate for billions of dollars or rubles to support it without some practical return in the form of military might or one-upmanship. None of these men were sending humans into space because they believed it was our destiny; there were more pressing matters to invest in, as far as they were concerned. No country can participate indefinitely in a space potlatch with taxpayer money.

Thus, going to the Moon had little to do with going to the Moon. This narrative—that we would go to Mars and beyond after the Moon—was created, in part, by space enthusiasts in the 1960s, swept up by the excitement of the Apollo missions. Naturally, many are disappointed today and view the past fifty years as an utter failure to reach that dream—a dream *they* had, not a dream that was a priority for any leader of the 1960s or 1970s, or even for most of the general public. For many US leaders then, space was interesting, to be sure; but the space race was too expensive to be sustainable or to justify to the American public after the 1969

*A military base on the Moon would serve no strategic purpose for Earth-based warfare for any nation because it would be too far away, too high of a higher ground.

Moon landing was accomplished, particularly with the growing expense of the US conflict in Vietnam. The concept of turning the 1970s into a decade-long Apollo-like march to Mars ended before it began, with Nixon sending clear signals to NASA that the White House wouldn't support it.[7]

In retrospect, it may seem to have been foolish to squander an investment in rocketry, namely the Saturn V, arguably the greatest feat of engineering in modern times. But during the 1960s, three deaths on the launchpad of Apollo 1 laid bare the danger; three near-deaths aboard Apollo 13 had many people questioning this danger and expense in the absence of an apparent purpose, since Americans had already beaten the Soviets to the Moon the year before. Even during the peak excitement in 1969, the majority of Americans did not think their country should be spending so much money on space activities.[8] The Moon and other deep-space destinations simply offered no military importance or economic potential around 1972, when the Apollo program was canceled, to justify the continued danger and expense of human exploration. The tax-paying public and the politicians representing them were coming to this understanding. Even most scientists preferred robotic lunar exploration over sending humans to the Moon.

Post-Apollo Missteps

For many a space enthusiast, it nevertheless remains incomprehensible that, a half century after landing on the Moon, all we have today in terms of human space exploration is six or seven astronauts in a tin can of a space station a few miles above Earth maintaining ant colonies and doing flips for schoolchildren. No one in 1970 could have predicted such limited human presence in space in the twenty-first century. Yes, access to space is staggeringly expensive, which

has limited the commercial investment in human spaceflight. And yes, there was no compelling reason for humans to be in space in the 1970s, other than for the sheer joy of exploration. That said, the International Space Station? Come on. Is that all there is?

Clearly there were missteps after Apollo that curtailed human activity in low-earth orbit—mistakes that we are living with today. Call it either naïveté or pure hubris, but human space exploration turned out to be much more difficult and expensive than we ever anticipated. The unexpected began to reveal itself in ugly, exorbitant ways. The Nixon administration had a desire to create a fleet of vehicles to lift satellites into low-earth orbit at a relatively low cost, in line with the fiscal realities of the time. "We must . . . realize that space expenditures must take their proper place within a rigorous system of national priorities," Nixon said in March 1970, just a few months after the successful Apollo 11 and 12 missions and a month before the ill-fated Apollo 13. "What we do in space from here on in must become a normal and regular part of our national life and must therefore be planned in conjunction with all of the other undertakings which are also important to us."[9]

Unfortunately, the "normal and regular" Nixon spoke of ended up as an inefficient bureaucracy, a government-funded space program that lacked the necessary directives, fiscal discipline, and managerial leadership to deliver results. The space shuttle program that originated in the early 1970s devolved from the bold promise of a cheap, biweekly, low-orbit ferry into a horrifically expensive fleet of rocket-dependent vehicles averaging only about four flights per year, with two of the five shuttles exploding and killing the crew. The shuttle program's greatest flaw was its emphasis on reusability, necessitating a level of maintenance that proved to be costlier and more time-consuming than using expendable rockets. This led to fewer launches, which further lowered the

cost efficiency. As the shuttle was to be NASA's primary launch mechanism, many subsequent projects suffered. Satellites designed for the specific dimensions and weight allowances of the shuttle's cargo bay were postponed or canceled. Cost overruns resulted in less funding for research and development for better rocket technologies, creating a negative cycle that led to NASA's access to space growing more and more expensive, not cheaper. Forget Mars. Forget the Moon, for that matter.

The United States continues to pay dearly today for the shuttle program, quite literally, as the nation lost its ability to place humans in space in 2011 with the retirement of the remaining three space shuttles. As a result, the United States must pay Russia $80 million to fly a single US astronaut into space. Similarly, the International Space Station (ISS) that originated in the early 1980s as "Space Station *Freedom*" for an estimated $8 billion ballooned into a $100-billion venture despite its modest size, having only enough room for seven visitors—a far cry from orbiting cities for 10,000 people that many thought could be built for a similar price.[10] The higher cost of the ISS was driven by the higher cost of the shuttle launches, as well as by poor design and management.

What are the chances of NASA taking us to Mars today or tomorrow, given the agency's post-Apollo performance in the realm of human spaceflight? Many politicians who control purse strings have lost patience with funding dreams that turn into fiscal nightmares, projects that grow so expensive that one debates the merits of canceling them before completion to cease the endless cost overruns. Moreover, in the United States, executive leadership changes every four to eight years, and NASA has had to continually change gears to accommodate the opposing whims of each new administration. As a result, a human flight to Mars has always been "two decades away," from 1970 onward. Indeed, as of the

publication of this book (2020), NASA has a plan for sending humans to Mars in, you guessed it, two decades.

Given the expense of working or playing in space, coupled with the examples of how NASA managed its last two human-spaceflight programs, what's needed to get and stay in orbit is a sound business plan. And that, finally, is what's emerging. That's what sets this moment apart from 1970, 1980, 1990, and 2000, when routine human spaceflight was more dream than practicality. There are now so many non-NASA players in the human spaceflight game that it is difficult to keep up with all the tangible developments. Whereas before we had only advances in animation to make it look easy, today we have commercial investment and actual products.

What It *Really* Takes to Return for Good

The leading spacefaring nations likely could set up a permanent village on the Moon or Mars within ten years from now. Such a feat, though, requires a major effort; a major effort requires a major financial commitment; and a major financial commitment requires a sound reason. So, what's the reason for human space exploration on celestial bodies? We can't do this just because it's neat. Neat isn't a sound reason. Many futurists and space enthusiasts have been reluctant to probe this critical question. Their vision of the future places us on the Moon, Mars, and clear out to the Kuiper Belt, immersed in nifty technology, none necessarily breaking laws of physics. But few ever delve into *why* we would initiate this, *who* would pay for it, and *how.*

If history can be a guide, nations or individuals will part with large sums of cash for big projects for three reasons: praise of deity or royalty, war, or the promise of economic return. The

astrophysicist Neil deGrasse Tyson, director of the Hayden Planetarium in New York, introduced this concept in an essay titled "Paths to Discovery."[11]

Praise of deity is what got us the pyramids and cathedrals; similarly, kings built palaces for their own sense of grandeur. Although neither type of project is seen much these days, war remains a familiar investment. The United States has spent more than $4.79 trillion on wars it has initiated in Iraq, Afghanistan, and related insurgencies since 2003, the price tag of at least forty massive missions to Mars, easily enough to establish a permanent space settlement there.[12] Historically, the Great Wall of China was big and expensive, but crucial from a military perspective. Other war-related projects include the Manhattan Project, the US Interstate Highway System (built to accommodate the transport of military equipment, if needed), and the aforementioned Apollo program. These modern military expenditures spurred economic development. But nevertheless, their purpose was militaristic.

Promise of economic return funded the likes of the Panama Canal and the journeys of Columbus, Magellan, and Lewis and Clark. Governments provided money for exploration with the hope of profit. Columbus was funded by the Crown of Castile not to prove that humans can overcome obstacles (that it is "in our DNA") but rather, primarily, to establish a profitable trade route—and to expand Catholicism (praise of deity) and to beat Portugal (military).

Our renewed interest in human activity in space may actually lead to a permanent presence out there because it is being driven in part by "war," but also by the promise of economic return. This is different from the situation in the 1960s, when war was the sole driver. A war might get us to the Moon or Mars; economic sustainability will keep us there.

War and Profits

War, you may ask? That's right, a new space race is upon us. China's clearly articulated ambitions in space—they have their own space stations (plural) and rockets to take humans there—is prompting the United States and other nations to return to the Moon to establish permanent bases by 2030. If China suddenly proposed a Mars-based settlement by 2032, the United States would strive to place its own there by 2031 and would find the money to do so. There is *currently* no political will to spend $100 billion to place four elite people on the surface of Mars for a few months, as there might be to spend that amount on, say, a missile defense system to keep three hundred million US citizens safe. But priorities would change quickly, should China throw down the gauntlet, as Russia did with Sputnik in 1957.

As for economic return, there are *near-certain* profits to be had in low-earth orbit and *possible* profits to be had on the Moon in the form of tourism and resource mining. The extent of these activities and degree of profit will depend on lowering the cost of access to space so that the return on investment becomes more attractive—something the new space race could help with. Investors are hoping for a snowball effect in which cheaper access to space brings more people there, further lowering the price while a space infrastructure grows. The rocket company SpaceX may be among the best known in the NewSpace scene, but dozens of private firms are building smaller and more economical rockets, miniature satellites called nanosats, and various components and services to accommodate the expected increased human activity in space in the hands of industry.★

★Yes, NewSpace is a thing; and the fact that there's a term in camelCase differentiating the emerging private spaceflight industry from Old Space

Admittedly, there is greater uncertainty for profit beyond the Moon. Unlike the situation in 1492, when Queen Isabella had a sense of a potential market to be exploited by better trade routes, Mars has precious little to make it a profitable colony, at least as things now stand. High cost, high risk, and low return on investment does not make for a viable business strategy. But lower the cost and lower the risk, and then there's a *possibility* of settling on Mars and establishing trade, particularly if a war-driven space race between the United States and China paves the way. Wheels are in motion; engines are firing.

All of this governmental and commercial activity—with companies actually making money business-to-business, not solely with government contracts—reveals not just the hope but an expectation that we will very soon create a viable space-based economy. Although humans have not ventured far from Earth in the past fifty years, we nevertheless have learned and accomplished much. We have placed several automated rovers on the surface of Mars and a multitude of satellites in orbit there, and we have greatly expanded our understanding of the Martian environment to a point that we better fathom the difficulties of living there. We have also successfully landed a probe on Titan, a moon of Saturn twenty-five times more distant from Earth than Mars is, a mind-blowing feat.

In short, we are reaping the fruits of labor led by NASA and the Soviet-cum-Russian space agency from the past fifty years. Wealthy individuals already have purchased tickets to be blasted into space, docked to an orbiting hotel, or shot around the Moon, starting in the 2020s.

Governments plan to outsource space transport to private industry to send researchers to live on the Moon for months at a

(governments and their primary contractors) further highlights how much things are different today.

time, as we do now in Antarctica. Private industry plans to follow, tapping lunar resources for profit. Mars will be in the near offing, as the space infrastructure expands to support it.

The Voyage Has Begun

This book explains how this development will unfold—an exploration of the practical motivating factors for settling new worlds and the earnest plans of engineers, scientists, and entrepreneurs striving to make this a reality. I do not wish to instill false hope and spew whimsical nonsense about teleporting, traveling at warp speeds, or living off-Earth in greater luxury than living on Earth. There can be nothing instant or magical in the establishment of space infrastructure. Human space activity will be fraught with challenges, from the economic to the physical and biological. At its core, though, our presence in space will be a natural extension of what we do now, every day, in terms of science, business, and leisure, to the extent that biology and economy can allow.

The voyage begins on Earth. Chapter 1 explores the three most space-like environments on our home planet: Antarctica, where hardy workers soldier through six months of frigid darkness with no new supply deliveries; nuclear submarines, where navy personnel live in self-contained isolation for months at a time; and high desert plateaus, where scientists try to simulate Martian habitats. What lessons have we learned so far? Chapter 2 prepares for our travels with a medical reality checkup, because the lack of gravity and abundance of cosmic radiation doesn't bode well for long-term survival. Can we overcome these challenges? Chapter 3 jumps into low-earth orbit. What plans are afoot to replace the International Space Station, which some see as a marvel of technology and others see as a colossal lost opportunity and waste of money? How will inflatable habitats provide space tourists with weeklong thrills and set the stage

for more permanent structures to house space workers and permanent settlers? How will we get into space: with traditional rockets or perhaps space elevators, space hooks, and other clever ideas?

Chapter 4 places us back on the Moon, where scientific bases will surely mimic the settlements on Antarctica and where mining and even tourism could make the venture very profitable. Following the money, Chapter 5 takes us to the next inevitable step into the Solar System, mining asteroids.

Chapter 6 features Mars, the source of endless fascination. Mars may be the first Solar System body that's actually settled by humans with the intent of raising families there, as opposed to the scientific and mining activities on the Moon. The close of the twenty-first century may see humans spread across the local Solar System, from Earth to the Moon and to Mars. By this time, we may begin to venture deeper into the Solar System to the moons of Jupiter and Saturn, which could harbor life and which could sustain small scientific bases. Closer to the Sun, Mercury is surprisingly habitable with advanced technology, while Venus is in some ways the most habitable planet in the Solar System aside from Earth, as long as you live in floatable cities above the clouds there.

Perfecting ways to live on Mercury or the moons of Jupiter and Saturn sets the stage for deep-space travel to the outer planets of Uranus and Neptune; the minor planets beyond, such as Pluto; and the icy rocks of the Kuiper Belt. I discuss all of these concepts in Chapter 7, along with the notion of space arks made of comets or asteroids to take us to other stars—perhaps our destiny hundreds of years from now. The Epilogue brings us back to Earth at a time when colonies are established throughout the Solar System. How will life on the mother planet change as a result?

So, let us now boldly, but prudently, go where no one has gone before.

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