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The Return of the Space Visionaries

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In 1969, the year that astronauts first walked on the Moon, Princeton physics professor Gerard K. O'Neill, "almost as a joke," posed a theoretical exercise for his students: Is Planet Earth the best location for a growing techno-industrial civilization? Working through calculations with them, he came to conclude that Earth is indeed not the best location—that other planets, and space itself, would be a better venue for an expanding technological species, offering more energy and raw materials, and risking less pollution of our home planet. "As sometimes happens in the hard sciences," he later explained in an article in *Physics Today*, "what began as a joke had to be taken more seriously when the numbers began to come out right."

O'Neill expanded the ideas into the now-classic 1977 book *The High Frontier*. It imagined large spinning habitats built from lunar materials and housing thousands of people. It would be paid for by selling power, using huge arrays, also from lunar materials, to collect sunlight and beam it down to Earth in the form of microwaves. Most industrial activity would be moved off of the home planet, which would become a giant nature park for both inhabitants and tourists visiting from space.

The idea inspired a movement. The L-5 Society—named for one of the stable points equidistant from the Earth and the Moon in the lunar orbital plane, where O'Neill envisioned the habitats might reside—was founded in 1975 to advocate for his vision. Its (now clearly optimistic) slogan was "L5 in '95!" Conferences held at Princeton and a summer study at NASA Ames Research Center, in Mountain View, California, subsequently helped to flesh out concepts on orbital mechanics, how to use the lunar resources recently discovered by Apollo, how to build closed-cycle life-support systems, legal and policy questions, and space-construction techniques.

Against the context of the more measured NASA aspirations we're familiar with—the blink-and-you'll-miss-it moonwalks, astronauts tinkering in low Earth orbit for decades, and far-reaching but uncrewed planetary probes—O'Neill's vision may sound like a pie-in-the-sky

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aberration. That was indeed how it struck many of his post-Apollo-era contemporaries. Asked about the possibility of federal funding for O'Neill's ideas, Wisconsin Senator William Proxmire famously said, "Not a penny for this nutty fantasy."

Yet O'Neill's vision is strikingly similar to the ones being offered by today's aspiring space tycoons, most notably Elon Musk, founder of Space Exploration Technologies (SpaceX), and Jeff Bezos, founder of Blue Origin. Musk, though focused like a laser on Mars, talks about "Making Humans a Multi-Planetary Species," as the title of a technical article he published last year put it. Bezos, for his part, doesn't confine his ambition even to settling other planets. His stated long-term goal is to get millions of people off of Earth, where they can pursue their own dreams, whatever those may be, whether on other planets or in permanent settlements in space itself. This May, he received the Gerard K. O'Neill Memorial Award for Space Settlement Advocacy from the National Space Society. In an interview given just after accepting the award, he expounded on his O'Neillian vision of a trillion people living in the solar system. In keeping with the theme, he also announced, with some of the show's cast in attendance, that he was saving from cancellation the science-fiction series *The Expanse* by having Amazon Prime take over its production from the SyFy Channel. The series, popular with the science-fiction community, depicts human settlement of the solar system and offers a realistic treatment of how the laws of physics would constrain such an endeavor.

Like O'Neill's movement, democratization is also a key goal of today's space tycoons. Physicist Freeman Dyson, a colleague of O'Neill's at Princeton, argued in 1978 that to avoid being "a luxury that only governments could afford," the cost of space colonization must be lowered to about $40,000 per person, which "would make it comparable to the colonization of America." That figure translates into about $150,000 today. Both the rationale and the dollar figure are strikingly similar to Elon Musk's argument that, in order for mass resettlement to Mars to be viable, the cost per person must become comparable to buying a house—a median of about $200,000 in the United States.

Despite some differences in approach, Musk and Bezos together represent a sharp departure from the conventional approach of America's public space program, which has always been more limited, focused on science and exploration, not human settlement, and has operated on the assumption that only big-government funding and organization could send humans to space. But a look at the history of ideas about space travel, going back much further than O'Neill and Dyson, shows that Musk

and Bezos are in fact returning to a longer tradition of dreaming about humanity's future in space—a tradition that, fittingly, is now coming to fruition in America. Musk and Bezos are on the cusp of fulfilling the dreams many others have had of settling space, and of making space travel commercially viable—neither of which Apollo, much less its middling low-Earth-orbit successors, were able to achieve, despite the tragically failed attempt to do so with the space shuttle. Indeed, Bezos and the foreign-born Musk, combining personal dreams with technical prowess and bold entrepreneurship, are much more thoroughly American in their visions than even America's own government-run space program.

With the Trump administration so far appearing more favorable than any previous administration toward the dreams of space entrepreneurs, there are a myriad of signs that the Apollo model—driven as it was by Cold War goals rather than by visions of the human future—will be the exception, not the rule, for how travel to other worlds will be achieved. And our new era in space will look much more like the dreams of early space visionaries, and of more recent supposed fantasists like O'Neill and Dyson, all of whom foresaw a broad, sustained, and prosperous human inhabitance far beyond Earth.

Early Space Visions

While humans have surely been gazing in wonder at the stars since the dawn of our existence, it has been for only a little over a century, after modern telescopes gave us a better sense of what lay in the heavens, that people started to dream of actually leaving the planet to head out toward them, and settle outer space itself.

In 1894, the American inventor and real-estate magnate John Jacob Astor IV (who later died heroically in the sinking of the *Titanic*) wrote the science-fiction novel *Journey in Other Worlds: A Romance of the Future*, depicting life on Saturn and Jupiter in the year 2000. One character in the book enthuses:

> We are all tired of being stuck to this cosmical speck, with its monotonous ocean, leaden sky, and single moon that is useless more than half the time, while its size is so microscopic compared with the universe that we can traverse its great circle in four days. Its possibilities are exhausted; and just as Greece became too small for the civilization of the Greeks, and as reproduction is growth beyond the individual, so it seems to me that the future glory of the human race lies in exploring at least the solar system, without waiting to become shades.

Astor's fictional character probably overstates the number of us who share his viewpoint, but it is one of the earliest known visions of space settlement.

A quarter century later, H. G. Wells saw the conclusion of the First World War as an occasion for optimism. He speculated that humanity might turn away from its recent bloodletting, adopting a global government and using its new technological powers to usher in a new era of history. In *The Outline of History* (1919–1920), Wells prophesied, "Life, for ever dying to be born afresh, for ever young and eager, will presently stand upon earth as upon a footstool, and stretch out its realm amidst the stars."

In 1929, Irish author J. D. Bernal wrote *The World, the Flesh and the Devil*, a work that science-fiction luminary Arthur C. Clarke later called "the most brilliant attempt at scientific prediction ever made." Bernal imagined space settlements on the inside surface of spherical shells, with tens of thousands of people inhabiting each, and speculated—indeed with brilliant prescience—about the use of solar energy, repair bases in space, and multi-stage settlement:

> On earth, even if we should use all the solar energy which we receive, we should still be wasting all but one two-billionths of the energy that the sun gives out. Consequently, when we have learnt to live on this solar energy and also to emancipate ourselves from the earth's surface, the possibilities of the spread of humanity will be multiplied accordingly.

In a subtly warier tone than Wells of a decade before, Bernal foresaw that "at first space navigators, and then scientists whose observations would be best conducted outside the earth, and then finally those who for any reason were dissatisfied with earthly conditions would come to inhabit these bases and found permanent spatial colonies."

Rocket Men

Probably the earliest person to have a vision of space settlement anchored in known physics—and to contribute to its technical realization—was the Russian schoolteacher and engineer Konstantin Tsiolkovsky, born in 1857. He is remembered as one the fathers of rocketry, and for the line "Earth is the cradle of humanity, but one cannot remain in the cradle forever."

Tsiolkovsky envisioned space settlements and, inspired by the radical new steel structure in Paris designed by Gustave Eiffel, space elevators

between Earth's equator and a geosynchronous orbit thousands of miles above it. He thought through the issues associated with habitats in a vacuum, and developed the concepts of airlocks and closed-cycle biological environments that could provide food and oxygen for residents of space colonies.

With a lifelong interest in mathematics and physics, he was also one of the first to work out the mathematics of rocketry. In 1903 he derived the exponential rocket equation, since named for him, that dictates how much velocity change one can get for a given amount of propellant, and the associated need for multi-stage rockets.

Tsiolkovsky's work was soon replicated by the American physics professor Robert H. Goddard. After learning physics, Goddard independently derived the rocket equation (Tsiolkovsky's work hadn't yet been disseminated outside of Russia), and published his seminal paper, *A Method of Reaching Extreme Altitudes*, in 1919. As told in Milton Lehman's 1963 biography *This High Man*, Goddard recalled how as a youth he was inspired by a vision on his family's farm in Massachusetts:

> On this day I climbed a tall cherry tree at the back of the barn…and as I looked toward the fields at the east, I imagined how wonderful it would be to make some device which had even the *possibility* of ascending to Mars, and how it would look on a small scale, if sent up from the meadow at my feet.…I was a different boy when I descended the tree from when I ascended. Existence at last seemed very purposive.

Goddard pioneered designs for rockets and actual working models, launching the first liquid-fueled rocket in 1926, a major milestone. Nevertheless, he was ridiculed in 1920 by the *New York Times* editorial board for the foolishness of suggesting rockets could work in space, in ignorance "of the need to have something better than a vacuum against which to react." Long after Goddard's death, three days before the first lunar landing, the astronauts well on their way to the Moon, the *Times* would offer an apology: "It is now definitely established that a rocket can function in a vacuum as well as in an atmosphere. The Times regrets the error."

Around the same time as Tsiolkovsky and Goddard were doing their work, similar ideas were being developed by a young physicist named Hermann Oberth, who was born in the Austro-Hungarian Empire but studied for his doctorate in physics in Germany. Inspired by Frenchman Jules Verne's radical new science fiction about voyages to the Moon, Oberth designed his own model rocket in 1909 at the age of fourteen.

In the 1920s, he wrote two books exploring his ideas on interplanetary rockets, *The Rocket into Planetary Space* and *Ways to Spaceflight*. The notion had earlier been rejected when he'd submitted it as a thesis proposal for his doctorate.

In Germany, the Verein für Raumschiffahrt—the Society for Space Travel—was founded in 1927, inspired in part by the work of Oberth, who became a member. Another member was the young aristocratic engineering student Wernher von Braun, who had dreams of human voyages to Mars. He and many other amateur rocketeers eventually became swept up in Hitler's program to build the V-2 rockets that bombarded Antwerp and London in 1944.

But von Braun never lost his dream. At the end of the war, he took several of his team and headed west toward Allied lines to escape the advancing Soviets and surrender to the Americans, in hopes that he would have better prospects to achieve his space dreams with them. At first, he was again put to work on ballistic missiles, but with the advent of the U.S. space program in the late 1950s, he was finally able to start applying his engineering and managerial talents, first to satellite launch, then to human spaceflight.

Another German engineer, Krafft Ehricke, was inspired by Fritz Lang's now-classic 1929 film *Woman in the Moon*. Like von Braun, he escaped to the West to avoid capture by the Soviets and to pursue his space dreams, and in America he became part of von Braun's new team, where he pioneered liquid-oxygen and -hydrogen rocket stages, and later ran his own consulting company focused on commercial applications in space. Ehricke developed an idea that he called "The Extraterrestrial Imperative," about the need for humanity to expand into the universe. He characterized life as a "negentropic" process—that is, one that created order, at least temporarily and locally, against a universe tending toward disorder. He thus viewed the expansion of life, first within the solar system and then to other stars and galaxies, as both inevitable and beneficial. (I was one of his students for an extension course he taught on the subject in the early 1980s at California State University, Northridge, toward the end of his life.)

Similar ideas came in the late 1950s from Princeton's Freeman Dyson—before his later work on the economics of space settlements—who wrote "A Space-Traveler's Manifesto." The essay was a paean to space settlement, and to nuclear propulsion, partly to promote his Orion concept of sequentially detonating small nuclear explosives behind a pusher plate to launch a rocket not only into space but across the solar system:

> It is in the long run essential to the growth of any new and high civilization that small groups of men can escape from their neighbors and from their governments, to go and live as they please in the wilderness. A truly isolated, small, and creative society will never again be possible on this planet.

An even more expansive vision came from Dandridge Cole, a physicist and aerospace engineer sadly cut down in the prime of his career by a heart attack. In the early 1960s, he conceived the idea of *Macrolife*, a sort of higher-level life form composed of a self-contained human colony in space, constituting the next step in evolution.

In 1969, it was conventional wisdom to see Neil Armstrong's first step as indeed a giant leap for mankind—not the end of a journey, but just the beginning of a new phase of human history in which the dreams of these space visionaries would at last come to fruition. But it would become clear in short order how wrong this impression was—that these initial dreams were not fulfilled but rather derailed by the Apollo program.

Three Rival Visions of Humanity's Role in Space

Rick Tumlinson, a longtime space activist and co-founder of the Space Frontier Foundation, argues that there are three general categories of space visionaries: the "Saganites," the "von Braunians," and the "O'Neillians"—after Carl, Wernher, and Gerard, respectively.

Saganites view the universe as a precious jewel. How beautiful! "Look at it—but don't touch it!" Tumlinson quips. Space is for scientific inquiry only, and that is best done by investigating it with robots. Later in life Sagan recognized the value of sending humans to other worlds, but as an astrophysicist and planetary scientist, his goals were focused on science, not economic development or settlement.

Since the end of Apollo, this vision has driven what many considered the "Golden Age of Space Exploration," with probes sent to all the known planets in the solar system, even Pluto. The scientific knowledge gained from these inanimate scouts of the space frontier has provided new insight not only into how to further explore the solar system, but also how we might send humans out to settle and develop that frontier.

For example, water has been called the "oil of the solar system," in that it is crucial both for the support of life and as a key constituent for the efficient rocket propellants of oxygen and hydrogen. The relatively recent discovery of significant quantities of water ice on our own moon means that we can make a good start at both "living off the land" and utilizing it

as propellant to reduce the cost of venturing beyond the Moon, reducing the amount of payload that must be launched from Earth. In fact, we now know that not just ice but liquid water is much more abundant in the solar system than we previously thought; some of the ocean moons of the gas giants Jupiter and Saturn make the "water planet" Earth a comparative desert. Nevertheless, the Saganite vision is focused on *knowing* about the universe but not *using* it.

What Tumlinson calls, perhaps unfairly, the von Braunian vision is akin to what I have called "Apolloism" ("Getting Over 'Apolloism'," Spring/Summer 2016): The government expends massive resources to send a handful of government employees off to explore another planet. It is what most people continue to consider the normal, perhaps only way to do human spaceflight—though Elon Musk, Jeff Bezos, and others are starting to change that perception.

Many have mistakenly interpreted the Apollo program as a natural derivation from a distinctly American vision for humanity's future in space. But Apollo was motivated largely by the Cold War strategy of beating the Soviets, not by any clear vision of human space exploration or settlement. In truth, Apollo was not a derivation from traditional American values but a deviation: In its rushed, centralized bureaucratic approach, and its hero worship, Apollo was much more a Soviet way of doing things. Its purpose was to win a crucial moral and technological battle in an existential war. It was certainly not a plan for the opening of a new frontier, which would have required a far different, more patient, and more cost-effective approach to getting humans into space and on to other worlds.

The O'Neillian vision is one of massive expansion of humanity into space, and it is much more in line with the visions of all who came before the historical anomaly and disruption of Apollo. But by the accident of history in which we first went into and explored space in the Cold War, the dominant visions have been Apolloistic and Saganite, both government-centric, led by NASA. But now, with reduced launch costs, and the growing interest of billionaires—not only Musk and Bezos but the Russian Yuri Milner, who last year announced his plan to send a privately funded probe to Enceladus, a moon of Saturn that we now know has complex organic molecules under the ice in its oceans—we may be returning to an era of astronomy and space science that is funded privately and philanthropically, as most American observatories were prior to World War II.

The O'Neillian vision could also in theory be driven by government, and one of the many straw-man arguments that opponents of massive space settlement use against it is the assumption that it will be funded

by taxpayers. Note again Senator Proxmire's warning, "Not a penny for this nutty fantasy." But it is unrealistic to imagine that there will ever be massive numbers of people going into space at taxpayer expense, at least on any kind of sustained basis in a democracy. It will only happen if they want to go, if they have the financial means to do so, and if, once there, they will be able to continue to pay their way.

In other words, space settlers' activity will of necessity be financially self-sufficient. Despite the criticism of it as outlandishly costly, the radical new approach that O'Neill proposed after Apollo was based on fundamentally economic logic: People living and working in space could provide goods and services that more than compensated for the cost of sending and keeping them there.

The Long Death of Apollo

Because of Apollo's successful proof-of-concept of how to get humans beyond Earth orbit, and the power of its legacy, federal space policy has remained stuck in its mindset, even as the political and budgetary will to back it vanished with Armstrong's first step. The last half-century of NASA plans for voyages to Mars or back to the Moon have thus largely been a series of failed attempts to repeat the 1960s glory days.

In a 1989 speech on the steps of the National Air and Space Museum, President George H. W. Bush laid out a goal of once again sending humans to other bodies in the solar system, most notably Mars. It was called the Space Exploration Initiative (SEI). Its very name carried the seeds of its doom: If the goal is exploration, that can be done much more cost-effectively with robotic space probes.

After the speech, a "90-Day Study" was initiated by NASA. The study's creators solicited input from all of the NASA program administrators on the best way to achieve the goals. Unsurprisingly, the administrators described how each of their programs' work was indispensable, and every existing technology sandbox and project was thrown into the pot. The purpose of the study became not achieving the objective but rather justifying what the agency and its contractors were already doing and, in the face of uncertainty, wanted to continue to do. Cost estimates, as reported by the *New York Times*, put the price tag for going to the Moon and Mars as high as $400 billion. In addition, as Robert Zubrin explained in *The Case for Mars* (1996), NASA leadership itself failed to support the project fully, as it saw the shuttle and space station programs as its only real priorities. And so the initiative was stillborn.

The idea of sending humans to Mars remained off the table through the 1990s. The Clinton administration viewed its space legacy as saving the space station program by a single vote in the House in 1993, in part by deciding to partner with Russia in an attempt to keep Russian engineers out of mischief with countries like Iran and North Korea (which didn't work), and by downscaling the project and changing the name of the space station *Freedom* to the International Space Station (even though it already had Europe, Canada, and Japan as international partners).

U.S. space policy plodded on, visionless and therefore aimless, until February 1, 2003, when the atmosphere sundered the shuttle *Columbia* on entry, scattering the remains of its hull and seven crew over east Texas and Louisiana. It was now clear that the shuttle program had outlived its usefulness, and it was no longer possible to avoid new policy. The following year, President George W. Bush laid one out, called the "Vision for Space Exploration." It was a plan to retire the shuttle in 2010, and to move beyond low Earth orbit for the first time in over three decades, first to the Moon, then on to Mars, with new space transportation systems.

Despite the "e" word in its name, the new plan in fact, for the first time, set policy aims beyond exploration. In a speech in March 2006, the late John Marburger, Bush's science adviser, stated that the vision "subordinates space exploration to the primary goals of scientific, security, and economic interests":

> The Apollo program was what mathematicians call an "existence proof," a demonstration that a problem does have a solution and that efforts to discover its details will not be in vain. Like all firsts, it was unique. No subsequent space endeavor can be quite like it. President Bush's vision also declares the will to lead in space, but it renders the ultimate goal more explicit. And that goal is even grander. The ultimate goal is not to impress others, or merely to explore our planetary system, but to *use* accessible space for the benefit of humankind. It is a goal that is not confined to a decade or a century. Nor is it confined to a single nearby destination, or to a fleeting dash to plant a flag. The idea is to begin preparing now for a future in which the material trapped in the Sun's vicinity is available for incorporation into our way of life.

This was probably the closest description of the O'Neillian vision in any official statement of U.S. space policy up to that time.

Unfortunately, Michael Griffin, whom Bush had appointed as NASA administrator a year earlier, had different plans. When Griffin rolled

out Constellation, his program for implementing the Vision for Space Exploration, he described it as "Apollo on steroids." NASA would build a new giant rocket and capsule to carry out the vision, using legacy hardware from the shuttle and Apollo programs. This returned the Bush vision firmly back to the familiar, with which Griffin probably knew Congress would be more comfortable. But as I wrote in these pages ("A Space Program for the Rest of Us," Summer 2009), the program soon grew out of control, leaving a space-policy mess for the incoming, inexperienced Obama administration to deal with.

Constellation was canceled by the Obama administration in 2010, with a plan to develop commercial capabilities instead. But Congress partially resurrected its aims in the Space Launch System program—a large heavy-lift rocket intended by Congress as a "follow-on launch vehicle to the Space Shuttle"—and in the Orion spacecraft that would take four astronauts beyond low Earth orbit sometime by the early 2020s, according to NASA's current projections. But like Constellation, its replacement remains plagued by budget overruns and schedule slips, and even if it eventually flies, it will do so even more rarely than the space shuttle did, at a cost of billions per flight.

The New Visionaries

The advent of Gerard O'Neill's vision, and the speculation it helped inspire, preceded by just a few years the first flight of the space shuttle in 1981. Many would-be space settlers naively assumed the shuttle would live up to its promise of low-cost routine spaceflight—the original plans called for a shuttle to launch nearly every week. But it was clear by the time *Challenger* was lost in 1986 that it was not going to do so. Fortunately, other developments in the early 1980s would help to sustain the dreams of space settlement, a vision to guide its advocates until they could find the means to realize it.

In 1980 Peter Diamandis—who later went on to found the X Prize Foundation, which offers rewards aimed at spurring major technological breakthroughs—then an M.I.T. undergraduate, co-founded an organization called Students for the Exploration and Development of Space. The following year, he wrote a letter about it to *Omni* magazine, inspiring the founding of chapters at other universities all over the country, including one at O'Neill and Dyson's Princeton. A few years later, a Princeton undergraduate named Jeff Bezos, who was majoring in computer science and electrical engineering and had spoken about space settlements in his

high-school valedictorian speech, took courses from O'Neill, and became head of the local chapter.

Meanwhile, in South Africa, an adolescent Elon Musk, fascinated by the planet Mars, was teaching himself to program the new devices called microcomputers. At the age of seventeen, he moved to Canada, and later to the United States, for studies at the University of Pennsylvania, Wharton, and (very briefly) Stanford. In an interview, he once said, "I wasn't born in America—I got here as fast as I could." He became a citizen in 2002.

Bezos was a young child during Apollo; Musk was born as it was coming to an end. Both were part of a generation that felt cheated that they had reached this planet too late to see humans walking on another. But there has been no consensus, at least in government, on the American plan for humanity's future in space. A unified vision has never existed, but it may be starting to coalesce with the ambitions of Bezos and Musk.

Motivated by the vision of thousands or millions of people living and working in space, both men know that this will never happen with expensive government launch systems. Their visions are broadly O'Neillian, even if Musk is obsessed with Mars while Bezos's dreams are destination-agnostic and more expansive.

Establishing human settlements on Mars, and more generally making humanity "a multi-planet species," have always been the stated *raison d'être* of SpaceX. Musk often quips that he wants to die on Mars, "just not on impact." In 2016, at the International Astronautical Congress (IAC) in Guadalajara, Mexico, he laid out in detail for the first time his flight architecture for an extended series of Mars colonization missions—with the first crewed flights beginning as early as 2022. Last year, he published a paper in the journal *New Space* and gave a follow-up presentation at the 2017 IAC in Adelaide, Australia, revising and expanding on the concept. The proposal was for a very large two-stage launcher, using SpaceX's new methane-fueled Raptor engines, dubbed "Big Falcon Rocket" (or BFR—inside the company, they often use a different "F" word). It would dwarf the largest rocket built to date, the Apollo program's Saturn V. He originally called the new overall space-transportation system the Mars Colonial Transporter, but has since renamed it the Interplanetary Transport System to make it seem more widely applicable to the entire solar system.

Bezos started his space company, Blue Origin, in 2000, two years before SpaceX. Until recently, it has been much more secretive about its plans. But while SpaceX has become famously associated with the astonishing feat of repeatedly launching and recovering vertical-takeoff, vertical-landing rockets, since 2015 Blue Origin has done the same with

its *New Shepard* vehicle (albeit only to suborbital speeds). Long viewed as the tortoise in the race for the suborbital space market, Blue Origin is probably now firmly in the lead, after the recent bankruptcy of XCOR with its planned Lynx spaceplane, and the continued delays in Virgin Galactic's new SpaceShipTwo vehicle after the catastrophic loss of the first one in 2014, killing one and injuring the other of its test pilots. (Virgin Galactic, however, may be closer to getting back on track after the successful partial-duration supersonic flight test of their new vehicle in May.)

With the repeated successful demonstrations of Blue Origin's rocket over the past couple of years, including a spectacular in-flight abort test—with the crew capsule pushing off from the rocket booster less than a minute after liftoff, which even the company expected would destroy the booster but did not—Blue Origin plans to start flying tourists to space next year. SpaceX, meanwhile, has indefinitely delayed its plan to send two tourists around the Moon, and while Virgin Galactic plans to begin their suborbital space tourism program next year, given the company's spotty track record of meeting previously set deadlines, Blue Origin's plan seems more likely to come to pass.

More importantly, experience gained in the development of the suborbital system is being applied to developing Blue Origin's own orbital launch systems, starting with what they call *New Glenn*, to fly by 2020. They also have plans in the future for a heavy-lift vehicle, which would compete with SpaceX's BFR, that they call *New Armstrong*. (Bezos apparently likes to name his rockets after NASA pioneers, all now dead.)

There has been some contentious but friendly Twitter banter between Musk and Bezos, as the two go head-to-head to help drive down launch prices through continuous improvement and competition. In addition to currently having ample financial resources, both men are technically trained—Musk has a physics degree, Bezos has degrees in electrical engineering and computer science—both have a deep understanding of their space vehicles, both understand the need for a competitive industry with multiple players, and both are driven by their space dreams.

Musk talks about humanity being a multi-planet species, in part as an insurance policy against earthly disasters, whether natural or manmade; he is particularly concerned about the potential danger to humanity posed by artificial intelligence. But he seems to consider two—Earth and Mars—to be a sufficient number for "multi." Musk could in fact be accused of an extension of what Carl Sagan called "planetary chauvinism"—the belief that life can thrive only on planets. But many analysts, I included,

don't understand the motivation, once having finally escaped the deep gravity well that has confined us to the planet on which we evolved, to dive down into another, albeit a shallower one.

By contrast, Bezos, as noted, aims for a massive human expansion, and not only to many other planets but to inhabitance of space itself. Wealthier than Musk—on some days he is the world's richest person—Bezos is also more willing to spend his own money. Last November he sold a billion dollars' worth of Amazon stock and claims to intend to do the same every year to provide the rocket company with its annual stipend, and he recently built a large facility at NASA's Kennedy Space Center in Florida to begin the manufacture of his large orbital rockets. Musk, on the other hand, always prefers, if he can find a way, to fund his dreams using OPM—Other Peoples' Money. In the case of Tesla and its subsidiary SolarCity, which sells solar panels for home and commercial use, he's done it with loans from Washington (which he has since paid off), various government subsidies for the production of electric cars, and tax credits offered to people buying electric cars or installing solar panels. In the case of SpaceX, extra funding has come, albeit in this case in exchange for providing a direct service, from NASA and U.S. Air Force contracts.

Over a decade and a half since both men launched their space companies, they have made significant progress in reducing the cost of getting to suborbital and orbital space. If their plans for large reusable launch systems come to fruition in the next few years, with SpaceX's BFR and possibly Blue Origin's *New Armstrong* offering larger payload capacities than NASA's non-reusable Space Launch System, they may well render it obsolete before the full Block 2 version flies. (The planned first flight of the initial Block 1 configuration of SLS has slipped to the end of 2019.) Before its second flight—probably no sooner than a year after its first—it may well be canceled for good, not to be resurrected, perhaps finally putting a stake through the heart of Apolloism.

Change on the Way

Six decades after the formation of NASA, it is finally becoming acceptable to talk about space settlement in polite company. But public policy has yet to catch up with the shift in visions. For instance, the Outer Space Treaty, over half a century old, was written for a different era, when few imagined private activities off the planet. It was modeled on the Antarctic Treaty, for a region whose resources were not to be exploited but only to be studied scientifically—which is perfectly compatible with the Apolloistic

and Saganite visions, but not with the O'Neillian one. But change may be on the way.

The Trump administration has reversed course from the Obama plan to skip the Moon, instead refocusing on it. In 2008, President Obama had endorsed "the goal of sending human missions to the Moon by 2020," but revealed a change of mind in a 2010 speech: "I understand that some believe that we should attempt a return to the surface of the Moon first, as previously planned. But I just have to say pretty bluntly here: We've been there before."

By contrast, Jim Bridenstine, the new NASA administrator confirmed by the Senate in April, has experience in the commercial space world and recognizes the value of the Moon and its resources. As a member of Congress, Bridenstine introduced a bill called the American Space Renaissance Act, a grab bag of ideas to make policy more friendly to commercial space activities. In a 2016 speech to the Lunar Exploration Analysis Group, he emphasized the value of lunar water to "service satellites with hydrogen and oxygen…for a fraction of the cost of launching energy or new satellites from Earth." Although satellites would have to be modified to use this fuel, "it would be a simple economic decision":

> The in-orbit maintenance, servicing, and refueling market, already being planned, could be greatly enhanced by an architecture that includes staging nodes, fuel depots, transit spacecraft and lunar landers. This architecture makes economic sense when considering the cost of building and launching new satellites. And the economics improve when considering the returns from orbital satellite assembly and a new generation of communication satellites with unprecedented bandwidth. To be clear, satellite servicing and assembly requires a lunar program that is permanent to include long term human habitation, machines, rovers, and resource production.

This is a visionary view of the near future that we've heard from no previous NASA administrator.

The space-science community is increasingly recognizing the necessity that their research not just be pure science with potential spin-off technologies on Earth, but have practical applications for the development of the new frontier. At the Lunar Science for Landed Missions Workshop at NASA Ames Research Center in January, the presentations were not just on how to determine the age or origin of lunar samples, but on how to assay the potential for water and other materials that could be used for life support, propellant, construction, and manufacturing. And because

the rides for new expeditions may not come from NASA, there were also presentations from a number of private companies planning to offer transportation to the lunar surface, including Blue Origin, with a program they call "Blue Moon."

The Trump administration has also recreated the National Space Council—it had been created during the administration of George H. W. Bush and lasted for only four years. While nominally headed by Vice President Mike Pence (a space-policy tradition going back to Lyndon Johnson's vice presidency under John F. Kennedy), it will actually be run by Scott Pace, an international affairs professor and the director of the Space Policy Institute at George Washington University. Pace is himself no stranger to the concept of space settlements, having long been involved in space activism, including in the L-5 Society and, later, the National Space Society. He recognizes the need for policy changes in light of changing technology and national goals.

A 'Global Commons'?

In December 2017, at the Galloway Space Law Symposium in Washington, D.C., Scott Pace gave a speech that contains hints of what the future of space policy may hold. In it, he laid out six key policy goals:

- U.S. policy will prioritize the interests of the United States and its friends.
- The United States will be the most friendly jurisdiction for private-sector participation and innovation in space.
- The U.S. government will use legal and diplomatic means to create a stable and peaceful environment for both government and commercial space activities.
- The private sector must have confidence that it will be able to profit from capital investments made in space activities and infrastructure.
- We need to resolve questions and ambiguities in the existing treaty structure about property ownership and rights.
- There is a need to develop international norms through both bottom-up best practices with partners, and top-down, non-binding, confidence-building measures without a need for changing existing treaties and arms agreements.

A key element of the speech was this shot across the bow, implicitly aimed at nations like Russia, with dramatic implications for the future of space development and settlement:

> …outer space is not a "global commons," not the "common heritage of mankind," not "res communis," nor is it a public good. These concepts are not part of the Outer Space Treaty, and the United States has consistently taken the position that these ideas do not describe the legal status of outer space.… [R]eference to these concepts is more distracting than it is helpful. To unlock the promise of space, to expand the economic sphere of human activity beyond the Earth, requires that we not constrain ourselves with legal constructs that do not apply to space.

These are international legal terms of art. The 1967 Outer Space Treaty (OST), to which the United States and all spacefaring nations are signatories, declares space activities "the province of all mankind." That is, it is a region in which all people who wish and can afford to can participate. The 1979 Moon Agreement, to which no spacefaring nation has acceded, uses the phrase "common heritage of mankind," implying that it is a commons that must be shared.* Many people within the space community continue to push behind the scenes for the United States to accede to the Moon Agreement. (It is worth noting that one reason space activists have for years fought U.S. ratification of the United Nations Convention on the Law of the Sea—also known as the Law of the Sea Treaty—part of which would regulate seabed mining, is that the Moon Agreement is modeled on it and, given how little seabed mining has actually occurred as a result, it would be a terrible precedent for the ability to mine space resources.)

Removing ambiguities about property rights is crucial for the dreams of space settlements. There will be no legal issue with private ownership of artificial habitats in space itself; ownership of apartments in them could be dealt with like a condominium on Earth. But if people are to live on planetary bodies, such as the Moon or Mars, it will be difficult for them to do so without clear titled property ownership, including mineral rights, and the ability to transfer ownership, borrow against it, and pass it on to their descendants.

Many space lawyers argue that these rights are either insecure under or outright prohibited by two articles in the Outer Space Treaty. Article II

* The Outer Space Treaty is formally known as the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies; the Moon Agreement is formally known as the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies.

states that "Outer space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means." In order to enforce a property right, a state must have sovereignty over the land on which the property lies—and this is prohibited by Article II.

Meanwhile, Article VI demands "continuing supervision" by governments of non-governmental activities. Commercial space activities have so far taken place close enough to Earth to allow for a soft interpretation of this clause. But farther from Earth—on the Moon or other bodies—it could well demand a more capacious reading, perhaps requiring a government minder to be physically present with any individual seeking to exploit space resources. This would constitute a practical if not a formal ban on securing private property claims on other planets. (I have previously discussed these issues in greater detail in these pages: "Property Rights in Space," Fall 2012.)

There is also the difficulty of the environmental-protection provisions in Article IX, which requires that states exploring celestial bodies must "avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter." Like the phrase "celestial bodies," what counts as "harmful" or "adverse" is not defined, and read even somewhat liberally, these terms would seem prohibitive to any meaningful human settlement of planets or moons, or the use on Earth of resources mined from them.

Scott Pace is well aware of these longstanding issues. His language about becoming friendly to the private sector, and being able to profit from investment, is indicative of a pivot of the new administration from the Apolloistic and Saganite models to a more O'Neillian one that envisions people—Americans and others—living and working in space for their own private purposes.

Pace's call "to expand the economic sphere of human activity beyond the Earth" echoes John Marburger's speech from over a decade earlier. But a president's science adviser has much less clout than the executive director of a National Space Council, particularly one who, like Pace, understands the levers of power in Washington. Reading between the lines of the speech, Pace seems to be saying that, while we believe we can operate within existing treaties, we will not allow them to prevent us from achieving our goals for American defense and private space industry. More recently, during an April Q&A session at the Hudson Institute, he described the OST and other treaties governing U.S. space activities as "broadly permissive" with regard to the stated national objectives. I'd

put it a different way: We should interpret the OST, and particularly its "province of all mankind" language, as making the solar system safe for traditional English common law, yet not requiring that it be universally applied.

One possibility Pace may imagine is working with like-minded governments, such as that of Luxembourg, which, with its investments in the companies Deep Space Industries and Planetary Resources, seems determined to become a leader in the use of space resources. Both the United States and Luxembourg have passed national legislation—the U.S. in 2015 with the Commercial Space Launch Competitiveness Act, Luxembourg only last year—allowing commercial use of space resources.

These laws, however, don't guarantee international recognition of space property claims. Many in the international space-law community believe this legislation is incompatible with the OST, and the two nations have been criticized for it. It is particularly important to find international partners to help push hard on this goal because Russia aims to counteract it, curiously continuing to push for an international regime based on the Moon Agreement, despite not having ratified it themselves. As space law expert Frans von der Dunk notes in a recent *Newsweek* article, Russia holds to the "common heritage of mankind" view, in which the harvesting of space resources should be treated as an "international enterprise," with the benefits generally shared among countries.

Securing Property Rights In Space

To work toward an international consensus on the legality of commercial mining in space, I would propose the development of multilateral agreements, both within the Anglosphere and with others of like mind, such as Luxembourg, Japan, the United Arab Emirates, Israel, and any other nation that wanted to participate.

Among other things, this agreement would require that Australia withdraw from the Moon Agreement. Now that it has decided to get more serious about space with the announcement in May that it is creating a space agency, and with Australian mining companies champing at the bit in anticipation of harvesting space resources, it has no good reason to continue to be a party to it, if indeed it ever did.

There is also a strong case to be made that the U.S. State Department ought to officially repudiate the Moon Agreement. The United States, under the Carter administration, was originally a key player in formulating it, and even though it was never ratified by the U.S. or Russia, it

continues to carry a great deal of informal weight in the space community. A formal repudiation would finally put a stake through its heart.

Beyond putting the Moon Agreement to rest, a set of multilateral agreements should be based on at least the following principles:

- A clear affirmation that the "province of all mankind" language of the OST is fundamentally incompatible with the "common heritage of all mankind" language of the Moon Agreement. Note that, whereas the "common heritage" in the Moon Agreement is the Moon and celestial bodies themselves, including their natural resources, in the OST the "province of all mankind" is "the exploration and use of outer space." It must be affirmed as logically impossible for states to be parties to both treaties at once, even though many parties to the Moon Agreement are also parties to the OST.

- Formal recognition of the utter impracticality of the view that whoever mines resources in space must "share any benefit with all states," as space lawyer Tosaporn Leepuengtham describes a prevailing interpretation of the "common heritage" principle. Many countries are still pushing for this view, as is clear from the April meeting of the Legal Subcommittee of the U.N. Committee on the Peaceful Uses of Outer Space, where some delegates urged that space mining be "exclusively for the benefit of all countries, regardless of their levels of economic and scientific development," and that discussions begin on "how an international mechanism for the coordination and sharing of space resources could be built." The notion that, say, the sale of liquid oxygen from the Moon to Elon Musk for a trip to Mars should somehow benefit Botswana is absurd. But for imports of space resources to Earth, one way of dealing with the issue could be a tariff that would fund a development bank, from which nations could borrow to fund their own space projects. This would meet the spirit if not the letter of the regime to be established by the failed Moon Agreement.

- A requirement that all parties to the agreements will recognize property claims of individuals from *any* nation, including non-party nations, subject to certain conditions. The U.S. Homestead Act of 1862 could be used as a model, requiring an individual to inhabit a prospective piece of real estate for some designated period of time, and improve it in some sense, in order to gain title. The General Mining Act of 1872 might also be used as a model, regulating mining

claims and requiring their purchase for a fee from a governing body, if they are considered to be found on publicly owned land. It is hard to see an argument for such recognition as a "national appropriation," which is what Article II of the OST prohibits.

- A distinction between resources extracted in space for personal use, such as harvesting lunar water for life support; resources extracted in space for space commerce, such as harvesting lunar water to create propellant to sell; and resources brought back to Earth from space and for sale in the terrestrial economy. The latter is the only kind of resource extraction that could justify the sorts of concerns targeted by the Moon Agreement, as it could disrupt commodity markets and disadvantage developing nations.

- A permissive interpretation of Article IX of the OST, which requires avoiding "harmful contamination" of celestial bodies. There is need for a clear interpretation of this clause that would not preclude, say, humans landing on Mars, yet would also ensure the preservation of heritage sites, such as the Apollo landing sites on the Moon or Viking landing sites on Mars.

- A more concerted consideration of establishing civilian national space guards. These agencies would be based on the model of national coast guards, cooperating with each other both for constabulary purposes and to help fulfill the 1968 astronaut rescue agreement, which requires mutual cooperation among nations to aid astronauts in distress. (See James C. Bennett, "Proposing a 'Coast Guard' for Space," Winter 2011.) It may also be desirable for the multilateral agreements to include wording ensuring that the requirement to return astronauts not be used as a means to deny asylum—that is, the space travelers have to want to be returned to their countries of origin.

These proposals, of course, will not be without controversy. There are many, both inside and outside of the United States, who do not in fact share an expansive vision of humanity in space, and some who even find human presence so tainted that they believe it should remain confined to the planet on which it evolved. But if we reject this pessimism in favor of the principles just described, after more than a century of dreams of massive human activity in space, new technologies and wealthy new visionaries may at last enable the most expansive space visions to come to fruition.