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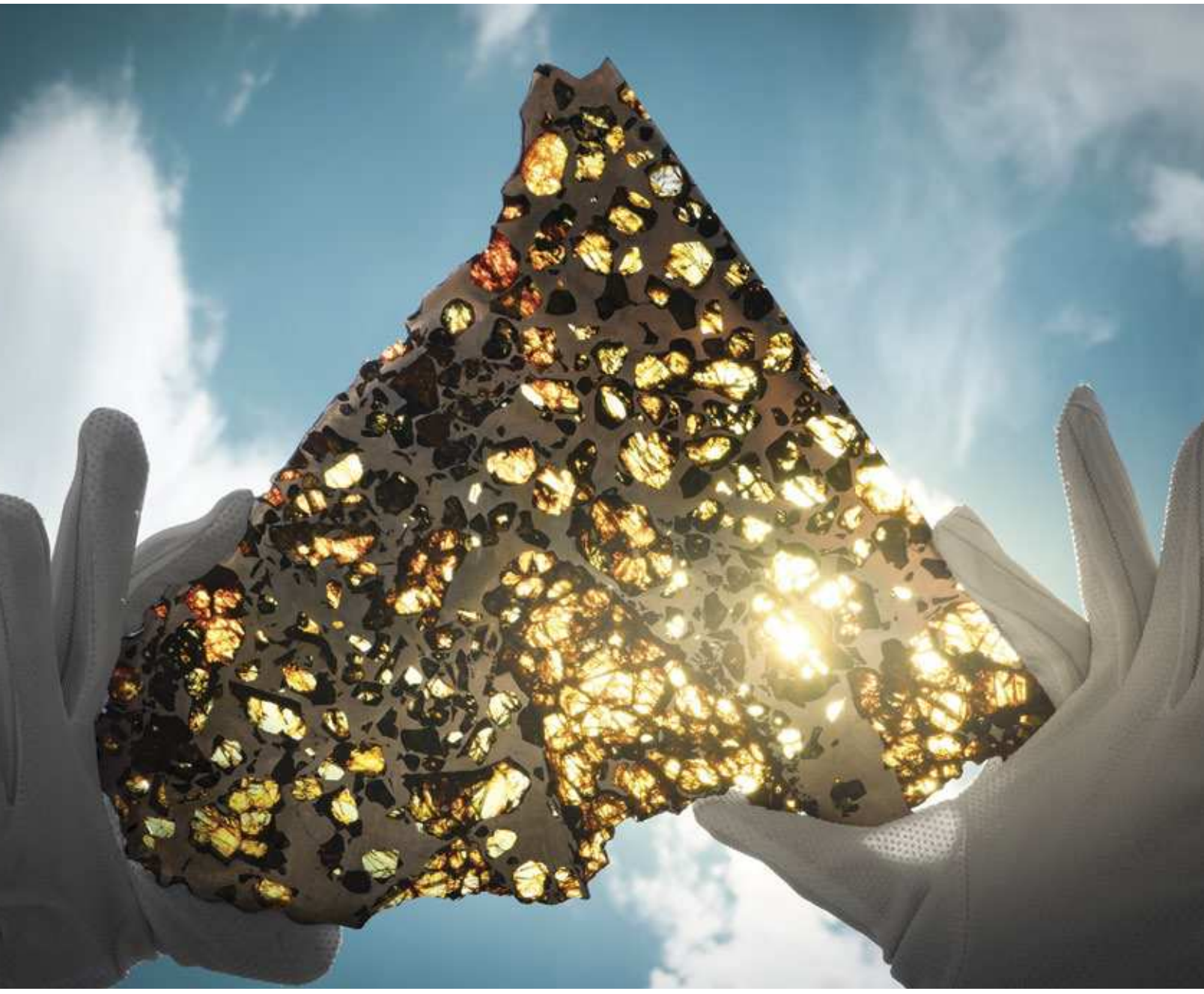
GIVE THE GIFT OF OUTER SPACE ... METEORITES



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COVER ILLUSTRATION:
"Pillars of Creation," the Eagle Nebula, Hubble Space Telescope image.
Credit: NASA

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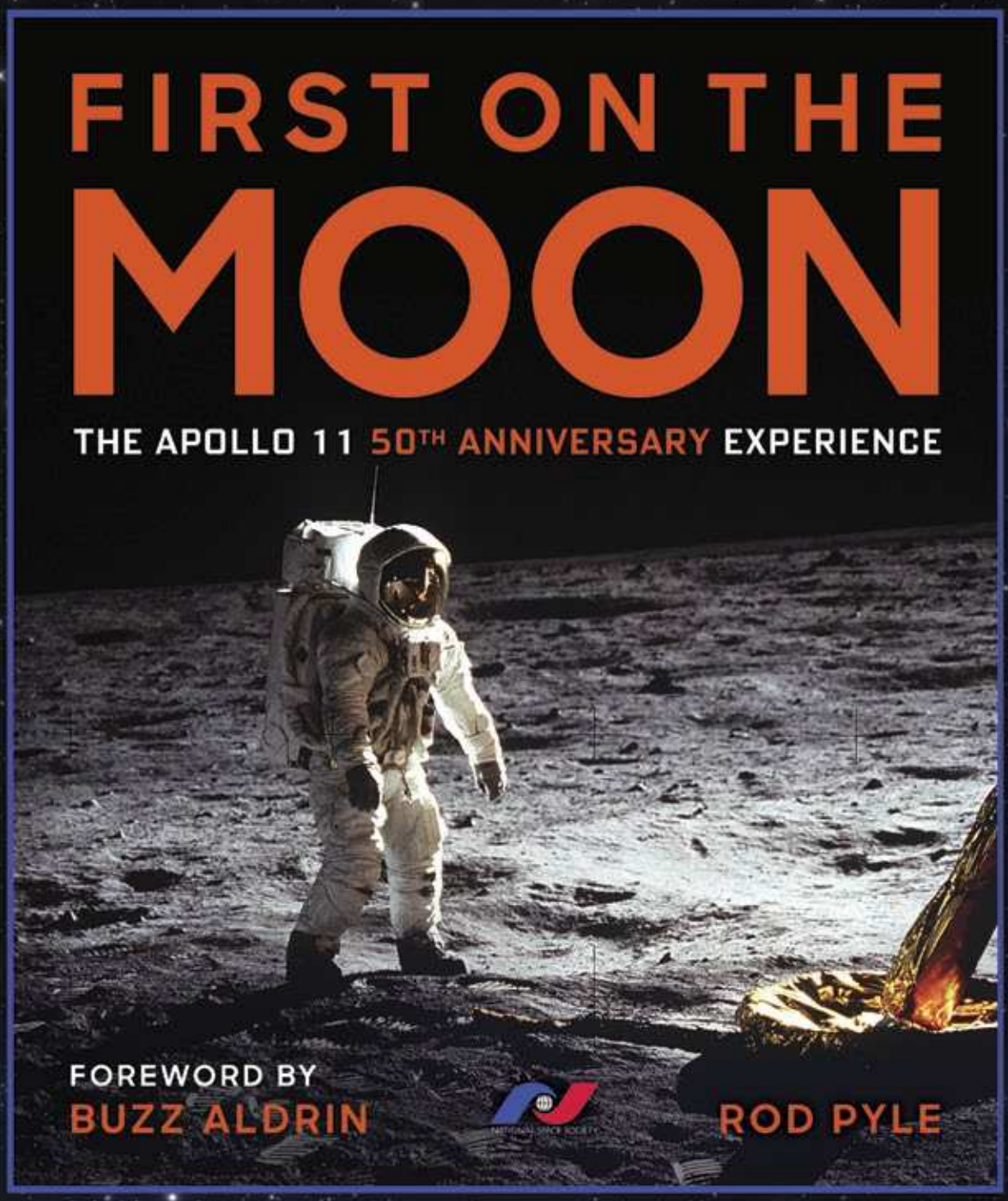

"Packed with archival images and documents, some of them previously unpublished, this book includes a foreword by Buzz Aldrin. It's ... gift-appropriate ...; and covers the mission from start to finish. Pyle has written several books on space exploration and is also the author of *The Apollo Missions* (Carlton, Sept.), which annotates first-person accounts from astronauts across the Apollo program."

—*Publishers Weekly*

"Science author Rod Pyle spent years combing NASA archives and private collections for memorabilia from the Apollo 11 mission. *First on the Moon: The Apollo 11 50th Anniversary Experience* ... brings us rarely seen archival images, as well as photo-compositions previously not available online, here for the first time color corrected and assembled into their originally intended montage format. In addition, the book is foreworded by Buzz Aldrin and includes never-before-published interviews with the children of Aldrin and of Armstrong."

—*PopScienceBookClub.com*

Published in association with the National Space Society, *First On the Moon: The Apollo 11 50th Anniversary Experience* is available from Barnes & Noble, Amazon and other fine booksellers, now at a reduced price. This prized volume includes rarely-seen images.new photomontages and exclusive interviews with the children of the astronauts. With a foreword by NSS Governor Buzz Aldrin and lavishly presented in hardcover, this is the definitive account of humanity's first steps on another world.

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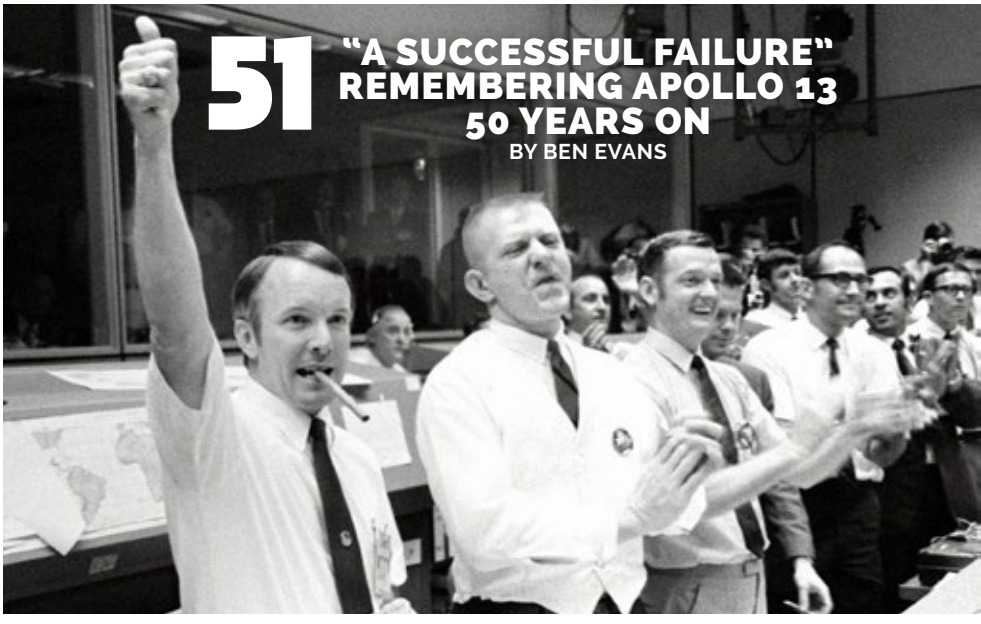

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THE POWER OF PERSISTENCE IN SPACE

Rod Pyle, *Ad Astra* Editor-in-Chief

There's power in persistence. In this issue, we celebrate two space missions that demonstrated this trait in very different ways, as well as some future ones that will be the result of great tenacity. First up, his year marks the 50th anniversary of the flight of Apollo 13. Shortly after launch in April 1970, the spacecraft experienced a nearly catastrophic explosion of an oxygen tank on the Service Module. It was only through the calm responses of the crew and heroic levels of effort on the part of Mission Control that the astronauts were able to return to Earth alive despite the staggering odds against them. This was persistence in the extreme: focused determination to save the flight from disaster. Ben Evans' tale of the rescue follows in these pages.

A second anniversary celebrated in this issue is the Hubble Space Telescope's 30th birthday. Launched on April 24, 1990, aboard the space shuttle *Discovery*, the telescope met misfortune immediately. Within weeks of its arrival in orbit, it became clear that the optics were flawed—the 8-foot (2.4-meter) mirror had been incorrectly formed (it was off by just 2,200 nanometers and only on the outer edge, but that was all it took), and the images were distorted. A solution was devised, and another shuttle mission in 1993 allowed astronauts to implant corrective optical elements into the telescope, correcting the flaw. As Nancy Atkinson tells us in her feature article, that mission resulted in a magnificent, decades-long program that changed how scientists understand the cosmos, and how the average citizen looks at (and appreciates) the heavens.

Next, in a rare look inside China's human spaceflight program, John Kross examines the history, and likely future, of human spaceflight in that country. The West does not get a lot of advance information about Chinese space efforts, but Beijing has been a bit more forthcoming of late, and if we've learned anything, it's that the country has big plans that are well-funded. It is a consistent approach that America has not enjoyed since the 1960s, and can today only admire from a distance.

Finally, we see the persistence of the individual. These are the women fighting for their proper place in spaceflight, whether in the past (see this issue's review of the new book *Fighting for Space* by Amy Shira Teitel) or in the upcoming lunar landing of the Artemis program.

On a sad note, the world has been beset by a tragic pandemic of unforeseen proportions. Accordingly, the International Space Development Conference® for 2020 will not be held, but plans are underway for a one-day online event called *A Day in Space*, and we are planning for a robust ISDC 2021 in Los Angeles. This is a final case of persistence—the NSS will continue to strive for the development and settlement of space; a goal which is now more urgent than ever. *Ad Astra*.

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UNITY IN THE SKIES

Karlton Johnson, Chairman of the National Space Society's Board of Governors

Years ago, I had an experience that impacted me profoundly and reinforced my belief that the future of humanity is truly written in the stars.

I was an officer serving in the U.S. military, stationed in Iraq supporting Operation IRAQI FREEDOM. Our team was responsible for assisting the Iraqi Ministries of Defense and Interior and the Counter Terrorism Service to improve the Iraqi Security Force's institutional performance. That support would help them to assume full responsibility for population protection, leading them toward the goal of becoming a self-sufficient nation.

This was very important but dangerous work. On a near-daily basis, our coalition of multinational partners was subjected to a number of threats: sniper fire, improvised explosive devices (IEDs), and mortar and rocket attacks. The weather was often arid, with dust storms arising with little notice that would block our vision, and we were often able to see just a few feet. Many of us were there on tours ranging from six to fifteen months, and just about everyone was on their second or third tour, having left family and friends back home. The days were long and filled with challenges, but despite knowing that at any time we could be called upon to make the ultimate sacrifice, we took each one as a gift, holding firm to the knowledge that we were making a difference in the lives of others.

I remember one night in particular. We were experiencing a lull in incoming fire during one of the few evenings with a clear sky. Things became very quiet, which in itself was somewhat disquieting as this often meant that something violent was about to happen, so I mentally prepared as my training kicked in. Then I heard several of our Iraqi partners repeating something over and over. At first, I could not make it out, so I approached a group of Iraqis who were looking skyward, pointing and saying, "ma hdha?" (which translates to "what is that?").

Standing shoulder-to-shoulder, we saw a very bright light arching upward from the horizon. Initially, we thought it might be an incoming rocket attack, but it was moving too slowly for that. We stood there, wondering what it was—then a young soldier smiled with realization and said, "I know what that is. I look for it sometimes at home, but never saw it like this! That's the International Space Station." I had never seen it either, except in pictures. But it now rose peacefully in the skies above us, and was strikingly beautiful. I asked one of the linguists to translate what we were seeing to our partners there, and they called to each other to come and look. Soon, soldiers of several nations marveled at this spectacular moment: Americans, Iraqis, Britons, Ugandans, and others. We could make out the solar panels, and even some of the individual modules, and for a long while we just stood there, watching that marvel of human ingenuity and sharing our wonder. As it glided overhead towards the horizon, someone translated, "One day, all of us, to the stars ... together." In truth, the dream of the stars was with us that night.

That amazing, powerful moment still inspires me today. There I was, thousands of miles away from home and in a combat zone, and the passion that drives humanity upward was still able to touch us. It brought nations together in a moment of unity, and gave us all something in common. That's why it is important to continue advocating for space settlement whenever possible. Space programs benefit us in many ways: they give us something to strive for, they ignite our creativity, they bring us together for a common cause (the survival, and future, of humanity), and they have the potential to solve many of the challenges we face here on Earth. If simply watching the majestic transit of the ISS could inspire nations, we as a society focused on advancing human presence skyward can inspire the world.

I want to thank each and every one of you for your ongoing support of the NSS and its mission. Looking forward, I hope to see many of you at future March Storm events, and at the ISDC® 2021 in Los Angeles. Until then, let's keep the dream alive for all of us.

Ad Astra and Yours in Success,

Karlton D. Johnson
Chairman, Board of Governors
National Space Society

Artist's impression of the Infrared Astronomical Telescope, or IRAS
Credit: NASA

COUNTDOWN

5 GANGWAY!

On January 29, two satellites narrowly missed colliding in orbit. One was a defunct one-ton space telescope called the Infrared Astronomical Satellite, launched in 1983, and the other a 1967 research satellite called the Gravity Gradient Stabilization Experiment, also long dead but still in orbit. The potential for a collision was reported a few days beforehand, and had it occurred would have added to the vast cloud of dangerous debris already in Earth orbit. They missed each other—but not by much—and this near-impact should serve as a wake-up call to governments around the world to take the threat of orbital debris seriously, and to develop a cooperative plan to deal with it effectively.

Artist's concept of a Mars sample return spacecraft
Credit: NASA/JPL-Caltech

4 BACK TO THE FUTURE

The notion of bringing a little bit of Mars back to Earth has been a part of mission planning since the 1960s. The Soviet Union planned an early mission, revised those plans, and then revised them again, but never mounted the mission. Similar robotic programs have been pondered in the United States, but to date none have gained much traction. Now, NASA's 2021 budget request includes a plan to bring home some of the core samples that will be obtained by the Mars 2020 rover's drill, sealed inside small tubes, and left on the Martian surface until another spacecraft can be sent to the Red Planet to arrange a pickup. If NASA's budget is passed as requested, a substantial sum—tens of millions of dollars—will be allocated to bringing us a bit of Mars for careful examination on Earth.

3 SPACE RANGERS

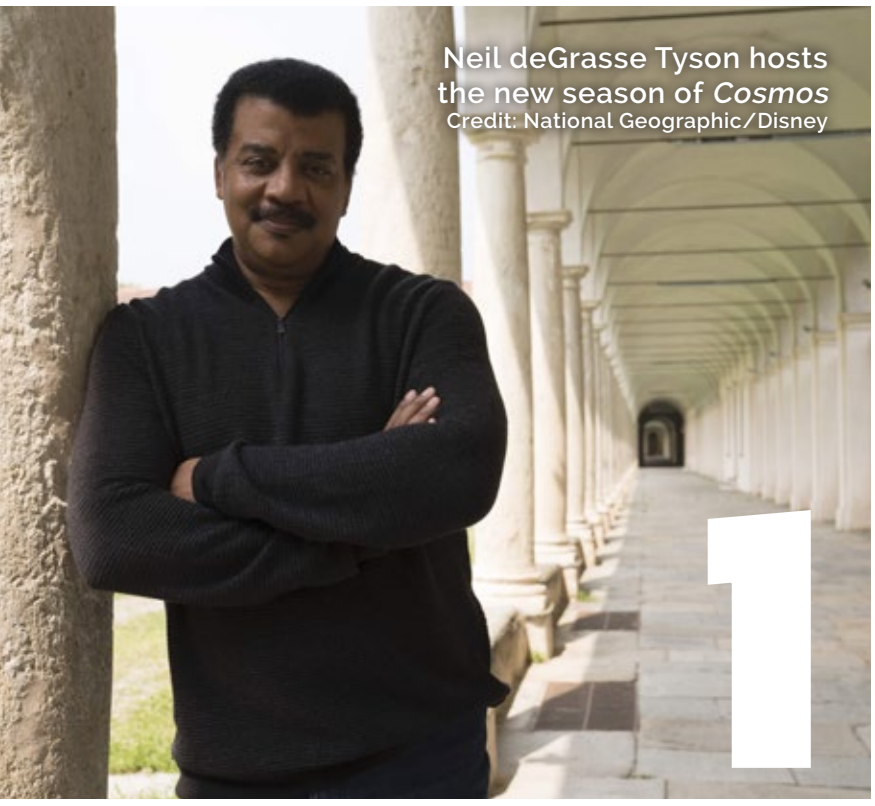
The United States Space Force is finally a reality within the U.S. military, having been officially established last December. Space Force subsumes the Air Force's Space Command, which was founded in the early 1980s, and will operate with the Air Force in a fashion similar to how the Marine Corps works with the Navy. Shortly after the announcement, a uniform for the new service branch made its debut—but to the consternation of some, it is not some exotic regalia out of *Star Wars*, but the same woodland-camo pattern used by other U.S. forces with a unique patch design. As pointed out by one Air Force official, "Space Force members control/protect assets *in* space but are not *in* space," so the choice clearly makes sense (though something exotic might have been fun).

The new Space Command patch
Credit: U.S. Space Command

2 NEW FOR CHINA

China quietly inaugurated a new version of its long-serving Long March rocket family, called the Long March 7A, which failed in a March 2020 launch attempt. The booster is part of the large family of Long March rockets, which have become increasingly large and powerful in order to better serve the needs of the increasingly ambitious Chinese space program. Future variants include the Long March 8, which may be reusable, and the Long March 9, a heavy booster-class suited for large lunar payloads.

A Long March 7 rocket
Credit: K.C. Lee



Neil deGrasse Tyson hosts the new season of *Cosmos*
Credit: National Geographic/Disney

1 COSMOS IS BACK

After a hiatus since 2014, a new season of National Geographic's *Cosmos* (hosted by Neil deGrasse Tyson) has arrived. The popular series is modeled after the 13-episode show helmed by Carl Sagan that debuted in 1980. The new show is overseen by Ann Druyan, Sagan's widow and a producer on the original series, along with Brannon Braga, a writer from the *Star Trek* franchise who is currently working on *The Orville*, and Jason Clark, a noted movie producer. The show contains many messages, including the importance of expanding the human presence in space. As Tyson put it, "It's an appeal for all of us to gather together, and imagine the future as a community—not as a country, not as a faction, but as a species."

SAMPLE SPACE LIKE COSTCO

Anthony Paustian, Ph.D.

Each year, the Consumer Electronics Show (CES) in Las Vegas, Nevada offers a chance to see the most promising and impactful technologies on the on the horizon, and to reflect on past shows to understand the trajectories technology has followed. It is at once inspiring and overwhelming. When I attended CES in 2000, many of the technologies we take for granted today—flash drives, Internet gaming, Bluetooth wireless technology, smartphones, and even cell phones with built-in cameras—didn't exist.

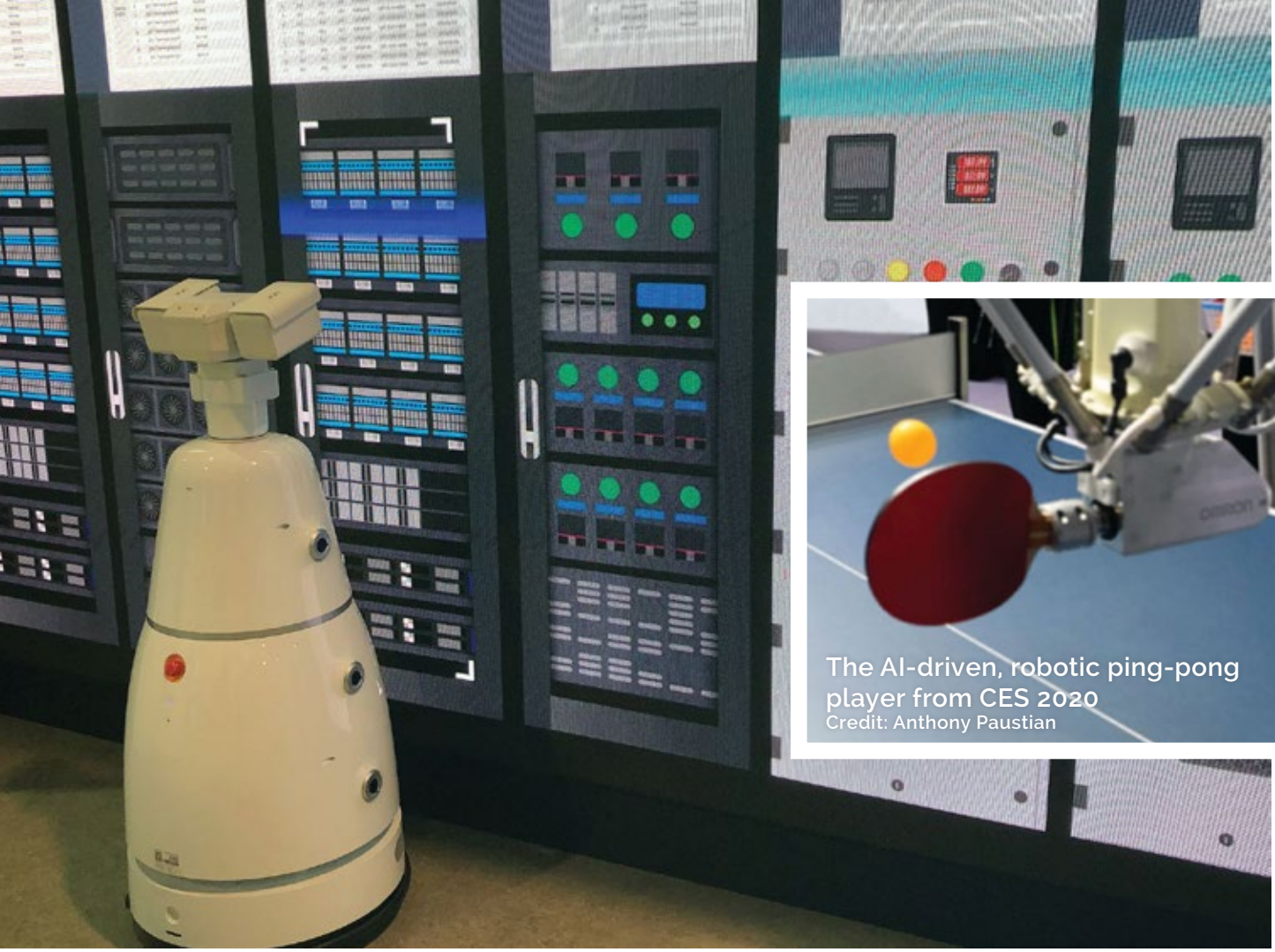
Many products on display now incorporate artificial intelligence (AI), virtual reality (VR), augmented reality (AR), automation, and robotics. This year's line-up included voice-activated automatic frying pans, "bionic" floor cleaning machines that simultaneously sweep, mop, and dry floors, golf balls with Bluetooth trackers to make them easier to find, baby beds that monitor an infant's vitals while rocking it to sleep, and wearable technology to monitor and quantify just about every metric of health.

The most obvious message is that of rapid change. Advances in computing power have made devices smarter and more connected, and the rise in AI and automation is making technology increasingly invisible to the user. Advances in consumer electronics aren't so different from those in space exploration, and I saw plenty of consumer applications for robotics and AI. I watched people lose at ping-pong against an AI-driven robotic opponent and autonomous vehicles and robots performing functions once exclusive to humans. But as I marveled at the ingenuity, I thought about how these technologies might change the way people experience space travel and exploration.

In his January 15th *Disruption Hub* article "Driving Emotional Transformation," futurist Gabor George Burt argued that "digital transformation should not be regarded as an end goal in itself, but as a means to the goal of perfecting human experiences." The late Steve Jobs also knew the importance of perfecting human experiences, and he had a reputation for disrupting markets with products that did not fit into an existing category. No one had ever combined the experiences of listening to music, talking on the phone, and browsing the web, but as Jobs said, "You've got to start with the customer experience and work back toward the technology, not the other way around."

The iPod and iPhone were both revolutionary designs that disrupted entire markets, radically changed human behavior, and completely infatuated people. Yet research into infatuation and perception routinely shows that over time, people get less excited about ongoing advances (like better cameras, longer battery life, or faster wireless). The emotional connection they once had with new technology wanes over time; that is, until the next big disruption comes along to capture people's hearts again.

It comes as no surprise that we see the same cycle of infatuation during the life of our human spaceflight program. The Mercury Seven, America's first astronauts, were treated like rock stars and the public was completely infatuated with them. Science fiction became fact as men left Earth to explore the heavens. Over time, interest in the program (including the Gemini and Apollo missions) would frequently cycle high and then low as each new success fascinated the public only to wear off shortly afterward. After the program reached its highest point during the first lunar landing, the remaining few peaks were offset by many longer lull periods until most people lost interest. This pattern has continued despite current commercial successes such as landing boosters for reuse or



The AI-driven, robotic ping-pong player from CES 2020
Credit: Anthony Paustian

An autonomous systems monitoring an AI-driven robot from CES 2020
Credit: Anthony Paustian

sending Elon Musk's red Tesla Roadster into space with Starman behind the wheel.

One might ask why the public needs to buy into this incredibly expensive endeavor when we've already been to the Moon several times and seen high-resolution pictures of the Martian surface. As we watch SpaceX, Blue Origin, United Launch Alliance, NASA, and others continue to perfect their rockets to successfully and more efficiently lift people and resources into orbit, it begs the question: is the primary focus on the technology itself or the experience people will have while using it (especially if they end up traveling to and living on both the Moon and Mars)?

This matters because technology is unlikely to be a limiting factor. Having seen the successes of the Apollo missions in the 1960s and the incredible advances in engineering and technology in the decades since, I know we can overcome the technical barriers. We aren't fighting our ability to innovate, but the public's apathy toward space. With so many problems here on Earth, it makes sense that many have trouble seeing why funding extraterrestrial projects is important. We could argue that there's been a massive return on investment from space-related research and innovation, but that's neither tangible nor obvious to most people. It definitely doesn't inspire like Neil Armstrong's first steps on the Moon.

Rod Pyle, the Editor-in-Chief of *Ad Astra* (who was at CES for a stage discussion to promote the NSS co-published book *Space 2.0*), said during his presentation, "Everything about space tries to kill you." Working and living in space carries a high level of risk along with a big price tag. Many people support constructing and maintaining roads, bridges, and other infrastructure because they often interact with those things and understand their value. While there will certainly be a need to send people to the Moon and Mars for research, maintenance, and other reasons, there will always be risk and it's our job to show people the value proposition that offsets those risks.

I keep thinking of what I saw at CES: based on the rapid advances in AI, VR, and all the other two-initial technologies, I realized that working and living in space could actually be *sampled* to inspire excitement and create a general understanding of why it's important to push the boundaries of technology and human capability. Whether it's the burgeoning space tourism business, companies like Proctor & Gamble and IKEA giving serious thought to future space experiences and designing

products for habitats on the Moon and Mars, or Hollywood's increased emphasis on space-related movies and television, the desire exists to craft space into a human experience.

Maybe the answer isn't another peak in popularity, though I believe it will come eventually (perhaps when we land the first people on Mars); I don't think that's the solution. Peaks are followed by lulls, and successes by letdowns. Perhaps the answer is to keep interest gradually rising, lifting the industry, and building excitement a little bit at a time. Costco, the incredibly successful warehouse store, is well-known for offering samples to whet their customers' appetites, encouraging them to buy products they wouldn't otherwise know about. This not only drives up sales in the short term, it also keeps those customers coming back for leisurely strolls through the store in search of new offers on any given day.

It may be that the secret to gaining support for future space exploration and settlement is to provide "a taste of space" using AI, virtual and augmented reality, and other technologies. Providing these regular, interactive space-related samples may be enough to encourage the public to care more about human spaceflight and other endeavors, regardless of who's in office or which political party is driving the agenda. This would let people know what's out there and hopefully keep them wanting more.

Paustian will chair the "Science Fiction to Fact" *track at ISDC 2021.*

A Great Big Thank You

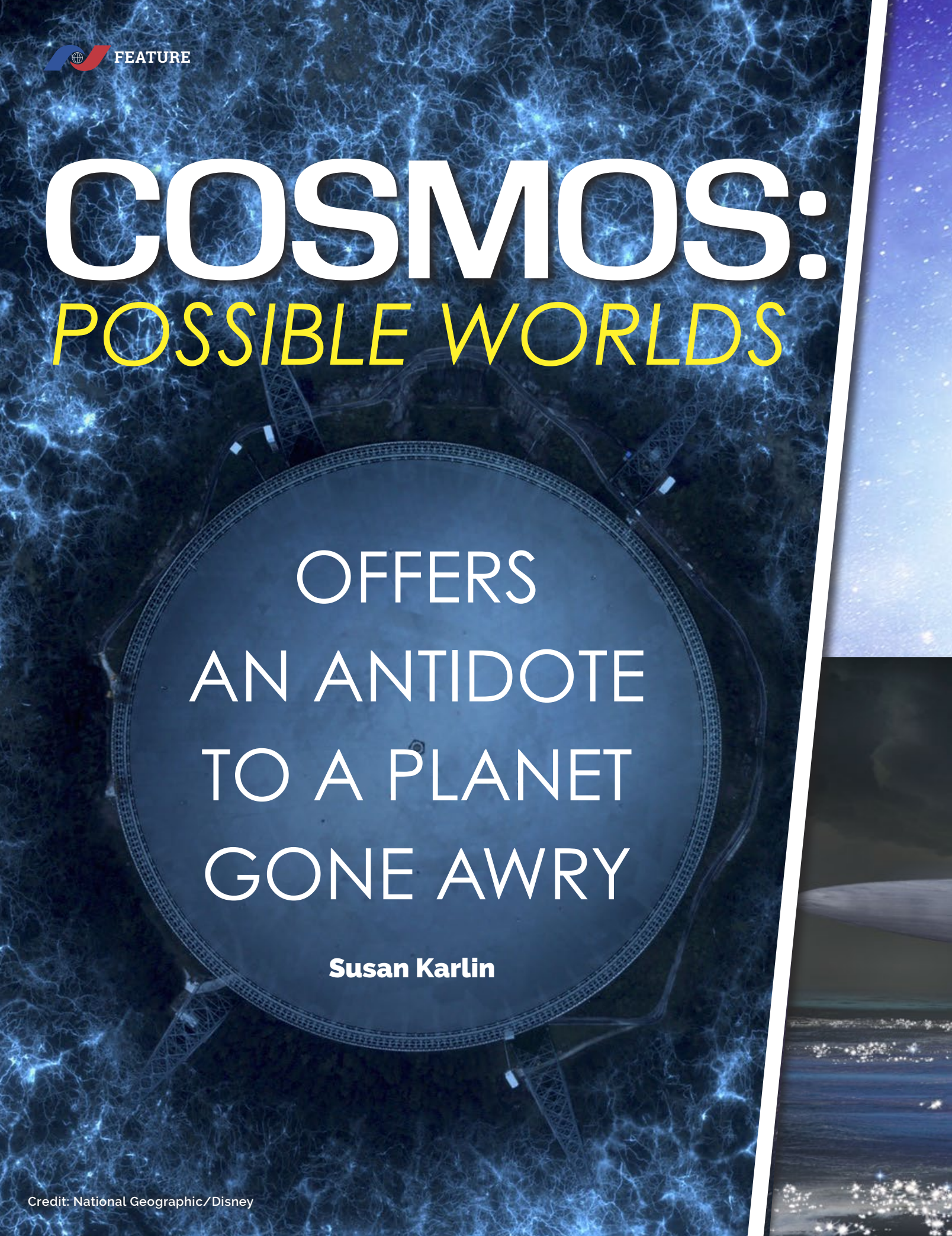
As chair of this year's International Space Development Conference, I've had the honor of working with some amazing people. While they may not always be seen front and center, these "doers" are truly passionate and put forth the majority of the effort to make it the great conference it is each year. I'd like to thank the leadership of the NSS for providing me the opportunity to get to know and work alongside these people. Like the workers handing out samples at Costco, they are part of the solution when it comes to inspiring people about our future in space.

Author and NSS member Rod Pyle speaks with Kira Blackwell, who heads NASA's iTech initiative, at CES 2020 Credit: Anthony Paustian

COSMOS: *POSSIBLE WORLDS*

OFFERS AN ANTIDOTE TO A PLANET GONE AWRY

Susan Karlin

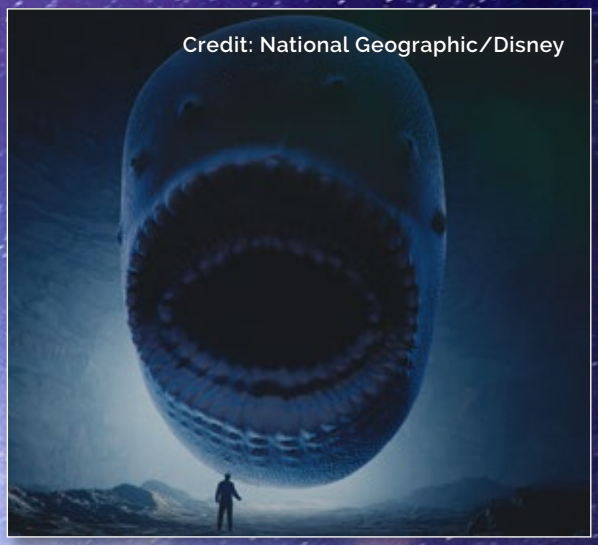


Credit: National Geographic/Disney

Science has been a polarizing subject for hundreds of years. From Galileo ruffling 17th century papal feathers by advocating a heliocentric model of the solar system to modern-day creationist, anti-vaccine, and climate change denial movements, those advancing scientific evidence have long struggled against even the most unsubstantiated beliefs.

This tension is what fuels the latest iteration of National Geographic's Emmy and Peabody Award-winning *Cosmos* series, *Cosmos: Possible Worlds*, which is hosted by astrophysicist Neil deGrasse Tyson. The new season debuted globally on March 9, but is slated to return on the Fox television network this summer. Earlier this year, Tyson joined executive producers Ann Druyan, Jason Clark, and Brannon Braga at the Television Critics Association press tour in Pasadena, California to discuss the current offering, which focuses on many of the exciting possibilities in the future—if humanity can get its act together.

"Our planet is at this moment going horribly awry," says Druyan. "The urgency of this season is that every story is in the service of this idea. 'We humans,' as Carl says in the beginning, 'are capable of greatness.' We've had our backs to the wall before. We can do this, but we can't do it unless we begin to take what the scientists have been telling us to heart." Carl is the late astronomer Carl Sagan, Druyan's husband and creative partner, who hosted the original *Cosmos* in the late 1970s, and although Tyson has brought his own charisma to the new version, Sagan's spirit still runs through it.


Credit: National Geographic/Disney


Credit: National Geographic/Disney


Credit: National Geographic/Disney

The World's Fair of 2037, as seen in the new season
Credit: National Geographic/Disney

"When the original series was made, Carl and I had many differences with our government, but we felt tremendous pride in the achievements of the space program and what it was doing," explains Druyan. "Now something has really changed in the government's attitude towards science, which was once its shining jewel. It's hostile and cynical. When anybody is hostile and cynical about our most powerful tool for apprehending reality, you know they're up to no good. *Cosmos* is our way of standing up for the awesome power of science."

The program explains why science is needed to move our civilization forward. "We make the point that the methods and tools of science are the most effective means to establish what is objectively true," says Tyson. "Rather than hit people over the head for their beliefs, we present the notion that if we're going to survive ourselves, at some point we have to establish what is true and what is not. If you understand that, you'll be in a much better position to make decisions that affect the survival of our species. It's an appeal for all of us to gather together and imagine the future as a community—not as a country, not as a faction, but as a species."

An animated sequence from the new season
Credit: National Geographic/Disney

Future space tourists in orbit above Mars
Credit: National Geographic/Disney

COMMUNICATING SCIENCE

Cosmos delivers its lessons through powerful storytelling,, enhanced by lush visual effects and animation, exotic locations, and sweeping musical scoring and cinematography. The Spaceship of Imagination transports viewers to the farthest reaches of the universe, the Cosmic Calendar compresses the history of the world into a single year, and historical reenactments show pioneering scientists embarking on their discoveries. This season, Seth MacFarlane (another *Cosmos* executive producer), Sir Patrick Stewart, Viggo Mortensen, and Judd Hirsch have all contributed. The show looks at early scientific ideas,

considers their impact on today's thinking, and imagines the effect they might have in the future.

The show will go out to 172 countries in 43 languages. "It's a really unique voice because it informs in a way that's not condescending, that's straightforward and uncompromising scientifically, but inspires and moves you," says Druyan. "If things emotionally move you—which seems counterintuitive to a science show—they're going to have a bigger impact and help you understand them on a visceral, cellular level."

Of course, the team is aware that not everyone will be swayed, considering that the 2014 season (however benign) still managed to push some buttons. "There's an entire website that was established after 2014 to rebut everything that happened in the 13 episodes of *Cosmos* from a religious point of view. They have a magazine that's anti-*Cosmos* that's appealing to creationists," says Tyson, to the surprise and bemusement of the other producers (*Ad Astra* was unable to locate the magazine Tyson mentioned.)

"I'm less worried about the next generations, because they tend to be a little more woke than the older generations," he adds. "I'm a little more unorthodox here, but I think the older folks are the ones that need to be hit with this. The younger ones will embrace it and it will empower them to do even more of what they're already doing to make sure the world they inherit from us becomes something they'd be proud to say their parents were good caretakers of."

SCIENTIFIC VETTING

A team of scientific advisors, helmed by Tyson (who also serves as executive science editor), ensured the accuracy of the series. The show even bases its universe-traveling visuals on what Clark refers to as "informed speculation," using Hubble images as reference and extrapolating based on known distances to stars to produce plausible views of the galaxy from vantage points other than Earth.

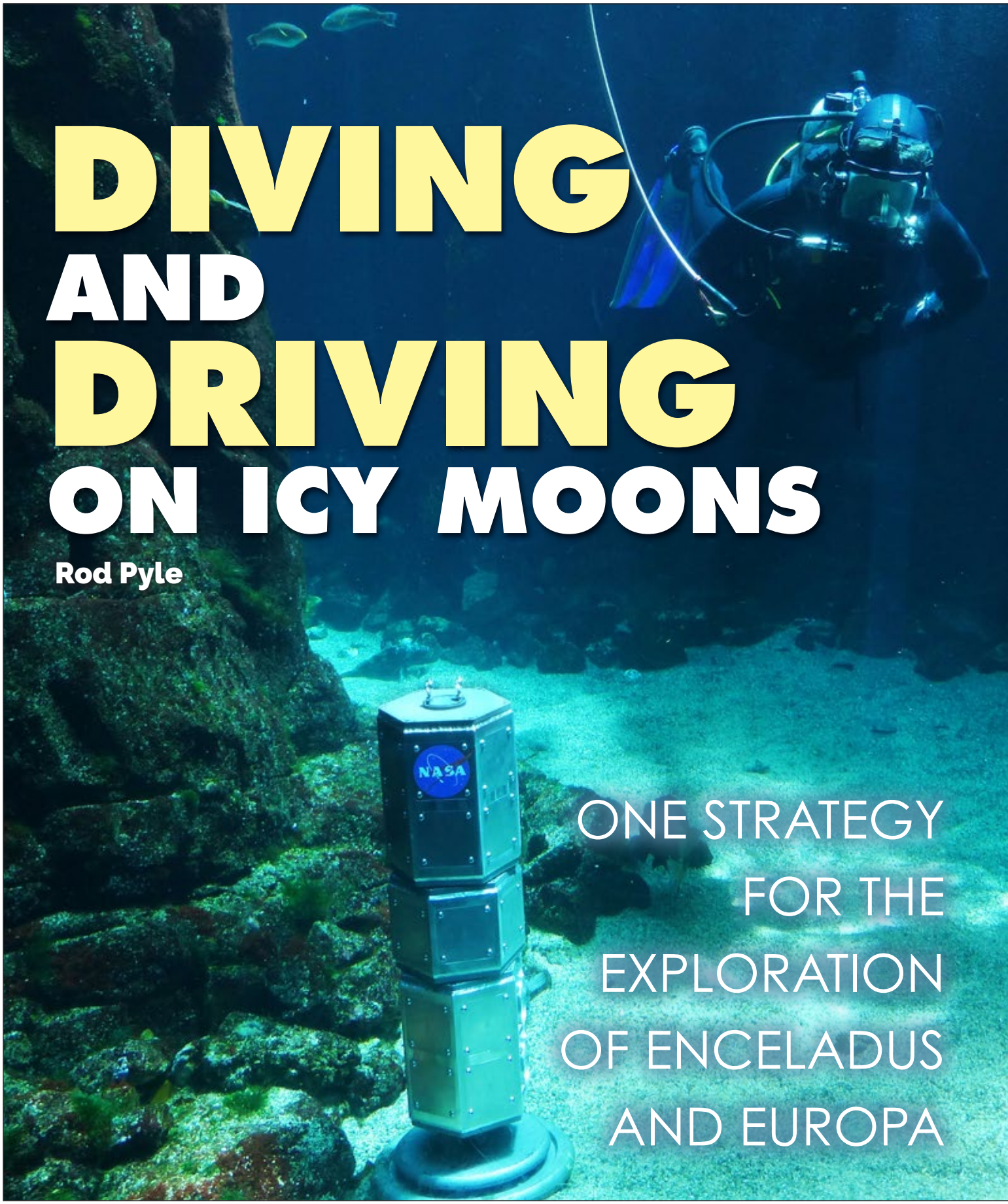
"Every star field was vetted by scientists," says Clark. "I know what it looks like from here on earth. But what would it look like if we were looking back from deep space? So we put every ounce of scientific knowledge to work. We used every image that we could find, and science is always evolving. A lot of what we're telling you here are discoveries we made since our last season."

Another *Cosmos* series is planned after this one, and with each the team intends the same overarching message: "The idea that science matters, that truth matters, and that science gets you to the objective truth," says Tyson. "That science may be our only hope to save us from our shortsighted decisions that we are all part of today."

Dramatic computer-generated graphic visualizations are a highlight of the new season of *Cosmos*
Credit: National Geographic/Disney

DIVING AND DRIVING ON ICY MOONS

Rod Pyle



ONE STRATEGY FOR THE EXPLORATION OF ENCELADUS AND EUROPA

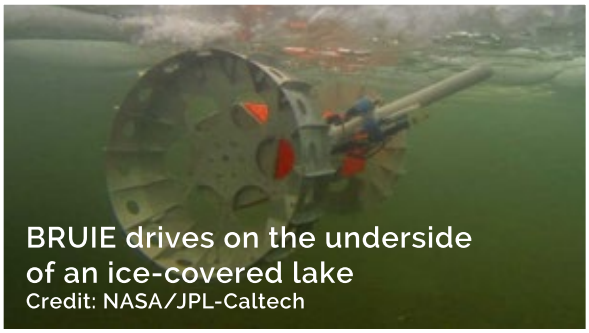
A diver tests BRUIE in a water tank at the Aquarium of the Pacific in Long Beach, California
Credit: NASA/JPL-Caltech

Over the past 60 years, NASA has explored the solar system from the sun to the Kuiper belt. While many of these missions, especially those beyond Saturn, have been one-shot flybys (such as the Voyagers and recently New Horizons), others have charted many of the moons of Jupiter and Saturn extensively by repeated orbital passes. The sole landing on these icy worlds was the Huygens probe, which parachuted to the surface of Saturn's moon Titan in early 2005 as part of NASA's Cassini mission, and which operated for about 90 minutes after touchdown.

The data gathered from a few of these moons has provided compelling evidence of possible warm oceans beneath their frozen surfaces, Saturn's Enceladus and Jupiter's Europa in particular. NASA would like to explore these subsurface seas, as they appear to offer promise for the potential of life. Between their internal geological activity, spurred by the tortuous gravitational complexities of Jupiter and Saturn's many moons that heat these cold worlds, and the watery plumes spouting from both, they are very compelling to planetary scientists (especially exobiologists).

There are a variety of missions under consideration for these moons, the most immediate of which is the Europa Clipper, currently slated for launch in 2025. But this mission, to be managed by NASA's Jet Propulsion Laboratory (JPL) and Johns Hopkins

BRUIE prepares for an underwater test in an icy environment
Credit: NASA/JPL-Caltech



BRUIE drives on the underside of an ice-covered lake
Credit: NASA/JPL-Caltech

University, is another orbiter and will not be sporting a lander.

Most current plans call for one of two approaches to learn more about the water within such a moon. The first is by sampling the geyser-like plumes that erupt from fissures and cracks on these moons, as the Europa Clipper will do, while the second involves landing on their icy surfaces and taking small samples aboard the lander for analysis. The latter approach of landing there presents much greater challenges than an orbiter collecting water from a plume.

More challenging still, however, would be the direct exploration of the oceans themselves. JPL is working on a variety of approaches to accomplish this. All of them hold some promise, but each approach requires a way to get through the ice to the water below. A number of technologies are being considered for this role, including exotic nuclear-powered "melters," but all face significant challenges. Europa's ice shell is thought to be as much as six to 19 miles (10 to 30 kilometers) thick, and Enceladus's between 19 and 25 miles (30 and 40 km) thick, so reaching the ocean below will likely be difficult.

One alternate possibility is to let nature do most of the work, by using the fissures that already allow bits of the ocean to escape via plumes. A few designs are being investigated, but when one is sending a small probe down a hole tens of miles deep, simplicity and flexibility are important assets. Once you do reach that warm ocean, reliability and autonomy will be critical.

Andrew Klesh, who recently oversaw the MarCo cubesat program (the two tiny probes that flew to Mars with the InSight lander, providing a radio link during the landing process), has been working on a project that combines both simplicity and flexibility to design "buoyant rovers." The rover is called BRUIE, for Bouyant Rover for Under-Ice Exploration, and is specifically designed to not only work while submerged,

but also to do so with a high degree of autonomy. “To get under the surface of Europa or Enceladus, we need to find the quickest way in,” says Klesh. He’s currently looking for ways to use natural points-of-entry to sub-ice oceans.

BRUIE is a submersible that is being tested in icy oceans on Earth. It has been autonomously probing underwater ice caves in Alaska with scanning LIDAR and visual imaging to prepare for more complex exploration of the gas giant moons. These test runs have taken place in watery holes called *moulins*—labyrinthine melt paths that can extend thousands of feet through glaciers into sub-ice ocean water. Melted water at the surface of the glacier is warmer than the ice and melts into it, carving different formations. Some moulins extend all the way through the glacier, creating a network of underwater passages.

This is one thing that makes BRUIE special. Rather than using a brute-force method to punch through a miles-thick ice shell, an evolution of this technology could navigate natural fissures that lead to the warm seas below. It might even use the channels marked by the plumes seen on Enceladus and Europa. As Klesh asks: “Can we map and navigate these subglacial lakes with robots? Are there accessible passageways hidden just beneath the surface?”

The BRUIE test robots are built with both commercially available components and custom 3-D printed parts, allowing for rapid-prototyping and quick revisions. Once the early prototypes were complete, Klesh and his colleagues took them to the Matanuska Glacier in Alaska for early tests. The robots were lowered into the frigid channels, allowing them to sink using controllable buoyancy while being maneuvered by small thrusters. While designed to operate autonomously when possible, the prototype probes were tethered to a surface control unit from which they could be manually navigated, and which recorded detailed measurements and data as they traversed the ice tunnels. This allowed Klesh and his colleagues to map these complex passageways with a compact LIDAR unit as they twisted and turned through the mass of the glacier.

A second robotic design has been developed by Klesh’s team to explore the bodies of water beyond the channel through the ice. It is a buoyant three-wheeled rover designed to operate completely autonomously that looks like a small paddle-wheeled tricycle. When

Andrew Klesh lowers a BRUIE prototype into a lake in Alaska
Credit: NASA/JPL-Caltech

A digital map of an underwater ice cavern, reconstructed from data provided by BRUIE as it navigated the tunnel
Credit: NASA/JPL-Caltech

dropped through a hole in the ice (in this case, sawed by Klesh and his colleagues), it actually drives along the underside of the ice sheet, like an inverted Mars rover, recording visual and other data as it goes.

Some of these field tests were controlled using a tether, with Klesh and others operating joystick control units, while others were autonomous. Still others were controlled remotely from JPL in Pasadena, California. "This was the first time an under-ice vehicle had been operated via satellite," Klesh said—researchers at JPL, over 3,000 miles (4,830 kilometers) away, were actually using a satellite to control the rover, adding more off-planet fidelity to the testing.

Current iterations of BRUIE can be operated at depths beyond 700 feet (over 200 meters), and with ever-increasing autonomy. More work remains to improve autonomous operation and resistance to the extreme cold and high radiation found in the outer solar system. But early experiments such as BRUIE are critical to developing, testing, and improving such technologies. "A lot of what we do in deep space is applicable to the ocean," Klesh said. "This is an early prototype for vehicles that could one day go to Europa and other planetary bodies with a liquid ocean covered by ice. It's ideal for traveling under the frozen crust of an icy world."

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FOREWORD BY BUZZ ALDRIN

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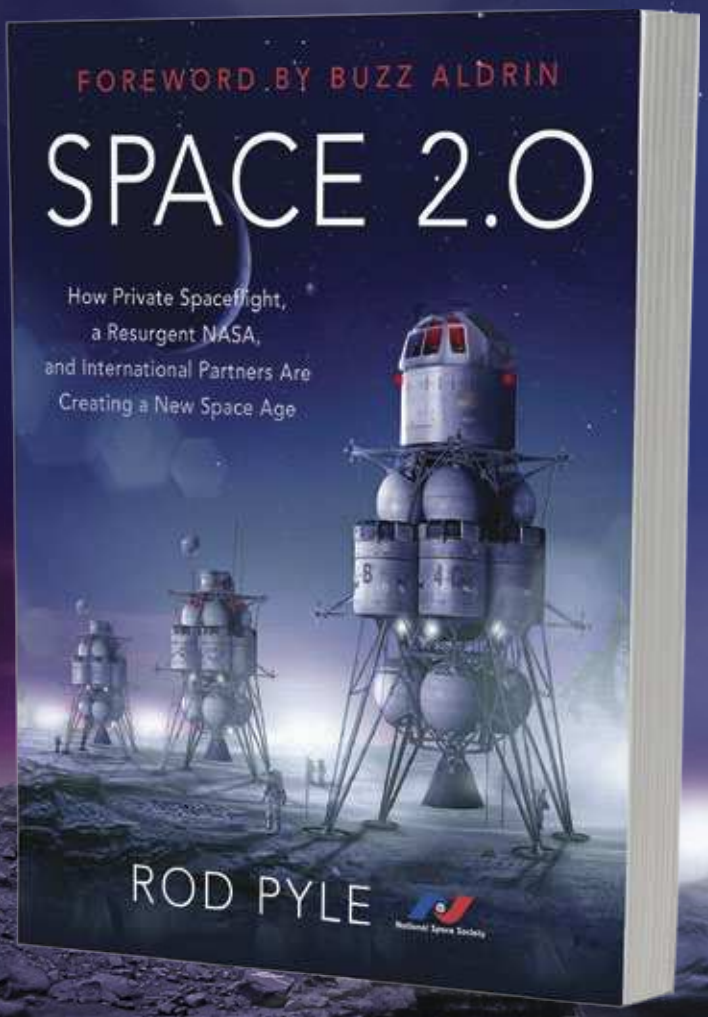

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A DRAG IN THE

Cislunar Space

China's Rise and America's Challenge

John F. Kross

Credit: Rod Pyle

Competing powers have sought the high ground for strategic and commercial advantage from the beginning of recorded history, and for good reason—those who controlled it have often set the rules and benefited accordingly. In the 20th century, the high ground migrated from the land to the air, and ultimately into space. During that time, the United States largely dominated the air and near-space environment, and no single nation could rival their hold on those realms.

However, a new competitor is emerging in the 21st century, and the high ground is expanding to include cislunar space (the region from low-Earth orbit to the Moon). The country preeminent in that sphere will wield enormous power and influence, so the stakes could not be higher, politically, militarily, and economically.

THE STAKES

Analysts have recognized the propaganda potential of space achievements for decades. Standing before a crowd of 40,000 at Rice Stadium in 1962, President John F. Kennedy proclaimed, "the eyes of the world now look into space, to the Moon and to the planets beyond, and we have vowed that we shall not see it governed by a hostile flag of conquest." A major justification for the Space Race between the United States and the Soviet Union was its propaganda potential. The military value of space extends back even further, as modern rockets stem from missiles developed by Nazi Germany during World War Two. Today's soldiers rely on space-based assets for command-and-control, communication, reconnaissance, and navigation.

Commercially, the global space economy exceeds the gross national product of many countries. Estimates vary, but the Satellite Industry Association values it at nearly 360 billion dollars. The Space Foundation reckons the world's space economy exceeds 410 billion dollars, with the satellite industry accounting for three-quarters of the total. Currently, there are nearly 500 satellites in geosynchronous Earth orbit, mostly relaying data and communications. In medium-Earth orbit, navigation constellations (such as GPS, Galileo, and the recently completed Chinese *BeiDou*, or "Big Dipper,"

China's Long March 5 rocket
Credit: Wei Junghua

system) circle Earth. Below these are observation and reconnaissance satellites, and constellations of internet telecommunications satellites, including SpaceX's Starlink system. The International Space Station (ISS) is there as well, and NASA has signaled its intent to partially commercialize the orbiting outpost.

In the coming decades, geosynchronous Earth orbit will continue to be a prized location, and the number of satellites in lower Earth orbits will expand into the tens of thousands as the quantity and scale of space operations increase. New applications may also arise beyond familiar communications, navigation, and remote sensing. Cislunar space, including the lunar surface, could well become a hub for new applications, such as harvesting and processing materials and energy, and locating propellant storage depots. Given these trends, officials at the Department of Commerce have projected the space economy will be worth at least one trillion dollars by 2040.

CHINA ASCENDANT

There is little question that, at present, the United States is well positioned to exploit the potential of cislunar space. It is the only country to have made crewed forays to this region, albeit only briefly during the Apollo era, and possesses an unmatched stable of launch vehicle and satellite suppliers. China is catching up rapidly, however.

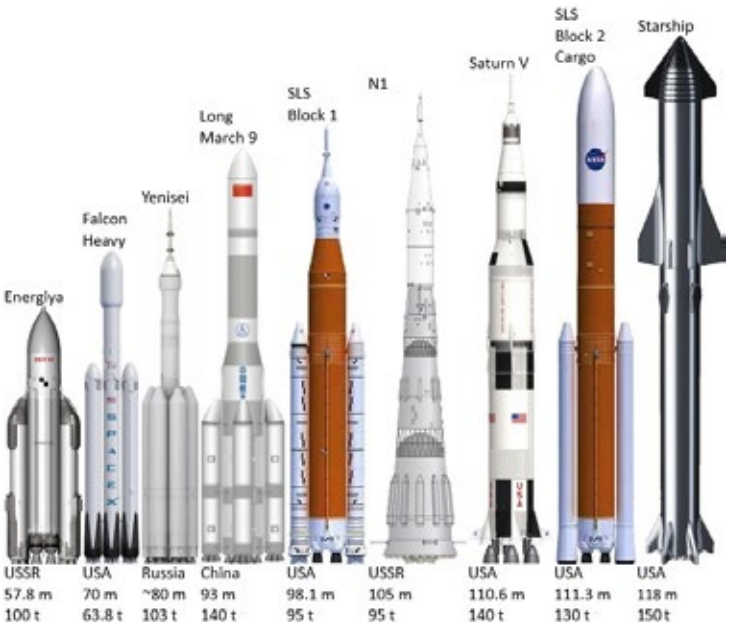
China's space program dates back 60 years and its entry into human spaceflight started with the launch of a "taikonaut" (Chinese astronaut) in 2003, making it the third country to send people into low Earth orbit. Since then, China has become a space juggernaut. In the previous two years, China has launched more orbital missions than any other nation, including the United States, and promises at least 40 orbital launches in 2020. The *Chang Zheng* ("Long March") family of launch vehicles has been the country's workhorses, but future plans by the China National Space Administration (CNSA) and its main contractor, the China Aerospace Science and Technology Corporation (CAST), depend upon a new generation of rockets.

The new Long March 5 rocket is roughly equivalent to United Launch Alliance's Delta IV Heavy in payload capacity and is crucial to China's plans over the next decade. These include Mars probes, lunar sample return missions, a space station, and a solar polar orbit telescope. The 187-foot (57-meter) tall vehicle is powered by four kerosene/liquid oxygen-fueled boosters and high-energy cryogenic hydrogen engines in the first and second stages, with an optional hypergolic third stage. It has a payload capability of nearly 31,000 pounds (14 metric tons) to geostationary transfer orbit (GTO) and 18,100 pounds (8.2 mT) to translunar injection (TLI). The Long March 5B variant will be able to deliver 55,000 pounds (25 mT) to low-Earth orbit (LEO) and is slated to loft the 44,000 pound (20 mT) *Tianhe* ("Heavenly Harmony") central module of a Chinese space station in 2021.

Development of the Long March 5 hasn't been easy, but Chinese engineers have doggedly pursued their space

The Chang'e 4 lander
Credit: CNSA

Taikonauts Nie Haisheng, Zhang Xiaoguang and Wang Yapin preparing to fly aboard Shenzhou 10
Credit: CNSA



Comparative lineup of modern rocket boosters, with the Long March 9 fourth from left
Credit: CNSA

ambitions. The rocket's second launch in July 2017 failed due to a faulty engine oxidizer turbopump. However, it was redesigned—at least twice—by adding guide vanes and nickel superalloys, and with the fixes, the rocket successfully returned to flight in December 2019, lofting the experimental *Shijian*-20 communications satellite.

The country's launch vehicle ambitions haven't stopped there. Responding to the American-led revolution in rocket reusability, China will debut the Long March 8 this year employing vertical landing techniques pioneered by SpaceX. The launcher can deliver 17,000 pounds (7.7 mT) to LEO and 6,200 pounds (2.8 mT) to GTO. Like the Falcon 9 and Falcon Heavy, the first stage of the Long March 8 will burn residual propellant to land vertically with the aid of grid fins—boosters on the rocket will detach and land by parachute. Such reusable capability will make China more competitive in the commercial launch market and avoid spent stages falling on populated areas (as has happened on several occasions). The China Aerospace Science and Technology Corporation intends to extend reusability to all its rockets by 2035.

The Long March 8 shares its first stage with the Long March 7, a kerosene/LOX-fueled vehicle, which debuted in 2016. This rocket and its variants are slated to become the backbone of China's rocket fleet, eventually comprising about 70 percent of all Chinese launches, including human missions. The vehicle has already launched the *Tianzhou* ("Heavenly Ship") cargo carrier and will ultimately supplant the Long March 2F as a crew-rated launch vehicle. Using up to four boosters, the Long March 7 is roughly equivalent to the Atlas V or Delta IV, with a payload capacity of 29,800 pounds (13.5 mT) to LEO and 12,100 pounds (5.5 mT) to GTO. A modified version will feature a cryogenic hydrogen/oxygen third stage to boost heavier payloads.

The United States' vibrant commercial space sector—particularly NewSpace players like SpaceX and Blue Origin—provides a significant competitive edge, and consequently, China has tried to copy that model. In fact, the number of "private" companies working in China's space industry has nearly tripled over the past three years. (many are private in name only, as most of these companies appear to have close ties to the Chinese military). "The truly commercial Chinese space program has been taking off ... [and could] make this a transformational era in China's space," predicted Jonathan McDowell, an astrophysicist at the Harvard-Smithsonian Center for Astrophysics. Commercial players include LandSpace, OneSpace, LinkSpace, and iSpace, which became the first private Chinese firm to achieve orbit in 2019.

Liftoff of a Long March 5 booster
Credit: K.C. Lee

Chinese media have reported there were 141 registered commercial space companies in China in 2018, including rocket and satellite manufacturers, all bolstered by a dual "civil-military fusion" national strategy, a joint effort of commercial and military interests.

The authorities in Beijing have carved out room for private firms—within boundaries—by encouraging private investment and making government launch sites and facilities available. However, the precise relationship between the central authorities and these ostensibly private companies is blurred. "The line between civil and military is markedly different in China than the United States or the rest of the Western world," acknowledged John Horack, the Neil Armstrong Chair in Aerospace Policy at Ohio State University. The private Chinese space startups are focused on microsatellites, reusable rockets, and low-cost launches, leaving military and high-profile missions to traditional state-run industries.

JADE RABBITS AND TAIKONAUTS

Robotic spacecraft bearing the Chinese flag have already orbited the Moon and landed on the lunar surface. Last year, *Chang'e 4* (named after the Chinese Moon goddess) made the first-ever soft landing on the far side of the Moon. It carried the *Yutu-2* ("Jade Rabbit") lunar rover, which was deployed about 12 hours after touchdown. Since then, *Yutu-2* has traversed 6.5 miles (10.5 kilometers) and become the longest-operating Moon rover ever. To facilitate communication with Earth, the Chinese also launched the *Queqiao* ("Magpie Bridge") relay satellite, which became the first communication satellite operating in halo orbit near the second Earth-Moon Lagrange point.

However, Beijing's lunar plans go much further. The country will launch the *Chang'e* 5 sample-return mission in 2020, retrieving two-to-four pounds (one-to-two kilograms) of lunar material, with the aid of the powerful Long March 5 launch vehicle. More missions are slated to follow. "Experts are still discussing and verifying the feasibility of subsequent projects, but it's confirmed that there will be another three missions after *Chang'e* 5," noted Wu Yanhua, deputy head of the China National Space Administration.

According to these proposals, the *Chang'e 6* mission will return samples from the south polar region of the Moon, while *Chang'e* 7 will survey the terrain and physical composition of the regolith there. The aims of the *Chang'e* 8 mission hint at China's grander ambitions—in

addition to science experiments, the mission will assess technologies central to a sustained human presence on the Moon. "For example, can we build houses on the Moon with lunar soil using 3D printing technology?" posited Wu. "We hope that *Chang'e* 8 will help test some technologies and do some exploring for the building of a joint lunar base."

These ongoing series of robotic lunar missions represent a logical progression meant to pave the way for human missions to the Moon. A blueprint released by Beijing in January underlines the country's lunar plans for the 2020s. In addition to orbiting, landing, and returning samples, China is planning a fourth phase of lunar exploration according to Peng Jing, deputy chief designer of the *Chang'e*-5 probe with the China Academy of Space Technology. "We temporarily [identify] the follow-up mission as the fourth phase of the lunar exploration program. The preliminary goal we set is to establish a lunar research base through two-to-three missions. In the foreseeable future, it will be an unmanned scientific research base for the long term where people would make a short visit," Peng said. CNSA head Zhang Kejian has promised that the country will land taikonauts on the Moon's south pole "within the next 10 years" (by 2030).

In support of that effort, Beijing is developing a next-generation spacecraft capable of deep-space travel. A recent video from the China Academy of Space Technology showed a two-element spacecraft consisting of a crew module and service module 30 feet (9 meters) long and weighing about 47,620 pounds (21.6 mT). This is slightly less than the mass of NASA's Orion spacecraft and the European Service Module (ESM). As with Orion, the unnamed Chinese crew module is shaped like truncated cone with blunt spherical aft end. The service module will supply power, propulsion, and life support for up to six taikonauts.

Until now, China has relied upon the Soyuz-inspired *Shenzhou* ("Divine Vessel") spacecraft for low-Earth orbiting missions. However, *Shenzhou* is not designed for the radiation environment of deep space nor high-speed reentry. To analyze reentry and landing, an as-yet-unnamed deep space crew module is slated for launch aboard the Long March 5B into an elliptical orbit with apogee of 5,000 miles (8,000 kilometers). Preliminary development is also in progress for a super-heavy-lift rocket, the Long March 9, with thrust similar to the Saturn V or Space Launch System (SLS). Several variants have been proposed, with the largest featuring four liquid-fuel boosters and payload capacity of 309,000 pounds (140 mT) to LEO and 110,000 pounds (50 mT) to Lunar Transfer Orbit. In 2018, a Chinese aerospace official confirmed testing of a scaled first-stage Long March 9 engine.

THE EAGLE AND THE DRAGON

China's meteoric rise as a space power reflects the ambition of the central authorities in Beijing to reap the benefits of cislunar space and become the United States' peer militarily, diplomatically, and commercially. Wu Yanhua asserted that Beijing's aim is to become a major global space power by 2030, and official white papers produced by China's State Council have detailed the country's strategic plan to establish China as a leading space power. Chinese officials have also compared the Moon and Mars to nearby strategic islands in the South China Sea, revealing how geopolitically important these destinations are in the context of China's territorial "core interests."

Beijing has both the financial resources and, importantly, the political will to assume a powerful position in cislunar space. To achieve this end, the country has implemented a civil-military fusion strategy that leverages key dual-use industries, such as aerospace, to give China a competitive edge against the United States. They have also adroitly adapted organizational models that historically underlie American space success. For example, China is creating a system that resembles Western defense procurement in which government agencies set policy but contract operational requirements to non-government-managed entities. Chinese space officials also recognize the benefit of affiliated science and technology centers analogous to the Jet Propulsion Laboratory (JPL) and Johns Hopkin's Applied Physics Laboratory (APL). Recently, for example, the University of Macau's Space Exploration and Science Center was created to aid deep space exploration.

China's space efforts are championed by a unified political structure that sets and single-mindedly pursues long-term goals, compared to the short-term outlook that has beset American space efforts for many decades. Partisan transitions in Congress and the White House have all too often led to radical resets in policy and cancellation of existing projects (e.g., the cancelled Constellation program and Asteroid Redirect Mission) causing delays and wasted effort. However, the United States has a mature space industry and level of entrepreneurship that is unrivaled by any current competitor, and it is not clear if China can match extraordinary NewSpace enterprises such as SpaceX and Blue Origin.

For now, the United States leads in space, but China's ascent raises questions about the relationship between these space powers. Congressional prohibitions on space cooperation with China—as stipulated by the 2011 Wolf Amendment to a NASA appropriations bill—is a legal constraint to cooperation. The International Traffic in Arms Regulations (ITAR) also restrict NASA's ability to cooperate directly with China on space exploration. Despite these limitations, the next few years will witness the rapid expansion of human activity into cislunar space. Whether it will be in the spirit of competition or cooperation is unknown. More certain is that the nation that spearheads that drive and occupies the "high ground" will profoundly shape the future of space development.

GAMING SPACE SETTLEMENT

TERRAGENESIS

Melissa Silva

Key players in the new simulation game *TerraGenesis*
Credit: Edgeworks Entertainment

Films like *The Martian*, *Interstellar*, and television series like *The Expanse* piqued the science fiction community's interest for their supposed dedication to scientific accuracy. Alexander Winn, CEO of Edgeworks Entertainment, took this interest one step further and developed a game based on a premise he had yet to see in another venue: actually terraforming a planet.

The game, called *TerraGenesis*, allows players to manipulate each factor involved in terraforming to build and manage settlements on other worlds. "I wanted to make a game that I would want to play," laughs Winn. Terraforming is a controversial topic—a hypothetical process by which the surface temperature, atmosphere, topography, and ecology of a celestial body is altered through human engineering so it more closely resembles Earth and becomes a more habitable environment. The concept is at the heart of many science fiction stories, including Kim Stanley Robinson's *Mars* trilogy, which also served as the primary inspiration for *TerraGenesis*.

Winn received a degree from the University of Southern California's prestigious film school, but his interest in web development started in high school when he and a friend created the immensely popular Halo 2 machinima series *The Codex*. Winn continued developing applications and games as a hobby until launching *TerraGenesis*, which almost immediately went viral. "*TerraGenesis* had the advantage of having almost no competition," says Winn of the game's success. "Every day, it was getting more downloads than the last."

Newcomers to *TerraGenesis* will quickly notice the intricate level of detail that went into the game's development. "A lot of the science I just knew, because I geek out about this stuff. But there were a lot of specific things I had to do some research on ... and some of that

information is not readily available." The challenges Winn encountered included determining how Venus' surface temperature would change if a player were to strip away its atmosphere. In addition, he found he had to account for some knowledge gaps, especially when it came to surface maps of celestial bodies which haven't been completely mapped yet, or remain to be mapped at all. Winn hired a cartographer who created fictionalized planets to develop the maps he'd eventually use in the game. "I love 'Easter eggs,' so that's what the science in the game is to me. The people who get it think it's great, and the people who don't, don't even miss it."

Winn's company just released version 5.0, the game's largest update since its initial release. This version includes seven new playable worlds, including "Historical Earths" and "Natives," where players can establish diplomatic relations with indigenous civilizations. These cultural aspects of the game were incredibly important to Winn, who was frustrated with the static nature of civilizations in other strategy and world-building games. "That's what the *Mars* trilogy was all about: value systems and cultural influences." In fact, Winn commented that the term "colonize" was completely dropped from the game. "Not only does it have incredibly horrific and negative connotations, but it doesn't even make sense in the context of the game. The term 'colonize' has a legal connotation, and if the victory condition is to establish independence from Earth, then the term really doesn't make sense in that context." Instead, players aim to "homogenize" a planet, or make it suitable for humans.

Winn recognizes that terraforming is a controversial topic, and some academics and researchers believe it would be unethical for humans to alter the chemistry of a planet for our use. He's accounted for that in the game; one of the four factions you can play as in it is "anti-terraforming," where the objective is to prevent contamination and preserve the balance of the planet's natural chemistry as the player's cities grow.

As for terraforming, despite agreeing with recent claims from researchers who say we do not possess the technology necessary to terraform Mars, Winn believes we'll get there eventually. "No disrespect to Bill Nye. I mean, I grew up with the guy, but I think the sheer distance will force human beings to become more self-sustaining" (Nye has referred to terraforming as "science fiction"). Winn is now working on new, exciting projects for his company and enjoying seeing the popularity of *TerraGenesis* grow. "We don't need to dumb things down … real science is exciting and it's important to keep it in fiction." Thanks to Edgeworks Entertainment's focus on science, *TerraGenesis* has even become a tool for the classroom; Winn says he receives messages constantly from students and educators alike. "The kids say, 'I have to play this game for a class, can you tell me how to beat it?'"

TerraGenesis is available on Google Play and Apple's App Store. Be warned, however; the game is highly addicting and sure to stump even the most veteran strategy or world-building game players. It has educational value as well, so don't be surprised if you learn a thing or two along the way.

Screen captures from *TerraGenesis*
Credit: Edgeworks Entertainment

FRAU IM MOND

A WOMAN ON THE MOON

John F. Kross

Twelve people have walked on the Moon. Virtually all were fighter or test pilots, most were in the military, and all were men. Fifty years later, NASA has pledged to make the next lunar foray more inclusive. Project Artemis—named after the twin sister of Apollo—aims to land the "first woman and the next man" on Earth's satellite by 2024.

The history of women in space is long but relatively exclusive. Of the nearly 600 space travelers to date, slightly more than 10 percent have been women. The Soviet Union started early, sending 26-year old Valentina Tereshkova on a solo flight in June 1963. The United States waited another 20 years before NASA astronaut Sally Ride boarded space shuttle *Challenger* to become the first American woman in space. Since then, American women have dominated the ranks of female space travelers with more than 50 making the journey to orbit.

Today, NASA has 17 female astronauts, including five from the newest astronaut class. They range from a submariner, to a geologist, and a test pilot, with specializations covering sea, land, and air. Advanced degrees are the norm (master's degrees and doctorates including M.D. and Ph.D.). All of them wear pilot's wings. "If we're going to make [the Moon landing] happen in 2024, we will need a highly skilled, already trained astronaut," explained NASA administrator, Jim Bridenstine. "I will tell you this, we have great women at NASA right now."

According to Bridenstine, prospective women Moonwalkers already fill the agency's ranks. "She is already in the astronaut corps," he hinted. "Somebody who has been proven, somebody who has flown, somebody who has been on the International Space Station already." NASA astronaut Christina Koch has logged more time aboard the ISS than any other woman. She spent 328 days on the orbiting outpost, breaking Peggy Whitson's record of 288 days. During her tour, Koch circled the globe 5,248 times, conducted six space walks, and spent a total of 42 hours outside the station.

A week after returning to Earth, Koch told *Ad Astra* it is a "very exciting time to be part of the NASA family when we are looking to go back to the Moon … to go to stay, to go for all and by all … Of course, [I] or anyone in my office would be honored to be a part of that mission and … carry people's dreams even farther into space exploration … to go even deeper … I'm just excited that I'll probably know the first woman and the next man to walk on the surface of the Moon … Any of us would be ready and honored to accept that mission." As 2024 approaches, one or more women will be assigned seats on Artemis III, and will step onto the lunar surface. One of them will become the first woman on the Moon.

BIOGRAPHICAL SKETCHES OF FEMALE NASA ASTRONAUTS

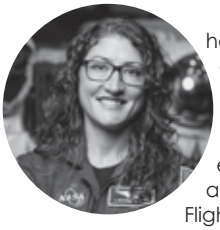
SERENA M. AUÑÓN-CHANCELLOR was selected as a NASA astronaut in 2009. She was trained as a medical doctor and is board certified in both Internal and Aerospace Medicine. Auñón-Chancellor served as a Flight Engineer on the International Space Station (ISS) for Expedition 56/57 logging 197 days in space.

KAYLA BARRON was selected by NASA to join the 2017 Astronaut Candidate class and graduated to active status in 2019. She is a graduate from the U.S. Naval Academy and subsequently earned a master's degree in nuclear engineering. Barron was a member of the first class of women to serve aboard submarines. She has been assigned technical duties in the Astronaut office while awaiting a flight assignment.

ZENA CARDMAN entered the Astronaut Candidate class in 2017 and successfully completed two years of astronaut training in 2019. Cardman earned a master's degree in marine sciences and has multiple field experiences on Antarctic expeditions and research vessels. She is eligible for a flight assignment and has been given technical duties in the Astronaut office.

TRACY CALDWELL DYSON has been a NASA astronaut since 1998. The California native earned a Ph.D. in physical chemistry and is a veteran of two space flights. In 2007, Caldwell Dyson flew aboard the space shuttle *Endeavor* on STS-118. In 2010, she served as a Flight Engineer on ISS Expedition 23/24. She has logged more than 188 days in space, including over 22 hours on three spacewalks.

JEANETTE J. EPPS was selected as a NASA astronaut in 2009. The New York native received a Ph.D. in aerospace engineering and was a NASA fellow during graduate school. Prior to joining NASA, Epps was a Technical Intelligence Officer for the Central Intelligence Agency (CIA). She currently serves in the ISS Operations Branch in support of space station crews. Epps has no spaceflight experience.



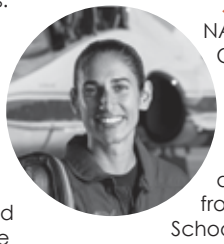
CHRISTINA H. KOCH has been a NASA astronaut since 2013. She graduated with a master's degree in electrical engineering and worked at NASA Goddard Space Flight Center on missions studying cosmology and astrophysics. After conducting research in the United States Antarctic Program, Koch contributed to instruments studying radiation for NASA missions, including the Juno and Van Allen probes. As an astronaut she flew onboard the ISS as part of Expedition 59/60 and Expedition 61, where she participated in the first all-female spacewalk with fellow NASA astronaut Jessica Meir. In February, Koch set a record for the longest single spaceflight by a woman with a total of 328 days in space.

NICOLE AUNAPU MANN was selected to be a NASA astronaut in June 2013. Her educational background includes a master's degree in mechanical engineering with a specialty in fluid mechanics. Mann was commissioned as an officer in the United States Marine Corps in 1999 and earned naval aviator wings in 2003. She is a graduate of the United States Naval Test Pilot School and has accumulated more than 2,500 flight hours in 25 types of aircraft. Mann is currently training for a crew flight test of Boeing's Starliner spacecraft.

K. MEGAN MCARTHUR became a NASA astronaut in 2000. She holds a Ph.D. in oceanography and performed research activities at the Scripps Institution of Oceanography. McArthur served as a Mission Specialist aboard STS-125, the final space shuttle mission to the Hubble Space Telescope. In completing her first space mission, McArthur logged almost 13 days in space. She currently provides support to crews in training and aboard the ISS.

ANNE C. MCCLAIN was chosen as a NASA astronaut in 2013. The Washington native attended West Point and subsequently earned master's degrees in aerospace engineering and international relations. Lieutenant Colonel McClain has more than 2,000 flight hours in 20 different aircraft. She most recently served as a Flight Engineer on the ISS for Expedition 58/59, where she logged 204 days in space and conducted two spacewalks totaling 13 hours.

JESSICA U. MEIR has been a NASA astronaut since 2013. She holds a master's degree in space studies and a Ph.D. in marine biology. From 2000 to 2003, Meir worked for Lockheed Martin's Human Research Facility, where she also served as an aquanaut in an underwater habitat for NASA Extreme Environment Mission Operations (NEEMO). She is currently onboard the ISS on her first spaceflight as part of Expedition 61/62, during which she took part in the first all-female spacewalk with NASA astronaut Christina Koch.



JASMIN MOGHBELI entered NASA's 2017 Astronaut Candidate class and successfully finished two years of training. The New York native earned a master's degree in aerospace engineering from the Naval Postgraduate School. She is also a distinguished graduate of the U.S. Navy Test Pilot School with more than 1,600 hours of flight time. She awaits a flight assignment while carrying out technical duties in the Astronaut office.

LORAL O'HARA was selected to join NASA's 2017 Astronaut Candidate class. She graduated to active astronaut status in 2019. O'Hara holds a master's degree in aeronautics and astronautics. As a student she participated in NASA's KC-135 Reduced Gravity Student Flight Opportunities Program and the internship program at NASA's Jet Propulsion Laboratory. She has been assigned duties as an ISS CAPCOM while awaiting a flight assignment.

KATHLEEN RUBINS became a NASA astronaut in 2009. Her educational background includes a Ph.D. in cancer biology. She completed her first spaceflight on ISS Expedition 48/49, where she became the first person to sequence DNA in space. Rubins also grew heart cells in cell culture, and performed quantitative, real-time microbiome experiments in orbit. She spent 115 days in space and conducted two spacewalks totaling almost 13 hours.

JESSICA WATKINS entered NASA's Astronaut Candidate Class in 2017 and holds a Ph.D. in geology. She graduated to active astronaut status in 2019. Watkins previously worked at NASA's Ames Research Center and Jet Propulsion Laboratory and was a collaborator on the Mars Science Laboratory rover Curiosity. She awaits a flight assignment and is carrying out technical duties in the Astronaut office.

SHANNON WALKER was selected to be a NASA astronaut in 2004. Her educational accomplishments include a Ph.D. in space physics. Walker worked on several space shuttle missions as a Flight Controller in the Mission Control Center. In 2010, the Texas native served as a Flight Engineer for Expedition 24/25, a long-duration mission aboard the ISS that lasted 163 days.

STEPHANIE D. WILSON is a veteran of three spaceflights (STS-120, STS-121, and STS-131) and has logged more than 42 days in space. She earned a master's degree in aerospace engineering and worked at Martin Marietta for two years. Selected by NASA as an astronaut in 1996, she flew her first space shuttle mission in 2006, and subsequent shuttle missions in 2007 and 2010. As a member of the Astronaut office she is currently the Mission Support Crew Branch Chief.

SUNITA L. WILLIAMS was selected as an astronaut by NASA in 1998 and is a veteran of two ISS missions (Expeditions 14/15 and 32/33). She is currently training for the first post-certification mission of Boeing's Starliner spacecraft—the second crewed flight for that vehicle—and her third long duration flight aboard the ISS. Williams attended the U.S. Naval Academy and holds a master's degree in engineering management. She graduated from the United States Naval Test Pilot School and was later an instructor in the Rotary Wing Department. Williams has spent a total of 322 days in space and is second on the list of total cumulative spacewalk time by a female astronaut (with 50 hours and 40 minutes).

A DRAGONFLY ON TITAN

Jordan Strickler

Landing sequence for NASA's Dragonfly probe at Titan
Credit: NASA

The text was from Ken Hibbard's Johns Hopkins University Applied Physics Laboratory colleague Elizabeth "Zibi" Turtle, Principle Investigator on the Dragonfly mission. "Hey, when you have the chance, can you swing by my office?" As soon as Turtle, Mission Systems Engineer for the project, reached her office, she was on the phone with NASA. Shortly after ending the conversation, she called Doug Adams, Spacecraft Systems Engineer, who was boarding a flight out of Los Angeles International Airport.

"Zibi said, 'we won!'" laughs Adams while recounting the call. "I said, 'we won what?' It took five minutes of her convincing me that she wasn't pulling my leg." Dragonfly was going to Titan. The one-billion-dollar mission, which is slated to rocket toward Saturn's largest moon in 2026, will not be the first rotorcraft to visit an alien world—that distinction will be going to the Mars Helicopter, which will hitch a ride with the Mars 2020 rover. However, it will be the first time that a flying rotorcraft will undertake detailed scientific research.

Saturn's largest moon has long intrigued scientists with a chemical composition that is believed to mirror that of a primordial Earth. Researchers hope that the samples evaluated by Dragonfly will help them to understand the chemical environment which gave rise to life on Earth, as well as determine the potential

habitability of Titan today. The probe will also search for any signs of microbial life.

Titan is located approximately 760,000 miles (1,223,100 kilometers) from Saturn and is the planet's largest satellite. The Dragonfly mission will be the most detailed exploration ever undertaken there. The moon was previously visited by the two Voyager spacecraft in 1979 and 1980; however, the dense atmosphere obscured the surface at visible wavelengths. In 1994, the Hubble Space Telescope imaged the moon at longer near-infrared wavelengths, revealing bright and dark regions on the surface.

The real details remained a mystery until Cassini made its visit a decade later. Using radar and imaging at near-infrared wavelengths, the orbiter was able to glimpse below the hazy

Dragonfly will be able to lift, hover, and relocate as it explores Titan's surface
Credit: NASA

atmosphere. In more than 100 flybys, it mapped much of Titan's surface and was able to make detailed studies of its atmosphere, as well as providing evidence of a global, salty ocean below the moon's icy crust. With Cassini came the European Space Agency's Huygens probe, which parachuted to Titan's surface in 2005, measured its winds and atmosphere, and imaged a small area of the surface in close-up detail.

Cassini showed us that Titan's surface has lakes, rivers, and even seas of liquid ethane and methane, as well as vast expanses of what appear to be sand dunes, but are probably composed largely of granular organic particles. Its climate is such that methane can form clouds and rain, as the moon's atmosphere is four times denser than Earth's and its gravity is approximately one-seventh that of our planet, which means Titan's raindrops fall much slower. Rainfall on Titan is rare, however—it may be hundreds of years between showers at a given location. Due to the fact that it is so far from the sun, Titan's surface temperature hovers around a chilly 290 degrees Fahrenheit (179 degrees Celsius below zero). Its surface pressure is also 50 percent higher than Earth's, perfect for a rotorcraft such as Dragonfly.

Titan's atmosphere is composed of around 95 percent nitrogen with about five percent methane. When exposed to sunlight, those methane and nitrogen molecules are split apart by ultraviolet light and recombine to form a variety of complex organic compounds. Organic molecules are the building blocks for life as we know it, and their presence on Titan (and possible compounds they could form) is promising.

"Titan is a really fascinating place," says Turtle. "It's the only moon that has a dense atmosphere. It's surprisingly Earth-like, which is intriguing. [Titan] was always this really mysterious place and one of the things that was fascinating is that it was revealed to have very Earth-like processes in the atmosphere and on the surface. It's also chemically very much like our own early planet, and it gives us the opportunity to study the pre-biotic chemistry that took place before biology developed here. We don't necessarily have the opportunity to study that here on Earth."

The ten-foot (three meters) long Dragonfly rotorcraft will land in dune fields near Titan's equator. From there, it will use its eight rotors to traverse dozens of sites across Titan's surface,

The Dragonfly team testing an early prototype
Credit: NASA

taking samples and performing analysis. “We know from the measurements of the upper atmosphere that there are very complex organic molecules,” explains Turtle, “So we want to understand how these molecules have interacted on the surface, especially if they’ve been able to be in contact with liquid water.”

As the probe enters the moon’s atmosphere, a drogue parachute will open at Mach 1.5 and slow Dragonfly for approximately 90 minutes until it reaches an altitude of two miles (just under four kilometers). Then the main parachute will deploy, followed by heat shield separation so that Dragonfly can acquire the ground with its range sensing instruments. In all entry, descent, and landing (EDL) should take about two hours. “The atmosphere is very thick,” says Adams. “We have a sequence where we do a direct entry into the atmosphere and we deploy a drogue parachute in conditions very similar to Mars as far as the supersonic deployment, and that’s not an accident. Interestingly, it takes about six minutes to get to those conditions after we encounter the atmosphere and that’s about the same time as the entire EDL on Mars, so it is much slower.”

Initially plans for Dragonfly called for a flotation ring that would allow the craft to land on one of Titan’s lakes. However, a more conventional box-with-skids layout soon emerged after it was decided that the areas between the dunes would be the focus of the mission. Besides offering a flat landing spot, the dunes could offer a wealth of information. “On Titan, the dunes are made of sand-sized particles, as one might expect, but the sand is [probably] organic,” said Turtle. “We don’t know how you form organic sand-sized particles, so that is one mystery. If there are different types of reactions going on, it will all be collected between these dunes, and we’ll be able to get measurements of sand and it will be very widely sourced.”

For robotic spacecraft, energy is everything. Titan is roughly 886 million miles (1.4 billion kilometers) from the sun, and at that distance solar energy is approximately 100 times weaker than on Earth. Additionally, the hazy atmosphere diminishes light by a factor of 10, so solar panels were ruled out and a nuclear power supply was chosen instead. “We use all of the waste heat from the MMRTG (multi-mission radioisotope thermoelectric generator) to keep the internal element of the lander warm in the cold environment,” Hibbard said. “Then we use the RTG (radioisotope thermoelectric generator) as a large charge source for a battery and most of the activities are done off the battery. That way we have thermal power that will sustain us for the surface lifetime.”

Unlike the Mars rovers (which spend a lot of time on the move), Dragonfly would be stationary most of the time, conducting experiments, transmitting data, and charging. “We’ll be communicating with Dragonfly so we’ll tell it where its initial landing site is, and in the longer term, we are going to work toward a large crater that is to the north of the initial landing site,” Turtle said. “That’s because in the impact cratering process, liquid water will be formed when the target is melted because Titan’s crust is made of water-ice and that is melted during the impact. So the impact crater is potentially a good location for the organic material to have mixed with water.”

Thanks to Dragonfly’s dual-quadcopter design and the thick atmosphere and low gravity, the drone should be able to fly at least 90 miles (145 kilometers), more distance than was covered by all of the Mars rovers combined. Dragonfly will also be able

navigate rugged terrain much faster and with less risk of damage than driving across the surface.

Data collected from the mission will allow researchers to assess the chance of Titan's habitability and see how far its chemistry has advanced toward something potentially biotic. Evaluation of the samples will attempt to pick up traces of water- or hydrocarbon-based life. Mass spectrometry will reveal atmospheric and soil composition, and gamma-ray spectrometry will be used to probe into the chemical composition of the shallow sub-surface. A suite of meteorology and geophysics sensors will record wind, pressure, temperature, and seismic activity, as well as a host of other factors. Finally, eight different cameras will let scientists peer at the nature of the moon's surface. These cameras will provide for forward and downward as well as ground and in-flight pictures. A microscopic imager aboard can inspect the surface material down to a sand-grain scale, while panoramic cameras will be able to survey sites in detail after landing.

"The primary objective is to understand the chemistry on Titan," said Turtle. "We know that all of the necessary ingredients for life as we know it are, or have been, present on the surface. There is this really rich photochemistry at the top of Titan's atmosphere; all of those organics fall out onto the surface where they have the opportunity to interact with each other and potentially interact with liquid water at sites of impact craters or possible volcanoes. So we know that all of those elements have been there for potentially millions of years and what we want to understand is what happens when you put all of these things together in this kind of environment. What kind of chemistry do you get? The reason we proposed a mobile vehicle is similar to the reasons that we send rovers to Mars—we want to be able to make measurements in parts of Titan that have had different histories. We also want to go where the materials have interacted in different ways so that we can get a sense of the chemistry … and how complex the organic synthesis gets."

Although the announcement was months ago, the news is still registering with much of the team. "Getting the green light is hard to put it into words," says Hibbard. "The shock is part of it. You're hearing them tell you that your project was selected, but there is a part of you that still doesn't quite believe it. There is an element of exhilaration and jubilation because you've worked so hard for something and to have it actually happen was almost difficult to imagine. Now, it's like 'wow, now we actually have to go do this.'"

The Dragonfly prototype goes through its paces
Credit: NASA

OUT

Sally Ride in space on her first space shuttle mission, STS-7
Credit: NASA

Gay Americans were persecuted throughout the 1960s, the decade when astronauts first flew. Coincidentally, it was the summer of 1969, when NASA triumphed with its Apollo 11 moon landing, when the Stonewall riots in New York began an assertive time of grassroots protest and demand for equal rights for gay and trans Americans.

IN SPACE

A HISTORY OF GAY ASTRONAUTS

Francis French

From the very beginning, human spaceflight has been about firsts as much as technology. Space exploration is, after all, a product of the Cold War—a "Space Race" where beating the other superpower was the justification. Sending the first person into space, carrying out the first spacewalk, being the first to reach the Moon, and the first to land on the lunar surface; these were headline-grabbing moments that elevated the prestige of the country responsible. Daring decisions were made, and lives were risked (and sometimes lost), in a race for supremacy.

There's another list of individual firsts along the way that had no particular operational reason for existing. From an engineering point of view, they were simple, requiring no changes, but for headlines and prestige, they were immense triumphs. These were about people.

Valentina Tereshkova, the first woman in space, became a media sensation. Her flight suggested—falsely, it turned out—that women in communist countries had more opportunities than those in the West. Vostok 6 was a severe embarrassment to the United States, prompting many questions in newspapers and Congress about whether the country was failing.

Most of the firsts that come to mind have occurred, with the exception of placing a woman on the Moon, and spacefarers from dozens of countries have flown on American space shuttles and Russian Soyuz spacecraft. In the case of the Chinese, they flew on their own rockets. The first African-American man, followed later by the first African-American woman, gained greater headlines than other flights performing similar missions. When the *Challenger* crew died shortly after launch, many remarked that the diversity of the crew—including two women, an African-American man, and a Hawaiian man of Japanese ancestry—represented the diversity of America, making their tragic loss all the more symbolic.

Many of these spacefarers celebrated being first, while others brushed it off or even resented being pigeonholed. They were engineers, pilots, and scientists, who were highly focused and worked hard at their careers. Many of them wanted to be defined more by their achievements than birthplace or ethnicity. When declining an interview request from a Jewish women's magazine, astronaut Judy Resnik tersely responded, "I am an astronaut. Not a woman astronaut. Not a Jewish astronaut. An astronaut."

Save for perhaps a few countries who have yet to put their first citizen in orbit, there are few firsts left to claim. Yet one title was often a cause of speculation: who would be the first publicly gay astronaut? Gay astronauts had not always been welcome in the space programs of the world, and in some places would still not be. In the Soviet Union, being gay was a criminal offense, so any gay cosmonauts from that era would have kept it a secret. Since the fall of the Soviet Union, no cosmonauts have publicly identified themselves as such.

Michelle Evans is a respected space historian and author, as well as a long-time advocate for LGBTQ issues. "Being LGBTQ in Russia was officially decriminalized in 1993," she relates, "but Vladimir Putin has instituted laws since then which all but in fact keep such people criminalized. It is not possible to openly talk about LGBTQ issues in Russia today, so no cosmonaut would be allowed to fly if they came out—or even if they just said they supported LGBTQ people."

Gay Americans were persecuted throughout the 1960s, the decade when astronauts first flew. Coincidentally, it was the summer of 1969, when NASA triumphed with its Apollo 11 moon landing, when the Stonewall riots in New York began an assertive time of grassroots protest and demand for equal rights for gay and trans Americans.

It was not until 2003 that the Supreme Court decriminalized homosexuality in the United States. Many repressive laws existed until then in states such as Texas, home of NASA's Johnson Space Center (where the astronauts are based), and there are still no laws in the state explicitly protecting gay rights. As federal employees, NASA's civilian astronauts were protected by federal law from discrimination, but this did not happen until 1995.

Before that, gay Americans were barred from federal employment as they were considered security risks, open to blackmail because of personal lives considered illegal by their very existence. These people were actively investigated by the FBI and a civil service that routinely "purged" employees under suspicion. Over 5,000 federal employees were fired during these purges, a hunt that did not end until after the Apollo program was over.

Astronaut Wendy Lawrence examines the tiles of space shuttle *Atlantis*
Credit: NASA

Sally Ride's partner, Tam O'Shaughnessy, accepts the Presidential Medal of Freedom on Sally's behalf from President Obama in 2003
Credit: NASA

Not all astronauts are civilian employees, however. Gay Americans were prohibited from serving in the military, a policy only eased slightly with 1996's "don't ask, don't tell" rule. Under this ruling, gay Americans could serve in the military, but only if this fact remained secret (if discovered, they had to leave). This policy was only scrapped in 2011 and any gay astronauts who were active military members before that would have spent their careers forced to keep their sexual orientation a secret.

Even if candidates had not faced discrimination in their work prior to applying to be an astronaut, they'd face a thorough background check (including visits from the FBI to key people in their past, asking questions about their personal lives). They'd also be put through a series of questions by psychologists, a profession that listed homosexuality as a mental disorder into the mid-1970s when it was downgraded to the marginally-less misguided "disturbance" of sexual orientation.

Dee O'Hara was assigned as the nurse to the original astronauts, and medically cleared each spacefarer before launch from the first flight in 1961 to the first shuttle mission in 1981. She knew the very conservative Houston culture of the era as well as anyone. "Given the times, a gay astronaut would not have been selected," she explains. "It was simply out of the question. Conformity was mandatory in all matters. An astronaut whose wife threatened him with divorce was made to immediately resign. Even long hair was out of the question, as well as beards. Although these restrictions were not written down, that was just how it was. I don't believe anyone even questioned it."

"Gay employees would almost certainly stay in the closet until after retirement, or even beyond," Michelle Evans explains. "A good example of the conservative nature of aerospace is Pete Knight, a pilot for the X-15 rocket plane who flew suborbital space missions, and how he handled his brother and his son coming out as gay in the late 1990s. He disowned them, then worked as a California state senator to create legislation to harm gay people by not allowing them to be married. It took 15 years to overturn the harm he did."

Hoot Gibson was a military test pilot, and an astronaut from 1978 to 1996. As the chief of the astronaut office for a number of years, he had a lot of say in who was selected as an astronaut. "Texas was not a very welcoming environment for gay people," he says. "Although I did meet some gay people there, it was kept pretty quiet. I'm certain that NASA would have gone ballistic if there had been any gay astronauts then. NASA was a 'don't rock the boat' outfit who shied away from anything controversial."

"An example was Mark Lee marrying Jan Davis after they were both assigned to the STS-47 shuttle mission," Gibson continues. "After I was made commander of that flight, Mark and Jan told me that NASA was going to remove her from the flight so they wouldn't have to worry about 'sex in space.' They had told Jan on a Friday that a press release would come out on Monday, taking her off the mission. Somehow NASA instead did the smart thing, which was to keep hands-off on the subject. Lo and behold, it was no big deal when they flew together."

"NASA was a 'don't rock the boat' outfit . . ."

The first spacefarer to publicly come out as gay did so in a remarkable way. Already one of the most famous astronauts in the world, Sally Ride had become America's first woman in space, flying her first shuttle mission in 1983. She had engaged in same-gender relationships since the age of 20, long before she applied to become an astronaut. As biographer Lynn Sherr explains, she was an expert in compartmentalizing her life and was never looking to be a standard-bearer for gay rights. She and her partner of 27 years, Tam O'Shaughnessy, chose not to publicly disclose their relationship until they picked a very impactful method. O'Shaughnessy simply stated their longstanding relationship in an obituary on the day Ride passed away in 2012.

The two ran Sally Ride Science together, and had been friends since they met as young girls on the competitive tennis circuit. They chose not to come out, Tam later explained, as they were concerned that they wouldn't be able to raise the corporate sponsorship money needed if the target companies knew they were a couple. It was also feared that more conservative families in less progressive states would have organized boycotts of the science events aimed at their children. "It is sad that she never came out publicly while she was alive," Michelle Evans reflects, "as that would have made a world of difference to young girls of the same sexual orientation. But I also completely understand her position, as that may have been extremely detrimental to her mission … we can only imagine the blowback she would have gotten in certain quarters."

Another possible reason was security, as with someone as famous as Ride there were always stalkers. It was something they grew used to dealing with, both for public appearances and at the company offices. Ride deliberately kept much of her everyday life intensely private for that reason, with a tight circle of long-time friends and colleagues acting as guardians and gatekeepers. Causing headlines about her personal life—and coming out would have been a big story—was not something that would have been in keeping with her personality.

Astronaut Wendy Lawrence was also involved with the organization. Chosen as an astronaut by NASA in 1992, Lawrence is a graduate of the Naval Academy and from a distinguished military lineage. Her father was the superintendent of the academy at the time she was there and had also been a finalist for selection in the original group of Mercury astronauts. His daughter became one of the Navy's most accomplished helicopter pilots, as well as making contributions in the fields of physics and oceanography before becoming an astronaut. She took on the demanding role of NASA's Director of Operations at Star City in Russia, overseeing this vital and internationally prestigious collaboration between the world's two major space programs. She made four space shuttle flights, including two dockings with the Russian space station Mir, and flew the mission that returned Americans to space after the shuttle *Columbia* tragedy.

After retiring from NASA in 2006, Lawrence only publicly chose to come out in December 2018 while accepting a very prestigious honor, the United States Naval Academy Distinguished Graduate Award. Each honoree during the award ceremonies was introduced with a video summarizing their lives and careers. Lawrence's included "Wendy is married to Kathy, and they live in Washington State," along with a photo of the couple. Her wife was in the audience, and Lawrence was sure to say, "I want to acknowledge my spouse Kathy."

The moment came and went without fanfare. For the first time, a living astronaut had publicly come out, though many close colleagues already knew. There were other former astronaut colleagues in the audience, however, who later related they'd had no idea. "It was wonderful how the statement from Wendy Lawrence about her wife hardly created a ripple," Michelle Evans relates. "That's the ideal way it should always be—that it simply isn't a big deal."

Lawrence's award ceremony, of course, honored someone who had long retired from NASA and the military. What was perhaps the final threshold had yet to be crossed—could a current NASA astronaut be openly gay? That final first was made within a year, although not in the way astronaut Anne McClain wanted. She was in space at the time and had no real control over the news. Chosen by NASA in 2013, the youngest person in her selection group, McClain was also a distinguished military helicopter pilot. In December 2018, the same month that Lawrence gave her speech, McClain launched into space, spending over 200 days in orbit working on the International Space Station.

McClain had wed in 2014, a same-sex marriage that did not become public until she was in space. The couple were already divorcing, and disagreements over intertwined finances sadly spilled over into orbit. When McClain accessed one of the couple's bank accounts from space, her estranged spouse complained, and the news made the newspapers in the summer of 2019. The stories concentrated on the potential of "space crime," and with no confirmation of a crime committed (only statements about ongoing investigations), the media soon moved on to another story about McClain—that she was set to make the first two-woman spacewalk, before an issue with spacesuit sizes postponed it.

The painful way in which this news came out overshadowed something historic: for the first time, an active NASA astronaut was in space and being reported as a gay American in the media. It's perhaps reassuring, despite the sad circumstances surrounding how the news broke, that this was only a minor part of the media stories. Not only because McClain was not able to choose the moment of her outing, but also because a gay astronaut no longer seemed an unusual

Astronaut Anne McClain aboard the International Space Station
Credit: NASA

idea to media reporters, as Ride's announcement seven years earlier seemed to have made the idea a familiar one.

Unlike prior first announcements in spacefarer diversity, the story of gay astronauts so far has been more complex. There has not yet been a moment where a NASA astronaut has publicly come out, by choice, while still active, or a gay male astronaut who has come out either. Today, NASA as an agency certainly would seem to be much more welcoming to the idea. A greater commitment to diversity in all forms has resulted in gay-friendly events for employees at NASA facilities. Since 2016, an LGBTQ Special Emphasis Group within NASA has also been working beyond what federal law requires. They provide advice to NASA leadership and support all of the agency's workers with awareness training and inclusion opportunities. Whether this openness applies to the more closed enclave of Houston's astronaut culture is not yet certain.

Charlie Bolden was an astronaut during the same era as Gibson and in 2009 became NASA Administrator, overseeing the entire agency. He believes things have changed since he became an astronaut in 1980. "There were rumors about gay astronauts, but they were rumors about astronauts from other countries," he explains. "When I was in Houston in the 1980s and 1990s, it might not have worked out very well due to the level of intolerance at that time. We had people leaving our Episcopal churches in Texas due to the ordination of women and gay priests. While I would hope we would have been different in the astronaut office, I still find it hard to imagine people being tolerant of an openly gay person then."

John Charles, the Chief Scientist for NASA's Human Research Program at the Johnson Space Center for many years (now the Scientist in Residence at Space Center Houston), explains that "Our push for accessibility and inclusiveness has already brought a public presentation by the LGBTQ support group at JSC. They spoke briefly and matter-of-factly about that aspect of their lives and then described the cool projects they are involved in. It was well-received."

There are other gay astronauts, though it is their choice when—or even if—to make this public. One former flight trainer says there are a number of gay men and women currently within the astronaut corps. The military culture within the astronaut corps, combined with the conservative Texas environment, still makes it a place where many would take pause before coming out. But considering that the number of known gay astronauts tripled in just the last year, it may only be a matter of time until this changes. Just as Ride was an enormously positive role model for young women looking to advance their careers in science, so a gay astronaut could be a role model for students looking to overcome prejudice and reach their own goals.

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Artist's impression of the Hubble Space Telescope
Credit: NASA

The Hubble Space Telescope

30 YEARS OF LIFTING OUR SPIRITS

Nancy Atkinson

From its vantage point 350 miles (563 kilometers) above Earth, the iconic Hubble Space Telescope (HST) has unquestionably changed our understanding of the cosmos. Now celebrating 30 years in orbit, no other space mission has been as enduring in revealing such a wide range of wonders and engaging the public. From confirming the existence of black holes, to studying the expanding universe, and peeking into the atmospheres of distant exoplanets, Hubble has provided tantalizing data and mesmerizing images of planets, stars, and galaxies. It has brought gorgeous views of space down to Earth for the public to enjoy while providing a treasure trove of scientific data that will keep scientists occupied for decades. As more than one NASA official has said with regard to public engagement, Hubble is "the gift that keeps on giving."

"It has been a wonderful, humbling privilege to be involved with this general-purpose but spectacular eye in the sky," said Dr. Jennifer Wiseman, currently the Senior Project Scientist for the mission. She continued, "Hubble has enabled us to understand our place in the solar system and in our unimaginably large universe with greater clarity than ever before." Wiseman, who has served in various roles with the mission since 2003, added that she is grateful to work with hundreds of experts around the world that make up the entire Hubble team. "To be able to work with people of such diverse talents, with exquisite engineering and scientific skills, has been wonderful," she said. "Their expertise has truly enabled a leap in humanity's understanding of the universe."

This leap has occurred, Wiseman believes, because of a monumental decision made early on by mission planners: images and archival data would be made available to the public and the science community freely and easily. That mindset set a precedent for subsequent observatories and space missions while having a profound effect on people around the world. "That decision was made even before the internet became an active way of sharing information," she said. "But with the internet, this ability to share images with the public just exploded. We now see Hubble images being used not only for research and education, but also providing inspiration in art, music, philosophy, poetry, and all types of human endeavors that lift our spirits."

HUBBLE'S STORY

While the Hubble Space Telescope wasn't the first telescope in space when it rocketed into orbit on April 24, 1990, many consider it the best and undoubtedly the most well-known. Ask people to name a telescope

The Antenna Galaxies as imaged by the HST
Credit: NASA

A hot, young star cluster in the Carina Galaxy
Credit: NASA

and most will probably say "Hubble." Walk into a classroom and you will likely see a picture of the HST on the wall. Name an astronomical conundrum and Hubble has likely studied it, maybe even solved it.

"For thirty years now, kids have been learning along with the discoveries Hubble has been making," said Larry Dunham, the Chief Systems Engineer for Hubble, who has been part of the mission since 1982. "It has become kind of cliché, but Hubble has rewritten our textbooks. This telescope has become part of iconic American space lore; it's what people think of when they think of NASA."

Hubble's history is full of close calls that nearly spelled disaster for the telescope. Well known are the early challenges of securing funding for the on-again, off-again mission, and delays and cost overruns of getting the innovative telescope ready to fly. Then came more delays because of the space shuttle *Challenger* accident in 1986. Finally though, when Hubble launched aboard shuttle *Discovery*, it didn't take long for astronomers to realize the biggest problem they had yet faced: the space telescope's eight foot (2.4 meter) mirror had a tiny flaw, a "spherical aberration," meaning it had been polished in slightly the wrong shape, off by just two microns (or a 50th the width of a human hair). But the miniscule flaw was enough to make images from Hubble look blurry.

Any other mission would have been finished, but with Hubble there was still hope. It was one of the very few space missions designed with modular instruments that could be swapped out and upgraded over time, and resides in low Earth orbit where shuttle astronauts can perform repair work. NASA already had a schedule of servicing missions planned, and the first could provide an opportunity to fix the flawed telescope. A worldwide effort ensued to figure out what could be done to deal with the faulty mirror.

In December 1993, seven astronauts aboard the space shuttle *Endeavor* conducted Hubble's first servicing mission. They installed two new instruments: the Wide Field and Planetary Camera 2, a new camera that provided internal corrections for the spherical aberration in Hubble's primary mirror, and COSTAR, the Corrective Optics Space Telescope Axial Replacement, which corrected the optics for the other existing instruments. From that time, the telescope's observations have been crisp and clear, and since then it has touched every aspect of astronomy and astrophysics, from our own solar system to the entire observable universe.

Over the past 30 years, Hubble's various parts and instruments have suffered the wear and tear of constant use in the harsh conditions in space, causing everything from warranted concerns, to hiccups in gathering data, and near-catastrophic failures. But subsequent servicing missions in 1997, 1999, 2002, and 2009 have kept the telescope operating, with new and improved instruments and other vital components.

The fifth and final Hubble Servicing Mission in 2009 was a microcosm of Hubble's life story: a close call that nearly didn't take place, followed by several delays, and nearly-disastrous failures onboard the spacecraft. "We had a very tumultuous period when we thought the final servicing mission wasn't going to happen because of the Columbia space shuttle disaster in 2003," said Wiseman. "But the Hubble team rose to the occasion, and because of that adversity, both the engineers and scientists came up with innovations in how

to get the best and most science out of Hubble in whatever time we had left."

The science team reconfigured their observation procedures to be more efficient, while the engineering team came up with ways to use Hubble in more innovative and effective ways. In the end, however, the servicing mission was reinstated (with much jubilation from the scientists and the public) and was a complete success. The astronauts fixed two broken instruments and installed two new instruments, new batteries, new gyroscopes, and a new scientific computer, all to prolong Hubble's life. The innovations in procedures are still in use today and engineers continue to assess Hubble's systems to help it remain viable, conducting other 'life extension initiatives' to prolong its operation as long as possible.

One major problem throughout Hubble's lifetime has been failure of the gyroscopes that allow the telescope to so precisely lock onto a distant target. Hubble has six gyroscopes in total, and three are required for optimal operating efficiency. Each contains a wheel that spins at 19,200 rotations per minute. "When we thought SM-4 [the final servicing mission] wasn't going to happen, we knew the gyroscopes would be a limiting factor for the life expectancy of Hubble," said Dunham. "We asked ourselves: could we possibly operate with less than three gyros?" he went on. "We headed up a team to develop a two-gyro science mode and working with the science team, we figured it out and even developed a one-gyro science mode. While reduced-gyro mode offers less sky coverage at any particular time, there is relatively limited impact on the overall scientific capabilities."

On the final mission, all six gyroscopes were replaced, and in the subsequent years, three of those have failed. However, the remaining three are newer, technically-enhanced gyroscopes that are expected to have significantly longer operational lives. "The gyros have so-called enhanced flex leads in the wiring," Dunham explained. "These are about the size of a human hair, and historically what has happened on the previous type is that they get brittle and break over time," he continued. "The enhanced flex leads have a silver covering on the copper, and according to the engineers, they should last forever. One of the gyros has close to 100,000 hours on it now. The hope is these last three gyros will outlast us all!"

LOOKING FARTHER, SEEING BETTER

The luxury of having Hubble operational for so long is that researchers can take advantage of modern advancements in technology. "The visionaries who decided to put a repairable observatory above the atmosphere were well aware of the rapid increase in technology advancement, especially in the area of astronomical detectors," said Dr. Olivia Lupie, Hubble's Instrument Systems Manager, who has been involved with the mission since 1983. "As a result, the new instruments built to replace the older ones had the cutting-edge technology at the time, so we've been able to improve the capability of the observatory over the years."

For example, after the first servicing mission, the Wide Field and Planetary Camera 2 detected some of the earliest galaxies that were 12 billion light years away. After the third such mission in 2002 when the Advanced Camera for Surveys was installed, it detected objects 13 billion light years away. Finally, after the fourth when the Wide Field Planetary Camera 3 was an installed (which Lupie described as "an exquisite instrument with pan-chromatic capability"), Hubble saw objects at 13.3 billion light years away. "That's mind-boggling, because astronomers have estimated the age of the universe to be 13.8 billion years old, which is another bit of data that Hubble helped refine," said Lupie. "So, we are now seeing some of the first galaxies that formed just a few hundred million years after the Big Bang."

Hubble's study of the evolution of stars and galaxies, as well as the distribution of matter in the universe, are some of the most the profound contributions to astronomy, showing us how the universe is dynamic and has changed spectacularly over time. "With Hubble, we've been able to image galaxies both near to us and in the very distant universe, which allows us, essentially, to look back in time," Wiseman explained. "Hubble has visually shown us that galaxies merge and grow over time. Generations of stars within these galaxies come and go and enrich the chemical makeup of the gas and dust within these collections of stars. This enrichment eventually enables solids like planets to form around subsequent generations of stars, such as in our own solar system."

Other unexpected Hubble discoveries abound. Ever since the discovery of the expanding universe in the 1920s, astronomers had struggled to measure and understand the rate of expansion. The telescope's observations of very distant supernovae showed that the expansion of the universe has not been slowing due to gravity as many thought it would. Instead, it has actually been accelerating. No one expected this, and none of the experts know exactly how to explain it.

"We realized that something must be causing the expansion rate of the universe to accelerate," Wiseman said. "The generic term for it is 'dark energy,' and measuring this cosmic expansion rate and its acceleration is helping us to understand at least some of the properties of dark energy over cosmic time." This work using Hubble resulted in a Nobel Prize for the team of astronomer Dr. Adam Riess.

Then there is the question of the other dark stuff in question: dark matter. "We understand that most of the matter in the universe is not visible like stars and galaxies," said Wiseman. "Most of the matter is this mysterious dark matter which is unseen, but we can use Hubble to 'see' its gravitational effects, and therefore map out where the dark matter is, giving us more clues to its properties."

Hubble has helped astronomers understand there is a cosmic tug of war between dark energy, which is basically pushing the universe apart, and dark matter, which is pulling things together with its gravitational pull. "This push-and-pull has been going on over time," Wiseman said, "but it looks like for the universe as a whole that dark energy is winning out on the large scale, while in gravitationally bound situations like clusters and galaxies, dark matter still holds sway."

Within our own solar system, Hubble has studied comets, asteroids, and moons, and made repeated observations of our

planetary neighbors, revealing short-term changes in our dynamic solar system. It found new moons around Pluto and dwarf planets in the Kuiper Belt at the rim of the solar system. Hubble has peered into the depths of the universe with efforts such as its Deep Field and Frontier Fields programs, showing us galaxies and other objects in space we never knew existed.

When the telescope was launched, there was a theory that the centers of some galaxies might contain a supermassive black hole. But nothing like this had been observationally confirmed until 1994, when it measured the mass in a galaxy called M87, located 50 million light-years away from Earth. It found evidence that supported the existence of a gravitationally-collapsed object at the galaxy's core. In the subsequent decade, Hubble found that black holes at galactic centers were ubiquitous. "This was a significant leap in our understanding of what goes on in the cores of galaxies and our understanding that supermassive black holes are, indeed, a strange reality," Wiseman said.

One of the most popular astronomical topics in the last decade has been the discovery of exoplanets, planets orbiting other stars. While Hubble doesn't have the ability to detect exoplanets on its own, astronomers have used the space telescope to study the atmospheres of these distant worlds, and found water vapor on several. Hubble captured the first-ever visible-light image of an extrasolar planet in 2008, moving in its orbit around the star Fomalhaut, located 25 light years from Earth. Later, in 2018, it detected a possible exomoon orbiting a distant exoplanet.

Another unexpected use of Hubble was to observe the light from an explosion of a kilonova that ignited when two neutron stars merged together in another galaxy, creating the long-sought gravitational waves detected by the LIGO (Laser Interferometer Gravitational-Wave Observatory) collaboration. "To me, this is one of the most thrilling aspects," said Lupie, "to be able to use Hubble's instruments for something they were never really designed to do."

Thirty years on, Hubble is still extremely productive. The orbiting telescope has made over a million observations and provided data used in more than 16,000 peer-reviewed scientific publications. "I believe that the dedication and ingenuity of my colleagues is one of the major reasons why Hubble has been so successful," said Lupie. "Hubble's legacy covers so many different areas and we've been fortunate to have visionaries all throughout the team—scientists and engineers who look forward to mitigate any problem and ways to avoid losing science time. Hubble is a wonderful example of what can be accomplished when people work together toward a common goal."

How long can the seemingly timeless Hubble last? Dunham said engineers are holding out hope the instruments and vital parts can last until at least the mid-to-late 2020's, well past its 15-year expected lifetime. Of course, with the end of the space shuttle program in 2011, no further servicing missions are scheduled. However, there is hope that one day the iconic telescope might be re-serviced or retrieved. A soft-capture docking mechanism was installed onto the telescope, and it has been suggested that another servicing mission could conceivably be mounted using SpaceX's Crew Dragon or NASA's Orion spacecraft. Such a mission could extend the space telescope's life in orbit, and a future spacecraft might even one day bring Hubble back home to a well-deserved resting place.

The Lagoon Nebula
Credit: NASA

A galactic collision in NGC 5256
Credit: NASA

"A Successful Failure"

The liftoff of Apollo 13
Credit: NASA

REMEMBERING APOLLO 13, 50 YEARS ON

Ben Evans

For centuries, thirteen has been considered an unlucky number, so it was no surprise when astronaut Jim Lovell's wife experienced an unmistakable pang of dread when he told her that he would command Apollo 13—the third landing of humans on the Moon. Lovell's reply, immortalized in the 1995 movie retelling of the story, was pragmatically simple: "It comes after twelve!" Yet bad luck did indeed stalk Apollo 13. If the plan to launch the mission at 13:13 Houston time, or the intent for it to enter the lunar sphere of gravitational influence on April 13, 1970, were not enough to tempt fate, German measles and an undetected design flaw in the spacecraft didn't help.

As Lovell, Command Module pilot Ken Mattingly, and Lunar Module pilot Fred Haise trained for their 10-day flight, backup crewmen John Young, Jack Swigert, and Charlie Duke shadowed them. Two weeks before launch on April 11, 1970, Duke was exposed to measles through the young son of a family friend. Although Duke was not found to be contagious, and Lovell and Haise were both immune, the case for Mattingly was uncertain and the disease's two-week incubation period meant he might get sick during the mission.

Switching Lovell's entire crew for that of Young was considered but rejected in favor of replacing Mattingly with Swigert. NASA Administrator Tom Paine feared a media and political frenzy if Mattingly fell ill in space and Lovell's entreaties were rebuffed by the flight surgeons, who felt that blurred vision or swollen joints caused by the illness could threaten mission success. Nor could Apollo 13 be delayed until the next lunar launch window in May, for that risked causing components of its Saturn V rocket to degrade. In addition, astronauts orbiting the Moon in the Command Module worked alone for long periods of time, and this made it simpler to swap out Mattingly for Swigert.

Apoll 13 was intended to be the first mission to land in a hilly region. The lunar highlands were thought to be virtually unchanged, morphologically and geochemically, since the Moon's youth, and exploring them might reveal rocks dating back billions of years. Lovell and Haise would land their Lunar Module, which they had named *Aquarius*, in a rugged locale called Fra Mauro, about 300 miles (483 kilometers) south of the southern rim of the vast Mare Imbrium impact basin. Carved by a cataclysmic collision in the Moon's infancy, ejected subsurface material from Mare Imbrium was believed to be widespread at Fra Mauro, particularly on the flanks of the thousand-foot-wide (305-meter-wide) Cone Crater. Sampling that material could shed new light on the nature of the original lunar crust and establish a date for when the impact occurred.

As Mission Control monitors the Apollo 13 emergency. Gene Kranz is seen at lower center, and Fred Haise is on the big screen
Credit: NASA

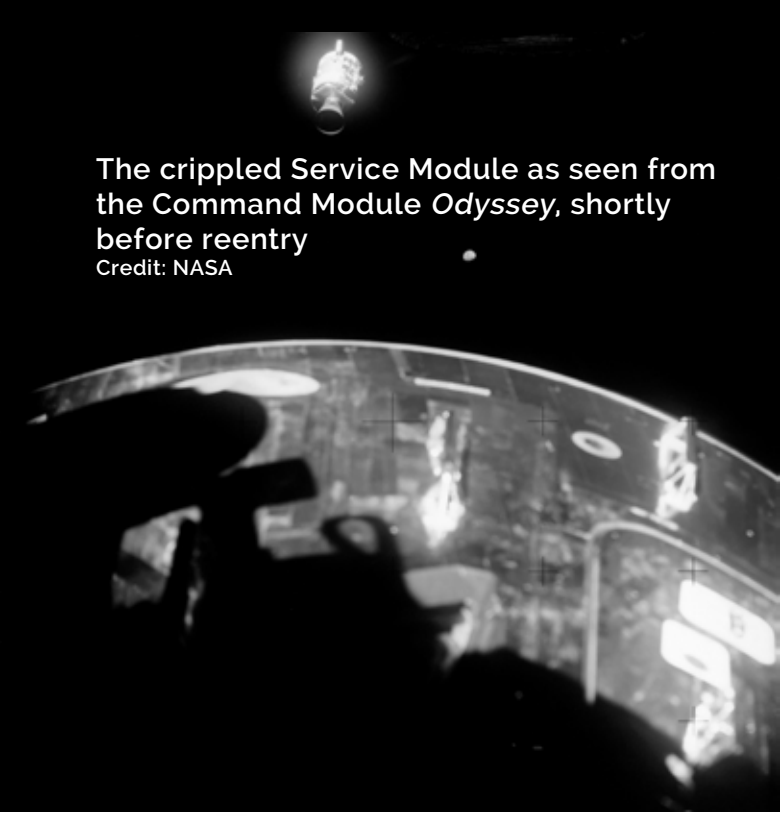
Almost as soon as it began, however, the Apollo 13 mission was touched by misfortune. Five minutes after liftoff, unexpected oscillations in the rocket's second stage caused the center J-2 rocket engine to shut down prematurely. The other four engines automatically compensated by firing a little longer, but even their input was not enough and it took an added push by the third (S-IVB) stage to put the heavy spacecraft—the Command and Service Module *Odyssey* and Lunar Module *Aquarius*—into a safe orbit around Earth. Finally, with all checks completed, the third stage fired a second time later that afternoon to propel them to the Moon.

For the next two days, the spacecraft was so well-behaved as it traversed the 240,000 miles (386,250 kilometers) between Earth and the Moon that flight controllers in Houston began to feel almost blasé. Swigert's biggest concern was forgetting to file his tax returns, an admission that caused laughter in Mission Control. Then, fifty-five hours after launch, disaster struck as the astronauts bedded down for their third sleep period.

The chain of events that unfolded that night would almost claim the astronauts' lives. Deep inside the Service Module were two cryogenic tanks that housed liquid oxygen and liquid hydrogen to feed three fuel cells, which provided the crew with electricity, water, and heat. But before Apollo 13 even launched, the second tank had exhibited problems. Tubing to fill and empty the tank had been accidentally damaged two years earlier, and in March that tank was loaded with cryogenic oxygen for a test. At the end of the test, the damage prevented the super-cold fluids from draining as they should. Engineers eventually boiled them off using the tank's electric heater, aided by ground equipment.

But another problem lurked in the system. Several years earlier, the Apollo spacecraft was upgraded from 28 volts to 65 volts. Its systems were modified to accept the change, except for a small thermostat in the oxygen tank, which remained rated at 28 volts and should have turned off the electric heater when temperatures hit 79 degrees Fahrenheit (26 degrees Celsius). Nobody caught the mistake, and as the tank's contents were boiled off during the test, excessive voltages triggered an arc that welded its electrical contacts shut. The test conductor's gauge went no higher than 86 degrees F (30 C); he could not possibly have known that temperatures inside the tank had risen to over 900 degrees F (500 C). This intense heat cracked Teflon insulation on wires to an electric fan that would periodically stir the tank's contents in space. Any spark or short-circuit could now set off an explosion, and when the tank was loaded with highly flammable liquid oxygen before launch, bits of Teflon debris and stripped-bare wiring created the perfect conditions for a ticking bomb.

That bomb detonated late on April 3, when Mission Control asked Swigert to stir the Service Module's tanks.



The crippled Service Module as seen from the Command Module *Odyssey*, shortly before reentry
Credit: NASA

Jubilation grips Mission Control upon splashdown of Apollo 13. From left: flight directors Gerry Griffin, Gene Kranz, and Glynn Lunney
Credit: NASA

The exhausted crew of Apollo 13 arrives at the recovery carrier *Iwo Jima* after splashdown. From left, Fred Haise, Jim Lovell, and Jack Swigert
Credit: NASA

In weightlessness, the liquid fuels tended to become stratified, and periodic stirring provided engineers with more accurate quantity readings. Swigert dutifully flipped the H2 FANS and O2 FANS switches. Seconds later, Apollo 13 shuddered with a dull bang. Lovell was floating through the connecting tunnel from *Aquarius* to *Odyssey* at the time. Instinctively, he guessed the culprit was Haise, who had a mischievous habit of setting off the spacecraft's noisy cabin repressurization valve as a mild prank. But the wide eyes of his crewmates quickly assured him that this was no light-hearted gag—his crewmates were truly and profoundly frightened.

Their attention was soon arrested by the blaring master alarm and the red glow of the 'Main Bus B Undervolt' light on *Odyssey's* instrument panel. It told them that one of the Command Module's twin electrical buses had lost power.

"Hey," Swigert radioed to Houston. "We've got a problem here."

"This is Houston, say again, please," replied fellow astronaut Jack Lousma, the CAPCOM currently on duty in Mission Control.

"Houston, we've had a problem," said Lovell. "We've had a main B bus undervolt."

"Roger, main B undervolt," replied Lousma. "Okay, stand by, 13, we're looking at it."

Mission Control's first thought was that it was an instrumentation hiccup, but this was quickly proven incorrect by recognizing that the astronauts had heard and felt a loud bang, which manifested itself as a visible flexing of the tunnel walls between *Odyssey* and *Aquarius*. As data streamed back to Earth, horrified flight controllers could only watch as the readings for the second oxygen tank crept down to zero. Aboard the spacecraft, more warning lights illuminated, revealing that two of the three fuel cells were now dead and that oxygen was slowly leaking out of the first tank as well.

The likelihood of so many simultaneous catastrophic failures—an oxygen tank gone, two fuel cells down, and one power bus dead—seemed impossibly remote. For engineers, whose years of experience had taught them that fluid lines might leak, electrical wires might short, but that physical structures should not break, it was a rude awakening.

Odyssey's behavior was also disconcertingly odd. The Command Module's computer shut down and then restarted, while its high-gain antenna lost functionality. Aware that Bus B was not functioning, Haise reconnected its systems over to Bus A, only to discover that it too was unpowered. With only one healthy fuel cell left, landing on the Moon was now out of the question, and getting home alive would be Apollo 13's new mission.

Thirteen minutes after the explosion—yet another reminder of the unlucky number, as if one were needed—Lovell craned his neck to the window and was startled to see a white cloud of vapor gushing from the side of the Service Module. As it emerged into the frigid cold of space, it crystallised and expanded into a broad, halo-like cloud.

"Houston, we are venting something into space," he reported. "It's a gas of some sort."

"Roger," replied Lousma, "we copy you're venting."

At that point, Apollo 13 lead flight director Gene Kranz says, the pieces of this puzzle snapped into place. A short-circuit and explosion in the damaged oxygen tank had ruptured the Service

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WHAT IS AVAXHOME?

Module, spewing its oxygen overboard and triggering a torrent of apparently unrelated failures. The blast had snapped shut two of the fuel cell's valves and starved the ship's electrical system, while fuel valves to the thrusters had also closed, making it difficult for the astronauts to regain control of the spinning spacecraft, and the escaping oxygen was now acting like a thruster, making the situation even worse.

Ninety minutes after the explosion it was obvious that *Odyssey's* third fuel cell was threatened as well. The only way to isolate the leak and save the surviving cell was to shut down the two dead cells. After that, the next issue would be getting home. Firing the engine at the base of the Service Module would enable Apollo 13 to do an about-turn and bring the astronauts back in a couple of days. But with the Service Module crippled, so too might be the engine, and there was now insufficient power to open the valves to its combustion chamber, much less swivel its nozzle or steer its five-minute burn. This maneuver would also have required jettisoning the Lunar Module, which was now their only fully-functioning component, and this was a risk Kranz was not willing to take.

They would keep the undamaged *Aquarius* as a lifeboat. Its rocket engine did not have the power to send them immediately back home, but it could put them onto a free-return trajectory, maneuvering them around the Moon and allowing its gravity to fling them back to Earth. Earlier lunar missions included this safety feature in their flight design, but the free-return trajectory also restricted the range of landing sites that could be reached. From Apollo 12 onward, a 'hybrid trajectory' was implemented to broaden the scope of lunar landing options—including Fra Mauro—but required the Service Module's propulsion system to power them back home.

As Lovell and Haise hurredly powered-up *Aquarius*, Swigert shut down most of *Odyssey's* systems to conserve them for reentry. One of his final tasks was transferring guidance and control over to the Lunar Module's computer, but with a huge cloud of shimmering debris around the spacecraft, it was virtually impossible to acquire accurate star sightings for proper navigation. The only option was to handwrite the data from *Odyssey's* computer, mentally calculate the differing frames of reference between the two ships, then input it into *Aquarius'* computer, all while acutely aware that time was of the essence as the Command Module was quickly dying. As they battled fatigue, the astronauts were reliant upon Mission Control to cross-check their arithmetic.

Finally, Swigert shut *Odyssey* down and joined his crewmates in *Aquarius*. Controlling the 60-foot (18-meter) long "stack" of two spacecraft from the Lunar Module carried its own idiosyncrasies, which Lovell compared to steering a wheelbarrow with a long broom handle, but he had little time to adapt to this unusual situation. Six hours after the explosion, he fired Aquarius' descent engine to put Apollo 13 onto a free-return trajectory around the Moon.

This committed them to splashing down somewhere in the Indian Ocean upon their return to Earth, but Lovell, Swigert, and Haise still needed four days to get home, far longer than *Aquarius* could sustain them. Discarding the heavy Service Module might bring them back in less than 40 hours, but its presence protected the Command Module's heat shield against solar radiation and the huge temperature extremes of deep space.

By now, the media had picked up the story, and their fervor was intensified by the assessment of senior NASA manager Chris Kraft that Apollo 13 was "about as serious a situation as we've ever had in manned spaceflight." Prayers were offered by Pope Paul VI in Rome, by pilgrims in India and at Jerusalem's Wailing Wall, and several nations, including the Soviet Union, offered recovery assistance if needed.

With plenty of oxygen aboard *Aquarius* for two now-forgotten Moonwalks, breathing during the journey home was not a problem, but carbon dioxide from the astronauts' exhaled breath was. Canisters of lithium hydroxide ordinarily scrubbed this toxin from the spacecraft's air, but the Lunar Module only carried enough for 45 hours (far short of the return-home travel time of 90 hours). More canisters were aboard the Command Module, but as the two spacecraft were built by different companies, the shapes and fittings of these filters were different.

Mission Control technicians, led by fellow astronaut Joe Kerwin, quickly rigged up a device to literally fit a square peg into a round hole. Using only bits and pieces that the astronauts had with them—socks, duct tape, plastic bags, a spare oxygen hose, and the cover of a now-obsolete flight plan—they improvised an effective fix. Instructions were radioed to the crew who built and

Fred Haise practices the deployment of a scientific instrument package on the Moon prior to the mission of Apollo 13
Credit: NASA

fitted it, and shortly afterward, to everyone's intense relief, carbon dioxide levels began to fall.

The next challenge was power, for unlike *Odyssey* the Lunar Module relied on batteries to support two men for 33 hours on the Moon's surface. Stretching those capabilities to three men and several days required switching off most of its systems, including lights, gauges, and even the computer. Apollo 13's homeward-bound route was further shortened by another burn of *Aquarius'* descent engine, executed shortly after their closest approach to the Moon. It cut the return journey from four days to only two-and-a-half.

All three men looked wistfully out the windows as they saw the forbidding lunar terrain, their lost goal, pass serenely beneath them. Lovell had seen this view on Apollo 8, but for Swigert, who never expected to fly on Apollo 13, and Haise, who had spent months practicing for a pair of four-hour walks on its surface, it was an intensely bittersweet moment.

After the engine burn, most of *Aquarius'* remaining systems were shut down. Temperatures inside its broom-cupboard-sized cabin plummeted, moisture formed on its windows, living conditions resembled a dank cellar, and the astronauts managed a couple of hours' sleep at best. Food stocks were frozen solid and water was seldom drunk for fear that the dumping of urine overboard could knock Apollo 13 off-course. Lovell's crew returned to Earth severely dehydrated and Haise suffered a kidney infection.

A few days later, Earth began to loom large in *Aquarius'* windows as the astronauts and Mission Control prepared to reactivate the Command Module after several days in frozen darkness. Writing reentry checklists usually took three months, but the experts in Mission Control put one together in only two days.

One question in the astronauts' minds was the health of Earth-bound Ken Mattingly. Lovell asked CAPCOM Vance Brand if the 'blooms' of rubella had finally hit his former crewmate.

"Are the flowers blooming in Houston yet?"

"Nope," replied Brand. "Still must be winter."

"Suspicions confirmed," retorted Lovell.

Later that day, a healthy Mattingly strode into Mission Control with a 39-page sheaf of 400 procedures to bring *Odyssey* back to life. For two hours, he talked Swigert through every switch throw and keystroke. Shortly thereafter, the crippled Service Module was discarded, revealing the true extent of the damage: an entire 13-foot-long (4-meter-long) side panel was gone, leaving a jumble of shredded wiring and torn plumbing.

Next they had to jettison *Aquarius*, which had served them through the darkest moments of their mission. Alone now, the Command Module plunged into Earth's atmosphere at 24,000 miles per hour (38,620 kilometers per hour), and super-heated plasma generated by intense friction from the atmosphere blocked communications with the ground. This blackout was expected to last for three minutes, but the unspoken fear in Mission Control that *Odyssey's* heat shield or parachutes had been fatally damaged was pervasive.

Jack Swigert helps to install the impromptu carbon dioxide scrubber aboard Apollo 13's Lunar Module
Credit: NASA

"*Odyssey*, Houston," radioed Kerwin after three minutes. "Standing by."

His voice echoed in the silent control room. There was no response.

Five thousand miles (eight thousand kilometers) away in the Pacific Ocean, the amphibious assault ship *Iwo Jima* and its detachment of Marine Corps helicopters had been scrambled as part of a massive search-and-rescue operation. They saw no sign of the Command Module or its parachutes descending through the crisp blue morning sky.

Four minutes of radio silence passed, and a feeling of dread crept into Mission Control. Kranz's words of "We will never lose an American in space" during an earlier briefing must have been haunting him.

At length, it was the Apollo Range Instrumentation Aircraft which reported it had acquired a signal from the spacecraft. The sighting was immediately relayed to Mission Control.

"*Odyssey*, Houston," repeated Kerwin. "Standing by."

Then came Swigert's voice saying, simply, "Okay, Joe." Huge sighs of relief escaped the lips of many millions around the world.

Seconds later, television pictures from *Iwo Jima* revealed the Command Module, descending beneath three red-and-white main parachutes.

"*Odyssey*, Houston, we show you on the mains," radioed an excited Kerwin. "It really looks great!"

Six days after leaving Earth to limited public interest, Apollo 13 was home safely. Against a multitude of odds, its ill-fated journey was ultimately followed by over a billion people. The "successful failure" was transformed into NASA's finest hour. Everyone associated with the mission—flight controllers, contractors, and the media—had stayed at work until the crew was safely home. Many had not seen their families since the night of the explosion. Gene Kranz would later reflect on their steely resolve. "I remember their eyes," he said, "dull with fatigue and shadowed by anxiety, but their confidence and focus never wavered."

THE NSS GOING VIRTUAL DURING COVID-19

Melissa Silva

In light of recent events, we felt it important to highlight the many ways you can participate in National Space Society events online. The NSS has been working hard to boost its virtual offerings in recent years and provide its membership with space-related content they can engage with year-round, from anywhere in the world, at their convenience. These include webinars, tools for education, and much, much more.

In April, Chapters Assembly chair Joseph Bland hosted the third installment in the *Breakfast on the Moon* series celebrating NASA's Apollo missions. April saw *Breakfast on the Moon #3* commemorating the seventh crewed mission in the Apollo program, which launched from Kennedy Space Center on April 11, 1970. The series has been growing in popularity amongst NSS membership; the Apollo 12 webinar had 90 registered participants and attendance for the April Apollo 13 webinar was higher, as the webinar also honered the 59th anniversary of Yuri Gagarin's record-setting flight on April 12. It further celebrated the 39th anniversary of the first orbital spaceflight of the space shuttle program, and the 30th anniversary of the Hubble Space Telescope's launch into low Earth orbit on April 24. A celebration of Apollo 14 will take place in January, and the final *Breakfast on the Moon* webinar, observing Apollo 17, will mark 50 years since the last time people set foot on the Moon.

Breakfast on the Moon Credit: Joe Bland

The SpacEdge Academy is also a valuable resource available to NSS members, and can be found online at spacedge.academy. According to Lynne Zielinski, the NSS Vice President of Public Affairs and Director of Education, the academy reached an estimated 10,950 students last year through their presentations. Estimates for 2020 are even higher as more teachers join the SpacEdge network. The SpacEdge Academy is a depository for lesson plans, projects, activities, and curriculum designed by teachers around the globe for all grade levels. The academy also offers teacher workshops and provides a platform where STEAM educators can collaborate with one another. The SpacEdge Academy Centers for Excellence allows university students to participate in cutting-edge challenges and gain access to research recources in important NewSpace and commercial fields.

As many members may know, the NSS recently transitioned to a new membership system provided by YourMembership. One of the many benefits of updating to a more modern system includes the ability to allow NSS members to access a forum where they can share their ideas on space-related subjects with other members; it's like being at the International Space Development Conference (ISDC) year-round.

Finally, the NSS also holds virtual town hall meetings hosted by Burt Dicht, the NSS's Vice President for Membership. These are currently planned to be held once a month and will cover a variety of space-related topics, including those relevant to NSS members such as the benefits available to them through the organization. These meetings are an opportunity for members to come together and explore different topics related to the goals of the NSS; this year, several ISDC presenters will be asked to give presentations.

National Space Society

The Gerard O'Neill Voyagers Circle

We are extremely grateful to our Circle and hope you will join this special group, too. Circle members have donated $500 and pledged to set aside part of their estates for NSS or donated at least $5000 to help bring about a future with millions of people living and working in space. Circle members include:

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National Space Society

FOR ALL MANKIND

CREATED BY: Ronald D. Moore, Ben Denivi, and Matt Wolpert **RUNNING TIME:** 65 minutes **RATING:** PG-13
DATE: November 1, 2019 **CATEGORY:** Television Show

>> Reviewed by Emily Carney <<

Alternate histories are nothing new to spaceflight literature, television, and film. As early as the 1960s, the late Martin Caidin provided a topsy-turvy, sometimes chaotic view of space and NASA's crewed launch center respectively in his books *Marooned* and *The Cape*. The former was even adapted into a wildly different-from-the-book feature film, with mixed success. Movies including the made-for-television *The Astronaut* provided nightmarish what-ifs about long-term spaceflight to Mars from a 1970s perspective. Within the last decade, alternate spaceflight histories have enjoyed a sort of renaissance and last summer's issue of *Quest* magazine—one of the premier space history periodicals—showcased a bevy of Apollo 11-related "what ifs" by prominent spaceflight writers.

So how does *For All Mankind*, helmed by Ronald D. Moore of *Battlestar Galactica* fame, stack up in this medium? It does what few, if any, space alternate histories have done: presume that the Space Race didn't screech to a halt shortly after humans stepped upon the lunar surface. The show includes women and minority astronauts who are working in a long-term Apollo program that focuses on settling the Moon rather than just walking on it a few times (note: some series spoilers are included in this review).

The show's astronaut protagonist, Edward Baldwin (played by Joel Kinnaman), starts the series mired in a cloud of frustration bordering on rage. The Soviets, still the biggest thorn in America's side, have trod upon lunar dust first. In a case of "loose lips sink ships," Baldwin sinks himself with some choice, unguarded words to a nosy journalist, but is soon redeemed and offered command of Apollo 15. The twist is that his Lunar Module pilot is one of NASA's newest recruits to the astronaut corps, former Mercury 13 candidate Molly Cobb (played wonderfully by Sonya Walger).

Cobb, with her messy hair and an even messier attitude towards training alongside the upright Baldwin (this mission takes place circa 1971, just like the real thing), emerges as the show's antihero, who you can't take your eyes off of. Indeed, she is the one who is determined enough to make a huge discovery inside of a lunar crater: water ice, which can be mined to fuel spacecraft. Following this discovery, subsequent episodes of the show explore a mid-1970s NASA struggling to find—and keep—its place amid increasing Soviet supremacy, and space vehicles taxed by politics and "go fever."

It's impossible to deny the fact that *For All Mankind* delves into soap opera-like side plots at this point, including one astronaut's lapse into mental illness during a lengthy lunar stay, a fatal accident involving Baldwin's only son, and even the explosion of a Saturn V on the pad. Moore likes a lot of dialogue and is not known for subtlety, but the show's characters are very compelling, particularly the women astronauts. While some of these situations may border on unbelievable, he makes a worthwhile attempt at making the women astronauts seem "real" and not mere "Astronaut Barbies."

The first four women Apollo astronauts aren't portrayed as impossibly idealistic divas with perfect blowouts and wrinkle-free jumpsuits, but as people with often big problems. Danielle Poole, NASA's first female African-American astronaut (played by Krys Marshall), might bear the distinction of being one of the first women assigned to a Moon settlement, but also tries her best to cope with the double whammy of workplace discrimination and a husband suffering from Vietnam-related PTSD. Ellen Waverly (played by Jodi Balfour) might be one of Apollo's first women commanders, but her struggle to hide her sexuality during a time that was not accepting of anything LGBT results in her entering into an ill-advised sham traditional marriage while she hides her one truly fulfilling romance with a woman.

Tracy Stevens, the dark horse female candidate who was at one point advised to leave the program due to inexperience (played by Sarah Jones), matures into one of Apollo's greatest Command Module pilots. However, like many women in the 1970s (and even at present time), her work-home balance isn't balanced at all—she has a troubled, adultery-plagued marriage to a fellow astronaut, and a chronically misbehaving son who seems to enjoy acting out during their frequent absences. Even Cobb, the first American woman on the Moon, isn't immune to the stresses of life. She smokes marijuana with her husband and muses aloud if anyone takes her presence seriously—ultimately NASA does, but only after her Moonwalk and (later in the season) a space accident results in her rescue and triumphant return. These women "have it all," but also experience the hell of "having it all."

It's here, near the end of the first season, that the viewer may realize the show's title is a clever pun, as the very title *For All Mankind* seems to strike out the presence of women in spaceflight. While the male astronauts do carry a massive load during this alternate version of Apollo, many of the show's women (and not just the aforementioned women astronauts) carry an equally massive, but less visible, load, juggling husbands, personal lives, kids, egos, and housework. The show's title begs the viewer to ask what is missing, what could have been, and what may one day be different.

The first season of **For All Mankind** *is available on Apple TV+ and the show has been renewed for a second season.*

FIGHTING FOR SPACE: TWO PILOTS AND THEIR HISTORIC BATTLE FOR FEMALE SPACEFLIGHT

AUTHOR: Amy Shira Teitel **FORMAT:** Hardcover, Kindle, Audio CD *(read by the author)* **PAGES:** 448
PUBLISHER: Grand Central Publishing **ISBN:** 1538716046 **DATE:** February 18, 2020
RETAIL PRICE: $30.00 (Hardcover), $15.99 (Kindle)

>> Reviewed by Francis French <<

Amy Shira Teitel is a fresh face in the field of space history, attracting new audiences with her video channels and other multimedia venues. It's an engaging, 21st century approach that the field of space history needs. Nevertheless, there's also something wonderfully satisfying about holding a printed book in your hands, and Teitel has now delivered just that. Having previously covered the early history of space exploration in *Breaking the Chains of Gravity: The Story of Spaceflight Before NASA*, in her second book *Fighting for Space: Two Pilots and Their Historic Battle for Female Spaceflight* she delves into a complex story of two women pushing for influence in the early years of human spaceflight.

When I heard that Teitel was writing a book about Jerrie Cobb and Jackie Cochran, I wondered what else there was to say that others hadn't said before. After all, there are already many books about Cobb and the so-called "Mercury 13" group of women pilots (who went through some of the same tests NASA used to select the Mercury astronauts). What was supposed to be a small, privately-run medical test opened up a great deal of speculation at the time as to whether America should choose women as spacefarers.

There are also a number of books written about Jackie Cochran, the first woman to break the sound barrier and a key player in getting women pilots engaged in World War Two. Cochran and Cobb had both written their own autobiographies, and there are also many well-researched and informative books written about the events in which they played roles.

I had met Cobb years before and had been intrigued by what seemed like a straightforward story of injustice. She was a talented pilot who wanted to do what some male pilots were getting to do: train to fly in space. Cobb pushed hard, lobbying presidents and legislators, but it didn't happen. On the surface it seemed like a case of equality denied, but as I read the book, the reality proved much more complex and almost the opposite of my original thinking.

Teitel cleverly intertwines the stories of these two female pilots. Born a generation apart, both pushed for inclusion in what was overwhelmingly a "man's world" of aerospace, but in very different ways and with varying degrees of success. Cochran, always a scrappy fighter, knew how to work with politicians and key influencers to get what she wanted. Cobb, a generally shy and awkward character who seemed most at ease alone in the air, tried to do the same with a purposeful sense of righteous destiny. Their collaboration ended with a painful, public showdown, something Teitel builds up to with tact and verve, and her focus on these two individuals delivers a fresh, original take on the events.

Teitel scoured archives for boxes of long-forgotten memos and personal letters, and brought to light some original materials that were previously only rumors. In many cases, what she found has changed what historians thought they knew of these women. She allows the story to breathe, which lets the lives of these characters, each of whom did their share of self-mythologizing, to develop organically in this telling. They are firmly grounded in clear explanations of the politics and aerospace progress of the time, something that many other books treat as an afterthought. As Cochran and Cobb's stories diverge from the more sanitized and campaign-minded versions they fed to the media, Teitel lets the reader develop a subtle, growing sense of unease. Soon, their self-promotions become a part of who they are, and a striking reason why neither achieved the heights they could have.

Most remarkably, Teitel allows us to feel personally engaged with both of these individuals. They are characters who are difficult to sympathize with, as historical figures often are, but we get to know Cochran and Cobb as individuals, laud them when they triumph, and feel for them when they make mistakes. Their complexities allowed both women to go far in life, while also holding them back. The history of women fighting for a place in aerospace history is all the more fascinating because many of the key figures were not squeaky-clean role models.

URBAN LEGENDS FROM SPACE: THE BIGGEST MYTHS ABOUT SPACE DEMYSTIFIED

AUTHOR: Bob King **FORMAT:** Paperback/Ebook **PAGES:** 224 **PUBLISHER:** Page Street Publishing
ISBN: 978-1624148965 **DATE:** October 15, 2019 **RETAIL PRICE:** $16.99/$9.99

>> Reviewed by Loretta Hall <<

In this era of "fake news," author Bob King's promise to demystify space myths is rather timely. I confess I was attracted by the whiff of sensationalism, to see dramatic legends brought down by facts. What I found in the debunking of those tales was a tantalizing taste of astronomy, one that whetted my appetite to learn more about the subject. I had never heard several of the myths before, and the responses like "Earth's axis flips from summer to winter" and "Mars appears as big as the full Moon when closest to Earth" were very informative. I also learned some interesting things about the tilt of Earth's axis and how social media hoaxes begin.

Many of the urban legends King discusses sounded familiar though. There's "Earth is flat" in the section about our planet; "we never landed on the Moon" in the section about our natural satellite; "there's a planet on a collision course with Earth" in the section on planets, comets, and asteroids; and "the sun will one day explode as a nova" in the section on the sun, stars, and space. Most of us already know these to be false, but some may not be so sure. I had always assumed the Moon's phases are caused by Earth's shadow, until I read his explanation. I thought that as the universe expands, galaxies speed away from each other, but King's clarification (illustrated by a clever analogy) gave me a different perspective. The size of the universe forces us into the realm of relativity theory, so some of the explanations require much deeper thinking as well.

Even among the simplest myths, King's explanations contain interesting information. The discussion of NASA's alleged extravagant spending on pens that can write in microgravity includes a brief history of writing utensils in space. The inexpensive alternative, the humble pencil, had proven to be problematic. An eraser particle could float around the cabin, possibly finding its way into an astronaut's nose or eye. Even worse, graphite is electrically conductive and flammable; a bit of broken pencil lead could cause a short circuit and start a fire. Addressing another myth, that the North Star is the brightest star, King broadens the discussion to the ultimate reliability of Polaris as an indicator of north. The precession of Earth's rotation makes the stars' relative positions change ever so gradually, and in the time of the Pharaoh Khufu, Thuban—a star most people today have never heard of—would have been the North Star.

Given that understanding many of these explanations requires careful thinking, it is unfortunate that a few confusing errors survived the editing process. One is fairly obvious as a redundancy: "27,000,000,000,000,000,000 quintillion molecules." Another, perhaps not terribly important in the grand scheme of things, is a reference to the Kármán line, at 62 miles (100 kilometers) altitude, as "the legal boundary of outer space." That designation is broadly accepted internationally, but it is not a codified into law (at least in the United States). NASA, NOAA, and the U.S. military use 50 miles (80 kilometers) as the definition of the border of space. Next came an interesting description of a sequence of interplanetary distances in our solar system that might indicate the absence of a planet where one would be expected, and what was perhaps a typographical error occurred in the sequence, "0.4 (Mercury), 0.7 (Venus), 1.0 (Earth), 1.6 (???), 2.8 (Mars)." The numerical values represent the distances of planets from the sun in astronomical units (multiples of the Earth-sun distance). The question marks, indicating where another planet would be expected, should have followed the 2.8 rather than the 1.6 (which is actually the location of Mars' orbit). Unfortunately, the discussion kept referring to the incorrect values, which would have placed the asteroid belt (mythically the remains of a destroyed planet) between Earth and Mars.

Urban Legends from Space is an enjoyable and informative read and a good introduction to astronomy for someone with little knowledge of that field. The few errors are overshadowed by the book's engaging glimpses of the mysteries that are present around us in the vast cosmos.

FIRST ON THE MOON: THE APOLLO 11 50TH ANNIVERSARY EXPERIENCE WITH A FOREWORD BY BUZZ ALDRIN

AUTHOR: Rod Pyle **FORMAT:** Hardcover/Ebook **PAGES:** 208 **PUBLISHER:** Sterling
ISBN-10: 1454931073 **DATE:** April 2, 2019 **RETAIL PRICE:** $16.47/$10.99
Published in association with the National Space Society
(Note: This review is based on the ebook version)

>> Reviewed by Martin Lollar <<

"On July 20, 1969 at 109:43:10 hours' mission elapsed time, I stepped onto the lunar surface." So begins astronaut Buzz Aldrin's foreword to noted space historian Rod Pyle's richly textured tale of what is arguably the greatest achievement of the 20th century. Of the many excellent books written about the flight of Apollo 11 last year, the 50th anniversary of the Moon landing, *First on the Moon* is set apart because of the author's gift for understanding and portraying the human side of the first lunar landing. The Apollo program was a socio-political and technical miracle given what was accomplished in such a brief period of time, just over eight years from its initiation in 1961, and with technology that had yet to be invented.

The book begins with a cliffhanger, leaving mission commander Neil Armstrong and Lunar Module pilot Buzz Aldrin approximately 33,000 feet (10,000 meters) above the lunar surface, staring at a program alarm on the computer that has to work perfectly for a successful landing to occur. The narrative then jumps back to the 1950s to begin the story of how the U.S. space program got its start and the events that lead us up to this point. That period was the beginning of the Cold War between the United States and the Soviet Union, and only one would be the winner in this high-stakes game of world-wide one-upmanship. The American military had been slowly building towards putting the first satellite in space, but on October 4, 1957 the Soviets shocked the entire world by launching Sputnik into Earth orbit, which sent a steady beep from 359 miles (578 kilometers) above.

The book follows the historical trail of the (sometimes unlikely) events that lead our nation and these three men in particular to be the first crew to land on the Moon. We learn of Wernher von Braun's rocket experiments during World War Two, the success of the V-2 ballistic missile, and his defection with some of his top rocket scientists to the U.S., their work at White Sands Missile Range (then later in Huntsville, Alabama). We observe the birth of NASA as a civilian agency in October, 1958 and the key personnel and decisions that lead to what was probably the most efficient managerial structure ever conceived. We experience the evolution of what is still the most powerful rocket ever launched, the Saturn V, and the enormous engineering and personnel effort (at one time involving over 400,000 people) is told at a pace that keeps the reader fully engaged.

The book includes, of course, full profiles of the crew of Apollo 11: Neil Armstrong, Buzz Aldrin, and Michael Collins. A brief but thorough biography is told for each of these men, detailing the paths they took that led them to become the team that put those first steps on the Moon. We meet Armstrong, the "cool under pressure" commander with an ironic sense of humor; Aldrin, with his Ph.D. in orbital mechanics and perfectionist personality; and Collins, the laconic and quick minded anchor for these opposite personalities, and the man who would pilot them to the Moon.

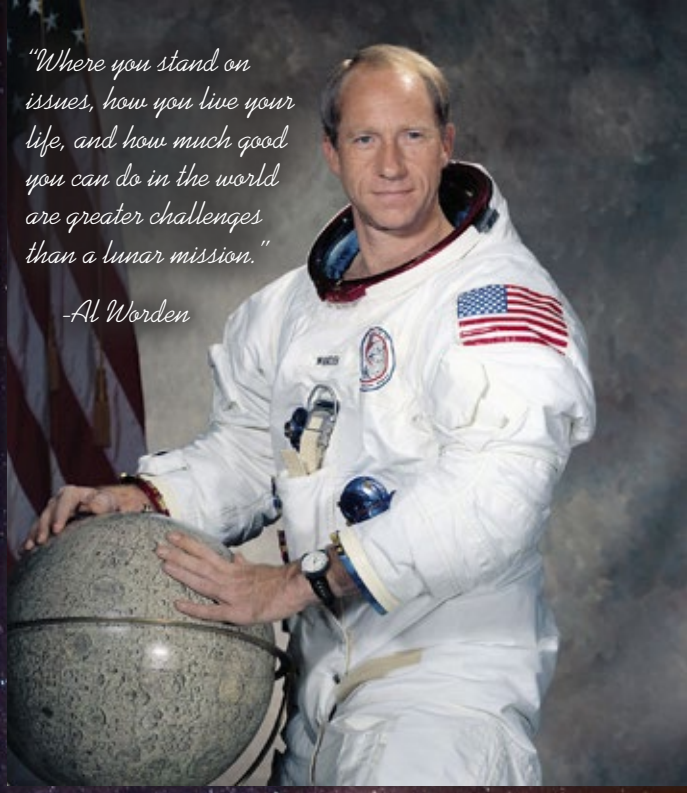
Another important aspect to this book are the sumptuous illustrations provided throughout. The author uses official NASA and government documents, period illustrations, engineering drawings, and archival photos to bring the words to life. Recently released images, long buried in the National Archives, have been assembled into new and exclusive montages by a commissioned digital artist. These illustrations will bring back memories for readers who lived through this period and draw the uninitiated deeper into the story. The pictures and illustrations by themselves may be worth the cost of the book.

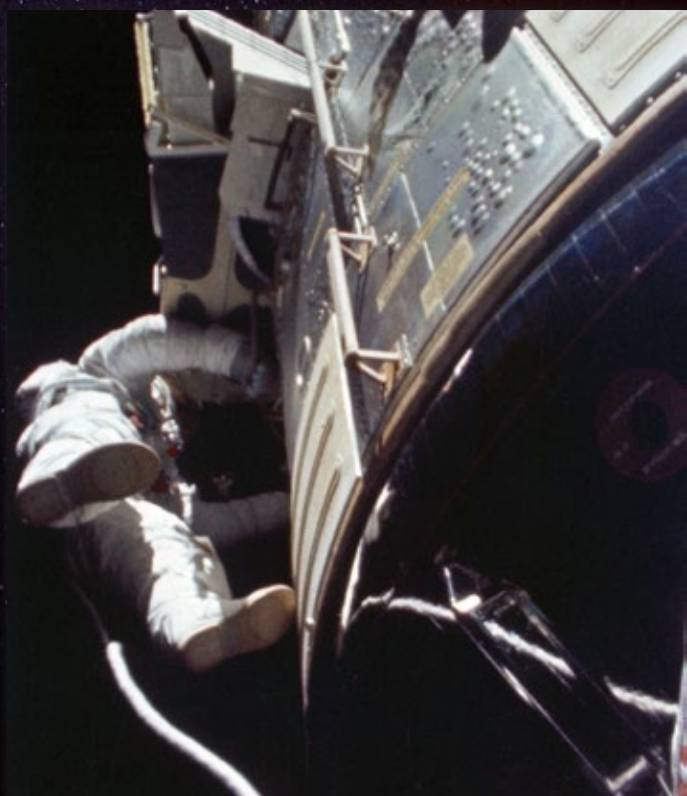
This is a very important, thoroughly enjoyable history of the Apollo 11 mission disguised as a decorative coffee table volume. *First on the Moon* offers people of all ages the complete story of how the United States managed to accomplish this historic event over 50 years ago. Engagingly told and emphasizing the innovations involved in this endeavor, it effectively relates what might have been our greatest adventure. A highly recommended read.

In Memoriam:

Alfred M. Worden

1932-2020





The National Space Society mourns the passing of Alfred M. Worden, a member of the fifth class of NASA astronauts who served as the Command Module Pilot for the Apollo 15 flight to the Moon.

Born in 1932, Worden graduated from West Point in 1955, flew with the United States Air Force, and earned a master's degree in aeronautical engineering from the University of Michigan in 1963. He then served as a test pilot prior to joining NASA in 1966.

Worden served on backup crews for Apollo 9 and Apollo 12 before being selected to fly on Apollo 15. During that flight, Worden spent almost three days alone in orbit around the Moon while fellow astronauts David Scott and James Irwin explored the lunar surface. The Guinness Book of World Records cited Worden as the "World's Most Isolated Human Being" during that flight due to his distance from Earth while passing the far side of the Moon.

During the mission, Worden conducted a record number of observations and scientific experiments, far more that had been accomplished on previous Apollo flights.

"Al Worden's achievements during the flight of Apollo 15 included the first extravehicular activity in deep space, and have inspired generations of people worldwide," said Al Anzaldúa, the NSS's Executive Vice President. "Mr. Worden's subsequent contributions to STEM education through both the Astronaut Scholarship Foundation and his own scholarship fund have helped countless young people to reach their full potential. The NSS expresses its condolences to his family and friends."

After the Apollo 15 mission, Worden worked at NASA's Ames research Center in California, then retired from NASA in 1975 and served in senior executive roles for a number of aerospace firms before becoming the chairman of the Astronaut Scholarship Foundation. He has founded other youth scholarship programs in subsequent years.

Worden wrote or co-wrote three books: *Hello Earth; Greetings from Endeavour* (Nash Publishing, 1974), *I Want to Know About a Flight to the Moon* (Doubleday, 1974), and *Falling to Earth: An Apollo 15 Astronaut's Journey to the Moon* with Francis French (Smithsonian Books, 2011).

Anthony Paustian, chair of the 2020 International Space Development Conference, said: "The world has lost a truly incredible man. Whether appearing on the Mr. Rogers show, raising money for student scholarships, or just going to local elementary schools to speak with kids one-on-one, Al was always willing to use his position to help inspire others. It was my utmost honor at last year's ISDC to present him with the NSS Space Pioneer Award—an award he definitely deserved."

Worden is survived by three children. The NSS expresses its deepest condolences to his family and friends and lauds his many life achievements. Worden appeared at at ISDC 2019, and was scheduled to speak at the 2020 conference. His cheerful and generous presence will be sorely missed.

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If you support the exploration and development of space and the creation of a spacefaring civilization, joining the National Space Society (NSS) is a good first step. But what if you want to do more?

If you want to meet others of like mind, if you want to explore how your special interests and abilities fit into the larger picture, If you want to share your enthusiasm, if you want to engage in research or teach others about space, then you should join an NSS Chapter. It's easy!

Your first step is to see if there is a chapter that meets your needs already. Chapter contact listings are in every issue of "Ad Astra" and online at **space.nss.org/nss-chapters-directory**. Then contact the local leaders or check their Chapter websites for upcoming events and activities near you.

Local chapters also often concentrate in special areas (e.g., rocketry, education, original peer-reviewed research on space settlement, etc.) and will generally welcome distant members who share their particular interests.

If there are no existing chapters that meet your needs, you may want to form a new one. Instructions are available on the NSS Web site at: **space.nss.org/community-chapters**. You may also contact Chapters Resources Coordinator Larry Ahearn to get a NSS Chapter Starter Kit emailed or mailed to you. Chapters in good standing with the NSS have access to assistance and resources from both NSS national and other nearby chapters. Resources from both NSS national and other nearby chapters. Resources include promotional materials, educational materials, and membership recruitment rebates. See **space.nss.org/resources-for-chapters** for more details.

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This June, we will have a special, virtual event: A Day in Space 2020

Keep your eye on the **ISDC2020.nss.org** website and on *Downlink* for updates on this virtual celebration of space in June.

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