Space
Space and Off-Planet Exploration

KEY INSIGHT

Human ambition, our quest for knowledge, and our curiosity have always driven our rush to explore space, and 2021 promises to be another important year for space initiatives. Some of the missions are crewed by humans, others feature robots, and a handful will bring earthly agriculture into space.

EXAMPLES

Last year was a triumphant one for the space industry. SpaceX successfully launched a mission to the International Space Station—the first such launch from American soil in a decade. Three missions to Mars took flight. And brand-new moon samples were returned to Earth. This year, a number of important missions will further shape our off-planet aspirations. NASA’s Mars 2020 mission successfully reached its destination, a point on the planet called the Jezero Crater. The Perseverance rover will look for microbial life forms and test new technologies required to sustain human life. The Hubble Space Telescope’s successor, the James Webb Space Telescope, is scheduled to launch in the fall. SpaceX will begin further testing its next-generation vehicle Starship, which is built for deep space exploration.

DISRUPTIVE IMPACT

Some estimates say the space industry is worth $330 billion and could double by 2026. From leisure travel to asteroid mining to telecom, myriad industries and businesses will spring from and benefit from space exploration.

EMERGING PLAYERS

- SpaceX
- Blue Origin
- Moon Express
- Astrocast
- Maxar Technologies
- Kyoto University
- Sumitomo Forestry
- Astroscale
- Advanced Quantum Scientific Technology
- BEI Precision
- SpaceFab
- Data Collective
- Boeing HorizonX Ventures
- Planet Labs
- Rocket Lab

Kyoto University and Sumitomo Forestry are developing satellites out of wood.
Space Mining

Vast amounts of precious rare-earth elements and metals—which are used in much of today’s technology hardware—exist on the moon and in meteors and asteroids. Mining those minerals in outer space could be a lucrative venture as well as a cunning geopolitical strategy, because China currently controls 95% of rare-earth element production.

In 1979, several members of the United Nations put forward the Moon Treaty, a framework to guide international space exploration, which, among other things, prohibited mining in outer space. None of the world’s spacefaring nations ratified the treaty. In 2020, NASA shared the Artemis Accords, an international agreement for civil space and moon exploration. While the agreement has nine signatories, including some of the United States’ closest allies, it has also been criticized for promoting commercial mining of celestial bodies. Notably, the other powerful space nations, including China, India, Russia, Germany and France, have not signed on. Whether or not celestial mining becomes a viable business practice in the very near term, the idea of commercial space exploration puts pressure on governments to create clear international agreements and frameworks for governing space.

Space Junk

Space is our next dumping ground. As many as 170 million fragments of metal and astro debris orbit the Earth. That includes 20,000 pieces larger than a softball and 500,000 about the size of a marble, according to NASA. This debris will pose a navigation hazard for many centuries to come as low-Earth orbit becomes more cluttered. At least 200 objects roar back into the atmosphere each year, including pieces of solar panels, antennas, and fragments of metal. All of them pose dangers for future astronauts: One plum-sized piece of gnarled space trash traveling faster than a speeding bullet could rip a 5-foot hole in a spacecraft. That collision, then, would throw off its own share of shrapnel, which would join the rushing river of junk already circling the planet.

In space, collisions beget collisions in a chain reaction known as the Kessler syndrome—a phenomenon that could eventually make some of our available orbits unusable. It’s not just Americans doing the dumping—China and Russia each have dozens of decommissioned satellites overhead—although the U.S. certainly does it with style. Where all that junk winds up isn’t something we can predict accurately. We could be unintentionally wreaking havoc on civilizations far away from Earth, catalyzing future intergalactic wars. Or we might cause far less scintillating problems. Space junk could start to behave unpredictably, reflecting sunlight in disruptive ways, altering our atmosphere, or even challenging our understanding of the universe and the laws of physics.
New World Spores

Far-future neutral scenario

Humanity looks beyond Earth and Mars when people begin to think of their future in terms of civilizations rather than years. But new human colonies in the cosmos cannot simply be built—they must be born. To prepare for future colonies, we send highly resilient spores to far-off planets that are deemed able to support life. The spores then have millennia to develop and evolve into basic life forms that could serve as valuable resources for human settlers later on. Sending these microscopic advance teams might be the kind of foresight that gives the explorers of tomorrow a headstart on our next planetary home.
Space Sustainability Initiatives
Space junk is becoming a bigger problem as more satellites are launched into the atmosphere. An innovative approach to reducing particulates is already underway at Kyoto University. Sumitomo Forestry, part of Japan’s Sumitomo Group, is developing microsatellite constellations with individual units made out of wood. It’s not the first time wood has been considered for such a job: NASA’s earlier Ranger program sent balsa wood structures to the moon. One benefit is that the wood won’t block the electromagnetic waves that satellites use to communicate. The project is set to launch in 2023.

Space Imaging
In 2019, scientists did what they thought was impossible: They captured an image of a black hole’s silhouette using the Event Horizon Telescope. A team of international astronomers and computer scientists spent a decade developing a new kind of technique that revealed a dark black center surrounded by a massive ring of orange and yellow light. In early January, scientists in Maui used the new Daniel K. Inouye Solar Telescope for the first time and took the highest-resolution photos of the sun ever recorded. (The surface looks like the cracked ground of the Atacama desert—if it were oozing and on fire.) New techniques and equipment for space imaging will advance the work of research scientists across many fields.

Satellite Megaconstellations
Within a few years, there will be vast megaconstellations of tiny satellites orbiting the Earth. In August 2020, the U.S. Federal Communications Commission approved Amazon’s latest satellite megaconstellation, which included 3,236 microsats built to provide high-speed internet—that’s more than double the total number of satellites currently in orbit. In early 2020, the Starlink constellation, a project from Elon Musk’s SpaceX, began sending clusters of 60 satellites into orbit every few weeks. By the end of this year, there could be a fleet of 12,000 overhead. U.K.-based OneWeb is set to launch up to 700. That’s just a small selection—it would take several pages to list every company and planned launch over the next five years. These satellite constellations comprise many small “microsats” or “cubesats,” which are capable of communicating with each other and continue to work when one satellite in the network goes down. Constellations are used for a variety of purposes, including taking photos and beaming internet access back down to Earth. But with thousands of planned spacecraft launches—carrying microsat and cubesat constellations, in addition to heavier satellites, rockets, and spaceships with rovers and human cargo—astronomers are warning that our view of the sky, and our ability to research the cosmos, is in jeopardy. Scientists have voiced concern that megaconstellations of microsats and cubesats will not only obstruct their view, but that they could also interfere with radio astronomy.
Space-Based Internet
Amazon, SpaceX, Google, and others are developing satellite technology that would beam internet services directly to our devices, and in the process bypass our internet service providers (ISPs). OneWeb has plans to power what it calls “fiber-like internet” coverage in the Arctic. New space-based internet services will rely on a complex array of microsat constellations and ground stations. SpaceX and Amazon are working on services to bring internet service to people in areas neglected by traditional wireless carriers and ISPs.

Self-Steering Satellites
Researchers at the U.S. Naval Research Laboratory are working on a concept that could not only help steer satellites back down to Earth when they’re decommissioned but also clean up space clutter in the process. The idea is to outfit new satellites with thin “umbilical cords” about a kilometer long. Running an electric current through the cord would enable a satellite to steer itself using its own electric field as well as the magnetic field from Earth. Think of it as an invisible sail that could someday enable old satellites to guide themselves home.

The Space Economy
New spacecraft, rockets, and other technologies are helping private commercial companies achieve liftoff—with plenty of eager investors footing the bill. Investors including Morgan Stanley are eyeing a new “fiber-like internet” coverage in the Arctic. New space-based internet services will rely on a complex array of microsat constellations and ground stations. SpaceX and Amazon are working on services to bring internet service to people in areas neglected by traditional wireless carriers and ISPs.

Space Tourism
As of 2020, SpaceX became the only NASA-certified company to send people into orbit. While Elon Musk’s goal is Mars, shorter flights on Starship could begin in the next year or two (initially round trips to and from Earth). Space Adventures is offering private spaceflight to the International Space Station (ISS) and eventually the moon. Already, Space Adventures has ferried more than a half dozen paid trips to the ISS via a partnership with Russia. In December 2021, two Space Adventures tourists will ride aboard the Soyuz spacecraft.

Galactic Ride Sharing
New technologies have spawned a new trend in space transportation: galactic ridesharing. In 2018, Spaceflight Industries launched its first rideshare mission called SSO-A SmallSat Express aboard a SpaceX Falcon 9. The company purchased all available payload space on the rocket to service customers who wanted to launch various items into space. These types of launches often include microsats and cubesats from multiple countries, but unusual items make it to space occasionally, too. A satellite from the Los Angeles County Museum of Art sent up a 24 karat gold jar with a bust of the first African American astronaut to reach space. Artist Trevor Paglen sent a self-inflating sculpture that reflects sunlight and can be viewed by the naked eye on Earth. Another craft, the Elysium Star 2 sent by Elysium Space, contained the cremated remains of people who wanted to become shooting stars. As more researchers, artists, and everyday people want to hitch rides on spacecraft, we anticipate new “rocketsharing” business models—followed by a potential wave of regulation.

Galactic Refueling Stations
Some satellites require fuel, and it turns out fuel is very heavy. After a satellite runs out, it’s no longer fully operational. For that reason, researchers have been developing new refueling stations and new techniques that would overcome some liquid dynamics challenges. Last year, startup Orbit Fab successfully completed the first set of experiments to see if water could be transferred between two satellite test beds. Orbit Fab has been working with satellite manufacturers on something called the Rapidly Attachable Fuel Transfer Interface, or RAFTI, which is a new kind of valve system that would allow satellites to be fueled on the ground before launch and, someday, refueled in space. This would eventually allow more satellites to stay in orbit and help reduce the creation of new space junk.
Off-Planet Living

NASA has said it wants to send humans to Mars by 2030, and in 2016 it selected six private U.S. companies, including Boeing, Lockheed Martin, and Bigelow Aerospace, to develop prototypes for deep space habitats. At the beginning of the year, Elon Musk talked about sending 1 million people to colonize Mars by the year 2050 using three Starship launches a day. SpaceX has taken steps to turn what sounds like science fiction into reality—this year, the company will bring astronauts to the ISS. However, astrophysicists have been quick to point out difficult hurdles to overcome in Mars-bound space travel, not the least of which is radiation. As Columbia University astronomer Caleb Scharf explained, “In the worst case scenario (which may or may not be a realistic extrapolation) there’s a chance you’d end up dead or stupid on Mars. Or both.”

Mercury Rain

New rocket propulsion systems for rocket engines would use mercury as a fuel, which could run the risk of spreading toxic chemicals through Earth’s atmosphere. NASA experimented with mercury in the 1960s because it’s a low-cost, high-power option for ion engines. Startup Apollo Fusion has discovered a new approach to using mercury—but there’s a catch. Mercury is heavier than the xenon and krypton powering other ion engines in use today. What customers might save on costs could pollute the atmosphere in potentially harmful ways. While the U.S. government has tried to reduce terrestrial mercury emissions since the 1990s, the rules do not specifically cover spacecraft hovering above us. The U.S. Federal Aviation Administration requires companies to disclose hazardous materials in flight, but its policy also doesn’t address satellites. This is an area where, yet again, technology has sped beyond the limits of the law.
China’s Space Ambitions

China’s space program is well underway. It’s well-capitalized, includes many space startups, and has the full support of the government. In 2021, China will start building a new space station, and it’s planning to send astronauts to the moon by 2030. But the country’s main focus is on the commercial space industry, as its private space business sets up shop manufacturing cubesat megaconstellations, larger satellites, rockets, IT infrastructure, communications networks, and all the other hardware needed by the global business. While China is a little late to the party compared to other world leaders such as the U.S. and Russia, it’s catching up quickly. Last year, China became the first country to land a robotic mission on the far side of the moon. It was a historic accomplishment—and a clear sign of new leadership from China. President Xi Jinping said, “The space dream is part of the dream to make China stronger … the Chinese people will take bigger strides to explore further into space.” China doesn’t just want to be seen as a powerful Asian nation—it wants to set the global pace for numerous geo-economic initiatives, environmental causes, and societal development.

Ultra-Long Space Missions

If climate change escalates and we are unable to mitigate its effects, humanity is going to need a plan B. Some scientists think our next best option is a 1,000-year space mission to save future generations from extinction. Their target is a planet called Proxima Centauri b, an exoplanet in a habitable zone of a star like our sun. This means that water might exist in liquid form there and, theoretically, could support human life. We don’t know what the atmosphere is like or whether the planet’s surface is too hot or cold to sustain living organisms as we know them. A program founded by science philanthropist Yuri Milner and the late Stephen Hawking is building a spacecraft weighing only a few grams that would be propelled by a 100-billion-watt laser fired at it from Earth. The craft would take 20 years to reach the Alpha Centauri solar system, where Proxima b is located. It’s a step toward building a new kind of spacecraft big enough to transport humans deep into space on a journey that would take a millennium to reach humanity’s new home.

A geologist once said to me, ‘We went to the moon six times. If you had come to New York state six times, would you have thought that you investigated the whole world?’

— Jeanette Epps, NASA astronaut