National Aeronautics and
Space Administration

NASA's Low Earth Orbit Microgravity Strategy

Leading the next generation of human presence in low Earth orbit to advance microgravity science, technology, and exploration

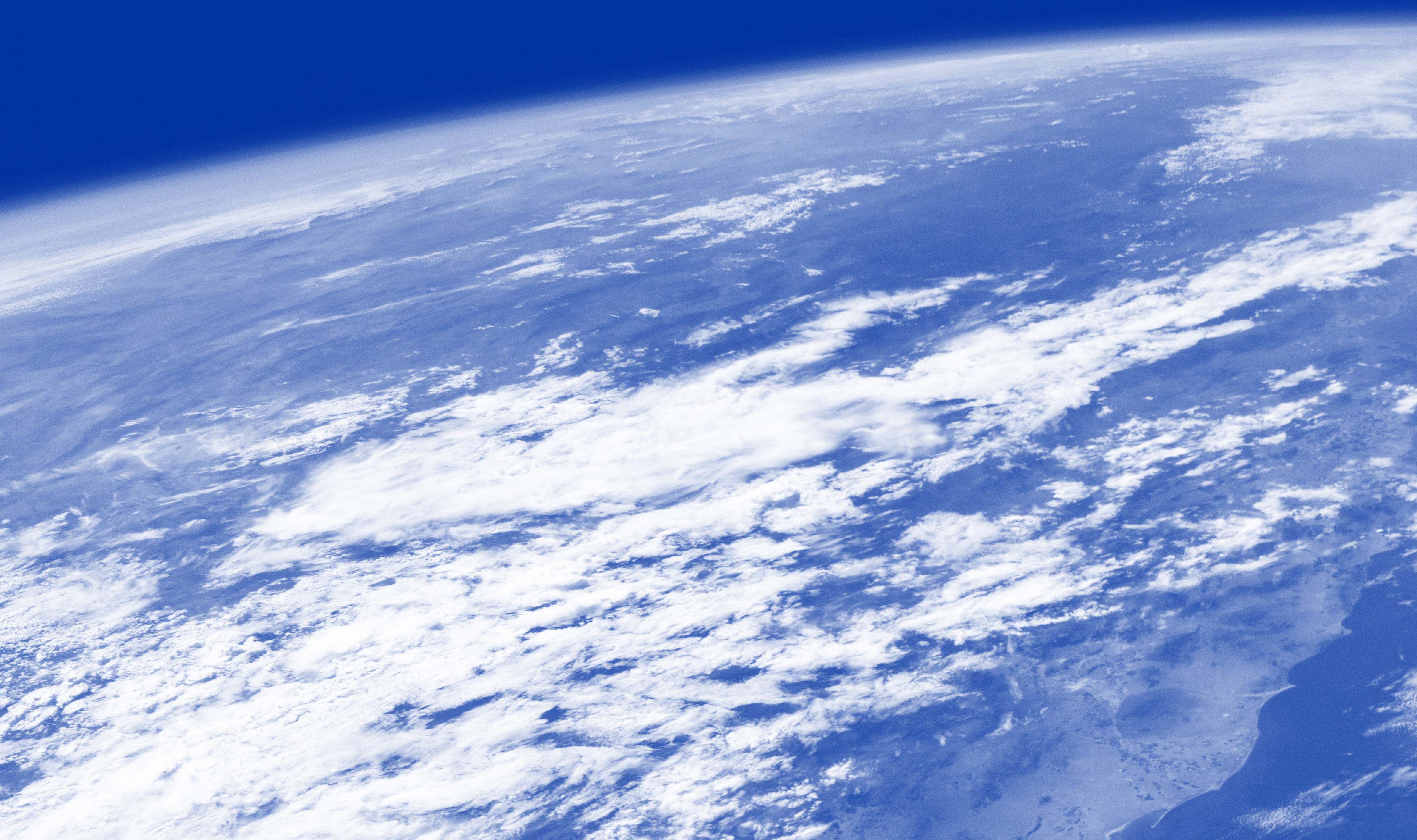

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Image on previous page: A sheet of clouds moves in over Baja California and the Gulf of California as the International Space Station soared 262 miles above.

Image on cover: An artist's concept of the International Space Station orbiting Earth. In the distance is the Moon, and a red star representing Mars.

In our pursuit of the stars, the low Earth orbit microgravity environment has always been a place of extraordinary opportunity – where science is advanced, technology is tested, partnerships are forged, and humanity stretches the boundaries of what is possible. As we look ahead, the continued use of this vital environment is essential to our future exploration endeavors. Low Earth orbit is not just a stepping stone to the Moon and Mars; it is a unique environment that has fueled progress in ways we could only imagine when one of humanity's greatest achievements – the International Space Station – first became operational.

NASA's Low Earth Orbit Microgravity Strategy outlines our commitment to ensuring that the U.S. remains the leader in space. With a rich history in human spaceflight, we've made transformative discoveries that have expanded the very boundaries of what we understand about space. But this is only the beginning. As we transition from a government-owned platform to a more commercial, partnership-driven future, we are facilitating the creation of an ecosystem that will allow both government and private entities to thrive.

This strategy is the product of extensive collaboration across many sectors: NASA's dedicated workforce, government partners, commercial partners, international space agencies, and academic institutions. The invaluable wisdom, insight, and innovation shared by these partners has helped refine and strengthen our path forward, and we are grateful to all who contributed their expertise and perspective to create this robust, forward-looking framework.

The goals and objectives in this strategy have affirmed that a continuous human presence in low Earth orbit is a fundamental requirement for advancing space science and technology, fostering innovation, and maintaining the momentum essential for the viability of our space industry and international space partnerships. For over 24 years, the continuous crewed presence aboard the International Space Station has driven research at an accelerated pace, demonstrated what it takes to live and work in space, and fostered a launch industry that has made low Earth orbit more accessible. Maintaining this unbroken presence will enable us to reduce risk for sending humans to Mars, fuel collaboration with our international partners, preserve the transportation model, and enhance operational skills. Moreover, the goals and objectives will lay the foundation for activities that will leverage low Earth orbit as a proving ground for critical technologies that are essential to future deep space exploration, including to the Moon, Mars, and beyond.

The future of space is bright, and NASA is uniquely positioned to guide the way. Our work is part of something much bigger than ourselves – something that will inspire, innovate, and leave a lasting legacy for generations to come.

These goals and objectives are a call to action for all of us – NASA, the private sector, international partners, and every individual who believes in the power of space. We have always been bold in our ambitions, and now, more than ever, we must work together to create a future where humanity thrives in space, where we keep a continuous presence in low Earth orbit, and where the next generation of explorers, scientists, and engineers can reach for the stars.

Jim Free
NASA Associate Administrator

NASA's Low Earth Orbit Microgravity Strategy document outlines what NASA intends to achieve by continuing human activities in low Earth orbit after the retirement of the International Space Station.

13 goals

44 objectives

The focus is on advancing scientific research, technology development, and fostering international cooperation and commercial growth. The goals and objectives in the strategy build on decades of experience from NASA's flagship human spaceflight programs, which have played a pivotal role in developing a robust commercial space sector. NASA's efforts in low Earth orbit have not only contributed to global technological advancements but also positioned the United States as a leader in space, attracting significant investments in commercial space technologies and international partnerships.

The International Space Station, now in its third operational decade, has been a key platform for long-duration microgravity research, helping to unlock transformative scientific discoveries. However, as the space station nears its planned retirement in 2030, NASA is collaborating with the private sector to develop new orbital platforms that will sustain and expand scientific and commercial activities in low Earth orbit. This transition will ensure continued U.S. leadership in space while enabling the next generation of scientific research and technological innovations.

Low Earth orbit will remain a vital testbed for the development of systems and capabilities necessary for NASA's missions to the Moon, Mars, and beyond.

In early 2024, NASA initiated an objectives-based approach to plan its future human activities in the low Earth orbit microgravity environment, focusing first on what the agency wants to achieve in this environment. In August 2024, NASA released a draft set of goals and objectives for public review, which was followed by workshops with international, industry, and academic stakeholders. These discussions led to the final 13 goals and 44 objectives in seven distinct focus areas.

Through the establishment of this strategy, NASA will lead the next generation of human presence in low Earth orbit to advance microgravity science, technology, and exploration, while also supporting the commercial space sector and international collaboration. The commercial space industry, having historically benefited from NASA's investments, plays a critical role in the future of space exploration. The shift towards commercially owned and operated space stations will provide continued access to low Earth orbit for research and technology demonstrations, while fostering economic growth, creating high-tech jobs, inspiring the next generation, and facilitating international collaboration.

The document highlights the critical need for a continuous human heartbeat in low Earth orbit to ensure that scientific research can continue without interruption and that commercial platforms remain viable. NASA recognizes that maintaining a predictable cadence of crewed missions is essential for both advancing science and technology development and sustaining the commercial space industrial base.

NASA's Low Earth Orbit Microgravity Strategy provides a clear vision for the future of human spaceflight in low Earth orbit. By maintaining a robust presence in low Earth orbit, NASA will continue to drive scientific discovery, technological innovation, commercial growth, and international cooperation, all while positioning the United States to remain at the forefront of space in the coming decades.

Image on previous page: A composite of a series of images photographed from a mounted camera on the Earth-orbiting International Space Station, from approximately 240 miles above Earth.

From the beginning,

NASA's flagship human spaceflight programs have built upon each other, expanding human knowledge and experience of living and working in space. These programs, including the International Space Station, have also enabled the development of a commercial space industrial base that serves many purposes, including driving innovation, creating a skilled technical workforce, and directly contributing to NASA's mission success. The commercial sector has also developed capabilities over the last several decades, ranging from rockets to science and technology demonstrations, which are contributing to the global economy and advancing humanity. These efforts have uniquely positioned the United States as a global leader, attracting investments in commercial space – and U.S. companies – at unprecedented levels.

In its decades of operations, the International Space Station has been a testbed for long-duration microgravity research and technology development. It is now in its golden era of peak utilization, or the "decade of results." However, the space station was not designed to last forever and is planned to be retired at the end of this decade.

NASA and American industry are collaborating to build new orbital platforms to continue the agency's work and expand commercial possibilities in low Earth orbit after the space station is retired. NASA is identifying and strategically investing in specific capabilities and technologies to lead the next generation of human presence in low Earth orbit and advance microgravity science, technology, and exploration. As the agency returns to the Moon under Artemis and prepares for the journey to Mars, human spaceflight in low Earth orbit remains critically important, and NASA will remain the worldwide leader in this endeavor.

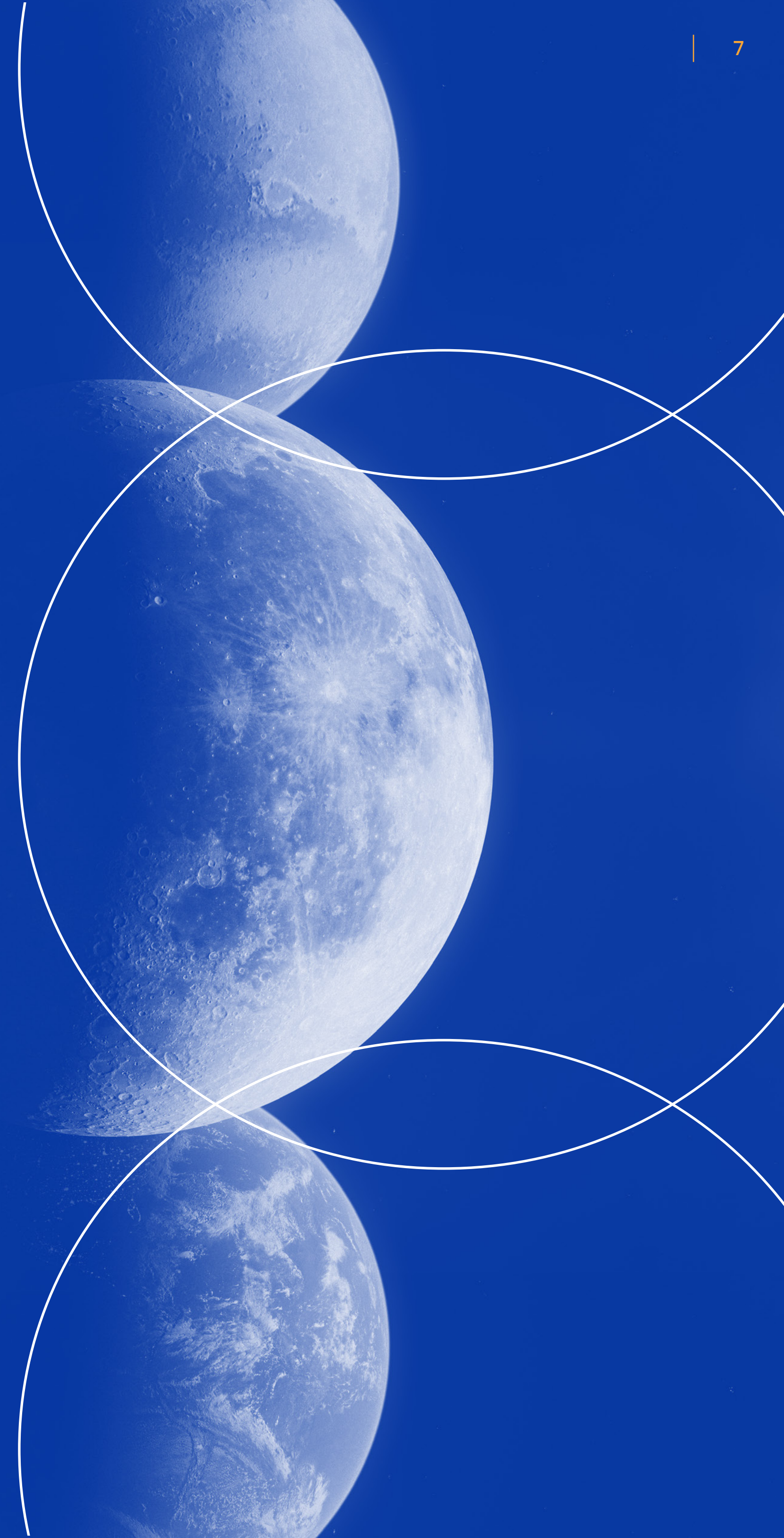
In early 2024, the agency began its effort to develop and document an objectives-based strategy regarding human activities in low Earth orbit as NASA transitions its operations from the International Space Station to commercially owned and operated space stations. This process focused on deciding **what** the agency wants to achieve in low Earth orbit before determining **how** to achieve it.

In August 2024, NASA outlined its approach, publishing a draft set of 12 goals and 42 objectives for public review and comment.

In September, the agency held stakeholder workshops with its international, industry, and academia partners to solicit additional feedback on the draft goals and objectives. Throughout the fall, an internal NASA team reviewed the feedback received and finalized the Low Earth Orbit Microgravity Strategy, adding one new goal and several new objectives for a final set of 13 goals and 44 objectives across seven distinct focus areas.

This document presents NASA's vision for the next generation of human presence in low Earth orbit and how the agency envisions achieving this future. It includes discussions on the scope of the goals and objectives as well as:

- The critical importance of continuing activities in low Earth orbit to maintain U.S. leadership in advancing science and technology.
- An objectives-based approach that will help better define the future of NASA's human activities in low Earth orbit.
- NASA's strategic next steps and how it will use these goals and objectives to achieve the agency's vision for crewed presence in low Earth orbit, particularly after the retirement of the International Space Station.



Scope

These goals and objectives focus on guiding NASA's future human presence and interrelated aspects of human operations in low Earth orbit. They do not encompass all of NASA's future activities in low Earth orbit, such as satellites for Earth observations, space science, communications, or precision navigation and timing. Likewise, they do not encompass all potential uses of sub-orbital and parabolic flight opportunities, except where these activities may help achieve the goals and objectives outlined in this document.

NASA's Low Earth Orbit Microgravity Strategy will guide the agency's plans for leveraging crewed commercial low Earth orbit platforms in a post-International Space Station era to support its missions.

Image on previous page: An image sent back from Ranger 7. The seventh in a series of early U.S. lunar impact missions, Ranger 7 sent back 4,316 stunning images before crashing into the Moon on the northern rim of the Sea of Clouds on July 31, 1964.

Image: An artist's concept of Mars, the Moon, and Earth.

NASA's Low Earth Orbit Microgravity Strategy is guided by a well-defined systems engineering process, beginning with the fundamental question, "Why go?" And in the case of low Earth orbit, an equally important follow up question is "Why stay?" Additional key influences on this approach also include the historical efforts in low Earth orbit and NASA's current activities.

Image: NASA astronaut Mark Vande Hei works inside the Life Science Glovebox (LSG) for the Celestial Immunity study.

Why Continue in Low Earth Orbit?

It is important to consider why the nation, and specifically NASA, should conduct future activities in low Earth orbit. The reasons are three-fold and align with the agency's position on human exploration of deep space.

Advance Science and Technology

One of the primary driving forces behind the U.S. civil space program is the quest for scientific discovery – exploring the unknown and gaining a deeper understanding of the universe to benefit humanity. NASA's research, conducted from the unique vantage point of space, complements and expands upon the research conducted here on Earth. For example, biological and physical systems in reduced gravity reveal second- and third-order effects that are otherwise overwhelmed by Earth's gravity, offering new insights that are leading to transformative advancements. The 2024 National Academies of Sciences, Engineering, and Medicine (NASEM) Decadal Survey on Biological and Physical Sciences Research in Space[1] underscores how much more there is to learn in these areas.

The accessibility of a crewed low Earth orbit platform provides the most cost-effective environment to explore these effects in depth, yielding discoveries that have the potential to directly benefit humanity. Furthermore, as NASA prepares to explore the Moon and Mars, the agency and its partners must rigorously test the technologies and capabilities required for these endeavors in representative environments. Low Earth orbit provides a proving ground, allowing these technologies and capabilities to be evaluated and validated over long durations, reducing risks and costs, and refining approaches ahead of more complex deep space exploration missions. For these reasons, NASA considers low Earth orbit essential for advancing science and testing technologies for deep space exploration.

1 https://nap.nationalacademies.org/catalog/26750/thriving-in-space-ensuring-the-future-of-biological-and-physical

Continue U.S. Leadership in Space

Achieving a bold vision for space exploration establishes not only national strength in science and technology innovation but also enhances our global competitiveness and international relationships. This, in turn, fuels economic growth in fields that might not have existed without the catalyst of space-driven innovation. Solutions to complex technological challenges in space have had profound, far-reaching impacts on other Earth-based problems and industries, often giving rise to entirely new disciplines.

Over its two decades of operations, the International Space Station has been instrumental in fostering the growth of the commercial space industry, which has had billions of dollars in national economic impact across the United States. NASA recognizes the role it has played to date in spurring the commercialization of low Earth orbit and advancing space technologies and capabilities through the Commercial Resupply Services and Commercial Crew Programs, as well as the agency's partnership with the International Space Station National Laboratory. The microgravity research performed on the space station has unlocked the potential for improving life here on Earth and has resulted in significant capital investment in emerging technologies, NASA technology, and spin-offs. These investments fuel growth in American industry and generate quality, high-paying jobs nationwide.

Space exploration, free from geographic boundaries, is also uniquely positioned to foster international partnerships to achieve feats that might not otherwise be possible. Building on the successful international partnerships forged in low Earth orbit aboard the International Space Station, current and prospective partners have highlighted the importance of low Earth orbit as an area for continued collaboration. Moreover, opportunities for cooperation in low Earth orbit are more accessible and cost-efficient for international partners in comparison to deep space exploration activities. By ensuring pathways for continued international partnerships in low Earth orbit, the U.S. can remain a partner of choice for nations seeking to explore or continue to operate in this region. Bolstering economic competitiveness, international partnerships, and global influence likewise reinforces national security interests.

20+

years of operations on the International Space Station

Inspire the Next Generation

Humanity's quest to explore the unknown has led to discoveries that have benefitted humanity and changed the course of history. Space exploration is no different, as it can thrill, inspire, and spark new insights from the humanities to the sciences. Building a workforce dedicated to science, technology, engineering, and mathematics (STEM) careers is of national importance. Additionally, NASA's communications and public engagement activities inform and inspire the general public, stakeholders, educators, and the next generation of the explorers and innovators who, if born after the year 2000, have never known a world without a human in space. A consistent and constant human presence in low Earth orbit ensures the availability of everyday opportunities for the crew to engage and inspire the next generation – the workforce of tomorrow – to pursue careers not only in STEM fields, but also in critical support roles for space exploration endeavors.

BILLIONS

of dollars in economic impact across the United States

Why Is the Low Earth Orbit Microgravity Environment Important?

Microgravity is an essential factor in NASA's future activities in and beyond low Earth orbit. NASA astronauts will need to operate in microgravity for extended periods as they travel to the Moon, Mars, and eventually to other destinations in the solar system. Maintaining the ability to develop and refine the operational skills and capabilities necessary for future deep space missions is critical.

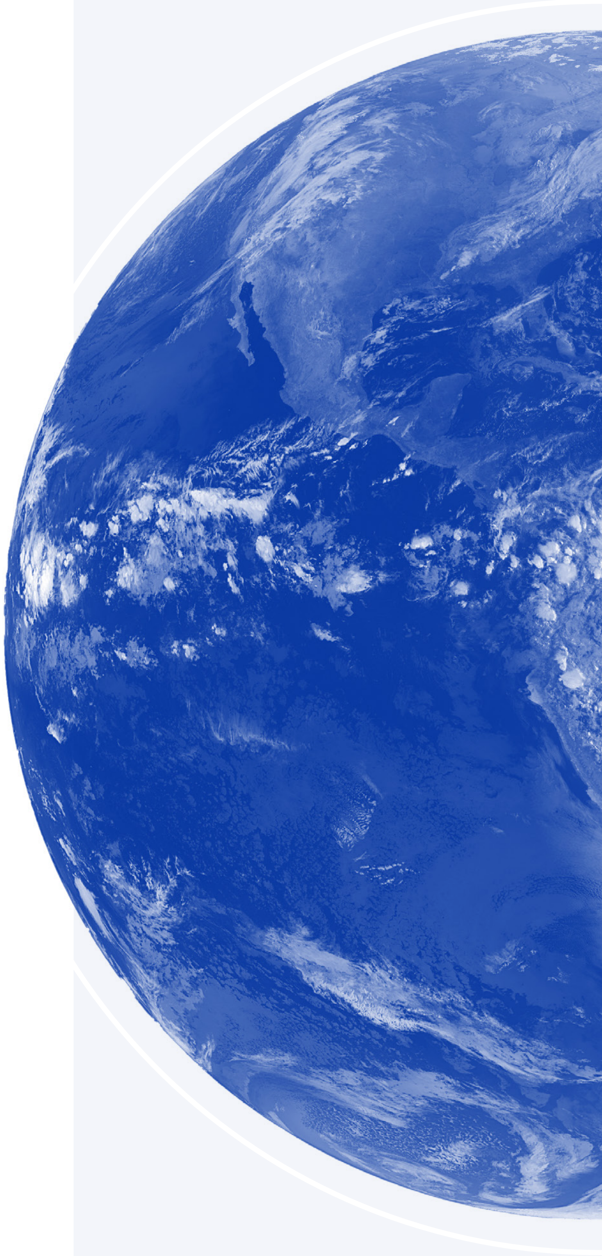
While NASA has discovered a great deal through its foundational human spaceflight programs, much more remains to be learned about key scientific phenomena in microgravity. Many of the most pressing scientific questions can only be answered through laboratory experiments conducted in space, where the effects of Earth gravity are greatly reduced.

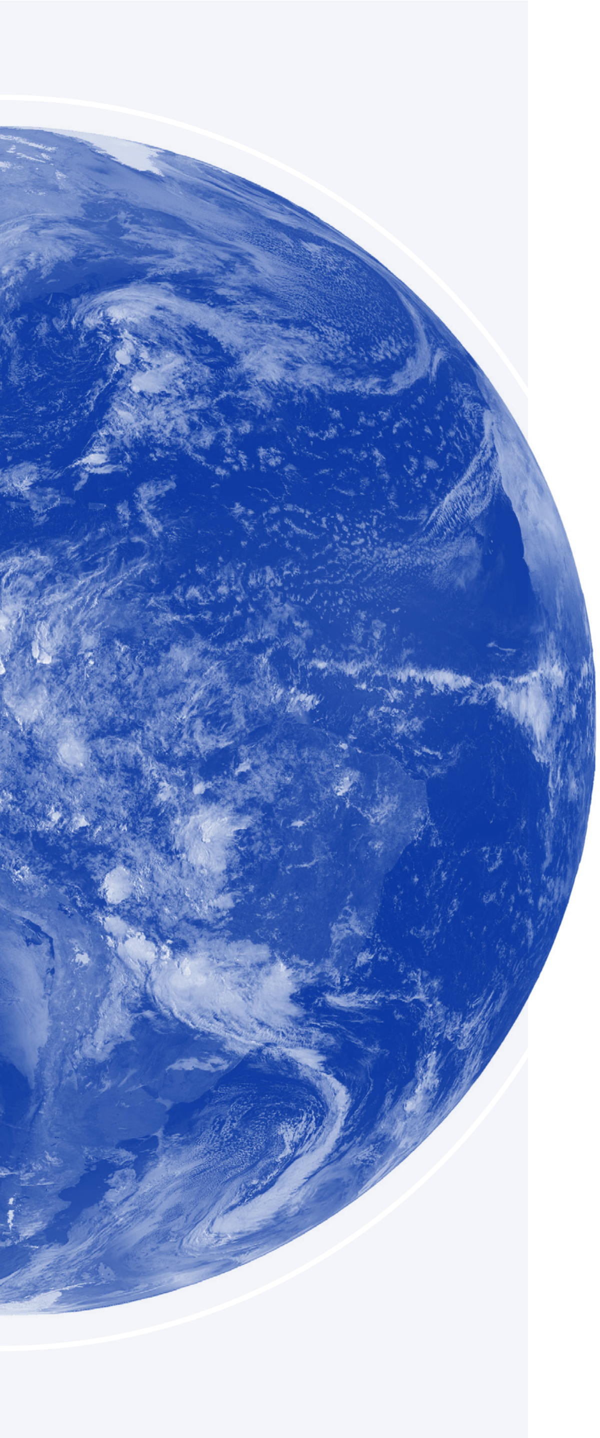
To answer these important scientific questions and develop technologies needed for future missions, a robust microgravity research ecosystem in low Earth orbit is needed—one that includes research personnel and commercial platforms equipped with research facilities. Microgravity infrastructure that is easy to access from Earth will be essential for conducting critical experiments and for developing optimized systems and effective physiological countermeasures that will enable astronauts to safely and effectively carry out missions to the Moon, Mars, and other destinations.

develop and refine operational skills and capabilities necessary for future deep space missions

learn about key scientific phenomena in microgravity

ability to test technologies in microgravity





In addition, having access to a microgravity proving ground near the Earth's surface will be valuable for early technology development, leading to a reduction in the logistics loads, and costs, of future deep space exploration missions. The ability to test technologies in microgravity is crucial to ensuring the cost-effectiveness and success of future deep space exploration programs.

NASA and its industry partners have also amassed a wealth of expertise in living and working in microgravity. Maintaining and expanding microgravity skills and capabilities will also be imperative to achieving exploration goals.

> **Maintaining and expanding microgravity skills and capabilities will also be imperative to achieving exploration goals.**

BACKGROUND AND CONTEXT

Consistency with U.S. Law and Policy

NASA's Low Earth Orbit Microgravity Strategy aligns with agency authorization and appropriations legislation across multiple Congresses, as well as U.S. national space policies spanning multiple administrations.

The NASA Transition Authorization Act of 2017 (51 USC §50111)[2] outlines the benefits spurred on by U.S. investment in low Earth orbit via the International Space Station, emphasizing its criticality as a testbed for future human exploration, a platform for ongoing expansion of scientific research, and a cornerstone for fostering international and commercial partnerships in space. It also underscores the space station's importance in maintaining continued American leadership in space. As the agency looks toward the future after the space station has been retired, the activities undertaken to achieve the agency's low Earth orbit microgravity goals and objectives will generate similar benefits, including enabling the development of an orbital platform for scientific research, facilitating the commercialization and economic development of low Earth orbit, and using the region as a testbed for technologies.

2 https://www.congress.gov/115/plaws/publ10/PLAW-115publ10.pdf

The goals and objectives outlined here also are consistent with the civil space policy guidelines outlined in the U.S. National Space Policy of December 2020[3] and the directives contained within that policy. These directives include strengthening U.S. leadership in space-related science and technology, strengthening and securing the national space industrial base, developing and retaining space professionals, strengthening interagency and commercial partnerships, generally strengthening U.S. leadership in space, and identifying and expanding areas for international cooperation.

Likewise, the U.S. Space Priorities Framework of December 2021[4], reaffirms that America will maintain its leadership in space exploration and space science while investing in the next generation of space professionals. These priorities are clearly reflected in NASA's goals and objectives for future low Earth orbit activities.

Finally, NASA's Low Earth Orbit Microgravity Strategy aligns with the priorities outlined in the National Low Earth Orbit Research & Development Strategy of March 2023[5]. This strategy calls on the U.S. Government, including NASA, to advance groundbreaking science and technology, strengthen government collaboration and partnerships, promote market opportunities, innovation, and sustainability, expand international cooperation, and stimulate STEM education and workforce development.

> **"As the United States leads the world in the exploration of the Moon and Mars, maintaining U.S. preeminence in space research is important as the use of Low Earth Orbit grows and the development of space enters a new era.**
>
> *– National Low Earth Orbit Research & Development Strategy of March 2023*

Continuous Presence in Low Earth Orbit as a Goal Versus Implementation

The International Space Station has operated with a continuously crewed presence for more than 24 years, setting an unparalleled historical record. With the planned deorbit in 2030 of the space station, should this unbroken "continuous heartbeat" cadence serve as an explicit goal for future activities in low Earth orbit?

In developing its low Earth orbit goals and objectives, NASA chose not to establish a specific goal requiring a continuous human presence solely for the sake of having one. Instead, NASA chose to let the goals and objectives inform the operational crew cadence needed to achieve its missions. Upon evaluating the resulting goals and objectives, as well as engaging with international, industry, government, and academia partners, NASA concluded that a "continuous heartbeat" – the same 24/7 operational tempo that has allowed the space station to return groundbreaking results for nearly a quarter century – remains NASA's requirement for ongoing operations in the era of commercial low Earth orbit destinations. With that in mind, the International Space Station's initial phase (1998-2000) involved crew-tended operations. Realistically, the transition to commercial space stations may require a similar and distinct assembly period of crew-tended operations which may overlap with the International Space Station's final phase of operations.

3 https://trumpwhitehouse.archives.gov/wp-content/uploads/2020/12/National-Space-Policy.pdf
4 https://www.whitehouse.gov/wp-content/uploads/2021/12/united-states-space-priorities-framework-_-december-1-2021.pdf
5 https://www.whitehouse.gov/wp-content/uploads/2023/03/NATIONAL-LEO-RD-STRATEGY-033123.pdf

NASA considered these key strategic, policy, and technical aspects when evaluating its posture on required future human presence in low Earth orbit:

Science

Today, most laboratory-based microgravity science conducted on the International Space Station benefits from having crew. To maximize the scientific output and impact of the research conducted, and move at a faster, more iterative pace, on-board crew and laboratory capabilities are vital and outperform experiments that are conducted once, with samples returned to Earth for analysis, and then potentially re-flown for further data. Technology demonstrations, such as life support systems, also require the metabolic load of a crew for sufficient periods of time to adequately demonstrate system reliability. Similarly, NASA's Human Research Program risk reduction plan requires many continued long-duration crewed flights of six months to a year to have the statistical data to mitigate the risks for deep space exploration missions, more than can be executed by the end of the International Space Station. Flights of 30 days to six months will have limited value, as well.

Viability of the U.S. industrial base

Commercial destinations and transportation rely on a predictable cadence of missions to sustain practicable business cases. A cadence of intermittent, crewed missions will not sustain the nation's industrial base for low Earth orbit. A significant gap in microgravity operations post-space station risks eroding the capabilities and skills NASA and its contractors have developed over decades, potentially also risking American leadership and global economic standing in space. Ensuring regular, routine access to and use of low Earth orbit requires a diversity of providers, which also strengthens the industrial base and supply chain by fostering competition and resilience. While some industry partners can pivot to working on NASA's deep space exploration efforts, the likelihood of negatively impacting the U.S. commercial space industrial base increases without an intentional effort to continue significant work in low Earth orbit.

Safety

The International Space Station requires crew onboard to mitigate certain technical issues if they arise; there are time-sensitive failures that without crew intervention could result in a loss of the station. The automation to cover all the scenarios is very challenging to achieve. The design of commercial space stations also may require crew aboard to mitigate such risks in order to be cost-effective.

National posture

Low Earth orbit will continue to offer international flight opportunities and opportunity for greater engagement with new and existing partners. Through the International Space Station, the United States has a key strategic asset that strengthens international partnerships. As NASA prepares for the retirement of the International Space Station, there are risks to narrowing the scope of future efforts – and the scope of possible partnership opportunities – in low Earth orbit. Maintaining a continuous presence in low Earth orbit will provide more consistent opportunities for international partnerships in the face of competing options.

Inspiration

A robust and recurring crew presence in low Earth orbit provides real-time examples of humans working in space and opportunities for public engagement, helping to make space exploration more accessible and achievable. Humans living and working in space on a regular basis offers a tangible, visible example of space exploration that motivates students to think about space as a potential career path, thereby nurturing the next generation of STEM professionals. While NASA also uses Artemis missions to inspire the next generation and general public, a persistent crew presence in low Earth orbit provides ongoing opportunities to engage with these audiences, capturing the imagination and curiosity of people worldwide.

Goals & Objectives

This section contains NASA's 13 goals and 44 objectives, along with the rationales behind each goal.

Together with NASA's long-term vision of human presence in low Earth orbit, the goals and objectives form the "what" the agency aims to achieve. This final set of goals and objectives has evolved from the initial set published in August 2024 and has been substantially improved by the feedback NASA received from U.S. Government stakeholders and our industry and international partners. While none of the goals and objectives mandate specific technical solutions or partnership approaches, they are sufficiently detailed to assess the success of proposed activities and technologies to achieve them.

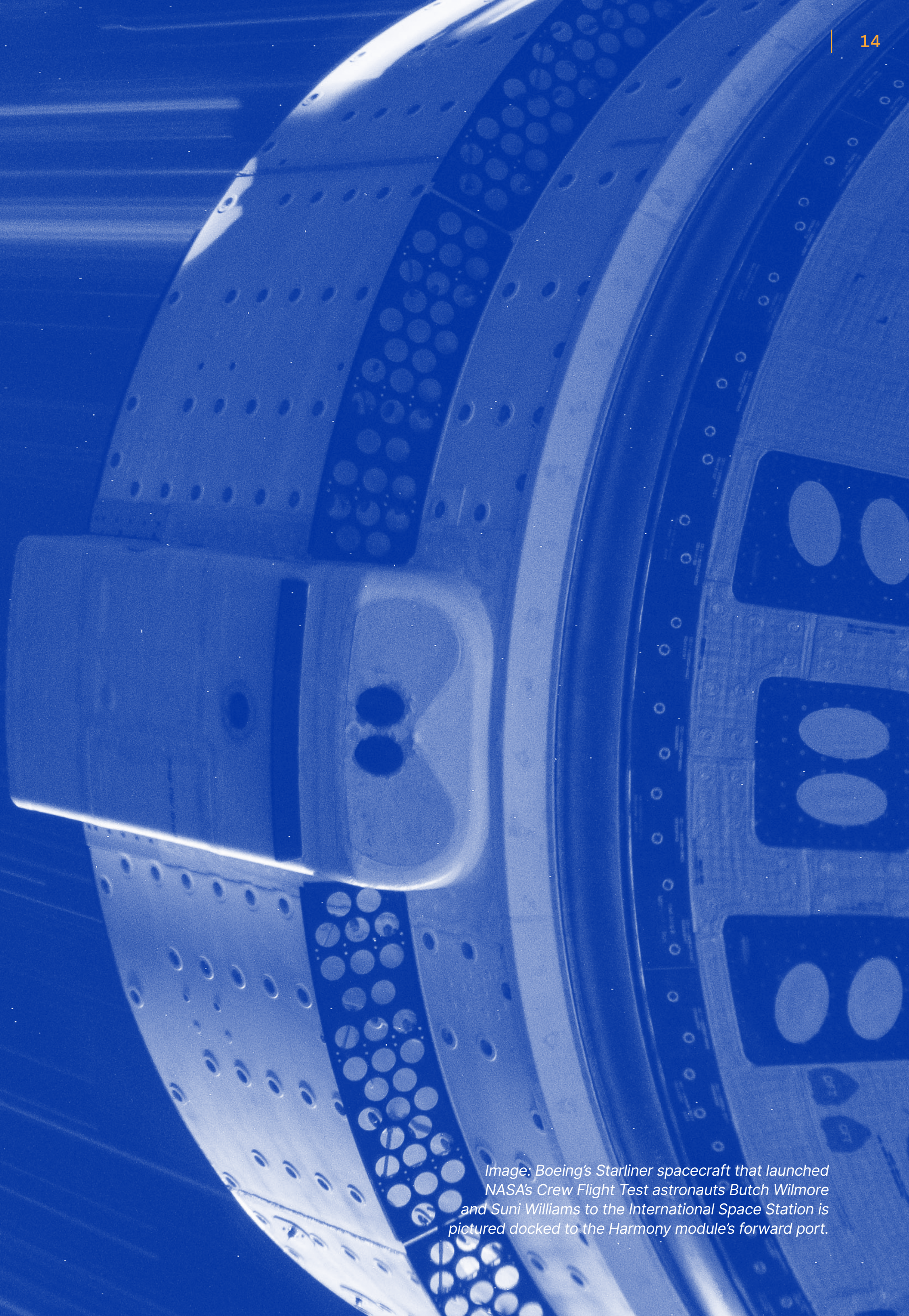


Image: Boeing's Starliner spacecraft that launched NASA's Crew Flight Test astronauts Butch Wilmore and Suni Williams to the International Space Station is pictured docked to the Harmony module's forward port.

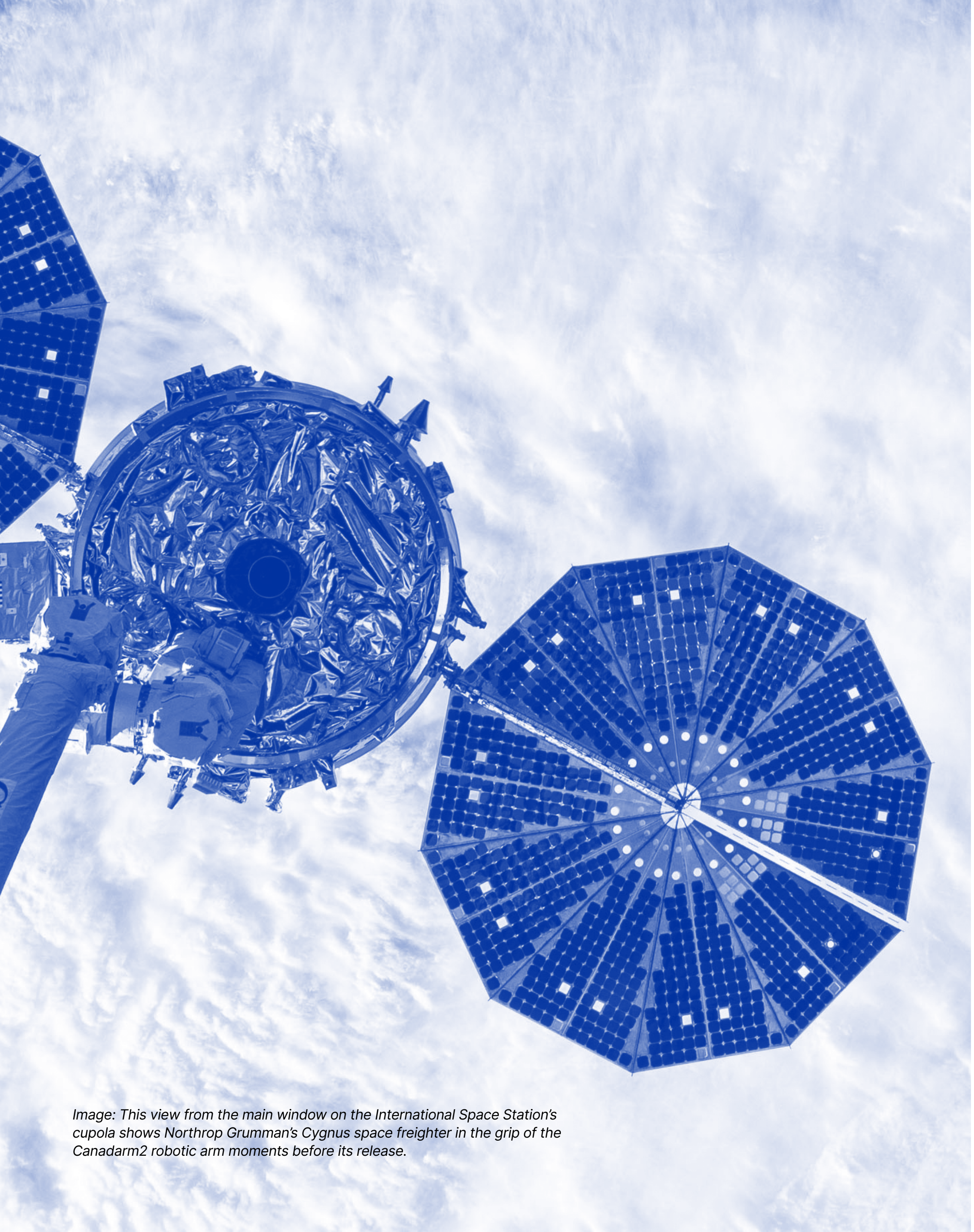


Image: This view from the main window on the International Space Station's cupola shows Northrop Grumman's Cygnus space freighter in the grip of the Canadarm2 robotic arm moments before its release.

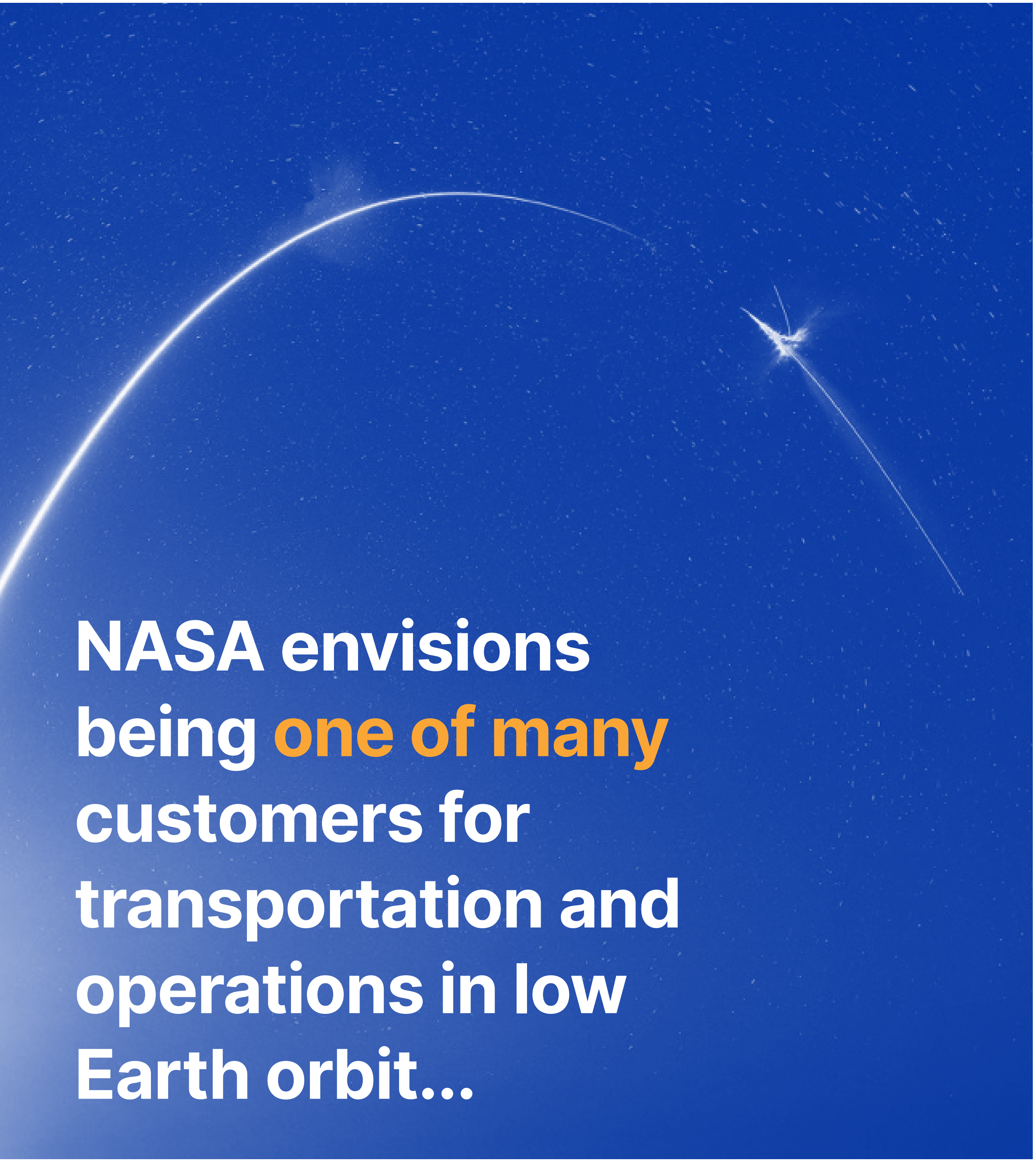
Commercial Low Earth Orbit Infrastructure

Transportation and Habitation

Goal: Strategically invest in U.S. private sector low Earth orbit capabilities to support NASA's activities and the U.S. space industrial base, while maximizing cost efficiency for NASA.

THI-1: Partner with the commercial sector to develop, deliver, and operate safe and reliable low Earth orbit destinations and services that are technically and financially viable over the long term and support NASA as one of many customers.

THI-2: Assure U.S. Government access to low Earth orbit through an operations tempo that sustains commercially owned and operated cargo and crew transportation capabilities.



NASA envisions being one of many customers for transportation and operations in low Earth orbit...

THI-3: Promote interoperability of systems to streamline the transition between the International Space Station and commercial low Earth orbit destinations, decrease risk, and facilitate transportation and user flexibility.

THI-4: Inform the development of policy and regulatory frameworks that facilitate the use of safe and reliable commercial destinations in low Earth orbit.

Rationale: NASA envisions being one of many customers for transportation and operations in low Earth orbit, purchasing services from commercial providers to meet the agency's needs. To enable this future in a cost-effective manner, NASA recognizes it must strategically invest in the development of safe and reliable destinations in low Earth orbit that support NASA activities, including scientific advancement, technology development and testing, human research, and crew accommodation, while also encouraging the broad investment in and use of commercial services that support the agency's activities in low Earth orbit.

Image: The SpaceX Falcon 9 rocket carrying the Dragon spacecraft lifts off from Launch Complex 39A at NASA's Kennedy Space Center in Florida on Tuesday, Nov. 4, on the company's 31st commercial resupply services mission for the agency to the International Space Station.

National Research and Development

> **Goal:** Support whole of U.S. Government research and development in low Earth orbit to provide benefits to humanity.

RD-1: Facilitate U.S. Government microgravity research and development to effectively achieve national scientific, technological, educational, and commercial objectives.

RD-2: Promote the development and maturation of high-value products that benefit from production in a microgravity environment through manufacturing or processing demonstrations in low Earth orbit.

Rationale: Through the International Space Station, NASA has demonstrated that microgravity research is critical to advancing both knowledge of ourselves and our planet. Today, the space station is used to study complex human health problems on Earth, observe the planet's changing climate, and facilitate the growth of research and development for commercial purposes. As we approach the transition from the space station to commercial platforms in low Earth orbit, NASA must enable the government's use of these platforms for further research and development across a spectrum of national objectives that strengthens economies and enhances the quality of life here on Earth for all people.

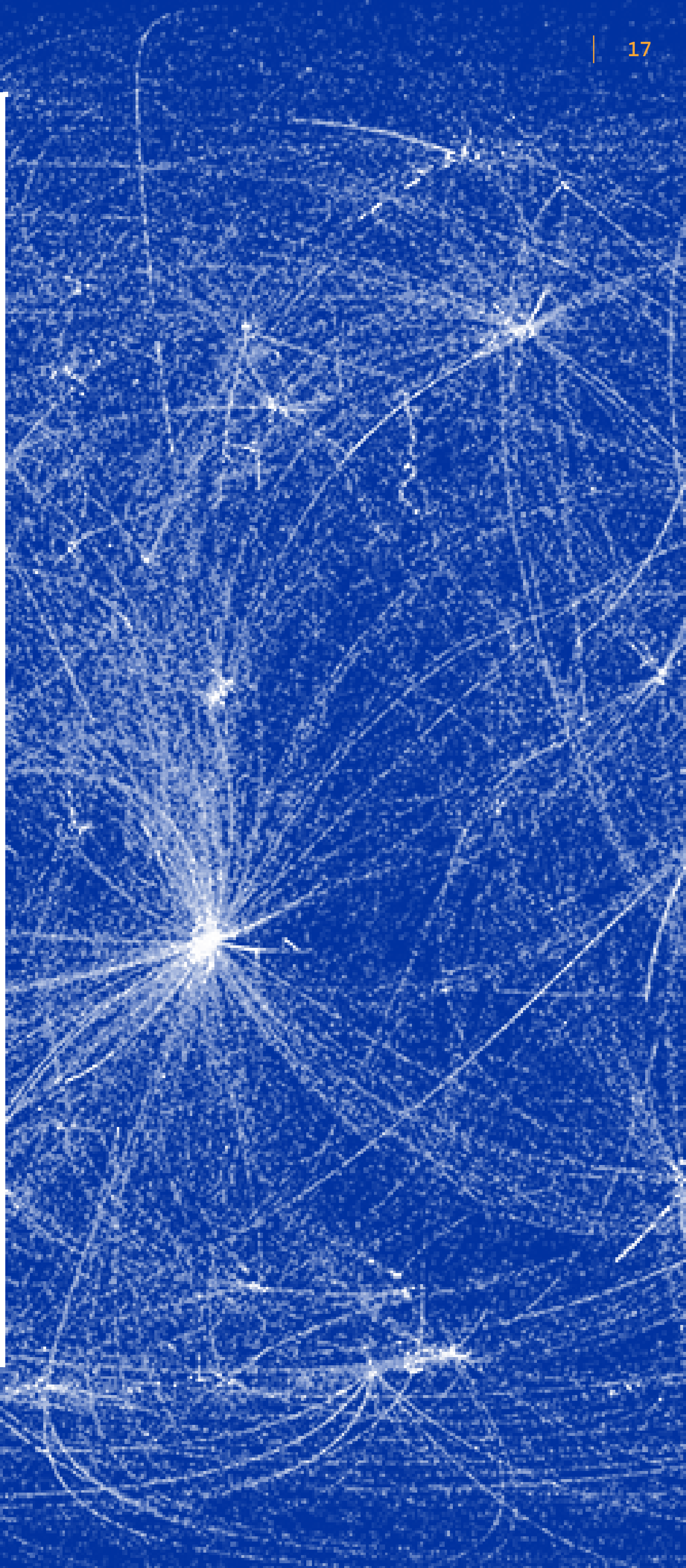


Image: This image of the whole sky shows 22 months of X-ray data recorded by NASA's Neutron star Interior Composition Explorer (NICER) payload aboard the International Space Station during its nighttime slews between targets.

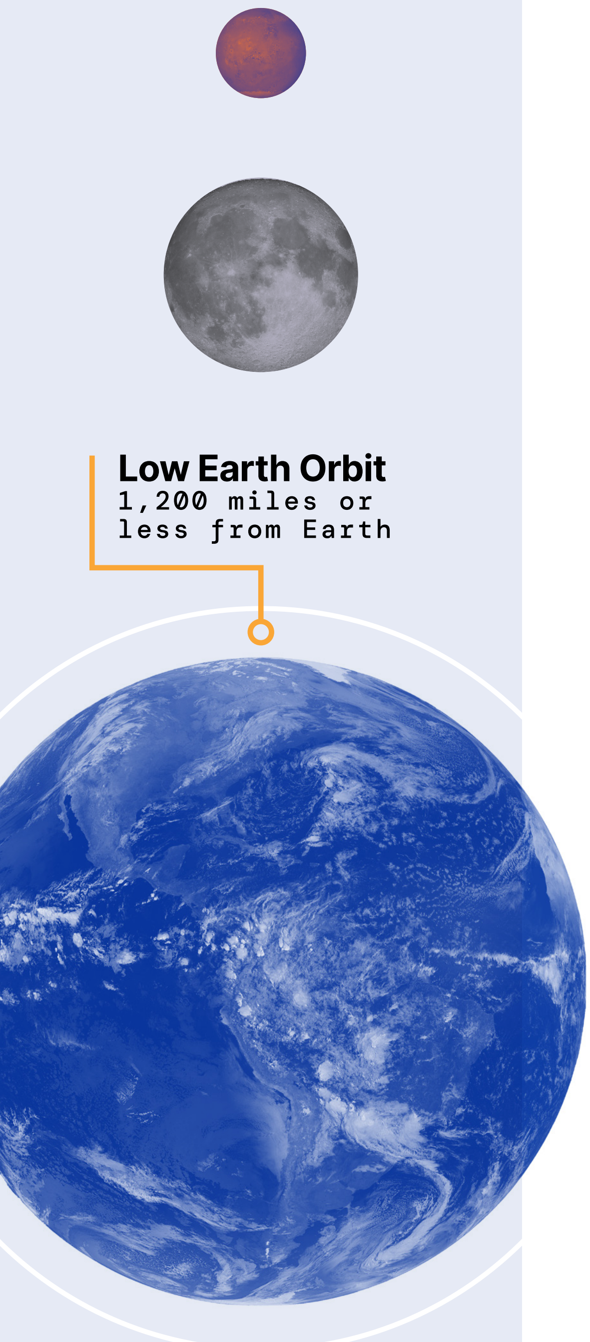


Illustration not to scale

GOALS & OBJECTIVES

Operations

Goal: Leverage low Earth orbit operations to develop and maintain microgravity skills to support NASA's human exploration missions.

OPS-1: Create opportunities aboard commercial low Earth orbit destinations for U.S. Government astronauts to develop skills and maintain proficiency operating in microgravity.

OPS-2: Develop and maintain U.S. Government and industry ground-based workforce skills and proficiency in designing systems, preparing science and technology for use in microgravity, and executing successful human exploration missions.

OPS-3: Organize joint missions in low Earth orbit with international partners to advance science, demonstrate technology, and develop joint operational experience in preparation for missions beyond low Earth orbit.

Rationale: Living and working in the microgravity environment requires a wide range of unique skills. Through its flagship human spaceflight programs, including the International Space Station, NASA has developed this operational expertise across its astronaut corps and the agency's ground-based workforce.

Low Earth orbit provides the proximity and ease of access to continue to develop and refine these skills. While specific flight assignments for future Artemis and eventually Martian missions will not mandate previous flight experience in low Earth orbit, skills required to effectively operate in microgravity will be critical to designing and executing successful deep space exploration missions, which will include extended operations in microgravity. In addition, through the International Space Station program, NASA has developed institutional knowledge and expertise in jointly planning for and executing missions with international and commercial partners, which will be critical to planning and executing future joint missions beyond low Earth orbit.

Living and working in the microgravity environment requires a wide range of unique skills.

Science

Biological Science

> **Goal:** Leverage crewed platforms in low Earth orbit to advance our understanding of how model organisms, human micro-physiological systems, and plants respond to microgravity and other spaceflight conditions.

BS-1: Understand the effects of a range of exposures to microgravity and other spaceflight conditions on living systems including ecosystems of cells, tissues, and organisms.

BS-2: Identify alterations in biological mechanisms required for organisms to survive the transition and adapt to living in space and understand the changes required to re-acclimate to life on Earth.

BS-3: Investigate how genetic diversity and life history influence physiological adaptation to the space environment and how related research could directly inform the development of personalized medicine for space and on Earth.

Rationale: NASA's biological sciences research both enables exploration and benefits life on Earth. Scientists use the unique conditions of space—including microgravity and increased radiation—to understand how life responds to harsh environments. Researchers study a range of living things—from DNA and cells to plants, animals, and microbes—to learn how they and space-based ecosystems form and change over time, as well as how they can be controlled to maintain balance. This research also has practical benefits on Earth, contributing to solutions for challenges like disease cures and food production.

Physical Science

> **Goal:** Leverage crewed platforms in low Earth orbit to probe phenomena hidden by gravity or terrestrial limitations to make groundbreaking advancements in fields such as materials science, fluid dynamics, and combustion.

PS-1: Understand the fundamental principles that organize the structure and functionality of materials to identify new states of matter, new physical phenomena, and emergent material properties.

PS-2: Investigate the fundamental laws that govern thermophysical properties, reaction kinetics, and material solubility under microgravity and other spaceflight conditions.

PS-3: Advance understanding of the chemical and physical properties and phenomena that govern the behavior of fluids and combustion under microgravity and other spaceflight conditions.

PS-4: Seek new discoveries in physics, including particle physics, general relativity, and quantum mechanics, that can only be discovered by experiments carried out in space, which will contribute to "new physics," understanding fundamental many-body quantum physics, and predictions of phase transformations in matter.

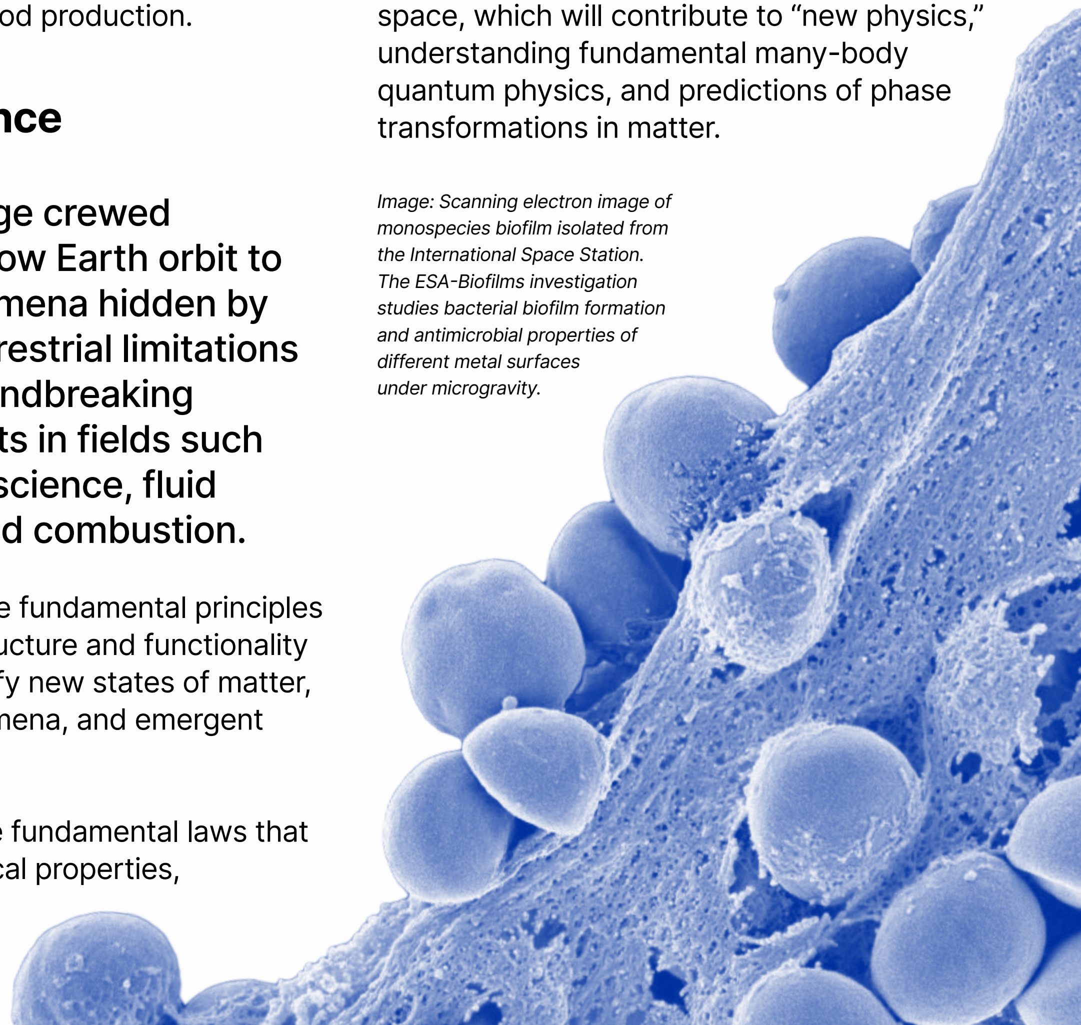


Image: Scanning electron image of monospecies biofilm isolated from the International Space Station. The ESA-Biofilms investigation studies bacterial biofilm formation and antimicrobial properties of different metal surfaces under microgravity.

Rationale: Outstanding questions in physics and the physical sciences remain. What are dark matter and dark energy? How can the standard model of particle physics be unified with general relativity? Important questions about the physical world, including quantum phenomena, can be answered only in the space environment, leveraging unique conditions such as microgravity. Effects of Earth's gravity hide key interactions in many experiments, and access to the space environment enables not just elegant but otherwise impossible research that opens up new insights. Physical sciences also concern the search for precise understanding of what happens to physical systems and processes in the space environment and how to use Earth-based and off-Earth materials effectively in space. Such knowledge of how to design, process, and use the solid, liquid, and gaseous materials that define the built environment of space travel and habitation is critical for sustaining long-term space exploration.

Rapid Low Earth Orbit Science

> **Goal:** Dramatically increase the pace of research in low Earth orbit through onboard analysis capabilities, in-situ measurements, sample and experimental preparation, and by having crew iterate research in real-time.

RLS-1: Develop new capabilities that provide on-orbit analysis, in-situ measurements, and sample and experiment preparation to allow for on-orbit iterative science to be conducted by trained crew.

Rationale: The future of research requires new capabilities to accelerate the pace and rate at which science can be accomplished in low Earth orbit. It is essential to develop and employ new capabilities that enable on-orbit analysis, in-situ measurements, and sample and experiment preparation necessary to conduct science in real-time. Having trained crew iterate science experiments in real-time maximizes the science conducted in low Earth orbit and accelerates the pace at which NASA and its partners make discoveries and develop products for use on Earth and in space.

Space and Earth Science

> **Goal:** Leverage opportunities provided by crewed platforms in low Earth orbit to advance scientific understanding and observational capabilities for both space and Earth science.

SES-1: Conduct cost-effective science and technology projects to demonstrate innovative space and Earth science observation techniques using crewed platforms.

SES-2: Employ crew capabilities, such as conducting Earth observations or payload deployment and repair, to enhance and supplement space and Earth science where advantageous and practical.

Rationale: Whether observing Earth below, the universe above, or the local space environment, measurements from low Earth orbit are essential for advancing NASA's space and Earth science disciplines. The use of crewed platforms for space and Earth science results from a cost-benefit trade against other alternatives, including NASA-developed robotic missions and commercial data buys. Human presence allows for flexible operations and simplified development and deployment of high-impact demonstration projects, and the ability to repair, replace, and reposition payloads, if needed, allowing for enhanced science with lower experimental risk. Persistent crewed platforms can significantly benefit long-term space and Earth science, including reduced cost and steady flow of vital data. Crew-led observations from space also offer insights into environmental phenomena, providing real-time, qualitative observations that complement satellite data, improving our ability to monitor and respond to events like hurricanes, wildfires, and droughts.

Important questions about the physical world, including quantum phenomena, can be answered only in the space environment, leveraging unique conditions such as microgravity.

Research and Technology Development for Exploration

Exploration Technology

> **Goal:** Leverage the unique environment of low Earth orbit to advance technologies that enable future human exploration on and around the Moon and Mars.

ET-1: Advance robotic and autonomous systems toward the independent achievement of diverse tasks.

ET-2: Demonstrate the performance of materials through exposure to the space environment to inform materials selections for future missions.

ET-3: Advance manufacturing and non-destructive evaluation techniques in the space environment to increase Earth-independence.

ET-4: Advance techniques for in-space assembly of structures towards autonomous assembly to enable increasingly complex mission concepts.

ET-5: Advance in-space performance of exploration environmental control and life support systems to enable multi-year exploration missions.

ET-6: Advance crew habitation, health, and performance technologies and systems to enable multi-year exploration missions.

Rationale: Establishing a sustained human presence on and around the Moon and Mars, and ultimately, throughout the solar system, requires advanced technologies and capabilities. Technology advancements are necessary to enable increasingly challenging exploration missions and will need testing in relevant environments to support eventual flight operations. For many advancements, low Earth orbit provides a relevant, more accessible environment to progressively demonstrate, test, and validate critical exploration-enabling technologies that cannot be optimally tested on Earth or in deep space.

Human Health and Performance Research in Exploration Analog Environments

> **Goal:** Advance understanding of how to sustain human health and performance using relevant exploration analog environments in low Earth orbit to reduce risks and inform Moon, Mars, and deep space missions.

AR-1: Evaluate the effects of short- and long-duration exposure to microgravity and other spaceflight conditions on human health and performance.

AR-2: Evaluate and validate the efficacy of progressively Earth-independent health and performance countermeasures, systems, and crew operations, with environments and durations representative of exploration missions.

AR-3: Demonstrate and evaluate the integration of crew and exploration systems in the space environment for understanding the effects on human health and performance.

Rationale: As human exploration extends beyond low Earth orbit, NASA must progressively demonstrate the ability to safely and effectively live and work in the lunar and Martian environments for extended durations. While some studies simulating certain conditions of exploration can be conducted on Earth, platforms in low Earth orbit provide more accessible space-based opportunities to perform intermediate, integrated applied research on crew health and performance, countermeasures, systems, and operations and to expand available data on a diverse population prior to testing or implementation in the lunar or Martian vicinity.

Using Low Earth Orbit Operations to Prepare for Deep Space Exploration

> **Goal:** Validate crewed mission operations in low Earth orbit as part of a timely and effective methodology to test the agency's evolutionary approach to living and working in environments relevant to Moon and Mars exploration.

EO-1: Evaluate the effects of extended mission durations on crew and systems performance, reduce mission risk, and shorten the timeframe for readiness validation prior to an exploration campaign.

EO-2: Simulate interactions between Earth-based mission support, crew members in space, a Martian surface team, and remote surface systems, considering communication delays, autonomy levels, and time required for return to Earth in a mission abort scenario.

EO-3: Evaluate, understand, and mitigate the impacts on crew health and performance of an extended-duration deep space mission and transition to gravity for surface operations by conducting mission operations that simulate key parameters.

Rationale: Low Earth orbit provides an opportunity to progressively work through operational aspects of Moon and Mars exploration missions that are best simulated with crew in space, including their ability to effectively function in a gravity environment immediately following extended time in microgravity. Crewed low Earth orbit platforms can provide opportunities for simulation of exploration operations and interactions between personnel on Earth and flight crew in a relevant environment. In the context of exploration operations in preparation for Moon and Mars missions, NASA would be responsible for conducting simulations and evaluations.

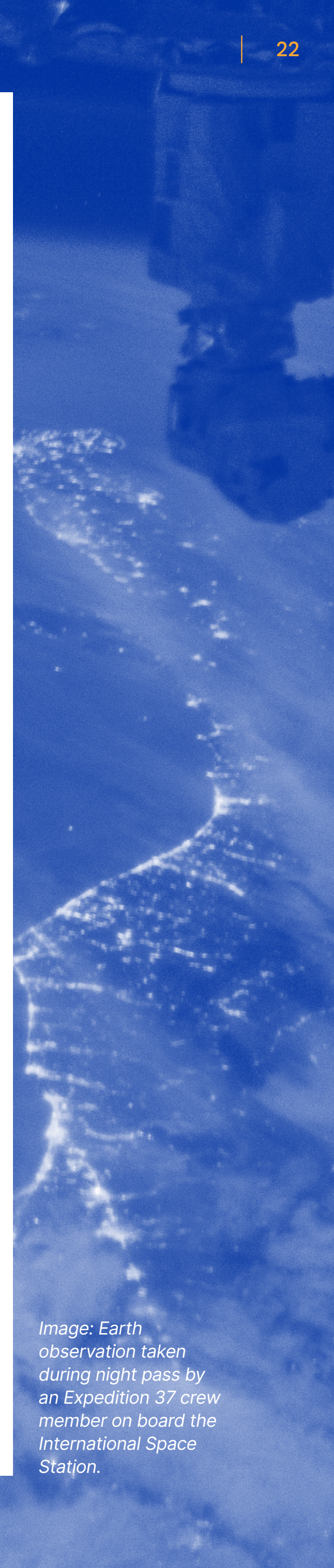


Image: Earth observation taken during night pass by an Expedition 37 crew member on board the International Space Station.

International Cooperation

Goal: Champion broad international participation in low Earth orbit by a diverse set of providers and users (government and non-government) to foster innovation, achieve NASA science and exploration goals, and maintain a strong, U.S.-led international presence in low Earth orbit.

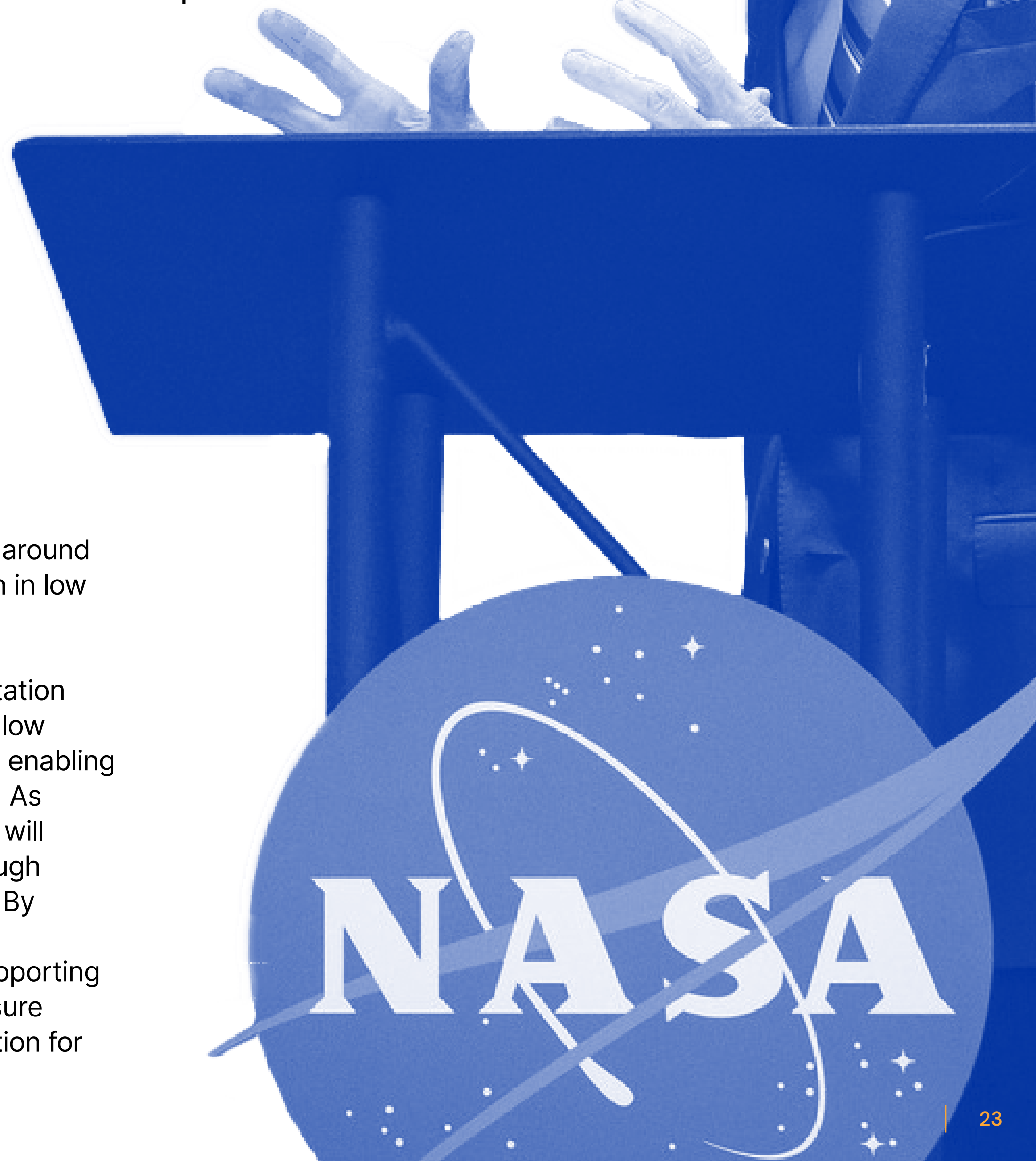
IC-1: Work with international partners, industry, and academia to define pathways to partnership in low Earth orbit and ensure these pathways are adaptable as low Earth orbit activities evolve over time.

IC-2: Cultivate mutually beneficial government-to-government international partnerships with long-standing and new partners that enhance the effectiveness of NASA programs and advance U.S. national interests.

IC-3: Drive the creation of robust low Earth orbit capabilities by encouraging international governments, industry, and research organizations to engage with U.S. industry.

IC-4: Support the harmonization of legal and regulatory frameworks around the world to promote safe, responsible, and sustainable collaboration in low Earth orbit.

Rationale: NASA's history of operations on the International Space Station exemplifies the agency's commitment to international cooperation in low Earth orbit. NASA's aim is to continue that tradition of cooperation by enabling paradigms for partnerships that will expand the global base of users. As participation in low Earth orbit expands, the international community will also benefit from a safe, sustainable, and peaceful environment through the development of harmonized global legal and regulatory regimes. By expanding opportunities for cooperation, enabling pathways for that cooperation, continuing to partner with foreign counterparts, and supporting a harmonized global legal and regulatory environment, NASA will ensure that low Earth orbit remains a frequent, accessible, and safe destination for science and exploration in the years to come.



Workforce Development and STEM Engagement

Goal: Engage, develop, and retain the diverse U.S. workforce needed to conduct future NASA missions by leveraging authentic connections to human space operations in low Earth orbit.

WSE-1: Develop a diverse U.S. workforce optimized for future science and space exploration by leveraging the knowledge, skills, and experience of the existing workforce supporting low Earth orbit operations.

WSE-2: Provide opportunities for secondary and post-secondary students to propose and develop experiments to conduct research and technology development in microgravity.

WSE-3: Build a pipeline of early career talent through career exploration and internship opportunities focused on human space flight.

WSE-4: Inspire, engage, and contribute to K-12 students' Science, Technology, Engineering, and Math (STEM) education through programming that provides connections to humans living and working in space.

WSE-5: Incorporate STEM engagement programming in onboard operations on a routine and recurring basis.

WSE-6: Leverage ground support and payload team personnel in STEM engagement programming.

Rationale: Future space exploration, in and beyond low Earth orbit, will require a diverse, inclusive, and skilled workforce (both U.S. Government and industry). Necessary areas of expertise will include a broad array of STEM fields, with space manufacturing, maintenance, operations, as well as in-space scientific research and technology development being particularly critical. To ensure a steady pipeline of workers today and in the future, NASA and its partners must engage students from the earliest grades through high school, trade school, undergraduate, and graduate study, involving them in authentic learning experiences and evidence-based programs designed to spark and maintain interest in STEM and space exploration and grow requisite skills. Likewise, it is critical to engage and retain the existing microgravity workforce to avoid losing expertise and creating a gap in workforce availability as we envision our future in low Earth orbit. The proximity of low Earth orbit provides routine access to the microgravity environment, enabling continuous opportunities to engage the next generation of explorers and develop and retain the workforce needed to meet NASA's future needs.

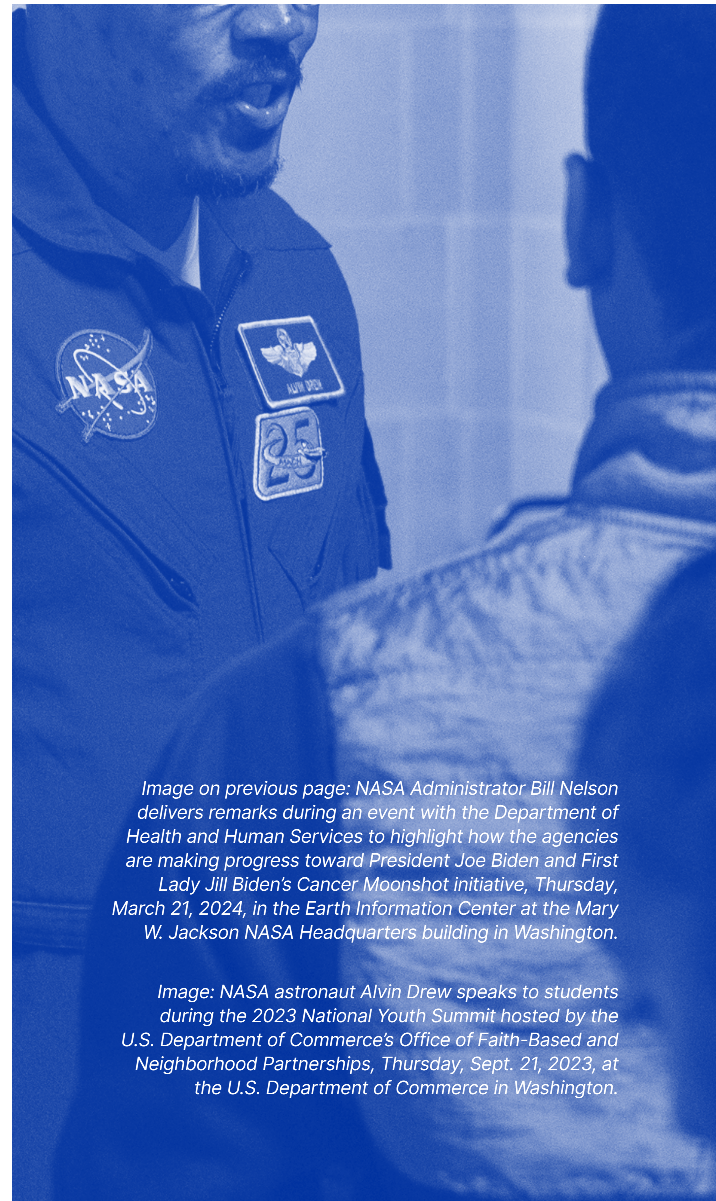


Image on previous page: NASA Administrator Bill Nelson delivers remarks during an event with the Department of Health and Human Services to highlight how the agencies are making progress toward President Joe Biden and First Lady Jill Biden's Cancer Moonshot initiative, Thursday, March 21, 2024, in the Earth Information Center at the Mary W. Jackson NASA Headquarters building in Washington.

Image: NASA astronaut Alvin Drew speaks to students during the 2023 National Youth Summit hosted by the U.S. Department of Commerce's Office of Faith-Based and Neighborhood Partnerships, Thursday, Sept. 21, 2023, at the U.S. Department of Commerce in Washington.

Image: Local students participate in an Earth Information Center (EIC) student engagement event, Friday, June 23, 2023, at the Mary W. Jackson NASA Headquarters building in Washington.

GOALS & OBJECTIVES

Public Engagement

Goal: Highlight agency-led efforts in low Earth orbit to educate and inform the general public to the widest practicable extent, focusing upon the many benefits humanity gains through science and technology development aboard crewed, orbiting research platforms.

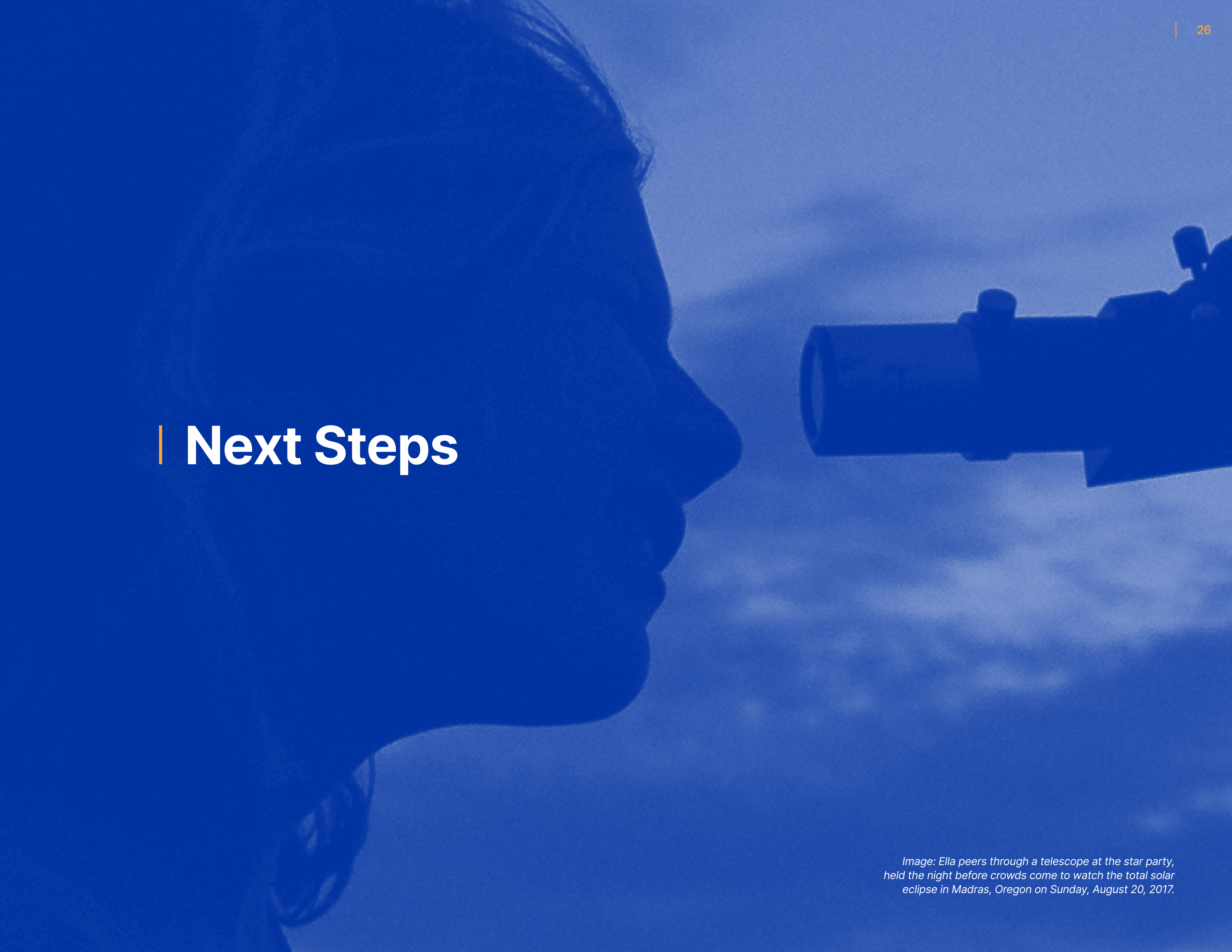
CPE-1: Engage and inspire NASA's many audiences and future generations of explorers through ongoing, real-time space operations.

CPE-2: Increase public and stakeholder awareness and understanding regarding NASA and its partners' activities in low Earth orbit, efforts to open access to space, and support for future deep space exploration.

CPE-3: Collaborate with industry and international partners on communications efforts and leverage partner capabilities to best engage new and underserved audiences.

Rationale: NASA has a responsibility to share its research, technological developments, and scientific achievements to the widest possible and appropriate extent to benefit and educate the public. NASA's operations in low Earth orbit provide a unique opportunity to inform the agency's diverse audiences and inspire the next generation of explorers. Through agency-enabled operations, future commercial destinations, and other activities, NASA will educate and engage its many stakeholders regarding the human operations, science, and technology development efforts in low Earth orbit and the many benefits returned to Earth.

NASA's operations in low Earth orbit provide a unique opportunity to inform the agency's diverse audiences and inspire the next generation of explorers.



Next Steps

Image: Ella peers through a telescope at the star party, held the night before crowds come to watch the total solar eclipse in Madras, Oregon on Sunday, August 20, 2017.

Next Steps

Establishment of NASA's Low Earth Orbit Microgravity Strategy is a critical starting point, but the agency's work is not complete. The goals and objectives outlined in this document present a vision for the agency's future activities in low Earth orbit. They will serve as essential reference points to guide coordinated actions, or strategy, within the agency. To achieve the strategy's goals and objectives, these actions include:

- **"Architect from the right"** by decomposing goals and objectives into characteristics, needs, functions, and use cases, and align these features with existing or new requirements, as appropriate.
- **Conduct an annual internal Low Earth Orbit Microgravity Concept Review** to track progress and adjust as the low Earth orbit environment evolves.
- **Regularly consult with stakeholders**, including workshops for feedback, to ensure NASA's low Earth orbit plans remain aligned internally and externally, with engagement in 2025 aligning with NASA's Phase 2 schedule for commercial low Earth orbit destinations.
- **Build a plan to seamlessly transition operations** and utilization between the International Space Station and commercial low Earth orbit destinations, carefully considering technical and operational factors to maintain a "continuous heartbeat" in low Earth orbit.
- **Create contracts with the private sector** so NASA can co-invest in the design and development of commercial low Earth orbit destinations, which is foundational to achieve the agency's long-term vision.
- **Support industry** in developing commercial low Earth orbit destinations by leveraging NASA's facilities, technologies, and decades of expertise.
- **Deploy and certify one or more commercial low Earth orbit destinations** to ensure safe and reliable operations for sustained low Earth orbit operations.
- **Define a sustained, coordinated launch cadence to support industry** by ensuring a diversity of U.S. launch providers and align pace of launches to account for overlap between the International Space Station and the new commercial space stations.
- **Develop and launch a U.S. deorbit capability** to safely retire the International Space Station by 2030, meeting U.S. Government policies and statute.
- **Prioritize NASA science and technology payloads** by planning for, developing, and investing in payloads for commercial low Earth orbit platforms.
- **Establish a follow-on capability** to the International Space Station National Laboratory with third-party management and interagency guidance to meet U.S. Government research needs after the space station's retirement.
- **Identify and integrate international partnership opportunities** for NASA science and technology activities and joint mission planning aboard commercial low Earth orbit destinations.
- **Train and develop NASA's workforce for mission operations support** by leveraging existing skills and experience to cultivate the talent needed for future low Earth orbit and deep space exploration missions.

Appendices

APPENDIX A.

The Utility of An Objectives-based Approach

Historically, NASA has often applied a capability-based approach when developing its major programs. The capability-based approach is generally governed by the question: What can be done within the existing budget? While this approach allows for the development of technology, it often lacks a vision or defined end state to guide that work.

In contrast, an objectives-based approach first considers what must be accomplished to fulfill NASA's mission. An objectives-based framework allows NASA to establish its priorities through specificity, rigor, and consistency while leaving plenty of flexibility for adopting and using new technologies and operational concepts that the agency or its partners may develop in the coming decades.

The first step in developing an objectives-based framework is defining top-level goals and objectives that the agency will use to create an integrated plan for accomplishing them. The objectives-based approach looks to the future and codifies long-term end-states, i.e. the "what" the agency aims to achieve. In schedule vernacular, the envisioned long-term end-states define "what right looks like" when one looks all the way to the right on the schedule.

With the long-term goals and supporting objectives established, NASA is then positioned to "architect from the right," working backward from the desired end states by decomposing the goals and objectives into a complete set of capabilities required to achieve success. By anchoring efforts to the end states, this process of "architecting from the right" can be carried down with increasing specificity to establish a fully developed and executable set of program plans.

> **An objectives-based approach first considers what must be accomplished to fulfill NASA's mission.**

Technical and Fiscal Resilience

Once finalized, the vision and top-level goals and objectives should remain consistent and resilient. In effect, they become points of reference for all stakeholders, including industry, academia, international partners, U.S. Government, and the NASA workforce, to guide their respective efforts.

Technical resilience. Sound and rigorous technical analysis must underpin any serious program planning effort. Using a technically sound approach enables this strategy to be easily understood by the workforce, which ensures accurate and consistent communication about the implementation plan internally and externally.

Fiscal resilience. NASA must operate in the face of inevitable budgetary constraints. This approach has been true throughout NASA's history, especially since the end of the Apollo program. Rather than abandon a rigorously defined plan to accommodate a given budget, the objectives-based approach helps NASA prioritize efforts and maximize returns on investment, as well as identify new opportunities when the fiscal environment allows.

While maintaining constancy of purpose is essential, it does not mean that change is not possible. New technical advancements, capabilities, and discoveries can all shape the direction of this effort. However, NASA must assess any proposed changes in the context of overarching goals and objectives this effort aims to achieve. Changes should be purposeful and only made with careful consideration.

Image on previous page: Peering through the International Space Station's Cupola, or "window to the world," the western coast of Chile is visible.

Glossary

Architecture: A set of functional capabilities, their translation into elements, their interrelations, and operations. The architecture enables the implementation of various mission scenarios that achieve a set of given goals and objectives.

Autonomous Systems & Robotics: A group of capabilities which are accomplished with the use of software and hardware devices that can assist the crew and operate during uncrewed periods, either autonomously and/or via remote operator control (tele-robotics).

Commercial: Private sector enterprises that bear a substantial portion of the investment risk and responsibility, and operate in accordance with typical market-based incentives for controlling cost and optimizing return on investment.

Demonstrate: Deploy an initial capability to enable system maturation in alignment with architecture objectives.

Develop: Design, build, and deploy a system, ready to be operated by the user, to fully meet architecture objectives.

Earth Science: The study of the Earth's physical properties, processes, and history. It encompasses fields such as geology, meteorology, oceanography, and environmental science to understand the structure, composition, and dynamics of Earth's systems, including the atmosphere, oceans, and crust.

Evaluate: Assessing crew, technologies, systems, and operations for safe and effective performance to meet architecture objectives.

Extended Duration: Time intervals approaching cumulative cruise, orbit, and return cruise times anticipated for exploration missions to Mars.

Ground-based workforce: Includes space operations ground personnel, including flight control, mission planning, crew training, and engineering support; microgravity research and technology development scientists and engineers; and associated skilled-technical workforce.

Live: The ability to conduct activities beyond tasks on a schedule. Engage in hobbies, maintain contact with friends and family, and maintain healthy work-life balance.

Long Duration: Time intervals long enough to demonstrate desired performance, with specific interval defined by individual application.

Mission: A major activity required to accomplish an agency goal or to effectively pursue a scientific, technological, or engineering opportunity directly related to an agency goal. Mission needs are independent of any particular system or technological solution.

Partner with: NASA provides some support in the form of funding, expertise, hardware and services to industry partners for the design, development, and demonstration of space capabilities and services, leading to NASA becoming one of many customers.

Routine: Recurring subject operations performed as part of a regular procedure rather than for a unique reason.

Short Duration: Minimum time interval required for scientific analysis, with specific time interval defined by individual research application.

Space Science: The study of outer space, focusing on celestial bodies, cosmic phenomena, and the universe's origins and structure. It includes fields of study like astronomy, astrophysics, heliophysics, planetary science, and cosmology to explore the nature of the universe, the potential for life beyond Earth, and the processes shaping planets and other cosmic bodies.

Sustainable: The ability to safely, peacefully, and responsibly conduct in-space activities indefinitely to meet the needs of the present generations while preserving the outer space environment for future exploration activities and limiting harm to terrestrial life.

Unique environment: Gravitational and radiation in the low Earth orbit environment.

Validate: Confirming that a system satisfies its intended use in a relevant environment; this should answer the question: did we build the right system?"

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