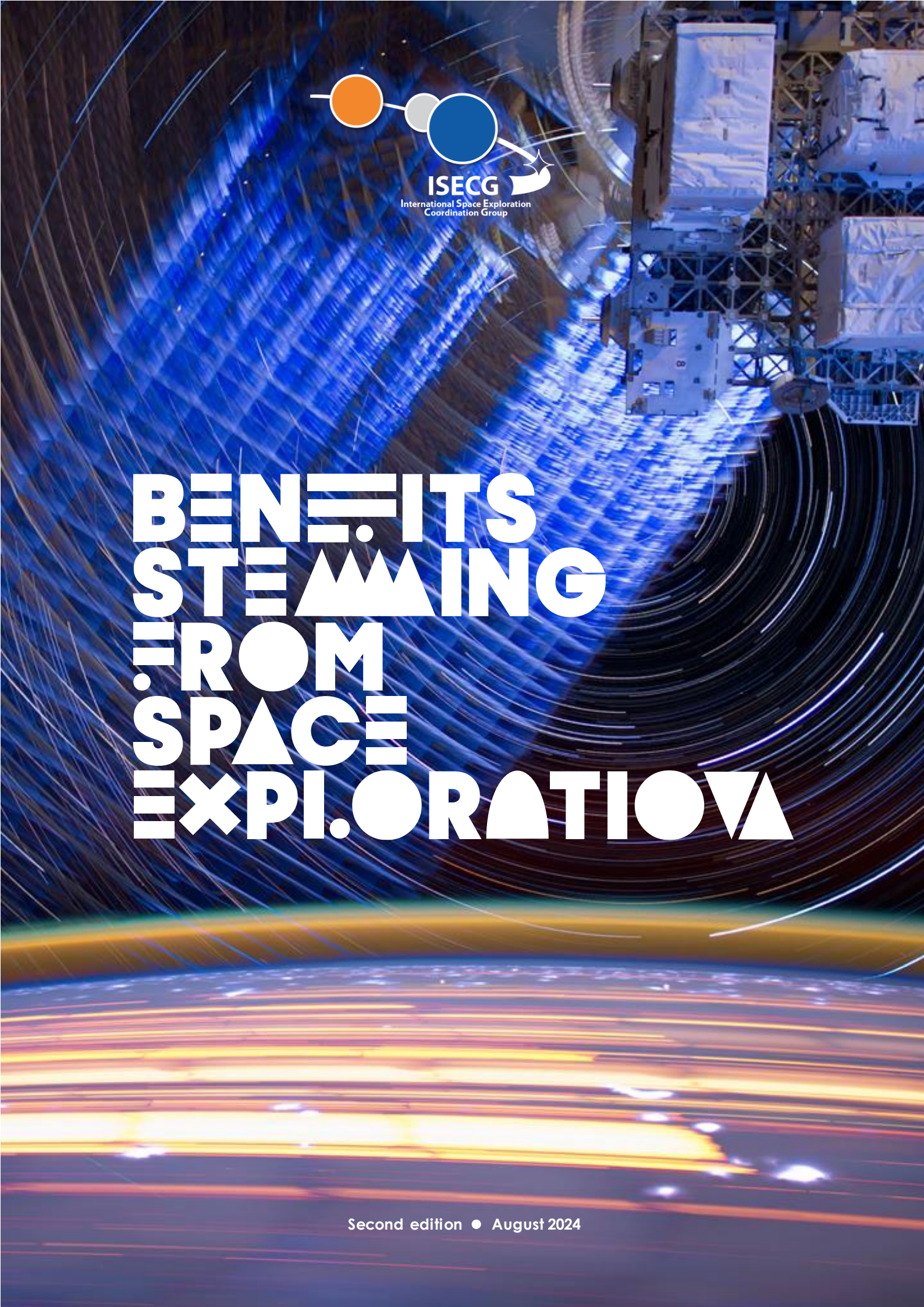

Second edition ● August 2024

First edition, September 2013
Second edition, August 2024

Front and back covers: star and light trail images captured from the ISS in 2012. (NASA/Donald R. Pettit)

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ESA/Olivier Pâques

Acronyms, abbreviations, and symbols

⍟	Example / highlight	
AEB	Brazilian Space Agency	Agênzia Espacial Brasileira
AEM	Mexican Space Agency	Agencia Espacial Mexicana
ASA	Australian Space Agency	
ASI	Italian Space Agency	Agenzia Spaziale Italiana
CNES	National Centre for Space Studies (France)	Centre National D'Etudes Spatiales
CNSA	China National Space Administration	中国国家航天局
CSA	Canadian Space Agency	Agence Spatiale Canadienne
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australia)	
DLR	German Aerospace Centre	Deutsches Zentrum für Luft- und Raumfahrt
ESA	European Space Agency	
etc.	"and other similar things"	"et cetera"
GDP	Gross Domestic Product	
GER	ISECG Global Exploration Roadmap	
GISTDA	Geo-Informatics and Space Technology Development Agency (Thailand)	สำนักงานพัฒนาเทคโนโลยีอวกาศและภูมิสารสนเทศ
ISECG	International Space Exploration Coordination Group	
ISRO	Indian Space Research Organisation	भारतीय अंतरिक्ष अनुसंधान संगठन
ISS	International Space Station	
JAXA	Japan Aerospace eXploration Agency	宇宙航空研究開発機構
KASA	Korea AeroSpace Administration (South Korea)	우주항공청
LEO	Low Earth Orbit	
LSA	Luxembourg Space Agency	
MBRSC	Mohammed bin Rashid Space Centre (UAE)	مركز محمد بن راشد للفضاء
NASA	National Aeronautics and Space Administration (USA)	
NZSA	New Zealand Space Agency	
NOSA	Norwegian Space Agency	Norsk Romsenter
POLSA	Polish Space Agency	Polska Agencja Kosmiczna
PTS	Portuguese Space Agency	Agência Espacial Portuguesa
ROSA	Romanian Space Agency	Agenția Spațială Română
SNSA	Swedish National Space Agency	Rymdstyrelsen
STEM	Science, Technology, Engineering and Math	
UAESA	United Arab Emirates Space Agency	وكالة الإمارات للفضاء
UKSA	United Kingdom Space Agency	
UN SDGs	United Nations Sustainable Development Goals	
VNSC	Vietnam National Space Center	Trung tâm Vũ trụ Việt Nam

Pioneer of space exploration

Yuri Alekseyevich Gagarin became the first human to journey into outer space. Travelling on Vostok 1, he completed one orbit of Earth on 12 April 1961.

Introduction

Space exploration

Space exploration stands as a beacon of human endeavour, unveiling a spectrum of benefits that transcend geopolitical boundaries on Earth. It serves as a catalyst for inspiration and education, captivating the imagination of present and future generations. The inspiring nature of space exploration missions fosters curiosity, stimulates interest in science, technology, engineering, and mathematics (STEM) fields, and favours international collaboration and diplomacy on a global scale, uniting nations to achieve common goals while encouraging mutual respect and understanding.

Focusing on robotic and human missions to…

low Earth orbit

the Moon

Earth-Mars closest approach: 54.6 million km (33.9 million mi)

Mars

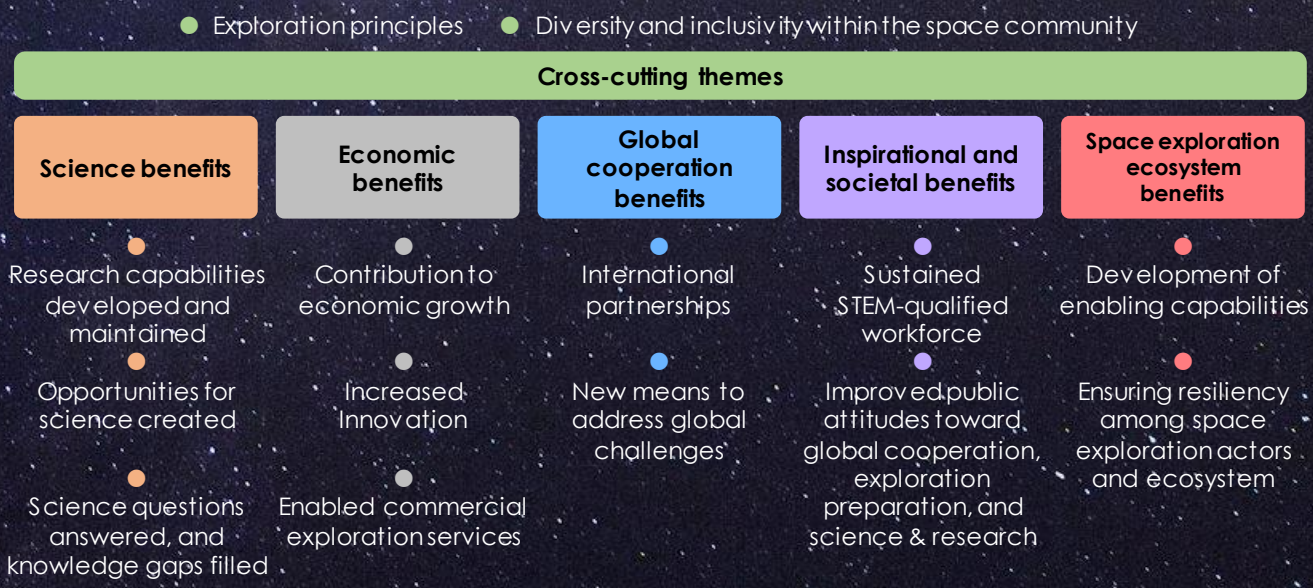
Earth-Moon-Mars distances to scale.
All planets and the Moon 100x larger.

Delivering widespread benefits for all

Benefits represent quantifiable positive changes from investments in exploration initiatives recognised by the different stakeholders. Benefits aid in the fulfilment of strategic goals, and they manifest as:

direct / indirect intentional / unintentional tangible / intangible immediate / intermediate / ultimate

ISECG benefits model



Space exploration has witnessed remarkable advancements in past decades. From the Apollo programme, which successfully landed humans on the Moon, to the collaborative feat of building and utilising the International Space Station (ISS), space exploration has been a unique source of scientific discovery, imagination, and inspiration. As humankind is now writing the new chapter of exploration in pursuit of more ambitious goals than ever before towards the Moon and Mars, the question of why we explore remains just as relevant.

Exploration of **low Earth orbit** (LEO), the **Moon**, and **Mars** continues to face financial, technical, and political difficulties. In a world where poverty and hunger still exist and the climate crisis is looming, critics argue that the benefits of space exploration may not always justify the substantial costs, sparking debates about resource allocation amongst competing societal needs. Concerns about the risks associated with space missions, including potential accidents and losses, persist.

Despite these challenges, more and more countries, space agencies, and companies are choosing to explore because it **benefits a wide range of people on Earth** in very real and concrete ways. Scientists and researchers use the unique data and samples collected during space missions to learn more about the universe and the ability of humans to live and work in space. Entrepreneurs see opportunities for new business ventures in the growing commercialisation of space exploration and develop new services and products that suit the needs of a wide range of customers. The new generation is fascinated by the courage and exceptional character of astronauts who venture beyond the known horizon and is motivated to pursue studies in science and technology. Countries work together peacefully to achieve the common goals of ambitious space exploration missions and use this joint work as a tool to promote diplomacy. Governments invest in the cutting-edge space technologies to stimulate an advanced economy and foster a highly skilled workforce. Nations develop a sense of pride and belonging as they accomplish remarkable feats and firsts in space. And all of humankind is inspired and brought together by the new perspective space exploration brings on our fragile and shared Earth.

The **International Space Exploration Coordination Group**[1] (ISECG) is a forum of 27 space agencies that advance the Global Exploration Strategy through coordination of their mutual efforts in space exploration, even though they all have different objectives, cooperation strategies, and funding schemes.

Effectively communicating the benefits stemming from space exploration is crucial for space agencies to cultivate robust relationships with their decision-makers and engage their citizens. This requires a collaborative, ongoing effort to articulate a unified perspective that encompasses both shared and agency-specific viewpoints, while also demonstrating how international collaboration amplifies socio-economic impacts and underscores the broader benefits for Earth. Consistent and transparent communication informs the public and decision-makers. By capitalising on these benefits, ISECG space agencies fortify partnerships and advance the vision of space exploration outlined in the ISECG **Global Exploration Roadmap**[2] (GER).

This document discusses **benefits as the driver for countries and organisations to invest in space exploration initiatives**, with the support of contemporary illustrative examples. As an integral aspect of this approach, ISECG has defined a **benefits model**. It comprises 12 benefits grouped into 5 benefit categories, all framed by 2 cross-cutting themes.

Separate chapters examine both cross-cutting themes, and each of the benefit categories.

[1] www.GlobalSpaceExploration.org

[2] www.GlobalSpaceExploration.org/wp-content/isecg/GER2024.pdf

Inspirational and societal benefits

“

That's here.
That's home.
That's us.

Carl Sagan

The pale blue dot

is a photograph of Earth taken by NASA’s Voyager 1, on 14 February 1990, at a distance of 6 billion km from the Sun. The image inspired the title of scientist Carl Sagan's book, *“Pale blue dot: a vision of the human future in space.”*

NASA/JPL-Caltech

Science benefits | Economic benefits | Global cooperation benefits | Inspirational and societal benefits | Space exploration ecosystem benefits

Breathtaking aurora's hues

NASA astronaut Scott Kelly took this photo of an aurora from the International Space Station's Cupola on 15 August 2015. In foreground, CSA's Canadarm2 robotic arm, NASA's Destiny laboratory, and ESA's Columbus module.

NASA

Cross-cutting themes

- **Exploration principles**
- **Diversity and inclusivity within the space community**

NASA

NASA astronaut **Christina Koch** takes an out-of-this-world space selfie. She ventured into the vacuum of space for 7 hours and 17 minutes to swap a failed battery charge-discharge unit with a spare on 18 October 2019.

Some ways ISECG members foster commercialisation

ASI – Agenzia Spaziale Italiana

Public-private partnerships, innovative procurement, and venture capital investments

Canadian Space Agency – Agence spatiale canadienne

Supporting lunar mission technology development and payload integration

CSIRO – Australia's National Science Agency

Facilitating industry collaboration for space missions and commercialising space technologies

DLR

Supporting commercial initiatives, fostering technology transfer, and spin-off commercialisation

New Zealand Space Agency

First fully privately funded mission to Venus, research for commercial space outputs, and cislunar transport technology

Since the founding of ISECG in 2006, the global space community has grown rapidly and significantly. ISECG space agencies have continued to advance the Global Exploration Roadmap (GER), and together with new and emerging actors from both the public and commercial sectors they have contributed to a more resilient space exploration ecosystem. Through national and international cooperation frameworks, the public and private sectors adhere to shared **exploration principles** that help achieve enduring, sustainable, and responsible human and robotic space exploration. The resulting increased **diversity and inclusivity** promote innovation, create new opportunities for cooperation, and extend the reach of exploration missions to a broader audience. These themes are present and reflected throughout the benefit categories discussed in this document.

Exploration principles

ISECG space agencies envision a future market by fast-growing partnerships and collaborations, and many new participants and stakeholders. This global effort aims to achieve the ambitious shared goal of extending human and robotic presence sustainably to different destinations.

Peaceful exploration and sustainability both bring tangible benefits back to Earth. Inclusive engagement with public stakeholders, particularly members of underrepresented communities, stands as a cornerstone of responsible exploration. Establishing robust feedback mechanisms ensures that public concerns and perspectives are not only heard but also integrated, fostering education and awareness about the profound significance of space exploration.

Benefits stemming from space exploration span across various domains, and they are guided by a set of **7 exploration principles delineated in the ISECG Global Exploration Roadmap**. These represent attributes of an enduring, sustainable, and responsible human and robotic space exploration.

1. **AFFORDABILITY – Build innovative approaches to enable more with available budgets.** Cost must be considered throughout exploration programme formulation and execution. Architectures should favour reusable and reliable in-space systems in partnership to share cost.

2. **EXPLORATION BENEFITS – Meet exploration objectives and generate public benefits.** Sustainable human space exploration must respond to exploration goals and objectives and provide value to the public and other stakeholder communities. Synergies between space and other domains are crucial.

3. **PARTNERSHIPS – Provide early and sustained opportunities for diverse partners.** International cooperation is critical for enabling and sustaining increasingly complex exploration missions. Collaborations should consider the long-term interests of each partner, large or small. Working with the private sector, where goals align, can enable new approaches and create markets for services to support space exploration.

4. **CAPABILITY EVOLUTION AND INTEROPERABILITY – Evolve capabilities with standard interfaces.** Building upon existing capabilities and increasing performance with each step. Using common interfaces and modular architectures facilitates addition of new partners, reduces mass, and increases safety.

5. **HUMAN-ROBOTIC SYNERGY – Maximise synergies between human and robotic missions.** Combining the unique and complementary capabilities of humans and robotic systems enables a greater set of goals to be met effectively, cost-efficiently, and safely.

6. **ROBUSTNESS – Provide resilience to technical and programmatic challenges.** Plans and actions must have flexibility to cope with unplanned changes or crisis situations, whether due to catastrophic events, changes in partner priorities, adjustments in available funding or the evolution of objectives. Dissimilar redundancies of critical functions should be applied early, where practicable.

7. **RESPONSIBLE EXPLORATION – Explore peacefully together.** Exploration activities should be conducted for peaceful purposes and in a manner that is consistent with international obligations and principles in space. This includes attempting to limit the impact of exploration activities on the space environment, preserving it for future generations.

Diversity and inclusivity within the space community

Global access to space exploration has increased in the past 20 years. More and more countries are creating their own space agencies, and the space industry is expanding quickly. These developments are making it possible for more organisations to support efforts to address urgent global challenges, motivate coming generations, and promote sustainable development.

Emerging and small space agencies

The increase in means to access space has made it easier for smaller and emerging space agencies to gradually increase their participation to space exploration missions. There are several ways in which emerging space agencies build capacity and develop their domestic industry to benefit from space exploration missions. Scientists and researchers participating to an international mission's science team contribute to advance the mission's science goals while also developing skills and workforce domestically. Small and emerging space agencies also contribute to the building of space capabilities, by developing scientific payloads or conducting space technology demonstrations. They also extend their focus to medical and life sciences, food security, and biosecurity through astronaut health studies. Introducing STEM subjects relevant to space exploration into high school and university curricula promotes a highly skilled workforce with translational skills in other sectors and increases the capacity of the talent pipeline at national level.

The engagements below demonstrate the domestic and global benefits of participating in space exploration.

The **United Arab Emirates** (UAE) serves as an exemplary case study of the transformative power of space exploration on education and workforce development. Before 2010, UAE produced very few PhD graduates. In 2017, doctoral students comprised less than 0.8% of the tertiary education population, and less than 5% of undergraduates pursued degrees in basic sciences. The Hope Probe mission, the first mission to Mars by any Arab country, spurred a remarkable surge in STEM education in UAE. Engagement in the Hope Probe mission has propelled UAE to pursue STEM university courses at an annual rate of approximately 12%, six times faster than the overall trend. This increase has coincided with a significant increase in female involvement in STEM fields, showcasing the impact of space exploration initiatives on educational diversity and gender equality.

- The Australian Research Council (ARC) Centre of Excellence in **Plants for Space (P4S)**[3] serves as an example of how space exploration programmes may spur innovation in vital fields like the biological and agricultural sciences. The centre's primary objective is to support long-duration space missions by developing sustainable food production systems beyond Earth and researching the viability of growing plants in space. By fostering international cooperation with other scientific institutions and space organisations, it advances knowledge of plant biology, optimises agricultural practices, and creates novel approaches to food production on Earth and in space. This multidisciplinary strategy advances scientific understanding, promotes technical innovation, and stimulates economic growth, giving Australia a major role in the international space exploration community.

- After encountering financial limitations and a lack of strategic direction at the programmatic level, the **Polish Space Agency** (POLSA) was able to articulate and capitalise on the societal and economic benefits of space exploration. The sustained effort led to a key milestone in August 2023, less than 10 years after POLSA's founding in 2014, when the Polish Ministry of Development and Technology allocated an additional €360 million for activities within ESA for the period 2023–2025. Out of this sum, €200 million was designated for Poland's participation in ESA programmes. This substantial contribution positions Poland to play a pivotal role in a dozen of projects, with over 90% of the funds benefitting Polish companies and scientific institutions. POLSA's instrumental role in securing this funding increase underscores its commitment to advance space exploration while positioning Poland as a prominent player in the global space industry.

Commercial sector

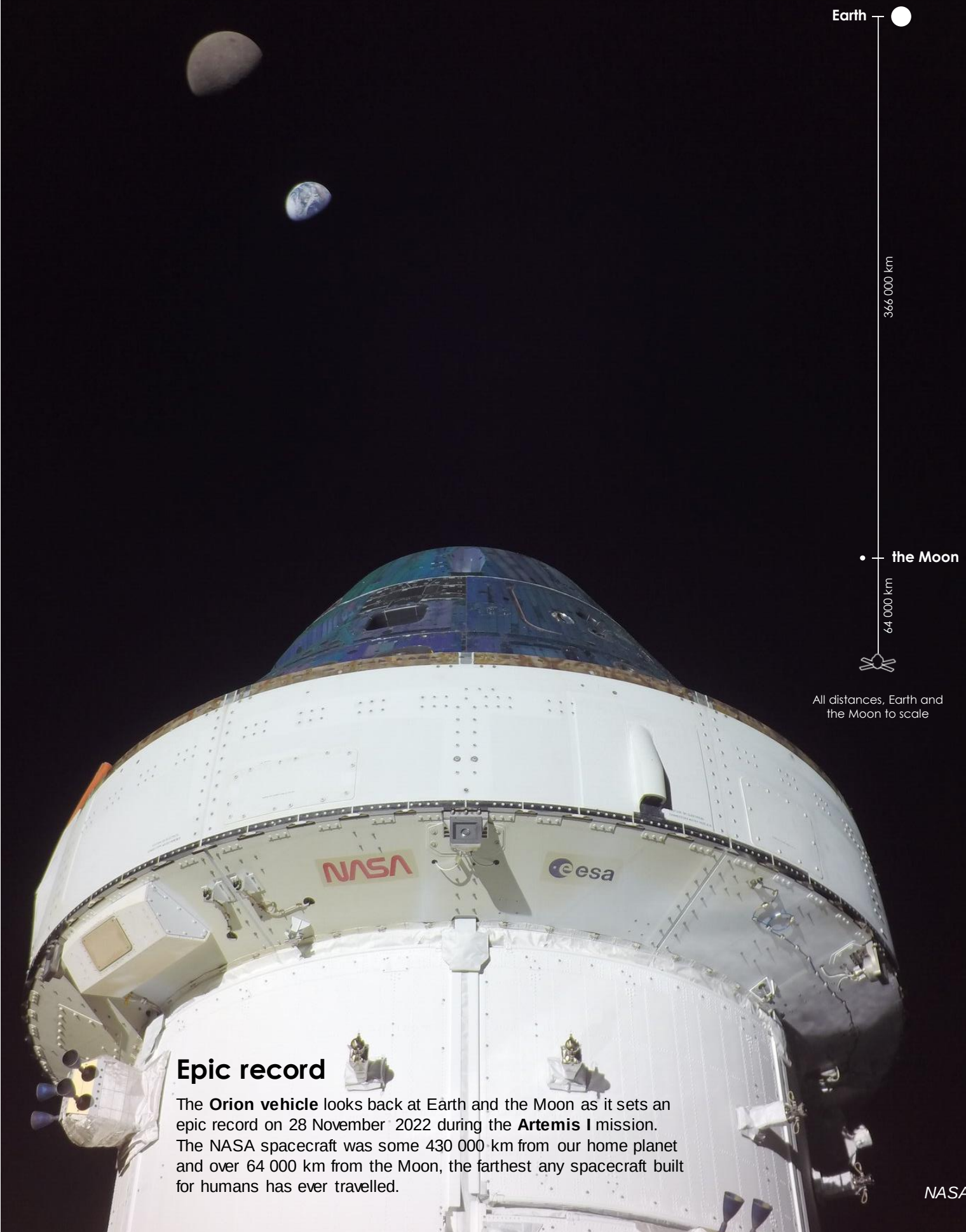
The evolution of space exploration is reshaping both governmental and private entities. Established space agencies are increasingly pursuing commercial ventures to diversify funding sources and alleviate pressure on public budgets.

Commercialisation strategies encompass a range of initiatives aimed at fostering private sector involvement internationally. These efforts entail private enterprises assuming a significant portion of investment risk and operational responsibility, while facilitating the transfer and application of space technology to terrestrial industries. In this context, collaborations between commercial entities and space agencies facilitate the pursuit of common exploration goals, often with private entities contributing specific components to solutions funded by space agencies. Such partnerships mitigate risks for private ventures, while public entities stand to benefit from resulting services.

The overarching goal of commercialisation is to catalyse innovation and develop new markets within the space industry. This involves offering comprehensive space exploration solutions developed, manufactured, and operated by commercial entities, or repurposing solutions initially utilised by space agencies. Commercialisation efforts aim to encourage private sector engagement in exploration initiatives independent of governmental or institutional stakeholders. This also facilitates the commercial utilisation of legacy assets from exploration programmes for research and technology developments.

[3] plants4space.com

Science benefits | Economic benefits | Global cooperation benefits | Inspirational and societal benefits | Space exploration ecosystem benefits



Epic record

The **Orion vehicle** looks back at Earth and the Moon as it sets an epic record on 28 November 2022 during the **Artemis I** mission. The NASA spacecraft was some 430 000 km from our home planet and over 64 000 km from the Moon, the farthest any spacecraft built for humans has ever travelled.

NASA

Science benefits

Global cooperation benefits

Inspirational and societal benefits

Space exploration ecosystem benefits

The “sky palace”

An image captured by Tianhe panoramic camera A during the first Shenzhou-13 spacewalk in November 2021 on the **Tiangong space station**.

CMSA/CCTV/Chinese Academy of Sciences

Science benefits

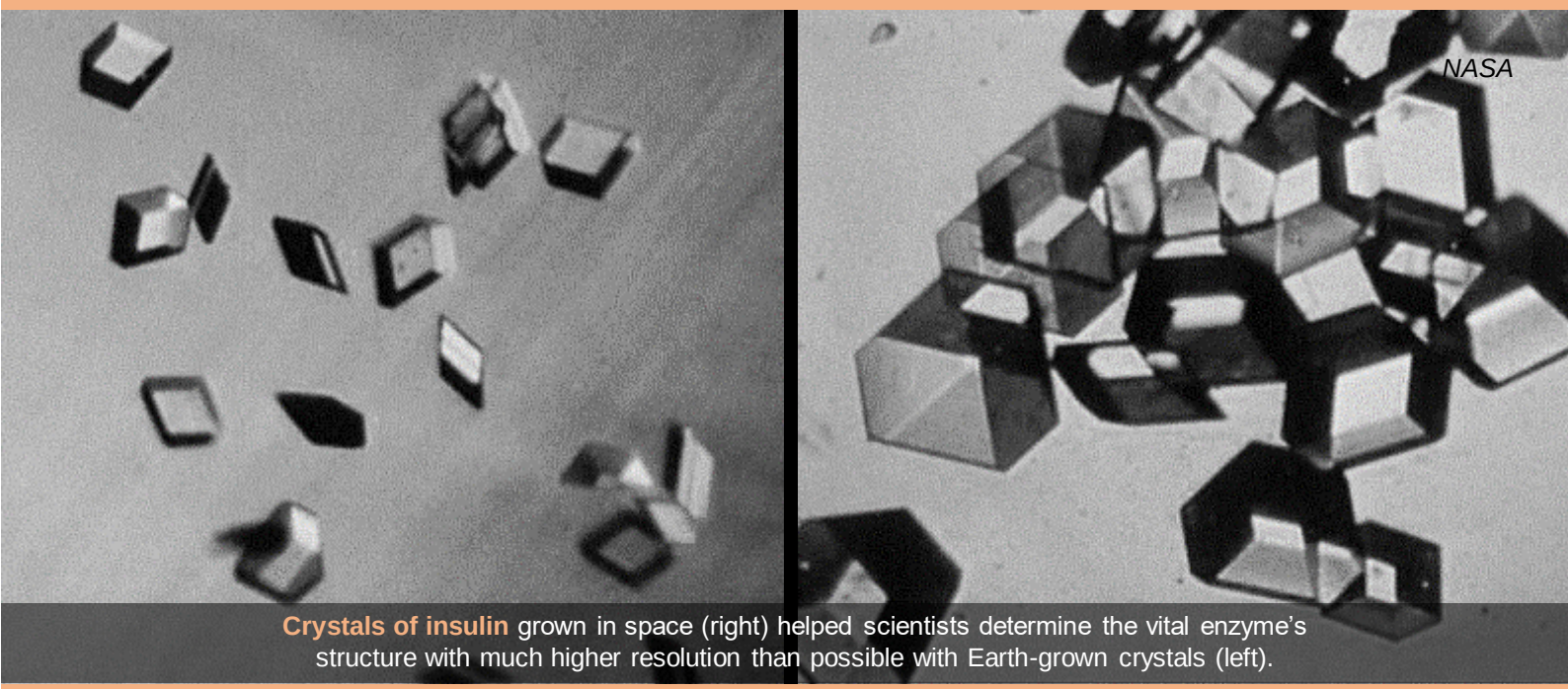
- **Research capabilities developed and maintained**
- **Opportunities for science created**
- **Science questions answered, and knowledge gaps filled**

The **Chandrayaan-3** mission's **Vikram lander** as seen by the navigation camera on **Pragyan rover** in August 2023.

The Space Station's **Japanese Experiment Module Kibo**.

Volunteers in **bedrest studies** spend three weeks in bed with their heads tilted 6° below the horizontal.

NEEMO 23 crew by the Aquarius underwater habitat.



Crystals of insulin grown in space (right) helped scientists determine the vital enzyme's structure with much higher resolution than possible with Earth-grown crystals (left).

The essence of exploration is to venture into the unknown to discover what lies beyond the limits of human knowledge. Due to this intrinsic link between science and discovery, one of the benefits arising from space exploration is the creation of new scientific knowledge. Learning more about the Universe and the human capacity to live in space accelerates scientific excellence and in turn facilitates the development of new technologies that enable deep space exploration.

The data derived from scientific research in space fuels discoveries, with tangible impacts on life here on Earth. The resulting technological and scientific advancements, spanning sectors such as health, transportation, public safety, energy, environment, information technology, and automation, reflect space exploration's significant contributions to our society.

Exploration initiatives to destinations like low Earth orbit, the Moon, or Mars offer opportunities to perform scientific investigations with exposure to space environments that are impossible to replicate on Earth. Robotic missions on Moon and Mars produce fresh insights into geophysics and planetary science. Fundamental scientific studies of the Martian environment, its evolution, and its current conditions produce foundational information about terrestrial planetary evolution, and could provide a model to help us understand climate change processes on our planet.

Research capabilities developed and maintained

The development and operation of research platforms and infrastructure for studying life in extraterrestrial conditions constitutes an early-stage benefit in the chain of space exploration activities, ultimately enabling the achievement of scientific objectives.

Scientists have successfully replicated diverse environments on Earth to serve as analogues for the challenging conditions in space and on the Moon and Mars. These terrestrial analogues are instrumental in conducting scientific investigations to better understand the effects of living and working in extreme settings.

- **Cooperative Adventure for Valuing and Exercising human behaviour and performance Skills** (CAVES) is an ESA training course in which astronauts from all over the world learn teamwork and problem-solving skills while conducting scientific experiments in the extreme conditions of a space-analogue cave environment. They journey deep underground to perform scientific experiments, map the environment, and document their activities.

- **Bedrest studies**, like EnviHab (DLR) and MEDES (CNES), offer scientists additional insights in how the human body adapts to weightlessness conditions, simulating aspects of the permanence in space. Volunteers spend several days in bed with a six-degree head-down tilt. They also eat, exercise and shower in a head-down-tilt position.

- **NASA Extreme Environment Mission Operations** (NEEMO) sees astronauts live in an underwater laboratory off the coast of Florida to simulate space missions and train for extravehicular activities. It is designed to train astronauts to live and work together as a team.

- The ESA / Russian Institute for Biomedical Problems (IBMP) **Mars500** experiment (2007–2011), and the activities at the ESA **Concordia** station in Antarctica explore the psychological and social dynamics of long-duration space missions, crucial for preparing future crewed missions to Mars.

The **ISS serves as an unparalleled research platform**, offering scientists access to prolonged radiation and weightlessness conditions for multidisciplinary scientific investigations spanning materials science, fundamental physics, chemistry, biology, medicine, and technology developments. Scientists also benefit from **infrastructure and missions in the lunar and Martian** vicinities, which provide new capabilities for research.

- Instruments mounted on the exterior of the ISS provide a wealth of data for applications such as **Eyes on Earth**, an immersive 3D web application that uses NASA data and imagery. Along with **other NASA Earth observation missions** in orbit, the space station is one of the main platforms for studying climate change, helping scientists track the factors influencing the climate over long periods.

- ISRO's **Chandrayaan-3** mission, which was the first mission to successfully land on the lunar south pole, provided new insights on prospecting the lunar surface. The science instrument onboard the rover made the first-ever in-situ measurements on the elemental composition of the lunar surface near the south pole. These measurements confirm the presence of sulphur in the region, something that was not feasible with instruments aboard lunar orbiters.

- In January 2024, JAXA's **Smart Lander for Investigating Moon** (SLIM) achieved Japan's first successful Moon landing, showcasing precision landing capabilities within 10 metres, and possibly as precise as 3 to 4 metres. It collected vital data for future precision landing technology, including navigation guidance and lunar surface imagery.

Opportunities for science created

An increasing number of institutional and commercial entities provide scientists a wide range of research opportunities in LEO as well as in the lunar and Martian environments. Preparatory activities for Mars sample curation and analysis are also underway.

Low-gravity platforms are becoming more accessible, with new actors joining in and seizing opportunities to cooperate with scientists and experts from numerous countries, producing crucial scientific data and breakthroughs. These collaborative efforts provide opportunities for scientists from diverse backgrounds to convene, develop research agendas, and establish consortia, shaping future research priorities.

Space agencies**'** **open calls for participation** attract scientists from all over the world, facilitating groundbreaking space research in fields such as medicine and technology. Space science presents a chance for smaller or emerging space agencies to participate in ambitious space exploration missions by engaging in international research forums.

- The ASI **Funding Announcement for Astrobiology**[4] aims to drive advancements in the field by supporting scientific projects and experiments. Through collaboration and synergies within the scientific community, ASI seeks to position Italy prominently in astrobiology research. Following its roadmap for astrobiology, ASI aims to fund experiments and initiatives that enhance human and robotic exploration capabilities using terrestrial analogues.

[4] ui.adsabs.harvard.edu/abs/2022cosp...44.2769N/abstract

Science questions answered and knowledge gaps filled

The relationship between science and exploration is mutually beneficial: exploration drives scientific enquiry, while scientific advancements enable further exploration. Robotic missions to the Moon and Mars trigger scientific questions that drive the development of new theories, applications and technologies. The development of new materials, propulsion methods, and life support technologies, enables long-duration missions to low Earth orbit, the Moon, and Mars.

The unique conditions of the space environment allow scientists to investigate biological and physical processes that are otherwise impossible to observe on Earth, leading to major discoveries and helping in definition of new missions.

Life sciences. Scientists can understand the various impacts of long-duration missions on the human body by investigating the physiology of astronauts aboard the ISS. The results of these studies are key in the development of better life support systems and countermeasures that mitigate the risks associated with human spaceflight.

Planetary sciences. Scientists rely on data produced by other exploration missions to understand planetary formation, geology, and potential habitability at the Moon and Mars.

Material sciences. The development of new materials with enhanced properties and a wide range of applications, both in space and on Earth.

Technology developments. Technology advancements in space exploration have also led to advancements on Earth, including improved solar panels, implantable heart monitors, light-based anti-cancer therapy, cordless tools, lightweight high-temperature alloys used in jet engine turbines, global search-and-rescue systems, and biomedical technologies.

The results of these many scientific investigations produce myriad journal articles, conference proceedings, book chapters, and PhD theses.

- Studies from NASA and JAXA show how **crystal research** conducted on the ISS is helping to identify potential treatments for some diseases[5]. By growing protein crystals in the weightlessness environment of the ISS for more than two decades, scientists have gained crucial insights into the molecular structures of proteins. This knowledge is instrumental in designing more effective and targeted medications with fewer side effects, benefiting human health on Earth.

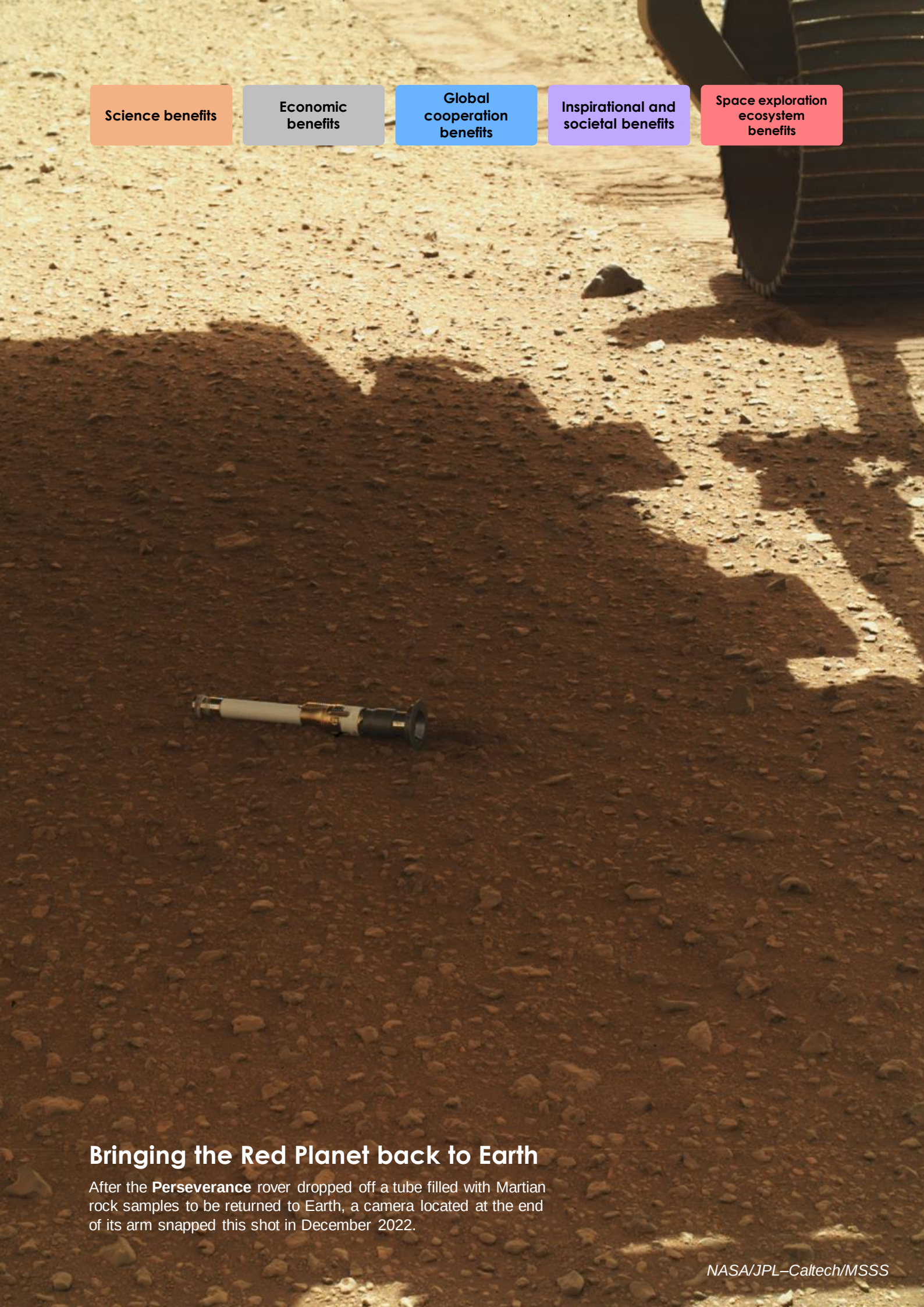
- ESA's **dry electrode technology**, initially designed to monitor their astronauts' health in weightlessness, allows foetal cardiologists to isolate and continuously monitor a foetal heartbeat on an electrocardiogram[6]. The non-invasive technology could pave the way for high-accuracy, at-home foetal monitoring.

- In 2020, JAXA's **Hayabusa2** mission made history by returning samples from the asteroid Ryugu, providing crucial data on carbonaceous asteroids, near-Earth asteroid environments, and Solar System formation. These samples, containing water and organic matter like amino acids, offer insights into the origins of life.

[5] www.nasa.gov/missions/station/iss-research/crystallizing-proteins-in-space-helping-to-identify-potential-treatments-for-diseases

[6] space-economy.esa.int/article/145/esa-technology-transfer-success-story-dry-electrodes-to-monitor-vital-signs-from-astronauts-in-space-to-foetuses-in-utero

Science benefits | Economic benefits | Global cooperation benefits | Inspirational and societal benefits | Space exploration ecosystem benefits



Bringing the Red Planet back to Earth

After the **Perseverance** rover dropped off a tube filled with Martian rock samples to be returned to Earth, a camera located at the end of its arm snapped this shot in December 2022.

NASA/JPL–Caltech/MSSS

Science benefits | Economic benefits | Space exploration ecosystem benefits

The world's first metal 3D printer in orbit is revolutionising space travel

The introduction of additive manufacturing in space in January 2024, specifically metal printing using stainless steel wire, marks a groundbreaking milestone in space exploration.

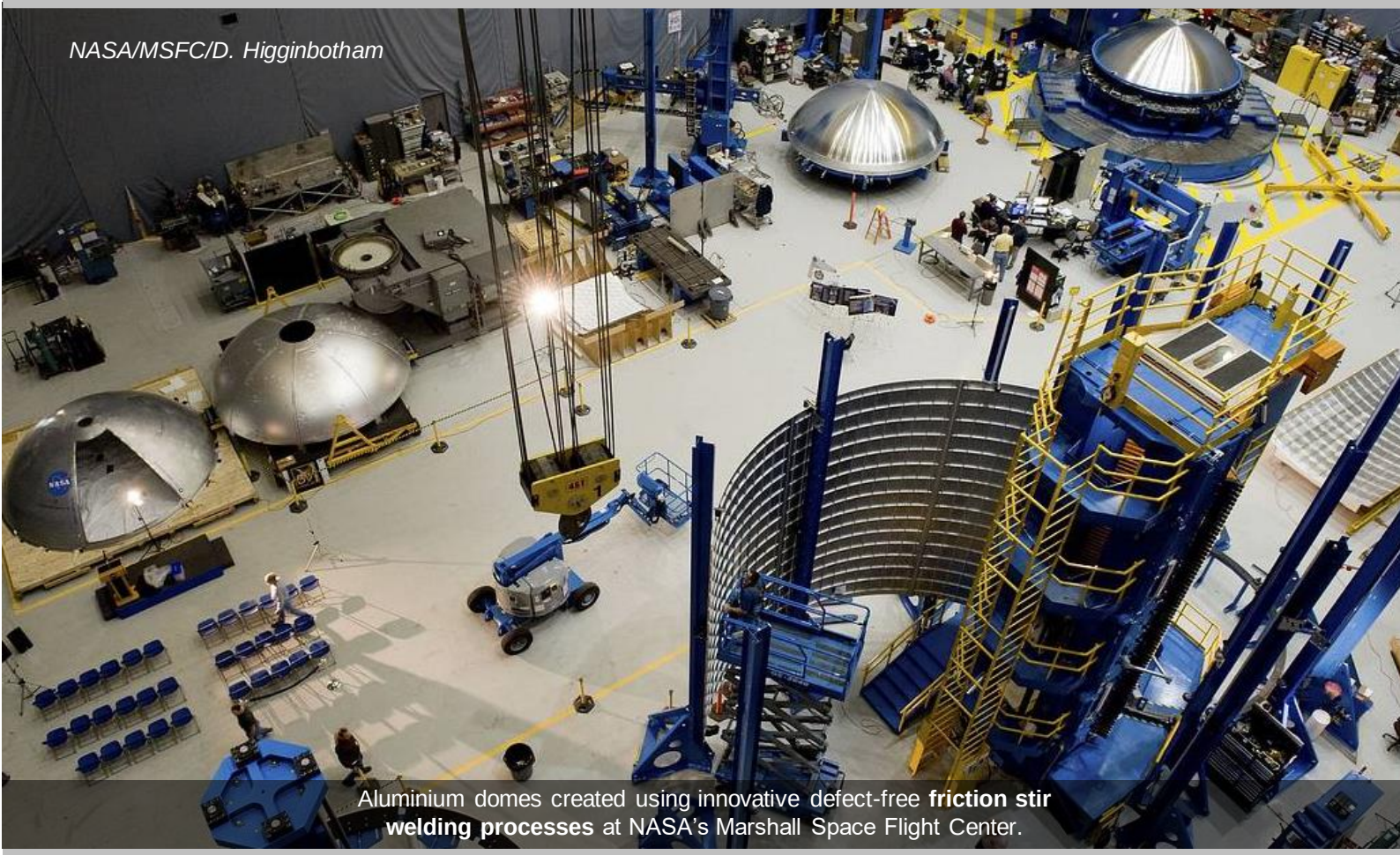
Airbus Defence and Space SAS

Economic benefits

- **Contribution to economic growth**
- **Increased innovation**
- **Enabled commercial exploration services**

The **Intuitive Machine 1** (IM-1) spacecraft beamed back first images of the near side of the Moon before landing.

The **Habitation and Logistics Outpost** (HALO) module for the Gateway lunar space station in progress at Thales Alenia Space, in coordination with prime contractor Northrop Grumman.



Aluminium domes created using innovative defect-free **friction stir welding processes** at NASA's Marshall Space Flight Center.

Space exploration is a catalyst for economic growth and technology-based innovation. Numerous high-value products and services can be linked to technologies that were initially developed for space, such as integrated circuits, miniature cameras used in smartphones, water purification systems, home insulation, and memory foams. Space exploration supports employment and entrepreneurial capacities, fostering highly skilled workforces in STEM fields and enabling the development of new markets. Space missions give rise to start-ups and small enterprises that specialise in cutting-edge technologies with tangible and visible economic returns.

Contribution to economic growth

The last decade has seen a surge in investments in space exploration from both the public and private sectors. Driven by ambitious lunar missions and human spaceflight opportunities in LEO, global government funding for space exploration is projected to reach $33 billion by 2032[7]. The returns on investments in space exploration programmes may not always be direct or immediate, but they always contribute to economic growth.

Investments in space exploration ripple through the supply chain and generate economic growth through direct, indirect, and induced impacts. There is **direct economic growth** from the generation of quality, high-paying jobs for staff working directly on space exploration activities and enabling the development of value-added space exploration products and services. There is also **indirect economic growth** from the money spent in the supply chain and **induced economic growth** from the private spending of employees and contractors in the wider economy. These economic impacts ultimately add and translate into increases in gross domestic product (GDP) and tax revenues for governments.

Space agencies measure the contribution of space exploration activities to economic growth through socioeconomic studies using various economic models. There is no lack of examples of governmental[8,9], private or academic[10] reports on the impacts of space exploration. Socioeconomic studies show that space exploration investments focus on sectors with robust output and employment multipliers, signifying its potential to drive significant economic growth.

- NASA's **economic impact analysis** reports that the programmes and projects of the Moon to Mars campaigns supported more than 90 000 jobs, $20 billion in total economic output and an estimated $2.2 billion in tax revenues across the US in 2021 fiscal year[11].

- The **SEI-2022 socioeconomic impact study**[12] on ESA's Terrae Novae programme reveals a promising trajectory for its participating countries' economies. The programme is projected to sustain more than 23 000 jobs over 2023–2030 and to add over €2.8 billion of gross value added (GVA) into the European economy while enabling governments to accrue more than €800 million in tax revenues. The economic projections reveal that for every €1 generated through Terrae Novae activities, an additional €3.4 to €3.8 is stimulated within the broader economy.

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7 digital-platform.euroconsult-ec.com/product/prospects-for-space-exploration

8 www.asc-csa.gc.ca/eng/publications/state.asp

9 www.bcg.com/publications/2023/italy-more-than-a-space-programme

10 www.pnas.org/doi/abs/10.1073/pnas.2221341120

11 www.nasa.gov/wp-content/uploads/2022/10/nasa_fy21_economic_impact_report_brochure.pdf

12 youbenefit.spaceflight.esa.int/sei-2022

Increased innovation

The unique and stringent challenges of space exploration accelerate innovation. Sustaining human presence in space requires leaps in many areas such as propulsion systems, life support systems, robotics, space medicine, and navigation and communications. Space instruments and infrastructure need to be compact, lightweight, and highly reliable, which requires engineers to develop innovative solutions to address strict constraints. In many cases, the **technological advancements** achieved through space exploration efforts would not have materialised otherwise.

These technological advancements find applications that lead to new products and services for commerce in space and on Earth. The process of innovation has bumps and curves, and the path taken by space technologies to be adapted or reused in day-to-day applications on Earth is not always direct. In some cases, space exploration technologies are designed with a terrestrial application in mind from the start. Sometimes, spin-off terrestrial applications come from the direct use or adaptation of space technologies. In other cases, spin-offs come as the result of past space exploration investments that find a viable commercial application years later.

- The company Heraeus Precious Metals has developed the AGXX technology, an **antimicrobial coating technology** tested aboard the ISS that prevents biofilm formation and bacterial growth through a redox reaction and micro-electric field effects. Originally devised for space, the technology has been applied in the agrifood sector through a collaboration with Aponix, a company pioneering **innovative crop management through high-density vertical urban farming**[13]. Positioned in urban areas, it bolsters local production and shortens transit distances, thereby reducing environmental impacts.

- The Columbus Automatic Identification System (AIS) was developed by the Norwegian Defence Research Establishment and companies Kongsberg Seatex and LuxSpace to evaluate **techniques to monitor sea-going traffic from orbit**. It started as a proof of concept on the ISS, and today Norway operates AIS receivers aboard five national microsatellites. They provide important traffic data that many maritime authorities use to monitor vessels at risk, identify vessels responsible for oil spills, and assist in rescue coordination.

- The Bio-Monitor[14] is an **all-in-one wearable technology** designed by company Carré Technologies to monitor and record vital signs during an astronaut's daily routine aboard the ISS. This system can be used on Earth to help people who are bedridden, housebound, or living in rural communities with limited access to medical support. It can also be used to monitor the health workers in dangerous environments such as mines, industrial sites, or factories, and to improve the performance of athletes.

- The tanks of NASA's Space Launch System (SLS) are constructed using friction stir welding, a **solid-state welding process** that results in stronger, nearly defect-free joints[15]. The company Nova-Tech Engineering LLC licensed NASA technology that significantly improves this welding process by using an auto-retractable pin tool. The innovation now allows the company's welding machines to perform effective welds for offshore drilling rig piping, armour plating, and rocket manufacturing.

- The **cold-plasma technology** developed for disinfection purposes on the ISS has been adapted by the company Terraplasma for similar food and health applications on Earth. One use is cold-plasma therapy which uses cold-plasma to optimise and accelerate wound healing[16]. Another spin-off application is the production of plasma-activated water to reduce bacteria and fungi on fruits and vegetables.

[13] youbenefit.spaceflight.esa.int/revolutionising-terrestrial-crop-management-with-space-tech

[14] www.asc-csa.gc.ca/eng/sciences/bio-monitor.asp

[15] spinoff.nasa.gov/pdf/Orion and SLS flyer.pdf

[16] youbenefit.spaceflight.esa.int/plasma-for-a-safer-world

Enabled commercial exploration services

Commercial exploration services are increasingly important drivers of space exploration. Space agencies aim to accelerate space exploration through the creation of a low Earth orbit, lunar, and in the longer-term, Mars economy. Commercial services provide numerous advantages, such as opening access to space to a wider range of users, allowing customers to only purchase the services that directly align with their needs and requirements, reducing cost risks to users, and increasing redundancy and competitiveness through multiple service providers. As an example, the cost and time to access space has continuously dropped since the 2010s due to the increasing availability of commercial launch services that respond to a wide range of needs from different users.

While space exploration remains largely driven by government investments, it is framed by a unique regulatory, policy and commercial context that is a fertile ground for innovation to enable and conduct business in space. During the last two decades, space agencies have paved the way for the development of **commercial use cases in low Earth orbit** by offering opportunities for companies to conduct science and test technology aboard the ISS. Looking toward the future beyond the ISS, the commercialisation of LEO services will continue to expand markets such as on-orbit manufacturing, pharmaceutical research, and private astronaut flights.

Bartolomeo is a platform attached to the European Columbus laboratory that hosts external payloads for institutional and private organisations alike. It can accommodate Earth observation, robotics, materials science, and astrophysics payloads.

JAXA is working to promote the private sector's utilisation of the ISS Japanese Experimental Module Kibo. Space BD Inc. and Mitsui & Co., Ltd. were selected from the private sector to provide **small satellite deployment services**[17]. Through this cooperation, 70% of the available deployment capabilities were transferred to these companies. Space BD Inc. was also selected to provide services using IVA-replaceable Small Exposed Experiment Platform (i-SEEP), one of the external experimental equipment.

As space agencies ramp up their deep space exploration efforts and the private sector gains more experience, commercial activity in space is rapidly expanding beyond low Earth orbit. The implementation of **commercial lunar payloads** demonstrates the important role that commercial space exploration services and private companies will play in enabling sustained lunar exploration.

NASA is working with several American companies to deliver science and technology to the lunar surface through the **Commercial Lunar Payload Services**[18] (CLPS) initiative. Under the Artemis campaign, commercial deliveries began in 2024 to perform science experiments, test technologies, and demonstrate capabilities to help private and institutional entities to explore the Moon and prepare for human missions.

In February 2024, Intuitive Machines conducted the first successful CLPS landing. The **IM-1 mission**[19] carried six NASA payloads to a landing site near the lunar South Pole, a region that could support a sustained human presence and is rich in scientific potential. The payloads focused on assessing risks for future Artemis landings by demonstrating communication, navigation, and precision landing technologies, all while gathering data about space weather and using rocket engines in the proximity of the lunar surface.

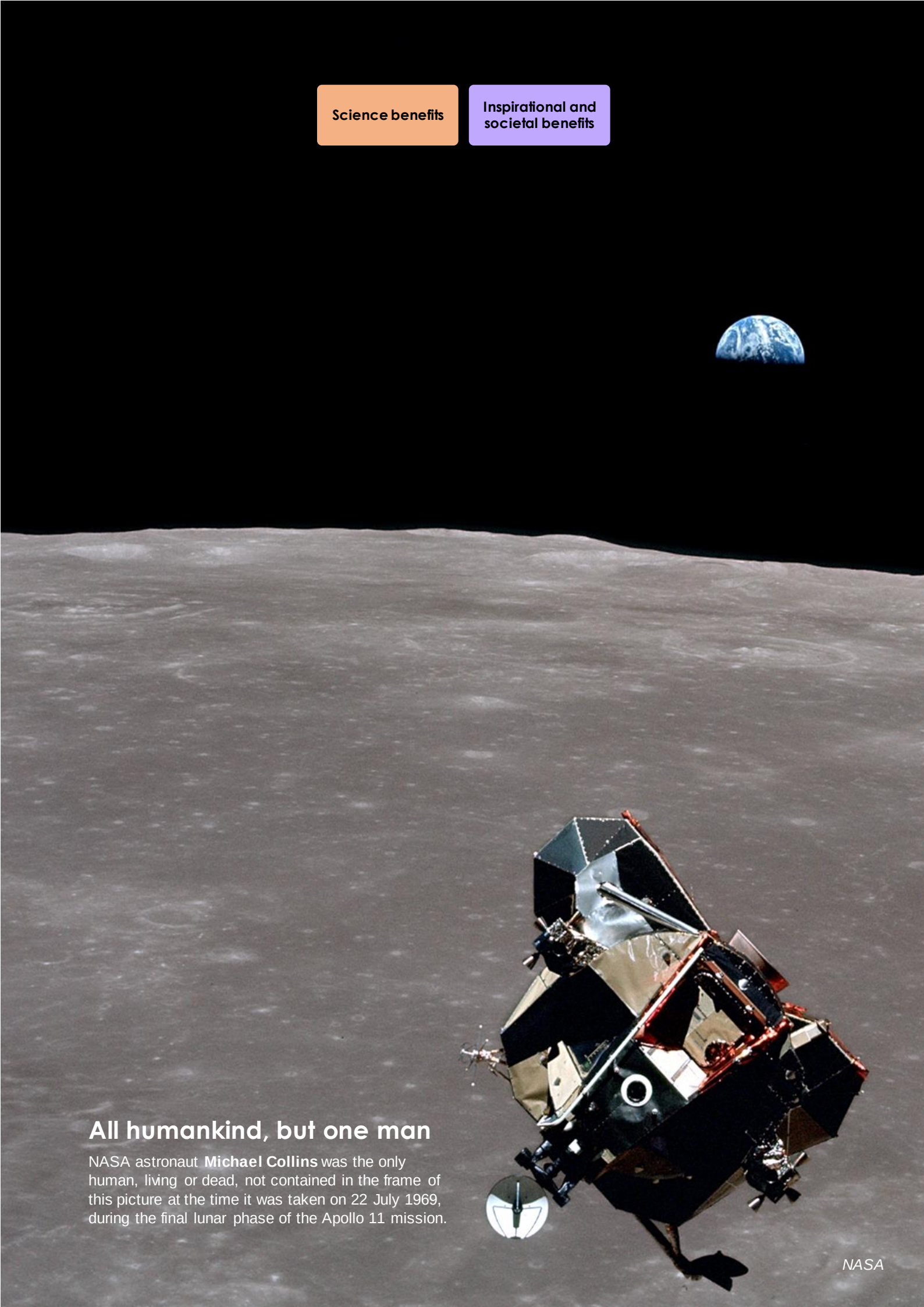
[17] humans-in-space.jaxa.jp/en/biz-lab/experiment/facility/ef/jssod

[18] www.nasa.gov/commercial-lunar-payload-services

[19] www.intuitivemachines.com/im-1

Science benefits

Inspirational and societal benefits



All humankind, but one man

NASA astronaut **Michael Collins** was the only human, living or dead, not contained in the frame of this picture at the time it was taken on 22 July 1969, during the final lunar phase of the Apollo 11 mission.

NASA

Science benefits | Economic benefits | Global cooperation benefits | Inspirational and societal benefits | Space exploration ecosystem benefits

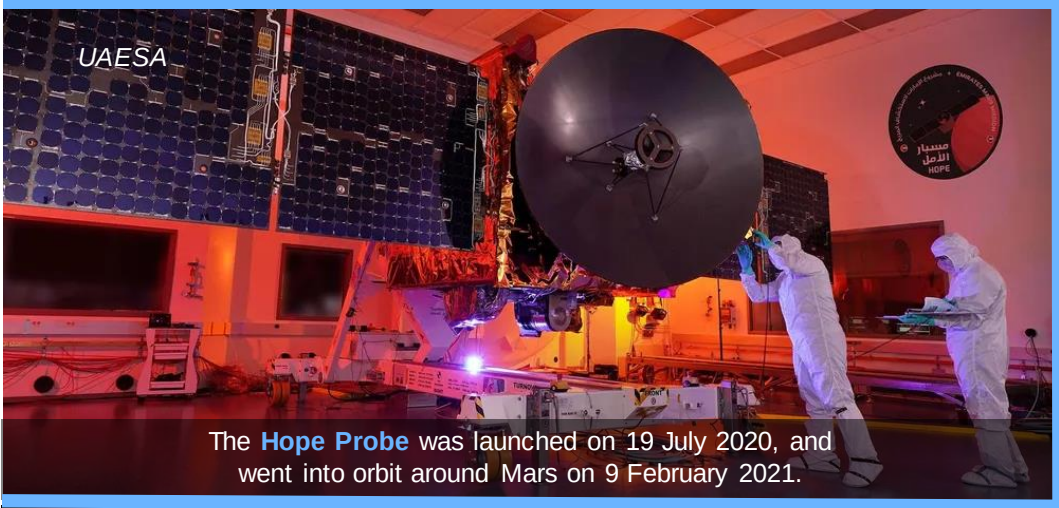
Space station with a view

NASA astronaut **Jessica Watkins** floats in the Space Station's Cupola, a vantage point in orbit to watch Earth and other celestial objects.

NASA

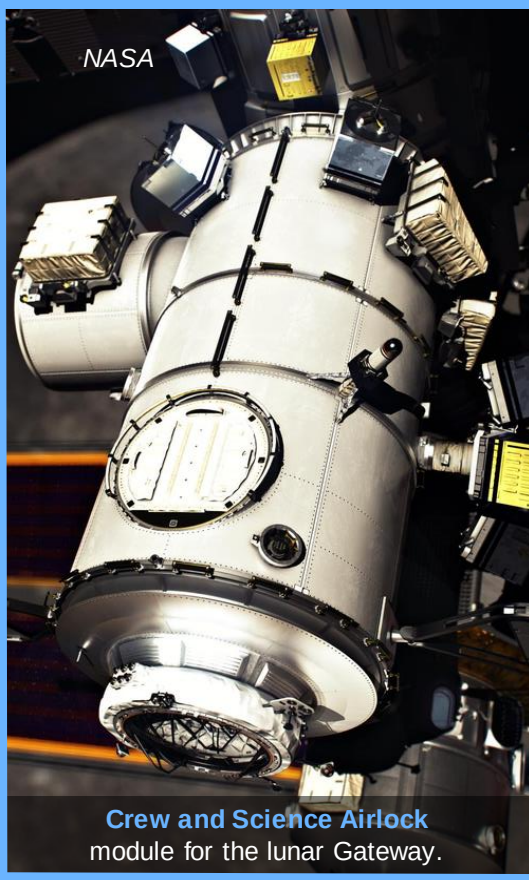
Global cooperation benefits

- **International partnerships**
- **New means to address global challenges**



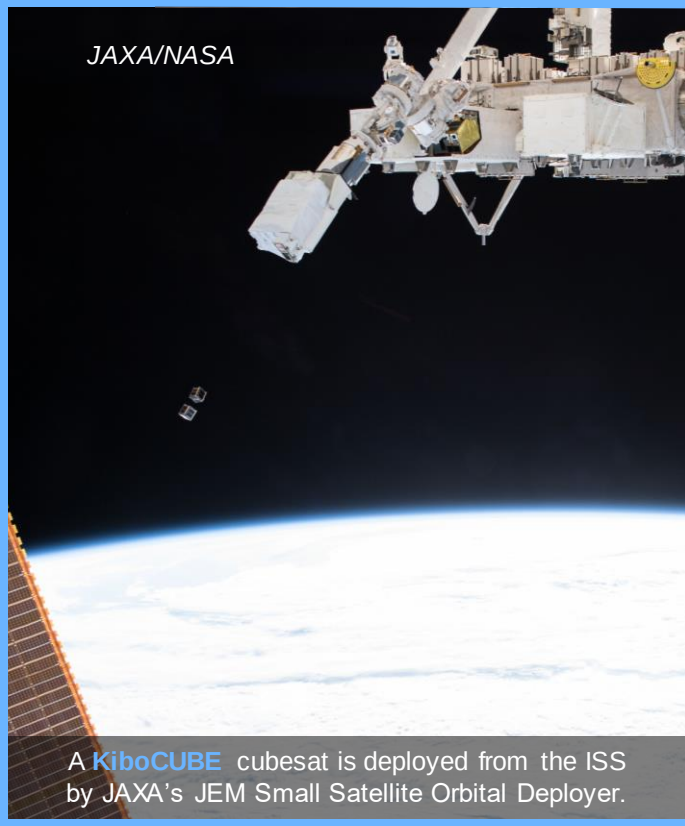
The **Hope Probe** was launched on 19 July 2020, and went into orbit around Mars on 9 February 2021.

The EZResus diagnosis solution has potential for medical emergencies in space and is already helping address **healthcare needs** of remote communities on Earth.



Crew and Science Airlock module for the lunar Gateway.

275+ astronauts form **22** countries visited the ISS. (Feb 2024 status)



A **KiboCUBE** cubesat is deployed from the ISS by JAXA's JEM Small Satellite Orbital Deployer.

Human and robotic space exploration missions require advanced technologies and substantial investments. Space agencies frequently seek cooperative relations with other organisations to achieve their objectives. Developing international partnerships and fostering continuous cooperation among these partners are crucial. This global cooperation enhances the sharing of resources, expertise, and paves the way for innovative solutions to address global challenges.

International partnerships

Space exploration builds on strong partnerships. International cooperation leads to the aggregation of expertise, technologies, and infrastructure to undertake ambitious space exploration missions that would otherwise not be feasible. Human spaceflight and deep space robotic missions are highly complex endeavours that require diverse resources and substantial sustained investments. Through international partnerships, small and large space agencies and increasingly private companies can contribute to major missions from their own national industry expertise, talents, and niches. In return, partners share the risks, decreasing the impacts of delays or failures on each contributor, while benefiting from these activities.

- One of the most ambitious cooperative projects ever attempted, the **International Space Station** (ISS), embodies the power of peaceful cooperation among countries to achieve common goals. Since 1998, the ISS has been continuously operated by a partnership of five space agencies, representing an incredible achievement in planning, coordinating and monitoring of the various activities taking place in the numerous participating organisations. It enables global scientific collaboration by providing opportunities for scientists and astronauts from around the world to access the orbital laboratory and share the benefits. International cooperation on the ISS has remained remarkably resilient to operational, economic, and geopolitical challenges.

- In support to the human return to the Moon, NASA is leading the **Gateway**[20] programme, the next major international collaboration in human space exploration that aims to establish the first lunar space station. This new outpost will be developed, serviced, and utilised in collaboration with international institutional and commercial partners. Gateway capitalises on the strong ISS partnerships and fosters new ones. In 2024, NASA and the UAE's Mohammed bin Rashid Space Centre (MBRSC) announced that UAE will provide the **Crew and Science Airlock**[21] for Gateway.

- The UAE is a relative newcomer to space exploration with the establishment of the UAE Space Agency (UAESA) in 2014. They have rapidly paved their way to become one of major players of this field, leveraging the extended global partnerships they have built. One of UAE's successful missions with international partnerships is the **Hope Probe**[22] in Mars orbit, tasked with providing the first ever complete picture of the Martian atmosphere using three state-of-the-art science instruments. The mission was carried out in cooperation with universities in the USA and launched from Japan in 2020.

New means to address global challenges

Achieving ambitious exploration goals requires **cooperative efforts to address global challenges on Earth**. Past investments in space exploration also led to major advancements

[20] www.nasa.gov/mission/gateway

[21] www.nasa.gov/news-release/nasa-united-arab-emirates-announce-artemis-lunar-gateway-airlock

[22] www.emiratesmarsmission.ae/hope-probe/instruments

in space-to-Earth applications. Despite constant technological progress, humankind continues to face significant societal and environmental challenges such as climate change, limited access to food, clean water and health care. The cooperation and technologies established for space exploration play an important role in tackling those challenges, enabling space agencies to contribute to sustainable development on Earth and in space in various ways. They can contribute to developing an educated workforce, introducing advanced technologies, and reducing inequities among nations.

KiboCUBE[23], a collaboration between the United Nations Office for Outer Space Affairs (UNOOSA) and JAXA, is a preeminent example of how global cooperation in space exploration can support sustainable development and access to space for all. The programme provides space emerging countries with opportunities to deploy cubesats from the ISS, thereby lowering the threshold for space activities, contributing to national capacity development in spacecraft engineering and supporting education and training for developing cutting-edge technology. Kibo has launched more than 70 satellites since 2015, including the first Kenyan-owned satellite **1KUNS-PF**[24], and the first Guatemalan satellite **Quetzal-1**[25].

Space agencies are increasingly working to ensure that the technologies developed to enable humans to live and work in space find synergies with terrestrial applications that benefit life on Earth. The hazards of isolation, confinement and distance from Earth sustained by astronauts share similarities to the hazards faced by people living in isolated communities or working in harsh environments.

Uneven access to healthcare and lack of fresh foods are challenges faced by many remote communities on Earth. The CSA's **Deep Space Food Challenge** and **Deep Space Healthcare Challenge** aimed to develop new technologies to produce food for future space missions and keep astronauts healthy while expanding opportunities for health care access and food production on Earth. It led to the development of CANGrow, a modular indoor food production system designed to operate in remote environments to produce nutrient-dense fresh food with minimal resources. It also led to the development of EZResus, an application that streamlines the information needed by emergency personnel in the critical first hour of resuscitation, from diagnosis to required drug dosage and equipment. It is already being used by thousands of medical personnel on Earth to assist with sometimes life-saving interventions.

Collisions of asteroids or comets with Earth are extreme natural disasters that humankind must prevent. Space agencies have been addressing planetary defences issues by aiming to learn the physical characteristics of potentially hazardous asteroids, develop technologies to avoid collisions, and generate the means to minimise damages.

NASA's **Double Asteroid Redirection Test**[26] (DART), launched in November 2022, was the world's first planetary defence technology demonstration. DART validated one technique of asteroid deflection using a kinetic impactor spacecraft, travelling for over 10 months before intentionally colliding with Dimorphos, a moonlet of asteroid Didymos. The mission's one-way trip confirmed that teams on Earth could successfully target an asteroid and change its orbital path. Fifteen days before impact, DART's CubeSat companion **Light Italian CubeSat for Imaging of Asteroids**[27] (LICIACube), provided by the Italian Space Agency (ASI), deployed from the spacecraft to capture images of DART's impact and of the resulting cloud of ejected matter.

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[23] www.unoosa.org/oosa/en/ourwork/access2space4all/KiboCUBE/KiboCUBE_Index.html

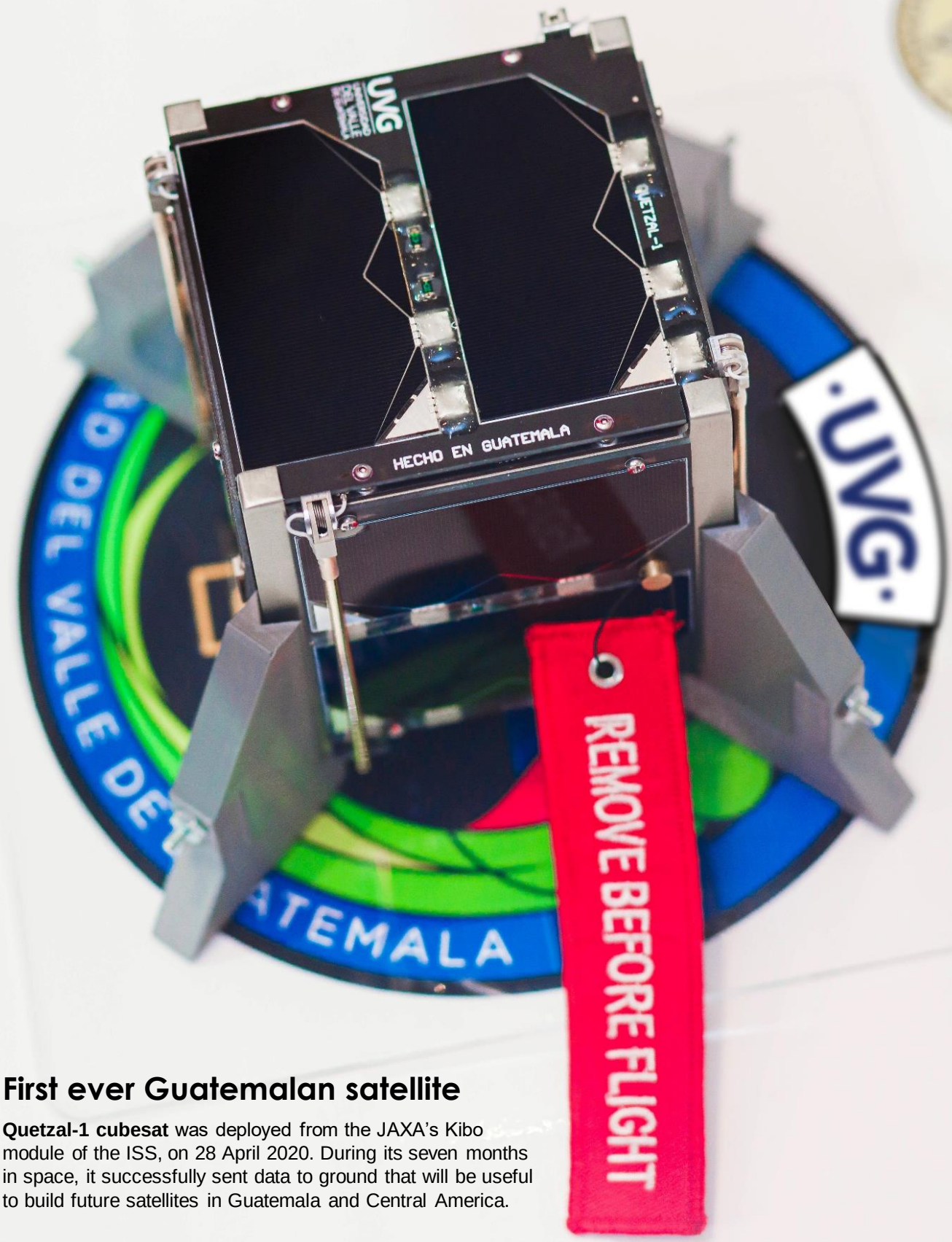
[24] global.jaxa.jp/press/2018/05/20180511_1kuns-pf.html

[25] iss.jaxa.jp/en/kiboexp/news/191227.html

[26] science.nasa.gov/planetary-defense-dart

[27] www.ssdc.asi.it/liciacube

Science benefits | Global cooperation benefits | Inspirational and societal benefits



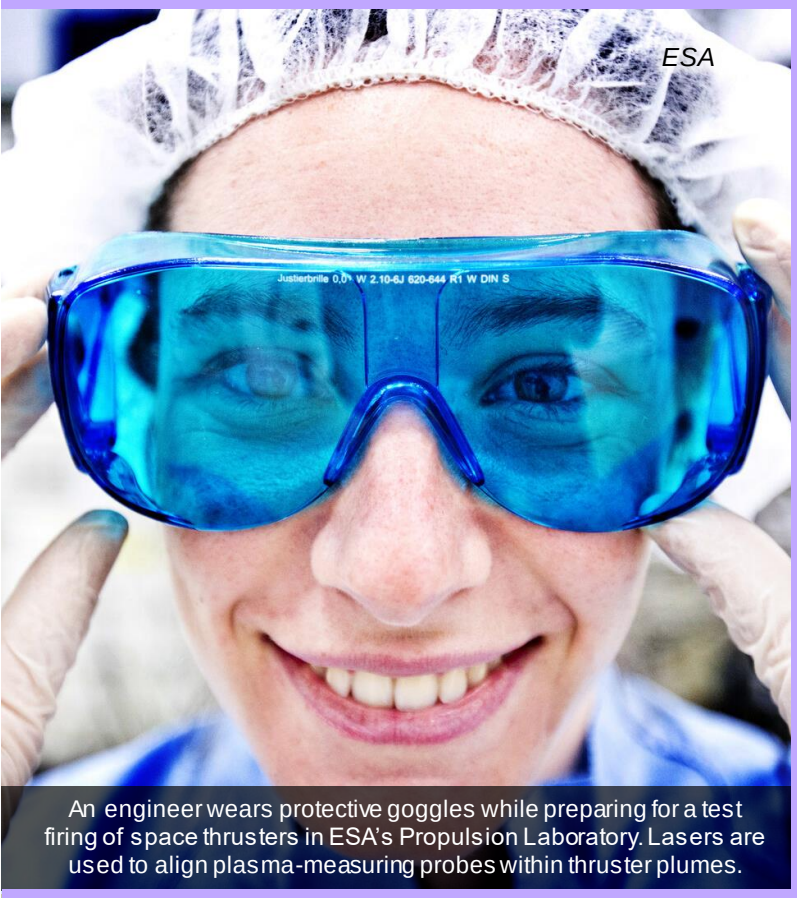
First ever Guatemalan satellite

Quetzal-1 cubesat was deployed from the JAXA's Kibo module of the ISS, on 28 April 2020. During its seven months in space, it successfully sent data to ground that will be useful to build future satellites in Guatemala and Central America.

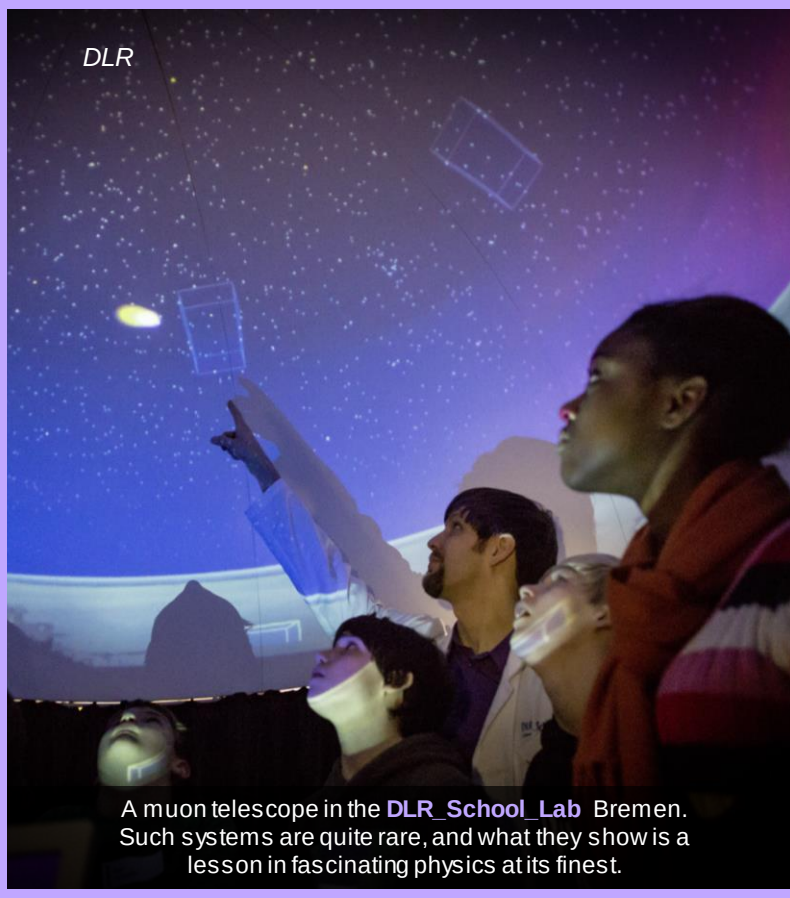
Universidad del Valle de Guatemala

Inspirational and societal benefits

- **Sustained STEM-qualified workforce**
- **Improved public attitudes toward science, research, and global cooperation**



An engineer wears protective goggles while preparing for a test firing of space thrusters in ESA's Propulsion Laboratory. Lasers are used to align plasma-measuring probes within thruster plumes.



A muon telescope in the **DLR_School_Lab** Bremen. Such systems are quite rare, and what they show is a lesson in fascinating physics at its finest.

The 35 winners of the **Astronaut for a Day Competition** completed the first zero-gravity flight from Luxembourg in October 2023.

From Yuri Gagarin's first trip to space to the announcement that the first woman and person of colour will land on the Moon as part of NASA's Artemis campaign, inspiration and societal benefits are at the heart of space exploration. Today's achievements will be a legacy for the future. Space exploration encourages humankind, especially the younger generations, to commit to working together.

As human spaceflight capabilities progress, we develop cutting-edge technology and achieve ambitious, inspirational missions. Over the course of space exploration history, numerous space agencies, both large and small, have inspired their own countries and the world through their incredible feats.

This rapid expansion of space exploration had a significant impact on society. With greater access to resources, media, and information, countries all around the world are expanding their capabilities to engage communities on space initiatives. The growing interest by society and younger generations in space exploration ultimately helps expand and sustain more robust STEM workforces and improves public attitudes toward global cooperation, future space exploration, science, and research.

Sustained STEM-qualified workforce

From early education to young professionals, the global space community has provided greater opportunities for young people to participate in and contribute to space exploration. Events, competitions, and educational programmes, help to inspire students to pursue STEM studies and connect with future leaders in space.

Many space agencies have established educational offices to further engage communities and programmes for students and young professionals. Hands-on STEM activities provide excellent opportunities to engage, educate and train students to develop the required knowledge base, competencies, and skills to address the global exploration challenges of the future. These programmes also expose younger generations to STEM career paths both in and outside of the space community.

Several agencies and organisations offer programmes that allow students to directly engage with real space missions or activities.

- DLR invites school classes, starting with 1st grade, to visit one of its sixteen **DLR School Labs**[28], where children and young students can discover the fascinating world of science. They are offered the chance to conduct their own experiments in a real research laboratory and learn about natural sciences, technology, and research.

- The German-Swedish **REXUS/BEXUS programme**[29], active since 2007, is a collaboration between the German Space Agency (DLR) and the Swedish National Space Agency (SNSA). Over 3000 European university students (2024 status) have conducted scientific and technological experiments on research rockets and balloons. Alumni highlight its effectiveness in motivating careers in space-related professions, often describing REXUS/BEXUS as a "springboard" for their careers in the space industry.

- NASA's **CubeSat Launch Initiative** (CSLI) and ESA's **Fly Your Satellite** programme (FYS) provide opportunities for students to participate in cubesat initiatives.

[28] www.dlr.de/de/schoollab

[29] rexusbexus.net

- Since 2011, JAXA has engaged students in space experiments through initiatives like **Asian Try Zero G**[30] and the **Kibo Robot Programming Challenge**[31] (Kibo-RPC). The 2023 Asian Try Zero G event received 570 proposals with 16 chosen for execution by astronaut Satoshi Furukawa on the ISS. The Kibo-RPC tasks students with programming free-flying robots on the ISS. In the 2023 challenge, 1685 students from 12 countries participated, inspiring them to pursue educational and professional aspirations in space science and technology.

- As humankind pushes the boundaries of space exploration, including and empowering the next generation of leaders and innovators is crucial. In 2022, the Portuguese Space Agency (PTS) launched the **Astronaut for a Day** initiative, offering Portuguese students between the ages of 14 and 18 the opportunity to fly in weightlessness. The competition, which is now in its third edition with a total of 90 students, has been replicated by the Luxembourg Space Agency (LSA). In 2023, the LSA elected 35 Astronauts for a Day to fly in weightlessness and become space ambassadors within their school community.

Improved public attitudes toward science, research, and global cooperation

With advancements in cutting-edge technology, expanding global cooperation and greater access to resources, more and more space agencies and countries can engage in space exploration. The inclusion of large and small agencies encourages humankind to confront challenging obstacles together.

Over the last decade, numerous emerging and established agencies have continued to push the boundaries of space exploration, achieving inspiring “firsts” that have not only garnered public support and national pride, but have influenced society to cooperate globally to achieve the impossible.

The expansion of capabilities and access to education and opportunities have also promoted greater diversity in the space community. Diversity of thought, background and identity have allowed agencies to connect with broader audiences and encourage greater participation from a variety of different communities. Workforce diversity still is a core value for many space agencies and contributes to employee satisfaction and retention.

- The **Hayabusa2** team conducted extensive outreach, engaging a global audience and garnering enthusiastic support for space exploration. With over 120 000 visitors to the capsule and sample exhibition and 330 000 followers across three official X accounts by April 2022, the mission serves as a beacon for inspiring societal interest in space exploration.

- In 2024, JAXA's **Smart Lander for Investigating Moon** (SLIM) achieved Japan's first Moon landing despite encountering engine trouble during the final touchdown phase. Although the lander toppled, making the solar panel deployment difficult, it demonstrated precision landing capabilities. The mission's small rover, SORA-Q, captured remarkable landing images while fulfilling scientific objectives. SLIM's resilience in overcoming challenges and surviving freezing lunar nights, despite not being designed for such conditions, has captivated and inspired people around the world.

[30] humans-in-space.jaxa.jp/en/biz-lab/kuoa/tryzerog

[31] jaxa.krpc.jp

- Following the successful launch and lunar landing of **Chandrayaan-3** mission, ISRO is planning a lunar sample return mission in the late 2020s, the Chanrayaan-4 mission. The success of the Chandrayaan-3 mission spurred a sense of national pride both in India and throughout the Indian diasporas around the world. Following the mission, India announced plans to further expand its human spaceflight programme, announcing plans to put Indian astronauts on the Moon by 2040.

- In August 2022, Korea Aerospace Research Institute (KARI) launched its first lunar orbiter, the **Korean Pathfinder Lunar Orbiter** (KPLO). Its science payload and ground control infrastructure are technology demonstrators. It surveys lunar resources such as water ice, uranium, helium-3, silicon, and aluminium, and produces a topographic map to help select future lunar landing sites.

- In March 2023, **UAE astronaut Sultan Al Neyadi** became the first Arab astronaut to participate in a six-month mission on the ISS. He conducted numerous science experiments and educational outreach activities and became the first Arab to perform a spacewalk.

- NASA's **Artemis II and III missions** are the first of their kind, sending the first woman and person of colour to the Moon, as well as the first non-US astronaut, astronaut Jeremy Hansen from Canada.

Greater accessibility and representation of space exploration in education and media have significant cultural impacts across society. Social media, online resources and outreach activities make it possible for the public to engage directly with space-related entities. Many space agencies or space-related entities maintain social media accounts that give viewers an inside look at ongoing missions, operations, or experiments. Agencies offer opportunities to engage directly with astronauts, scientists, and engineers through online sessions or in-person meet and greets.

The inclusion and visibility of space exploration in other disciplines, such as art, film, and photography, have further aided in inspiring society and increasing public support.

- Companies Felix & Paul Studios, and TIME Studios worked with NASA to develop **"Space Explorers: The ISS Experience"** [32], an immersive cinematic experience using footage captured by astronauts onboard the ISS with specialised made-for-space virtual reality cameras. Following the success of the Space Explorers franchise, Felix & Paul Studios aims to leverage its technology and expertise by landing the first virtual reality camera on the Moon to capture high quality visual content for a new series. CSA provided the company with an investment to further develop this camera technology for lunar use.

- In order to engage the film and art community in space exploration, some space agencies organise competitions like ESA's **New Worlds Film Competition**[33] (2021–2022), and NASA's **CineSpace,**[34] a collaboration with the Houston Cinema Arts Society (HCAS). Filmmakers are invited to create short films inspired by space themes, fostering creativity and public interest in space exploration. These collaborations give artists a platform and offer space agencies a way to connect with wider audiences.

[32] www.felixandpaul.com/?spaceexplorers

[33] newworlds.esa.int

[34] www.cinespace.org

Science benefits | Global cooperation benefits | Inspirational and societal benefits | Space exploration ecosystem benefits

Aiming high

ESA astronaut **Luca Parmitano** during a spacewalk to upgrade the Alpha Magnetic Spectrometer's (AMS) thermal pump system, in December 2019.

ESA/NASA

The beauty of cultural diversity

The unique representation of the Moon and Mars, employing a light-yellow hue and red instead of the conventional grey and orange used in many other countries, is the manifestation of Japan's distinct cultural and artistic perspectives.

JAXA's International Space Exploration logo symbolises the guidepost of the humankind. The three lines flowing like large rivers, connecting Earth, Moon and Mars represent the exploration roadmap, the origin of water and life, and JAXA's fundamental principles. The folding fan shape symbolises expansion in Japan, while the children cuddling and looking up at the sky represent our dream and hope that space exploration will bring a bright future for humankind in outer space.

Economic benefits

Space exploration ecosystem benefits

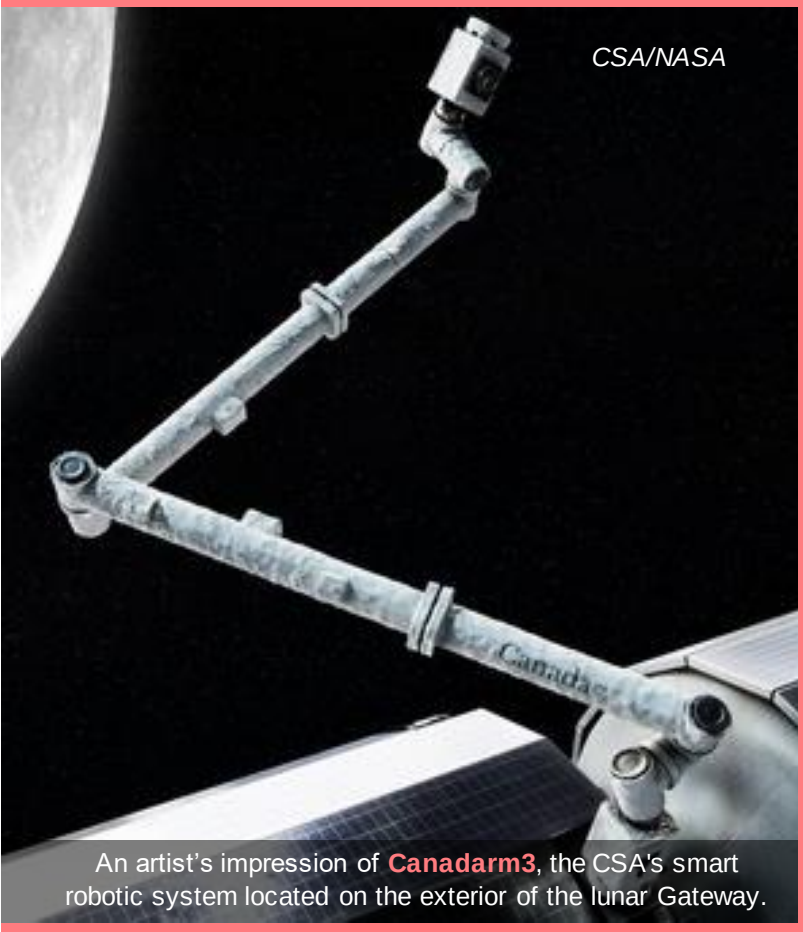
Raptor force

All the Super Heavy booster's 33 Raptor engines power **Starship** toward a successful integrated flight test on 14 March 2024.

SpaceX

Space exploration ecosystem benefits

- **Development of enabling capabilities**
- **Ensuring resiliency among space exploration actors and ecosystem**



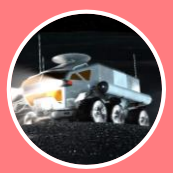
An artist's impression of **Canadarm3**, the CSA's smart robotic system located on the exterior of the lunar Gateway.

Artist's impression of the JAXA's **Crewed Pressurised Rover**.

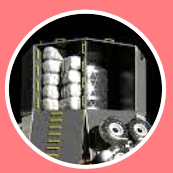
What's needed

Boots on the moon → Exploration and mobility → Mars forward, habitation, and ISRU


Unpressurised rover


Multi Pressurised rovers


Utility rover


Logistics


Habitation


Astronauts & EVA suits


Crewed landing & ascent system


Medium-class cargo lander


Science payloads


ISRU plant


Communications relay


Surface terminal


Fission power


Power element

Space exploration missions are inherently complex, require a significant amount of time from conception to implementation, and are often carried out in cooperation between different space agencies. Emerging space agencies can contribute to larger exploration missions by providing key technologies.

Development of enabling capabilities

The development of key enabling technologies can be transversal to different types of space missions. These technologies can enable not just a specific exploration mission, but also future missions in other areas for instance, Earth observation or telecommunications. New technologies also require various preparatory activities, from the development of key enabling technologies to the development of cooperation agreements and feasibility study activities of the possible contributions of individual partners, as well as mission architectures.

The new **Axiom Extravehicular Mobility Unit** (AxEMU) spacesuit will provide astronauts advanced capabilities for space exploration while providing NASA with commercially developed systems for living and working around and on the Moon. The advanced spacesuits ensure astronauts are equipped with high-performing, robust equipment and are designed to accommodate a wide range of crew members.

Specialisation in niche areas of enabling capabilities is a way for smaller and emerging space agencies to make meaningful and valuable contributions to the broader exploration landscape. By doing so, their national industry cultivates expertise, earn credibility, and position themselves for future collaborations and roles.

In 2016, the Luxembourg Space Agency (LSA) launched the **SpaceResources.lu** initiative, which aims to position Luxembourg as a pioneer in the peaceful exploration and sustainable utilisation of space resources for the benefit of humankind. Luxembourg has a long history at the forefront of the commercial satellite communications industry, which started more recently participating in the space exploration landscape. By implementing a strategy to address the technical, regulatory, financial, and business challenges of space resources utilisation, Luxembourg is aiming to remove barriers to commercialisation and to position and prepare its national industry to be a key player in In-Situ Resources Utilisation (ISRU) on the Moon and Mars.

Canadarm is Canada’s most famous technological achievement in the field of robotics. This robotic arm supported US space shuttle missions for 30 years and allowed the Canadian industry to develop niche expertise and technology in space robotics that continues to yield results decades later. It positioned Canada to play roles in the subsequent chapters of space exploration through Canadarm2 on ISS, Canadarm3 on Gateway, and potential Canadarm3 technology on future stations in LEO.

The ISS plays an important role in future exploration efforts. It is not only a giant space laboratory, but also a testbed for enabling capabilities, such as life support systems, in-space food production, and deep space habitats.

The **Joint EVA and Human Surface Mobility Test Team** (JETT) is an interdisciplinary team that develops, integrates, and executes human-in-the-loop tests and analog missions to prepare for lunar surface operations. JETT has conducted various studies including field hardware preparation, testing in a lunar-like terrain, and a fully integrated Artemis III mission consisting of simulated moonwalks. This technology enables lunar surface mission goals and development of operationally effective systems.

Ensuring resiliency among space exploration actors and ecosystem

Involving large, small, and emerging space agencies facilitates the emergence of innovative mission types, fostering diversity in space exploration initiatives.The benefits realised while preparing for exploration extend beyond individual space agencies, institutions, academia, and companies. These benefits enhance the chances of participating in international space missions and contribute to the overall growth and diversification of the global space community. The increase in the number of space agencies involved in global space exploration stimulates national and international industries and academic institutions, fostering increased global participation and collaboration. Commercialisation of space exploration also facilitates participation and engagement from new organisations and countries. The preparatory activities for the return of humans to the Moon create opportunities for new actors to participate in a robust lunar economy.

In collaboration with the Japanese automotive industry, JAXA is now conducting research and development for a **Crewed Pressurised Rover**. The rover provides long-range traverse and broad surface exploration capabilities for robotic and crewed missions, and it is expected to play a major role for sustainable lunar exploration.

JAXA's **Space Exploration Innovation Hub Center**[35] was founded in 2015 as a catalyst to bring new industrial and academic players into the space sector. It aims to benefit space exploration and terrestrial business applications by jointly addressing common technical barriers between space and Earth through research and development. As of 2023, it has received more than 1100 technical proposals that could potentially solve exploration challenges, and over 150 joint research projects have emerged. More than 230 entities have participated, and remarkably, 90% of them were from the non-space sector, spanning industries such as construction, health care, energy, materials, chemistry and more, all of which are necessary for sustainable activities in space and could improve sustainable development on Earth.

CSA's **Lunar Exploration Accelerator Program** (LEAP) aims to position the country for significant roles in the long-term exploration of the Moon. By providing varied opportunities for Canadian science and technology activities on and around the Moon, LEAP facilitated collaboration among over 50 Canadian organisations across various sectors, fostering innovation in areas of domestic strength such as artificial intelligence, robotics, science, and health, supporting the commercialisation of ideas from small and medium enterprises.

Numerous space agencies and private companies are leveraging the **challenge prize mechanism** to increase the number of solutions in a particular problem area where few existed prior and to introduce new actors from the terrestrial sector to the space sector. Easily identified examples with similarities are remote healthcare, in-situ resource utilisation, automatic and autonomous exploration technology, and food production.

In 2007, Google launched the competition **Google Lunar X Prize** for private entities to launch, land, and move on the surface of the Moon a robot that would send photos and data back to Earth. Of the 30 teams originally registered, only 5 managed to book the launch by the deadline, but none managed to launch. Although the competition ended in 2018 without a winner, it is considered as having been instrumental in creating an ecosystem of companies with innovative commercial solutions to reach the lunar surface. Even after the competition ended, several teams continued to work on their solutions, which were the precursors to several commercial missions to the Moon that have already launched or are planning to launch, either through independent funding or through NASA's CLPS program.

[35] www.ihub-tansa.jaxa.jp/english

Economic benefits

Inspirational and societal benefits

Space exploration ecosystem benefits

Advancing astronaut mobility

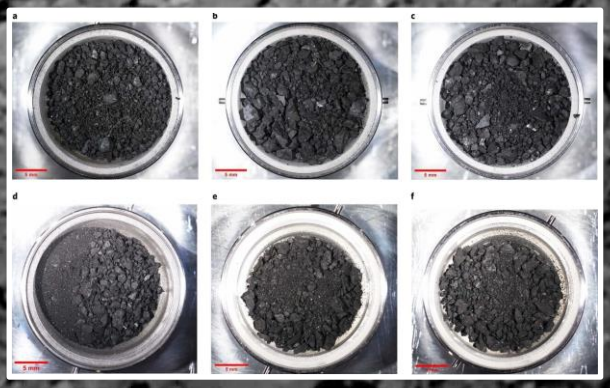
An Axiom Space engineer wearing the **AxEMU** (Axiom Extravehicular Mobility Unit) spacesuit kneels to collect simulated lunar samples using a scoop during testing at NASA's Johnson Space Center. Presented in March 2023, the final version will be worn for the first time by Artemis III astronauts on the Moon's surface.

Axiom Space

Science benefits

Inspirational and societal benefits

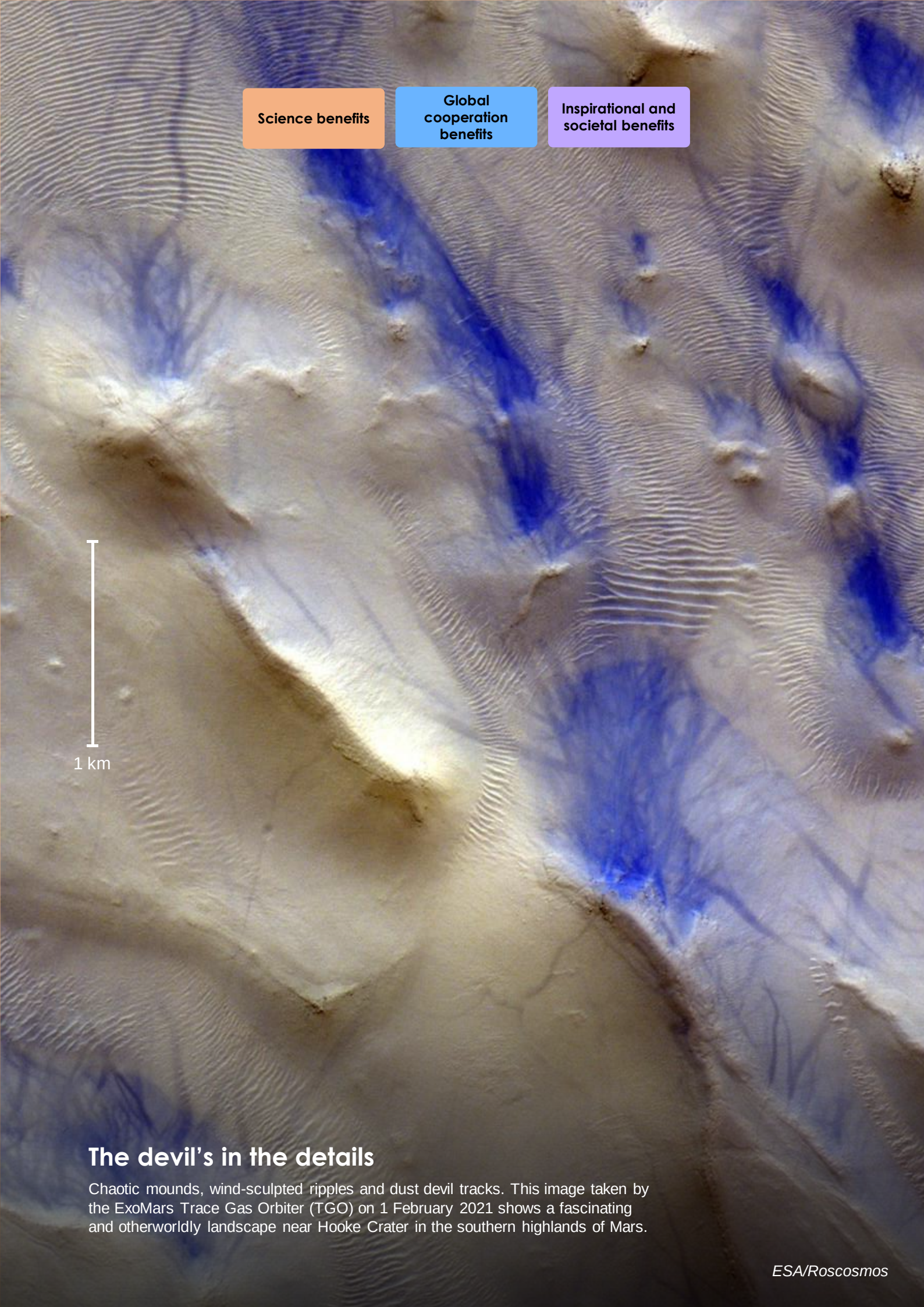
Space exploration ecosystem benefits



Asteroid explorer

The shadow of JAXA's **Hayabusa2** spacecraft cast over the asteroid Ryugu in 2018. It surveyed the asteroid for a year and a half and returned samples to Earth on December 2020.

JAXA

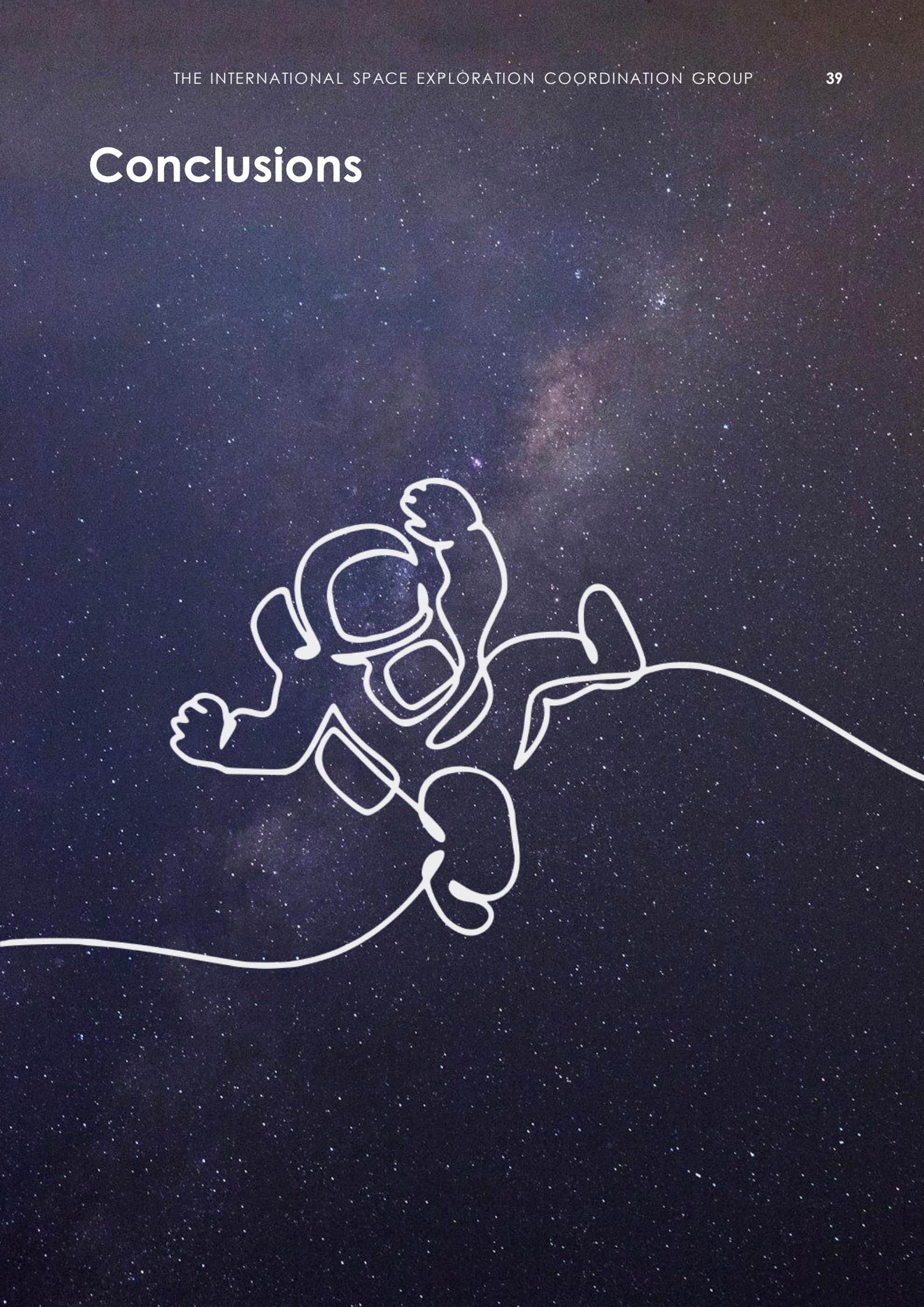


The devil's in the details

Chaotic mounds, wind-sculpted ripples and dust devil tracks. This image taken by the ExoMars Trace Gas Orbiter (TGO) on 1 February 2021 shows a fascinating and otherworldly landscape near Hooke Crater in the southern highlands of Mars.

ESA/Roscosmos

Conclusions



Space exploration stands as a beacon of human endeavour, transcending geopolitical boundaries to unveil a wide spectrum of benefits. Missions to low Earth orbit, the Moon, and Mars, drive innovation, economic growth, and societal progress. Discussions about cost-benefit ratios and mission risks in international cooperation contexts have increased significantly. Effective and transparent communication of the benefits stemming from space explorations is crucial to secure funding and public support.

On cross-cutting themes. Public-private cooperation drives innovation and inclusivity. Partnerships aim to address global challenges, inspire future generations, and drive sustainable development. Small and emerging space agencies play a crucial role by diversifying the space community and expanding the involvement of academia and research organisations. Different commercialisation strategies seek to diversify funding and foster private sector involvement, opening new markets within the space industry.

On science benefits. Space exploration drives scientific progress, yielding technological breakthroughs with wide-ranging impacts. Low-gravity research platforms provide unique environments for studying space conditions, while analogue initiatives simulate extreme environments for human adaptation research. Collaborative efforts enable scientists worldwide to contribute to ground-breaking research, leading to medical advancements and deepening our understanding of the Solar System's origins. These endeavours highlight the symbiotic relationship between exploration and knowledge advancement, offering transformative discoveries with profound implications for humankind.

On economic benefits. Space exploration fuels economic growth through job creation and supply chain stimulation. Space technologies spur business innovation, leading to commercial spin-offs that benefit industries on Earth. Initiatives position countries as leaders in space exploration, while partnerships between space agencies and private companies enable commercial exploration services, opening new markets and exploration opportunities.

On global cooperation benefits. Space exploration thrives on global cooperation, uniting nations to achieve ambitious missions and address pressing global challenges. Collaborative endeavours foster scientific collaboration despite operational hurdles. Initiatives showcase how international partnerships drive major advancements in space exploration, enabling newcomers to rapidly become significant players. Cooperative efforts in space exploration yield terrestrial benefits, addressing societal and environmental challenges. Exploration programmes and initiatives facilitate global cooperation while promoting sustainable development and innovation. Living and working in space presents similar challenges to those on Earth. Space exploration can offer solutions for global terrestrial issues.

On inspirational and societal benefits. Through educational programmes and hands-on STEM activities, space agencies engage young minds, fostering a diverse and skilled workforce for the future. Increasing representation in and accessibility of media and cultural spheres amplify public support and engagement, while collaborative efforts push the boundaries of exploration and innovation. Exploration endeavours leave a lasting legacy of inspiration, cooperation, and advancement for generations to come.

On space exploration ecosystem benefits. Space exploration demands intricate preparation and cooperation among multiple space agencies. Developing enabling technologies and leveraging space infrastructure are crucial for future missions. Engaging diverse agencies fosters innovation and strengthens the entire space community. Commercialisation efforts open new opportunities, while initiatives showcase international cooperation and innovation. Challenge prizes drive solutions in key areas, drawing expertise from various industries to advance space exploration.

The world’s space agencies have many and different exploration goals, but they share common drivers: expanding human presence in the Solar System, enabling the study of the origin and evolution of Earth, the Moon, Mars, and the cosmic neighbourhood, and understanding our place in the Universe.

The realisation and communication of the benefits formally identified by ISECG aligns with the goals and objectives of the ISECG **Global Exploration Roadmap**[36] (GER).

[36] www.globalspaceexploration.org/wp-content/isecg/GER2024.pdf

Global cooperation benefits

Inspirational and societal benefits

The woolly specialist aboard Artemis I

After his successful mission around the Moon and *baaa-ck*, already part of space history, **Shaun the Sheep** was in the public eye for his post-flight tour. No sheep has ever travelled so far.

ESA/Aardman

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