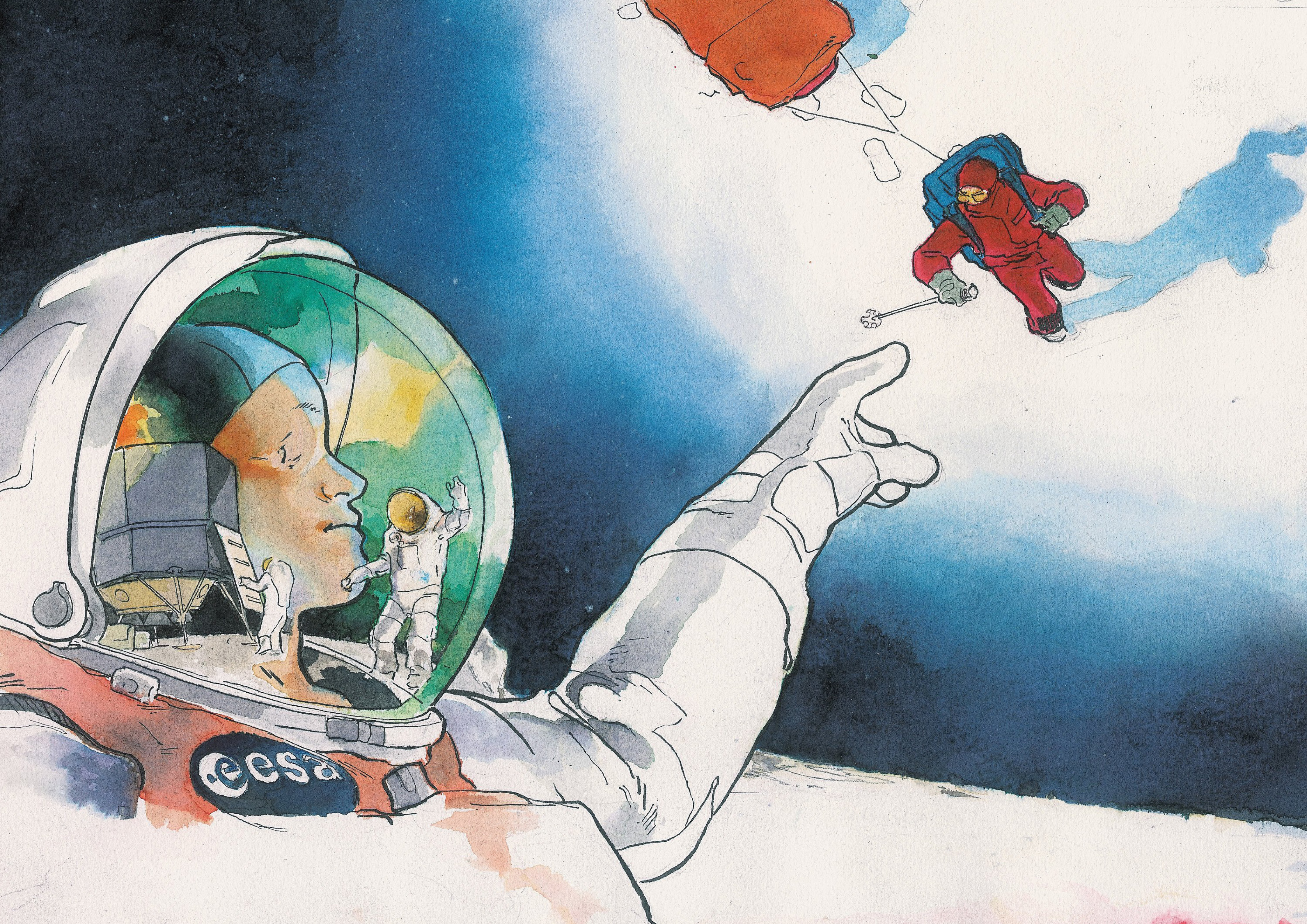
EXPLORE 2040

THE EUROPEAN EXPLORATION STRATEGY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FOREWORD

Space exploration is accelerating faster than ever across the globe, as both traditional and new actors pursue far-reaching plans driven by political agendas.

In this context I am delighted to introduce ESA's Explore2040, which is a refined European exploration strategy for which ESA Member States take ownership in response to the Seville 2023 Space Summit Resolution.

At the core of the strategy is a bold vision to establish continuous, sustainable, and responsible human and robotic exploration of the Solar System by providing unique contributions and benefiting society. It ensures that Europe will not lag behind when others accelerate.

Space exploration is unquestionably an investment in our future prosperity. It creates high quality jobs and produces immediate economic benefits. Exploration science and technology boosts innovation and makes industry more competitive. Space exploration is inherently exciting for all, inspiring and motivating for the younger generations.

Explore2040 firmly asserts science, the economy, cooperation, and inspiration as primary strategic drivers for Europe's continued exploration efforts. The refined strategy puts exploration into a wider perspective, serving ESA's 2040 vision and underlying the close links between space transportation, critical space-based infrastructure and related terrestrial applications and science.

In this respect, a targeted service-driven approach, support for commercial initiatives and challenge-based competitions must emerge to result in an even more innovative, competitive and thus cost-efficient implementation, accompanied by a transformation on both the ESA and industry sides.

At the same time, Europe's political posture needs to move to a self-determination and leadership mindset, to strengthen existing cooperation and foster new partnerships. The strategic considerations in this document provide a coherent European exploration path to all stakeholders in Europe as well as send a message to our valued international partners that Europe has a direction of travel.

I am confident that Explore2040 will empower Member States, ESA, and European industry and science communities to achieve this renewed ambition for European human and robotic exploration, beginning with a gradual yet farsighted decision and implementation at the ESA Council meetings at ministerial level in 2025 and 2028, so that ESA and its stakeholders can turn Explore2040 into reality.

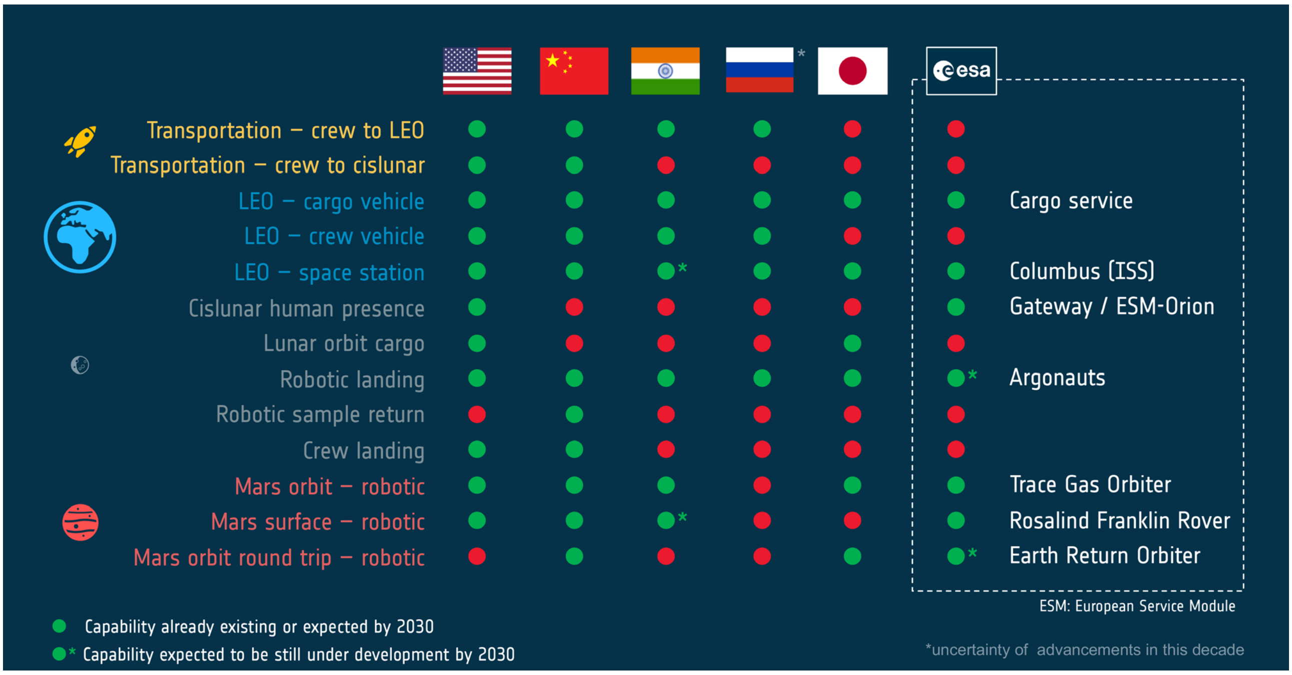
Daniel Neuenschwander
Director Human and Robotic Exploration Programmes
European Space Agency

CONTENT

PREAMBLE

Exploration drivers and benefits. The 2014 European exploration strategy[1] set out in detail the reasons for exploration and these remain the same in this new strategy: namely, science, economics, international cooperation and inspiration. For example, the current programme has 1,600 active scientists from 36 countries, sustains over 15,000 high- quality jobs, contributes €2.8 billion in gross added value to the European economy, and reaches 30,000 teachers and 1.3 million students annually. Numerous success stories are documented[2] on direct and measurable benefits both in fundamental and applied research solving challenges on Earth. Furthermore, the value to the economy of a bold European space exploration programme has recently been assessed[3]. Exploration is more than a mere space programme, providing a plethora of benefits that exceed the immediate contribution of its core activities and spilling over into the wider economy by affecting every aspect of human activities, on Earth and in space.

Europe has a long and rich tradition of human and robotic exploration, including its science dimension. Building on its significant achievements so far, Europe is a highly regarded contributing partner in LEO and is assuming more ambitious roles in international exploration campaigns to the Moon and Mars.



	🇺🇸	🇨🇳	🇮🇳	🇷🇺 *	🇯🇵	esa	
Transportation – crew to LEO	🟢	🟢	🟢	🟢	🔴	🔴	
Transportation – crew to cislunar	🟢	🟢	🔴	🔴	🔴	🔴	
LEO – cargo vehicle	🟢	🟢	🟢	🟢	🟢	🟢	Cargo service
LEO – crew vehicle	🟢	🟢	🟢	🟢	🔴	🔴	
LEO – space station	🟢	🟢	🟢*	🟢	🟢	🟢	Columbus (ISS)
Cislunar human presence	🟢	🔴	🔴	🔴	🔴	🟢	Gateway / ESM-Orion
Lunar orbit cargo	🟢	🔴	🔴	🔴	🟢	🔴	
Robotic landing	🟢	🟢	🟢	🟢	🟢	🟢*	Argonauts
Robotic sample return	🔴	🟢	🔴	🔴	🔴	🔴	
Crew landing	🟢	🟢	🔴	🔴	🔴	🔴	
Mars orbit – robotic	🟢	🟢	🟢	🔴	🟢	🟢	Trace Gas Orbiter
Mars surface – robotic	🟢	🟢	🟢*	🔴	🔴	🟢	Rosalind Franklin Rover
Mars orbit round trip – robotic	🔴	🟢	🔴	🔴	🟢	🟢*	Earth Return Orbiter

ESM: European Service Module

🟢 Capability already existing or expected by 2030

🟢* Capability expected to be still under development by 2030

*uncertainty of advancements in this decade

Figure 1: Expected exploration capabilities by 2030

The geopolitical significance of human exploration is greater now than ever. The international exploration landscape has undergone substantial transformations in the last few years. The US, China and now India are on an exploration uplift trajectory aimed at asserting their leading positions. Russia, Japan and other, new players are, for their part, seeking to follow this trend (see Figure 1). Simultaneously, private space players are increasing their investments and gaining in influence worldwide.

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[1] *https://esamultimedia.esa.int/docs/corporate/Final_resolutions_1_2_3_from_CM_2014_Releasable_to_the_public.pdf*
[2] *http://youbenefit.spaceflight.esa.int/*
[3] *https://www.bcg.com/publications/2023/italy-more-than-a-space-programme*

Embracing leadership ambition. Without new European exploration objectives, corresponding capabilities and the commensurate scientific output, dependencies will increase as the global scene develops in the 2030s. Despite Europe's accomplishments, it will require effort to avoid being left behind by international institutional and private players who are engaged in a remarkable pace of acceleration. The time is ripe to make the political and technology leap towards self-determination based on a vision in which:

> Europe will be at the forefront of sustained, sustainable and responsible human and robotic space exploration by providing unique contributions and returning benefits to society.

This vision adds a new strategic drive to develop a European sovereign attitude and leadership mentality.

Non-dependence within "open cooperation". Learning from the past and anticipating the changes under way, Europe needs to decrease its dependence by choosing a distinctive role within indispensable cooperative exploration initiatives. Becoming a leader in unique areas and remaining a valued partner in others will bring significant additional geopolitical benefits.

Keeping the focus. Space exploration is multifaceted and is a function of cultures and national policies or postures. For Europe, the inherent purpose crystallises around research and discovery while a human presence potentiates the scientific output.

Responsible behaviour.
Coherent, joint, fully coordinated action is essential if Europe is to promote responsible use of outer space in its programme implementation. Only by being at the forefront can Europe shape its own, unique perspective and be part of defining the way humanity continues on its path of exploration.

Captivating the next generation.
Space exploration – due to its inherently inspiring and fascinating nature – will always spur huge efforts to push the technological envelope as well as possessing a cultural, even philosophical dimension capable of captivating and engaging the young generation. It can be used to demonstrate that "space is the place", while infusing an optimistic, can- do attitude within a global endeavour.


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MULTIPLE DESTINATIONS, ONE STRATEGY

Robotic exploration spans as far as technology permits to travel into the Solar System and address scientific questions, implemented through various ESA programmes. The coming decades will see a continued human presence in LEO, a sustained presence on the Moon and eventually – in the foreseeable future – expeditions to Mars. A combination of human and robotic assets will be required to address the many scientific questions and to spark inspiration. It will also foster international ties through technical and scientific cooperation, while bringing economic and societal benefits.

The robustness and resilience of Explore2040 will be ensured thanks to an **end-to-end architecture** within an ESA-wide approach, taking into account Member States strategies and postures, and building on a strong heritage of science and technology in LEO, the Moon, Mars and other Solar System bodies.

Setting clear long-term objectives in a stepwise approach allows for options and choices and makes the ambition affordable and achievable.

The Explore2040 high-level destination goals are to:

Achieve continuity with a sustained European **presence in low Earth orbit** in the interests of science, de-risking deep-space habitation, and unlocking commercial opportunities.

Allow Europeans to **explore the Moon**, to contribute to unveiling the mysteries of the Solar System’s formation and trigger technological innovation in preparing for the human journey to Mars.

Expand **knowledge of the Red Planet** and prepare to take Europeans to this horizon goal and return them safely to Earth and, in so doing, test the limits of science and technology while devising and cementing an approach to international cooperation.

Key to the strategy implementation will be the reinforcement of the existing strong ties with traditional partners, while at the same time building up new cooperation with emerging actors. Careful assessment on which cooperation activity for what goal will guide detailed studies and technology advancements to anticipate in advance priority shifts and seize new opportunities for self-standing capacity building or being part of larger initiatives.

Maximising freedom of action is therefore a priority, especially in an unprecedentedly competitive setting between the US, China, India, or other ISS partners, as well as new institutional and private players. Therefore, the strategy is intended to be resilient over multiple decades by focusing on leadership in selected areas (see Figure 2) with check points to adapt to the inevitable rapidly evolving geopolitical situations and adopt game- changing technological and commercial approaches.

In this context, European uniqueness lies in a **purposeful** human and robotic presence in the Solar System. Europe must foster a science and knowledge-driven thread for exploration as a goal commonly shared with all space faring nations. It endeavours to pursue a **responsible** exploration through being non-confrontational, promoting planetary protection, being accountable for local resources utilisation and respecting pristine science opportunities, while striving for **sustainability**, for instance by handling waste and observing a zero debris policy. The strategy will be **sustained** in a coherent step-by-step implementation, balanced between all destinations.

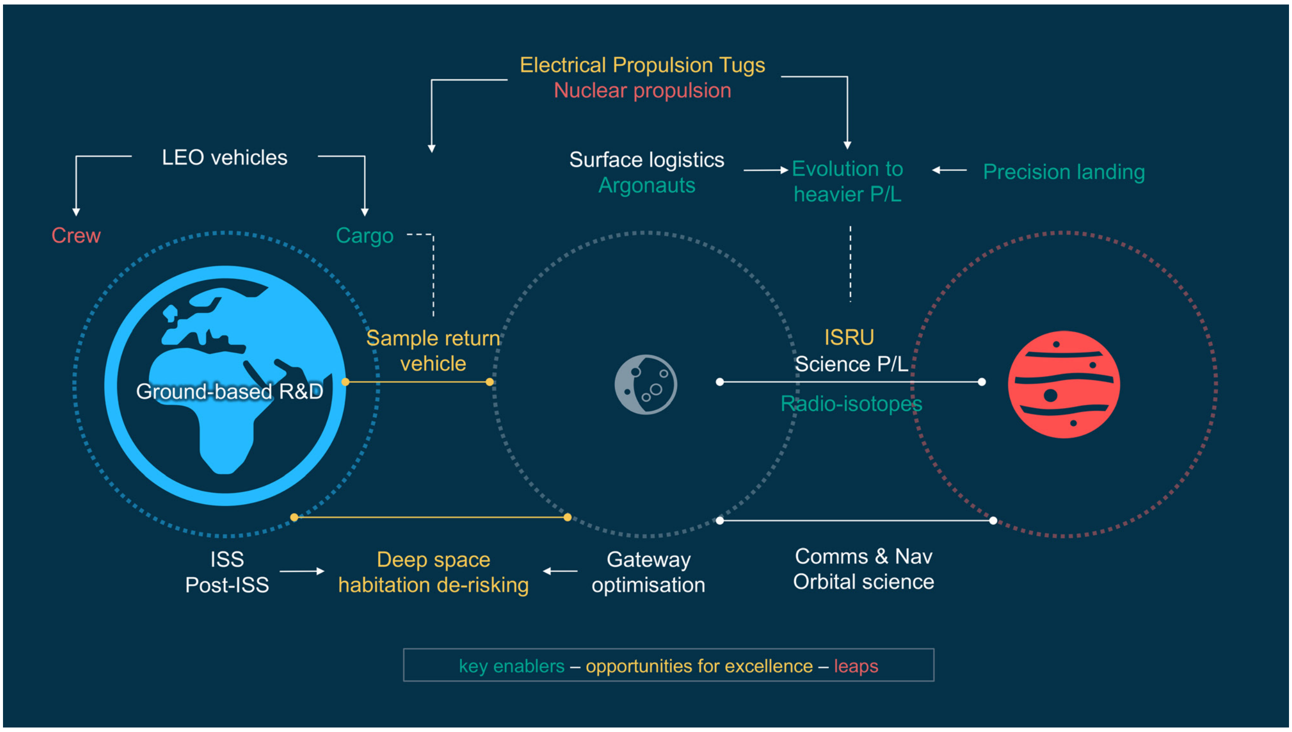


Figure 2: Explore2040 – examples of areas of strategic importance across destinations

Based on heritage activities, and in addition to existing activities, new **"key enablers"** will play the essential role of expanding transportation and surface logistics in order to anticipate the growing level of engagement of partners and leverage the scientific output. In addition, European "opportunities for excellence" within the international exploration scene will be used to disruptively leapfrog instead of copying (see Figure 2 above). For both the "key enablers" and "opportunities for excellence", some functional duplication will be necessary vis-à-vis foreign institutional or private capabilities to create and maintain self-determination and reduce strategic dependencies.

Synergies among the exploration destinations (see Figure 3) and beyond (see last paragraphs of this section) will be built into the exploration architecture and will further optimise scientific results and exploit technological commonalities to increase affordability and resilience. Continued build-up of expertise and anticipation will be crucial as the lead- time for typical full systems development can exceed a decade. The strategy will also leverage the broad European portfolio of ground-based R&D platforms and analogues to prepare the essential elements for the utilisation of LEO, as well as the exploration of the Moon, Mars and beyond.

Additional synergies will be sought beyond the space and exploration domain in the fields of health, mobility, energy, security and advanced aeronautics. Attracting non-space stakeholders will improve efficiency and reciprocal spillovers of Earth-bound societal concerns that connect with the new generation. The emergence of new private actors will be encouraged in a more competitive and cost-effective procurement approach, leveraging faster implementation of projects and promoting new industrial and commercial services.

Explore2040 provides the narrative needed to support political decision makers and inspire European citizens. Exploration is an investment in future prosperity, which generates high- quality jobs and immediate economic returns. Exploration science and technologies are drivers and accelerators for sustainable development and have the unique potential and demonstrated capacity to transform into innovative solutions to make life on Earth cleaner and more productive, creating a circular economy and securing a safe future for humanity and life on our planet.

This growth in ambition should lead to a realistic but sustained increase in financial means – subject to political decision – commensurate with Europe's stance among world-leading players and the growing number of private actors and competitors in space exploration.

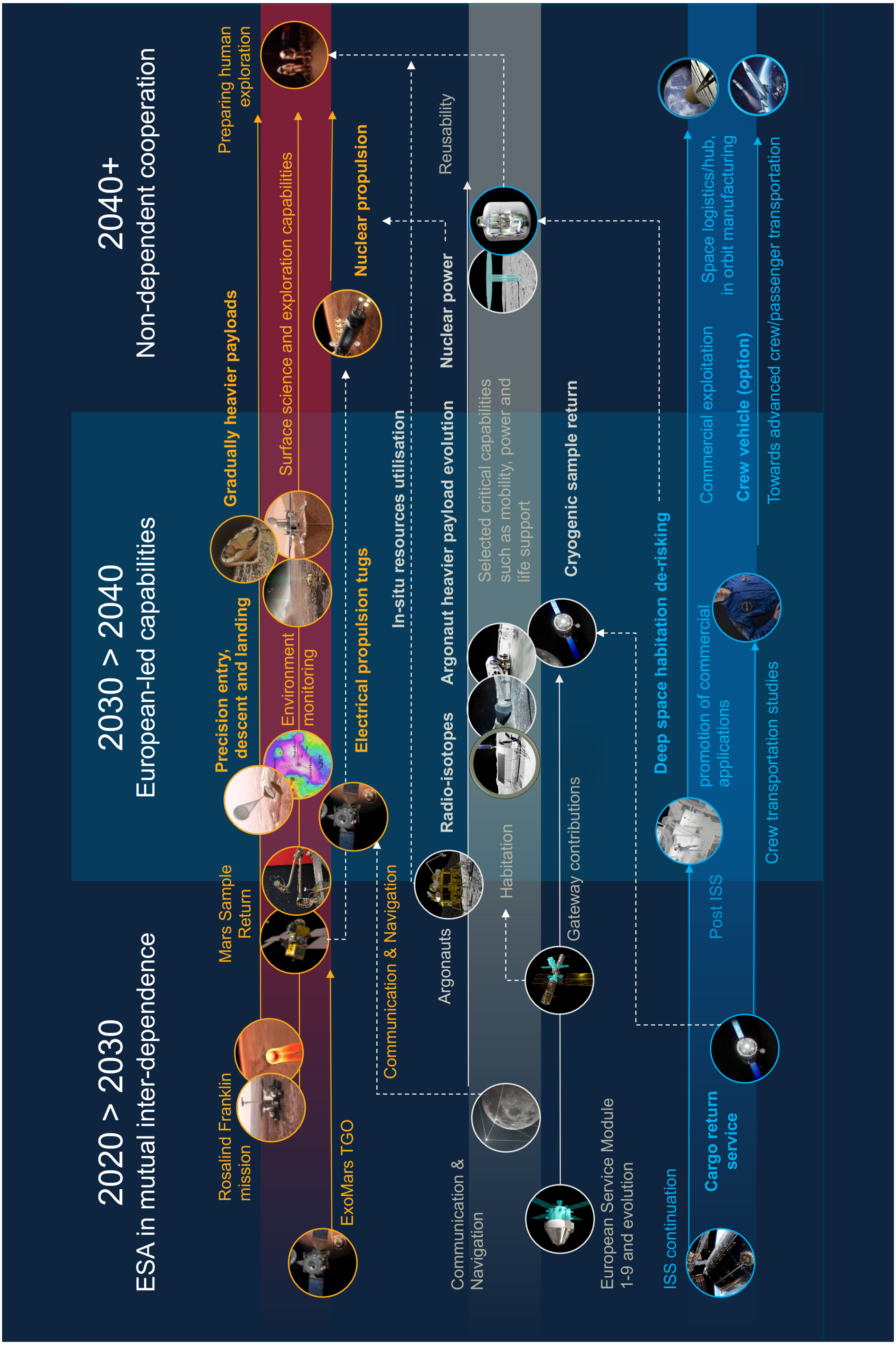


Figure 3: Explore2040 capabilities roadmap and beyond for Terrae Novae with notional timelines

Low Earth orbit

Achieve continuity with a sustained European presence in low Earth orbit in the interests of science, de-risking deep-space habitation, and unlocking commercial opportunities.

A sustained European human presence in LEO is the backbone of ESA's exploration programme (see Figure 4 below). Supported by a robust European Astronaut Corps, it entails a continuous use of the ISS until its decommissioning and preparation to allow a smooth transition to the next-generation infrastructure(s). European firms should be supported, based on past heritage, to participate in private consortiums for the provision of new space stations, to ensure European access while creating value in Europe and European participation in the commercial benefits.

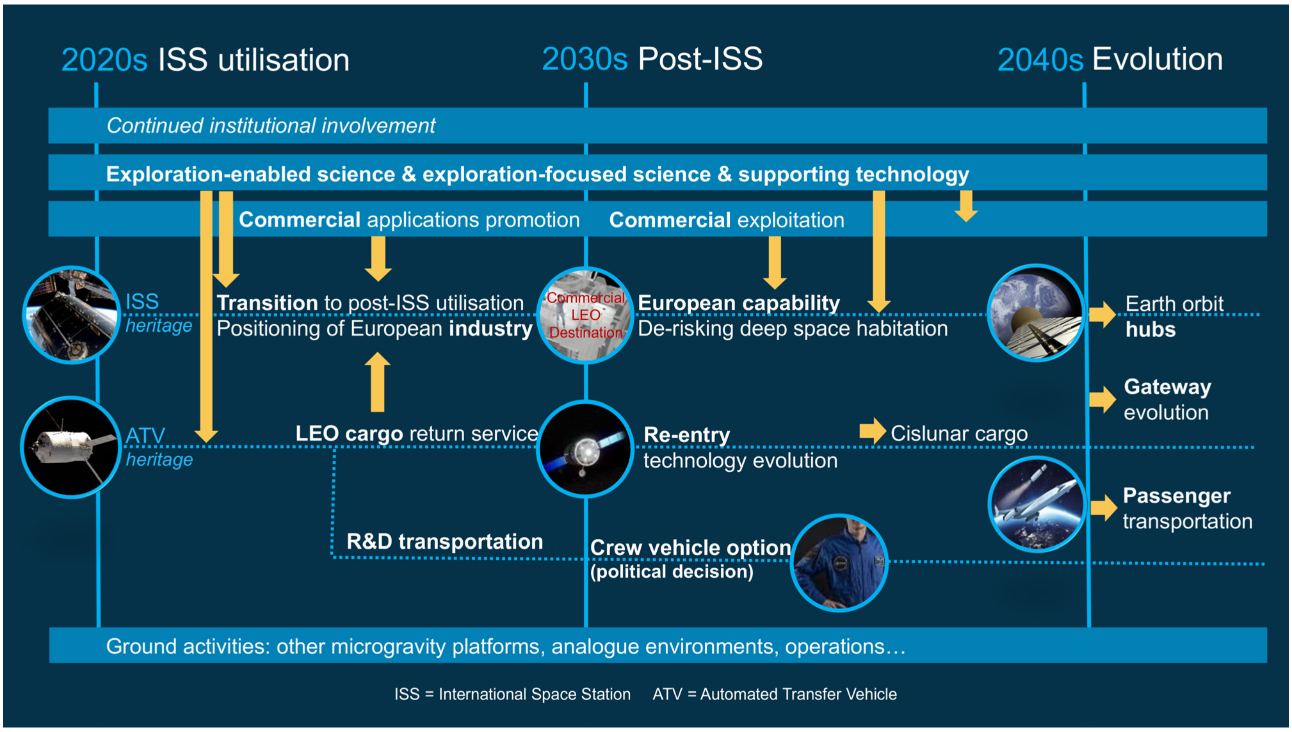
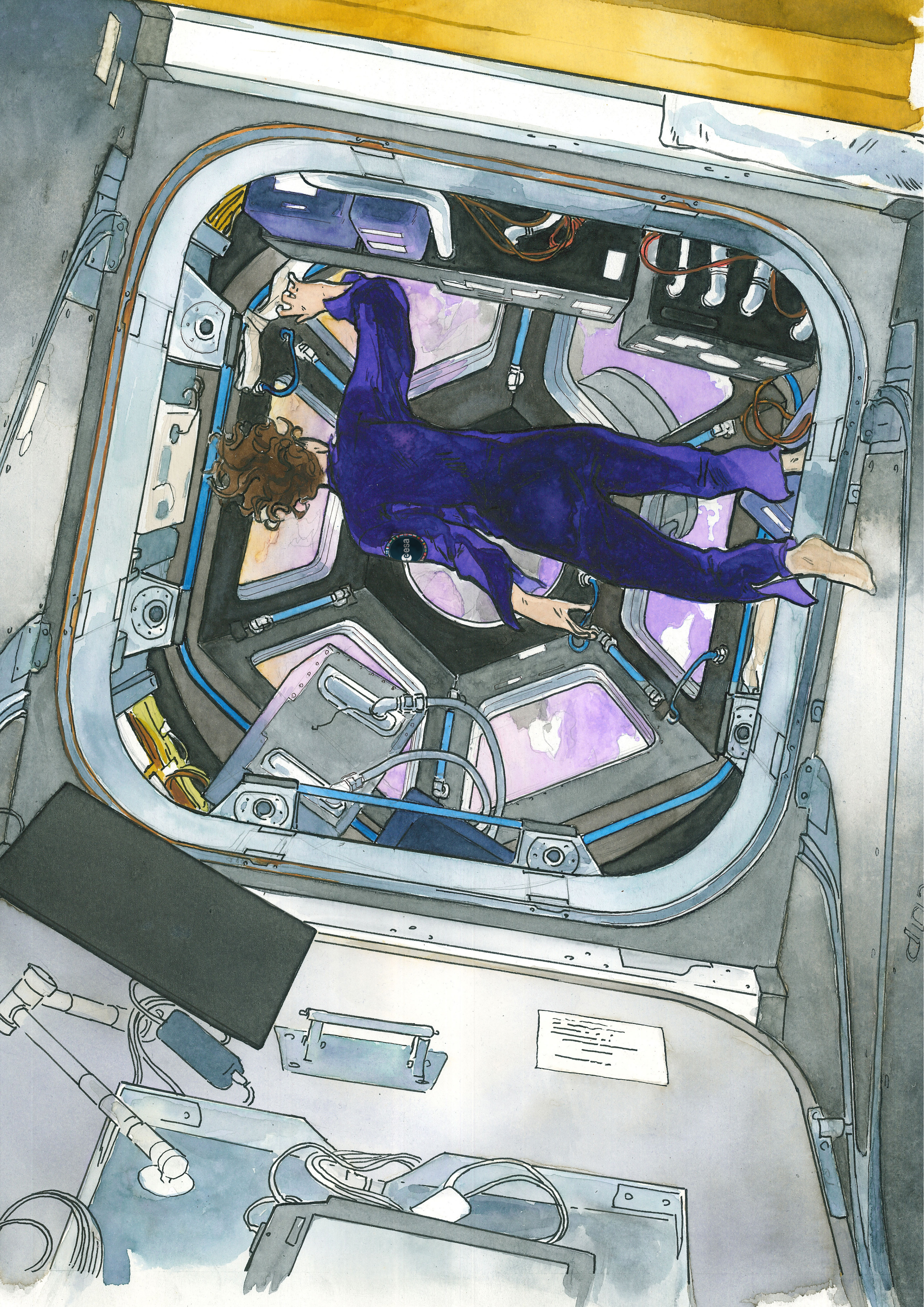


Figure 4: Explore2040 @LEO

Although today exploration is fundamentally driven by institutions, recurring elements should, when possible, be increasingly procured through competitive services. A commercial cargo transportation service is considered the most cost-effective way to establish a low Earth orbit cargo return capability that could be used to offset ESA's needs for scientific utilisation and European astronaut flights in the next decade.



> Transport to and from LEO represents 70% of the total cost of an infrastructure's exploitation.

In addition, it will make it possible to develop European providers in a competitive logistics market. This strategic choice of a cargo service will also secure technology bricks to support a crew vehicle development in a reasonable timeframe, if and when that is decided at the political level.

Europe needs to consider several options to participate in LEO infrastructures by supporting commercial actors and promoting public-private partnerships and service-based solutions as part of an ESA-wide approach. Due to the uncertainties around the viability and nature of such private-led solutions, options must be preserved to achieve institutional strategic objectives and ensure self-determination.

Such institutionally-driven activities are needed to maintain affordability of scientific research and enable the de-risking of an extended human presence in deep space beyond low Earth orbit. The nature of activities centred around extended human space exploration may attract non-space actors for R&D co-funding. Special emphasis will be placed on communicating on these 'win-win' opportunities and widening the user base through attractive measures.

LEO activities as a springboard to, around and on the Moon and Mars

Commercial use of LEO infrastructures driven by the needs of private entities covering end- to-end costs is a longer-term prospect. Therefore, institutional support covering transport, on-orbit infrastructure and crew time will first be needed to stimulate a potential market for a certain period of time. This strategic choice will contribute to a lowering of the barriers for private entities to develop and pursue industrial activities in LEO and so secure European participation in the LEO economy. Such accompanying measures must decrease, for example once the demand from other non-institutional users has increased.

> **Moon**
> Allow Europeans to explore the Moon, to contribute to unveiling the mysteries of the Solar System's formation and trigger technological innovation in preparing for the human journey to Mars

Within NASA's Artemis programme aimed at returning humans to the Moon in a sustained way, Europe seized several opportunities (see Figure 5 below). It provides Service Modules on the critical path of transportation and became a major partner in the cislunar Gateway. The latter will continue to be used for scientific investigations and will possibly be extended to serve as a deep-space habitation testbed. Europe also aims to play a significant role on the Moon's surface, mainly for science. Landing and operating on the surface are prerequisites for substantial research activities. A first step will be the development of the Argonaut lunar lander preferably in a hybrid configuration with applications such as a science platform (including science deployment and mobility) and cargo logistics for human missions that could evolve towards the landing of heavier payloads required for science or within the Artemis architecture, aligned with the Mars surface logistics capabilities in the 2040s.

> Only a significant contribution to a Moon surface architecture will take European astronauts regularly to the Moon's surface to explore its environment and bring benefits back to Earth

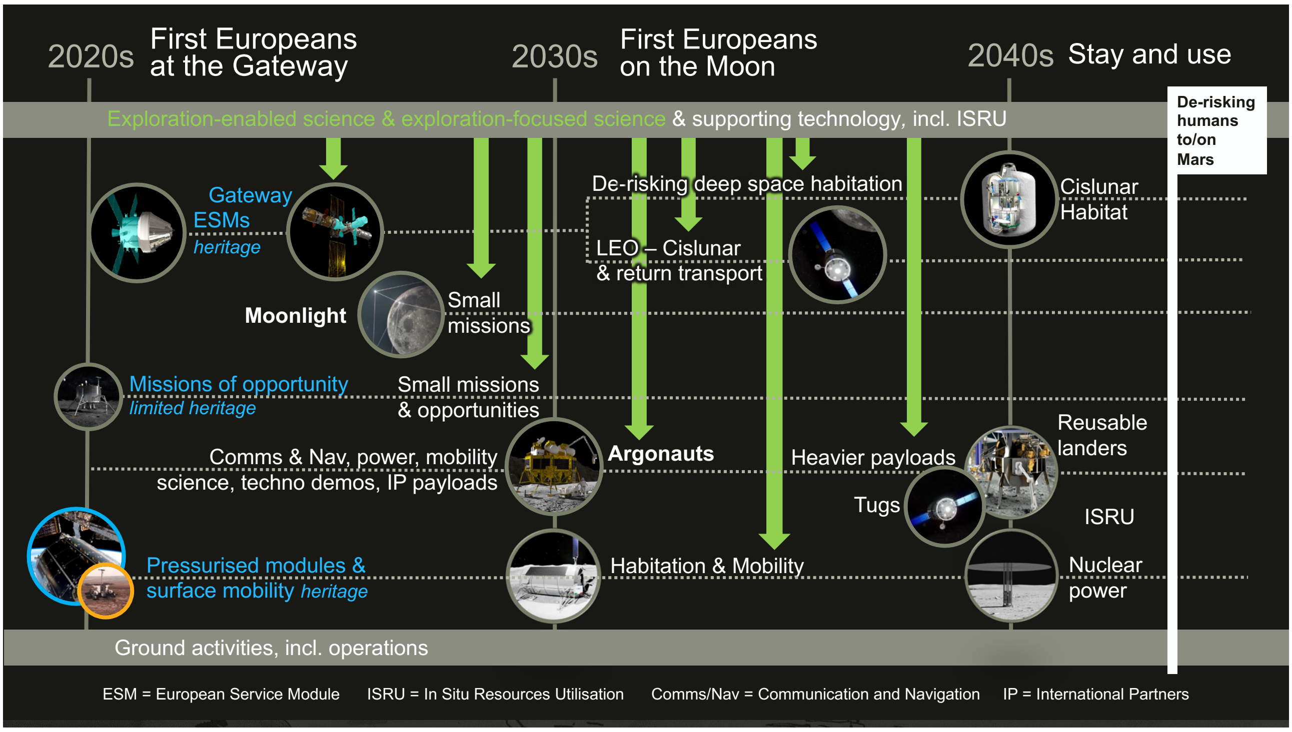


Figure 5: Explore2040 @Moon

Europe needs to step up still further if it is to remain a reliable player in the next phases of using the Moon for science and as a testbed for Mars stays[4] by making focused technological choices.

Contributions to the lunar surface architecture and technology demonstration missions will increase the scientific output and prepare for the next phases of lunar exploration. Habitation, including life support, power systems, medical support systems, mobility, mapping and surface characterisation together with communications and navigation means are critical capabilities for expeditions lasting more than a few days. Longer stays and increased robotic surface mobility will enable wider lunar surface and subsurface characterisation which will help to assess the potential for using lunar resources to support long-term astronauts stays and thus extended lunar exploration, which directly feeds into human exploration of Mars. A responsible and efficient use of local resources, including in-situ waste management and recycling, will be a prominent feature and a differentiating factor of a sustainable exploration by Europe.

More specifically, surface autonomous mobility with sample acquisition and analysis will significantly enhance the in-situ science, prospecting for in-situ resource utilisation (ISRU) and sample return selection. It will also free-up a predicted scarce crew time by fostering collaborative robotics, supported by artificial intelligence (AI). Orion has limited return mass capabilities and a European automated vehicle launched by a European launcher that can fly to and back from the Gateway could constitute a significant contribution to the overall Artemis architecture, with synergies with LEO Earth return vehicles and electric tugs. Resupply of the Gateway, and return capability of lunar surface samples, including cryogenically preserved, biological samples and waste items would be typical payloads for such a cargo.

[4] *The NASA Moon2Mars initiative will use Artemis to prepare the next big leap*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Mars

Expand knowledge of the Red Planet and prepare to take Europeans to this horizon goal and return them safely to Earth and, in so doing, test the limits of science and technology while devising and cementing an approach to international cooperation

The technical challenges posed by robotic and human Mars exploration require a stepwise approach (see Figure 6). An important first step is the Rosalind Franklin mission that will see Europe lead the search for life on the Martian surface – and below. In addition, Europe will fly the Earth Return Orbiter (ERO) using an electric propulsion space tug as part of the Mars Sample Return campaign. This international partnership will return scientifically- selected samples from Mars to Earth. Mars Sample Return represents a very first step on the way to future crewed missions to the Red Planet.

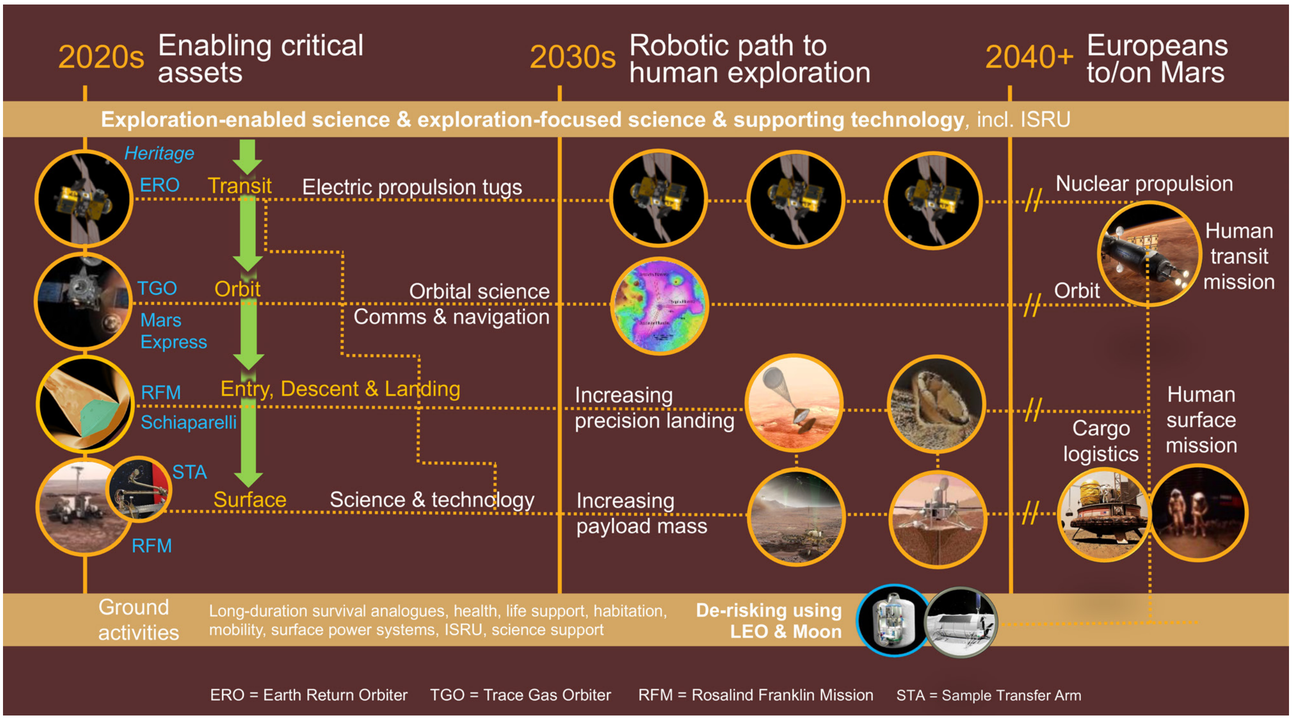


Figure 6: Explore2040 @Mars

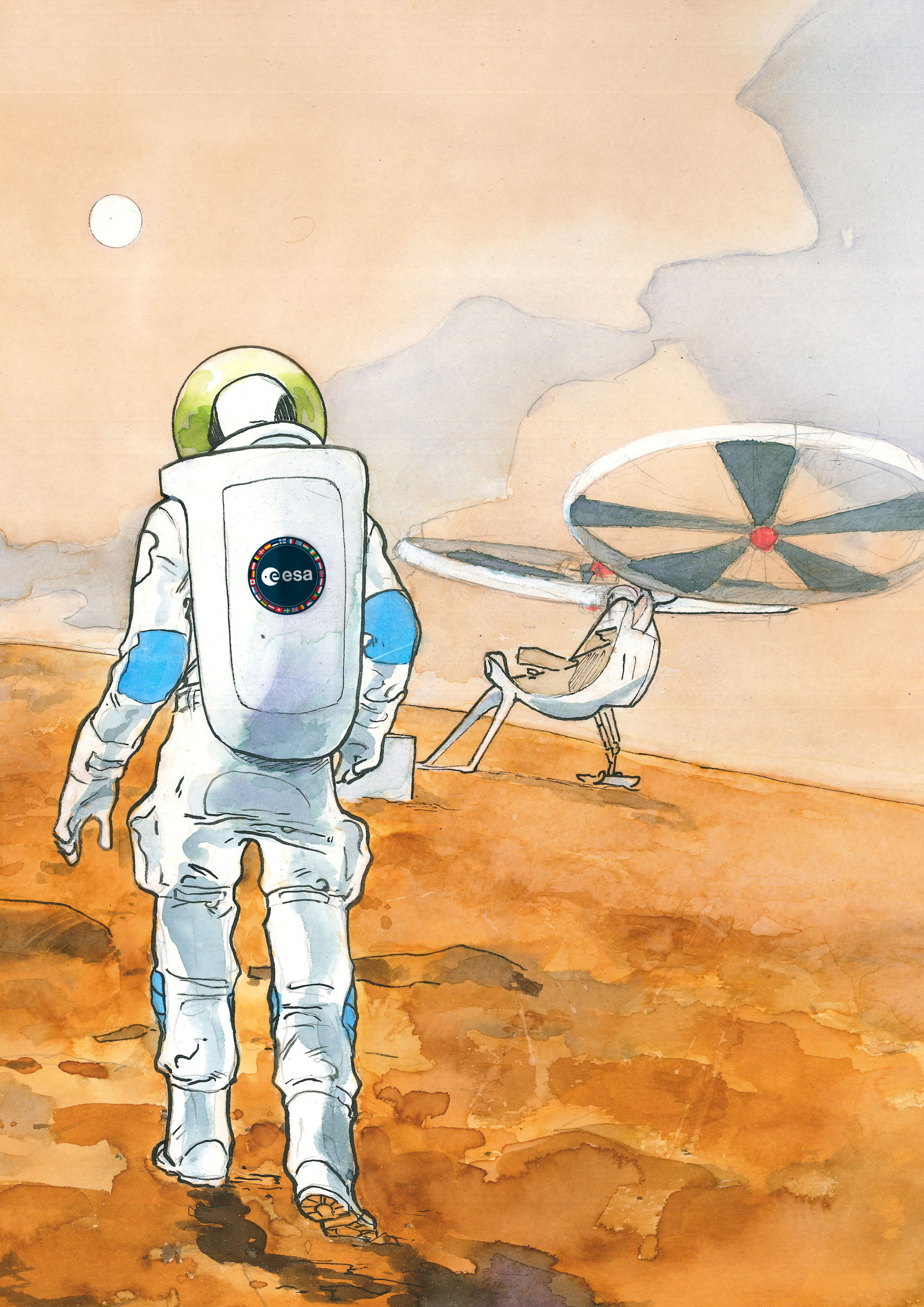
The Martian surface is extremely varied and requires precise landing to optimise the science output

For surface missions, the next steps will focus on building key strategic capabilities for Entry, Descent and Landing (EDL) of payloads with increasingly higher precision and mass. This evolution will enable breakthrough subsurface, surface, atmospheric, and climate science, and will support fundamental technology developments for ISRU and human safety. Eventually, more advanced EDL will deliver heavy logistics landing, including power, habitation, and mobility, as will be required to establish a human presence on the surface of the Red Planet.

Around Mars, orbital precursor missions will carry scientific payloads to identify the most interesting scientific areas and help bring about safe precision landing due to a better environmental knowledge through understanding the Martian atmosphere and terrain. The addition of orbital communications and navigation systems in the early orbital missions, building on European heritage in LEO and around the Moon and Mars, will significantly improve the reach and capability of successive missions.

Mission concepts studies for major opportunities in the next decade (with 2033 and 2035 set to provide favourable orbital oppositions) will prioritise scientific investigations and technology demonstrations. Concepts for furthermore ambitious missions will guide long- lead-time critical technology studies.

For orbital and surface missions, the next-generation electric propulsion space tugs, with the potential to evolve towards nuclear propulsion, will help lower the costs, leading to more frequent missions carrying ever larger payloads between Mars, the Moon and Earth.



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The first human landing mission, needing multiple large landings, will most probably only materialise in the late 2040s. Such a timeline is aligned with the robotic preparatory demonstration missions of gradually heavier payloads. However, a human round trip may happen independently before that first landing. Complementary ground- based analogue facilities will be a cost-efficient way to address all aspects of long-term habitation, isolation and confinement. Additionally, they will serve to optimise the development of flight systems to be tested in low Earth orbit, then the Lunar Gateway, and subsequently to develop habitation infrastructures for the round-trip, including orbital presence, on human missions.

Synergies with other robotic exploration destinations

Create efficient synergies with other exploration-related activities, such as the science- driven missions to other Solar System bodies as well as space safety, space weather, and spacecraft operations

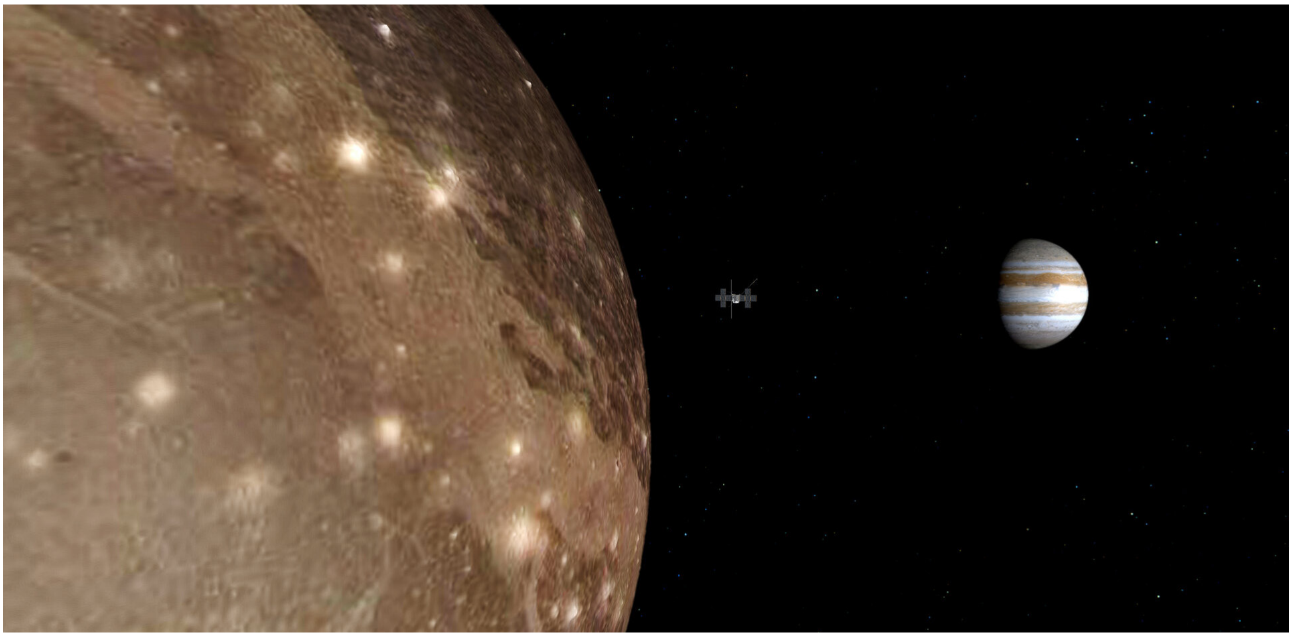
Exploration shares many destinations in the Solar System with the missions of the Science Programme. Mars Express is an example of a scientific mission that has led to breakthrough science, while at the same time providing precious knowledge needed for future human exploration of Mars.

Beyond LEO, the Moon and Mars, other destinations such as asteroids, comets and the moons of the giant planets are subjects of great human curiosity[5].

Comet Interceptor, the first Fast mission in the Science Programme planned for launch in 2029, aims to perform multi- point/ multi-spacecraft analyses and observations of a pristine comet. The knowledge needed for and derived from such missions, including technological capabilities, greatly complement the knowledge and capabilities needed to explore the main Terrae Novae destinations. An implementation roadmap will be issued as a follow-up to the Explore2040 strategy that will outline these synergies.

ESA's Voyage2050 long-term plan includes three scientific themes for "Large" (flagship) missions beyond 2035[6]. The first of these themes is the study of the "Moons of Giant Planets". Also significant are the technologies of common interest with human and robotic exploration, notably electric propulsion (solar-powered or eventually nuclear-powered), landers and possibly local mobility (rovers, drones, etc.) for an in-situ element to characterise the local surface and subsurface environments, as well as to handle, select and transport samples stored at cryogenic temperatures. Terrestrial laboratories will be required to receive and curate the samples.

Another area of commonalities relates to space safety and space weather, in particular missions and activities to understand hazards originating in space and protect Europe's critical space and ground infrastructure, including near Earth objects deflection capabilities. Related advanced sensors and optical technologies, active debris removal capabilities, AI- enabled automated operations, matured Cislunar Space Traffic Management technology, and in-orbit production and recycling capabilities are all relevant technologies, and will potentially provide synergies with the aim of establishing sustainable activities in the Terrae Novae main destinations and beyond.



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[5] *e.g. JUICE - JUpiter ICy moons Explorer - first large-class mission in ESA's Cosmic Vision 2015-2025.*
[6] *ESA/SPC(2021)20*

ENABLING FEATURES

On the technical an implementation side, the common capabilities thread for all three destinations centres on more autonomous logistics (for examples, see Figure 7 below), that will allow Europe to assume strategic roles in terms, for example, of:

- **Non-dependence.**
  - European non-dependence from launch to landing, to define Europe's science and technology roadmaps in defined areas;
  - Small missions creating opportunities for newcomers to lead end-to-end missions.
- **Uniqueness.** Deciding on European-led missions as part of a bigger international cooperation campaign to ensure resilience:
  - **Evolved partnerships.** For example, institutional contribution to post-ISS infrastructure(s), cis-lunar return transportation;
  - **Co-leading.** Proposing options for leadership by inviting other partners into European activities. For example, medium-size Mars precision landing mission;
  - **Astronaut training.** Basic and evolved, such as in Moon surface analogue environments.

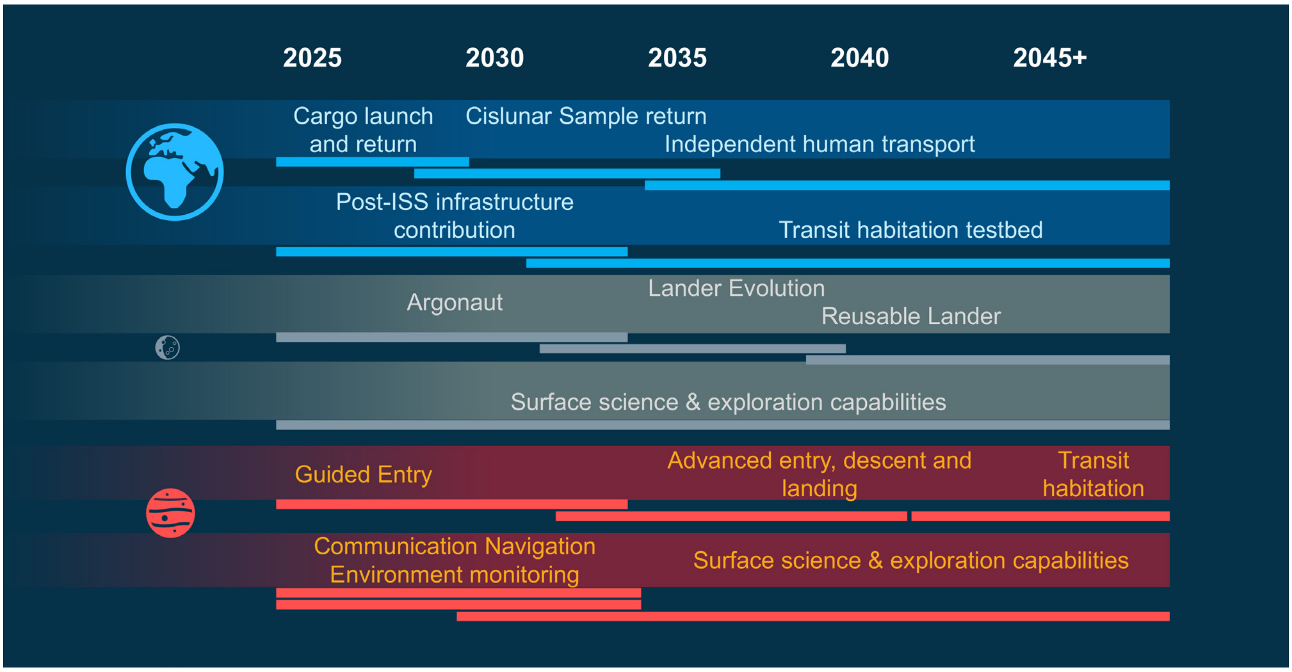

Figure 7: Examples of gradual build-up of enabling features with corresponding timely decisions

The 15+-years strategy will have to be able to cope with expected risks and opportunities. In particular risks related to competing capabilities possessed by other partners and especially by the foreign private sector must be taken into account.

To avoid putting at risk the non-dependence and uniqueness of the strategy and subsequent implementation plan, risk analysis and mitigation measures must be assessed in a dynamic manner.

Exploration will also be a driver for **future launchers and in-space transportation** synergies. In particular, a launcher that is compatible with a crew flight needs to be considered in parallel with a potential crew vehicle design. High-velocity re-entry, for LEO or from cis-lunar orbits, is another area of common interest. For robotic missions, safety certifications for launchers and ground infrastructure to use radioisotope power systems are "key enablers" of the strategy. Additional commonalities are for rendezvous, docking and refueling, especially for dual launches to increase the payload masses for Moon and Mars missions, including fuel depots. A related end-to-end roadmap will be drawn up based on Explore2040 and the ESA strategy on space transportation.

SCIENCE AND ENABLING TECHNOLOGIES

Figure 8 below describes the balance between exploration-enabled research and exploration-focused science.
Current and new exploration capabilities, platforms and missions in Earth orbit and on and around the Moon and Mars will deliver the next level of “exploration-enabled” research in physical, life and planetary sciences (exploration for science). The science content is selected bottom-up, based on scientific merit to obtain world-class, unique results.

“Exploration-focused” science will address areas defined top-down using relevant scientific and technical expertise (science for exploration). It will generate knowledge to create the know-how and derived innovative technologies to undertake long-duration deep space human and robotic exploration safely.

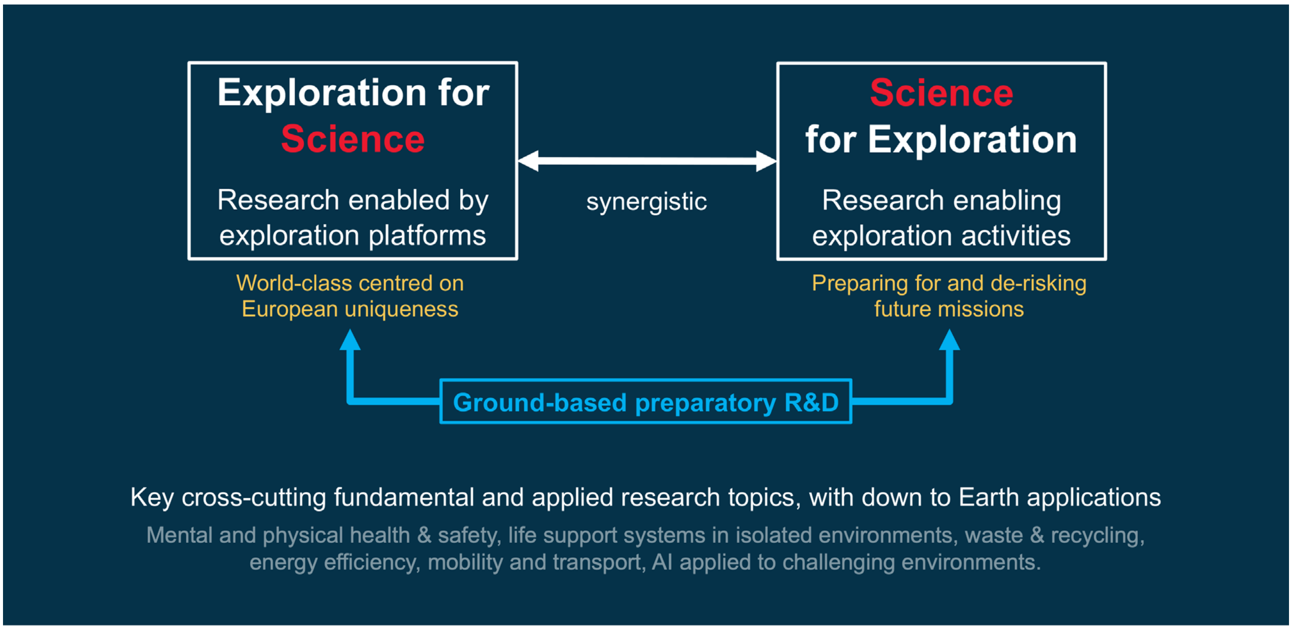

Figure 8: Balance between exploration-enabled research and exploration-focused science

The follow-up Explore2040 strategy implementation roadmap and derived engineering and programmatic considerations will provide a top-down prioritisation. Some key areas will be:

- de-risking crew survival, maximising crew mental/physical health, crew support and performance (e.g., counter-measures to address adverse effects such as radiation or the absence of gravity, advanced medical and life support, waste management and recycling, virtual presence and AI embedded in all aspects of the spacecraft subsystems and human support);
- understanding new locations and their environments, how these environments will affect human activities, and how human and robotic activities affect these environments (e.g., surface mapping, radiation, dust, impactors, atmospheres and exospheres);
- searching for potential resources at the Moon and Mars and understanding their potential to support sustained exploration (e.g., water ice, volatiles, metals, and other materials).

“Exploration-enabled” and “Exploration-focused” research are synergistic and will be complemented by research and technology for system and concept studies as well as technology maturation to prepare future missions. To ensure maximum scientific return, robust and reliable exploration technologies are required to access specific locations and to operate and perform scientific activities: power, communication, subsurface access, mobility, scientific instrumentation and capabilities for the selection, extraction, handling and return of samples to Earth.

Exploration-enabled research in life sciences and the search for extra-terrestrial life will also advance exploration-focused research, for example to preserve crew health and safety. In many cases, these activities generate new science results that are relevant to human life on Earth. Fluid physics and cell biology may also advance technologies for recycling and life support systems. Material sciences are both a field of high interest for exploration-enabled science, and a driver for exploration-focused science. Atmospheric science will contribute to performing high-precision landing. The search for resources will provide insight into planetary evolution and Solar System history. Environmental science will support technology development, operations and crew safety.

Europe has built up a unique portfolio of world-class ground facilities and analogues mimicking the space environment. Ground-based and sub-orbital preparatory fundamental science and applied research are essential for both exploration-enabled and exploration- focused science and, as such, constitute a fundamental capability required to implement the Explore2040 strategy.

Practical knowledge, products, services, and applications which are created through these research activities have the potential to address global challenges and European policy priorities by providing innovative solutions in areas such as environment and climate (e.g. responsible consumption, resource management, waste management and carbon footprint) and healthcare and well-being (e.g. novel medical technologies). Innovative implementation mechanisms, such as challenge-based competitions, will trigger fast-track implementation and links with the relevant non-space sectors.


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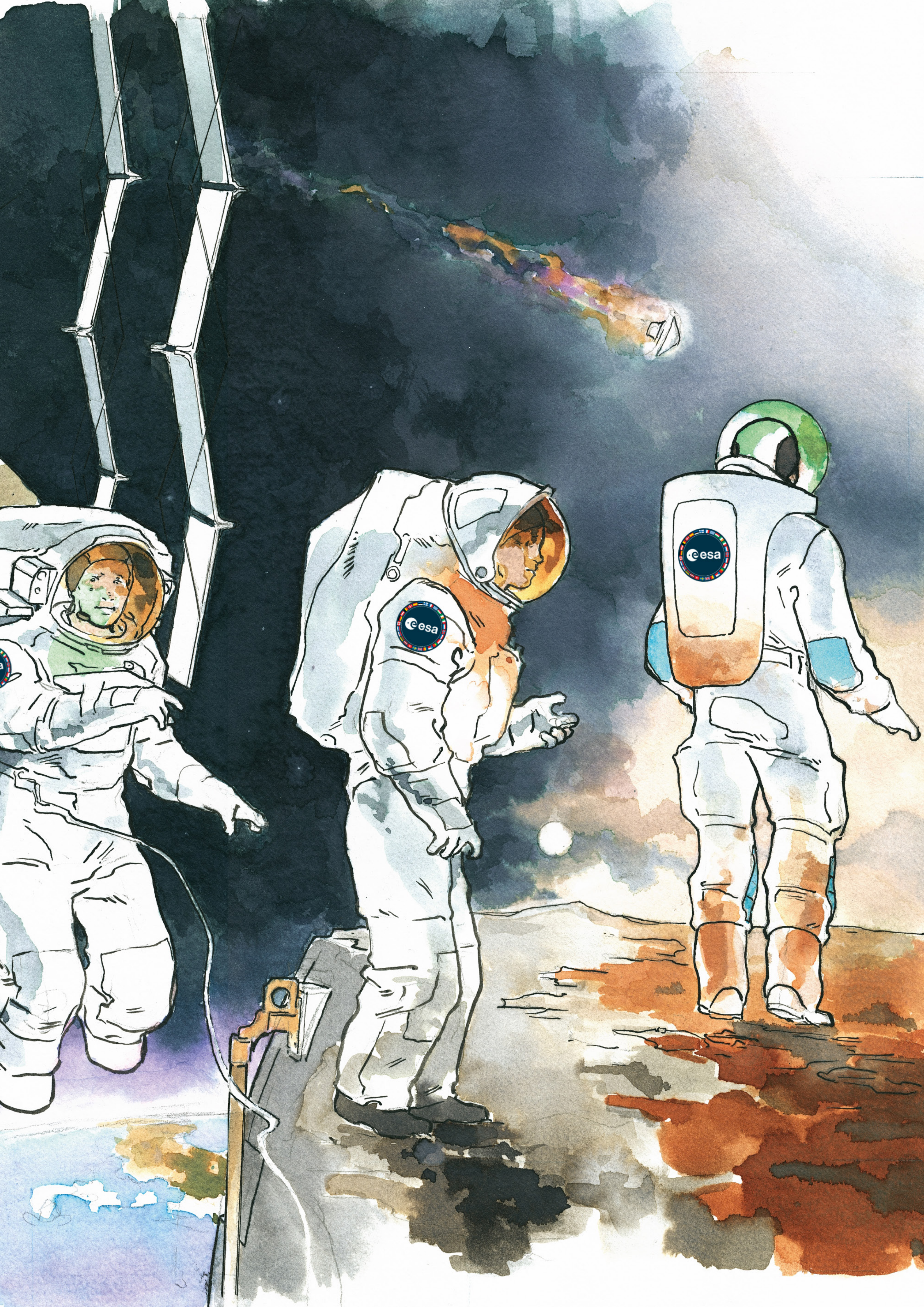
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ESA's Terrae Novae exploration programme

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