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EUROPEAN SPACE AGENCY

HUMAN SPACEFLIGHT, MICROGRAVITY AND EXPLORATION PROGRAMME BOARD

Draft refined Exploration Strategy - Explore2040

Summary

In 2014, the ESA Member States Ministers adopted the Resolution on Europe's space exploration strategy. The international exploration landscape has undergone substantial transformations in almost 10 years, attracting more players and is very high on the agenda of the space powers with a new competition. It is therefore timely to refine the European exploration strategy – Explore2040 – to reflect the changes that have occurred and reconsider the European role in this evolving context.

In parallel, at Agency level, the first discussions with the Heads of Delegations on the ESA 2040 strategy to be elaborated in the coming weeks highlighted the need for more European autonomy by unleashing a leadership mindset that is underpinned by new partnerships and at the same time strengthening existing international cooperation. The Explore 2040 strategy will be fully aligned with the ESA 2040 strategy and will follow the same timeline for their endorsement to ensure their full coherence.

Required Action

The Human Spaceflight, Microgravity and Exploration Programme Board is invited to take note of the content of the document and provide comments that will be incorporated into a further updated version to be finalised at the 2024 February Programme Board and recommended to ESA Council in March 2024 for endorsement.

Next steps

Upon its endorsement, the Explore2040 strategy will be detailed further in a specific implementation roadmap.

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Explore2040

A renewed European exploration strategy

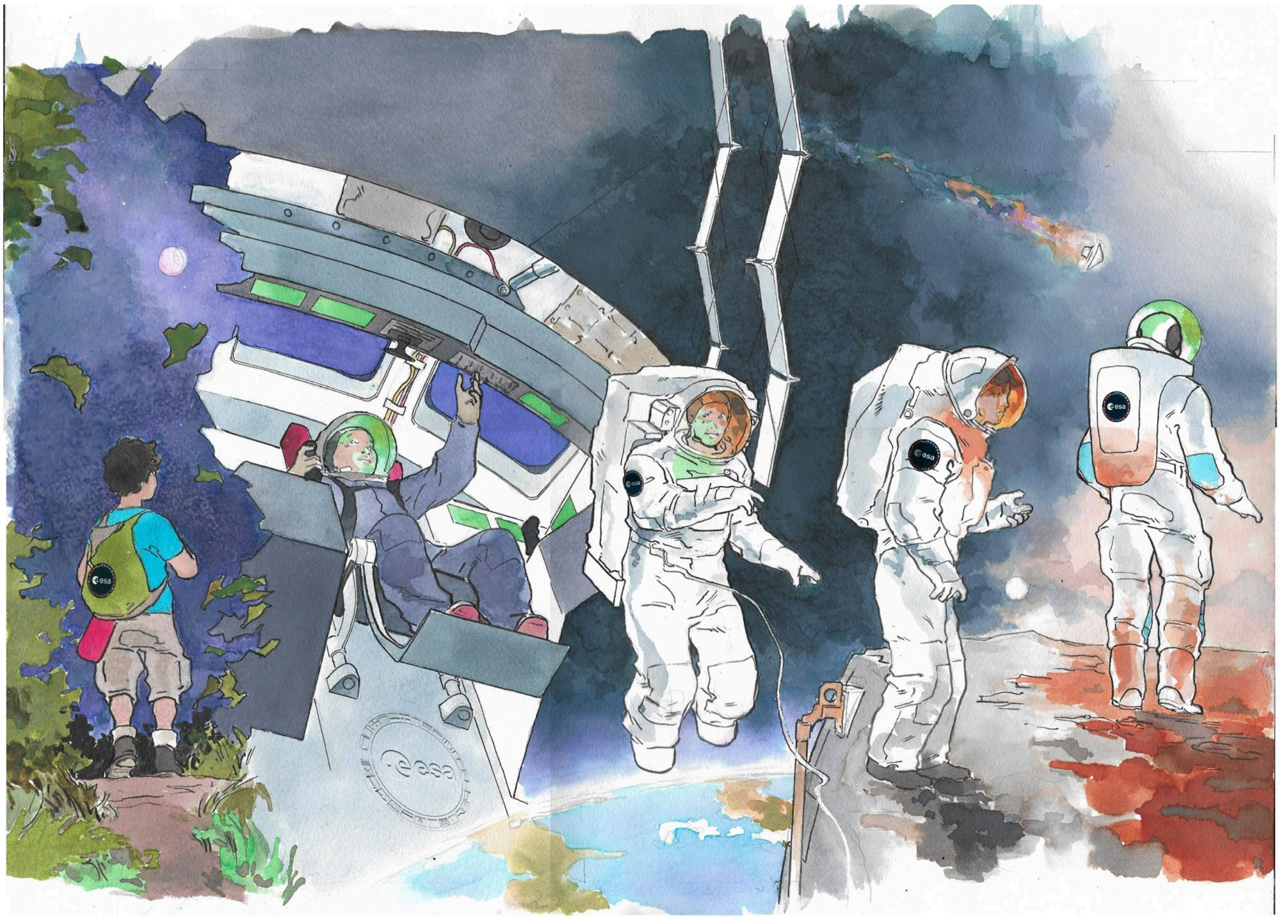


Table of Content

Executive Summary

Space exploration activities are developing world-wide at an unprecedented pace with far-reaching initiatives supported by political announcements. US, China, Russia, and now India, have a leading posture while more countries and private actors are gearing up as well. A coherent and coordinated European strategy is essential for Europe to remain a relevant player. An uplift and self-determination mindset will be crucial to boost the highly inspirational value of space exploration for Europeans.

The Explore2040 strategy has been elaborated in response to the Sevilla 2023 Space Summit Resolution, considering lessons learnt on European strengths and weaknesses over the last 50 years. The bold vision of establishing a sustained human and robotic exploration in the Solar System by providing unique contributions and returning benefits to society, is at the essence of this overarching scheme for which ESA Member States will take ownership.

The current Terrae Novae programme (E3P) is the backbone of Explore2040. Together with a wider view on commonalities with other ESA activities and taking into account European national activities it aims to build up an end-to-end architecture view that maximises freedom of action. In this respect, boosting international cooperation with historical partners is a given, as well as looking for new partnerships. Overall, the thread of being able to launch and deliver payloads to low Earth orbit, the Moon and Mars is a strategic long-term objective, to ensure constant science outcomes and technological innovation, assuring Europe a seat at the big table of space explorers.

The strategy prioritises orbital and surface architectural elements that are essential for transportation between solar system bodies and surface logistics and identifies commonalities leading to “European uniqueness” options on the international exploration scene that leapfrog instead of duplicate. The Explore2040 high-level destination goals are:

(1) obtain a sustained human presence in and utilisation of LEO,

(2) enable Europeans to explore the Moon in the 2030s, and

(3) prepare for taking Europeans to Mars at the end of the 2040s.

Having in mind this horizon goal of human presence on Mars, an “Earth to LEO to Moon to Mars” approach is favoured for human exploration by defining science and technology priorities maximising synergies and commonalities between all three destinations, as well as maximising supporting ground-based activities. Setting clear long-term objectives in a stepwise approach allows for options and choices to be made in due time and makes the ambition affordable and achievable.

Both humans and robots have a role to play in achieving scientific investigations and technology validation needed to enable sustained human presence, complemented by world-first-class curiosity-driven research. In addition to science, benefits include economics, inspiration, and cooperation. As for the programme content and narrative, these benefits will also be better communicated to decision-makers and the public.

A targeted service-driven approach, support to commercial initiatives and challenge-based competitions must emerge to engage into a more innovative, competitive and thus cost-efficient implementation, accompanied by a transformation on both ESA and industry sides.

1 Preamble

Exploration drivers. The 2014 European exploration strategy[1] assertively introduced the objectives and therefore the why and the benefits for society and citizens that remain the valid raison d'être of exploration, namely science, economics, international cooperation, and inspiration.

Europe has a long and rich tradition in human and robotic exploration including its science dimension. Building on significant achievements so far, Europe has gradually become a contributing partner in low Earth orbit (LEO), and in international exploration campaigns to the Moon and Mars (Annex 1).

The geopolitical significance of Human exploration is reinforced. 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 to assert their leading positions. Russia, Japan as well as new players, have the ambition to follow the trend. Simultaneously, private space players are increasing investments and gaining in influence on a global scale (Figure 2).

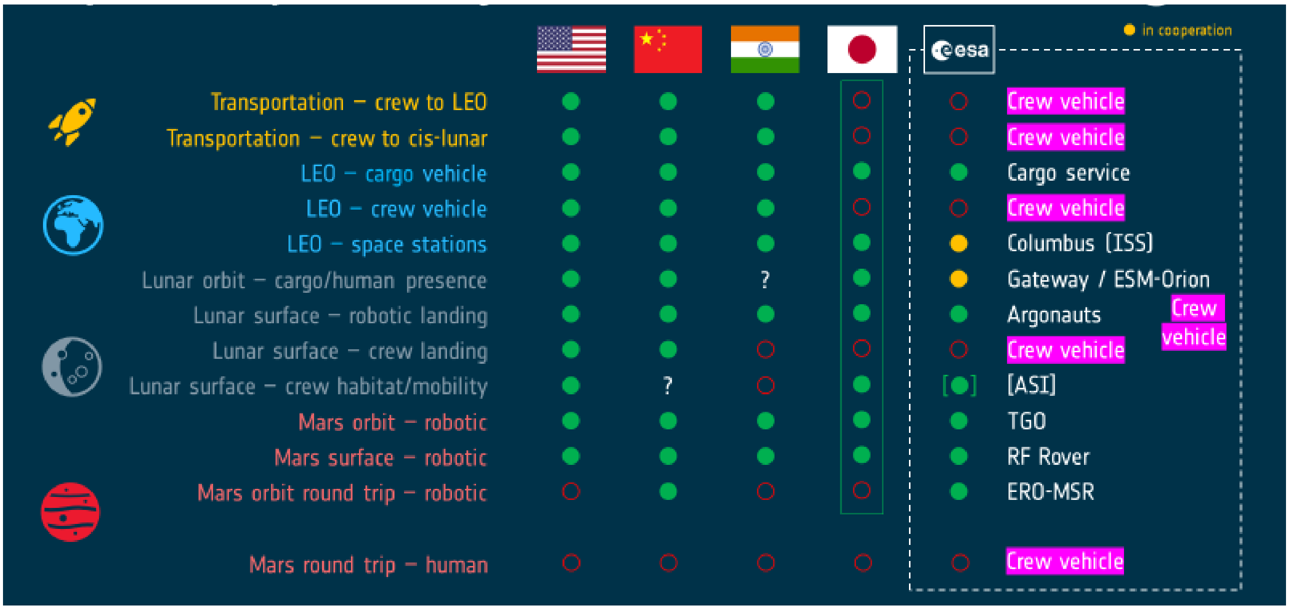


Figure 2: Expected exploration capabilities by 2030

Shifting to a leadership ambition. Without new European exploration capabilities matching the new international trend, the already existing unbalance and dependencies will increase further as the global scene develops in the 2030s. The wake-up call for Europe is now, to move from a minor and follower role to making the political and technology leap for self-determination with the vision that

> Europe will be at the forefront of a sustained human and robotic exploration of the Solar System by providing unique contributions and returning benefits to society.

[1]https://esamultimedia.esa.int/docs/corporate/Final_resolutions_1_2_3_from_CM_2014_Releasable_to_the_public.pdf

The ambition for a sustained European presence in the Solar System adds a new strategic drive to develop a sovereign attitude.

Non-dependence within an "open cooperation". Learning from the past (Figure 3) and anticipating the current changes, Europe needs to increase its autonomy 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.

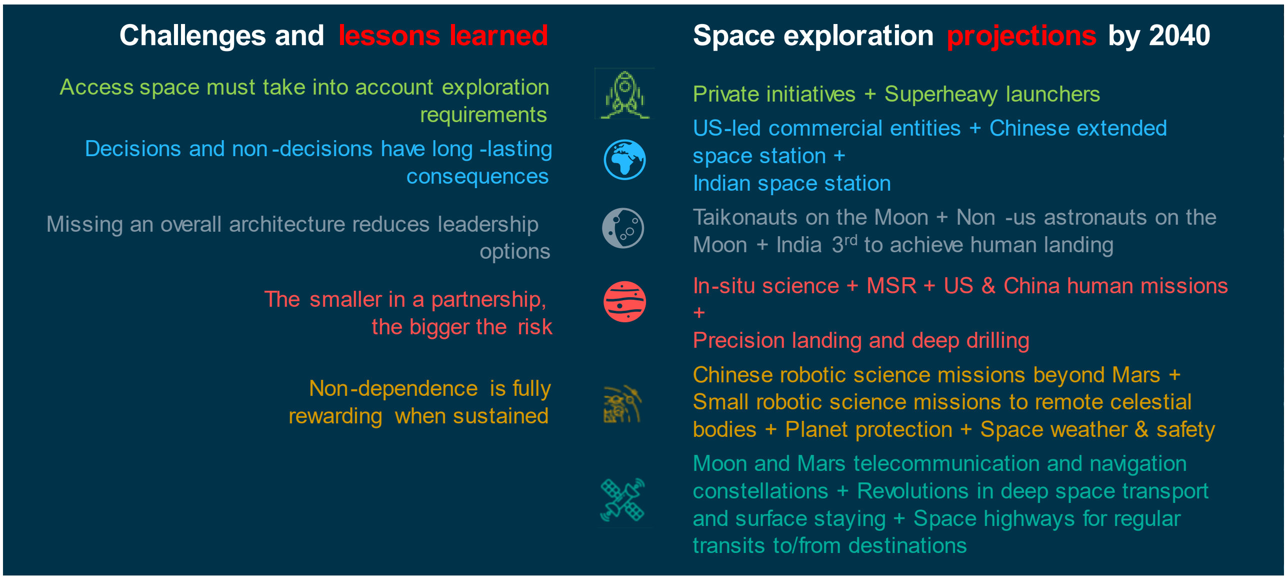


Figure 3: Exploration challenge, lessons learned and projections by 2040

Fostering a responsible use of outer space. In a dynamic and uncertain international context, a coherent, joint and fully coordinated European action is essential. Only at the forefront can Europe shape its own perspective and create a European identity in space exploration.

A move for the next generation. Space exploration, being inherently inspiring and motivating, contributes to the pursuit of a sense of purpose in the young generation. It can showcase that "space is the place" to infuse an optimistic can-do attitude within a global endeavour.

2 Several destinations, one strategy

Choices ahead for Europe depend much on the advancements of US-privately led initiatives such as cheaper super-heavy access to space, post-ISS infrastructures, the lunar human landing systems and surface operations, or the pace of upcoming human Mars exploration preparation.

Explore2040 aims to build up an **end-to-end European architecture** that maximises freedom of action to secure the benefits stemming from exploration. It is an ESA strategy taking into account European national activities.

A future-proof strategy of ESA and its Member States must in addition identify leadership in remaining niche areas (see figure 4) and involve check points to adapt to potential technology breakthroughs or geopolitical changes, especially in a more than ever competitive setting between US, China, India, or other ISS partners and new players.

To efficiently deliver on the strategy the emergence of new private actors will be encouraged for more competitive and cost-effective approach, leveraging faster implementation of projects, and promoting new services.

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:

(1) obtain a sustained human presence in and utilisation of low Earth orbit,

(2) enable Europeans to explore the Moon in the 2030s, and

(3) prepare for taking Europeans to Mars at the end of the 2040s.

The strategy furthermore:

a. Prioritises **“Must have”** orbital and surface architecture elements that are essential for transportation and surface logistics;

b. Identifies **“European uniqueness”** options on the international exploration scene that leapfrog instead of copycat.

Destination synergies (Figure 5) will further optimise scientific results and exploit technological commonalities. Additional synergies will be sought beyond the space and exploration domain, in the field of health, mobility, energy, security and advanced aeronautics. The strategy will also leverage the unique European portfolio of ground-based R&D platforms and analogues to prepare the essential elements for the exploration of LEO, Moon, Mars and beyond.

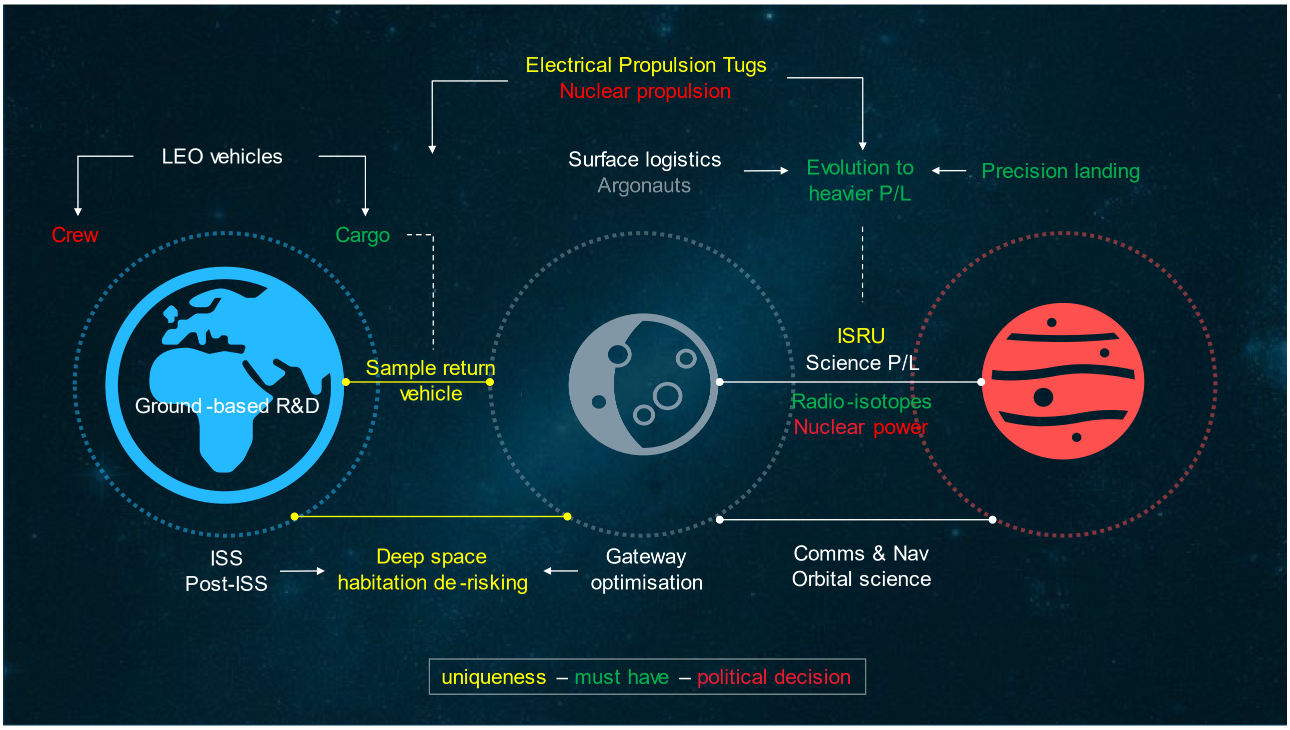


Figure 4: Explore2040 exploration niches across destinations

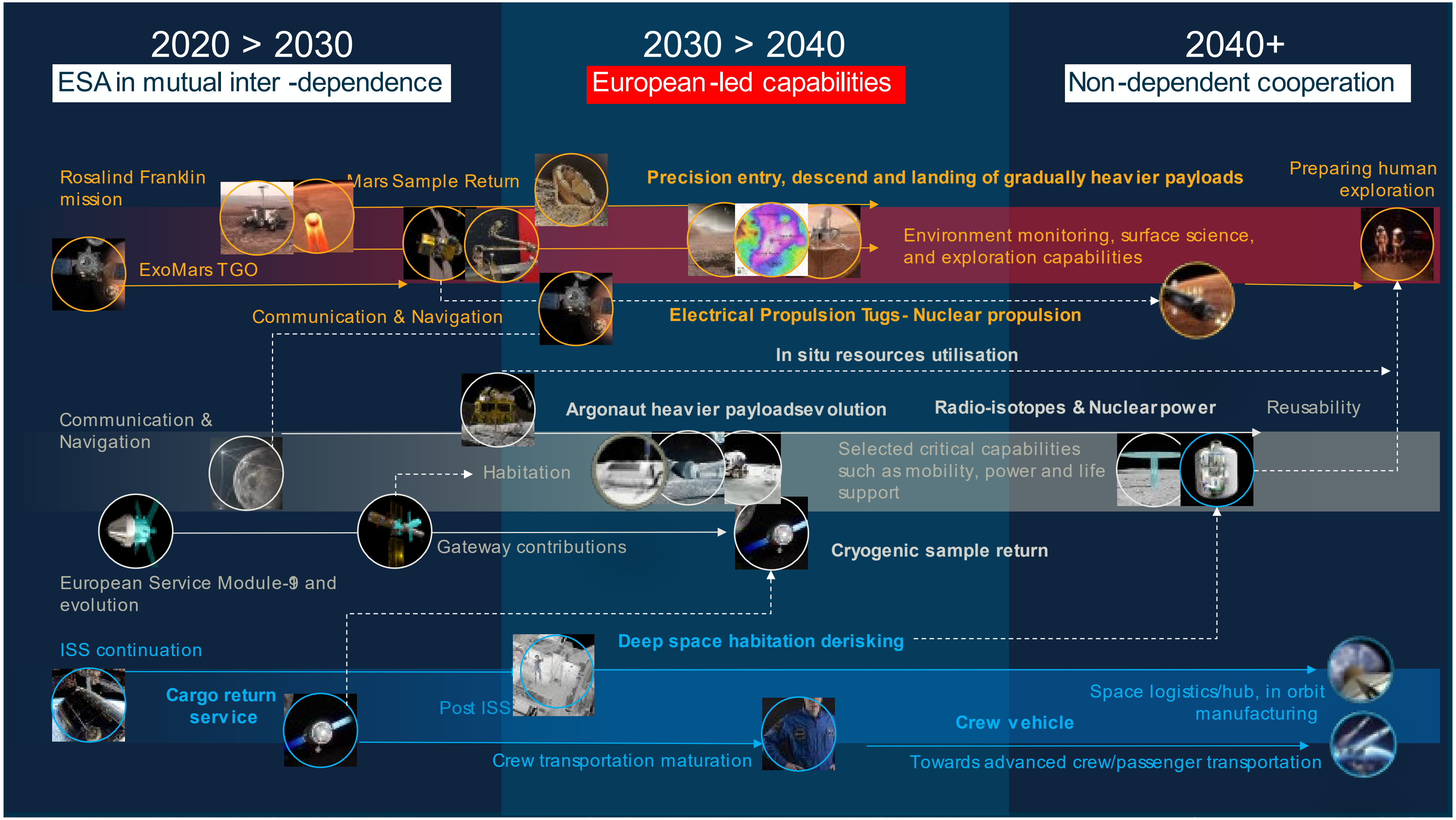


Figure 5: Explore2040 roadmap and beyond for Terrae Novae

Low Earth orbit
Optimise the utilisation of the ISS during its remaining lifetime and prepare human post-ISS activities, including fostering a commercial use and supporting scientific and technological research for deeper space exploration

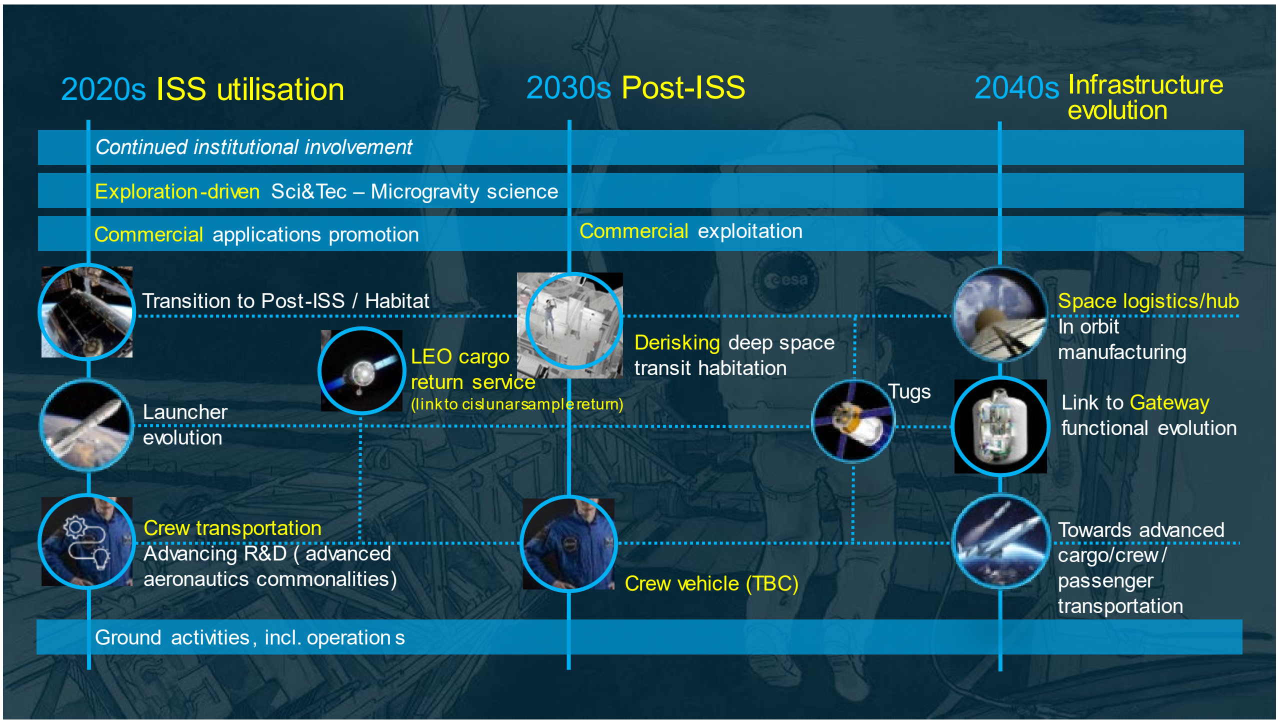


Figure 6: Explore2040 @LEO

A sustainable European human presence in LEO is the backbone of ESA's exploration programme. Supported by a robust European Astronaut Corps, it entails a continuous use of the ISS until its decommissioning and the preparation for a smooth transition to the next generation infrastructure in Earth orbit.

Transport to and from LEO represents 70% of the total cost of an infrastructure

Although exploration is fundamentally driven by institutions today, some recuring elements are expected to be increasingly procured through competitive services. A commercial cargo transportation service is considered as the most cost-effective way to establish a sustainable low Earth orbit cargo capability to offset ESA's astronaut flights in the next decade. Furthermore, it will enable to develop European providers for a growing logistics market. This strategic choice will in addition create the option for also developing a crew vehicle when politically decided.

LEO activities as a springboard to further destinations

Private initiatives must be complemented by institutional strategic self-determination. Europe needs therefore to consider the provision of a module on a LEO infrastructure for R&D activities through a public-private partnership. Such a self-standing initiative will help to de-risk novel systems needed for extended autonomous human presence in deep space. Capacity not institutionally needed for exploration preparation and science can be used by the private partners to generate additional revenue. The nature of activities centred around extended autonomous human survival in space is prone to attract non-space partnerships for R&D co-funding.

Commercial use of LEO infrastructures by private entities covering end-to-end costs is a longer-term prospect. Therefore, an institutional support covering transport and crew time will be needed first to stimulate a potential market. This strategic choice will contribute to lowering the industrial barriers to enter LEO industrial activities and secure a European participation to the LEO economy. Such accompanying measures will decrease once the demand of other non-institutional users will increase.

Moon
Bring Europeans and technologies to the surface of the Moon to ensure future sustained access and stay, for scientific discovery and to prepare the human journey to

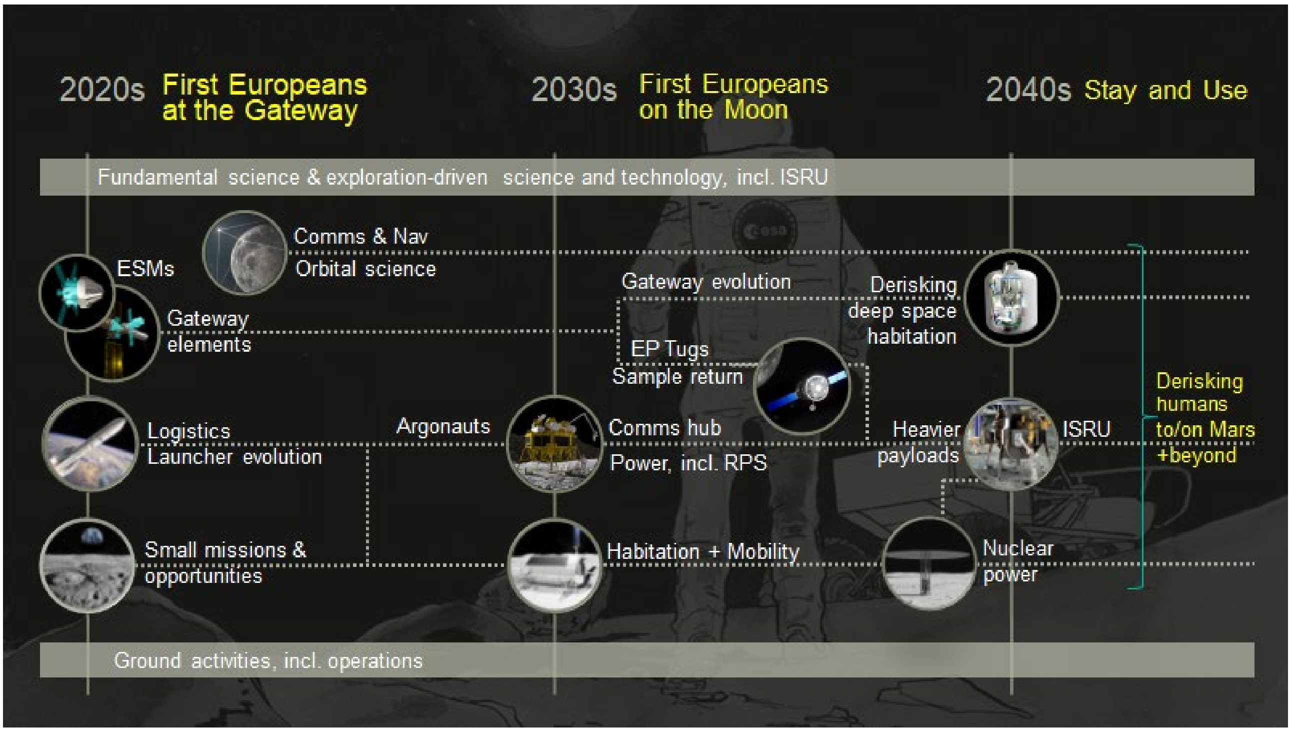
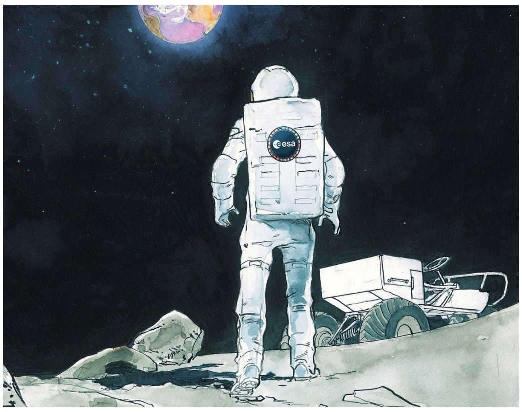


Figure 7: Explore2040@Moon

Only a significant contribution to a Moon surface architecture will bring European astronauts regularly on the Moon surface

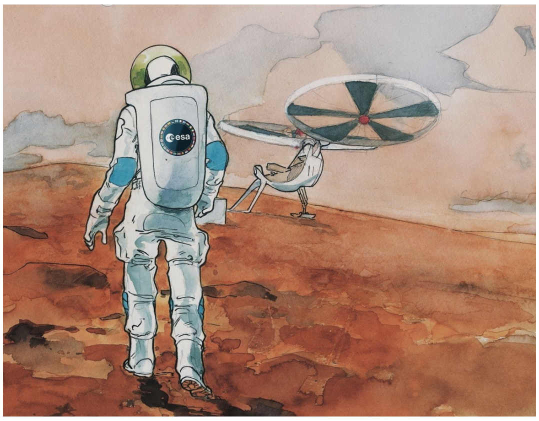
Within the NASA's Artemis programme aiming at returning humans to the Moon in a sustained way, Europe seized the opportunity to provide European Service Modules on the critical path of NASA's transportation capability and became a major partner in the cis-lunar Gateway. Europe also aims to play a significant role on the Moon surface, including science. A first step is the development of the Argonaut lunar logistic lander, that could evolve towards heavier payloads landing needed in the Artemis architecture, aligned with the Mars surface logistics capabilities in the 2040s.



If Europe wants to remain a reliable player in the next phases of Moon exploration and as a testbed for Mars stays[2], it will need to further step up. Contributions to the lunar surface architecture and complementary technology demonstration missions will increase the scientific output and prepare for the next phases of lunar exploration. Habitation, complemented by life support, power systems, mobility and communications and navigation means are critical capabilities for expeditions longer than a few days. Subsequently, responsible in situ resource utilisation may pave the way for long-term sustainable exploration of the Moon and preparing for Mars.

In addition to analytical research on the Moon, samples shall be brought to Earth. 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 be a significant and cost-efficient contribution to the overall Artemis architecture, with synergies with LEO Earth return vehicles and electric tugs.

Mars
Undertake robotic missions to continue the search for life, the study of planetary evolution and climate change, and the preparation of European capabilities for human



The technical challenges of robotic and human Mars exploration require a stepwise approach. A first critical step is the Rosalind Franklin mission that will see Europe lead the search for life on the Martian surface – and below. In addition, Europe shall fly a return mission using an electric propulsion space tug as part of the Mars Sample Return campaign. This international partnership will return scientifically selected samples from Mars back to Earth. Mars Sample Return is a very first step to future crewed missions to the Red Planet.

[2] The NASA Moon2Mars initiative will use Artemis to prepare the next big leap

> The Martian surface is extremely varied, which needs precise landing to optimise the science output.

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, open to international cooperation, will enable breakthrough sub-surface 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, required for human presence on the surface of the Red Planet.

Orbital precursor missions will carry scientific payloads to identify the best landing sites and help precision landing by understanding the Martian atmosphere and terrain. The addition of orbital communications and navigation systems will significantly improve the reach and capability of successive missions.

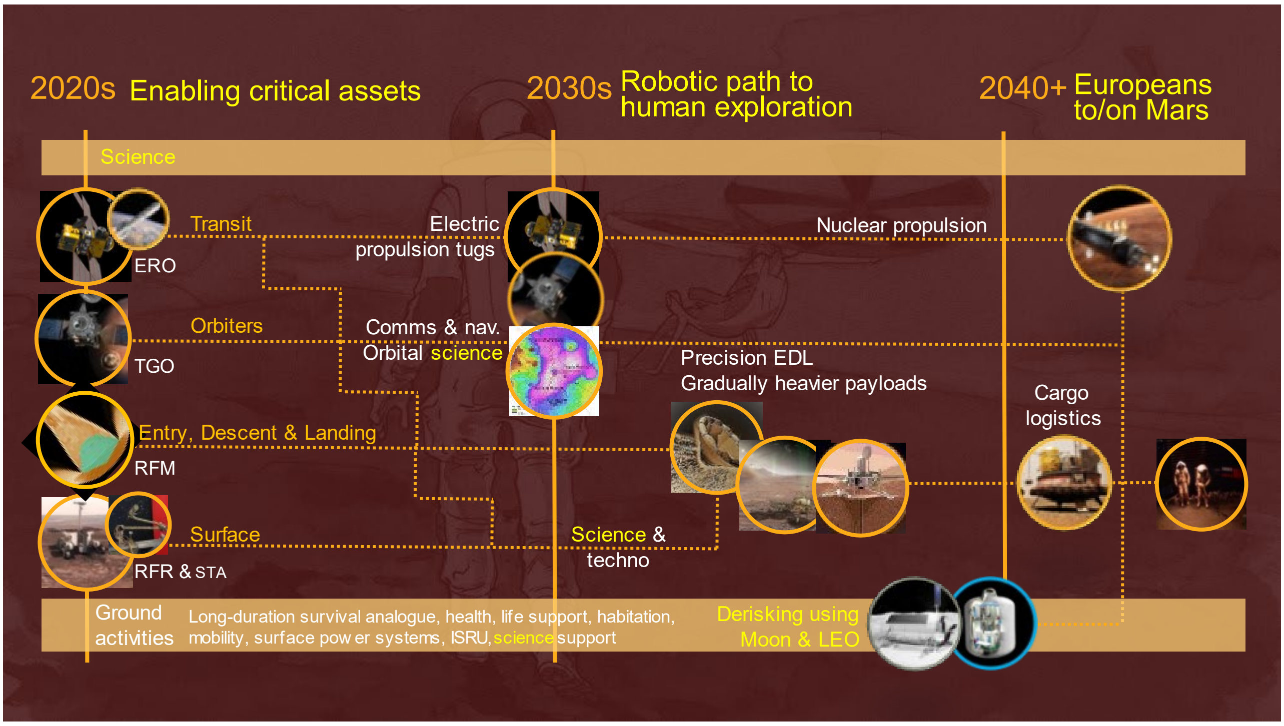


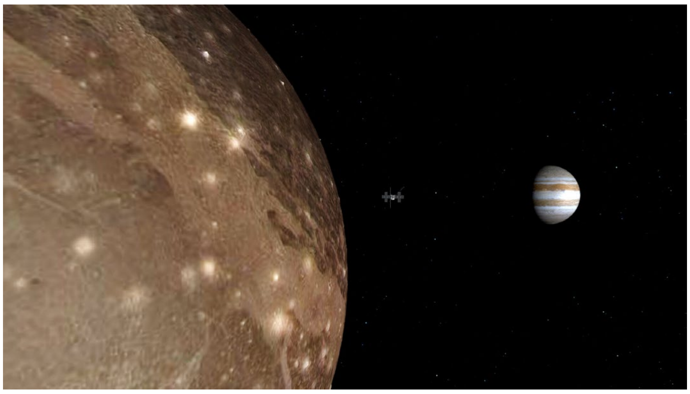
Figure 8: Explore2040 @Mars

For orbital and surface missions, the next-generation electric propulsion space tugs, with a potential to evolve towards nuclear propulsion, will carry ever larger payloads between Mars, Moon and Earth.

Ground-based analogue facilities will be a cost-efficient way to address all aspects of long-term habitation, isolation and confinement before developing flight systems for low Earth orbit, then the Lunar Gateway, and subsequently developing habitation infrastructures for round-trip human missions to Mars.

Further destinations
Create efficient synergies with other exploration-related activities, such as the science driven robotic exploration of other Solar system destinations and space safety, space weather, and spacecraft operations

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



Beyond LEO, Moon and Mars, other destinations such as asteroids, comets and the moons of the giant planets are subjects of great human curiosity. Comet Interceptor, the 1st Fast mission planned for launch in 2029, aims at 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 (and partially overlap) with the knowledge and capabilities needed for exploring the main Terrae Novae destinations. Explore2040 implementation roadmap envisages to maximise these synergies.

ESA's Voyage2050 long term plan includes three scientific themes for "Large" (flagship) missions beyond 2035[3]. The first of these themes is the study of the "Moons of Giant Planets". Technologies of common interest with human and robotic exploration are also significant, e.g., electric propulsion (solar-powered or eventually nuclear powered), landers and possibly local mobility (rover, drone, etc.) for an *in situ* element to characterise the local surface and subsurface environments, and handling, selecting and transporting of samples stored at cryogenic temperatures, including terrestrial laboratories 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, artificial intelligence enabled automated operations, matured Cis-lunar Space Traffic Management technology, and in-orbit production and recycling capabilities are all relevant and having potential synergies with the objective of establishing sustainable activities in the Terrae Novae main destinations and beyond.

[3] ESA/SPC(2021)20

3 Enabling features

The common thread for all three destinations is autonomous logistics capabilities (examples provided in Figure 9). This will allow Europe to take up strategic roles in terms of, e.g.:

- **Non-dependence.** European non-dependence from launch to landing to define Europe's science and technology roadmaps in defined areas
- **Uniqueness.** Deciding on European led missions within a bigger international cooperation campaign for resilience:
  - **Evolved partnerships.** E.g. Institutional contribution to post-ISS infrastructure, cislunar return transportation
  - **Co-leading.** Proposing options for leadership by inviting other partners into European activities. E.g. medium size Mars precision landing mission
  - Basic & evolved astronaut training

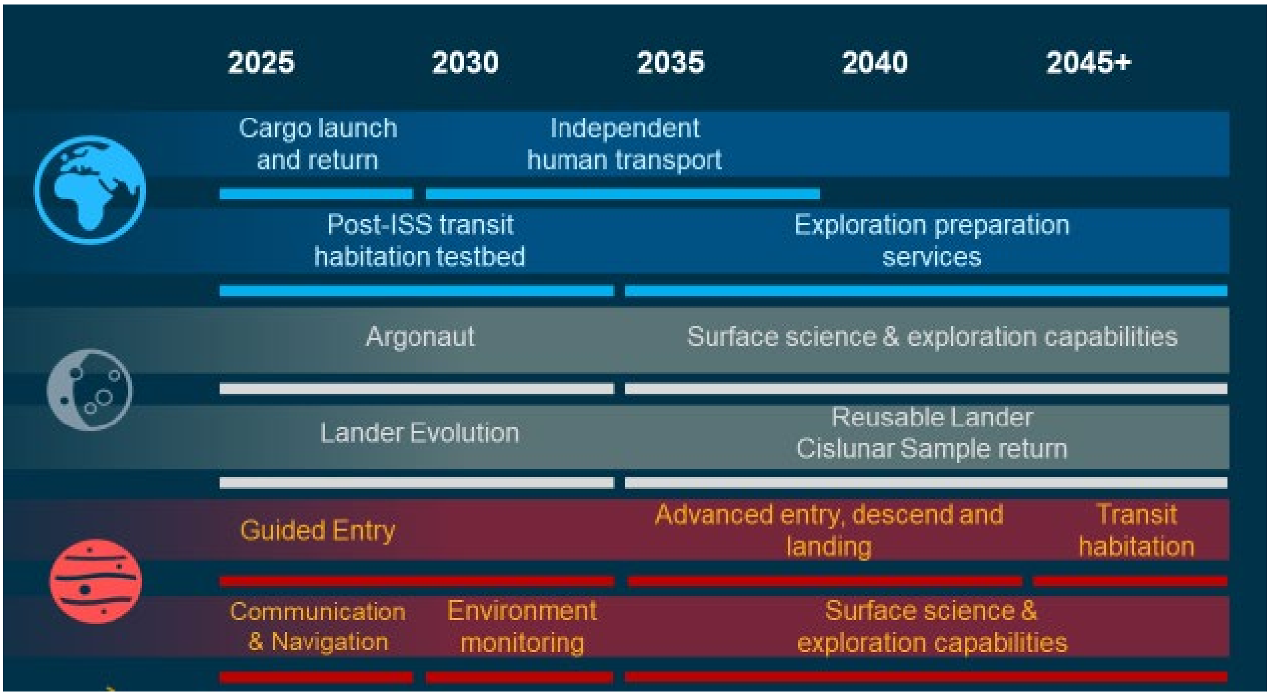


Figure 9: Example of gradual build-up of enabling features with corresponding timely decisions

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 of a potential crew vehicle design. High-velocity reentry, for LEO or from cis-lunar orbits are another area of common interest, e.g. with Space Rider. For robotic missions, safety certifications for launchers and ground infrastructure to use radioisotope power systems are a must have element 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.

4 Science & enabling technologies

Curiosity-driven ("exploration enabled") as well as targeted ("exploration focused") research are essential to create the know-how and derived innovative technologies to safely undertake long-lasting deep space human and robotic exploration. The Terrae Novae implementation roadmaps and derived engineering and programmatic considerations will provide a top-down prioritisation for research and development. Some key areas are:

- De-risking crew survivability, maximising crew mental/physical health, crew support and performance (e.g., countermeasures to adverse effects such as radiation or the absence of gravity, advanced life support, waste management, virtual presence and AI);
- Understanding new locations and their environments, how these environments will affect human activities, and how human 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 more sustained exploration (e.g., water ice, volatiles, metals, other materials).

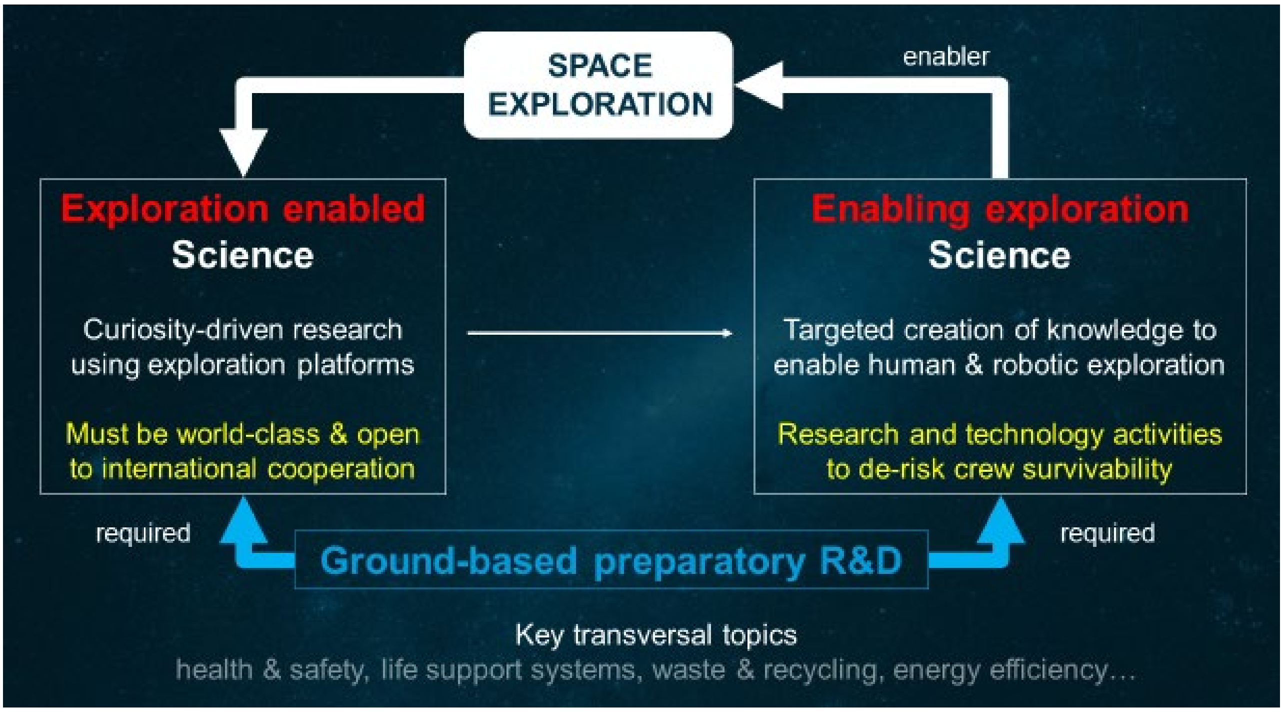


Figure 10: Balance between science enabling / enabled by exploration

The new exploration capabilities, platforms, and missions in Earth orbit and on and around Moon and Mars will enable the next level of curiosity driven research in physical, life, and planetary sciences. The international science community selects this science bottom-up, based on scientific merit. To ensure maximum scientific return, robust and reliable exploration technologies are required to access specific locations and operate and perform scientific activities: power, communication, subsurface access, mobility, scientific instrumentation, and capabilities for the selection, extraction, handling, and return to Earth of samples. A complete overview of the technology areas for exploration is in Annex 5.

Overlaps exist between basic science and exploration-driven science. Fundamental research in life sciences and the search for life will also advance the knowledge to preserve crew health and safety. Fluid physics and cell biology may also advance technologies for recycling and life support systems. 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 preparatory science and research is essential for both exploration enabled and exploration enabling science and therefore a fundamental capability to implement the Explore2040 strategy.

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

5 Conclusion

The Explore2040 strategy expresses an ambitious vision for European exploration of the Solar System. It shall serve as the reference to deliver a unique and coherent ESA and Member States exploration programme, starting with an incremental implementation at the ESA Councils at ministerial level in 2025 and 2028.

The strategy puts exploration into a European-wide perspective, from human space transportation, including future launchers, to utilisation of low Earth orbit, up to sustainable Moon and Mars exploration. Overall, the thread of being able to launch and deliver payloads to LEO, the Moon and Mars is a strategic long-term objective, to ensure constant science outcomes and technology developments, assuring Europe a seat at the big table of space explorers.

Importantly, the strategy provides the narrative needed to support political decision makers and inspire taxpayers. Exploration is indeed an investment for future prosperity. It generates high quality jobs and immediate economic return (cf. Annex 2). Exploration science and technologies are a driver and accelerator for sustainable development and have the unique potential and demonstrated capacity to transform into innovative solutions that make life on Earth more productive, clean, and sustainable, securing a safe future for our planet and generations to come.

Europe's political posture towards space is often one of "catching up". Explore2040 has the ambition to change this trend for European human and robotic exploration of the Solar System. The strategic considerations in this document provide a clear European exploration path to all stakeholders in Europe (governments, space agencies, the science community, and industry including the non-space sector) as well as a message towards our international partners.

Annex 1: Setting the scene

> *"There is no favourable wind for the sailor who doesn't know where to go."* (Seneca)

The 2014 *Resolution on Europe's space exploration strategy*[4] has laid down the foundation of Europe's engagement in exploration through a single ESA programme created in 2016. It has since positioned Europe in international exploration activities in low Earth orbit, Moon and Mars. In 2021 the ESA exploration programme was branded Terrae Novae. Additional ESA-wide and national activities are complementing its core elements. A snapshot of the current activities is illustrated in Figure 1.

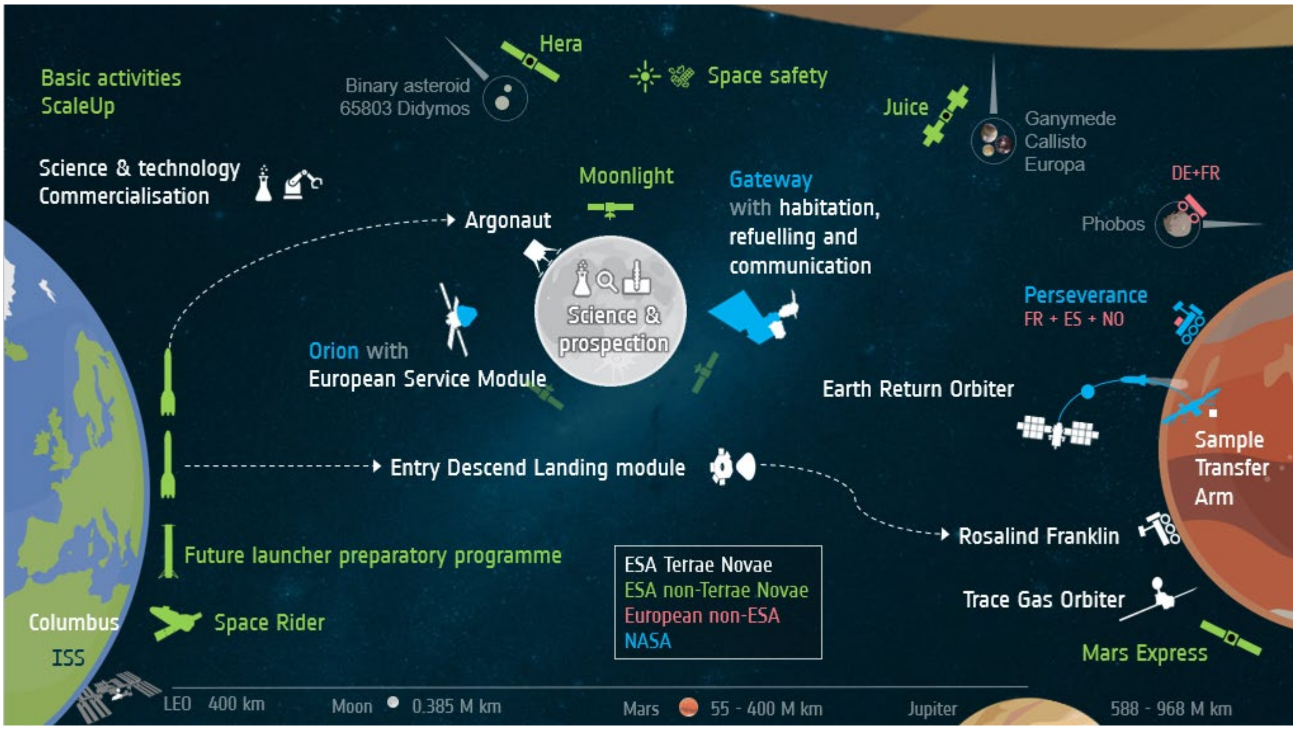


Figure 11: Synthetic representation of the current main elements of the European space exploration activities (including examples of national contributions)

In the last ten years, space exploration has fundamentally changed, and the pace of evolution will further increase (cf. Table 1). In particular,

- the original "institutional only" International Space Station (ISS) cooperation approach will be very different in the post-ISS era, driven by increasingly private-led initiatives;
- a multifaceted Moon race has started, between the US and China, with many new entities striving to be active participants and no more spectators;
- for the two superpowers, the Moon is becoming the last steppingstone before the big leap to Mars;
- finally, private initiatives, especially of a few wealthy influential individuals, are shaking the landscape from access to space to exploration, shedding a new light on a public-private and exploration versus exploitation relationship, with inherent opportunities and threats.

[4] ESA/C-M/CCXLVII/Res.2(Final), 2014

Table 1: Space exploration related projections by 2040

Private initiatives will drive in-space hub concepts for assembly & refuelling Superheavy launchers will enter the commercial market beyond exploration Launch capacity, cost and cadence will be a significant driver for exploration
US-led commercial entities will sell flights to numerous countries Chinese extended Space Station will regularly host foreign astronauts India will have its own space station; other countries their own modules
Chinese astronauts (taikonauts) will land several times on the Moon Non-US astronauts will walk on the Moon as part of the Artemis Accords India will be the third nation to achieve a human Moon landing
Mars in-situ science and returned samples will reveal secrets of the red planet The US & China will both announce a human Mars mission scenario preparation Precision-landing and deep drilling will be the next challenges to search for water & life
Robotic science-driven missions beyond Mars will become a prestige label for China Small countries will lead small robotic science missions to remote celestial bodies Planetary protection, space weather & safety will complement exploration
Telecommunication & navigation constellations will extend to Moon & Mars Nuclear reactors will start revolutionising deep space transport & surface stays Cyclers to/from destinations will enable “highways” for regular transits

The changing global context asks for an overarching strategy putting all critical elements under one coherent roof. Several elements are taken into account to shape the updated strategy:

- the ambition and imperative need for Europe to shift to a more leading position mindset in relation to its relative economic and political weight worldwide;
- the necessity for a stepwise approach, with clear checkpoints including related decisions at the highest political level;
- the adjustment of the benefits of exploration in relation with the evolving societal challenges;
- rebalancing of existing cooperation relations and initiating new structural opportunities in a dynamic international context.

Europe has made significant progress in space exploration over the last 50 years through investment in key capabilities (e.g. pressurised modules, heavy lift launchers) along with cooperation with partners (e.g. ISS, Gateway). At the same time, there are important lessons learned over the last decades from Europe’s exploration activities (Table 2) which need to be considered in a refined strategy.

Table 2: Summary challenges and lessons learned for Explore2040

Access to space must take into account exploration requirements

Europe succeed in autonomy of access to space, however:

- Exploration high-level requirements will be factored into future launch services
- Future services from access to space and exploration vehicles to be embedded in a single open architecture
- Commonalities with in-space transportation activities will be enhanced

Decisions and non-decisions have long-lasting consequences

Europe has provided the Columbus module and the Automated Transfer vehicle to the ISS partnership, however:

- With its own crew vehicle Europe would not be dependent on arrangements with and goodwill of others to fly its astronauts
- Post-ISS options must include European transportation means and infrastructure elements
- Focused research will avoid dilution of scientific outcome relevant to exploration

Missing an overall architecture reduces leadership options

Europe is contribution the European Service Module and Gateway modules to the Artemis programme, however:

- Europe is lacking an operational robotic Lunar landing capability at a time when many nations deploy theirs
- Long-term commitments to major recurrent elements in a partnership constrains substantially self-determined options
- A contribution to the cis-lunar Gateway was not followed-up by an outlook to participate in surface activities

The smaller in a partnership the bigger the risk

Europe is leading in exobiology and provides critical mission elements to the US-lead Mars Sample Return campaign, however:

- Science hardware-centric projects are inherently dependent on transportation providers
- Reducing programmatic risk within partnerships requires implementing self-standing mission elements
- Technology developments and exploration focused science have been too scarce to prepare for human missions to Mars

Non-dependence is fully rewarding when sustained

Europe has a leadership in bottom-up selected space science and technology, however:

- The Rosetta probe & Philae lander was an inspirational landmark but only one of a kind
- Mars Express demonstrated feasibility of cheap fast track but without follow-up in an exploration context
- The Hera space safety mission is only a recent initiative to be consolidated further

Annex 2: Benefits underpinning exploration

Continuously inspired by the Global Exploration Strategy[5], ESA's engagement in exploration has always kept the scientific, economic, societal, and inspirational benefits in line of sight. The 2023 Space Summit Resolution affirms these strategic orientations as a beacon for Europe's continued exploration efforts.

Self-determination adds to Europe's soft-power

At the same time, the changing societal dimension, as well as the lessons learned from exploration (cf. Annex 1) are urging Europe to strive for the necessary resilience and robustness within continuous cooperation. Non-dependent cooperation is fundamental to retain the capability to create future exploration opportunities with roles that deliver proper benefits. A more self-determined attitude boosts the inspirational value for Europeans.

Astronauts are role models and ambassadors for Europe's ambition in Space

Table 3: Explore2040 benefits

Science Strengthening European excellence in exploration-driven scientific research through opportunities for in-situ and sample return investigations, and the development of top-notch instrumentation and enabling technologies	**Economics** Contributing to the competitiveness and growth of the European industrial sector by pushing the frontiers of knowledge and developing new technologies able to be applied in all fields of economic value
Establishing a global cooperative framework to carry out a number of space exploration projects, involving current and new partners, while creating renewed means to address global challenges **Global cooperation**	Attracting society and especially the young generation to expanding the limits of our knowledge, to study STEAM, to learn the value of cooperation, and to value the preparation of sustainable human presence beyond Earth **Inspiration/society**

Sustained exploration
Through non-dependent cooperation ensuring that future opportunities exist for Europe to participate in exploration missions, with roles that deliver proper benefits

[5] https://www.globalspaceexploration.org/wordpress/wp-content/uploads/2013/10/Global-Exploration-Strategy-framework-for-coordination.pdf

The value for the economy of a bold European space exploration programme has been assessed by the European Space Policy Institute and Boston Consulting Group (Figure 12). The study from 2023 shows that exploration is more than a mere space programme. It will provide a plethora of benefits that will exceed the immediate contribution of its core activities and will bring benefits up to the level of the overall economy, thus affecting every aspect of human activities, both on earth and in space. Three levels of benefits have been considered:

- immediate economic returns
- cross-fertilisation within the space industry
- significant broader improvements and outcomes for the economy and society at large

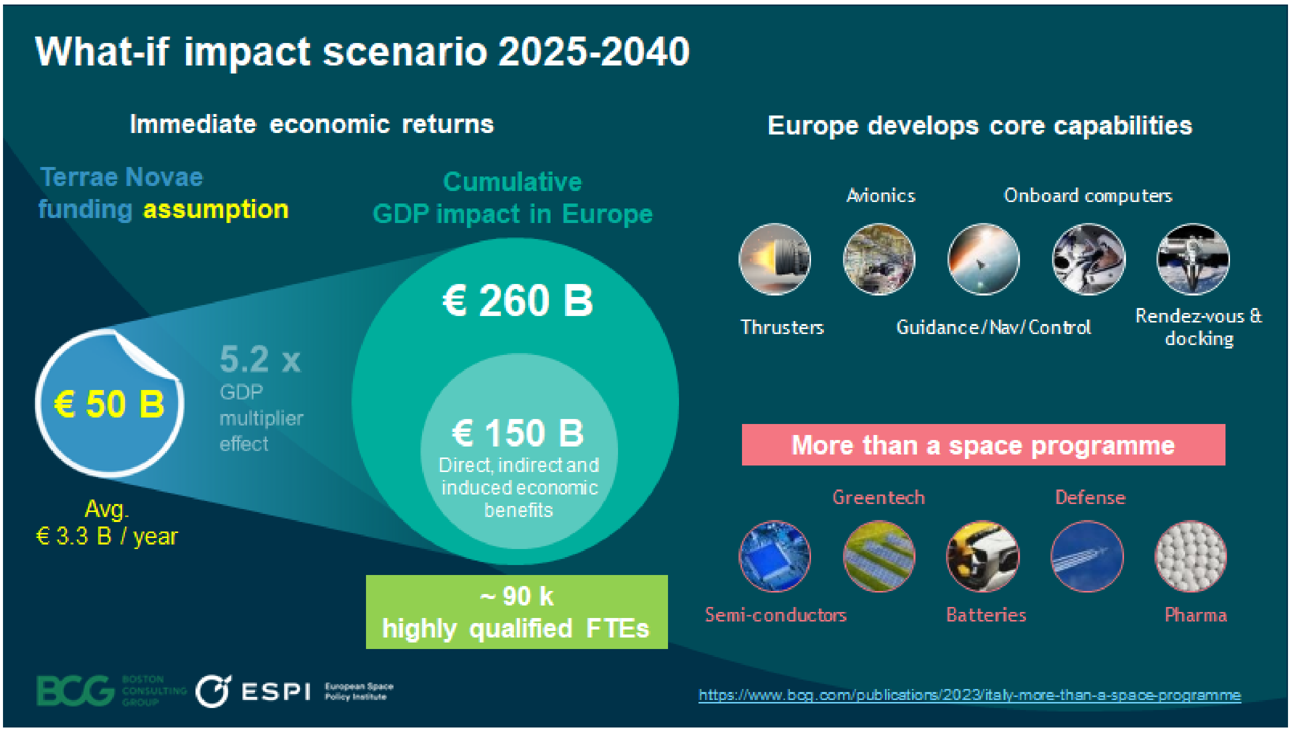


Figure 12: Different levels of economic benefits from space exploration activities

Annex 3: European wide strategy

The strategy is European wide, taking into account national activities. At ESA level, the core of the strategy will be implemented via the Terrae Novae programme. It will be complemented by activities from other programmes that share high-level needs and requirements with exploration (Table 3). The implementation of this strategy will require ESA and its Member States to choose where to lead and where to contribute to the international exploration architecture.

National activities and strategies shall be better coordinated with ESA programmes as a multiplier effect for the European involvement in exploration. An increased effort to find synergies will reciprocally boost each other. Only then can the Explore2040 be overarching and give the best output for a proper positioning of Europe towards international partners.

Table 4: ESA-wide synergies in exploration

Space transportation systems

- As a future customer of launch services, influencing performance and design evolution of launchers
- Potentiating applications for in-space transportation
  e.g. orbital manoeuvrability, in-orbit re-fuelling, creating hubs, or spill-over to advanced aeronautics

Navigation and communication

- Providing telecommunications and navigation assets and services for Moon and Mars vicinity and surface
  e.g. to lower mission costs

Bottom-up space science

- Developing synergies with bottom-up purely science-driven missions
  e.g. search for life on Jovian Moon; Martian atmosphere…

Operations and space safety

- Understanding of threats and propose counter-measures
  e.g. meteorites and asteroids impact risks
- Space weather modelling and prediction
  e.g. radiation effects on critical systems and humans

Earth observation and science

- Using remote sensing technologies and modelling
  e.g. high-resolution imagery for precision landing; comparative planetology

Commercialisation and competitiveness

- Commercial exploitation of exploration destinations and assets

Technology and engineering

- Supporting selected enabling technology developments

Legal and international matters

- Facilitating of open architectures, standards and cooperations

Annex 4: Synergies & commonalities

Several destinations share a significant number of challenges. The technical choices must consider commonalities beyond exploration needs and evolvability over several decades. Addressing such synergies will be a constant exercise to define priorities. The big picture is to deliver a roadmap from “LEO to Moon to Mars and beyond”. Examples of such commonalities are depicted in Figure 8.

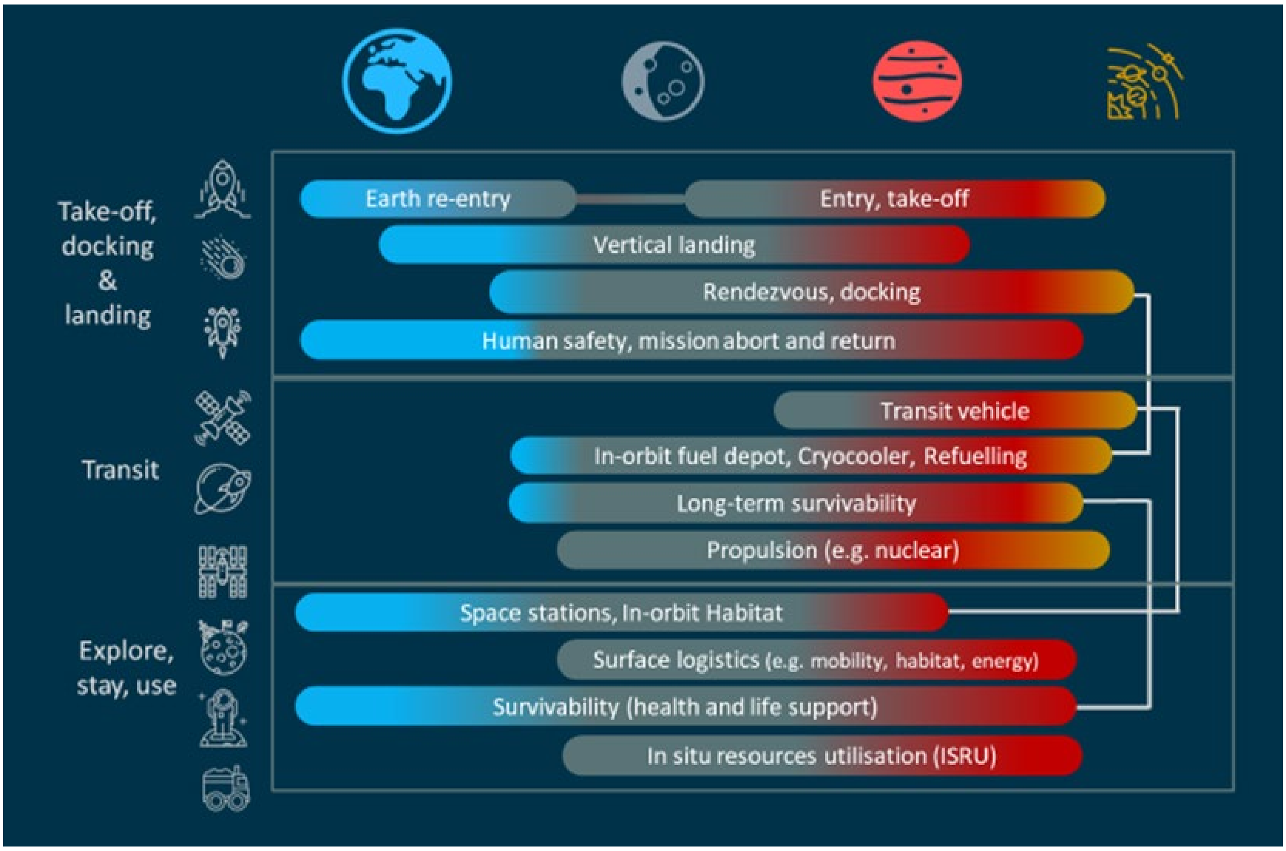


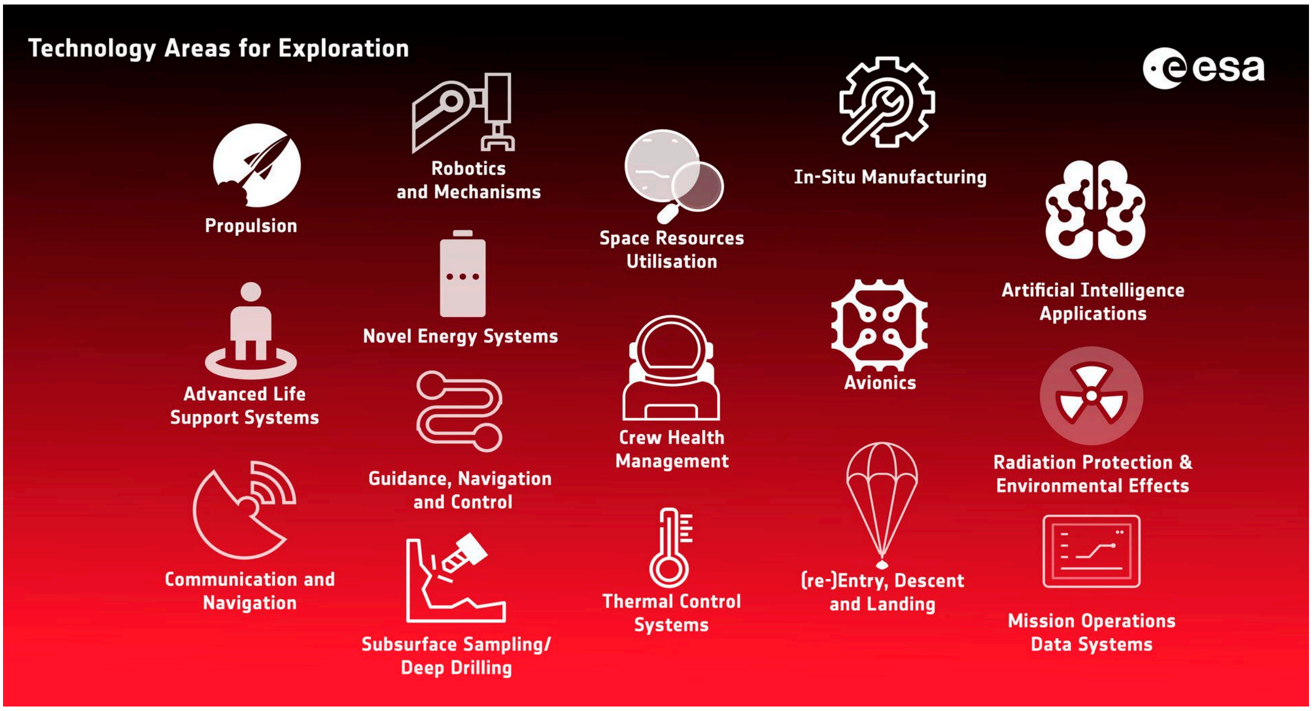
Figure 2: Notional representation of examples of synergies and commonalities between exploration destinations

Additional synergies will be sought beyond the space and exploration domain, in the field of health, mobility, energy, security or future of aeronautics. Commonalities and synergies will bringing additional benefits, in various fields:

- Atmospheric entry for future hypersonic passenger transport
- AI-rich autonomous surface mobility in harsh environments
- Cryogenic fuels handling
- Energy optimisation, nuclear reactors miniaturisation and safety
- Mental and physical health improvement, virtual presence
- Waste management and recycling for the circular economy

To trigger common R&D with non-space sectors, a co-funded milestone-based challenges approach will be used.

Annex 5: Technology areas for Exploration



Propulsion
With chemical propulsion, the propellants and associated performances can cover a wide range of scenarios, including high-thrust capability. Interplanetary missions in the frame of exploration require electric propulsion systems to cruise and perform orbit transfer at the destination.

Novel energy systems
Fuel cells can store and provide energy when required, in particular during periods of reduced solar illumination, have high specific energy densities and allow the use of native resources present in the destination environment. High power, high voltage, high efficiency autonomously deployable surface solar arrays are needed to generate reliable electric power for orbital and surface assets over the mission duration. Radioisotope power systems allow expansion into a new era for space exploration relying on mass-efficient, high-energy solutions to provide power to deep space vehicles.

Robotics and mechanisms
These are technologies for surface or orbit applications at the Moon and Mars, inside and outside the International Space Station (ISS), autonomously or tele-operated, in the area of robotics and mechanisms for space exploration.

Artificial intelligence applications
Artificial intelligence is an enabling technology for new exploration scenarios, changing the way spacecraft and missions are designed, implemented and operated. Autonomous systems for space exploration are key and can support varying levels of autonomy.

Advanced life support systems
Life support systems and technologies are essential to human exploration missions. Whether based on physico-chemical or biological processes, the systems must be regenerative and provide higher closed-loop life support to increase mission feasibility.
In-situ manufacturing
In-situ manufacturing or assembly of new (sub)systems and components, or dedicated tools if needed during an exploration mission uses both metallic and non-metallic materials, potentially through recycling, either autonomously or by robotic operations.

Crew health management
Crew systems with an integrated system approach, shift responsibility from the ground to the vehicle. The vehicle, its medical system and the crew all contribute to decision-making and task execution, thus radically increasing autonomy, flexibility and responsiveness.

Space resources utilisation
In-situ resources utilisation represents a paradigm shift in how we will approach exploration in the future, reducing or removing the logistical burden of support from terrestrial sources and instead moving towards self-sufficiency and enhanced mission capabilities by identifying and using local resources.

Radiation protection and environmental effects
Characterisation of the radiation environment experienced by humans and electronics during Moon and Mars exploration is paramount. Measurement techniques and protection methods will be used to mitigate the effects of proton, heavy ion and neutron irradiation.

Communication and navigation
Future robotic and human missions to the Moon and Mars and its vicinity will demand an increase in current communication data rate and bandwidth capability. Accurate navigation and tracking is key to improving the performance of surface asset communication and navigation.

Subsurface sampling/deep drilling
Drilling for access and sampling on the Moon and Mars at depth, in support of science, resource prospecting and utilisation.

Guidance, navigation and control
The proximity manoeuvres between a spacecraft and the target (spacecraft rendezvous or landing surface) are considered critical from the point of view of the guidance, navigation, and control operations. Accurate navigation is needed to precisely and safely guide and control the spacecraft towards the target object.

Avionics
Exploration missions can require ad-hoc development of avionics items to meet specific requirements of dependability, performance, interoperability, autonomy and criticality level.

(re-)Entry, descent and landing
Entry, descent and landing systems for future Moon and Mars robotic and eventually human exploration missions, including Earth return.

Thermal control systems
Thermal control systems maintain the system within its nominal (non-)operational temperature throughout the mission duration. All future vehicles (both crewed and non-crewed) will require thermal control systems.

Mission operations data systems
Operations systems, data systems and ground technologies are key for exploration missions.