ASD-EUROSPACE
The Space group in ASD

NEW PROGRAMMES TO ACCELERATE THE USE OF SPACE IN EUROPE: A PORTFOLIO OF INDUSTRY PROPOSALS

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As expressed in ESA Agenda 2025, ESA DG Josef Aschbacher is proposing to have a European "Space Summit" and to start a reflection about new flagship programmes of Europe in space. To support these reflections, the European Space manufacturing industry, brought together within Eurospace, is honoured to propose its most innovative ideas.

DISCLAIMER: Please note that the following Industry concepts for possible new Flagship Programmes of Europe in space are a collection of proposals from one or several Eurospace members, they are presented here as a collective effort of the European space industries to contribute and support ESA ambitions for the future of Europe in space**. Proposals referenced in the present document are therefore not necessarily supported by all industries as they can be conflicting with already substantial private investments decided by certain companies**. They are listed in no particular order of priority.

Eurospace insists that the initiatives proposed in this paper are without prejudice to the mode of financing that the industry wishes to see provided (and the possible procurement approach), nor the business model, nor the future governance. Indeed, the future flagship programmes can unite various actors, including public and private, under a shared umbrella and blending cash, in-kind contributions and other public policy measures.

Industry inputs on new Flagship Programmes

Preamble

European Space Flagship Programmes, besides their direct key importance for the European space sector and for the benefits of the European citizens are also an excellent opportunity for Europe to devise and to build collectively concrete and visible projects with positive, long-lasting impacts on the environment, economy, society and day-to-day life of European citizens; ultimately, they can be considered landmarks in the construction of Europe.

Galileo, Copernicus and EGNOS positioned Europe in a global leading role in the areas of Earth observation and navigation. Copernicus is a game changer and rapidly became, through its space component, the largest provider of free and open Earth observation data in the world. Galileo is currently the world's most precise satnav system, offering metre-scale accuracy to more than two billion users around the globe. EGNOS is the world's most advanced Satellite-Based Augmentation Systems (SBAS), offering unprecedented and guaranteed position accuracy, not only to the aviation sector but also to other transport and agricultural sectors. **Their continuity and evolution need to be secured. Any future addition to the existing EU Flagship programmes in space shall of course be accompanied by adequate budgetary means.**

Highly discussed during the past months, an ambitious new strategic satellite system for global connectivity would, in an area where European industrial and design capabilities have already been demonstrated, answer some of the most important challenges set out by the European Union "Digital Transition" goals, while at the same time having a beneficial effect on the competitiveness of the European space sector as a whole – particularly in the aftermath of the Covid-19 pandemic. This third European Flagship, officially launched by the European Commission, will help Europe to remain a leading international player with freedom of action in the space domain, and will support the competitiveness and innovation capacity of space sector industries within the continent. Most importantly, Europe's legitimate goals in terms of strategic autonomy and security of its communications would be ensured. **After its upcoming endorsement via a legislative amendment to the "EU Space Programme Regulation", the European space-based Global Secure Connectivity System needs to be rapidly implemented and to leverage on EU and ESA capabilities.** Indeed, the urgency to implement this new Flagship, based on a mature service coverage, system architecture and deployment schedule, allowing to plan and to engage the appropriate European-based technological developments and industrial investments is key. Thanks to the existing European industry assets and to its experience on commercial mega-constellations systems, the European space industry believes that a first system can be deployed as early as 2025.

Achieving the objectives of the "Green Deal" and ensuring Europe is "fit for the digital age" are also strong drivers for a significant increase of the European space budgets. Europe will be able to catch up with the other space powers (the USA and China especially) by tripling the collective efforts. To motivate such a change of scale, new Flagship Programmes that can both inspire the new generations and support the economic and social development of Europe and its influence in the world are to be proposed.

Europe must contribute to the sustainability of activities in space.

Europe must democratise the use of space data.

Europe must follow a spirit of discovery and push further the frontier of space.

Under the four headlines[1] of "Sustainable Space", "Space Data for Citizens", "European spirit of Space discovery", and "Active contribution of Space against Climate Change" that speak both to the European leaders

[1] *Headlines and associated priorities are not restrictive i.e., new Flagship Programmes concepts may answer cross-cutting priorities (in addition to the ones supported by the headline in which they are referenced).*

and to the general public, the European space industry is proud to propose several concepts for new Flagship Programmes for implementation (the order of importance is of course left to the democratic institutions).

In order for the new Flagships to be further defined and assessed for feasibility and relevance for European society, the European space industry believes that a budget of around 200M€, to be committed by ESA Member States during ESA Council meeting at ministerial level of 2022, will be necessary to fund Phases O/A/B1 of the mission lifetime cycle.

Industry, which is already largely "Europeanised" today, acknowledges that the governance of space in Europe is complex but does see as an opportunity that efforts of Member States can be consolidated at intergovernmental level to prepare the ground for new capabilities that can eventually be "magnified" and sustained at supranational – EU – level at a later stage. Copernicus, for instance, is an infrastructure offering unparalleled scientific public services, that would not have been achievable without the combined efforts of multiple public European stakeholders. This is a European strength, upon which new flagship programmes can be built and this is the reason why Industry strongly supports the initiative taken by ESA Director General.

Sustainable Space

Space Traffic Management

Rationale for action:

The number of satellites in orbit around the Earth is deemed to increase exponentially fuelled by the planned mega-constellations trend. Space Traffic Management (STM) will be more than ever needed and international regulations will progressively become a necessity (despite international consensus being slow to achieve). Europe, as a space power, shall be at the core of the negotiations of the regulations and have its sovereign means to monitor the situation and offer a reliable service that provides both institutions and private operators an alert system enabling to react pro-actively in some cases, via e.g., orbital manoeuvres or debris removal. STM is needed to ensure long term sustainability and safety of space activities and businesses in an increasingly congested and polluted environment, to safekeep European strategic autonomy in accessing to space, to promote European technological leadership and to foster the development of new services and applications.

The issue is extremely complex with a diversity of actors at national, European and international levels, with emerging national regulatory requirements, multiple layers of required action, from ground and space monitoring solutions and sensors to active debris removal technology proposals to evaluate.

Europe, with ESA and the EU, is in a unique position to promote the emergence of a system that is driven by civil needs and is not hampered by the strategic dominance of nationally promoted initiatives (indeed, initiatives driven by military concerns can be less inclined to be open to international cooperation).

The STM framework is a subset of the currently Space Situational Awareness (SSA) activities that are initiated by various EU and Member States (also in a defence context).

What is to be expected?

A unification of the SSA, SST and STM civilian activities under a fully coordinated EU-ESA flagship programme would be a unique opportunity for Europe to weight on the international regulations to come, to federate and grow the European SSA/SST surveillance system from a ground-based system to a ground- and spaced-based system, to enable and maintain a EU-Centric Space Domain Common Operating Picture, encompassing threats from space objects, space weather and RF interferences, to develop a more reactive and autonomous STM approach, and to develop active responses in the form e.g. of autonomous orbital manoeuvre, on-orbit spacecraft monitoring and surveillance and active debris removal systems, possibly in synergy with other in-orbit services and operations (e.g. orbital maintenance, refuelling, assemblies etc.).

Building on the relevant European industry capabilities (i.e., Ground radars, optical telescopes, sensors, autonomous robotics systems, services delivery, data processing) a new flagship could federate energies in Europe through a stepped approach in time: promote a European-led orbital information service for the World, drive the consolidation of STM regulations at European, then at international levels, deploy a space-based SSA system as part of an overall SSA/SST system of systems architecture, and the associated services, and develop an operational debris removal capability around the middle of this decade.

The European Space Agency and the European Commission could jointly lead the way towards a first operational STM system by 2025, to be progressively completed and evolved going forward.

This endeavour will require different mandatory flows:

- The development of a regulatory framework by the European Institutions and Member States, notably aiming at fostering the creation of an internal European market for SSA data and STM services;
- The development of new standards;
- The creation of dedicated ESA/EC programme lines to:
    - Design the overall end-to-end architecture of such STM programme;
    - Design, develop and launch the necessary space and ground infrastructures not planned in any national programme;
    - Develop unique European space-based SSA capabilities to monitor space assets, through:
        - A "European Satellite Monitoring Patrol" in the form of a highly manoeuvrable small satellites swarm which could inspect and monitor the safety of European assets in space;
        - European ground and in-space SSA capabilities, for example based on ongoing studies on SSA sensors, SSA C2 and space-based early warning systems.
    - Design and implement a European SSA/STM service platform which would:
        - Interface with national and private SSA/STM solutions;
        - Interface with satellite operators and commercial providers to gather ancillary data (satellite information and status, orbits, launch trajectory…);
        - Ensure data management, quality and integrity;
        - Archive data and interface to secure storage;
        - Ensure data distributions to institutional and commercial users' quality within defined Service and security level;
        - Allow processing and the development of third-party applications and hosted services.
    - Act as anchor customer in order to possibly trigger national and private investments, both at SSA/STM assets and services level.

Timeframe:

First operational STM system by 2025, to be progressively completed and evolved going forward.

Resilience of the European space infrastructures

Being able to assess the space environment and to actively manage traffic in space are indispensable measures to reduce the risks of accidents, damages, and loss of unique space assets. Nonetheless, given the increased reliance of Europe on space-based capabilities (for societal, strategic and economic reasons), it is of key importance to ensure an adequate level of resilience of the whole European space infrastructure, including allowing for a quick capabilities' recovery and restoration from any kind of potential accidents.

Rationale for action:

A Flagship Programme to increase the resilience of the European space infrastructure, so to ensure continuity of European space-based services from all domains (EO, remote sensing, surveillance, navigation, satcom) for European institutions and decision-makers.

What is to be expected?

The Programme would be based on different components:

- Augment the resilience of European systems in space by developing satellite platforms and payloads suited with independent and intelligent situational awareness capabilities, through: on-board sensors, manoeuvre abilities, inspection capabilities...;

- Ability to quickly deploy or replace lost space assets (due to natural or human-related causes) with responsive space launch capabilities, by developing standardized satellites platforms, and interfaces to serve different missions, which could be stored at different ground infrastructures in Europe and quickly launched to space by:
  - Air-launched systems[2] that could quickly deploy (launch within 48 hours) very small payloads (up to 300 kg).
  - Vertical mini launchers that could deploy (launch within 7 days) small to medium payloads (up to 1200 kg).

Users:

The different components of the Programme would benefit any European institutional entity, governmental, military or civil, who owns or uses critical space assets, as well as European commercial operators.

The need to enable a common EU Operational Picture, possibly involving both SSA and STM should also be considered.

Any existing and future European institutional satellites and infrastructures will benefit from the overall increased resilience to natural or human-caused threats, reducing the risk for accidents, loss of sovereign capacities and enabling higher continuity of services.

The enhanced in-space SSA capabilities would also grant Europe the capacity to monitor and ensure global compliance with current and future international Space Traffic Management (STM) and space debris regulations, as well as EU regulations and standards - in a similar way as the Copernicus CO2M for global carbon emissions monitoring.

Space activities and environment sustainability

Rationale for action:

Satellites have become an essential part of our daily life, from predicting the weather to monitoring climate change, from providing navigation to connecting people everywhere in the world.

As of mid-August 2021, around 7500 satellites orbit around the Earth among which around 5000 are still operational. ESA reports the number of debris as 36500 debris objects greater than 10 cm, 1000000 objects from greater than 1 cm to 10 cm, and 330 million objects from greater than 1 mm to 1 cm[3]. Not only has the number of satellites doubled over the last 3 years, but also the amount of space debris.

It is forecasted that in the order of 10 000 satellites could be launched in the next ten years, supported mostly by the emerging mega-constellation trend. This will increase the congestion of the orbital environment, in particular where it is already most congested, in the lower earth orbits.

Future space missions need to be smarter and innovative in order to counteract and better manage the future in space.

What is to be expected?

A new flagship programme targeting sustainable space should focus on the future of space systems and therefore foster activities answering global sustainability. This goes from managing the legacy satellites and

[2] *Air-launch orbital capabilities are location-agnostic (can be served by any suitable airstrip) and the launch campaign, which includes standardized payloads and pre-stored spacecraft, is in the time-frame of hours or days, rather than the months required for medium and large launchers.*
[3] https://www.esa.int/Safety_Security/Space_Debris/Space_debris_by_the_numbers

their end of life to changing the paradigm of the design of future satellites with in-orbit assembly and manufacturing, also through recycling, to improve their life cycle management with a more frequent access to space adding transportation needs.

The following four pillars presented could dovetail into a flagship programme:

- On-Orbit Servicing for life extension and end of life management:
  - Direct management of satellites while they are operating in space by enabling refuelling, scalability and modularity with unit upgrade capabilities to counter obsolescence. As a result, their lifetime will be extended and the necessity to send up a new satellite to fully replace it will be delayed;
  - A low orbit depot of satellite propellant could be developed to demonstrate in orbit refuelling;
  - The servicers provide an end-of-life removal solution either by tugging satellites into their graveyard orbit (GEO) or by putting them back towards the Earth for them to disintegrate in the atmosphere (LEO);
  - Development of a regulatory framework by the European Institutions and Member States to ensure that deorbiting system and capability are mandatory for each and every spacecraft;
  - Ensuring that standards are developed worldwide for interoperability of in-orbit servicing and refuelling:
    - Satellites need already to be prepared today with specific standard interfaces and grapples fixtures in order to better enable these new advanced operations in space like refuelling, upgrading, or payloads plug&play implementation allowing mission evolution;
  - As a complement, the Satellite life cycle management shall be pursued through e.g., standardisation of the interfaces, digital twin satellite at design and test levels and implementation of miniaturisation;
  - A European sovereign solution is key in order to avoid a foreign solution approaching European assets.
- In-Orbit production for space assets optimisation:
  - Manufacturing and assembly in space with an orbital factory that will create the space assets of tomorrow;
  - In-Orbit manufacturing will allow optimised sustainable satellites and space infrastructures manufacturing thanks to the possibility to launch raw material instead of system/components that have to sustain launch loads;
  - As a further step, use of in-situ resources as well as waste management and recycling to-be-dismissed satellites will even further strengthen sustainability and green space approach;
  - In-Orbit Recycling will close the loop of the entire circular process, because the mostly used raw materials will be recovered from the expired satellites or converted to propellant at End of Life (wide range of benefits, partially solving the problem of in orbit waste).
- Autonomous controlled re-entry for end-of life requirements:
  - Advanced techniques for controlled re-entry making use of new design drivers based on smart propulsion subsystems as well as new concepts of reliability in space for constellations;
  - For environmental reasons, satellite propulsion should shift from chemical to electric.
- Demisable materials for low impact and guaranteed risk-free end of life operations:
  - Enhance the usage of demisable materials in the design of the satellites, creating a certification standard related to reliability metrics;
  - Design and develop an operational debris removal capability;

- Key advancements in end-of-Life demisability and compliance will prove to be a great asset in the support to the evolution of ESA Cleanspace into an ambitious Programme.

It is worth mentioning that the new EU Space Regulation recalls that "*Space debris has become a serious threat to the security, safety and sustainability of space activities*". The SST sub-component is therefore essential to preserve the continuity of the Programme's components and their contributions to Union policies. In that context, it could support the preparation of European Earth orbit "clean-up projects".

Users and timeframe:

The new flagship programme shall therefore enhance the sustainability of space activities as well as space environment, by implementing appropriate measures, including development and deployment of technologies to secure our sustainable future.

A legal framework for these future activities with standards and regulations is needed from the institutions (for instance, the space debris situation is not yet regulated at international level). All these new initiatives will enable Europe to spearhead a paradigm shift towards sustainable space development.

The evolution towards standardisation to foster cost-saving solutions and resource re-use is a mirror image of what is on-going on Earth. Therefore, it will benefit for and from similar companies working on terrestrial applications such as waste management, digital twin implementation for testing and validation, robotics and artificial intelligence that can be brought into space.

European Orbital Platform (Platform as a Service)

Rationale for action:

The rationale would be to provide a simplified, standardised, lower cost access to orbital assets to validate and develop space related applications and business cases. The European orbital platform would be a long duration shared facility, able to accommodate a variety of missions and payloads throughout its extended operational lifetime taking advantage of modularity and plug & play approaches.

The programme would deploy a large carrier Platform in LEO with the purpose of deploying operational EO instruments, scientific experiments, slots for IoD/IoV, and a variety of further applications depending on the choice of payloads by institutional and commercial customers.

What is to be expected?

The concept would be very similar to an external platform on the ISS but on a much larger scale. It would host several slots of different standard sizes, with standardized interfaces for thermal, mechanical, power, data handling, pointing (e.g., gimbal).

Payloads can be brought to the Platform by a kick-stage type spacecraft, handled and set up in place by a robotic arm, and safely removed after their useful life by a services spacecraft, and returned to Earth when deemed necessary through an atmospheric re-entry vehicle.

The benefits of such a Platform would include:

- Excellent usage and further development of European robotics capabilities, including on-orbit servicing, operations, and assembly;
- No need for a dedicated mission/platform for each payload;
- Ability to fly payloads at a much lower cost;

- Modular expansion of the Platform capabilities to cover additional services, such as intersatellite links;
- Create a market opportunity for European launchers, micro-launchers in particular (launch of payloads and kick-stages);
- Interoperability of a range of payloads in the same orbit (particularly useful for EO due to correlation of data at the same timestamp);
- Return to Earth capability for the payload.

Space Data for Citizens

Space-based system of systems for real time services (real time data monitoring overlay system) – complementing and augmenting the Secure Connectivity Initiative

In the definition enforcing the scalability of the new Secure Connectivity Initiative (third European Flagship after Copernicus & Galileo/EGNOS), the integration, on top and at a later stage, of such a space-based system of systems for real time services complementing and augmenting the Secure Connectivity Initiative shall be foreseen.

Rationale for action:

The idea is to evolve in the definition for a global environment able to integrate current EO satellite data but more importantly to provide guidelines for future systems. Those future systems shall adhere to a concept that will allow the integration of information from multiple missions and the delivery to the final users of EO based information in the same way as the navigation information is delivered today.

This proposal, "mission of missions", will benefit of a mega-constellation concept and will facilitate directly added-value applications for emergency and security services and industrial verticals by integrating separated services. It will provide extensive coverage and enable real-time applications based on the combined used of different constellations and multiple payloads.

What is to be expected?

This Flagship Programme foresees the development of space and ground infrastructure integrating different missions to obtain EO satellite and alerts data in real time to meet the requirements of critical services and to be distributed to the users as soon as available.

Space, ground and user segment concept has to be revisited.

It will require the enhancement of current space segment concept (both EO and communication) developing in-space services that could be directly accessed from users through mobile terminals that establish communication with the signals broadcasted by the satellites. The possibility for users to be able to elaborate data to reduce the data calculation footprint on Earth should also be considered.

In addition, complex and evolved ground segments should allow big data communications (ground segments will have higher capabilities for networking, processing huge amount of data, providing real-time services, system of constellations automated control and planning).

Complexity of network of ground segment and development of inter-satellite services will allow expanded coverage. Added-value information could be disseminated to users through web-portals (ground dissemination) or directly to mobile terminals from satellites. Also, satellites should be seen as possible users (e.g., EO satellite to use this system to send out data).

The current space segment concept (institutional and commercial missions willing to adhere to the future system) will be complemented with:

- Communications inter-satellite (data relay systems and synchronization and distribution of clock signals to other satellites);

- Standards definition for satellite interlink;
- On-board automation and processing capabilities for in-space services (including AI capabilities) to provide ready-to-use products;
- Re-configurable and flexible payloads (coverage, frequency bands

The current ground segment concept (institutional and commercial missions willing to adhere to the future system) will be complemented with:

- The current Ground station network has to be updated in order to download the data and process them in real time (antennas with capabilities fast-reconfiguration and processing of multiple beams in parallel);
- Integrated Mission Planning to check the availability of the ESA and contributing missions and ground stations;
- Automated Control capabilities to operate system of systems of constellations;
- Real Time data processors adapted to services and needs of the services.

The user mobile terminal will allow direct signalling to user from Satellite.

There are several technological challenges to address:

- The combined processing of images coming from different payloads from different satellites (both on-ground and in-space providing services directly to users' terminals);
- On-board automated processing capabilities;
- Standardisation of inter-satellite communication;
- Flexible and re-configurable payloads;
- Higher bandwidth efficiency for the communications (satellite-ground segment);
- Satellite backhauls to expand coverage for mobile services.

Users and timeframe:

The system shall take advantage of the existing infrastructure (UE, ESA and national) building an open system of systems where new elements can be added both from private and public initiatives.

Emergency bodies, Search and Rescue, Maritime security applicable to most industries (i.e., agriculture, forestry, mining, fires monitoring, ocean plastic pollution detection including video) are as many potential users of such a Programme.

In terms of timeframe, several steps are foreseen:

1. A study must be carried out about the real-time needs and the gaps that could be fulfilled with space technology;
2. Analysis of the existing ESA and Third-Party space infrastructure that could contribute to Real Time System of Systems;
3. Identification of the missions that should to be planned to fill such gaps together with the ground segment and in-space services;
4. Concept Demonstration: Ground Segment definition and set up to prototype and validate the concept based on the current space infrastructure;
5. Operational Deployment: Based on the identified missions needed to fill the gap, design and implement the steady deployment of the space segment needed to reach a full operational system.

Precision Mobility - GNSS complement based on LEO Satellites

This proposal leverages, and augments, on the existing Galileo/EGNOS Flagships Programmes

Rationale for action:

Most GNSS systems rely on MEO constellations comprising several tens of satellites to provide global coverage. On top of these MEO constellations, regional service augmentations have been also developed throughout the years relying on a few GEO (Geostationary) or IGSO (inclined Geostationary Orbit) satellites flying at higher altitudes. Local augmentation services using ground-based infrastructures also exist.

GEO/IGSO satellites can provide additional ranging signals, a communication channel for the broadcast of augmentation data or a combination of both.

Current GNSS systems, including GEO/IGSO based augmentations have a number of known limitations, mainly with regard to service resilience to interference and external attacks (jamming, spoofing), and limited capability to transmit data for value added services such as high accuracy.

A GNSS complement based on LEO satellites could overcome the mentioned limitations and bring additional advantages as outlined below.

Several studies and initiatives (private and public) are currently ongoing to develop LEO-based GNSS complements targeting specific applications and market niches impacted by current GNSS limitations.

What is to be expected?

The main anticipated advantages would be the following ones:

- Increased robustness of transmitted signals, in terms of increased power and cryptographic protection.
    - The increased power would offer additional resistance to interference and make it to possible to provide PNT (Position, Navigation and Timing) services in scenarios and applications where current GNSS is limited, such as indoor or underground/under water scenarios. The cryptographic protection would make the signals more robust to intentional attacks.
- Increased data broadcast capacity:
    - The current bandwidth offered by GNSS satellites for data broadcast is limited to 200-500 bps. A careful selection of the signal modulations could make it possible to increase the data rate up to a few kbps. The increase data rate would make it possible to transmit data for added value services such as high accuracy services with fast convergence (which requires the transmission of very fast update of atmospheric corrections).
- Fast convergence in high accuracy applications:
    - The faster LEO satellites motion has been anticipated to offer significant advantages in high accuracy applications based on the PPP (Precise Point Positioning) technique, making it possible to reduce the convergence time and discriminate large multipath errors.
- Potential integration with communication services:
    - LEO constellations are also employed in space-based communication systems (e.g.; Iridium, Globalstar, etc.). The combination of a PNT capability with a two-way communication capability would offer significant advantages in many applications such as for instance, IoT or asset tracking related applications.
    - Satellites autonomy:

    - LEO satellites can benefit from the PNT services provided by higher altitude GNSS constellations, so that certain functions such as orbit determination and time synchronization are carried out autonomously onboard, thus simplifying the ground segment complexity.

The main anticipated technological challenges would be the following ones:

- Signals to be transmitted through LEO satellites:
    - The signals transmitted by LEO satellites shall be fully compatible and interoperable with current GNSS systems. Consequently, a careful selection of bands and modulations is essential to ensure the success of the concept and avoid interference.
- Integration at receiver level:
    - GNSS adoption success has been motivated, among others, by the availability of low-cost high performance receiver chipsets and integrated receiver solutions. The new LEO signals should be easy to integrate in currently existing receiver solutions to facilitate adoption by users.
- Cryptographic signal protection:
    - With the exception of GNSS governmental services like GPS-M code and Galileo PRS, GNSS signals are usually transmitted on an open basis freely accessible by all users. While the new LEO signals could be encrypted to offer additional resilience to external attacks (e.g.; spoofing, meaconing), the cryptographic protection should be such that could be potentially adopted by all users and not only restricted to governmental users.

Users and timeframe:

Premium PNT applications requiring:

- Enhanced signals robustness and resilience;
- Signal reception in scenarios not currently served by GNSS systems (indoor, underground, under water);
- Integration with 2-way communication channels with high data rate.

The above-mentioned premium applications could include, but not limited to, governmental applications.

The development of the proposed LEO system could be developed in 3 phases:

1. Phase 1 – Concept Demonstration:
    - The concept would be demonstrated in a laboratory environment complemented by signal transmissions in a controlled ground environment (e.g., making use of pseudo satellites). The estimated duration of this phase could be around 2 years;
2. Phase 2 – In-Orbit Demonstration:
    - A few LEO satellites (4 as minimum, ideally 20-30) would be launched to demonstrate and validate the concept with real signal transmissions from space. The estimated duration of this phase could be around 2 years;
3. Phase 3 – Full Deployment:
    - A full LEO constellation capable to provide independent PNT services may require the launch of 200-300 LEO satellites. The deployment of such a large constellation would be a challenge in terms of production and launch schedule. The full deployment of the constellation could take up to 5 years.

Very High Resolution EO Data constellation – including and leveraging on Copernicus

This proposal leverages on, and augments, the existing Copernicus Flagship Programme.

Rationale for action

Digital twins are expected to impact every industry by enabling real-time comprehensive oversight over physical objects, products, systems and processes, be those satellites and constellations, vehicles, manufacturing processes and supply chains, built infrastructure or entire cities. This enabling drastic advances in efficiency, predictive, design and simulation capabilities.

In addition to Digital Twin Earth programme, the proposal is to deploy a constellation of small satellites to provide very high-resolution (VHR) EO data with frequent revisit times, to overcome the current European dependency on foreign-provided data and increase Europe's autonomy in space-based monitoring services for its environmental and security strategic goals.

Such a proposal, intended to augment the EU Copernicus programme, could possibly benefit from existing capabilities and infrastructure already located within the European space industry and developed for commercial and institutional customers.

What is to be expected?

Specifically, the programme would be composed of:

- A space segment with two types of small satellites acquiring very high-resolution data, relying on, but not only:
    - Multi- or superspectral optical sensors;
    - X-band Synthetic Aperture Radar (SAR);
    - Automatic Identification System (AIS).
- A ground segment to operate the space segment and to process, archive and disseminate the data/services to the users.

Users and timeframe:

Such a Flagship Programme targeting a Very High Resolution (VHR) EO Constellation would represent a significant step forward for Europe in terms of sovereignty for citizen's security purposes, and would be the basis for services related to:

- Border and coastal security, coordination of emergency support to crisis regions after environmental hazards (incl. consequence of climate change), terrorism prevention, cyber and energy security, tackling organised crime, etc.;
- Cooperation with non-European states could be envisaged in order to reinforce Europe's position as worldwide strategic partner;
- A system-of-systems approach would enable the enhancement of already running programmes like Copernicus.

A rough estimate of the budget and timeframe required to develop, build and operate such a solution has been estimated in the frame of the METEOR study (joint EDA/ESA initiative).

Dedicated EO Constellation for Maritime Surveillance - including and leveraging on Copernicus

This proposal leverages on, and augments, other initiatives on Maritime Surveillance and the existing Copernicus Flagship Programme.

Rationale for action:

Maritime Surveillance involves all domains of sea-carried human activities, from the shore line to deep blue sea (e.g., navigation, fishing, research & exploitation, trading, immigration, illegal pollution, smuggling, drug trafficking, security & intelligence, sovereignty).

As a blue border, Maritime surveillance requires therefore a precise, reliable and permanent knowledge of traffic and its trends, and of the operational activities operating offshore or in the coastal waters, in order to anticipate any action at sea. Historically coastline and ship-based, Maritime Surveillance relied upon shore coastal observation and/or aircraft. It is now complemented by space (AIS + imagery) and unmanned systems assets.

Consolidated user's needs expressed by the Maritime's users' community (e., European Maritime Safety Agency - EMSA) have identified the operational concept and major requirements for a global solution, addressing:

- Worldwide coverage, costal & high sea;
- All weather conditions, day and night capabilities;
- High revisit, up to permanent monitoring;
- Systematic recurring and on-demand images acquisition and data;
- Timeliness of data to match reaction efficiency;
- Detection, tracking, characterisation and identification;
- Cooperative as well as non-cooperative vessels;
- Cost efficiency and affordability of the system;
- Interoperability of the various systems, software and hardware with existing assets;
- Secured solution (cyber protected) benefiting from latest data analytics/mining technology;
- Decision support tool or data (analytics) simplifying the access and analysis to the heterogeneous and huge datasets, supporting the work of analysts and operators while helping to focus on operational activities (actionable insights).

With respect to these needs (for a global coverage), some gaps have been identified considering the existing relevant assets:

- Terrestrial infrastructures with a limited range of operation i.e., basically ground radar range;
- Navy's vessels with a very limited range of operation around the vessel itself;
- Air patrolling systems on demand with a limited duration of operations in the order of hours;
- Automatic Identification System (AIS) satellites with limited performance/revisit and a non-guaranteed data reliability (data collision or spoofing);
- Radar/optical reconnaissance or environmental satellites e.g., Sentinels which can be tasked on demand for maritime surveillance purposes, with low revisit (days) and a timeliness adaptation (hours);
- Decision support systems for the exploitation of EO satellite derived products merged with commercial AIS (terrestrial and satellite) for the detection of cooperative and not cooperative vessels and anomaly detection.

To cope with the aforementioned gaps, a dedicated constellation of small Synthetic Aperture Radar (SAR) satellites with Radar sensors specifically designed to guarantee large swaths acquisitions as well as high resolutions for identification and tracking has been recognised as the best solution. The overall end-to-end system (including ground stations and data-exchange digital infrastructure) shall be based on advanced cloud and cybersecurity items, in order to cope with civil and military applications.

Such a proposal could possibly benefit from existing capabilities and infrastructure already located within the European space industry and developed for commercial and institutional customers.

What is to be expected?

Specifically, the programme would target a constellation system with the following characteristics:

- Working in conjunction with existing Copernicus capacities (for detection S1 and S2 or S3 for sea environmental conditions);
- Various constellation potential configurations:
  - Homogeneous constellation based on the same type of satellite/sensor deployed for maximum revisit with same nature/performance of acquired data;
  - Heterogeneous constellation based on various instance of the same sensor class (for instance combining, low resolution with large swath with high resolution and reduced swath SAR satellites);
  - Hybrid, combining in a single constellation different satellite sensors deployed in a common operational scheme.
- Staggered deployment allowing at the same time constellation maintenance and improvements:
  - For instance, a constellation of SAR small satellites which may be built from an initial capacity of 6 small SAR satellites, growing progressively to a typical 20 satellites for very high revisit performance and augmented area coverage.
- These constellations shall be composed of following assets:
  - Efficient and affordable Earth Observation small satellites being launched in groups;
  - Various mission and sensor satellites:
    - SAR Small satellite with X-band Synthetic Aperture Radar (SAR);
    - Optical Small satellite with GSD up to 50cm;
    - Permanent monitoring optical geo-satellite (weather but also observation);
    - IoT satellite or embedded payload for Automatic Identification System (AIS) + VDES.
- A Multi-mission and multi-sensor ground segment to operate the space segment and to process, archive and disseminate the data/services to the users:
  - Advanced big data analysis supported by advanced data exploitation and fusion algorithms like Artificial Intelligence;
  - Cyber-secured system to guarantee all along the value chain the integrity, reliability and reliability of the data and generated information.

Users and timeframe:

Such a programme targeting a dedicated constellation for Maritime Surveillance would represent a significant step forward for Europe:

- To develop a solution which fulfills the full range of the European needs (e.g., migration, trafficking, smuggling, crisis management, environment monitoring);
- To develop a European sovereign solution;
- To implement a staggered and affordable approach;
- To generate the emergence of a sustainable public/private based service.

The proposed solution shall respond to users' community needs (e.g., institutional entities, EMSA, insurance companies, logistics companies, fishing control entities,). It would enable a worldwide coverage using a dedicated maritime surveillance system with adapted tasking and timeliness performance, with high revisit capability (down to 1 hour or better), and guarantee tracks continuity reconstruction anywhere. Satellite image resolution is adapted to detection, characterisation and identification. Data validity/reliability are guaranteed (cross-checked AIS/VDES payloads) by big data and cyber-security compatible data treatment centres. Inter-operability and complementarity with other maritime surveillance assets shall be guaranteed as well.

A staggered approach can be used for the development of the System of Systems solution based on different components:

- High-efficiency and high-performance observation satellites;
- New constellations for innovative AIS & data collect missions (AIS-X, VDES);
- Evolutive ground segment and data processing centres.

European spirit of Space discovery

Human spaceflight

Rationale for action:

All major spacefaring nations (i.e., USA, China, Russia, India) target long term human presence in space, with established plans for the Earth orbit and beyond (Moon and Mars). The USA and China have well established exploration roadmaps now, with Moon settlements before the end of the decade. For them Mars is more than just a long-term ambition: both China and the US have active rovers on the Mars surface and are planning to further collect scientific data in preparation of future human landings.

Europe is currently bartering with the USA its astronaut flights against the provision of space hardware. The role of Europe in Exploration might become marginalised in the future when numerous human spaceflights to LEO and the Moon will be launched.

This is why developing a human space flight independent capability should be a goal for Europe, in a world where space capacity will be a key asset for playing a role in the booming space economy altogether with reinforcement of global influence. Securing independent access to space for human missions for European astronauts will serve many objectives i.e., exploration, science, Lunar activities, space mining and resources, in-orbit manufacturing and operations, but it will also enable capabilities for other future applications like point-to-point space transport or space defence.

Europe cannot afford not being part of this evolution, or to simply take a back seat.

What is to be expected?

This endeavour can be prepared incrementally, based on strong existing assets. The European industry is already involved in human spaceflight, via ISS Programmes. It develops the Orion European Service Module (ESM) and highly reliable launchers.

Europe should aim for the development of a full-fledged human-rated and cargo space transportation capability that will allow Europe to catch up with the USA & other major spacefaring nations. It would own a civil (and potentially dual use) strategic asset for the development of critical technologies, and renew the European pioneering spirit through a flagship project.

The vehicle, fully developed in Europe, will notably leverage on:

- European crewed capsule and cargo capabilities derived from past programs/studies (e.g., ATV, Hermes, X-38 CRV, Columbus, ARD, IXV, Orion ESM, Space Rider);
- Re-entry capabilities (e.g., IXV, Space Rider...);
- All the investments made for European launchers, e.g., in propulsion that would require minor adjustments to serve human rated flights;
- All skills developed in aeronautics;
- The European spaceport(s).

An ambitious flagship programme targeting human spaceflight shall put all the necessary means to:

- Adapt European launcher for crewed and cargo flights within a stepped approach;
- Need to develop a rigorous end-to-end safety process to protect our European astronauts;

- Develop a human rated vehicle based on strong European heritage, with a versatile design to enable an array of missions, including: cargo to the Moon, habitat and transfer modules;
- Develop space infrastructures to create Space Highways in the Solar System starting from the infrastructures serving routes between Earth and Mars;
- Develop innovative and critical technologies to raise the standard of European access to space and embrace growing in-space and from-space applications;
- Adapt European Space Ports towards new access to space services, and in particular human launch;
- Develop life support techniques (air and water revitalisation). These technologies would also benefit on Earth in response to the increased need for more circular economy.

Users and timeframe:

Such a programme will serve both institutional and commercial human-rated and cargo transport demand for:

- LEO orbits (e.g. to ISS, commercial stations and free-flying missions) with versatility to address cargo as well;
- GEO orbit (e.g. In-Orbit Data Centres, Solar Power Stations);
- Lunar destinations and beyond.

European private sector would gain access to a rapidly growing market of significant strategic interest, and spin-offs would be created (e.g., point-to-point transport, reusable Upper Stage, full reusability).

Institutions would master all required space capabilities to secure European participation in relevant fields of growth and future sovereign questions (e.g., industrial policy, access to resources, future growth).

A first flight in LEO could be demonstrated before 2030.

Oxygen/Hydrogen in-situ production and distribution for a sustainable presence in Space

Rationale for action:

In-space production of O_2 and H_2 would be the cornerstone of multiple on-orbit operations and exploration-related applications such as long-term space transportation (O_2/H_2), life support (O_2), energy production and storage (H_2). It is a critical enabler solution for long term planetary exploration goals.

It would enable, e.g., the life extension of launch vehicle upper stages to support orbital operations, debris reduction, reduced mission Total Cost of Ownership as well as allowing a sustainable presence in space.

If Europe positions itself quickly on the implementation of gas and cryo refuelling stations in orbit, this could give Europe an agnostic federating and transversal role and promote collaboration between other space powers such as the US, China, and Russia.

Finally, the development of these technologies for space would benefit energy transition on Earth via spinoffs. Would be of particular interest to all aspects related to the emerging hydrogen and fuel cell economy.

What is to be expected?

The demonstration and the set-up of O2/H2 in-space production and distribution infrastructures would require three steps:

1. Step 1: Orbital demonstration basic technology building blocks

   - Sending water as "passenger" in unused volumes of the launchers;
   - Demonstrate
      i. Water storage in orbit;
      ii. Electrolysis in orbit into O_2/H_2;
      iii. Liquefaction;
      iv. Transfer/refuelling to spacecraft in orbit;
   - ➢ Premise of a deposit of rocket propellants in orbit.
2. Step 2: O_2 in situ resources for processing, e.g.
   - Demonstrate:
      i. O_2 extraction from Lunar regolith;
      ii. O_2 Storage;
      iii. Refuelling of lunar vehicles;
      iv. O_2 transfer to on-orbit propellant depot;
3. Step 3: H_2O in situ resources for processing
   - Demonstrate:
      i. H_2O extraction from the Moon;
      ii. H_2O Electrolysis
      iii. Transfer O_2/H_2 from the Moon to the different propellant depots in orbit
      iv. H_2 for on orbit energy production

Users and timeframe:

The implementation of H2O, O2, H2 value chains in space from space resources could completely reinvent the way space missions are designed, by being able to go deeper, stay longer, extend the lifetime of spacecrafts, and consequently reduce again the cost of access to space.

The users will be rocket upper stages for long duration transportation (O2/H2 refills), manned spacecrafts (H2O and O2 refills for life support), lunar surface mobility (H2 energy), and every process requiring energy in orbit or on the Moon surface (H2 Energy).

The processing of in-situ lunar resources could be demonstrated before 2030.

This would address the sustainability of space activities, reducing carbon footprint on Earth and debris production in Space, for the benefit of international cooperation associated with Europe leading the path forward on sustainability. Being at the forefront of these technology and solution developments would strongly benefit Europe's space economy and industry, and foster a needed cross-sectoral collaboration (space and non-space industries will be needed to build end-to-end value chains).

Europe should be an actor in the exploration and governance of the space resources on the Moon. It should reaffirm the values that should structure the current and future lunar momentum, in particular the multilateral approach and sustainable development.

Moon economy - Science and exploitation

Rationale for action:

The Moon race is currently dominated by the USA and China, with Europe (via ESA) being a partner to the American programme (Orion, Gateway) and studying future important elements (lander, cargo) and considering taking parts in the Chinese and Russian International Lunar Research Station (ILRS) programmes. However, a permanent presence on the Moon in the long run will only happen with some key drivers, such as science, research, pride, political and societal ambitions, geo-political considerations (the new 'space race') and with unlocking the critical enablers, in particular the harnessing and exploitation of local in situ resources. An important contribution to these goals should be envisaged if Europe's role is to be more than a supplier to American or Chinese programmes.

For an effective exploitation of the Moon from both a commercial and scientific viewpoint, the availability of suitable infrastructures for telecommunication, navigation, resource generation and delivery is mandatory. Europe could therefore reinforce its role by investing on them.

What is to be expected?

The European industry has world-class unique capabilities which are fully relevant to develop the "Moon economy": lander technologies (from exploration), surface mobility with rovers, space astronomical payloads (optical or radio) that could be installed on the far side, unique in-situ resource technique to extract water, radioisotope power sources or Regenerative Fuel Cell Systems to survive the lunar night, communications and navigation satellites, etc.

A commercial market for the Moon exploitation will take some time to establish and European institutions could foster this development by funding the first steps of exploitation (communications, surface mobility, science, resources) and support the European industry to propose services to the future Moon base in the next decade.

Among the above-mentioned needed technologies, the electric power distribution to the users across the lunar surface is one of the fundamental services to be provided. The development of a network of wireless transmitters/receivers (e.g., via laser or RF beams) that transfer the power from the solar power plants operative on the daylight hemisphere of the Moon surface to the users in the night zone (e.g., human outposts, scientific observatories) can provide the solution to this issue.

Two possible solutions exist:

1. Produce electric power on the Moon surface;
2. Produce the electric power in Moon orbit and deliver it wireless on surface.

Some studies and first prototypes have been carried out in the past, the demonstration and set-up of these solutions would require two steps:

1. Step 1: prototype and demonstrate the solutions on Earth with an on-orbit test to evaluate the possibility and performances;
2. Step 2: deploy the solution(s) on the Moon surface and/or orbit on time with regard to the commercial and scientific missions. The deployment should be done step by step growing with the demand of power and energy.

Users and timeframe:

Such a programme will serve both institutional and commercial Moon mission demand for power and energy on surface.

The European private sector would gain access to a rapidly growing market of significant strategic interest, and Europe could play a significant role in the Moon race (and beyond) as provider on a vital infrastructure for Moon colonisation.

A first on Earth demonstration should be targeted before 2023 with a first small infrastructure deployed on the Moon before 2026.

Active contribution of Space against Climate Change

European In-Orbit Data Centres

Rationale for action:

Digital technology has immense benefits, but its energy consumption and carbon footprint have already largely surpassed the world aviation industry, and even worse, that footprint is predicted to double every 10 years.

Space technology has now reached a level of maturity that makes possible a revolutionary - yet feasible - solution: the installation of internet data centres outside the Earth's atmosphere.

The decarbonisation of data centres, which are now among the world fastest growing energy users, would contribute substantially to Europe's commitment to become the world's first climate neutral continent by 2050. This would not only put Europe as a leader in the fight against the strong inflation of energy consumption on Earth and its associated climate change, but also as a leader in low cost, green access to space, on-orbit assembly and operations, space power generation, and optical space telecom. In addition, Europe would control its own secured and sovereign cloud.

In addition, in-orbit data centres will be under European sovereignty rather than hosted in foreign countries not applying RGPD.

What is to be expected?

Europe has set the very ambitious goal of zero net emission of greenhouse gases by 2050, all the while ensuring economic growth and boosting European competitiveness. Today the global greenhouse gas impact of IT is evaluated to 4%, with predicted annual increases of 8% (more than double every 10 years). Data centres alone contribute to about 30% of this fast-growing footprint.

The installation of internet data centres in orbit, in form of orbital station or multiplane satellite constellation, would eliminate this problem: energy would be drawn directly from the sun, used locally, and heat would be dissipated in space outside the earth's atmosphere. Only data would be exchanged with Earth stations. Digital technology has progressed to allow for the use of COTS while remaining resistant to radiation. The architecture would be based on modular building blocks (where also a single satellite can be seen as building block of the data centre), assembled and maintained in orbit, using robotics and AI for predictive maintenance.

Repair and recycling will be included in the system concept, which will foster Europe's leadership for clean space operations, starting with a necessary well mastered European Space Traffic Management capability.

This privileged position in space would also offer a number of intrinsic advantages e.g., easier cyber security protection, 5G connectivity, edge computing, a quantum communication framework, as well as a permanent space station capability that could serve many other purposes.

Installing a complete data centre in orbit would require launching considerably more mass and equipment than a LEO satellite constellation due to the high-power requirements of data centres. It would thus require extremely large solar power stations/equipment and the necessary infrastructures to house complete data centre technical assets. These space structures or big constellation, while larger than anything currently in space, are within Europe's technological capability.

Users and timeframe:

This programme will generate a very significant launch demand, at least one order of magnitude above the current level. To assure the environmental objective, it must be supported by heavy, environmentally friendly and affordable launchers. The capacity to satisfy such a demand is within Europe's reach and would eventually position Europe as the leader in terms of launch competitiveness. The environmental and energetic impact of the launches must be assessed in details, but it is assumed that it will be sufficiently low in comparison with the energy savings that will result by operating the data centres in orbit through their operational lifetime.

Such a large-scale project would also federate all the European leaders in cutting edge technologies such as secure cloud autonomy, 5G architecture, quantum, reusable eco-friendly launchers and on-orbit robotics and operations and would strongly reinforce European digital sovereignty.

Regarding the timeframe, after a system phase A study and a system architecture is consolidated, the first operational objective would be a small scale in-orbit power station and data centre (typically 5-10 MW), as a minimum viable product (MVP) to demonstrate performance and provide feedback for the final development. Such a station or satellite could be assembled in orbit before 2030. This demonstrator would target first use cases for which processing and data storage in space is already needed i.e., Copernicus or Weather data. The development of a full-scale orbital data centre of typically 500 MW could target the objective of deploying it by 2035-40.

Such orbital stations will have to be replicated at scale and as needs arise in order to have a larger impact on the climate at a planetary level. Having demonstrated the carbon footprint benefit of the first full scale data centre in orbit, Europe would be in position to lead an international cooperative project for a planet-level deployment.

This project would change the scale of the European digital and space industry, giving it a worldwide leadership role in on-orbit operations, and access to space with enormous competitive benefits for other sectors.

Europe should be at the forefront of this major challenge facing mankind, and this flagship programme would place Europe as the leader in the fight against climate change.