ESRE

ASSOCIATION OF EUROPEAN SPACE RESEARCH ESTABLISHMENTS

ESRE Input to the European Commission

for

Horizon Europe "Space"

Work Programme 2021 – 2022

Provided by ESRE

The Association of European Space Research Establishments, July 2020

Table of content

I. Introduction

This document has been produced by ESRE, the Association of European Space Research Establishments, to provide the European Commission with concrete R&TD elements for the first “space” work programme of Horizon Europe (2021-2022).

It provides topical recommendations with regard to the on-going definition and future implementation of the research related to space by two complementary approaches. The first part (1-15) deals with elements for large and small-scale road-mapped research (under a potential Co-programmed European Partnership, CPEP); the second part (16-41) addresses elements for traditional collaborative research and small-scale low TRL road-mapped research.

A summarized version of these R&TD elements has previously been listed in the recently published ESRE White Paper 2020[1] on “*Selected Trends and Space Technologies Expected to Shape the Next Decade*” (January 2020). Altogether with the ESRE Position Paper 2020 entitled “*ESRE reflections on space-related R&TD and its governance in Horizon Europe*” (May 2020), they give a clear and comprehensive view on the topics and on the associated governance proposed by ESRE.

Each topical recommendation starts with the reference to the SRIA (Strategic Research and Innovation Agenda for EU-funded Space research supporting competitiveness) technology-based activity line(s) and ESRE White Paper 2020 trends related to the element(s).

ESRE
The Association of the European Space Research Establishments — ESRE — was formally established in March 2016 as an international non-profit organisation. Present member organisations of ESRE are the national space research centres CBK (Poland), CIRA (Italy), DLR (Germany), INCAS (Romania), INTA (Spain), NLR (Netherlands), ONERA (France) and VZLU (Czech Republic).

Through ESRE, these national space research centers strengthen their cooperation and propose European Research and Development (R&D) actions to advance science and technology both to support the competitiveness of the European space sector and to address the grand societal challenges.

https://www.esre-space.org/

[1] https://www.esre-space.org/publications/

II. Proposals for Space Work Programme 2021-2022

A. Large-scale and small-scale road-mapped research / Co-programmed Partnership

1. Distributed payloads on-board clusters of small satellites

SRIA corresponding technology-based activity lines: 3.2 Future space ecosystems: on-orbit operations, new system concepts

ESRE White Paper/major trend: Transversal Trends

Specific Challenge: In the mid- and long-term the competitiveness of the space segment data sector and its ability to serve the Union's internal needs depends on the continuous innovation and advancement in the satellite manufacturing sector.
To ensure the leading role of European companies in the development of next-generation Earth Observation, communications and science systems, Europe shall reflect the current trend of Small Satellite applications. The CLUSTERs of small satellites implementing fractionated systems and instrumentation, which can deliver comparable or better mission capabilities in comparison with large monolithic satellites, are responding to the pressure for more flexible and robust systems. The demonstrated new technologies will greatly strengthen the competitiveness and growth of European companies in the global market.
Today most of the space segment data are provided by the fleet of large satellites. Due to the technology advance in the recent years, followed by a sunrise of the “New Space” companies and their risk-tolerant approaches, the CLUSTER of small satellites is capable of delivering comparable or better mission results compared to monolithic large satellites. Furthermore, formations of small satellites which perform their tasks in cooperation seem to open a wide field of opportunities.
To be able to fulfill such promises the small satellites shall have the precise formation flying capability with sub-centimeter tracking error accuracy and low change in relative velocity in a frame of formation members, which allows maintaining the desired formation in space.
Moreover, the customers (private and institutional) generally want to improve space missions by means of lower costs, lower development time, technology edge positioning, flexibility and versatility. To achieve these goals the use of fragmented and/or distributed instrumentation onboard of several small platforms is considered advantageous. The main challenges of this approach are formation flying precise enough for Earth Observation applications, a highly-accurate attitude determination and control system, multi-node inter-satellite link equipment and distributed miniaturized payloads for Earth Observation. The solutions of such challenges shall take advantage of contemporary and future results from fields as nanotechnology, artificial intelligence, 3D printing, robotics and image sensors.

Scope: The distributed system is not dependent on the formation flying only. Earth Observation and scientific payloads need also a high pointing accuracy to be able to deliver the desired results. But such pointing shall be performed by each satellite in formation in a coordinated manner which allows to reach the required resolution. This cannot be achieved without multi-node inter-satellite link equipment, which will assure the control and coordination among the CLUSTER’s nanosatellites.
All the above mentioned technologies are necessary for enabling the usage of distributed payloads. Such distributed payloads need a new generation of miniaturized equipment for all kind of missions (Earth Observation, Science, Telecommunication) together with the appropriate distributed control software for this purpose.

The key technologies are:

- Formation flying control system,
- Attitude Determination and Control System (ADCS),
- Inter-Satellite Link (ISL) equipment,
- Miniaturized payloads.

Each proposal shall address only one of the following topics:

- Development of an efficient and stable formation flying control system for nanosatellites compatible with Earth Observation requirements,
- Development of a highly-accurate Attitude Determination and Control System (ADCS) for nanosatellites which enables coordinated pointing of the fractionated instrument constrained by the formation flying and which paves the way to reach high spatial resolution on ground,
- Development of a multi-node Inter-Satellite Link (ISL) equipment for nanosatellites control and coordination,
- Development of a fractionated instrumentation based on miniaturized payloads for Earth Observation.

Expected Impact:

- Increased performance of formation flying control systems for nanosatellites,
- Increased performance of Attitude Determination and Control System (ADCS) for nanosatellites,
- Multi-node Inter-Satellite Link (ISL) equipment for nanosatellites,
- Enhanced, innovative fractionated instrumentation based on miniaturized payloads for Earth Observation.

Year of the call: 2021

Type of Action: Grant - Research and Innovation Action

Based on a roadmap: Yes

2. Elaboration of new concepts with regard to collaborative small satellite constellations

SRIA corresponding technology-based activity lines: 3.2 Future space ecosystems: on-orbit operations, new system concepts

ESRE White Paper/major trend: Transversal Trends

Specific Challenge: Currently few satellite constellations are in operation. The most notable applications for which satellite constellations have been established are in the domains of navigation and communication. GNSS systems require continuous global coverage, which is only possible through the usage of constellations. Similarly, for large coverage applications within the communications field, constellations are employed. Constellation design within these fields are therefore, and have been for some time, quite well understood.

With regard to small satellite constellations, it is important that Europe is not dependent on international partners, who focus on their own advancement. Instead, Europe should investigate and develop the technologies which are crucial to Europe. The focus should be more on reusable resources, cost-effective solutions or more dedicated mission profiles. Working on constellation concepts within Europe will create a positive view of the future, in which all members can contribute and return the technology advances into their own economy.

Within the concepts to be developed, challenges to be encountered vary from technical to operational. There will be an incentive to eventually make use of COTS products, which could necessitate a technology push or revision to ensure the required quality. Several of these challenges are (but not limited to): satellite positioning, pointing accuracy, orbital control, power density/distance, in-orbit replacement (upgrades), operations/constellation management (scheduling), on-board autonomy (AI/Machine Learning), EOL procedure, debris mitigation, STM.

Scope: There are a large number of applications for which satellite constellations could be beneficial. Examples of such applications – though not exclusively – that would benefit from innovative small satellite constellation concepts are:

- Modular constellation design, whereby each satellite has a dedicated functionality (e.g. space-based solar power, space telescope),
- In-orbit servicing of satellites,
- Space debris removal systems (i.e. pick-up sats + main disposable unit),
- Combined fabrication systems (split factory functions over multiple small sats),
- Earth Observation constellations (for coverage and/or accuracy),
- Lunar orbiting systems (GPS/LO),
- Mars orbiting system (GPS/MO/Meteo),
- Lagrange point swarms.

Expected Impact:

- Enabling new constellation types to be exploited for European interests,
- Pioneering new space applications with global coverage,
- Enables supporting infrastructure for future Lunar and Mars missions,
- Boosting the European space economy and expanding cooperation between European partners.

Year of the call: 2021

Type of Action: Grant - Research and Innovation Action

Based on a roadmap: Yes

3. Pre-development of a lidar instrument for an active CO2/GHG Copernicus precursor mission

SRIA corresponding technology-based activity lines: 3.1 Foster competitiveness of end to end systems and associated services

ESRE White Paper/major trend: Earth Observation

Introduction/Specific Challenge: Nowadays, Earth Observation satellites are equipped with a huge portfolio of different possible passive and active sensors, spanning the optical, infrared and radar regions of the electromagnetic spectrum.
Further momentum in the field is expected to come from the development of new classes of sensors (e.g. vegetation fluorescence sensors, low-frequency Synthetic Aperture Radars, LIDAR trace gas detectors). In particular, the possibility to monitor greenhouse gases (GHG) from space, through active lidar sensors, promises to become another breakthrough for environmental monitoring applications and should be considered as a priority in the Copernicus roadmap.

Scope: In the frame of collaborative research projects both the technological and scientific readiness level for active Greenhouse Gas (GHG) monitoring missions shall be leveraged. Such missions, spaceborne, but also (as an initial step towards this goal) as airborne demonstrations, will complement the Global Climate Observing System (GCOS). In order to help guide valuable GHG emission-reduction actions in response to climate change and to advance technical capabilities (for example, new satellite observations and sensors) WMO has initiated the development of an Integrated Global Greenhouse Gas Information System (IG3IS). The proposed action shall thus contribute to these global initiatives.

It is generally accepted that a realization of an active GHG monitoring mission requires progress in the following fields:

a) Technological maturation and demonstration of technological building blocks: transmitter technologies (solid state lasers, laser amplifiers, non-linear optics, fiber and hybrid lasers, frequency combs, coatings), single and multiple beam steering technologies, detector (single or array) technologies, frequency reference and diagnostic equipment or telescope technologies,
b) Optical system engineering and optoelectronics (e.g. optical filters and onboard diagnostic equipment),
c) Airborne demonstrators and ground support equipment, not only with regard to future space missions but also for using this technology onboard of high altitude stratospheric platforms or aerial platforms (such as aircrafts and/or balloon) to monitor local scales,
d) Model performance and measurement concepts (e.g. multi-wavelengths concepts),
e) Calibration and validation of satellite and airborne instruments (by e.g. in-situ sensors),
f) Exploitation of sensor fusion and synergies with other active and passive remote sensing (onboard satellites, aerial platforms such as aircrafts and/or balloons or high altitude stratospheric platforms) and in-situ instruments or networks (e.g. ICOS), respectively,
g) Model studies related to regional and city-scale modelling and GHG budgeting.

Central matter and prerequisite to enable a future space mission, however, is the realization of airborne demonstrators that should be the core topic of a set of collaborative research projects. Only by means of a demonstrator on an aircraft/balloon or high altitude platform it is possible to:

- Demonstrate the maturity of systems/subsystems in a relevant environment,
- Provide real data from a satellite-like viewing geometries in order to develop and test algorithms and advance methods for regional scale model and GHG budgeting.

Furthermore, the use of such demonstrators paves the path for a variety for scientific opportunities such as:

- Studying local to regional scale GHG sources, sinks, and fluxes,
- Providing integrated calibration/validation capacities for both active and passive remote sensing GHG satellites (Sentinel 5, CO2M, GOSAT 2 and 3, etc.).

Therefore, the advancement and new development of airborne demonstrators for active GHG monitoring shall be tackled within the frame of several collaborative research projects that can be performed independent of each other:

- Airborne Demonstration:
  - Scientific requirements definition study,
  - Facilitation of European aircraft infrastructures to carry active remote sensors,
  - Aircraft integration of existing GHG lidar instruments,
  - Enhancing the performance of current GHG lidar instruments (e.g. by optimized detectors, frequency reference system, laser improvements, energy calibration subsystems, etc.),
  - Flight campaign
    Data processing and measurement quality assessment vs. requirements.

- Emerging Technologies:

    - Assessment of potentially suited transmitter and detector systems for space application,
    - Development of a next generation of laser transmitters (e.g. solid state lasers, non-linear optical devices, fiber lasers),
    - Field deployment and ground truthing of lidar transmitters, including calibration and validation by in-situ sensors,
    - Test flights.
- Cross-frontier Studies
    - Algorithm development for air- and spaceborne GHG lidar missions,
    - Model performance and measurement concepts (including synergies with other sensors),
    - Estimation of the impacts of proposed designs using Observing System Simulation Experiments (OSSEs). Model studies related to regional and city-scale modelling and GHG budgeting,
    - Promotion of contributions to the goals of e.g. GCOS and IG3IS,
    - Development of an integrated calibration/validation concept and for GHG satellite missions, both active and passive,
    - Preparation of an integrated cal/val infrastructure for GHG satellite missions, both active and passive,
    - Community networking to facilitate an efficient usage of GHG lidar data.

Year of the call: 2022

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: Yes

4. Synergies among remote sensing platforms for improved spatial/temporal/spectral resolution

SRIA corresponding technology-based activity lines: 3.1 Foster competitiveness of end to end systems and associated services

ESRE White Paper/major trend: Earth Observation

Introduction: Earth Observation satellites provide a large set of free/low-cost images covering large areas. However, such data suffer from many limitations in terms of spatial/spectral resolution, revisit time, weather conditions, etc. These limitations can discourage end users from using satellite technologies because they might be unsuited for their application needs. Such limitations can be successfully overcome by planning, for example, the mission tasks in order to facilitate the multi-scale/multi-temporal/multi-sensor fusion of the acquired data.
Also, satellite data can be integrated with those provided by small Remotely Piloted Aerial Vehicles (RPAS) by planning the RPAS acquisitions within specific time windows and fusing data. Cross-calibration among sensors may be needed.
Considering emerging technologies for new remote sensing platforms, low-cost micro-satellite constellations and High Altitude Pseudo-Satellites (HAPS) should be considered to increase the temporal frequency of the acquisitions.

Specific challenge: The spatial/temporal/spectral resolution required by applications (environmental protection, citizens' safety, security, etc.), can be achieved implementing synergies among space (and also non-space) remote sensing platforms through two complementary challenges:

- To make available data from different platforms close in space and time, in order to gather comparable data;
- To use different data sources, developing approaches and tools to overcome the gap in terms of different spatial resolution, type of sensors, etc.

A specific application domain (i.e. environmental protection, agriculture, disaster response, etc.) must be selected to show the spatial/temporal/spectral resolution improvement obtained by means of the proposed synergy.

Scope: The scope of this call is to develop process and/or technological tools to match the increasing spatial/temporal/spectral resolution requirements from end users (e.g., environmental protection agencies, local governments, public bodies, etc.), implementing synergies among different space and non-space remote sensing platforms.
In particular, the call aims to foster two complementary strategies, based on technologies for environmental applications that shall be further developed and improved with respect to their current readiness level:

- Synergy among heterogeneous satellite missions;
- Synergy among aerial platforms (including RPAS/HAPS) and EO satellites.

Projects that proposes both the above strategies are strongly encouraged.

Expected impact: Increasing the capabilities of the future EO system, in terms of spatial/temporal/ spectral resolution through the:

- Improvement of synergies among homogeneous and/or heterogeneous (i.e., optical and radar) satellites,
- Improvement of synergies among satellite platforms and small RPAS,
- Improvement of synergies among satellite platforms and HAPS,
- Boost the development of downstream applications,
- Improved synergy among free data sources (i.e., the Copernicus programme) and commercial data sources.

Year of the call: 2021

Type of Action: Grant - Research and Innovation Action

Based on a roadmap: Yes

5. Design, test and development of a prototype Galileo System Time based on a Composite Clock algorithm

SRIA corresponding technology-based activity lines: 3.4 Enabling technologies (cross-mission, space and ground)

ESRE White Paper/major trend: Navigation

Specific Challenge: Our present society can no longer be imagined without the positioning and timing services provided by Global Navigation Satellite Systems (GNSS). The organization and the management of today's mobility and global transport system more and more depend on GNSS, not only for navigation but also for tracking and tracing of vehicles and cargo. In this respect, the Galileo program is a major asset for Europe.

For the future, these mobility applications will demand considerably improved position accuracy, reliability and signal availability (e.g. in cities and indoors). In addition, more and more critical infrastructure in our society relies on the GNSS system time for time synchronization.
The timing capability offered by satellite navigation systems is at the core of most vital infrastructures: telecom networks operation, energy distribution, financial transactions, and TV broadcast are some examples of areas where GNSS is used for timing and synchronization (T&S) purposes. GNSS provides a unique offering to the timing and synchronization user communities by delivering a free, stable and very accurate time and frequency source available worldwide. The expansion of telecom networks (e.g. Small Cells, 4G) makes GNSS more and more essential, driving future developments and the T&S community is facing many challenges linked to an increased need for resilience, reliability and security, supported by an evolution of the regulation.
The Galileo System Time (GST) is a main element within the Galileo system. In case of interruption of GST the Galileo system can run out of service for a while. When defining new approaches like distributed clocks or distributed system time generation, the interruption or failure of one element of the new Galileo System Time does not lead to the complete outage of the Galileo service.
The Galileo System Time is currently operated by two hot redundant Precise Timing Facilities (PTF). The generation of the GST is based on a PTF master clock principle. This generated GST is used for synchronizing the whole Galileo system elements. Therefore, the two PTFs have a central role in Galileo operation. In case of a failure of the active system, the backup system takes over the action. If there is an error in the backup system (e.g. a single additional failure), the operation of the whole Galileo system is interrupted. This interruption of service can also happen when one PTF is in maintenance and an error occurs at the active PTF chain. Using the approach for distributed clocks in a common way (Composite Clock algorithm) the aforementioned errors do not lead to the failure of the Galileo service. The distributed clocks can consist of clocks of the Galileo Control Centre, the clocks of the Galileo Sensors Stations (GSS) and the clocks on the Galileo satellites as well as of clocks of well-established National Metrology Institutes (NMIs).
The objective of the R&D activities proposed in the following is to establish a robust system time for Galileo and to promote the provision of a reliable timing service for Galileo and EGNOS.

Scope: The key goals are to achieve a stable and robust Galileo System Time, which can tolerate the outage of one or more clocks, and to demonstrate the added value of the robust timing service and encourage adoption. Thus, the scope of this call encompasses the following technologies to be developed in Europe, preferentially by roadmapped research projects in Horizon Europe:

- Design, test and development of a prototype (TLR > 6) of a Galileo System Time based on a Composite Clock algorithm using the Galileo ground clocks of the Precise Time Facilities located in Fucino, Italy, or Oberpfaffenhofen, Germany,
- Design, test and development of an optical link between one PTF and an NMI demonstrating the usage of the distributed clocks with highly accurate measurements,
- Design, test and development of a prototype of a robust Galileo Timing receiver implementing upcoming EGNSS Robust Timing Service recommendations,
- Design, test and development of a prototype (TRL > 6) of a Galileo System Time based on Composite Clock algorithm using the Galileo ground clocks of Precise Time Facilities located in Fucino, Italy, and Oberpfaffenhofen, Germany. For the communication between the two PTFs standard time transfer techniques like Common View over GNSS satellites and/or Two-Way Satellite Time and Frequency Transfer (TWSTFT) will be used,
- Design, test and development of a prototype (TLR > 6) of a Galileo System Time based on Composite Clock algorithm using the Galileo system clocks, both on the ground and in space.

Expected Impact:

- Further development of the Galileo system to meet future user requirements,
- Strengthening the European space industry and establishing long-term technology leadership in space-based navigation systems.

Year of the call: 2021

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: Yes

6. Design, test and development of a GNSS-based Emergency Warning System for dissemination of alert messages over diverse communication means

SRIA corresponding technology-based activity lines: 3.4 Enabling technologies (cross-mission, space and ground)

ESRE White Paper/major trend: Navigation

Introduction/Specific Challenge: The compelling need for a global warning system is fundamental for the society and public authorities in the light of the increasing number of crisis management situations occurring very often across Europe. Past activities have helped consolidate the users' requirements and resulted in dedicated platforms mostly relying on terrestrial or satellite communication means to enable data distribution between the involved parties (population, first responders, public protection authorities, etc.). Nevertheless, the advantage offered by GNSS-based systems has been more recently recognised in this context because of the capability to distribute warning messages to a large set of users independently of the specific location. To this end, upgrade of the existing GNSS architecture functionalities and related services are envisioned jointly with the extension of the terrestrial network capabilities to enable efficient message distribution and big data exploitation. In this respect, also the extension of GNSS operational frequencies to lower ones are also to be considered in order to guarantee signal penetration into building or through vegetation.

Scope: The objective of this call is to provide Europe with a GNSS-based Early Warning System able to distribute warning information timely and reliably to population at risk as well as the needed operational support to first responders on the field. As such, the main goal is to enable anytime-anywhere penetration of warning messages, owing to the large coverage of GNSS systems as well as the forwarding of messages throughout the available terrestrial infrastructure. Moreover, the designed system should be able to reach populations at risk in both indoor and outdoor environments, by making use of the currently available infrastructure along with additional lower GNSS operational frequencies to allow signal penetration into masked environments (i.e., building).

Expected Impact: The expected added value of this activity will be the exploitation of GNSS systems in the current version (EGNOS and Galileo) and their future evolution so as to provide the necessary support in every kind of disaster management situations, meeting the first responders' requirements and also matching the institutional constraints that may vary country by country across entire Europe.
The overall impact will be considerable for entire Europe not only in terms of a unique platform for authorities and populations at risk but also in terms of new market opening, given the highly

multi-disciplinary nature of the considered system to be developed (e.g., big data, telecommunication integration, GNSS integration, data fusion, etc.).

Year of the call: 2021

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: Yes

7. Demonstration of feasibility and technological maturity of optical feeder links for very high throughput satellites in geostationary orbit

SRIA corresponding technology-based activity lines: 3.1 Foster competitiveness of end to end systems and associated services

ESRE White Paper/major trend: Communications

Introduction/Specific Challenge: Optical feeder links with geostationary orbit satellites might become the backbone of the future global internet thanks to the almost unlimited bandwidth provided by optical wavelength. However, effective countermeasures against the impact of the atmosphere on data transmission have to be designed and demonstrated. The challenge here is to consolidate the reliability and availability assessment of high data rate optical communication systems that can be implemented using either a digital or an analog modulation of the optical carrier.

Scope: The scope of this proposal is to define the optical link format (framing, modulation, coding) and designing suitable on-board processing techniques to handle the conversion from optical feeder links to RF user links and vice versa, as well as development of a first prototype for a bidirectional hybrid transponder. The objective would be to support a throughput as high as 500 Gbps as initial technology demonstration (2021). Another objective would be to assess the expected availability and consolidating the link budgets via an extensive characterisation of atmospheric parameters (transmission and turbulence) in relevant ground segment locations (2021).
Investigating the feasibility of dense phase modulation based format given the specificities of the optical channel (including fading mitigation techniques limitations) (2022) could be the third direction for research and development. Demonstrating 10W-class space-qualified booster amplifiers and in-lab demonstration of high optical power amplifiers (typ. 100 W/channel) compatible with phase modulation format (2022) could be seen as a follow-up of the activities envisioned for 2021.

Expected Impact: Existing architectures based on RF feeder links are not arbitrarily scalable: as the throughput increases to reach Tbps and beyond, the number of required ground stations will become unfeasible. Optical feeder links are therefore an essential technological enabler to allow space technologies to bring billions of people into the global economy by allowing broadband connectivity to otherwise uncovered or limited coverage areas.

Year of the call: 2021

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: Yes

8. R&TD on quantum-safe optical telecommunications

SRIA corresponding technology-based activity lines: 3.1 Foster competitiveness of end to end systems and associated services; 3.4 Enabling technologies (cross-mission, space and ground)

ESRE White Paper/major trend: Communications

Introduction/Specific Challenge: Quantum key distribution (QKD) offers inherently secure means for exchanging secure keys among communication partners. Together with quantum resilient (or post-quantum) coding schemes, encryption keys distributed via QKD can be used to communicate securely using conventional encryptors via traditional networks, as e.g. the internet. However, fiber based QKD systems are limited to distance of about 100 km. To enable QKD on a European or even world-wide scale, satellite systems must be deployed and research is necessary on the space and ground segment. Several national and international initiatives towards that goal exist. It is important to develop these initiatives and extend them towards the development of future quantum networks. Thus, the ground segment as quantum receiver and network node has a very important role to connect terrestrial networks, e.g. in the future European quantum communication infrastructure. QKD is the first commercial technology and innovation driver in quantum communication but certainly not the last. Therefore, future applications of quantum communications (entanglement distribution, connection of quantum computers, etc.) must be considered in current research plans.

Scope: The main goal shall be a feasibility demonstration of satellite-based long distance quantum key distribution for the secure inter-connection of European stakeholders, critical infrastructures and networks. Furthermore, applications of beyond QKD must be taken into account in the conceptual design work of the quantum communications system. Important boundary condition is the European technology sovereignty. Key elements to be investigated and developed are optimized QKD protocols for the satellite-ground and satellite-satellite channel, quantum channel models, ground station concepts with respect to network integration, highly efficient P2P links, implementations for high rate sources, entanglement distribution, interfaces to space quantum memories and development of demonstrator experiments (including space- and ground-segments). The ground station is of particular importance for the European Quantum Communication infrastructure since it forms the physical interface between the satellite system and terrestrial network. In contrast to the SAGA program, the focus in this proposal is on the development of particular core components with lower TRL (<=5) and no complete satellite system and mission but rather breadboard demonstrations.

Expected Impact: Access to secure communication means is a prerequisite for economic development and the transition towards an information society. QKD will enable long-term security for transmission of sensitive data. The work will support obtaining European sovereignty in this critical technology. The envisaged TRL<=5 will support appropriate cooperation with industries that can sustainably conduct commercialization of the developments. Furthermore, the inclusion of applications beyond QKD will leverage subsequent innovations in this field.

Year of the call: 2021

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: Yes

9. Design and demonstration of technological maturity of a CubeSat constellation optimised for IoT applications

SRIA corresponding technology-based activity lines: 3.1 Foster competitiveness of end to end systems and associated services; 4.4 Modern, flexible and efficient European test, production and launch facilities, means and tools

ESRE White Paper/major trend: Communications

Introduction/Specific Challenge: The IoT market is growing with an increasing number of applications and end users to an estimated number of 100 billion devices by 2025. A large share of those applications will be located in remote areas for purposes such as monitoring and tracking agriculture, oil and gas extraction plants, water consumption or containers. A constellation of nanosatellites in LEO, connected via optical inter-satellite links and RF-based user links with advanced protocols, promises to solve the communication bottleneck and allows exponential growth of the possibilities.

Scope: Two main development blocks are required to make the presented scenario a reality:

- An optical communication terminal for ISL communication within a constellation of nanosatellites in LEO needs to be designed and developed. To support the end user communication as a backbone, the target data rate is 100 Mbit/s.
- The RF user links need to improve efficiency to cope with the large number of end users. Therefore, dedicated waveforms need to be designed, implemented and tested to push the user links from/to the IoT devices to data rates between 120 bit/s and 2 kbit/s.

Beyond this scope, the developments are suggested to be demonstrated on at least two nanosatellites, integrating both technological developments.

Expected Impact: A constellation of nanosatellites in the LEO, connected via optical links, can serve as a communication backbone for the most relevant IoT applications in remote areas. Especially agriculture and transportation play a major role in the global economy and are drivers for globalization. Supporting the growths of IoT applications in these fields and areas also supports the growth of the European economy.

Year of the call: 2021

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: Yes

10. R&TD on subcomponents for very high resolution optical and radar surveillance / observation sensors

SRIA corresponding technology-based activity lines: 3.1 Foster competitiveness of end to end systems and associated services

ESRE White Paper/major trend: Defence

Introduction: The Earth Observation community, including security and defence users, is continuously demanding higher spatial/temporal/spectral resolution images. The current technological edge in spatial resolution of optical panchromatic data is close to one foot, and visible and near-infrared (VNIR) multispectral data is only slightly worse. State-of-the-art short-

wave infrared (SWIR) and thermal infrared (TIR) sensors used for remote sensing have increasing ground pixel sizes, with the thermal imaging sensors currently limited to 100 m/pixel. On the other hand, if high spectral resolution is pursued in the VNIR, the spatial resolution is reduced, and pixel sizes around 30 m are targeted for current or near future hyperspectral sensors (e.g. PRISMA, EnMAP, HyperScout). In the microwave range, submeter resolution is possible in the X band, although improvements in bandwidth are needed to go down to the foot level and to improve the image quality.
The trends in the use of Earth Observation data shows that the number of potential users of Very High Resolution (VHR) images through Europe is huge. Such users cover a very wide range of applications and societal challenges: secure societies, urban climate, resource efficiency or sustainable agriculture to name but a few. Providing these users with the improved VHR images they need (in optical, thermal and microwave ranges) would necessarily help in the response to those challenges.
From the technological point of view, Europe is already competent in some of the fields outlined here. But in others, Europe is lagging behind other economic areas. The research promoted by this project might help in closing that gap.

Specific Challenge: The current state of the art shows that improving sensor spatial resolution is mainly needed in hyperspectral, SWIR and TIR sensors, and to a less extent in SAR systems. In the VNIR range, the demand is to achieve the current resolution with compact, low cost sensors that could be suited for large constellations of satellites.
The high spatial/temporal/spectral resolution required by many users of Earth Observation data, including security and defence applications, can be achieved in two ways: developing sensors with increased performance or implementing processing algorithms or operational solutions (e.g. constellations, very agile platforms, etc.). The challenge considered by this project is to reach improved resolution through increasing sensor performance. This challenge was also partially addressed in H2020 WP 18-20, call LC-SPACE-14-TEC-2018-2019: Earth Observation technologies; the present topic stresses the need of improvements in this area.
An implicit objective is to reduce the European dependence from external suppliers for the basic materials/subcomponents/subsystems required to build Very High Resolution (VHR) sensors.

Scope: The objective of the project is to address the resolution requirements from end users (in security and defence but also in other fields) by fostering sensor technology and the corresponding assembly, integration and verification/testing facilities. Following the European Defence Agency, high resolution is intended here as a general term that applies not only to the spatial domain but also to the spectral and radiometric ones.
A wide range of technologies could produce improvements on VHR imaging. A preliminary list of fields where research is requested is shown below, although of course unexpected, disruptive ideas and technologies could also benefit this topic.

- Advances in SWIR (1-2.5 microns), MIR (3-5 microns), and TIR (8-13 microns) detectors,
- Research in TIR concepts allowing very high resolution (optics and detectors),
- New concepts for hyperspectral sensors,
- Optics and structures for compact, stable and lightweight optical sensors,
- Design tools and algorithm for optimization of designs containing free-forms,
- Manufacturability of new materials in free-form way,
- Phased array antenna distributed across platforms,
- Very high bandwidth components (both for RF & baseband SAR subsystems).

Whenever applicable, activities shall be complementary with other European R&D activities in the same domain, and connect with results from previous Horizon 2020 projects, i.e. LC-SPACE-14-TEC-2018-2019. In addition, the proposal shall show how it addresses relevant available roadmaps, including roadmaps developed in the context of actions for the development of Key Enabling Technologies supported by the Union.

Expected impact:

- Improvements on any field of VHR imaging technology at medium TRLs,
- Achieving a European capacity in all technologies related to VHR sensors, helping European strategic non-dependence in this field.

Year of the call: 2021 or 2022

Type of Action: Grant - Research and Innovation Action

Based on a roadmap: Yes

11. Miniaturisation of all kinds of sensors for small satellite constellations, HAPS and RAPS

SRIA corresponding technology-based activity lines: 3.1 Foster competitiveness of end to end systems and associated services

ESRE White Paper/major trend: Defence

Introduction/Specific Challenge: With respect to the space sector, smaller sensors translate to smaller satellite systems. With much of a satellite system's cost coming from the launch segment, the smaller the satellite the lower the cost. Many of the "New Space" opportunities arise from creating global coverage through the deployment of constellations of smaller satellites. As such, lowering the cost of each satellite greatly lowers the threshold for creating a constellation of satellites. This enables the possibility of greater space economic activity. Alternatively, smaller sensors can mean the usage of more sensors on board the same system, which can be used to create safer systems through redundancy or greater performance through sensor fusion. All enabling technologies related to electronics, optoelectronics and microelectronics integration and/or qualification for space perfectly fit within the so-called "Strategy for the Non-Dependence" of Europe. A huge market (given the increasing number of cubesats being launched) would open to any stakeholder capable of offering reliable components, detectors, or complete subsystems or sensors for the small satellites market.

Looking at the current state of sensors used in space, many sensors themselves have already reached quite an advanced step of miniaturisation. For instance, star trackers are currently available at a size of around 10 cubic centimetres. Since many of the actual sensors themselves are already quite compact, the project will mainly focus on aspects that reduce the overall size of the system the sensor is integrated in.

Miniaturisation comes with many challenges, especially when the scope of the main objective is broad and encompasses many different types of sensors. Among the main challenges that are generally applicable to all sensor types, there is the effect miniaturisation has on performance, material requirements, thermal design, manufacturability and ultimately cost. Reduced power consumption is another driving requirement that must come along with miniaturisation, for any sensor to be easily accommodated in a small satellite. Many systems are difficult to scale. In some cases, the performance is directly related to the dimensions, as one can see in, for instance, optical systems. In other systems, material properties are a bottleneck or the lack of sufficient research into alternative materials hinders the development of smaller and smaller sensors.

Heat dissipation is largely related to size as well as causing further difficulties for the design of small sensors. Demanding the same performance on a smaller volume often means an increase in the system's relative complexity as well, causing the manufacturability to be further challenged, demanding higher and higher precision of the machines used to create the sensors and the people who operate them. The same applies to the associated electronics and signal processing:

increased capabilities are desirable to produce smart sensors, increase performance and autonomy, reduce data transmission or storage needs, etc. All these challenges may result in increased costs, at least during the development phase.

Scope: Focus should then be put on payload sensors. However, the number of different sensors is as large as the number of mission applications: from passive optical sensors in different ranges of the spectrum, to compact lidars or radio sounders. Due to this, during a first stage it will be more practical to work on Key Enabling Technologies needed for the development of a number of sensors, rather than targeting very particular sensors themselves. Of course, the rough definition of the technology needs should be linked to particular target applications. Initially, the following areas are identified:

- Deployable structures for optical systems, thermal control (deployable radiators) and antennas,
- Free-form optics for compact optical designs for Earth Observation applications,
- Mixed-signal microelectronics (ASICs) development for sensors' front-ends,
- Die-level integration and packaging technologies for the creation of System-on-Chips based on existing COTS (detectors plus front-ends),
- Particular detectors (e.g. CMOS APS, Silicon Photo-Multipliers, etc.),
- Ultra-stable materials with minimum thermal expansion coefficient for the construction of precision supporting structures.

Expected Impact:

- Enabling getting the same performance out of smaller satellites,
- Bringing down the costs for satellites,
- Supporting the creation of constellations,
- Boosting the European space economy.

Year of the call: 2021

Funding instrument: Grant – Research and Innovation Action

Based on a roadmap: Yes

12. Technologies for autonomous and cooperative swarm exploration

SRIA corresponding technology-based activity lines: 3.5 Contribution to space science

ESRE White Paper/major trend: Research under Space Conditions and Robotics

Specific Challenge: Among the variety of applications of satellite swarms, three are seemed to be distinctly attractive in scientific and industrial space applications: extra-terrestrial in-situ exploration, single orbital telescope formation and Earth Observation.
Considering the economic aspects of launching a swarm into space, the size of a single object of the swarm needs to be optimized. Hence, many engineering challenges arise. The main issue is the miniaturization of electronical and mechanical subsystems, e.g. the OBC, communications, sensors and actuators. Furthermore, thermal management and radiation protection are problematic when the system is small. In the functional aspects, for the in-orbit operation and satellite formations, the main focus is the automated consensus agreement of the flying formation for the constellations (e.g. by optimizing the power consumption) or the automated support for the assembly of in-orbit structures (e.g. by optimizing suitable efficiency indexes). In the area of surface and planetary exploration the goal is to use cooperative multi-robot teams in

space exploration by using heterogeneous, reconfigurable, intelligent and interoperable robots to enhance the robustness, application areas, the duration and the operational capabilities and range of future missions.
In the context of the PERASPERA roadmap, the H2020 ERGO project has already demonstrated some technological enablers for the development of highly autonomous space robotic missions and for the automated (re)planning of single and/or collaborative space robotic means, to attain high-level goals with Time-Space-Resources constraints. However, further work is needed for the development of perception and autonomy methods based on swarm intelligence, for decentralized and local cooperation, and for the management of possible emergent behaviors in the multi-robot teams. The reference project shall advance space applications by applying and innovating technologies about distributed artificial intelligence and swarm computing to ensure autonomic properties (i.e. self-managing, self-configuration, self-optimizing, self-healing and self-protecting) for the agents involved in space missions. This will require also the introduction of learning capabilities for the agents, which shall dynamically adapt to the unknown features of the harsh and unstructured environments (e.g. swarms of rovers shall learn the characteristics of unknown surfaces and distribute the information within the swarm). Some protocols shall be designed to provide interoperable systems, allowing collaboration amongst agents specialized in different tasks. Verification shall be especially analyzed to guarantee the absence of unintended behaviors by means of new techniques for intelligent swarm verification (e.g. applying formal methods, safety monitoring based on learning assurance, etc.).

Scope: The TRL enhancement of autonomous and cooperative swarm systems includes activities for:

- Prototyping of a robust high-rate data communication system for swarm applications,
- Development of a swarm-based navigation system with sub-meter localization accuracy,
- Demonstration of the principle of swarm exploration and navigation based on sensor data,
- Development of swarm-based (re)planning tools for the autonomous mission management of space multi-robot teams,
- Development of verification methodologies for the validation and the certification of swarms,
- Solutions for energy aspects for long-term operation in an environment without sunlight,
- Addressing the radiation protection of small systems,
- Addressing the thermal management of swarm elements.

Expected Impact:

- In astronomy and astrophysics: large scale space telescope arrays composed of distributed small objects;
- In Earth Observation: the opportunity of high resolution and stereographic imaging;
- In robotic exploration: new opportunities and increased robustness for the in-situ exploration of solar system bodies;
- General technology advancements on the intelligent cooperation of many small objects for space to Earth technology transfer.

Year of the call: 2022

Type of Action: Grant - Research and Innovation Action

Based on a roadmap: Yes

13. R&TD on new perception, reasoning and planning methods, based on Machine Learning and AI

SRIA corresponding technology-based activity lines: 3.4 Enabling technologies (cross-mission, space and ground)

ESRE White Paper/major trend: Research under Space Conditions and Robotics

Introduction/Specific Challenge: With the upcoming launch of the first European satellite to make use of machine learning/artificial intelligence algorithms on-board, and the relatively limited number of overall spacecraft to make use of this technology to date, Europe is well positioned to stay competitive in the field of space-based autonomous systems. Creating further expertise in the field of machine learning/artificial intelligence would improve many existing systems and enable many others.
One of the major challenges in developing artificial intelligence and machine learning for space applications will be to bridge the different fields of expertise. Since the usage of such algorithms in the space field is to date still quite limited, the building up of expertise and creating sufficient understanding of machine learning/AI among space engineers and creating sufficient understanding of space engineering among machine learning/AI experts will be an important challenge.
Another important aspect will be the interpretability and explainability. Interpretability deals with the extent to which a system's cause and effect can be observed and understood, while explainability concerns the ability for human agents to understand the inner workings of the system, once given some form of autonomy. In space-based systems, which are no longer "fixable" once launched into orbit and which are also incredibly expensive, requirements on the interpretability and explainability are expected to be prevalent.

Scope: On the satellite front, 2020 will see the launch of the first European satellite to demonstrate an instance of on-board artificial intelligence: PhiSat. The satellite will filter the images taken by the hyperspectral camera for cloud cover. Since this is the first demonstration of using machine learning/artificial intelligence algorithms on board a satellite, the field itself is still a frontier. NASA has used machine learning/artificial intelligence in its EO-1 satellite previously, wherein it was trained to detect several features such as cloud cover but also volcanic eruptions.
With respect to rovers thus far, in particular the Mars rovers run some of their tasks autonomously, mainly for scientific tasks such as the AEGIS software used on board the Mars Curiosity rover, which identifies targets for rock and soil analysis by looking at images from the ChemCam system. Considering the incredible potential for further autonomy in space systems, while at the same time still being rarely utilised in the field today, there is a lot of room for further innovations.
Further advancements in the field of vision-based navigation can aid rovers in traversing rough terrain, especially in places such as Mars whereby the signal delays are too great to directly pilot the vehicle. Such algorithms can also be trained for in-orbit conditions whereby they can serve to enable autonomous docking, which will become more and more relevant with the advent of on-orbit satellite servicing. The active removal of uncooperative debris also requires the satellite's capability to "learn" the debris' spin rate in order to determine the best method to collect it.
Algorithms should be developed for satellites to have the on-board capability to perform constellation management based on telemetry received from other satellites within the constellation through intersatellite links. With constellations currently planned to exceed, in some cases, thousands of satellites, it will not be cost-efficient anymore to manage the satellite operations solely with human operators.
Satellites must become capable to auto-correct their orbit in order to cover potential blind spots that can occur when one of the satellite malfunctions, or when demand in a particular area

temporarily increases. Another important aspect is for satellites to learn to autonomously respond adequately to collision risks.
On the Earth Observation front, we are seeing a greater utilisation of Low Earth Orbit, in particular by small satellites. Lower orbits translate to a higher resolution for the same instruments, but simultaneously decrease the communication time with the ground. This puts greater strain on the number of images that can be transmitted to the ground with each pass. Smarter image processing algorithms should therefore be developed in order to send down the images with the greatest value, both through selection of images with the most information and post-processing the images in order to reduce the amount of data required to be sent down for analysis on the ground.

Expected Impact:

- Improved on-board processing of scientific data
  - Less stringent communication system requirements due to better filtering of data
    - Eased requirements on link time allow for lower orbits, enabling higher resolution,
  - Enable better on-board data fusion from multiple instruments,
  - Enable on-board information extraction.
- Improved rover autonomy,
- Enable in-orbit autonomous constellation management.

Year of the call: 2021

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: Yes

14. Partial demonstration of promising reusable launcher concepts

SRIA corresponding technology-based activity lines: 4.1 Innovation for launchers competitiveness targeting initial operational capability by 2030

ESRE White Paper/major trend: Access to Space

Introduction/Specific Challenge: Nowadays, the reusable launchers must face new “working environment” in terms of aerothermal and mechanical loads, due to the differences in mission operations compared to expendable launchers. Moreover, the extension of the conventional “Ground Segment” and “Launcher Segment” needs to cover not only the mission part Entry-Descent-Landing, but also the post-landing operations activities. This additional development needs to cover a wider envelop of procedures to be defined and matured to cover the needs of a reliable and affordable cycle of recovery, refurbishment/reconditioning and reuse of launcher sub-systems.

Scope: The scope of this proposal covers innovative restartable engine with modular thrust including high Isp, low thrust engine; CMC engine nozzle; Guidance, Navigation and Control algorithms for reentry, descent and landing of stages; 3D printing/ALM components for engines. Additional developments for technologies related to descent and landing devices would be deemed necessary. Health monitoring systems to ensure the proper functionality of the vehicle, monitoring of launcher structure during flight, including non-destructive inspection is considered of great interest for the development of reusable launchers.

Additional developments are needed for the ground segment to ensure the safe operations of the potential recovery of the stages and their refurbishment.

Expected Impact: Mastering reusability for every stage of a launcher would be a great achievement which could not only reduce launch cost of small to medium sized launchers, lead time from order to launch, but also increase flexibility in launch date and flexibility in launch destination. The optimized operations of the reusable launch vehicle would also diminish the resulted space debris. It would mitigate the risk and it would increase opportunities to fly new technologies, new services and applications.

Year of the call: 2021

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: Yes

15. Pre-identified structural optimised parts designed for Additive Layer Manufacturing (ALM) to improve ongoing or new missions

SRIA corresponding technology-based activity lines: 4.1 Innovation for launchers competitiveness targeting initial operational capability by 2030; 5.3 Technology transfer

ESRE White Paper/major trend: Synergies with Other Sectors

Specific Challenge: To further improve Europe's authority in the space sector by benefiting from cutting-edge technologies and methods, it is needed to identify and to empower entities which will provide an end-to-end process for structural optimized parts designed for ALM manufacturing. Even though ALM manufacturing is not a new technology, it is hard to get it accepted as an agreed manufacturing method for space components because of repeatability issues, powder manufacturing (which may provide contamination if the powder is not completely removed and the resulted part has not been checked thoroughly) even though there are a lot of concepts and studies that prove the benefits. According to the available public research, a part made through structural optimization and designed for ALM (commonly known as topology optimization or generative design) provides an impressive mass difference compared to a part made through traditional manufacturing.
By identifying additional opportunities in ongoing strategic missions or in new ones, powered by the use of structural optimization, new benefits shall be represented by minimizing the mass and the number of different parts, which may lead to a simpler overall design and a lower mass. Furthermore, implementation of structural optimization in the engineering process from the conceptual phase reduces greatly the design time and iterations and speed-up production time and cycles.

Scope: The general objective is to identify opportunities and necessities for specific S/C & launchers missions related to the development of structural optimized ALM parts/components. The goal is to obtain better structural components with lower mass and same or better structural properties than the traditional manufactured concept. The mass reduction is considered as the main goal given the fact that every extra kilogram of payload implicates significant costs to the missions.
A structural optimized part, component or assembly will be developed. Such a product shall be designed for ALM manufacturing with respect to the identified opportunity or for the given

necessity, from concept level to detailed design, with the structural analysis done in each development step.
Also, the printability and prediction of distortions will be investigated (e.g. for titanium the direction of print is of importance). The structural analysis shall be compared with a part designed to be manufactured through conventional manufacturing but keeping in mind also a list of pros and cons (i.e. manufacturing and post-processing cost, mass, ETA, structural properties, environmental issues).
Manufacture a batch of three identic parts by using methods to prove that the printed material has similar structural, microstructural properties on the entire outside volume of the targeted part which is intended to be manufactured.
Identify appropriate NDT/NDI methods to verify potential criticalities like structural integrity, fusion, and loose powder. Qualify the batch of parts:

- Substantiating stable & repeatable AM production process(es) and demonstrate the required material quality level and its consistency in order to qualify for space applications,
- Making a set of checks (mass, dimensions, etc.) and mechanical tests to verify the similarity between the ALM parts,
- Using the test results of each ALM part to compare them with the structural analysis,
- Using the test results of each ALM part to compare them with conventional manufactured test results.

Expected Impact:

- Development of innovative ALM-oriented design methods which benefit from greater freedom in exploring the design space but at the same time take into account the new technological constraints introduced by additive technologies,
- Development and standardization of an end-to-end process for space applications of ALM manufacturing,
- Adoption of the technology at the industry level and offering the framework for ALM equipment improvements in terms of printing envelope, surface finish, precision and tolerances,
- Increasing of automation level in the manufacturing process, rendering the possibility of the complete production of parts allowing to minimize the necessity of complex assemblies and reducing needed time for the quality assurance processes,
- Enabling in-situ process monitoring/control for further improvement of the process consistency and the ALM products quality.

Year of the call: 2021

Type of Action: Grant - Research and Innovation Action

Based on a roadmap: Yes

B. Traditional collaborative research / small-scale low TRL road-mapped research

16. R&TD on compact and smart sensors for planetary exploration

SRIA corresponding technology-based activity lines: 3.5 Contribution to space science

ESRE White Paper/major trend: Space Science, Space Exploration and Human Spaceflight

Specific Challenge: The main challenge for the proposed activity is the necessity to identify miniaturized technological solutions that are acceptable in the course of a qualification based on ECSS standards or similar processes used in scientific missions worldwide. It will be critical to develop electronics sub-units that can be integrated into systems very limited in power, mass and size. Yet the systems will have to function with immense precision in rough environments with strong day-night temperature changes, a challenging radiation environment and sometimes even only roughly known environmental conditions preflight. For the penetrators only thermal sensors and accelerometer were implemented in an in-situ flight experiment. Therefore, different possible sensor technology needs to be assessed for their applicability. The entire development of all systems and subsystems must then be validated by a test campaign in order to prove the appropriate level of performance and technology readiness on Earth before proposing it as a part of a space project.

Scope:

- The assessment of possibility of extending the capabilities of planetary penetrators treated as a platform equipped with a sensor with extended capabilities. Identification of necessary actions meant to raise the TRL of considered solutions,
- The assessment of implementation possibility for the increased miniaturization of active spectroscopy solutions (LIBS, Raman) to make them suitable for small robotic exploration systems starting at roughly 20 kg in (thermally) challenging environments (Moon, asteroids, comets),
- Definition of testing and test methodology development aimed at performance validation of the systems based on compact sensors,
- Implementing prototypes and testing in space-like conditions,
- Selecting missions that could benefit from including the devices in the payload.

Expected Impact:

- Development of innovative less costly devices that can be applied in variety of missions that include in situ measurements,
- Demonstrative case study of refurbishment of existing technology into space applicable solutions,
- Valuable new devices to be added to European scientific instrumentation portfolio.

Year of the call: 2022

Type of Action: Grant - Research and Innovation Action

Based on a roadmap: Yes

17. Technological maturity and demonstration of very low temperature electronics for scientific exploration missions

SRIA corresponding technology-based activity lines: 3.5 Contribution to space science

ESRE White Paper/major trend: Space Science, Space Exploration and Human Spaceflight

Specific Challenge: The challenge of this research topic is to enhance technological maturity and demonstration of very low temperature electronics for scientific exploration missions. The exploration of Ocean Worlds like Europa, Ganymede, Enceladus or Titan are key scientific targets for the European science community in the coming years. Even the exploration of northern and southern land of Mars, far from the equatorial zone, are also relevant to study the planet's evolution and search for possible existence of extinct life. What all those bodies have in common is that their environment is quite extreme, in terms of radiation but also in terms of ambient temperature. Mean surface temperature at Europa is 102 K, at Titan 90 K and at Enceladus 75 K. In addition, the power resources are very low due to their distance to the Sun. Also considering Moon exploration, one challenging task is surviving night periods when temperature drops to 80 K, same considerations are related to Mars exploration, where an expected nighttime lows might be 174 K (-99 °C). Beside the extreme environment, it has to be considered the scarce power availability due to sun distance and so the heating capabilities.
One way to overcome the low temperature operational conditions is to have components and microdevices capable to operate, efficiently and reliably, in temperature ranges well below the range of those used in current space applications. The specific challenge will be to enable faster maturation of promising technologies, as a necessary step towards demonstration actions.

Scope: The goals of scientific space missions are to develop science-driven architectures and technologies, to create knowledge from scientific data, and to develop capabilities for assessing and managing complex missions. Taking into account extreme space environment conditions, nowadays, companies are working to extend the temperature envelope for a suite of electronic systems by developing components and systems that provide tolerance to hostile environments. To roadmap for being components and microdevices with enough level of maturity to be used in future missions has, as minimum, the following steps:

- Selection and characterization of existing space-grade, military and/or COTS devices for operation in very low temperatures,
- Development of a standardization methodology for validation of devices in low temperatures,
- Analysis of existing and development of new packaging techniques,
- Development of libraries to design blocks to be used in complete circuits to be used in very low microelectronics.

Expected Impact:

- Strengthen the leadership of Europe in new instrumentation technologies for future exploration missions,
- Foster cooperation between scientific, engineering and industrial teams, within and outside Europe, to develop instrumentation and systems for exploration missions beyond the current technology limits,
- Develop a know-how that could be used on Earth applications for instrument or devices that require operating at very low temperatures.

Year of the call: 2021 or 2022

Type of action: Grant - Research and Innovation Action

Based on a roadmap: Yes

18. Technological maturity and demonstration of freeform optics

SRIA corresponding technology-based activity lines: 3.5 Contribution to space science

ESRE White Paper/major trend: Space Science, Space Exploration and Human Spaceflight

Specific Challenge: Freeform optics is a promising and emerging technology based on the use of optical surfaces with non-radial symmetry in mirrors and/or lenses. It complicates the manufacturing and testing process but improves significantly the final optical performances of the instrument.

The design of freeform optics into optical systems remains as a major challenge. Although the current optical design software is powerful enough to design complex optical systems, there is still a strong need of new design methods to establish the initial configurations of new optical systems. The goal here should be to focus on more efficient design methods of freeform optics particularly for imaging applications. The other two challenges in freeform optics are manufacturing and testing. With respect to testing, the current interferometric methods, wavefront sensing and others have some limitations in both the dynamic range and the accuracy.

Freeform optics is widely used in ground technologies like biomedical, mobile displays, communications, automotive and energy research. However, the transition to a more widespread use in space applications is still pending. It represents the revolution against the historical tradition to design with spherical surfaces or exceptions based on off-axis surfaces. Nevertheless, the implementation of freeform optics technology in space instrumentation implies to dominate three basic pillars: design, manufacturing and verification.

The proposal foresees to work in parallel in the three areas, and mainly in the last one, the verification, facilitating a significant advance in the development of those optical systems where the mass and optical performance budgets are pretty penalized by the number of optical elements. Metrological verification of free-form optics requires the development of a specific test configuration, usually unique and associated with the free form of the target surface. This requires a combination of different test techniques: wavefront sensing based on Shack-Hartmann sensors, interferometry and generation of custom wavefronts using spatial light modulators. One of the main purposes is to advance the design and implementation of such systems.

In addition, this technology is applicable as theoretical support to understand misbehaviors in the alignment of large aperture optics when they are submitted to its gravity loads, large mirrors for instance. In these cases, freeform theory allows to explain how the combination of deformation in one mirror and tilt in others may produce an observed aberration pattern.

Designing optical systems (freeform or not) usually rely on starting from known configurations and by a mix of experience where trial and error adapt the preliminary design to the optical specification of interest. However, in the field of freeform optics, experience and known solutions are seriously lacking given the relative freshness of the field. It is therefore of interest to develop numerical methods capable of generating optical designs with limited human input. This can be done by further developing current research on freeform design by numerical integration or iterative construction or by leveraging recent breakthrough in artificial intelligence and apply these methods to the field of optical design.

Design tasks also include the specification of the different optical components and the effort required to reach specified performance, for example the accuracies required in producing the optical freeform surfaces. There exists a wide variety of freeform optical manufacturing methods and they all have different characteristics in terms of typical manufacturing defects.

Optics are not only sensitive to the magnitude of these defects, but also to their geometrical properties (such as spatial frequency). It would be beneficial to expand knowledge available to designers of the manufacturing processes and make it easier to simulate numerically their expected impact on the instrument performance. Doing so, would tremendously reduce the risk associated with using more complex optics such as freeforms, while reducing development time.

Scope: The promotion of free-form optics could address a wide range of science and engineering issues, including, but not limited to, the development of procedures, design methods and verification technologies within a framework that ensures the exchange of information and experience to expand this technology in space applications.

Expected Impact: The rapidly increasing demand of more compact optical systems for spatial applications, for example in CubeSat technology, make the freeform optics a preferred solution where the mass-performances ratio shall be optimized. It is foreseen that in the next decade there will be an explosion of small missions based on CubeSat platforms for EO, communications and even surveillance purposes where optical instrumentation based on freeform optics shall play a prominent role to meet the principles of the “New Space” philosophy: faster, better and cheaper. This can be achieved by:

- Promoting interaction between centers/companies with a clear interest in developing such a technology: workshops, conferences, etc.,
- Identifying proposals where freeform optics is applicable, trade-offs of classical versus freeform concepts in any space instrument,
- Establishing a roadmap for analyzing the potential use at theoretical level of freeform optics creating the proper network of interested centers and companies,
- Consolidating the freeform technology in the fields of design, manufacturing and verification up to get a maturity level compatible with its use in space,
- Provide the means to transfer this technology to the industry.

Year of the call: 2021 or 2022

Type of action: Grant - Research and Innovation Action

Based on a roadmap: Yes

19. Technological maturity and demonstration of efficient and compact spectrometric technologies

SRIA corresponding technology-based activity lines: 3.5 Contribution to space science

ESRE White Paper/major trend: Space Science, Space Exploration and Human Spaceflight

Specific Challenge: Many of the exploration missions have spectrometry as the core of their payloads. Rovers, landers and orbiters are equipped with ultraviolet, visible, infrared spectrometer for mineralogy and chemical analysis; Raman is another technique that will for first time in the near future, extending the chemical analysis capabilities for molecular detection. A Mossbauer spectrometer has been used for the detection of Fe minerals on Mars as well as X-ray diffraction. New designs of compact imaging spectrometers could be flown to survey large patches of the atmosphere. Besides that, other groups are more focused on surface exploration that requires sample analyses with instruments such as mass spectrometers or a tunable laser spectrometer associated to gas or liquid chromatography or capillary electrophoresis. Moreover, air quality assessment for human life support systems can be a key technology for future human space exploration.
In addition to spectrometer technologies with flight heritage, some other highly promising technologies for future missions require a lot of development efforts, like magnetic resonance spectroscopy for the chemical analysis of molecules.
In any case, miniaturization, robustness and sensitivity are the main goals for current design improvements of instruments and for new developments: miniaturization to optimize payloads in

terms of volume, power consumption, mass and capability to increase the number of instruments in each mission; robustness to survive in more extreme environments than current missions, like Venus, Europa, Enceladus, etc. A high sensitivity of instrumentation is needed to detect and identify low concentrations of molecules during sample analysis.

Scope: Miniaturization and robustness could address a wide range of science and engineering issues, which include but are not limited to:

- Characterization of detectors and optical components that allow the two goals;
- Identification and characterization of new components concepts for emitting sources, like lasers, high power LED, etc., with reduced electrical consumption but improved spectral stability;
- Identification and characterization of technologies like microfluidic for sample preparation integration with compact spectrometers;
- Determine the compatibility of the new development with planetary protection methodologies.

Expected Impact:

- Strengthen the leadership of Europe in new instrumentation technologies for future exploration missions,
- Foster cooperation between scientific, engineering and industrial teams, within and outside Europe, to develop instrumentation and systems for exploration missions beyond the current technology limits,
- Increase the scientific return for future and complex missions to Solar System bodies.

Year of the call: 2021 or 2022

Type of action: Grant - Research and Innovation Action

Based on a roadmap: Yes

20. Autonomous systems with high reliability, and able to work in all lighting conditions (Automated Rendezvous & Docking, proximity operations, target-relative navigation)

SRIA corresponding technology-based activity lines: 3.2 Future space ecosystems: on-orbit operations, new system concepts

ESRE White Paper/major trend: Space Science, Space Exploration and Human Spaceflight

Specific Challenge: On-orbit cooperation between spacecraft, large space debris removal, assembling structures in on-orbit environment, are examples of tasks where at least two objects, called target and chaser, interact with each other. These types of maneuvers on circular or elliptical orbits in close proximity, usually several meters apart, are performed with the objective to reduce the distance.

The final stage of such maneuvers is usually planned with some mechatronic systems such as robotic arm (or arms), net, harpoons or tentacles mounted on the chaser satellite. The final results of operation of that system is to catch the target to reduce its relative motion and allow to modify its status (change the orbit, repair, dismount, etc.). Such maneuvers require precise and reliable guidance navigation and control (GNC) system which will work autonomously in dynamically changing environment. In context of on-orbit operations the environment changes arise from rotational motion of spacecraft (ex. tumbling), lighting conditions (multi-reflections from MLI), movable obstacles (ex. S/C solar panels). From the theoretical perspective such

systems are non autonomous (time dependent) and require a special approach to develop stable control systems.
New, ambitious space missions, that are currently planned, will rely extensively on the advancements in space robotics. Such missions include Active Debris Removal (ADR) and On-Orbit Servicing (OOS). This includes European Space Agency's (ESA) e.Deorbit or Space Tug mission, which will demonstrate ADR capabilities by capturing and removing spacecraft from orbit.
Extensive tests of payload (manipulator, nets, tantacles, its control systems and sensors suites) prepared for such missions are required at various stages of development. Tests of space robotic technologies should be performed in relevant conditions. The microgravity is the aspect of space environment that is especially important for robotic technologies. There are several ways to simulate microgravity. Tests can be performed in the underwater conditions with neutral buoyancy vehicles, using weight-reducing suspension systems, on tests-beds based on industrial manipulators, during parabolic flights, using drop towers, and on air-bearing microgravity simulators. All terrestrial test-bed systems have different drawback. The main drawback of tests performed with neutral buoyancy vehicles is that the medium in which the tests are performed has high resistance (in can be especially problematic in case of high-speed motions). Moreover, such tests require dedicated waterproof hardware. In the weight-reducing suspension systems the cables disturb the free motion of the tested system. Moreover, allowable motions are significantly limited. In test-beds based on the use of industrial robots the motion of the chaser and the target satellite in microgravity conditions is calculated in real time based on the environmental model (e.g. on-orbit dynamics) or measurements and then later executed by industrial robots. Thus, in such approach the motion of the tested system is recreated, but not emulated. The behavior of the system is influenced by the accuracy of the model and by the accuracy of industrial robots used to execute the motion. The methods that offer equivalency with the actual environment also have some disadvantages. During parabolic flights it is possible to achieve 25 s of free fall. However, the microgravity conditions are highly disturbed. The average value of the residual gravity acceleration during the zero-g parabola is around 10-2 ÷ 10-3 g. Moreover, after the period of free fall acceleration can reach 2 g. The residual gravity acceleration is smaller in tests performed in the drop towers: 10-3 ÷ 10-6 g. However, the maximal time of experiment is much shorter (in most facilities the free fall lasts only up to 10 s). Another disadvantage of using the drop towers is the very limited space in the dropped capsule. Due to these facts the planar air-bearing microgravity simulators seem to be especially useful for validating space robotics technologies required for ADR and OOS missions. On such test-bed mock-up of a satellite equipped with a manipulator is able to move and rotate freely. Thus, influence of the manipulator motion on the state of the satellite can be simulated with a high fidelity. Moreover, a phenomena such as contact between chaser and target might be analyzed without frequency limitation. With only a few notable exceptions microgravity conditions on air-bearing tests-beds can be simulated in two dimensions (on one plane).
The International Space Station (ISS) would be very good place for testing the "Automated Rendezvous & Docking" (AR&D) technologies; however due to high costs there were not many realized projects. One example was NASA's Sphere project where the relative motion of a spherical object was analyzed on the ISS. Also CubeSat's platforms could be an interesting opportunity to realize tests with relative navigation and proximity operations. In both cases the key aspects are to compare results of space experiments with results obtained in terrestrial laboratories and to do cross validation of obtained results.
Scope: The TRL enhancement of AR&D technologies includes activities for:

- Improvement of performance, robustness, and reliability of the control systems dedicated for proximity operation of spacecraft's,
- Improvement of control system operate during contact between target and chaser mechatronic susbystems,
- Miniaturization and accommodation of mechatronic devices on CubeSat platforms,
- Miniaturization and accommodation of vision sensors on CubeSat platforms,

- Improvements of path planning algorithms to include autonomous obstacle mitigation during path realization,
- Improvements of navigation filters to include nonlinear behavior of systems,
- Development of sensors suites dedicated to rapidly changing lighting conditions,
- Validation of testbed systems dedicated to AR&D missions.

Expected Impact:
- Analysis of lighting conditions impact on guidance, navigation and control system dedicated to AR&D missions,
- Preparation of database with test results of AR&D technologies done on different testbed systems both on Earth as well as on orbit,
- Analysis of the stability of AR&D control systems in different mission phase (e.g. contact between target and chaser),
- Increase the level of autonomy of robotic systems,
- Increase the involvement of Europe's terrestrial robotics industry in space developments,
- Foster cooperation between international industry, scientific, and engineering teams.

Year of the call: 2022

Type of Action: Grant - Research and Innovation Action

Based on a roadmap: No

21. Mechatronic devices for subsurface sampling, drilling and excavation of planetary regolith in reduced gravity field

SRIA corresponding technology-based activity lines: 3.4 Enabling technologies (cross-mission, space and ground)

ESRE White Paper/major trend: Space Science, Space Exploration and Human Spaceflight

Specific Challenge: Different engineering and scientific interests motivate planetary substrate drilling, sampling and excavation of planetary regolith: the geologic, hydrologic and climatic history; the search for life and the identification of potential hazards and resources for future robotic and human exploration; and the possibility to greatly reduce the direct expense of humans going to and returning from the Moon and Mars, and then to build toward self-sufficiency (ISRU) of long-duration manned space bases to expand our exploration efforts. In-Situ Resource Utilisation (ISRU) is the collection, processing, storing and use of indigenous materials instead of transporting materials from Earth to reduce overall mission cost and risk. Oxygen and water have been identified as the most important candidates for ISRU. They are essential for life support and the production of propellants, reducing the necessity of transport from Earth. Extracting useful resources from the Moon, Mars or other planets, covers a wide range of processes and techniques which can be broadly split into three distinct, but interrelated categories:
- Prospecting and Excavation – locating, sampling, drilling, excavating and transport of the raw material;
- Chemical extraction – beneficiation (processing a raw material to improve its properties) and extraction of the useful resource from the raw material;
- Infrastructure – the facilities required to produce the resource.

Each of these technologies must operate in autonomous way mostly by robots.

The key aspect of sampling, drilling and excavating process is related to energy effective and reliable movement of subsurface planetary regolith from its origin to desired place. This is a well-known process in terrestrial industry, however the significant and nonlinear impact of gravity is almost unknown in planetary environment. Such a nonlinearity was determined in several scientific papers showing evidence that low gravity has the nonlinear influence on continuous or discrete excavators. This is mainly due to difficulties to exert tracking forces between machines and regolith in low gravity environment. Therefore, other types of devices should be considered. Moreover, different and unknown environmental constraints (low gravity, temperature, vacuum, radiation, dust, etc.) have a strong influence on the effectiveness of devices, mining methods and mission operational difficulties.
There are several ways to simulate microgravity. Tests on Earth can be performed in the underwater conditions (with neutral buoyancy vehicles), during parabolic flights, on tests-beds based on industrial manipulators or on air-bearing microgravity simulators. Another possible option is to perform tests on the ISS. Increasing accessibility to test-bed system dedicated to space robotics should allow higher reliability of developed systems. These options should be used to examine efficiency and reliability of different concepts of sampling devices, drills and excavation systems.
Another key aspect of sampling, drilling and excavating processes is the generation of dust clouds that, in the reduced gravity field combined with electrostatic forces under vacuum, can levitate during long periods of time and reach distant places. The trajectories of mobilized dust can be simulated numerically to assess their undesired impact on life support system. Countermeasure and mitigation techniques can be tested in vacuum chambers and on the ISS.

<u>Scope</u>: The goal of subsurface sampling, drilling and excavation of planetary regolith, or In-Situ Resource Utilization (ISRU), is to harness and utilize space resources to create systems and services which enable and reduce the mass, cost and risk of long-term space exploration.
The TRL enhancement of sampling systems, drills and excavation systems includes activities for:

- Analysis of the interaction between regolith particles during operation of the systems,
- Analysis of gravity impact on different types of systems,
- Conceptual work on excavators dedicated to low gravity environment with special focus of its operation in dusty vacuum environment,
- Comparison of performance, robustness, and reliability of different systems,
- Miniaturization and accommodation of sensors in sampling systems,
- Solution of energy and temperature aspects for long-term operation in an environment without sunlight,
- Analysis of dust and vacuum impact on long-term operation of the excavators,
- Definition of Fault Tolerant Control system of drills and excavator,
- Definition on key functional parameters of a chosen excavator such as: rate of regolith excavation, power requirements, reliability figure which will be evaluated during tests;
- Improvement of terrestrial testing facility to accommodate testing of drills and excavators in low gravity environment,
- Preparation the ISS for testing sampling systems, drills and excavators,
- Realization of tests and cross correlation between tests in different facilities,
- Sampling and sample processing for life detection and other downstream applications.

<u>Expected Impact</u>: ISRU can be the key element to implement an affordable space program to explore the Solar System and beyond. Potential planetary resources include water and vast quantities of metals and minerals, that suitable processing can transform these raw resources into useful materials and products.
Some impacts might be:

- Analysis of gravity, vacuum and dust impact on drills, sampling and excavation systems and based on that selection of most promising technologies,

- Analysis of the undesired side-effects of dust cloud generation and determination of countermeasure techniques,
- Determination of performance of the systems and integration with ISRU flowchart,
- Testing of technologies in terrestrial and ISS environment. Correlations of mathematical models with obtained tests,
- Determination of long-term performance of the system and definition of system maintenance,
- Increase TRL for in situ life detection and assessing any potential biological hazard to humans,
- In addition, the technologies required for lunar exploration and development will be used to improve products and services on Earth.

Year of the call: 2021

Type of Action: Grant - Research and Innovation Action

Based on a roadmap: No

22. Conceptual and subsystem R&TD related to space debris mitigation, avoidance and removal

SRIA corresponding technology-based activity lines: 3.2 Future space ecosystems: on-orbit operations, new system concepts

ESRE White Paper/major trend: Transversal Trends

Introduction/Specific Challenge: Space debris is a growing concern and a threat for sustainable space activities in orbit, due to the increase of space objects (space debris, active or out-of-service satellites, spent rocket upper-stages, etc.). For these reasons an increased effort is needed on mitigation measures, collision avoidance and space debris removal. Important challenges are performance and cost-effectiveness (for any kind of systems), the particular case of mega-constellations and how to address non-cooperative debris with characteristics that are not precisely known.

Scope: The topic is globally devoted to key technologies and potential game-changing concepts that could address the space debris issue and eventually reduce the threat of a collision in orbit for space assets. The range of technologies to be considered includes End-of-Life Disposal strategies (e.g. drag augmentation devices), collision avoidance systems (e.g. laser system for orbit deviation) and Active Debris Removal (e.g. robotic or net capture by a space tug).

Expected Impact: The expected impact is the identification of key technologies that could significantly reduce the space debris risk for a realistic cost, as well as a TRL increase for these technologies. Eventually, the impact will be sustainable on-orbit activity through the mitigation of space debris risk.

Year of the call: 2021

Funding instrument: Grant - Coordination and Support Action

Based on a roadmap: No

23. R&TD on subsystems and standards for larger CubeSats

SRIA corresponding technology-based activity lines: 5.5 Standardisation and qualification approaches

ESRE White Paper/major trend: Transversal Trends

Introduction/Specific Challenge: In the last few years we see new parties entering into the information-market, driven by technological advancements and the opportunities enabled by (small) satellites today. Previously the space market was dominated by institutional players, while today we also see smaller parties and academic institutions designing and launching satellites. We also see a large number of new commercial companies rising with ambitious business cases. Many of these companies focus on global coverage services in communications and Earth Observation, giving rise to more constellations of satellites. This shifts the focus from larger satellites in higher orbits, which would be too expensive to use in a constellation, to smaller satellites in a lower orbit.

Traditionally, satellites are tailor-made and sized according to the mission requirements. The CubeSat standard is different, in that the dimensions are standardized, making it easier and quicker to develop subsystems, components and instruments to fit a wider market, but at the same time constrains the maximum achievable performance. As such, we see the CubeSat standard being applied up to 27U (~40 kg), but for most of the 20-200 kg range, satellites are built in the traditional custom way, without applying a given form factor standard. This makes the range 20-200 kg unattractive as they have a relative bad performance for each dollar.

However, a lot of the market potential lies in the 20-200 kg range that is currently less accessible for new players due to the lack of similar standardisation, while applying the CubeSat standard beyond 27U would be counterproductive to the strength of designing 10x10 cm units.

It could therefore be a huge boost to the European space market if the bar for entry to the upper range of small satellites (20-200 kg) can be significantly lowered by providing a new standard or an extension to the existing CubeSat standard.

Scope: In order for a new standard to have the desired impact, there would need to be broad support from both the satellite integrators as well as the subsystem manufacturers. As such research should support the needs of both sides. In order to achieve this goal, on top of developing the standard itself, prototypes and demonstrators would have to be developed in order to demonstrate the added value of the standard and provide a proof-of-concept.

The standard itself would therefore involve:

- A standardisation of the architecture of the satellite bus,
- Design of a deployer,
- The selection and detailing out of electrical interfaces, both for command & control as well as data,
- A scope of the instruments that can be hosted by the satellite bus,
- Backwards compatibility to CubeSat components.

Demonstrators can be designed for the following subsystems:

- Thermal control systems (heatpipes, cooling loops, radiators, etc.),
- On-board computing (COTS-based, non-space-qualified),
- Structures (ALM/3D-printing, composites, integration of solar panels, etc.),
- Attitude Control,
- Orbital control (including constellation management),
- Intersatellite communication (RF/optical),
- Sat-to-ground and ground-to-sat communication (command & control, data),
- Power,
- GSE.

Expected Impact:

- Enable new space applications that are too demanding for CubeSats but too expensive to custom-build, like local weather forecast, local measurement of air quality, SmartFarming, traffic monitoring, city development, etc.;
- Boost to the European space economy, both on the integration side as well as the subsystem manufacturing side;
- Easier MAIT for satellites in the range 20-200 kg;
- Lowers the bar to entry into the high-performance small satellite market;
- Improve small satellite performance.

Year of the call: 2022

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: No

24. R&TD on next generation radar and passive optical sensors and related image processing for satellites, HAPS and RPAS

SRIA corresponding technology-based activity lines: 3.1 Foster competitiveness of end to end systems and associated services

ESRE White Paper/major trend: Earth Observation

Specific Challenges: The challenge is to advance and mature application-oriented technologies in the domain of Earth Observation which are expected to underpin competitiveness of the European space industry and contribute to the integration of space in society and economy. Activities shall focus on improving timeliness and reactivity of observations, their resolution and swath extension, the performance of sensors and the underlying technologies, while addressing also challenges associated with the increasing data volumes in remote sensing missions. Current trends using small satellites high altitude platforms (HAPS) and remotely piloted aircraft systems (RPAS) for Earth Observation, surveillance and reconnaissance shall also be considered.
Radar activities shall focus on bistatic and multistatic SAR systems that enable new observation capabilities. The implementation of fractionated SAR system concepts, i.e. separated transmitter and receiver satellites, shall be considered as well as the potential increase in information gain with the number of receivers, the reconfiguration and the fine-tuning of the satellite formations.
Optical activities shall focus on hyperspectral and high-resolution systems in the visible and infrared spectral range. The new hyperspectral technology shall enable new capabilities for the measurement of spectral properties and to identify constituents on land, water, and in the atmosphere. Compact rugged lidars for land and troposphere profiling shall be matured in order to meet the airborne requirements.

The R&D shall focus on global hyperspectral mapping systems (probably as a fleet of compact sensors in orbit) combined with other sensor systems (multispectral/panchromatic/active) for data fusion purposes in order to generate analysis-ready-data as a basis for the development of higher quality information products, which can be used to record the dynamic processes of aquatic and terrestrial ecosystems.
The overarching objective is to improve the performance of EO systems and missions, building on previous activities supported by the Union, Member States and ESA.

Scope: The aim of this call is to demonstrate, in a relevant environment, technologies, systems and sub-systems for Earth Observation from satellites as well as from HAPS and RPAS. Proposals should demonstrate significant improvements in areas such as miniaturization, power reduction, efficiency, versatility, and/or increased functionality, and should demonstrate at the viable extent complementarity to activities already funded by Member States and the European Space Agency. Proposals should also ensure system readiness for operational services and provide leverage on industry competitiveness, particularly on export markets.
Each proposal shall address one or a combination of the following subtopics:

- Advanced Optical: New technologies, concepts and architectures shall be investigated, e.g. new detector technologies together with higher pixel numbers and higher frame rates; methods of MS/PAN sharping for hyperspectral systems; slit homogenizer for hyperspectral system to improve the spectral characterization; compact hyperspectral optical designs e.g.: Dyson or innovative static fourier transform spectro imager; light-weight or deployable optics for compact optical systems; innovative optical components and designs enabling compact multispectral imagers and/or lowcost snapshot LWIR imagers. Compact fiber lasers and lidar architectures based on innovative components;
- Advanced SAR/Radar instruments and systems: new sensing concepts and system architectures based on e.g. digital beam-forming also in combination with large deployable reflector antennas that enable a quasi-continuous, high-resolution monitoring of the Earth surface in three dimensions; bi- and multistatic systems for single-pass interferometry, radar tomography; fractionated SAR systems, i.e. separated transmitter and receiver satellites/platforms; miniaturization of radar components for installation on small HAPS and RPAS; disruptive technologies for radar sensors;
- Data processing: integrated multi-instrument on-board payload data processing for resource-constrained missions; solutions for high observation reactivity and real-time applications such as very high performance payload processing; on board data/image optimisation and compression for advanced video and image pre-processing as well as smart on-board data/image analysis; on-ground focusing of bistatic and multistatic radar data, including tomographic processing; data flow optimisation, including impacts on the evolution of associated ground segment, for enhancement of overall processing power and speed over the full chain and for supporting massive data processing and machine learning in EO applications; processing and information extraction from circular flight data coming from HAPS or RPAS.

Low cost solutions based on components-off-the-shelf (COTS) are encouraged. Participation of industry, in particular SMEs, is encouraged. Activities shall be complementary and create synergy with other European activities in the same domain.

Expected Impact:

- Improvement in the capability, including through miniaturization and power reduction, precision, efficiency or other characteristics with respect to existing Earth Observation sensors and missions, opening new avenues for future space and drone systems;
- Substantial improvement in state-of-the-art technologies in key areas such as optical and radar systems, radio occultation sensors, sounders, lidars for troposphere and Earth Observation, and related key technologies, as for instance detectors, antennas, optical multiplexers and couplers;
- Strengthening Europe's position in industrial competitiveness in technologies for Earth Observation payloads and missions;
- Greater industrial relevance of research actions and output as demonstrated by deeper involvement of industry, including SMEs, and stronger take-up of research results;

- Fostering links between academia and industry, accelerating and broadening technology transfer.

Year of the call: 2021

Type of Action: Grant - Research and Innovation action

Based on a roadmap: No

25. Development of multi-temporal and multi-sensor algorithms for future Copernicus long-term monitoring products

SRIA corresponding technology-based activity lines: 3.1 Foster competitiveness of end to end systems and associated services

ESRE White Paper/major trend: Earth Observation

Specific Challenges: The Copernicus programme offers information services based on satellite Earth Observation and in situ data addressing all domains of the Earth environment, including the atmosphere, land (including inland waters) and oceans. The systematic data and information provision by Copernicus help assist governments and stakeholders from the regional to global level in developing strategies and actions to assess, track and attain the goals set out in various policy fields. Next to EU policies, there is an increasing focus on how Copernicus services can provide relevant information to support effective monitoring of progress towards the United Nations' Sustainable Development Goals (SDGs). Copernicus services are not static, but are constantly evolving based on emerging user requirements as well as advances in the state of the art with respect to algorithms and data exploitation capabilities. R&D activities in this topic shall support the evolution of Copernicus services to provide new or greatly improved long-term monitoring products.

Scope: Projects shall develop and demonstrate new and improved algorithms that can contribute to an evolution of the future Copernicus data portfolio for the long-term monitoring of dynamic processes in different spheres of the Earth. Specifically, projects shall focus on multi-temporal and multi-sensor algorithms for the generation of new or improved long-term monitoring products in one of the following areas:

- Biosphere: new concept for forest mapping and deforestation monitoring, forest structure, development of deforestation early-warning systems, biomass and biomass change, forest status and degradation, related green-gas emissions and impact on the carbon cycle;
- Cryosphere: ice/snow mapping, snow parameters evolution, ice velocity mapping, grounding line tracking, ice structure, glaciers mass balance, avalanche risks, monitoring of permafrost regions;
- Hydrosphere: soil moisture, water cycle, water surface height, water surface temperature, atmospheric water vapor, oceanography;
- Geosphere: surface deformations monitoring, subsidence, man-made structures stability and risk assessment, tectonics and earthquakes effects, landslides, and mining activities.

Projects shall provide a proof-of-concept or a prototype demonstrating the feasibility of the integration in the existing Copernicus portfolio. Use of existing data from other missions, both spaceborne and airborne, for algorithm development and testing is encouraged. New IT tools should be considered and innovative solutions should be proposed for better data exploitation,

processing and distribution, e.g. cloud and HPC computing, distributed computing, Artificial Intelligence, machine learning, image processing, data fusion, ensemble modelling, model coupling & nesting, software as-a-service.
R&D activities should aim at a better integration of space research with other non-space domains (e.g citizen science including social media) focusing in particular on policy areas addressing global and societal challenges highlighting horizontal synergies and multidisciplinary approaches. In particular, proposals should clearly mention which EU policies and/or which UN Sustainable Development Goals the project will support.

Expected Impact:

- Reinforcing the link with the academic and scientific sector for derivation and consolidation of new algorithms for the definition of future Copernicus EO mission data portfolio; proposed proof-of-concept or prototype, as outcome of the project, should clearly demonstrate an improvement of the Copernicus service evolution;
- Enabling synergetic use of heterogeneous sensor suites and integration of different observation capacities with a clear demonstration of an increase in the service performance (compared with the existing one);
- Increased coverage of EU policies and/or the UN SDGs, clearly identifying which and how the project intends to address them;
- Fostering links between policy, academia and industry, accelerating and broadening technology transfer and uptake.

Year of the call: 2021

Type of Action: Grant - Research and Innovation Action

Based on a roadmap: No

26. Real-time data processing of multi-source data from space, aerial (including stratosphere) and terrestrial sensors, developing both novel coordinated tasking approaches and data fusion technologies, e.g. in the areas crisis management and multi-mission planning

SRIA corresponding technology-based activity lines: 3.1 Foster competitiveness of end to end systems and associated services

ESRE White Paper/major trend: Earth Observation

Introduction/Specific Challenge: The challenge is to advance and mature application-oriented technologies in the domain of Earth Observation (EO), which are expected to underpin competitiveness of the European space industry and contribute to the integration of space in society and economy. Activities in EO will focus on improving timeliness and reactivity of observations, their resolution and swath extension, the performance of sensors and the underlying technologies, while addressing also challenges associated with the increasing data volumes in remote sensing missions. Current trends using small satellites, high altitude platforms (HAPS) and remotely piloted aircraft systems (RPAS) for Earth Observation, surveillance and reconnaissance shall also be considered.
The spatial/temporal/spectral resolution required by some real world applications (environmental protection, citizens' safety, security, etc.), can be achieved implementing synergies among space (and also non-space) remote sensing platforms. Such synergies can be developed through the use in synergy different data sources (optical sensors like panchromatic, multispectral and

hyperspectral as well as radar sensors like L-band, P-band), developing approaches and tools able to overcome the gap in terms of different spatial resolution, acquisition time, and type of sensors.

Scope: The aim of this call is to demonstrate, in a relevant environment, technologies, systems and sub-systems for real-time processing of Earth Observation data from multi-mission satellites as well as from HAPS and RPAS.
Development of data fusion technologies and analytics, and methodologies addressing industrial requirements and/or societal challenges with Earth Observation data at their core, scaling up to the increased data volumes of Copernicus' archives. They shall aim to develop new, enabling, operational solutions to improve capabilities and performance of the Copernicus value chain. Proposals shall focus on data fusion methods in order to generate automatically Analysis-Ready-Data as a basis for the development of higher quality information products, which can be used to record the dynamic processes of aquatic and terrestrial ecosystems. Proposals are also required to seek end-user involvement to drive the research with their requirements and test the developed solutions, with a clear path to the exploitation of the results.
Proposals are strongly encouraged to make use of existing European data infrastructures such as (but not limited to) Copernicus' DIAS and to develop solutions that can be plugged into DIAS and/or other existing European data infrastructures to enhance their capabilities and offer.
For proposals under this topic:

- Participation of industry, in particular SMEs, is encouraged;
- Involvement of post-graduate scientists, engineers and researchers and promotion of gender balance is also encouraged.

Expected Impact:

- Enabling synergetic use of heterogeneous sensor suites and integration of different observation capacities with a clear demonstration of an increase in the service performance (compared with the existing one);
- Increased capacity of processing and analyzing Earth Observation data, with powerful tools that demonstrate their applicability in real-world settings;
- Increased performance and/or automation of processes involving the processing of Copernicus data;
- Demonstrated adoption of results of the Copernicus data analysis in decision-making (in industry and/or society);
- Strengthening Europe's position in industrial competitiveness in technologies for Earth Observation data processing;
- Greater industrial relevance of research actions and output as demonstrated by deeper involvement of industry, including SMEs, and stronger take-up of research results;
- Fostering links between academia and industry, accelerating technology transfer.

Year of the call: 2021

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: No

27. Development and validation of concepts and models for environmental bioindicators that can be monitored from space

SRIA corresponding technology-based activity lines: 3.1 Foster competitiveness of end to end systems and associated services

ESRE White Paper/major trend: Earth Observation

Introduction/Specific Challenge: Bioindication provides information on the response of living organisms to the integrated effects of environmental contaminants, which cannot be determined by direct analytical measurements. Compared to chemical and physical measures of environmental quality, bioindicators are capable of capturing cumulative impacts of multiple pollutants and habitat changes, in an early stage and over time. As an example, cyanobacteria are good bioindicators of water quality, and providing rapid response detection could be considered desirable as an 'early warning' indicator of change. The assessment of the presence, abundance and performance of living organisms in the field can give insights on the impact of environmental stress on the composition and health of the ecosystem.

Scope: The aim of this call is to develop and validate concepts and models for environmental bioindicators that can be monitored from space. Development of new, enabling, operational solutions to improve capabilities and performance of the Copernicus value chain. Proposals can address individual elements of the value chain or the value chain as a whole, and should provide quantitative measures of the progress beyond the state of the art. Proposals are also required to seek end-user involvement to drive the research with their requirements and test the developed solutions, with a clear path to the exploitation of the results.
Proposals are strongly encouraged to make use of existing European data infrastructures such as (but not limited to) Copernicus' DIAS and to develop solutions that can be plugged into DIAS and/or other existing European data infrastructures to enhance their capabilities and offer.
For proposals under this topic involvement of post-graduate scientists, engineers and researchers and promotion of gender balance is encouraged.

Expected Impact:

- Increased capacity of processing and analyzing Earth Observation data, with powerful tools that demonstrate their applicability in real-world settings;
- Demonstrated adoption of results of the Copernicus data analysis in decision-making (in industry and/or society);
- Strengthening Europe's position in industrial competitiveness in technologies for Earth Observation;
- Fostering links between academia and industry, accelerating and broadening technology transfer.

Year of the call: 2021

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: No

28. Continuous data calibration between satellite-received data and simultaneous flight formation laboratories

SRIA corresponding technology-based activity lines: 3.1 Foster competitiveness of end to end systems and associated services

ESRE White Paper/major trend: Earth Observation

Introduction/Specific Challenge: The emergence of new sensing opportunities (e.g. unmanned aerial vehicles (UAVs)) in parallel with continued advances in satellite platforms present a unique opportunity to develop new insights with potentially far reaching societal and economic benefits. While this high resolution geospatial information revolution could constitute a game changer in the ability to derive time-critical and location-specific insights into dynamic land surface processes, challenges prevail in combining and profiting from multi-sensor data streams. Advanced harmonization techniques are needed to ensure consistency in observations across sensors regardless of sensor design and platform, spectral responses, radiometric performance, absolute calibration accuracy, and view and illumination geometry.

Scope: The aim of this call is to define an innovative and holistic strategy for the cal/val activities for and across the existing and planned missions in an operational perspective.
The proposals shall focus on an automated harmonization framework for ensuring interoperability and consistency across sensors. The framework should incorporate gap-filling techniques and the use of a machine learning approach is encouraged. The framework should be largely insensitive to sensor input and calibration (i.e. it can work with DNs, radiances, or reflectances).
Proposals are strongly encouraged to make use of existing European data infrastructures such as (but not limited to) Copernicus' DIAS and to develop solutions that can be plugged into DIAS and/or other existing European data infrastructures to enhance their capabilities and offer.
For proposals under this topic:

- Participation of industry, in particular SMEs, is encouraged;
- Involvement of post-graduate scientists, engineers and researchers and promotion of gender balance is also encouraged.

Expected Impact:

- Consistent approach for the calibration and validation for and across Copernicus Sentinels;
- Coordination of networks and space agencies and institutions contributing to Copernicus Sentinels cal/val activities;
- Strengthening Europe's position in industrial competitiveness in technologies for Earth Observation data calibration;
- Greater industrial relevance of research actions and output as demonstrated by deeper involvement of industry, including SMEs, and stronger take-up of research results;
- Fostering links between academia and industry, accelerating and broadening technology transfer.

Year of the call: 2021

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: No

29. Coverage improvement, resistance to interference and spoofing

SRIA corresponding technology-based activity lines: 5.2 Dual use and synergies with defence

ESRE White Paper/major trend: Navigation

Introduction/Specific Challenge: Satellite navigation has become so common-place that society has come to depend on it to a large degree. It is by now well-known that this also imposes risks, due to weak signals which can easily be disturbed or even purposely altered. The awareness of the risks is growing, and so is the number of countermeasures implemented in receivers. Nevertheless, there is currently no single solution that is commonly available, resistant to most threats and reliable in all cases.
In this research topic the above challenges are specifically addressed, aiming at non-military applications. There are many of such applications in varied forms: ranging from relatively non-demanding (pedestrian navigation) to more technically complex (indoor navigation) to very complex and critical (highly-automated driving and commercial air transportation). Each application has its own unique set of challenges and requirements. As demonstrated by interest groups such as Galileo Services, European industry has high stakes in these developments. It is important that the industry is at the forefront of developments to ensure that not only Europe claims a significant piece of the positioning market, but also to ensure that Galileo uptake is increased and that the European GNSS systems obtain and maintain a leading role.

Scope: This research topic focuses on specific downstream technologies aimed at increasing the robustness and usability of navigation devices. The focus on non-military applications is applied to prevent overlap with restricted technologies.
Key technologies to focus on could be (but are not limited to):

- Dynamic filtering algorithms in challenging environments (e.g. urban areas);
- Adaptable spoofing detection and suppression algorithms;
- Multipath suppression techniques (e.g. urban environment, vehicle structure);
- Smart and cost-effective antennas (e.g. to reject interference);
- Ionospheric scintillation suppression techniques;
- Bridging technologies for outdoor and indoor navigation;
- Sensor data fusion architectures and algorithms for lower cost devices;
- Implementation of all civil Galileo Services on low cost devices;
- Merging of non-GNSS (e.g. 5G) networks and GNSS in order to achieve coverage improvements;
- Cost-effective and resilient GNSS positioning technologies for small satellites (LEO, MEO).

Proposals may focus on developing one of the above techniques, or on the integration of several techniques into a combined model.

Expected Impact:

- Increased reliability of end-user navigation devices,
- Reduction of risks related to GNSS-dependent navigation in society,
- Bringing state-of-the-art technologies to lower end devices,
- Enabling use of positioning technologies for new critical applications,
- Ensuring a technological advantage for European companies.

Year of the call: 2021

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: No

30. R&T on optical beam forming technologies

SRIA corresponding technology-based activity lines: 3.1 Foster competitiveness of end to end systems and associated services

ESRE White Paper/major trend: Communications

Introduction/Specific Challenge: Lasers and optical beamforming networks will be essential components for future control and action in space: laser communication for global internet, ground-to-space and space-to-ground optical links, RF phased arrays, inter-satellite optical communications, laser ranging, precision docking, active imaging, on board self-probing and diagnosis, etc. Indeed, many functions will rely on space and ground subsystems involving a laser and will require compact beam formers to obtain optimized beam shapes. Technologies that could provide such capabilities are emerging but their maturation on the timescale of "New Space" is challenging and requires specific support.

Scope: The scope of the collaborative research would be to offer key emerging technologies on a short timescale imposed by system development roadmaps. In the field of RF links between satellites and ground, optical technologies are involved in optical "beam-formers" which drive passive phased array RF antennas. In the field of optical links between satellites and/or ground, overcoming laser beam spreading is needed so as to reduce propagation constraints on link budget. Different technological solutions, like Photonic Integrated Circuits, coherent beam combiners, optical multiplexers or multi-plane light converters, have to be assessed to fulfil requirements imposed by space communications (spatial environment, optical bandwidth, etc.).

Expected Impact: New commercial activities are expected to be provided by low-flying small satellite constellations using hundreds or even thousands of satellites in LEO or MEO. To provide needed services, these constellations should benefit from progress in optical communication and optical beamforming for RF links. Beamforming is an essential technological enabler for laser sub-systems, technologies should be usable in space for monitoring, communication and action in space or on the ground for ground-to-space communications links.

Year of the call: 2021

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: No

31. Next generation light-weight robotic arms and hands for various use cases

SRIA corresponding technology-based activity lines: 3.2 Future space ecosystems: on-orbit operations, new system concepts

ESRE White Paper/major trend: Research under Space Conditions and Robotics

Specific Challenge: The overall challenge is to enable major advances in space robotic technologies for on-orbit missions requiring robotic activity and proximity operations. Robotic manipulators are key technologies required to perform autonomous or semi-autonomous in-space manipulation such as satellite servicing or the assembly of large space structures like space-telescopes or the future Cis-lunar gateway. Reducing the mass of these robotic systems would extend their scope of application by allowing them to be used on small servicers. However, this

mass reduction also implies a stiffness decrease and therefore in precision. To address these points specific control and sensor fusion algorithm should be considered.
It is mandatory to have force/torque redundant space robot arms available that are applicable for assembly, maintenance, repair, service tasks, and active debris removal of (non-)cooperative targets, whose performance is comparable to current professional light weight-service robots. There is a global push to have this technology ready for new space applications and it is vital to prepare the technologies in Europe for an in-orbit demonstrator to be implemented in the 2023-2027 timeframe.

Scope: Flexible robot development for various in orbit tasks:

- Joint design as basic blocks,
- Different kinematic chains,
- Joint design for different loads but same interfaces,
- Gripper design for various use cases,
- Tool change adapter for different loads,
- Smooth integration into available space ready arm,
- “New Space” approach,
- Component level,
- Validation,
- Verification,
- Robot control including sensor integration and sensor fusion.

Expected Impact: These space robotics technologies will enable “New Space” business cases among currently unavailable services such as assembly, maintenance, repair, service tasks and active debris removal. The space proven robots need an increase in performance in a cost-effective manner.

Year of the call: 2021

Type of Action: Grant - Research and Innovation Action

Based on a roadmap: Yes

32. Compact, space qualified, high performance sensors for robotic in-situ exploration

SRIA corresponding technology-based activity lines: 3.4 Enabling technologies (cross-mission, space and ground); 3.5 Contribution to space science

ESRE White Paper/major trend: Research under Space Conditions and Robotics

Specific Challenge: Europe contributes to space exploration by developing and implementing world-class space missions in the context of national and ESA mission, and often in partnership with major international players. In-situ exploration is the next big step in planetary science, and many space mission concepts either focus on the in-situ exploration with landed assets or contain a deployable payload for in-situ investigations.
The latter include nano-rovers, crawlers, or platforms that maneuver by hopping, but aerial platforms like balloons and helicopters have also been proposed. Mass limitations of such systems require innovative high performance instrumentation, primary challenges being miniaturization, reduction of power consumption, power sources, radiation hardness (or tolerance), operation in a wide temperature range and the reduction of data volume by innovative on-board processing capabilities. Furthermore, the deployment of sensor arrays requires autonomy, fast data-

communication capabilities and modularity of the instruments. Finally, new technologies can be levered to develop entirely new classes of instrumentation (e.g. micromechanical devices, laser-interferometric methods, fiber networks).

Scope: Mobile surface elements could address a wide range of science and engineering questions, which include but are not limited to:

- Efficient sampling from surface and subsurface, and sample processing for downstream analytical instruments (e.g. biogeochemical analyses);
- Characterization of mechanical properties of surface materials to assess robot-surface and human-surface interactions;
- Characterization of the space environment to assess risks for human exploration;
- Characterization of the seismic environment to assess risks associated with thermal fatigue of habitat structures and micrometeorite impacts;
- Characterization of planetary atmospheres and interiors to assess formation, evolution, and the habitability of terrestrial planets;
- Characterization of shallow subsurface and caves to assess the materials and to detect water and potential biomarkers not degraded by the external environment (radiation);
- Research and innovation projects addressing the development of space instrumentation to answer these questions could include the development of micro-imagers, microscopes, spectrometers, biosensors, accelerometers, geophones, seismometer, geophysics sensors, gyroscopes, magnetometers, gravimeters, humidity and gas sensors, temperature and wind sensors as well as electrical and radiation sensors. Projects could also address networks of sensors, their interactions and their intelligent data processing.

Expected Impact:

- Strengthen the leadership of Europe in in-situ space science and exploration;
- Foster cooperation between scientific, engineering and industrial teams, within and outside Europe, to develop instrumentation and technologies enabling space science and exploration;
- Provide technological solutions to support a safe and sustainable human presence on the Moon and other celestial bodies;
- Increase the scientific understanding of the formation, evolution and habitability of terrestrial planets, including the asteroids, comets, Earth's Moon and the icy moons of the outer planets.

Year of the call: 2021

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: No

33. Robotic CubeSat missions for testing cooperative tasks, e.g. formation flying, infrastructure assembly in on-orbit conditions

SRIA corresponding technology-based activity lines: 3.2 Future space ecosystems: on-orbit operations, new system concepts

ESRE White Paper/major trend: Research under Space Conditions and Robotics

Introduction/Specific Challenge: Cooperative satellites will enable many new applications or enhance current capabilities for small satellites. Formation flying is the first essential stepping stone to manage clusters of satellites and perform collaborative tasks. Mastering cooperation, formation flying and inter-satellite communication gives access to in-orbit assembly of larger systems. This will grant access to future breakthroughs in space science and technology such as giant telescopes, antennas, radar systems and other payload systems, bypassing constraints imposed by fairing size, launch mass and deployable structures. It also allows maintenance on existing systems in order to extend their lifetime or upgrade their capabilities. Expected applications are cutting-edge concepts in astrophysics, Earth Observation, and exploration missions to the Moon or Mars. The goal of this topic is to design CubeSat missions providing a testbed for key technologies involved in complex cooperative tasks.

Scope: Formation flying is no longer a novelty, even for small satellites it is becoming more common and advanced. Soon-to-be technology demonstrators are expected to perform complex tasks such as autonomous satellite docking. However, relatively large platforms are still required (200 kg for PROBA-3), and limitations include poor accuracy (sub meter for CanX-4/5) or short mission lifetimes due to low ΔV budget.
In order to demonstrate formation flying or infrastructure assembly capabilities, proposed missions should address one or several of the following issues:

- There are countless concepts and applications for formation flight and cooperative satellites; however, these possibilities are very dependent on the relative position knowledge and position control. In order to reach acceptable performances for most applications the mission specification must aim for a centimetre relative position knowledge accuracy on a 6U CubeSat or smaller and provide sufficient ΔV and impulse control to match operational mission duration, typically resorting to electric propulsion or enhancing the current liquid propulsion systems.
- In the context of the PERASPERA roadmap, the key technologies needed to perform autonomous on-orbit assembly have been assessed by H2020 PULSAR and H2020 MOSAR projects. However, further work is needed on critical scenarios, for example desaturation using electric propulsion and constraints on structures and materials caused by the space environment. Missions involving a number of CubeSats could address robustness, scalability and safety issues regarding mission planning, resource management and coordination of the formation flying architecture.
- Close proximity manoeuvers should also be considered, in order to demonstrate the ability to deal with unaccounted perturbations, either by considering communications delay with the ground in the formation control, or by relying on independent on board sensor systems to monitor the safety of the operations and allow autonomous disengagement.
- Specific key subsystems must be demonstrated such as optical or radar sensors, on-board intelligence for autonomous operations, inter-satellite communications and sensing, etc.
- Other related space operations can be relevant, e.g.:
    - On-orbit servicing for inspections, maintenance and refueling,
    - Distributed Earth Observation payloads including geometry dependent measurements such payloads which use time-differences,

- Earth Observation sensor fusion,
- Secondary platforms in interplanetary missions for mission risk mitigation and for support to the main spacecraft.

Expected Impact: These missions will serve as milestones for in-orbit demonstrations of complex space operations such as formation flying and large infrastructure assembly. These technologies are essential keys to enable European space industries to develop future complex space systems. Such systems, relying on CubeSats, will offer higher resilience, reduced costs and improved performances and will possibly be game-changing technologies in the next decade. Beyond the developments in existing technologies also lies the possibility of opening new business opportunities and markets for European space industries, such as on-orbit servicing. These technologies also open the possibility to perform debris removal operations, and could match future needs following evolutions in international regulations. Demonstration missions involving CubeSats in the near future will serve as a testbed for key technologies involved in complex cooperative tasks and provide an opportunity for European space manufacturers to develop new product chains anticipating the future market trends.

Year of the call: 2022

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: Yes

34. Low cost, high performance digital processing systems, including AI solutions, for space applications

SRIA corresponding technology-based activity lines: 3.4 Enabling technologies (cross-mission, space and ground)

ESRE White Paper/major trend: Research under Space Conditions and Robotics

Specific Challenge: Currently observed market trends reveal enormous lack of coherency between data processing capabilities of nowadays low-cost consumer electronics in comparison to much more expensive on-board data processing systems in space missions. The latter represent at least a decade of technology development delay in terms of computing power, power consumption and flexibility when put next to modern smartphones or even wearable devices but still demonstrate much higher reliability. As the space application challenges grow (e.g. Earth Observation, Navigation and Telecommunications) satellite-to-Earth data transmissions are increasingly becoming a bottleneck as the radio frequency bandwidth is the common resource to be shared. Data transmission speed advancements do not keep up with increased on-board data generation and still in most cases sparse communication windows with the ground infrastructure points to the decision-making process (e.g. data filtering, feature extraction, compression or selection observation targets) to be conducted autonomously on-board. For the above reasons, next generation data processing systems for space should optimize the superposition of the cost, computing power, resources consumption, reliability/availability, time-to-market for target applications and flexibility.
The most of these issues may be properly addressed by careful selection and system-level adaptation of the most advanced commercial-of-the-shelf (COTS) electronic components with a major level of application versatility that support standard software-based processing making use of general purpose Central Processing Units (CPU) with hardware acceleration by means of Field Programmable Gate Arrays (FPGA) , Graphics Processing Units (GPU), Digital Signal Processors

(DSP) and recently introduced Artificial Intelligence (AI) solutions like Vision/Neural Processing Units (V/NPU). Additionally, there are currently no space-qualified (radiation hardened by design) products that could meet present memory capacity/transfer rates requirements (DDR3/3, NAND FLASH), so adaptation of COTS is an obvious choice in this field.
The key aspects of successful application of the COTS components in space environment are their characterization for space radiation induced effects, traceable procurement, application of fault protection, detection and mitigation techniques (redundancy) at system level (hardware and software), addressing harsh-environment related issues (e.g. wide temperature ranges, heat dissipation without air convection, vibrations during launch) as well as thorough testing both at component and system level. These components often come with vendor's or open-source toolchains that facilitate application development and shortens time-to-market, but often they lack a methodology of integrating the building blocks in a redundant or multi-level architecture which is critical for development of high performant but reliable space systems.
Classic satellite payloads (e.g. communication) have the drawback to have their architecture fixed for the lifetime of the satellite (few to 15 years) and therefore cannot adapt to changing communication standards and market/application evolution (like multimedia applications). Above mentioned ranges of COTS components have capabilities for in-flight functional reconfiguration which can help to overcome this issue, but there are specific measures to be taken in order to maintain vital functions performing safely while reconfiguration or commissioning of new experimental functions take place (e.g. partial reconfiguration of FPGAs, use of hypervisors, vital software image protection, fallback solutions).
The last of major challenge for the advancements in digital processing systems for space is the standardization of the interfaces and form factors, which are different for terrestrial industry. Next generation digital processing systems must be flexible, scalable and adaptable enough to fit of targets ranging from CubeSats missions to constellations of full-scale satellites.

Scope: The activity of developing next generation data processing systems for space applications covers wide range of science and engineering issues, including, but not limited to:

- Definition of clever procurement methodology for COTS (traceability, inspection, testing);
- Characterization of the most promising COTS components for radiation effects (Single Event Effects – functional interrupts, Total Ionization Dose – parameter shifts);
- Development of benchmarking applications including for Earth Observation, Navigation and Guidance including AI processing (e.g. Convolutional Neural Network) and comparison of candidate architecture performance versus power consumption;
- Development and validation of system-level availability assessment methodology and Fault Detection Isolation and Recovery (FDIR) techniques based on redundancy;
- Research on re-configuration capabilities: its fields of utilization as well virtual sandboxing features – their flexibility, resource -effectiveness and reliability (partial reconfiguration, hypervisors);
- Elaboration of standard application development ecosystem including automatic code generation, high level synthesis, AI development toolchain (e.g. Tensorflow) and software library reuse;
- Research for new reliable component to PCB assembly methods (especially for Ball Grid Arrays);
- Identification of the existing interfaces (hardware, software, communication) used among space market stakeholders and development of new backward compatible interface standards;
- In-flight demonstration of selected architecture and form-factor implementation in a CubeSat or a microsatellite EO mission.

Expected Impact: The rapidly increasing demand of compact, more performant, lighter, less power consuming, reconfigurable and less expensive yet still reliable digital processing systems for space applications is expected to continue especially for commercial microsatellite/CubeSat missions (Earth Observation, communications and even surveillance). Large extent of budget missions failed already because of blind use of COTS modules neither designed nor properly adapted for space applications. Proposed activity is supposed to decrease failure rate and time-to-market for small satellites as well as increase cost-effectiveness of their missions. Key impact may be as following:

- Strengthening Europe's position in industrial competitiveness in technologies for Earth Observation data processing;
- Greater industrial relevance of research actions and output as demonstrated by deeper involvement of industry, including SMEs, and stronger take-up of research results;
- Fostering links between academia and industry, accelerating and broadening technology transfer;
- Envisioned environmental responsibility satisfaction by application of satellite platforms that may serve different purposes through their long lifetime before deorbitation (thanks to safe dynamic reconfiguration features).

Year of the call: 2021

Type of Action: Grant - Research and Innovation Action

Based on a roadmap: No

35. Execution of small-scale ground and flight experiments (including COTS components and high speed flights) to determine optimal system configuration for (partly) reusable launcher

SRIA corresponding technology-based activity lines: 4.1 Innovation for launchers competitiveness targeting initial operational capability by 2030

ESRE White Paper/major trend: Access to Space

Introduction/Specific Challenge: The recent development of reusable launcher concepts and its demonstrated technical implementation induced a significant increase of financial and technological competition within the space transportation sector. Consequently, (partial) reusability by stage recovery is needed to achieve cost reduction and ensure the competitiveness of European launcher systems. This concept demands optimized engine cycles and control systems as well as health management strategies to reduce engine refurbishment costs.

Scope: The scope of the proposal is to test demonstrators of new or optimized engine configurations. These configurations require new sequencing strategies for (re-)ignition and throttling of the engine(s). It is therefore necessary to perform small-scale ground tests of engine demonstrators for the demonstration of advanced engine cycles (e.g. cycles including electric driven pumps and COTS) and their operation using sophisticated test facilities and measurement capabilities. This includes adapted engine control concepts for (re-)ignition strategies and throttling of such engines.

Expected Impact: These activities will strengthen the European research and development capabilities and accelerate technological development for (partly) reusable launchers. They will allow determining optimal system configurations based on experimental validation data also for models describing transient and steady state engine behaviour to minimize development risks.

An expected outcome is to reduce operating costs by lowering refurbishment costs through engine health management strategies. Finally, this will lead to flexible and cost-efficient, and therefore competitive, space transportation system in Europe.

Year of the call: 2022

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: No

36. Guidance Navigation and Control Systems for Reusable Launch Vehicle

SRIA corresponding technology-based activity lines: 4.1 Innovation for launchers competitiveness targeting initial operational capability by 2030

ESRE White Paper/major trend: Access to Space

Introduction/Specific Challenge: With the development of reusable launch vehicles (RLV) the challenge is to offer reliable and flexible systems able to cope with a high launch volume and with the best cost-effectiveness. Further improvement of Guidance Navigation and Control (GNC) systems are needed for the overall effort, particularly in the fields of hybrid navigation, autonomous navigation and health and usage monitoring of launch systems.

Scope: With an aim at further increasing safe launch volume, activities will address on-board systems ensuring greater autonomy for various applications (proximity navigation, safe and controlled precision landing, recovery and reusability of several launcher parts including upper stages considering high velocity constraints). Technologies could deal with high integrity hybridization systems including optical sensors and processing or multi-constellation and multi-frequency GNSS receiver, and health and usage monitoring system with fault detection isolation and recovery systems.

Expected Impact: Mastering new GNC technologies for RLV is essential for assuring reusability at an affordable cost by providing the means to optimize launches and maintenance. The development of such enabling technologies embeds the great potential to support the European community aims (both scientific and industrial) in lowering launching costs, maintaining, and eventually increasing its role in future “access to space” global market.

Year of the call: 2021

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: No

37. Investigations on innovative lightweight structures and tanks production technology

SRIA corresponding technology-based activity lines: 4.1 Innovation for launchers competitiveness targeting initial operational capability by 2030

ESRE White Paper/major trend: Access to Space

Introduction/Specific Challenge: The optimization of liquid propellant tanks shape and internal structure, and their full integration in space structures, can further increase margins of weight savings in space launchers, landers and spacecrafts. Unifying the requirements and the set of design parameters, as much as possible since the beginning of design phase, and including the technology constrains in an integrated process of optimization makes theoretically possible to explore residual and new integrated solutions, which are not evident a priori.

Scope: The scope of the research is to investigate innovative integrated combinations of lightweight structures and tanks, and their feasible production technologies, through prototypes design, production and testing. Several research subtopics will be addressed as: constraining set of requirements typical of tanks and structures for space application; objective function and optimization variables definition; optimization methods application; prototyping; production of demonstrators.

Expected Impact: European industry is challenged to increase its capacity to design and manufacture competitive large liquid propellant tanks for space applications, to enlarge European space work programme system capabilities and performances and enable emerging missions.
This will allow progress in terms of: development of materials and innovative automated processes for lighter and lower cost tanks; integration of design methods in concurrency engineering; demonstration at high TRL for the adoption of the technology at industry level in emerging programs.

Year of the call: 2021 or 2022

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: No

38. Advanced low-cost reusable propulsion system

SRIA corresponding technology-based activity lines: 4.1 Innovation for launchers competitiveness targeting initial operational capability by 2030

ESRE White Paper/major trend: Access to Space

Introduction/Specific Challenge: The highly competitive landscape of the global launch service market, characterized by a growing number of competitors with new capabilities from all over the world, is proposing attractive launch service prices on the commercial market. It requires Europe to move forward to warrant its own independence in accessing space for small satellite markets. Reusability is seen as the main driver for the cost reduction of the small launcher operations and designing and developing such systems is critical for the European space sector.

Scope: Elaboration of concepts and research for low-cost reusable propulsion systems, including green propellant, throttle-able engines, low-cost thrust vector control system for application to small launchers, propulsion injector head technology and manufacturing approach (additive layer manufacturing, cross-feeding and thermal protection). The development of these sub-systems is deemed critical for the European space sector to ensure its increased competitiveness at international level.

Expected Impact: Efficient engine reusability appears as one of the promising developments for future launchers. The benefits brought by full or partial European reusability are as follows:

- Flexibility and reactivity with regards to market variation;
- Launch cost reduction;
- Environmentally friendly and sustainable space transportation system.

Year of the call: 2021

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: No

39. R&TD in LOx/CH4 systems development

SRIA corresponding technology-based activity lines: 4.1 Innovation for launchers competitiveness targeting initial operational capability by 2030

ESRE White Paper/major trend: Access to Space

Introduction/Specific Challenge: The "New Space" paradigm has led to strong pressure on the launcher sector to strive for reusability, greater competitiveness, improved design processes and industrial optimization, and environmental sustainability. In this context, methane and hydrogen appear to be better candidates than conventional rocket fuels. All major players in space exploration are developing methane rocket engines. As of today, there is an urgent need for methane engines qualified for flight and therefore there is a need of studies on methane combustion.

Scope: Analysis of the behaviour of methane in different phenomena linked to rocket engine applications, such as ignition, detonation, combustion dynamics, temperature stratification, thermal loads and engine component lifetime.
Analysis of the phenomena linked to the presence of some impurities in methane, which is the smallest hydrocarbon, in different available sources, in particular in liquefied natural gas (LNG).
These analyses require combining fundamental experiments, demonstrator level tests and numerical and modelling approaches.

Expected Impact: Verified experimental data, demonstrator tests, and mastering modelling of the combustion process in rocket engines will increase reliability and competiveness. Furthermore, methane has the potential to replace toxic storable propellants as a green alternative, helping to maintain compliance with evolving EU regulation (REACH).

Year of the call: 2022

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: No

40. Development of technologies strictly related to entry, descent, and landing

SRIA corresponding technology-based activity lines: 4.1 Innovation for launchers competitiveness targeting initial operational capability by 2030

ESRE White Paper/major trend: Access to Space

Introduction/Specific Challenge: Precision landing on Earth from LEO and on Mars (or other celestial bodies), impose very stringent requirements in relation to the EDL systems as:

- Improved landing accuracy (≤ few hundred meters), in order to reduce footprint dispersions when trying to reach the pre-selected areas;
- Enhanced performances to break the current design limits, and extend the applicability range of thermal protection systems;
- Enhanced robustness reliability of the systems, in order to increase the mission success rate against the big uncertainties associated with the initial/boundary conditions of the re-entry and return (e.g. flight path angle, attitude, position, atmosphere, terrain, etc.);
- High mass and volume efficiency, in order to increase considerably the mass to be re-entered and to be landed, allowing missions with high payload ratios such as the next generation Mars exploration missions as well as LEO re-entry and recovery of launchers' stages.

Scope:

- Systems to assist the descent and landing as guided parafoils, propulsion devices (retro-rockets) and movable aerodynamic devices (deployable wings);
- Advanced, reliable and robust techniques (algorithms) for navigation, guidance and control;
- Green propulsion systems for controlled landing of returning vehicles or stages, including the development of the related descent and reaction control engines;
- RCS systems fed from propellant tanks of returning stages to reduce the number of propellants, components and therefore mass and costs;
- Thermal protection systems as innovative high-performance ceramic rigid TPS, as well as inflatable and deployable heatshields.

Expected Impact:

- Support the European space work programme with radical improvements in system capabilities and performances, enabling emerging missions;
- Strengthening the competitiveness and growth of European space-sector actors (scientific and industrial) developing innovations to meet the needs of the global markets;
- Allow development or spinning-off of new enabling technologies to civilian systems;
- Developing entry, descent, landing technologies which could be used for both reusable launchers and for landing on extra-terrestrial bodies (Moon, Mars).

Year of the call: 2021 or 2022

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: No

41. Future inter-planetary travel ascent and landing technologies demonstrators

SRIA corresponding technology-based activity lines: 4.1 Innovation for launchers competitiveness targeting initial operational capability by 2030

ESRE White Paper/major trend: Access to Space

Introduction/Specific Challenge: Looking at the "New Space" business trend of being able to reuse space technologies, it can be seen that efforts have been made in the launcher's scene, with companies and institutes proving that such demonstrations will lead to a more challenging scene in terms of competitiveness. This comes not only from being able to recover parts of technology to investigate and potentially reuse, but also from being able to test faster, provide reliability through utilization of previous proven procedures, having the means to deploy new tech at an accelerated rate and to be able to mature technologies much more easily. The specific challenge is that such reusability opens the possibility to push the frontier into demonstrating access to space from Earth to other planets and back. In this regard, the development of small-scale vertical take-off and landing demonstrators will accelerate technologies maturation that can render the feasibility of CONOPS for inter-planetary travel.

Scope: The scope of the proposal is to enable competitive research, development and demonstration of multiple concepts and technologies throughout Europe with a single set of high-level requirements with reference to inter-planetary travel. Multiple inter-institutional teams shall be given the opportunity to leverage own technologies and integrate them into demonstrators with the aim to advance inter-planetary travel CONOPS TRL as well as maturing sub-system technologies. The teams will have to demonstrate feasibility of their own concepts by verifying and validating the top-level requirements and performing a generic mission provided.

Expected Impact: The proposal shall assure fostering of collaborative research as well as ensuring the implementation of multiple creative ideas in different European locations / institutions / consortiums. Secondarily, multiple demonstrator development shall accelerate collaboration at institutional level by allowing leveraging of already available technologies in a cross-European environment and provide a framework for multiple space technology hubs creation through a demonstrative approach. The expected impact is also to provide cost reduction at technology/sub-system level for the launcher sector, creating and maintaining new in-flight testing platforms to be used by the industry for technology advancements, validate and advance TRL of inter-planetary travel CONOPS and increase accessibility of small business, academia and research and development institutes to the "Access to Space" segment.

Year of the call: 2021

Funding instrument: Grant - Research and Innovation Action

Based on a roadmap: No