ESSC-ESF POSITION ON THE SPACE 19+ PROGRAMMES OF ESA

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0. Executive Summary – Findings and Recommendations

In preparation for the 2019 ESA Council at Ministerial Level, the European Space Sciences Committee (ESSC) of the European Science Foundation (ESF) wishes, as in the past, to convey a number of recommendations to the European Space Agency (ESA) and its Member States, but also to other European actors and stakeholders relevant to space scientific programmes, like the European Commission (EC). In the case of ESA, this concerns the proposals issued by the Science (SCI), Human and Robotic Exploration (HRE) and Earth Observations (EO) Directorates. In the case of the EC, this concerns current and future calls related to space (for instance, Horizon Europe).

The ESSC welcomes ESA's long-term strategic vision and planning of the scientific elements of the different programmes through the proposals submitted to the Member States in the context of the Space 19+ Council at Ministerial level.

The ESSC has taken note of the three ambitious and high-delivery ESA programme proposals. It was noted with satisfaction that the current and future programmes contain elements that are in line with recommendations expressed by ESSC on the occasion of the last ESA Council at Ministerial level in 2016.

The Mandatory Science Programme has demonstrated its capability to deliver a diverse and successful series of missions on a tight budget. In the future, the Voyage 2050 initiative, an enhanced bottom-up approach that runs until after 2065, shows the intention of the Agency to engage a wide community through a broad consultation process.

The ESSC also highlights the outstanding achievements of the European Exploration Envelope Programme (E3P), encompassing several different areas from experiments on the ground and on ISS to planning ambitious accomplishments in Moon and Mars investigations. This programme is already contributing to the development of sample return missions and human exploration. The envelope nature of the programme has well served the expectations of the science community, primarily via a well-thought-through implementation of the SciSpacE element. The ESSC also notes the robustness of the portfolio of platforms, ground- and space-based, allowing for an integrated approach to scientific questions and optimised use of more costly, and less readily available, facilities.

For Earth sciences, the community is proud and grateful to be part of the amazing European EO programmes which serve the science, meteorological, and operational communities via several missions and satellites as well as via the Copernicus programme. This community strongly supports the FutureEO-1 proposal.

The ESSC has interacted both with ESA representatives, EU representatives and the science community to produce the inputs and recommendations provided hereafter.

The ESSC encourages ESA to pursue its intense efforts for international collaboration whenever possible and to work towards a more robust European position in the international space cooperation context, with the aim of promoting common development and partnerships in areas of common interest and in particular for the optimisation of scientific programmes.

Highlights from the ESSC recommendations

Overall, the ESSC welcomes the increased ambitions of the Space19+ scientific programmes proposals and notes that the (reasonable) levels of resources requested are associated with a significant gain in programmatic efficiency. Therefore, the Committee strongly advocates allocating the corresponding support in order to provide ESA with the means of its ambition to meet the expectations of the scientific community.

In this context, the ESSC recommends that special attention be given to an efficient and fruitful dialogue between the scientific community on one side and policymakers and programme managers on the other.

ESSC Position and Recommendations on the Space19+ Mandatory Science Programme Proposal

The ESSC highlights that, although Member States have an obligation to subscribe to this programme, it should not be seen as a forced entry fee upon them, but as an opportunity to invest in a programme which, by its nature and history, plays a key role as a driver for science and technology development on the European landscape.

The ESSC strongly recommends the development of an ambitious and sustainable Mandatory Science Programme, including the required technology developments, that constitutes the backbone of European space sciences and inspires generations to come.

The proposed programmatic support from ESA to national payload provision is viewed positively by the community in order to avoid possible delays and to facilitate coordination within a mission architecture development.

The exploration and understanding of our Solar System, with some emphasis on the astrobiological potential of some of its objects, like Mars, and some icy moons, is of high relevance to our knowledge of the Solar System formation, the Earth's origin and emergence of life as well as of the Geospace; these are therefore a core element of the Mandatory Science Programme. In addition, the exploration and observation of our Universe with challenging large missions are mandatory to establish and maintain ESA's major role in investigating fundamental questions in astronomy and astrophysics. For this, different complementary categories of space missions implemented with regular cadence are necessary to ensure the robustness and efficiency of the programme.

ESSC recommends continuing the development and exploitation of the promising ESA Mandatory Science Programme with the current cadence. In particular, the ESSC highlights the need for both L- and M-class missions, addressing strategic and ground-breaking science questions. ESSC also recommends establishing a regular F-class missions line allowing, through fully open calls, for any scientific community to apply and lead a timely mission with a focused objective at a reasonable cost to supplement the main programme.

For the future, the ESSC recommends exploring ways to increase the synergies and science return between ATHENA and LISA, while ensuring the timeliness and integrity of the Cosmic Vision programme.

Given the scientific value it will provide – within a controlled cost environment – the ESSC recommends assessing the unique opportunity offered by an M-class mission to the Ice Giants, and its integration into the future programme as an international endeavour.

The ESSC also highlights the importance of continuing to exploit the opportunities offered by international collaboration, notably through missions of opportunity.

The ESSC encourages ESA to continue to maintain and develop the archive databases from space missions, building on the growing need for combination of data from different missions and the fast development of data mining tools. This would lead to an optimised science return from past, current and future investment in missions.

After a first expert exploitation by the scientific teams in charge of the instruments, ESA and its Member States need to ensure that data retrieved from space missions is delivered in a calibrated and useful format to the scientific community as soon as possible, reducing proprietary periods to a reasonable time span.

ESSC Position and Recommendations on the Space 19+ European Exploration Envelope (E3P2) Proposal

The ESSC emphasises that, within the European Exploration Envelope Programme (E3P), science should be considered as one of the main drivers. It should be well-balanced -and well-articulated- with technology development, human spaceflight and industrial interest. This has been found to reflect the spirit of the envelope approach in general and of the E3P Phase 2 (E3P2) proposal in particular. ESSC expresses the community's satisfaction and support.

ESSC supports the E3P2 proposal to transition towards a full envelope programme in view of securing an optimised science return via an ambitious and well-balanced exploration programme.

In view of (a) the planned extension of the availability of the ISS and the opportunities arising from this, both in scientific research and in commercial utilisation, and (b) the rise of new areas (such as the Gateway, the Lunar and Martian research within SciSpacE, etc), the ESSC recommends that the budget allocated to SciSpacE and other science elements of the E3P2 programme within the envelope be increased to a level that would permit reaping the benefits of the expanding scope of research opportunities.

Fundamental research in physics, medicine and life sciences should be continued on ISS. The ESSC also emphasises the urgent need for problem-orientated research in these disciplines as a basis for human spaceflight beyond low Earth orbit.

ESSC recommends that ESA plans and executes an upgrade of existing ISS facilities in order to make the best use of these facilities during the remaining ISS lifetime.

Following the plan for a substantial extension of the ISS lifetime, the ESSC strongly recommends optimising the science return from the coming decade of research on the ISS. It should consider i) completion of current experiments ii) the selection of new experiments and new project lines which may even need new hardware, as well as iii) experiments targeted to prepare human exploration of Moon and Mars.

ESSC emphasises that non-ISS microgravity platforms are essential elements of the programme to prepare and advance research on ISS and therefore should be continued and supported at an adequate level.

ESSC also acknowledges that eventually ISS will come to an end and emphasises the need to get prepared. It also notes that scientific activities on or around the Moon should be well defined and planned.

ESSC recommends that well-articulated roadmaps be developed and implemented for identifying and addressing emerging and future needs, opportunities and infrastructure in LEO after the ISS lifetime. These roadmaps would serve and allow to better plan targeted scientific research in physical and life sciences under space conditions.

This foresight exercise needs to be initiated as soon as possible and should involve relevant topical teams at ESA, as well as international consultations to look for shared interests and needs in the future.

The ESSC recommends identifying new specific scientific topics in the field of life and physical sciences that could benefit from being performed on – or around – the Moon.

The ESSC recommends that – for relevant ExPeRT technologies and SciSpacE experiments – interactions be developed and maintained between the ExPeRT and the SciSpacE elements of E3P2. Interactions with the Mandatory Science Programme are also recommended.

The ESSC highlights that ESA has a major role to play in future exploration missions on the Moon and beyond. When relevant, these endeavours can benefit from existing solid collaborations with historic partners (e.g. ROSCOSMOS and NASA), but also from developing further emerging and new partnerships.

The ESSC views very positively the ExoMars multi-component project, highlighting the current successes of the TGO and the promising future surface elements (Rosalind Franklin Rover and Kazachok lander) which will provide new science and important technological achievements, along with landing and surface mobility capabilities.

The ExoMars mission is an important pillar of the E3P programme, with a highly-successful Trace Gas Orbiter mission currently operating and exceptional scientific and technological results expected from the ExoMars lander element, which the ESSC strongly recommends for a safe and timely delivery.

The collaboration and strategic role of ESA in the Mars Sample Return (MSR) endeavour providing the necessary structure for the first round-trip mission to the surface of Mars to return precious samples and accomplish a vital step towards human exploration of the red planet, are recognised as major breakthroughs by the science community, with high expectations for sample handling and curation facilities in Europe too.

ESSC Position and Recommendations on the Space 19+ Earth Observation (EO) Programme Proposals

The ESSC acknowledges that the proposed FutureEO-1 programme constitutes the vital pillar for the development of European Earth science. FutureEO-1 has the capacity to provide the necessary innovations in observation capability and to permit the addressing of critical issues for humanity such

as Climate Change. In order to contribute to *"excellence in science and technology by, inter alia: fostering the development of cutting-edge Earth System science and related EO techniques",* a strong support from Member States is necessary; this will ensure at the same time the optimisation of the science return and investment in technology.

The ESSC acknowledges the FutureEO programme as a fundamental basis for future achievements in Earth Science as this programme prepares for future science and technology activities which include new Earth Explorers and scientific exploitation of the data and therefore encourages a strong subscription from Member States.

The development of SmallSats provides an effective mechanism to demonstrate new technologies and to progress science.

ESSC notes that a more cost-effective implementation of the Copernicus programme could benefit from international cooperation, as is the case for Sentinel-6 via the MoUs with NASA and NOAA.

Special findings and recommendations based on dedicated ESSC studies

This year saw the completion of the three ESSC studies above, which provided to the science community a much needed instrument to gather, analyze and distil the needs and gaps of current efforts on these topics and recommend actionable solutions and a way forward. We acknowledge the support from the International Space Science Institute (ISSI) and would welcome dedicated sponsorship from ESA to continue to identify and operate on other high-priority scientific topics of common interest.

Calibration and Validation of Earth Observation data

The ESSC has implemented a study on Calibration and Validation (Cal/Val) of Earth Observation data. This study discusses the current status, gaps and challenges regarding long-term Cal/Val of Earth Observation satellites and recommends the creation of a European coordinating entity for satellite product calibration and validation. The study has been submitted to the *International Journal of Remote Sensing* and it is currently under review.

The ESSC strongly supports the TRUTHS mission which clearly aligns with the Committee views on the importance of Cal/Val.

As Copernicus evolves, it is time to take decisions on a clear ownership of Cal/Val at a European level.

It is imperative and timely that Europe takes a leadership role in ensuring a higher level of coordination of EO-related Cal/Val activities.

This would benefit all Copernicus services including the climate service, providing a public good and ensuring there are no barriers to trade in Earth Observation data and products.

Consolidated European Approach to Space Weather

The ESSC has implemented a study on Space Weather assessing European activities in the realm of space weather and formulated a set of recommendations to ESA, EU and their respective Member States, about how to prepare Europe for the increasing impact of adverse space weather effects on man-made infrastructure and our society as a whole.

The ESA Space Situational Awareness (SSA) approach toward decentralisation, networking, inclusion, proximity between scientific research, and transition to operations, is considered to be the best possible model to yield immediate societal benefits while allowing the field to mature in parallel.

> **There is an urgent need to define an operational space- and ground-based network that measures essential space weather parameters, which in turn can drive the space weather predictions required to protect our society's infrastructure.**

European space weather user requirements should be (re-)assessed and prioritised taking into account regional and societal differences and needs, also addressing the different needs of various infrastructure systems.

> **Support must urgently be provided for the next-generation space missions and the maintenance and augmentation of the ageing ground-based infrastructure.**

Exploration of Ocean worlds

The ESSC has implemented a study in collaboration with the European Marine Board, the International Space Science Institute (ISSI) and US experts to investigate "exo-oceans", places that have the potential to harbour under-surface liquid water oceans and are, as such, of high astrobiological potential. The exploration of these outer solar system bodies is of high relevance for space exploration.

> **In parallel with the implementation of the JUICE mission, the ESSC recommends that ESA takes an active role – in collaboration with other agencies – in future missions targeted to understanding and exploring the icy moons.**

In this context, the Earth Observation Programme can be of great value, and the science results from studying our own planet's oceans and their interactions with the atmosphere offer important insights on the investigation of foreign ocean worlds. The exchange of inputs from different scientific communities who have recovered large amounts of data to analyse would provide a strong asset in reaching a better understanding of Exo-Oceans.

The ESSC highlights that lessons learned from the exploration of the terrestrial oceans can help optimise the return from missions to the icy moons, both in terms of defining scientific objectives and of choosing or developing the right instrumentation. The study of extreme environments on Earth can help to better understand how to efficiently explore far-away bodies with strong habitability potential.

ESSC Position and Recommendations on ESA Partnerships

The ESSC notes that there are areas of common relevance between ESA and the EU and that these would benefit from improved coordination between ESA and the European Commission.

> **Such coordination could be defined and implemented through the work of a reinforced EU/ESA mechanism with improved tactical and operational capacity, carefully acknowledging access to all EU members to ESA-led projects, without bias or exclusion.**

The ESSC recommends that ESA develops a strategic plan towards the establishment or reinforcement of national and international partnerships, in order to coordinate and harmonise European space activities in an optimal way.

For several years the ESSC has advocated a reinforcement of the relations between ESA and EU bodies in order to promote a united and collaborative spirit across Europe to foster European identity, efficiency and cohesion along with the achievement of excellence in space sciences and technology. ESSC noted with interest and optimism the resolutions approved at the ESA Intermediate Ministerial Meeting in 2018 in Madrid, which indicate improved coordination between ESA and the EC.

The ESSC commends the EC Framework Programmes for their repeated (even though not continuous and rather limited) financial support of overarching scientific data exploitation of space missions throughout Europe, by dedicated and targeted calls.

The ESSC would like to see EC support to scientific data exploitation of space missions grow into a standing feature of every annual call with increased dedicated budgets. This would contribute to reinforcing the basis for increased ESA-EU collaboration and improved coordination of European scientific communities.

ESSC recommends developing a collaboration strategy for the next four years with traditional and new partners. International partnership agreements should always involve fostering access to mission data, in a well-described and forward-planned manner.

The ESSC urges ESA to envisage exchanges and discussions with potential partners as early as possible in the mission definition phase to ensure an optimised scientific return from the mission. Besides institutions, the scientific community should also be involved in these exchanges.

The ESSC recognises that ESA needs to establish a leading role in the space science and exploration landscape by developing and operating ESA-led missions. At the same time, the current portfolio of ESA's programme contains many missions and concept studies that are performed in collaboration with other space agencies, NASA and Roscosmos in particular, but also JAXA and the Chinese Academy of Sciences. This is essential for ensuring a more efficient implementation and science return of elements of common interest in times where the resources worldwide do not abound.

Involving both academic and industrial actors in study consortia should be set as a tendering requirement when relevant.

The Microgravity Applications Programme helped raise the interest of industry to microgravity tools and should be continued in order to attract new industrial partners.

Finally, ESSC encourages ESA to develop space science STEM activities for schools/teachers in order to foster "daily" attention and interaction of the new generation with the space sector.

1. Introduction

ESA is at a turning point. It was created within a particular context – the building of Europe – to provide the continent with adequate means to develop a world-class space programme and build a solid base for European industries. It has operated in the last four and a half decades with a unique approach based on international cooperation and consensual decision-making processes. It has reaped the benefits of bold choices and strong multi-national commitments, which have led Europe to develop daring missions that cover the full spectrum of space-related activities and wavelengths.

But space is changing fast.

Beyond the institutional broadening (there are today 50-75 space agencies and offices world-wide, depending on criteria used), extremely powerful new actors have seized a share of the activities with a view to developing profitable markets in access to and use of Low Earth Orbit (LEO) and, possibly, in space resources. Initial doubts about the feasibility and profitability of their accomplishments are now hard to reconcile with the billions injected in these endeavours by private companies such as SpaceX or Virgin Galactic, with heavy support from NASA.

An immediate observation: up to now, most of the companies of the so-called NewSpace industry are American. No major European aerospace company has yet joined that adventure, even though the European industry has accompanied the development of science-orientated missions since the beginning of ESA. One can argue that the corresponding business model is far from being proven and that European companies do well to be cautious but equally this reluctance may cost the European industry its place in the future phases of space utilisation and exploration.

After the major successes of the Horizon 2000 and 2000+ and the Cosmic Vision in the mandatory science programme, the impressive long-term stability and strength of the Earth Observation Envelope Programme, the unique achievements of the life and physical sciences in space communities, the Ariane family robustness, or the Copernicus and Galileo accomplishments, one has the right to ask: what next?

Can equally bold decade-spanning programmes emerge from a fall-back attitude, one of budgetary restrictions and timid support? Clearly not, at least at previous cadences. Past studies have shown that, despite a 1 to 6-7 ratio of investments as compared with NASA's, Europe can do a lot. But the reality is that the budgets of ESA's scientific programmes are not in line with their ambitions and that, besides having to cancel calls or descope missions, the Agency will simply not be in a position any more to afford the very ambitious programmes it used to carry out in the past.

Decision-makers need to understand that this trend should be reversed in order for Europe to remain one of the leading actors in space. Of course, this entails that ESA needs to adapt its ambitions by taking advantage of more contributions to international missions, exploring the possibility of commercial partnerships, producing a reasonable schedule for calls and implementation and at the same time ensure the satisfaction of the scientific community and the *juste retour* principle. In addition, ESA and the EU need to come on board with a strong collaboration and coherent approach to optimise the return of benefits for science and society.

In the ever-changing and evolving landscape of space activities in Europe and in the international arena, ESSC has been closely following all the developments of space missions and related activities and the composition of the different programmes, regularly offering valued inputs from the scientific community as an independent advisory body.

The European Space Sciences Committee (ESSC – www.essc.esf.org) of the European Science Foundation is an independent body that provides advice to European and national research organisations and agencies that support space sciences in Europe.

Hereafter we detail the ESSC's perception of the achievements garnered by ESA and the EU, set out the Committee's activities and previous recommendations emerging from regular consultations with the European scientific communities and interactions with the ESA and EU, as well as with other space agency representatives, and present our recommendations in view of the scientific community's identified needs and expectations.

2. Developments in European Space Sciences since 2016

2.1. Achievements in ESA's space sciences programmes

- With about 100 white papers, 200 applications for topical teams and 10,000 responses from the public consultation, the Voyage 2050 programme calls have outshined previous calls and demonstrated the interest of Europeans in supporting the ESA Science Programme, in continuation of the Cosmic Vision.
- With more than 4,700 registered users and more than 300 scientific publications per year, the ESA Earth Explorer programme provides key assets for a better understanding of our planet
- Within E3P, 135 experiments were performed on the ISS, on the ground and in sounding rockets, leading to major advances in life and physical sciences.

The European scientific community certainly recognises the major advances brought by space science and the central role of ESA space programmes in these achievements. As a representative of the whole community, ESSC highly values the considerable and ground-breaking results of the space missions covering both the ESA Mandatory and the Optional Programmes, together with their important advances in technological developments. ESSC also notes ESA's efforts in outreach and citizen science activities (notably for the Rosetta/Philae mission).

These achievements have largely increased the visibility of the European space landscape and its capabilities. They provide an optimistic view for the future of European space exploration. In this context, the EU support for space-related projects and the resources allocated to the Agency by its Member States will be crucial to ESA's future ambitious successes.

The next challenge is now for the Agency to keep the pace in the long term, to continue setting high standards and to innovate. This should be accomplished while ensuring that its communication with the public is at the level deserved by such successes, along the lines laid out by the cover of the Rosetta mission, applied to all missions and initiatives. Outreach and citizen involvement need to be included in every mission design.

ESA Mandatory Science Programme

Europe is at the forefront of achieving scientific and technological results via space missions making up the current Cosmic Vision Programme within the Mandatory Science Programme Directorate (SCI). Fundamental successes have marked our understanding of the solar system and the universe via past or current missions with essential or leading European contributions such as Herschel, Planck, Rosetta, Venus Express and Cassini-Huygens, which ended recently. Among the current ones, we note that the

European science community is strongly involved in the ESA missions or flagship observatories in operation, such as Bepi-Colombo, Cluster, Gaia, INTEGRAL, Mars Express, SOHO, SWARM, XMM-Newton and more. European scientists are also involved in missions of other agencies such as Chang'E 4, Hayabusa2, Hinode, Insight, Magnetosphere Multi-Scale Mission, Mars Science Laboratory, Maven, OSIRIS-Rex, Parker Solar-Probe.

European participation in missions under development, whether ESA-led or as part of an international collaboration, is also impressive, and covers all fields of Astronomy (CHEOPS, JWST, SVOM, XARM, Euclid, PLATO, Litebird, ARIEL, ATHENA), Solar System and Exploration (Solar Orbiter, Mars2020, Taranis, MMX, Comet Interceptor, JUICE), and Fundamental Physics (PHARAO, LISA). Intense activities are also ongoing within the community in the three missions currently under study at ESA for the M5 mission. In addition, there are a number of promising/exciting missions being studied in other ESA programmes such as ESA's SSA programme (HERA, Lagrange) and other Earth Observation Programmes (e.g., Daedalus).

It is not the purpose here to fully describe and/or praise the scientific and technological achievement so far, but we can mention a few examples that have been particularly appreciated by scientists and public alike and have forced admiration for ESA's capabilities in science and technology. Over the past three years, the Mandatory Science Programme has had major achievements in most domains of space sciences.

- After three data releases in 2011, 2013 and 2016, the Planck mission continued producing outstanding scientific data firmly establishing the standard cosmological model with a fourth and final release in July 2018. Hundreds of scientific papers have been published based on publicly available data, casting new light on our knowledge of the origin of our universe; the mission team was awarded several prestigious awards, among which the Gruber Cosmology Prize in 2018.
- The ESA-led Rosetta mission has been a spectacular success in translating the earliest processes of planetary formation into our current scientific understanding. The worldwide success of the Rosetta mission has rewarded the high risk taken by ESA in the achievement of such a bold and ambitious endeavour. This challenging mission has provided the science community with a large quantity of data of extraordinary scientific value, with high impact papers still in continuous production. Several awards have been given for the remarkable scientific and technical efforts associated with this first landing on a comet.
- After a first one in 2016, the Gaia mission team released a second set of data in 2018. This mission is the game-changer in mapping our galaxy, it is expected to produce more than a trillion accurate measurements, including stellar positions, motions, and physical properties. Gaia puts Europe as the world leader in space astrometry.
- High impact publications, as well as many awards, have accompanied the scientific and technological successes of the Huygens probe as part of the Cassini-Huygens mission that ceased operations in September 2017.
- Ongoing missions such as SOHO, Cluster, MEX continue to produce outstanding science results, sometimes in new, unexpected partnerships with other agencies.
- The successful launch of BepiColombo on 20 October 2018 is one of the major achievements of the past period with great promises to gain knowledge on the origin of planet Mercury.
- LISA Pathfinder is a particularly successful technology mission which demonstrated that the sensitivity of its detectors exceeded the LISA requirements. Together with the detection of the electromagnetic counterparts of gravitational-wave events (e.g. as done by INTEGRAL), these results pave the way to the development of European leadership in gravitational-wave physics.

- While ground-based surveys and exoplanet missions have increased the number of known exoplanets, future ESA missions such as CHEOPS, PLATO and ARIEL will allow for addressing the key questions of Exoplanet characteristics, including atmospheric composition, and strengthen European leadership on exoplanet science.

The past period also witnessed a strengthening of the European international collaboration with NASA and JAXA and new partnerships with China, with the approval of the SMILE mission and the Einstein Probe coming up as a mission of opportunity. This evolution is strongly supported by the ESSC. Moreover, the ESSC commends the ESA Missions of Opportunity in general as a very good way to develop and strengthen international collaboration.

To ensure future successes, the ESSC recognises that a regular and balanced cadence of small, medium and large missions represents an efficient way to embark upon ground-breaking science questions. It has to be implemented at a pace in line with national capacity and capabilities. The ESSC also welcomes ESA's long-term strategic vision and planning of the scientific programme through the Voyage 2050 initiative and particularly appreciates the broad consultation process engaging a wide community. These two elements are in line with recommendations expressed by ESSC at the occasion of the previous Council at Ministerial level. The ESSC stresses the importance of transparency and continuous community involvement in the implementation of the Voyage 2050 programme. Ninety seven received white papers and proposals in response to the Voyage 2050 call more than doubles the response received for Cosmic Vision. This clear demonstration of interest shows that the European science community is healthy, vibrant and growing, and thus more than capable of utilising an increase in ESA's science missions for an ever-growing number of applications and research fields.

ESA European Exploration Envelope Programme

ESA develops and operates its activities in Human and Robotic Exploration within the European Exploration Envelope Programme (E3P), which covers a large diversity of missions serving goals and projects on the ground, in Low Earth Orbit (LEO) and beyond, at and around the Moon and towards Mars exploration (both robotic and human).

The ESSC highlights the outstanding achievements of the E3P programme since its approbation at the last ESA Council at Ministerial level. The coherent structure of the SciSpacE element and its efficient implementation led to the completion of 122 experiments on the ground (including sounding rockets) and 13 experiments on the International Space Station. The ESSC highlights that these experiments provide a coherent picture in terms of balancing exploration-enabling research with more fundamental research and application-orientated investigations enabled by the SciSpacE element. The ESSC also notes the robustness of the portfolio of platforms, ground- and space-based, allowing for an integrated approach to scientific questions and optimised use of more costly and less readily available facilities. In this context, Topical Teams is a very efficient scheme to delineate and mature promising concepts such as, for example, hibernation.

The very early re-activation of the Ground-Based Facilities programme only six weeks after the decision made at the previous Council at Ministerial level in 2016 is particularly commendable.

Concerning ISS, the four European missions (logging more than 22 months in space) allowed ESA to make the most of its contribution, even exceeding its 8.3% allocation to the programme. Many remarkable success stories were reported. To mention a few, important achievements were made in the field of medicine, such as in the understanding of human thermoregulation and brain ageing. The physics of complex plasmas has considerably progressed (project PK4) and is shedding light not only

on the dynamic behaviour of classical condensed matter on Earth, but will also help to understand the problems of charged dust in reduced gravity, crucial for Moon and Mars exploration. The installation and commissioning of the Atmosphere–Space Interactions Monitor (ASIM) payload is also considered as a substantial achievement and an additional example that the ISS programme can bring added value beyond the traditional life and physical sciences in the space domain. Considering the level of under subscription on the E3P programme from the previous council at ministerial level, in particular for the SciSpacE element, there is little doubt that the envelope approach enabled the optimisation of resources available and maximised the scientific output of the programme. The ESSC also appreciates the work performed within the preparatory studies of the ExPeRT programme element.

Considering the renewed interest and rapid development of concepts for robotic and human exploration of the Moon in Europe and internationally, the ESSC indeed recognises the scientific value for a return to our satellite in order to acquire a better understanding of its unique position but also common origin with the Earth, its place as a witness to Earth's early history and origin and the evolution of our Solar System, the possible unique platform for astronomy, and to begin a search for resources and develop technological advances.

The ExoMars Trace Gas Orbiter (TGO), launched in 2016 and operational since early 2018, is a major milestone in the understanding of Mars atmospheric composition with a precision never achieved so far. This mission started producing scientific knowledge (several papers already published to date in high-ranking journals) and will be a key asset for the second upcoming programme element with the Rosalind Franklin Rover and the Kazachok lander as part of the ExoMars 2020 mission, which should be safely delivered to the ground of the red planet and is expected to open a new era of exploration for European scientists and engineers. The ESSC also welcomes the recent programmatic decisions made on the Mars Sample Return project with seminal contributions from ESA on the Fetch Rover in conjunction with NASA's elements, as well as ensuring European scientists' access to the samples via specialised facilities upon their return.

ESA Earth Observation programmes

ESA's Earth Observation (EO) programmes aim at putting to the service of the scientific community and the general public a large fleet of space missions, along with diverse innovative instruments and environmental sensing technologies with the purpose of observing our planet to address questions dealing with meteorology, air quality, climate change, monitoring, and operations.

Both basic science and European technology developments and synergies therein are included within the Earth Explorer missions and studies as well as the Copernicus programme and Climate Change initiative. These activities are developed in close consultation with the Earth sciences scientific community, and also serve as technology demonstrators for the European industry.

With more than 4,700 registered users and more than 300 scientific publications per year, the ESA Earth Explorer programme provides key assets for a better understanding of our planet. Since the last Ministerial Council, the ESA Earth Explorer programme saw the continuous contribution from SMOS and CryoSat observations in increasing our knowledge of the environment and its evolution as well as the refinement of our understanding of the Earth's magnetic field with the SWARM mission. This period also saw the deployment of the first wind UV Doppler LIDAR in space (ALADIN) with the launch of the ADM-Aeolus mission on 22 August 2018. The unique measurements provided by this mission open the way to global wind-component-profile observation.

With more than 260,000 registered users (more than tripled in three years) and a daily distribution of 250 TB of free and open data, the Copernicus programme – implemented in cooperation with the European Commission – continues to strengthen Europe's global leadership in operational Earth observation. The size of the Sentinel fleet grew from four satellites in December 2016 to seven today with the launches of Sentinel-2B in March 2017, Sentinel-5P in October 2017, and Sentinel-3B in April 2018. Sentinel 2B improves the re-visit time of the MultiSpectral Instrument by a factor of two, Sentinel 5P is the first atmospheric Sentinel mission focusing on global observations of the atmospheric composition for air quality and climate, and Sentinel 3B improves global land and ocean monitoring.

Besides the achievements and successes of the Earth Explorer and Copernicus programmes, the ESSC also notes the importance of the ESA Climate Change Initiative and its contribution to the production of Essential Climate Variables (ECVs) defined by the United Nations Framework Convention on Climate Change (UNFCCC). In line with the 2016 ESSC recommendations, ESA has taken the lead in a programme that addresses Fiducial Reference Measurements (FRMs). This is an important step towards a sustainable strategy for calibration and validation of Earth observation data. Likewise, ESA has initiated the DIAS programme, which should lead to easy access to EO data for a wide user community. Finally, ESA has actioned initiatives for faster deployment of missions through Smallsats and HAPS.

2.2. Projects and initiatives supported by the European Commission Horizon 2020 programme

Besides the Copernicus and Galileo programmes, the European Commission is devoting €1.48 billion for space within its Horizon 2020 programme between 2014 and 2020. It has to be noted that a very significant part of this envelope is dedicated to Flagship programmes, entrepreneurship, and security. However, other programmes, such as infrastructure or ERC, have also supported space sciences and are not accounted for in this envelope.

Projects supported by the European commission contribute to structuring the community, to identifying research priorities and to generating knowledge from ESA mission data.

The Europlanet 2020 Research Infrastructure project supported at the level of €10 Million for the period 2015-2018 has allowed for more than 350 research teams to access research facilities and planetary analogue sites. This project also provides access to online datasets and provides opportunities to network the European planetary science community. The European Commission's successive allocation of funding since 2005 has led to the development of a robust scientific community that is now coming under the umbrella of the recently created Europlanet Society which has the potential to grow into a successful European counterpart to the US Division of Planetary Sciences.

Additional EU-projects have provided, among other things, a better understanding of the reasons behind cometary activity (MIARD project that studied data from the Rosetta mission) and new accurate maps of dark matter (DEDALE project). Space hardware and space technology development were also supported by Horizon 2020 through projects such as HYPROGEO (research into a hybrid satellite propulsion engine) or DEMOCRITOS (large spacecraft and their propulsion).

Finally, over the past years, the ESSC has advocated for continuity of vital topics supported within the European Commission programmes. In this context, the ESSC welcomed the introduction of the Strategic Research Clusters (SRCs) mechanism in Horizon 2020 in close collaboration with related ESA and national bodies. The two SRCs implemented so far are focussed on technology development (space robotic technologies and electric propulsion). These SRCs allow the integration of well-focussed

projects following strategic planning and subsequent calls. This scheme should be reviewed, evaluated, and refined in order to maximise its potential, taking into account ESA's plans.

The ESSC commends the EC Framework Programmes for their repeated (even if not continuous and rather limited) financial support of overarching scientific data exploitation of space missions throughout Europe, by dedicated and targeted calls.

The ESSC would like to see EC support to scientific data exploitation of space missions grow into a standing feature of every annual call with increased dedicated budgets. This would contribute to reinforcing the basis for increased ESA-EU collaboration and improved coordination of European scientific communities.

2.3. ESSC Role and Actions in the European Landscape

The European Space Sciences Committee (www.essc.esf.org) is the European body providing independent scientific and science policy advice across all domains of space sciences. It is represented within the ESA advisory structure, sits as an observer in ESA Council at Ministerial level and maintains continuous interactions with the European Commission as well as national space agencies and research organisations. In relations with international partners, the Space Studies Board of the US National Academies in particular, but also similar bodes in Russia, China, Japan, etc., the ESSC follows the evolution of European and international space sciences and expresses opinions and recommendations on how to maximise the scientific output from public investment.

ESSC members are drawn from experts active in all fields of space research on the basis of their scientific expertise and recognition within the community; they are nominated ad-personam and therefore do not represent any organisation or country.

The ESSC covers the whole spectrum of space-related sciences and is structured around four panels: Astronomy and Fundamental Physics, Earth Sciences, Life and Physical Sciences, Solar System and Exploration. The mission of the ESSC is to facilitate, support and foster space sciences at the European level by providing unbiased and expert advice on European space research and policy via recommendations or reports directly to decision-makers, stakeholders and all interested parties at national and international level. Furthermore, the ESSC provides a unique focal point to assist national European councils and agencies to achieve optimal science return and harmonise strategic priorities in space activities.

The ESSC particularly values the regular interactions with the ESA Director General and with the Directors of Earth Observation, Human Spaceflight, and Robotic Exploration and Science or their representatives. These regular exchanges give the ESSC a knowledgeable vision of the ESA scientific activities and therefore to express well-argued and well-founded positions and recommendations[1].

Since the 2016 Council at Ministerial level, the ESSC has again provided regular inputs to the ESA scientific programmes, either through direct exchanges with executives during the Committee plenary meetings and side meetings or through opinions and statements expressed by the ESSC Chair on the occasion of the Advisory Committee meetings. The ESSC also contributed to the Public consultation on

[1] See for example the ESSC Statement Following the ESA Council at Ministerial level 2016, 2018 http://www.essc.esf.org/studies-and-publications/

the next EU Research and Innovation Programme (Horizon Europe) and to the 2018-2020 Space Work Programme of the European Commission Horizon 2020[2].

Furthermore, over the past years, the ESSC has identified three topics of priority on which it has devoted specific studies: i) the exploration of Exo-Oceans (liquid water oceans under icy moons), ii) Calibration and Validation of Earth observation data and iii) European Space Weather Activities. These topics have been addressed through the setting-up of ad-hoc study committees and will be published as peer-reviewed scientific vision papers, serving as high-level policy advice (see part 3.4).

Over the past years, the ESSC has continuously highlighted the high level of complementarity between the Space work programme of the European Union's research and technology development programme and ESA's programmes. In particular when considering the exploitation of scientific data after mission termination as well as the definition of early scientific concepts before the mission proposal steps. The development and implementation of the EC Horizon Europe programme will represent very valuable opportunities to contribute to ESA scientific objectives, including by supporting the development and maturation of technologies. In this context, the ESSC urges the European Commission to acknowledge the transversal nature of space sciences across all the topics to be addressed in Horizon Europe.

The decisions taken at the Intermediate Ministerial Meeting held in 2018 in Madrid and the mandate given to ESA Director General on that occasion are certainly seen as good opportunities to move forward. At a more programmatic level, the ESSC notes the success of ESA-EC relations in the Copernicus programme. Taking into consideration the new EU Space Programme proposed by the upcoming Multiannual Funding Framework of the European Union, the ESSC recommends that the perimeter of such a programme and the interface with ESA be well defined, this would be pre-requisite for the emergence of programmatic synergies. The experience gained through the Copernicus programme would be very relevant here.

ESSC called for stronger interaction within the ESA advisory structure, and notes with satisfaction that the latest period saw a very significant increase in cross-participation of ACEO, HESAC and SSAC members to the regular meetings of the other programmes' advisory committees, facilitating information exchange and awareness on the programme evolution and offering the possibility for more efficiency in science matters within the programme.

The ESSC also continuously expresses strong concern – and makes recommendations – that data produced through all ESA missions be made openly available in a fast and efficient way; and that a cross-directorate data policy should be established.

[2] ESSC Input to on H2020 – Space work Programme 2018-20 and ESSC Input on Horizon Europe – October 2019, found at http://www.essc.esf.org/studies-and-publications/

3. Looking towards the future

Thanks to the funds attributed by the Member States to the Mandatory Science Programme and the optional programmes, European space sciences have benefited from dedicated financial support for long-term planning.

The level of resources to sustain the vibrant European space community needs to be increased. Only this will make it possible to deliver on the current schedule, achieve balanced programmes across all scientific disciplines and maintain the scientific programmes as backbone of ESA's and Europe's investment in scientific progress in space.

In particular, the allocated increase of budgets must be sufficient to keep ESA among the key players in a fast developing (more countries, increased national budgets) and rapidly diversifying (emergence of NewSpace actors) sector.

Overall, the ESSC welcomes the increased ambitions of the Space19+ scientific programme proposals and notes that the (reasonable) levels of resources requested demonstrate a significant gain in programmatic efficiency. Therefore, the Committee strongly advocates allocating the corresponding support in order to provide ESA with the means of its ambition to meet the expectations of the scientific community.

In this context, ESSC recommends that special attention be given to an efficient and fruitful dialogue between the scientific community on the one hand and policymakers and programme managers on the other.

Beyond the space science arena, ESA space science programmes have the capacity to trigger and feed the curiosity of the younger European generation, starting in primary school and throughout higher education, with specific attention to female students and their attitudes towards STEM for the space sector.

ESSC encourages ESA to develop space science STEM activities for schools/teachers in order to foster "daily" attention and interaction of the new generation within the space sector.

3.1. ESSC Recommendations on the Space 19+ Mandatory Science Programme Proposal

The ESSC highlights that, although Member States have an obligation to subscribe to the ESA Science Mandatory programme, it should not be perceived as a forced entry fee upon them, but as an opportunity to invest into a programme which, by its nature and history, plays a key role as a driver for science and technology development on the European landscape.

The ESA proposal to the Ministers ESA/C(2019)32 recalls the ESA constitution and scientific goals, its achievements, as well as a summary of the increased ambitions of the Mandatory Science Programme. It calls for an increase in the Level of Resources (LOR) in the order of at least 10-15% over 3 years.

In line with the overall Space19+ approach, the Mandatory Science Programme proposal puts science, research and development at the core of ESA's future plans and at the crossroad of the Agency's key priorities. In this context, the proposal argues that – by its nature and history – this programme has a key role to play as one of the drivers for reaping the benefits of an increased investment in space science and technology development on the European landscape.

The ESSC strongly recommends the development of an ambitious and sustainable Mandatory Science Programme, including the required technology developments, to constitute the backbone of European space science and inspire generations to come.

The Mandatory Science Programme proposal also highlights the role of ESA as a unique European asset to strengthen coordination amongst national programmes. The desired coordination of the space policy at European level and its progressive integration into the European landscape is a needed and very welcomed development.

The proposed programmatic support from ESA to national payload provision is viewed positively by the community in order to avoid possible delays and to facilitate coordination within a mission architecture development.

The ESSC recommends that ESA develops a strategic plan towards the establishment or reinforcement of national and international partnerships, in order to coordinate and harmonise European space activities in an optimal way.

ESSC note that the programme proposal presents an excellent opportunity to pursue the ambitious and exciting goals proposed by the European Science Community in the Voyage 2050 exercise.

Goals and Objectives

The overarching role of the Mandatory Science Programme and basic activities proposal is to enable the European scientific community to lead in key fields in science in and from space. The ESSC fully supports this ambition together with the corresponding necessary investment.

Programme Structure

To ensure future successes, a regular cadence of small, medium and large missions represents an efficient way to embark upon ground-breaking science questions. It has to be selected in a transparent way and implemented at a pace in line with national capacity and capabilities. L-class missions are European flagships for breakthrough science. M-class missions are indispensable to address the scientific questions of large communities in a timely fashion. The smallest missions (F-class) should provide an efficient way to integrate new innovative ideas and schemes in the programme.

All of these classes of missions are essential to satisfy the needs of the community and to provide European industry with high-level challenges and capabilities. The definition of mission classes and their cadence should be flexible enough to allow for exploiting additional unique opportunities (for instance contributions to missions of partner agencies and missions of opportunity). The selection should be made by or in direct consultation with ESA's established advisory structure.

The ESSC emphasises that the strength of the Cosmic Vision programme comes from the involvement of the community through the advisory bodies of ESA. These structures guarantee the transparency and the bottom-up approach of the mission selection process. Their conclusions should form the basis of the recommendations to the SPC. When senior or ad-hoc committees are called upon for any selection involving the programme content, the SSAC should be involved at an adequate level.

ESSC recommends continuing the development and exploitation of the promising ESA Mandatory Science Programme with the current cadence. In particular, the ESSC highlights the need for both L- and M-class missions, addressing strategic and ground-breaking science questions. ESSC also recommends establishing a regular F-class mission line allowing, through fully open calls, for any scientific community to apply and lead a timely mission with a focussed objective at a reasonable cost to supplement the main programme.

Missions

ATHENA and LISA are the next large L2 and L3 missions in the ESA Cosmic Vision programme, as decided after consultation with the community on priority science themes. They will be unique facilities in their own scientific domains. Moreover, building on the recent success of multi-messenger astrophysics, specifically the detection of the electromagnetic counterpart of the LIGO-Virgo gravitational-wave event, the appealing opportunity arises to explore maximal synergies between Athena and LISA in terms of their operational timelines.

For the future, the ESSC recommends exploring ways to increase the synergies and science return between ATHENA and LISA, while ensuring the timeliness and integrity of the Cosmic Vision programme.

Uranus and Neptune, the "ice giants"

The outer solar system beyond Saturn is one of the unexplored territories for ESA. The ESA advisory committees should investigate the possibility of studying the ice giant planets, by teaming up with NASA when this opportunity presents itself, after the publication of the upcoming SSB Planetary Science Decadal Survey.

Given the scientific value it will provide – within a controlled cost environment – the ESSC recommends assessing the unique opportunity offered by an M-class mission to the Ice Giants, and its integration in the future programme as an international endeavour.

Open Data

Free and open data access policy is the foundation on which the scientific community wishes to work. It also reflects requests by policymakers and the broader society to avail of the results of publicly-funded research. The current proprietary data policy of ESA needs to be considered and discussed in this context, involving the community. Possible adaptations need to be well articulated with the requirement and constraints of space research.

The ESSC encourages ESA to continue to develop and maintain the archive databases from space missions, building on the growing need for combination of data of different missions and the fast development of data mining tools, leading to an optimised science return from past, current and future missions.

After a first expert exploitation by the scientific teams in charge of the instruments, ESA and its Member States need to ensure that data retrieved from space missions is delivered in a calibrated and useful format to the scientific community as soon as possible, reducing proprietary periods to a reasonable time span.

Programme Implementation opportunities

Roadmapping

The Exoplanets series of missions has enabled ESA to build a sensible and robust roadmap in the field, taking into account ground-space synergies as well as the international landscape in the field. This example could also be used to consider other opportunities for strategic sequences of missions to serve a given priority topic, however, any such approach should carefully consider a fair balance of themes covered by the programme. The recent ESSC report on "Ocean Worlds" can be used as input to such a roadmap (see section "Ocean Worlds" below).

Selection process

The Voyage 2050 exercise has led to a remarkable set of 97 well-thought-through proposals from which only a few can be selected. Due to the enormous importance of the Voyage 2050 vision, it is important that the theme selection process be conducted in a fair and transparent way.

Basic Activities

Early Elements of the Seamless Grid of Innovation

While commendable, it seems over-ambitious to aim for an increase in cost efficiency by one order of magnitude at every generation. It is important to build on lessons learned from past exercises, in particular concerning the technical readiness and feasibility of selected missions. This may require developing industrial management capabilities and monitoring the mission development to avoid BepiColombo-type situations.

Develop and Maintain Common Infrastructure

It is recommended to explicitly mention generic and programmatic benefits from such an approach. For example, how does/could EU profit from this infrastructure, how does it compete with national/international assets, how is it evaluated/validated and maintained in several aspects?

The list of infrastructures should be accompanied by a management approach and prioritised in terms of budget used in case of under- or over-subscription.

In addition, there is a clear difference between ESA's 15-year investment cycle and the pace of national legislation. This should be taken into account when developing plans.

Considering the rising complexity and amount of mission data, enhanced data archiving capacity should be considered as a priority topic.

The European Network of Operation Centres (NoC) is an interesting concept which deserves to be developed.

The manner in which national/industry assets will be embedded in the programmes, and ESA's role in coordination (apart from implementation), are key issues to be considered when developing the European network of operation centres concept.

Planetary Protection is an issue requiring attention. Technologies and infrastructures should be developed taking into consideration these aspects, particularly the issue of sample return.

3.2. ESSC Position and Recommendations on the Space 19+ European Exploration Envelope (E3P2) Proposal

The ESSC welcomes ESA's proposal for the second period of the European Exploration Envelope Programme. E3P2 demonstrates the success of the concepts established in the first period of the E3P programme in terms of achievements, strategic vision and programmatic framework. The envelope programme meant that the essential funding for the continuation of scientific activities could be preserved. The new strategic vision offered is one of a comprehensive set of missions and objectives leading to sustainable exploration and scientific exploitation of the destinations Low Earth Orbit, Moon and Mars.

ESSC would like to underline the importance of the envelope structure in offering access to all components of the programme to users from all participating states in the programme.

Speaking on behalf of the scientific community, ESSC is excited about the scientific opportunities offered by E3P2, namely the extension of the lifetime of the ISS, the new opportunities on Gateway and for Lunar and Martian research and the new means of access through commercial entities, next to the more institutional access already in existence.

E3P2 epitomises the crossroads between the past and the future of Europe in the area of Human and Robotic Exploration. On the one hand, this is the time for harvesting the results of past investments in the ISS infrastructure and its scientific capabilities, with excellent achievements demonstrated both in fundamental and applied research. On the other hand, E3P2 offers exciting new perspectives to deliver new results in medicine, biology, fundamental and fluid physics, materials sciences, and Solar System sciences, including the fascinating areas of emergence and existence of life on Earth and beyond, as well as concrete benefits to the quality of life on Earth.

In view of (a) the planned extension of the availability of the ISS and the opportunities arising from this, both in scientific research and in commercial utilisation, and (b) the rise of new areas (such as the Gateway, the Lunar and Martian research within SciSpacE, etc), the ESSC recommends that the budget allocated to SciSpacE and other science elements of the E3P2 programme within the envelope be increased to a level that would permit reaping the benefits of the expanding scope of research opportunities.

More detailed comments on the different cornerstones are given below.

Humans in Low Earth Orbit (Cornerstone 1)

After a period of uncertainty, ISS partners have reached a consensus to extend the lifetime of the ISS, at least until 2024, possibly until 2030. This recent development will allow the execution or completion of many experiments which have been delayed due to operational limitations or technical problems. Additionally, this prolongation allows the start of new science topics that must be identified as soon

as possible to be achieved within this time frame. It can be noted with satisfaction that ISS is now equipped with a remarkable set of facilities, allowing several sophisticated experiments to be performed. It should also be noted that some facilities used for traditional life and physical sciences have been extensively used and would require an upgrade.

An example of very promising experiments belonging to fundamental physics is the "hot" topic of quantum physics in space with two significant projects within E3P: ACES and Space-Quest. Research in this field will not only lead to important fundamental advances, but also to applications: for instance in better clocks or quantum telecommunications. With the PK4 project, important new results are expected in the physics of complex plasmas with potential application to the understanding of the behaviour of dust in reduced gravity, crucial for exploration goals. Other important advances result from integrated pieces of evidence on disease development and interlinking osteoporosis or heart and brain and immune disorders that could be induced and accelerated in microgravity conditions. Altogether, this leads to the understanding of accelerated ageing in space as a unique model for Earth's needs.

Fundamental research in physics, medicine and life sciences should be continued on ISS. This is one of the most important heritages of ESA and represents a field of European leadership. Limiting the effort to problem-orientated research targeting operational needs would neglect other research that delivers an even stronger impact in the longer term.

ESSC recommends that ESA plans and executes an upgrade of existing ISS facilities in order to make the best use of these facilities during the remaining ISS lifetime.

On the other hand, there is an almost endless list of science issues to be clarified to enable human exploration. One of the most serious concerns is radiation: long-time exposure is known to lead to multiple diseases, including lethal events in critical cases. While technological solutions are being researched for shielding, fundamental studies are nevertheless needed. So far, these studies are only supported by agencies, except in a few specific cases such as the nuclear industry, in which the parameters (radiation quality, dose, time of exposure) are quite different. It is known that some individuals are more resistant than others, but the reason for this is still an open question. Another important topic for exploration concerns dust (see Cornerstone 2).

Apart from these two examples which emphasise the need for joint and cross-disciplinary approaches, several additional topics should be investigated. Simple fluid flow in microgravity is now reasonably well understood and numerical modelling is appropriate, but the behaviour of multiphase flow of complex fluids is not yet mastered. Much more research is still needed in materials science, complex plasmas and combustion too.

ESSC emphasises the urgent need for research in physical sciences as a basis for human spaceflight beyond low Earth orbit. ISS offers opportunities to solve open issues in this area.

In the field of life sciences, a very important effort is necessary for the fields of physical and psychological health and well-being, torpor and hibernation, rationalised combination of robotic and human approaches. It was observed recently that bacterial biofilms do not have the same structure on

Earth and in the ISS. Mutation in reduced gravity is different, and bacteria can, for instance, become active in corrosion (damaging electric wires). On the other hand, bacteria could possibly be used for recycling purposes. Stem cells were also shown to evolve differently in microgravity, and it is important to understand why, in view of the increasing potential applications of these cells

The notion of "omics" appeared quite recently and is associated with important topics such as the behaviour of the microbiome in space that all deserve special attention. Developing sustainable closed-loop life support is obviously mandatory, and the panel saw with interest the installation of the ESA's new Advanced Closed Loop System ACLS onboard the ISS in autumn 2018.

ESSC also emphasises the urgent need for research in medicine and biology as a basis for human spaceflight beyond low Earth orbit. ISS again offers opportunities to solve open issues in this area.

The Atmosphere–Space Interactions Monitor (ASIM) payload is also expected to bring important information, widening the field of science activities in the ISS.

Following the plan for a substantial extension of the ISS lifetime, the ESSC strongly recommends optimising the science return of this upcoming decade of research on the ISS. It should consider i) completion of current experiments ii) the selection of new experiments and new project lines which may even need new hardware, as well as iii) experiments targeted to prepare human exploration of Moon and Mars.

The ESSC appreciates that essential non-ISS platforms such as bed rest, parabolic flights, drop tower and sounding rockets were conserved. These elements do not only allow for the preparation of more elaborate experiments in the ISS but in many cases lead to significant scientific advances as well as the involvement of young researchers. The ESSC also appreciates the new opportunities offered by ESA, such as CubeSats. Their cost is still manageable for academic actors, with the support of national agencies.

ESSC emphasises that non-ISS microgravity platforms are essential elements to prepare and advance research on ISS and therefore should be continued at an adequate level.

Despite its longer-than-expected life, ISS will eventually come to an end. Obviously, other solutions are needed to pursue science activities after ISS closure, even if only to address the numerous scientific problems posed by human space exploration. New plans should include all current and potential partners and help to identify the key areas in which Europe is leading and where investments are needed to maintain this leadership position.

ESSC recommends that well-articulated roadmaps be developed and implemented for identifying and addressing emerging and future needs, opportunities and infrastructure in LEO after the ISS lifetime. These roadmaps would serve and allow better planning of targeted scientific research in physical and life sciences under space conditions.

This foresight exercise needs to be initiated as soon as possible and should involve relevant topical teams at ESA, as well as international consultations to look for shared interests and needs in the future.

Humans Beyond LEO (Cornerstone 2)

In addition to the traditional life and physical sciences, SciSpacE will also encompass new areas such as the Gateway, lunar and Martian research during Period 2.

Sending humans to the Moon (and Mars) raises many concerns, amongst which the most important are perhaps radiation and dust. Dust poses important problems for a lunar landing, impacting its accuracy, amongst other aspects. It constitutes a serious hazard for humans on the lunar and Mars surface. The physics of granular media is far from being fully mastered on Earth, and knowledge of the behaviour in reduced gravity is lacking. Studies focused on these important hazards could take advantage of the facilities available in the ISS.

Research could also be performed in the Gateway. However, the space and resources that will be available in the Gateway are quite reduced compared to those in the ISS. Furthermore, the cost of payloads will be distinctly higher due to much more expensive transportation and the need to develop new payloads complying with the specific requirements of the Gateway. It is therefore clear that the Gateway will not replace the ISS after its end.

Another point of concern relates to the science that can be done on the Moon. Various projects of planetary science are envisaged. The Moon can represent a valuable location for astronomical observations on its hidden side because of the quiet environment in radio frequencies. ESA recently opened a consultation to widen the science perspectives and the response level has been very good.

The ESSC recommends identifying new specific scientific topics in the field of life and physical sciences that could benefit from being performed on – or around – the Moon.

Lunar robotic exploration (Cornerstone 3)

The current programme of lunar exploration that ESA has established with its Russian partners is very promising and should be pursued. The ESSC recognises that lunar robotic exploration is a mandatory step before establishing a human presence on the Moon. In this respect, ESSC commends ESA for its plans to develop a new lander, drawing on current and previous studies including HERACLES. This lander designated 'European Large Logistics Lander (EL3)', will be an entirely European achievement and will no doubt be challenging and beneficial for the European industry.

In the context of future Sample Return (SR) missions, the Moon is a justified target for SR missions in the near term.

Mars robotic exploration (Cornerstone 4)

ESSC stresses the scientific merit of sample return from Mars (and from other target bodies in the solar system) independent of human exploration.

The Committee has noted with interest the proposed mission-critical role of ESA in the overall Mars Sample Return (MSR) campaign. It is clear that Europe's role and contribution to the various aspects and steps within the Programme need to be supported in order to ensure a major role for Europe in this ambitious endeavour, which will certainly provide fundamental scientific output from the analysis of the returned samples and become an essential step towards human exploration. The capacity to be able to deliver the European MSR elements on schedule will add credibility to the Agency's enhanced skills and reinforce its international trust. ESSC has voiced the importance of guaranteed access to the

samples for Europeans, the establishment of sample curation and handling facilities, and the importance of a joint ground segment.

The ESSC recognises that ESA has a major role to play in the future exploration of the red planet, starting with the currently scheduled lunar missions and ExoMars in collaboration with Roscosmos and leading up to the return of samples from Mars to the Earth via an ambitious scenario with strong ESA-NASA collaboration. The robotic exploration to the Moon and Mars leading to the fulfilment of the MSR programme is extremely important for European scientists, industrial partners, and stakeholders.

The ESSC views the ExoMars project very positively. It highlights the current successes of the TGO and the promising future surface elements (Rosalind Franklin Rover and Kazachok lander) which will provide new science and important technological achievements, along with landing and surface mobility capabilities.

The ExoMars mission is an important pillar of the E3P programme, with a highly-successful Trace Gas Orbiter mission currently operating as well as exceptional scientific and technological results expected from the ExoMars lander element, which the ESSC strongly recommends for a safe and timely delivery.

The collaboration and strategic role of ESA in the Mars Sample Return (MSR) endeavour providing the necessary structure for the first round-trip mission to the surface of Mars for the return of precious samples and to accomplish a vital step towards human exploration of the red planet, are recognised as major breakthroughs by the science community, with high expectations for sample handling and curation facilities in Europe as well.

Technology developments and system studies: ExPeRT

The ESSC welcomes the long-term scenarios as well as the mission concepts and studies proposed by the ExPeRT element. This approach will not only permit the preparation of the agency and community for future exploration endeavours, it will also allow for the European industry, and particularly SMEs, to develop innovative solutions and technologies to support the achievement of ambitious goals. The upstream integration of the technology development effort to the overall E3P picture is certainly seen as strengthening the programme.

The ESSC notes in particular that some of the enabling technologies for the future exploration missions proposed are partly or fully relevant to the scope of the SciSpacE element of the programme This is particularly the case for radiation protection and mitigation, advanced life support solutions, Space Resources/ISRU and in-space manufacturing.

Furthermore, in the context of future Sample Return (SR) missions, ESSC recognises the potential of world-class science outputs that would arise as a result of advancements in human-robotic partnerships achieved through E3P2 activities. The Moon and Mars are unique and achievable targets for SR missions in the near term. However, it is important to maintain a longer-term vision and new ideas and approaches should be incubated for SR missions from other target bodies in the Solar System such as asteroids, comets, moons and planetary bodies that are deemed to be of unique scientific value in addressing major outstanding questions related to the origin and evolution of the Solar System. Such an approach will not only better support ESA's effort in expanding the human presence

deeper into the Solar System but also yield world-leading scientific outputs in their own right. In this context, it seems important that the SR development efforts in E3P are envisaged and implemented in relation to and in coordination with the Mandatory Science programme.

The ESSC recommends that – for relevant ExPeRT technologies and SciSpacE experiments – interactions are developed and maintained between the ExPeRT and the SciSpacE elements of E3P2. Interactions with the Mandatory Science Programme are also recommended.

Programmatic approach

The ESSC congratulates ESA on the flexibility of the envelope programme and values the efforts of the Executive to substantially support the funding of SciSpacE, which permitted a successful utilisation during its first period, including science in space as well as in ground research facilities.

ESSC supports the E3P2 proposal to transition towards a full envelope programme in view of securing an optimised science return via an ambitious and well-balanced exploration programme.

Impact on European industry and research and academic communities

ESSC recommends that the ESA commissions a study to provide bibliometrics data for European research in life and physical science in space. This would provide a much better underpinning of the knowledge gain than, e.g. the number of scientists or the number of experiments.

3.3. ESSC Position and Recommendations on the Space 19+ Earth Observation (EO) Programme Proposal

General

The ESSC welcomes the ambitious programme proposed, building on the EO Europe 2040 strategy: "Address key societal challenges by developing novel observations from space and excellent science for Europe through a reinforced end-to-end mission approach including innovative data exploitation, driven by user needs." The Committee specifically welcomes the further enhancement of the Sentinel fleet and the ambitions for the Earth Explorer missions.

ESSC commends ESA on its trailblazing and internationally-admired current fleet of missions and encourages continuation and support from stakeholders.

The FutureEO-1 Programme

The ESSC acknowledges that the FutureEO-1 programme constitutes a vital pillar for future developments of Earth science by providing the necessary innovations in observation capability.

The ESSC acknowledges the FutureEO programme as a fundamental basis for future achievements in Earth Science as this programme prepares for future science and technology activities including new Earth Explorers and scientific exploitation of the data and therefore encourages a strong subscription from Member States.

In addition, ESSC argues below that Member States should also adequately fund national programmes for scientific data exploitation and associated Cal/Val activities within the Earth Explorer programme.

Other Space Agencies

The ESSC appreciates ESA's ambition to take the leading role in Earth Observation and climate monitoring. The extremely valuable data from Copernicus, which is fully open access, is now heavily used by the scientific community, and EU scientists face problems in acquiring enough funding for competitive data exploitation. To leave enough funds for scientific data exploitation, cost-effective implementation of EO infrastructure with other world-wide agencies, therefore, remains important. This international cooperation received little attention in the FutureEO-1 programme, except for cooperation with NASA in the preparation of the Mission of Opportunities. Although the community is aware that international cooperation may lead to complications (e.g. EarthCare) and recognise the member states' wishes to support the EU space industry, these factors should not hamper future collaborative activities.

ESA's leading role in Earth Observation should be maintained. In this role, ESA is in a strong position to stimulate, coordinate, and shape international cooperation with other space agencies.

Scout missions/SmallSats

The ESSC appreciates ESA's intention to use small satellites for scientific applications. Small satellites typically use new approaches, e.g. allowing for more risks in the development (cutting cost and development time) and using agile development methods. This will lead to new insights on how to use Smallsats for cutting-edge science.

Furthermore, to fully exploit the potential of SmallSat missions and to convince the scientific community of the usefulness of SmallSat missions, the activities (including Cal/Val) and funding should be continued after the in-orbit commissioning (IOC) phase.

The development of SmallSats provides an effective mechanism to demonstrate new technologies and to progress science. The SmallSat strategy requires adequate funding for data exploitation after launch to fulfil the science goals.

Earth Explorer missions

The development of the ESA Earth Explorer (EE) missions should be continued in order to prepare new ground-breaking advances in Earth sciences and technology developments. Not only do the Earth Explorers enable the preparation of the technology and the science required to develop the new generation of EO missions, but they are key enablers in the advancement of national EO missions in Europe as well.

However, the EO landscape is changing quickly and climate change may trigger urgent observation requirements. Anticipating future EO needs might require alterations in the work-flow of ESA (e.g. the long-term planning, selection, and launch of EE-missions). Although the Copernicus programme provides a solid basis for future EO monitoring, upcoming new commercial players in the field and the SmallSats mentioned above may start modifying the EO landscape rapidly. In this context, a true "paradigm change", which enables fast technological and scientific progress, would require larger financial resources.

While the longer-term and operational monitoring proceeds in the Copernicus programme, anticipating new science and technological developments in the frame of the Earth Explorer missions is of paramount importance. In addition to the Earth Explorer missions, new developments such as AI4EO and SmallSats should benefit from larger financial resources.

Grand Science Challenges

In general, the ESSC appreciated the proposed new approach to advance Earth system science in full coordination with the DG-RTD Horizon Europe. Such an approach would greatly enhance the scientific exploitation of European EO data.

In the past, the Horizon 2020 programme has been criticised by academia because there is far too little funding for fundamental research. When the ESA programme is tightly linked to Horizon Europe, there is a risk that the under-representation of fundamental research may spread to the ESA programme. Moreover, European projects within Horizon Europe are usually very large with many partners, while ESA projects are usually smaller and more focussed.

The peer-review process implemented in the Horizon 2020 programme and the feedback to applicants it provides could serve as an example for ESA. Over the past years, ESSC has seen improvements in transparency and communication concerning ESA's procedures, e.g. the selection of EE missions. These efforts help to improve the community's perception of the assessment and selection process and should be continued.

ESA should continue to propose well-focussed R&D activities in complement to large EU projects.

The Copernicus Space Component (CSC) 4 programme proposal

It is impressive to see the further development of the Sentinel programme, in both continuation and expansion. Although the ESSC recognises that the Copernicus Sentinel programme is not primarily driven by scientific requirements, uptake of Sentinel data by the global science community is large.

Cal/Val

As outlined further in the section Calibration and Validation below, the ESSC identifies the need for better coordination of Cal/Val activities. One could argue that Cal/Val should reside in the Copernicus In Situ Component, or that Cal/Val is part of the Sentinels' Mission Performance Centres (MPCs). However, the ESSC recommends that Cal/Val activities need clear leadership and should be an activity overarching the various Sentinel missions.

International Partners

As with our comments on the FutureEO-1 programme, ESSC notices limited attention for international cooperation with other Space Agencies.

> **The ESSC praise the EU leadership, but also note that a more cost-effective implementation of the Copernicus programme could benefit from international cooperation, as is the case for Sentinel-6 via the MoUs with NASA & NOAA.**

The Committee is aware of the efforts for synergy between TEMPO, GEMS, and Sentinel-4, and a more general vision might convince the funding states that all efforts are made to implement the Copernicus programme in a cost-effective and coordinated way.

Earth Watch

> **The ESSC strongly supports the TRUTHS mission which clearly aligns with our views on the importance of Cal/Val.**

Many missions, including the proposed carbon dioxide (CO2M) mission, will benefit from better characterisation of radiances as influenced by the surface albedo and aerosols. It is clear that the TRUTHS mission will also be beneficial for many other EU and non-EU missions.

The ESSC further supports the proposed strategy in the Earth Watch proposals for Global Development Assistance and Altius phase-E.

3.4. Special findings and recommendations based on dedicated ESSC studies

This year saw the completion of three ESSC studies on Exo-Oceans, Cal/Val and Space Weather (the two later are published). These exercises were very well received by the community as they provided a much-needed instrument to gather, analyse and distil the needs and gaps of current efforts on these topics and recommend actionable solutions and a way forward. This work has also identified the ESSC as an appropriate platform to conduct such exercises.

> **The committee would welcome future support from ESA for similar activities, along with our regular sponsors, and is ready to work with ESA to identify and operate on high-priority and timely scientific topics of common interest.**

Calibration and Validation of Earth Observation data

The global downstream market for satellite Earth Observation (EO) data was worth $28.3 billion[3] in 2017 and is growing. The comprehensive EU Copernicus programme provides a major contribution to the global effort. Even so, achieving the necessary global and temporal coverage requires synergistic cooperation and associated interoperability of the worlds' sensors through organisations such as the ESSC on Earth Observation Satellites (CEOS).

Increasingly there is a need for trustworthy, fit-for-purpose and available on-demand information, derived from a multitude of data sources and sensing technologies. Data sets for applications, as

[3] Source : https://londoneconomics.co.uk/wp-content/uploads/2018/07/LE-IUK-Value-of-EO-to-UK-Government-FINAL-forWeb.pdf

diverse as climate change, food security, pollution monitoring amongst many, all require the user to have some quantitative level of confidence in the data/derived information.

Whilst significant effort is made to ensure that every satellite sensor is well-calibrated, characterised, and traceable to international standards before launch, it is well-known that the severe conditions during launch and the harsh environment of space impact sensor performance. Therefore, missions rely on additional well-characterised measurements from a range of geographically and environmentally representative locations.

In 2018-2019, the ESSC implemented a study on calibration and validation (Cal/Val) of Earth Observation data; Cal/Val can in principle be obtained from a mix of aircraft, UAV, balloon and ground-based measurement techniques (remote or direct). The European Space Agency (ESA) has, in the last few years, initiated a number of projects with that purpose, in a number of applications such as surface temperature, ocean colour, altimetry, SAR, greenhouse gases, and vegetation. Similarly, the EU has supported numerous projects in parallel to develop strategies and methods to the same end, including GAIA-CLIM, QA4ECV, Fiduceo, and METEOC.

These projects have significantly advanced the state of the art and the principles and methods that should be followed; sustainable long-term comprehensive Cal/Val has yet to be achieved. In many cases, reliance is made on ad-hoc national/regional funding programmes or campaigns, which are tied to specific short-term objectives or to the life of individual missions.

As Copernicus evolves, it is time to take decisions on a clear ownership of Cal/Val at a European level.

Earth Observation is rapidly evolving with the emergence of new actors and new technologies including innovative constellations of Cube- and Nano-satellites. The opening of new markets and opportunities is adding complexity and increasing the urgency with which Cal/Val must be optimised. At present, however, there is little quality assurance or transparency to ensure the customer can judge between products in a fair and open manner. The means to independently assess and validate products ensuring that European entrepreneurs have an open marketplace in which to offer services in a competitive manner requires good public infrastructure to independently assess quality.

Similarly, constructing accurate long-term climate records places increasing demands on the necessary accuracy, and research to meet the uncertainty and decadal stability requirements for many parameters. This is urgently needed and should be carried out in a coordinated manner to minimise duplication of effort.

It is therefore imperative and timely that Europe takes a leadership role in ensuring a higher level of coordination of EO-related Cal/Val activities. This would benefit all Copernicus services including the climate service, providing a public good and ensuring there are no barriers to trade in Earth Observation data and products.

Consolidated European Approach to Space Weather

Over the last decades there has been an ever-increasing international awareness of risks to modern society from adverse and potentially harmful – and in extreme cases even disastrous – space weather events. Many individual countries and even international organisations like the United Nations (UN) have begun to increase their activities in preparing for, and mitigating effects of, adverse space weather. At the European level, both ESA and the EU are preparing overarching programmes to

increase Europe's ability to meet the emerging threats from our space environment. In response to such growing interest and the increasing international awareness about potential threats from adverse space weather to our modern society, the ESSC has conducted and published a study, looking into a European approach to Space Weather risk assessment and parallel scientific and service activities[4].

The situation of Space Weather today is that we do understand the underlying principles of Sun-Planet interactions, but we are still far from an operational system for Space Weather predictions as we know them from Earth weather forecasts. The recent ESSC study has identified the six main issues that require attention.

Enabling critical science to improve our scientific understanding of Space Weather

The coupled Sun-Earth system in the space age still contains critical gaps in its scientific understanding.

> **Support must be urgently provided for the next-generation space missions and the maintenance and augmentation of the ageing ground-based infrastructure.**

Development and coupling of advanced models by applying a science-based system approach which utilises physics-based modelling

> **Better physics-based models need to be developed and metrics should be defined that facilitate the assessment of different models and encourage their transition to operations.**

Assessment of risks at national, regional and European levels

> **The EU Member States should regularly assess their exposure to Space Weather risks and coordinate and combine their studies at regional and European level.**

Consolidation of European User Requirements

> **European Space Weather user requirements should be (re-)assessed and prioritised taking into account regional and societal differences and needs, also addressing different needs of various infrastructure systems.**

Definition of ways in which Space Weather scientists can interface with candidate organisations for Space Weather services.

Unlike terrestrial weather, which is a mature science, space weather is in its scientific infancy. The emerging nature of the field, the complexity of data sets, and the rapidly evolving character of models make the close involvement of active researchers highly beneficial to space weather services.

> **The ESA Space Situational Awareness (SSA) approach toward decentralisation, networking and inclusion, proximity between scientific research, transition to operation, is considered to be the best possible model to yield immediate societal benefits while simultaneously allowing the field to mature in parallel.**

[4] Assessment and recommendations for a consolidated European approach to space weather – as part of a global space weather effort - https://doi.org/10.1051/swsc/2019033

Define and implement an operational network for future Space Weather observations

There is an urgent need to define an operational space- and ground-based network that measures essential space weather parameters, which in turn can drive the Space Weather predictions required to protect our society's infrastructure.

The analysis and detailed recommendations for each identified issue, as well as additional issues to be addressed in Europe, are detailed in the ESSC report "Assessment and Recommendations for a Consolidated European Approach to Space Weather – as part of a Global Space Weather Effort".

That report concluded that there is an urgent European need for the coordination of Space Weather efforts in individual countries as well as in and among European organisations such as the European Space Agency (ESA) and the European Union (EU).

This coordination should not only improve the ability to meet space weather risks but also enable Europe to contribute to on-going global space weather efforts. While space weather is a global threat that needs a global response it also requires tailored regional and trans-regional responses that require coordination at all levels. It is therefore important for ESA and EU to establish a robust collaboration framework for European space weather efforts and Europe's role in a global Space Weather system.

Exploration of Ocean worlds

Ocean worlds, or "Exo-Oceans", research focusses on worlds that have the potential to harbour sub-surface liquid water oceans and could, therefore, help to improve our understanding of the origin and development of life on Earth.

In order to make progress in our investigations of these bodies, future missions to the so-called "ocean worlds" are mandatory. Both ESA and NASA have inserted the possibility for such missions in their space programmes. The scientific community is currently working to define a science policy briefing detailing a science strategy for the exploration of the outer solar system's icy moons putative oceans and space missions like ESA's JUICE and NASA's Europa Clipper are being developed for launch in 2022, while the Dragonfly mission has been selected by NASA for a return to Titan within the New Frontiers 4 programme.

The exploration of outer solar system bodies with high astrobiological potential is of high relevance to the space programme and to our understanding of the solar system's formation, the Earth's origin and the emergence of life.

In parallel with the implementation of the JUICE mission, the ESSC recommends that ESA takes an active role - in collaboration with other agencies - in future missions targeted to understanding and exploring the icy moons.

In this context, we show how the Earth Observation Programme can be of high value, and the science results from studying our own planet's oceans and their interactions with the atmosphere offer important insights for the investigation of foreign ocean worlds. This exchange of inputs from different scientific communities who have recovered a large amount of data to analyse would provide a strong asset in reaching a better understanding of Exo-Oceans. A study was initiated by the ESSC in collaboration with the European Marine Board, the International Space Science Institute (ISSI) and US experts. It was considered very timely in view of current ESA and NASA foreseen missions. The purpose

of the study was to investigate "exo-oceans" or "ocean worlds", places that have the potential to harbour under-surface liquid water oceans and the implications as described above, partly based on the present understanding of the origin and development of life on Earth 3.5 to 3.8 billion years ago.

As a result of these efforts, a book is being composed of chapters on various subjects that will be of use for future exploration of icy moons and habitable worlds.

Lessons learned from the exploration of the terrestrial oceans can help optimise the return from missions to the icy moons, both in terms of defining scientific objectives and of choosing or developing the right instrumentation. The study of extreme environments on Earth can contribute to a better understanding of how to efficiently explore far-away bodies with strong habitability potential.

4. ESA-EU Relationships

The ESSC highlights that there are areas of common relevance between ESA and EU and that these would benefit from improved coordination between ESA and the European Commission.

Such coordination could be defined and implemented through the work of a reinforced EU/ESA mechanism with improved tactical and operational capacity, carefully acknowledging access to all EU members to ESA-led projects, without bias or exclusion.

The planned setting up of the €16 billion Space Programme for the next long-term EU budget 2021-2027 on one side and the development of Horizon Europe on the other represents great opportunities to further develop synergies between ESA and the European Union's institutions

In this context, the ESSC wishes to express strong appreciation and support for the future vision and extensive commitment demonstrated by the ESA Director General in his proposal on "A United Europe in Space", which was adopted by ESA Member States on 25 October 2018. This far-sighted (2019-2028) long-term plan strives to identify the *"…substantial evolution expected to occur in the various fields of space activity and the different role that players and stakeholders, and primarily the Agency's activities and programmes will be called upon to play in the coming years*." The ESSC also witnesses with satisfaction the notable progress that has been achieved in improving coordination between ESA and the European Union institutions. The ESA Member States adopted a resolution on 25 October 2018, giving mandate to the ESA Director General to establish appropriate relations between ESA and the European Union.

The ESSC recalls that for several years it has advocated a reinforcement of the ESA-EU relations in order to promote a united and collaborative spirit across Europe which will foster European identity, energy, cohesion and efficiency in the achievement of excellence in space sciences and technology.

ESSC noted with interest the Inter-Ministerial meetings in 2018 in Madrid where the adopted resolutions led to the belief that improved coordination between ESA and the EC would be established in the future.

Some benefits could emerge from stronger European Commission/ESA coordination in selected relevant topics:

- The issue of data management in the context of big data is an area where the European Commission (through the Horizon Europe programme) and ESA should strengthen cooperation; this would allow for better science return on European investment.
- Space Situational Awareness is also a topic that would benefit from stronger collaboration and coordination between EC and ESA, but also with other institutions (see part 3.4 above).
- Considering the relevance of life science research in space to contemporary health issues (e.g. ageing) the Horizon Europe Health programme and E3P2 SciSpacE elements should envisage stronger interactions. The same can be said of E3P SciSpacE physical sciences (e.g. metallurgy) and more generally for the uptake of technologies developed through ESA programmes. Life and Physical Sciences should work in close consultation with corresponding elements in Horizon Europe.
- Most, if not all, Key Enabling Technologies identified by the European Commission (micro and nanoelectronics, nanotechnology, industrial biotechnology, advanced materials, photonics, and advanced manufacturing technologies) are also directly relevant to space activities. Common initiatives and developments in these domains would certainly bring significant synergies and cross benefits.
- ESA, member states, and the EU should coordinate on the overarching support for the scientific exploitation of ESA missions by European scientists irrespective of direct instrument involvement.

5. International Partnerships

Europe has the great advantage that it can collaborate with all space agencies. We expect that Europe would be well-served by multiple partnerships with its traditional partners (NASA and Roscosmos), but also with China, Japan, India, etc. In particular, Europe is in an excellent position to stimulate and participate in the rapidly developing Chinese space science programme.

It also has the opportunity to strengthen and develop further collaboration with many other countries. Some of these countries are not in a position to develop collaboration with the USA and this can represent an advantage for Europe.

The current positive situation of International collaborations for Europe may change in the future and it is important to develop a collaboration strategy for the next three years with traditional and new partners. International partnership agreements should always involve fostering access to mission data, in a well-described and forward-planned manner.

There is a strong consensus on the importance of international cooperation in space missions as providing both potential and often very concrete benefits to the participants. The benefits of international collaboration can come from many directions: coordination of individual missions and/or mission architecture (e.g. orbital crossing times), coordination of different observations (e.g. ocean colour), providing instruments, spacecraft, life and physical sciences experiments on the International Space Station and launch capabilities. These are all well-known examples. International collaboration potentially offers important assets such as optimising the mission definition, enhancing the science return, enhancing its likelihood of success, and, last but not least, reducing the cost of the mission (as has been the case for Soho, Cluster, Themis missions in the past).

There are many examples where international collaboration has been critical to mission success: the Cassini-Huygens mission started and evolved as a very successful collaboration among ESA, ASI, and NASA. Space programmes like HST, Hayabusa, Planck, Herschel, SOHO, Cluster, Hinode and LISA, as well as ground-based programmes that come in support of space missions (like e.g. ALMA, and global networks of ground-based space-plasma instruments in support of multi-spacecraft missions like ESA's Cluster and NASA's Themis missions) are excellent examples of fruitful international collaboration. There have also been many excellent examples from Earth Sciences over the years – e.g., TOPEX/POSEIDON, ASTER, and the succession of ocean colour measurements, as well as data sharing and exchange within several Earth sciences missions.

The ESSC recognises that ESA needs to establish a leading role in the space science and exploration landscape by developing and operating ESA-led missions. At the same time, the current portfolio in ESA's programme contains many missions and concept studies that are performed in collaboration with other space agencies, NASA and Roscosmos in particular, but also JAXA and the Chinese Academy of Sciences. This is essential for ensuring a more efficient implementation and science return on elements of common interest in times where the resources worldwide do not abound.

It is indeed of paramount importance to the scientific communities to be part of non-EU space missions and activities and at the same time to have onboard European missions the expertise that can be brought by foreign colleagues. In recent years, bilateral discussions with NASA have led to European participation in NASA-led missions (such as WFIRST) within the 'Mission of Opportunity' framework of the science programme and have also permitted scientific and payload contributions to ESA-led missions like JUICE and vice-versa to the NASA Mars 2020 mission.

Similarly, the new avenues opened up for collaboration with China via the SMILE joint mission with the Chinese Academy of Sciences (CAS) are very promising, in particular in view of the Einstein mission. Possibilities for additional Missions of Opportunity are also under discussion with JAXA.

All scientific communities are very favourable to and have embraced a wide range of collaborations. However, there is also the recognition of important challenges and impediments in some cases. These include technologies that are often proprietary and not easily shared (ITAR issues); differences in data policy; varying planning processes; questions of security and sharing of resources, such as for instance in launching a foreign nuclear-powered mission on a European launcher and vice-versa.

Despite challenges, however, the track record of international collaboration with a positive outcome is remarkably good. It is essential, therefore, for ESA to identify more ways to collaborate internationally in an efficient and mutually beneficial way.

The ESSC encourages ESA to pursue its intense efforts for international collaboration whenever possible and to work towards a more robust European position in the international space cooperation context, with the aim of promoting common development and partnerships in areas of common interest and, in particular, for the optimisation of scientific programmes.

The ESSC urges ESA to envisage exchanges and discussions with potential partners as early as possible in the mission definition phase to ensure an optimised scientific return from the mission. Besides institutions, the scientific community should also be involved in these exchanges.

ESSC would like to acknowledge the International Space Science Institute (ISSI) for their support in the realization of the ESSC studies and for a large number of meetings, workshops and publications that enormously help the European scientific community, by providing an international venue and financial sponsorship for the attendees.

ISSI has thus been instrumental for the cross-fertilization of ideas in the space sector in the last 24 years and the ESSC would strongly recommend that ESA, along with the other partners, continues to support the activities of the Institute.

6. Academia-Industry Relations

The collaboration between academia and industry for the development of instrumentation or experiments has undoubtedly been – and still is – an element of growth for both the academic and the industrial sectors. These can be the source of new ideas, new protocols, as well as creative new approaches, and eventually be highly beneficial to space activities at large.

ESSC has examined the challenges that face academia and industry cooperation in the space domain, as well as tried to identify the opportunities to foster such cooperation.

Challenges for the cooperation between academy and industry

The European academic world is multifaceted. While the academies train people to become productive members of society and thus supply the main body of the workforce for both academia and industry, academia and industry do not always collaborate in an ideal way. National, institutional and disciplinary specificities should therefore not be overlooked when endeavouring to foster cooperation between European academia and industry in space activities. In addition, the industry should be understood in the context of this contribution as going beyond the traditional aerospace industry, to include industrial users, and interactions between academia and industry should not only focus on hardware providers: indeed, the space environment also brings opportunities to the industrial sector as a user.

Research organisations and industries work at a different pace and have different time horizons. They also use different procedures and languages. Research institutes that are deeply involved in both areas already benefit from the experience of working at the interface and could thus be considered as valuable entry points.

The issue of confidentiality and intellectual property is seen as another major hurdle for improved academia-industry collaboration. The industry may be more reluctant to share data and results because of commercial competitiveness reasons, while academics want, and need, to publish and disseminate their results freely and openly.

Although academy and industry share some common interests some divergence can appear in the development of hardware and instruments. The industry is sometimes not deeply involved in the early definition of a given instrument and gets development responsibility comparably late. This may result in a gap between what has been defined at an early stage by the science team and what can be accomplished during real development. Also, developments can sometimes be perceived as being too technology-driven without appropriate consideration to user and scientific requirements.

Stability in the programmes (and related funding), as well as a clear vision on medium to long term programmatic and scientific priorities, are seen by both the academic and the industrial actors as a requirement to develop and implement strategic planning, including the development of knowledge, know-how, and talents. Such stability can also allow to better plan and envisage cooperation and collaboration early in a programme or a mission. A good example of such stability is the Earth Observation domain: the maintenance and continuity of observation and data collection allow industry and scientists to collaborate more deeply on issues related to instrument performance improvements, development of more mature and operational EO applications and services as well as improved EO data processing capabilities.

Graduate and post-graduate training in Europe does not help to reach a common understanding between engineers and academic scientists. Very few career bridges exist between academia and industry. This dichotomy takes root before the first professional appointment, as the graduate and post-graduate training programmes in Europe are often very polarised between technical and scientific domains.

Opportunities for improved cooperation between academy and industry

Training Schemes and support to early career

It is important to trigger common understanding and interest as early as possible. In this context, the European Commission Innovative Training Networks (ITN – Part of the Marie Skłodowska-Curie actions) can be considered as a valuable benchmark. These networks allow the development of (doctoral) training courses that involve different partners from HEIs, research centres, and industry.

Studies

Studies represent an important part of the defining of future activities. From concrete topics to forward-looking subjects, they help to identify, delineate and characterise valuable options and trade-offs.

Involving both academic and industrial actors in study consortia should be set as a tendering requirement when relevant.

Projects

Research and technology development projects supported by ESA should systematically require the involvement of academia and industry.

ESA's Discovery, Preparation and Technology Development (DPTD) Basic Activities programme is considered as a very good benchmark for academia-industry cooperation. ESA Microgravity Application Programmes (MAPs) are also considered as good models to provide a common platform for (non-space) industry and researchers to work and gain knowledge on issues having clear application potential.

The Microgravity Applications Programme helped raise the interest of industry to microgravity tools and should be continued in order to attract new industrial partners.

Ice Cubes are new means of access to a microgravity environment through commercial entities, in addition to the more institutionally-provided access already in existence. The ESSC welcomes this

initiative and looks forward to successful outputs. The ESSC recommends that ESA makes clear the 'commercial' access to space and how it interacts with traditional access.

Consultancy

Consultancy is perceived to be a good way to initiate cooperation between academy and industry. Under such an arrangement, a company asks a researcher to work on a specific issue that requires a rapid solution. This approach works well for well-identified problems and challenges that can be addressed in a fast-track manner, without involving important means and without requiring long timelines.

Challenges

Challenges may also be a way to trigger cooperation between industry and academia.

Such challenges set a goal with measurable objectives and result in a prize for the team who manages to solve the challenge. In the USA, NASA (as other agencies) regularly issues such challenges.

Events/Networking

Networking opportunities are also perceived as a tool to foster academia-industry cooperation.

A potential benchmark could be the 'Marine Science meets Maritime Industry' event organised yearly by the Flanders Marine Institute in Belgium. Other good examples are the ESA 'Grand Challenge Innovation Exchange' events and the Copernicus Academy initiative[5].

7. Concluding Remarks

The European Science Community strongly supports the space programme by regularly submitting numerous and well-conceived proposals in response to ESA as well as EU calls for scientific themes that require access to space. This enormous richness of ideas illustrates the need for continuation of the stakeholders' support to the ESA space programme and to the request for an increase in the Level of Resources for ESA, as well as the need to argue for significant support from the European Union to complementary space-related activities.

Past ESA missions have resulted in a plethora of discoveries. The relevant scientific and technical expertise is available now to build on these discoveries and push the boundaries. These should be exploited in future coordinated sequences of missions, balanced across all research areas, which aim at a deeper understanding of fundamental scientific questions. The selection process of all missions needs to remain transparent and thorough, based on expert bodies such as the ESA advisory structure and ensuring best science, technological advances and timeliness.

The ESA mandatory science programme has offered European scientists the possibility to perform research, putting it at the forefront of the international landscape. At the same time, there are also promising new fields (e.g., new astrobiological targets, exoplanets, sample return opportunities, life

[5] http://copernicus.eu/main/copernicus-academy

and physical science opportunities, etc.) that will result in new discoveries, and which in turn will also require their own follow-on coordinated sequence of missions.

The exploration of the Solar System and of the Universe in all its complexity requires new, improved missions carrying innovative instrumentation to tackle critical and ground-breaking questions. ESA is addressing this challenge in its Space2019+ proposals and at the same time offers opportunities to increase our understanding, with improved synergies between missions (as with ATHENA and LISA) and contributions to interesting international missions of opportunity.

Speaking on behalf of the scientific community, the ESSC is also very supportive of the scientific opportunities offered by ESA's proposal for the second period of the European Exploration Envelope Programme – E3P2. Such a position is fully justified by the flexibility offered within a full envelope programme and the expanding scope of research opportunities offered within, by:

- the extension of the lifetime of the ISS
- the new opportunities on the Gateway and for Lunar and Martian new investigations
- the new means of access through commercial entities, jointly with the more institutional access already in existence.

ESSC strongly recommends full funding of the E3P2 programme and, in particular, its scientific component SciSpacE, as an essential element to provide both scientific results and applications using existing infrastructures, and perform enabling research for future programme elements. This investment is vital in order to sustain the European leadership in this field.

ESA is the stand-out EO organisation worldwide, with an excellent balance of ambition, vision and practicality. The FutureEO and Copernicus programmes show that Europe is leading in Earth Observations, both for scientific purposes and monitoring applications. In that sense, cost-effective implementation of the EO programme, leaving more funding for scientific data exploitation, could benefit from international cooperation with other CEOS members.

The ESSC also acknowledges the FutureEO programme as a fundamental basis for future achievements in Earth Science as this programme prepares for future science and technology activities, including new Earth Explorers and scientific exploitation of the data, and therefore encourages a strong subscription from Member States. It is imperative and timely that Europe takes the leadership role to ensure improved coordination for satellite product calibration and validation. This would benefit all Copernicus services including the climate service, providing a public good and ensuring there are no barriers to trade in EO data and products.

European scientists and citizens have high expectations from the space programme proposed to them for the next years. The ESSC believes that the proposals of the European Space Agency's scientific programmes, complemented with the opportunities offered within the European Commission calls, hold unique promises that can be met if the stakeholders allow for adequate means to be made available. The ESSC therefore encourages all actors to invest in these high-return scientific, economic, and societal value programmes.

8. European Space Sciences Committee – Membership

Chair

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