European Space Sciences Committee

RECOMMENDATIONS TO THE EUROPEAN SPACE AGENCY MINISTERIAL COUNCIL 2016

3 November 2016

Contents

Summary of Recommendations and Findings

The European Space Sciences Committee (ESSC - www.esf.org/space) of the European Science Foundation is an independent body that regularly provides expert advice to European and national research organisations and agencies that support space sciences in Europe. ESSC members are drawn from experts active in all fields of space research on the basis of 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, 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 European Space Sciences Committee has taken note of the ESA programme proposals and has interacted with ESA representatives and the science community to produce the inputs and recommendations described in this document. A summary of extracted recommendations is given in this section. The science programmes proposed aims to maintain and reap the benefits from current strengths and big successes. They plan to pursue efforts in science and technology excellence by augmenting the portfolio and the scientific themes represented with new calls and opportunities.

Overall, the ESSC strongly supports the scientific programmes proposed to the ESA Ministerial Council 2016. In a situation of global economic torpor, it urges Member State delegations not to overlook or underestimate the unique potential space science has on triggering not only socio-economic benefits and wellbeing for European citizens as well as industrial innovation processes and growth, but also on inspiring interest, enthusiasm and vocations in its citizens. Space science is not a cost, it is a high-return investment with a broad and exciting leverage effect on the people and the economy.

Studies that measure the socio-economic impact of space activities in Europe have shown that there is a positive return on investment for states that fund such areas. Acknowledging and catalysing the role and potential that space science has for innovation in Europe would strengthen these links between research and application and facilitate industry uptake and appropriation of investigations performed in and from space. The ESSC notes that the development of 'New Space' activities may allow for faster and cheaper access to space for observing systems, experiments and humans. Eventually these new actors may lead to a more diversified set of opportunities for the European space sciences community, society and the European private sector. In particular, the ESSC recognises and commends the ESA's continuous improvement in public relations over the past years.

ESSC positions and recommendations on ESA Science Programme Proposal

The ESSC recognises the structuring effect of the scientific programme on the European scientific community and the involvement of this community in defining science priorities. The ESSC strongly believes that ESA is effectively pursuing the guidelines of the Cosmic Vision 2015-2025, aimed at addressing fundamental scientific questions concerning planetary system formation and evolution, emergence of life, solar system, origin of the Universe and its fundamental physical laws.

- **The ESSC recommends that ESA continues to develop the scientific programme along the fundamental science questions of the Cosmic Vision programme. This would ensure continuity of the space programme in these areas while at the same time paving the way for new fields and new ideas to emerge within the European scientific community.**
- **The ESSC recommends maintaining a regular cadence of small, medium and large missions. It also recommends supplementing this cadence by investing in the technologies required to meet new challenges associated with promising emerging science concepts. This would ensure Europe's competitiveness and open new perspectives in the different space research areas.**
- **The ESSC recommends that a long-term strategic vision and planning of the scientific programme be further developed. Such a strategic vision, also addressing the risk element and being developed in consultation with the scientific community, would complement and/or update the Cosmic Vision programme.**
- **The ESSC notes that the level of resources requested in the mandatory programme proposal (increase of 2% on top of constant purchasing power) is fully consistent with its successful furtherance and ambitions. The Committee recommends that the Member States fully subscribe to the budget requested.**
- **The ESSC highlights that strengthening the level of control on the expected cost and schedule of missions, in particular during the study phases, would permit better management of the (financial) risk associated with any given mission and would eventually protect the mandatory programme and its outcomes.**
- **The ESSC supports the programmatic and feasibility pre-assessment of proposals submitted in response to a call; however, it recommends that the preliminary cost and technology assessment procedure be made more transparent and more independent and encourages ESA to pursue a more interactive approach so that all stakeholders involved are convinced of the robustness of the process and better proposals are produced in follow-up calls.**

ESSC Positions and recommendations on the ESA E3P proposal

The ESA exploration strategy is well reflected in the E3P proposal. We note the outstanding outcome of the ELIPS programme in increasing European knowledge, capacity and capability in fundamental and applied sciences as well as on exploration-related research. Overall, the programme proposed is well balanced in terms of scientific content, as well as between science, technology and exploration-driven activities. The programme proposed builds on current strengths and big successes and coherently connects the continued efforts on ISS with a promising exploration programme going from the Moon (including CisLunar Space) to Mars (and its moons).

- **The ESSC strongly supports the concept of an envelope programme for European robotic exploration and human spaceflight in LEO and beyond. The ESSC particularly welcomes the coherent long(er)-term vision of the E3P approach, as it is forward-orientated, integrative, adaptive, and well balanced. The envelope approach should permit getting the most out of each individual programmatic element and contribute to making E3P a highly competitive programme overall on the international scene.**

- **The ESSC notes that the level of resources requested in the programme proposal is fully consistent with the ambitions it carries. The requested funding should permit implementation of the scientific and technology-driven elements of the programme proposed while providing adequate resources to plan and be well prepared for future achievements.**
- **The ESSC therefore recommends that the participating Member States subscribe to the E3P at the level of resources requested in the programme proposal.**
- **The ESSC recommends that the overall programmatic balance, philosophy and diversity (at programme completion) be preserved; in this context, the interplay of budget decisions and their consequences should be carefully considered. The ESSC also recommends that budgetary decisions on any of the science-orientated programmatic elements be governed by scientific excellence, based on a transparent and independent (peer) review process, as can be expected in the context of a science-led programme.**

SciSpacE - Science in Space Environment

The SciSpacE element is well integrated within the ambitions of the E3P programme and ESSC recognises that, if supported at the adequate level, it will become a strong and leading pillar of this programme.

- **In order to permit the achievement of SciSpacE's ambitions, the ESSC supports the ISS Extension to 2024 and the two long-duration ESA astronaut missions proposed in the E3P programme.**
- **The ESSC welcomes the balanced share of experiments within the proposed SciSpacE (1/3 application orientated, 1/3 exploration orientated and 1/3 fundamental research) and strongly recommends that this balance be kept as bottom line and guiding principle in the years to come.**
- **The ESSC strongly recommends starting to prepare for the future and in particular for the post-ISS era. It would be sensible to develop prioritised scientific roadmaps that will take into consideration key scientific challenges and objectives as well as the platforms (including commercial) and technology required to achieve these.**
- **In order to reap the full scientific benefits of the effort and investment made in ELIPS, as well as to maintain the knowledge capitalisation and transfer processes, the ESSC recommends that all possible effort be made to implement the experiments currently in the pool ensuring continuity of the programme.**
- **The ESSC recommends that an Announcement of Opportunity be issued in the E3P period and that the Topical Team scheme (as vector to define, develop and bring to maturity new innovative concepts) should be continued.**

Exploration - Mars

ExoMars is the first astrobiology programme to the red planet and an important milestone in performing science operations on the Martian surface. The 2016 mission has seen the impeccable orbit insertion of the Trace Gas Orbiter in October 2016, and the entry and descent phases - but not a successful landing - of the Schiaparelli module.

- **The ESSC is convinced that both ExoMars missions (2016 TGO and 2020) will produce novel and excellent new science.**
- **The Committee highlights the strategic requirement for European non-dependence to continue developing Europe's capability in EDM technology, building on lessons learned from the 2016 EDM failed last stage.**
- **The ESSC considers it critical that funding decisions be made during the ESA Ministerial Council 2016 to remove any remaining uncertainty on the mission implementation and urges**

participating Member States to fully fund the 2016 TGO operations and the ExoMars 2020 mission.

- **In the future, Mars Sample Return is definitively considered by the ESSC as a longer-term investment with presumably the highest value in scientific, technological and cooperation levels.**
- **The ESSC strongly supports further development of the MREP-2 programme, as this will enable technologies for Europe to play a major role in the future sample return programme with the ultimate goal of Mars Sample Return, including the timely design, building and commissioning of sample receiving and curation facilities.**

Exploration - Moon

The continuity between Rosetta, ExoMars and Luna Resource Lander to foster specific European technology and science elements (precise and safe landing, end-to-end sampling including drilling) is considered as a sustainable and efficient approach by the ESSC.

- **The ESSC supports efforts by the ESA Executive to secure funding for Europe's continued participation in the Luna-Resource and Luna Glob missions. These, along with the proposed Lunar Polar Sample Return (and Phobos Sample Return) mission with Russia should be an integral part of ESA's wider exploration strategy.**
- **The ESSC also recommends widening collaboration in this area to include other international partners with expertise in lunar and other small body exploration, in the spirit of the recently formulated Global Exploration Roadmap.**

ExPeRT

- **The approach proposed in the Exploration Preparation, Research and Technology (ExPeRT) element is considered valid and promising in providing coherent longer-term planning, well integrated and incorporated into the broader human space and robotic exploration programme.**

ESSC Positions and recommendations on the ESA Earth Observation programme proposal

The ESSC commends the achievements of ESA's Earth Observation programme as well as its coherency and consistency. This programme has delivered a large number of original and ambitious missions, including the unique *Copernicus Sentinel Satellites* that produce excellent data for scientific research. Moreover, there is a large number of Earth Explorers and Sentinels in the pipeline.

- **The ESSC strongly endorses the EOEP-5 envelope programme and recommends that it be fully supported by the EOEP Member States.**
- **For the Sentinels, ESSC recommends that ESA discuss the bottlenecks to validation of the Sentinel Satellites with the European Commission, to achieve a sustainable programme covering all scientific and operational requirements.**
- **'Bringing the users to the data, instead of the data to the users' is an important concept that is part of EOEP-5 and the ESSC supports this approach. ESSC recommends the implementation of supporting platforms as a continuous activity that starts small but with a scalable design. Furthermore, users should be actively involved in the development of the platforms from the beginning.**
- **For implementing a Sentinel CO_2 precursor around 2025, the ESSC recommends developing a small mission to demonstrate the technology.**

- **The Altius mission in the Earth Watch programme is important for the continuation of occultation and limb measurements of the stratosphere; this has been identified in several gap analyses. Because of the urgency of the stratospheric observations, the ESSC recommends following the timeline with a delivery in 2020 and actively investigating a launch opportunity.**
- **ESSC recommends designing a strategy for developing satellite missions in less than five years and demonstrating this strategy using micro satellites and/or high-altitude platforms.**

ESSC Positions and Recommendations on ESA Space Situational Awareness Programme Proposal

Space weather

The more dependent our civilisation becomes on the availability of navigation, Internet, and other modern amenities, the more vulnerable we are becoming to what occurs in space. Improving our understanding of these effects and improving our resilience to them is thus crucial to modern society.

- **ESSC recommends that in order to safeguard the European technological systems in space and on the ground, and in order to ensure the highest level of safety for human flight and exploratory human missions, Europe and ESA cooperate and participate in the global/international development of a coordinated robust space system of sun-heliosphere monitoring in order to acquire exhaustive real-time data sets and improve space weather understanding and predictions.**
- **ESSC recommends that Europe participate in the global space weather monitoring effort by providing a spacecraft system composed of two or three elements, strategically distributed in space, to monitor solar activity, solar eruptions, and their effects on Earth.**
- **The ESSC recommends that the 'space weather enabling science' be preferably part of the science directorate activities within the normal background of the Cosmic Vision programme and in competition with other fields, based on scientific excellence.**
- **As for predictive services and a value-added combination of space weather data for European end-user needs, ESSC highlights that a broader European approach should be handled by the EU within the H2020 programme.**

Near Earth Objects

The near-earth space harbours natural near-earth objects (NEOs) in their voyages through the inner solar system, and space-debris objects (SDOs), which are leftovers from artificial earth-orbiting satellites. Both NEOs and SDOs pose a significant threat to humans and our space-based and ground-based assets. From the purely scientific point of view, the primitive NEOs are also very interesting targets for exploration as they contain key information on chemical and physical processes pertaining to the early solar system.

- **ESSC recommends focused research on the physical and chemical properties of NEOs and SDOs in the near-earth space, increasing our knowledge-based preparedness for mitigating the threats posed by these objects. An increased understanding of the science and resource potential of NEOs as a result of these investigations would be an added benefit.**

Transversal issues

Data archiving, exploitation and dissemination

- **The ESSC strongly recommends that data produced through all ESA missions be made openly available in a fast and efficient way; a cross-directorate data policy should be established.**

Cross-talk between science directorates

- **It is the ESSC's belief that enhanced consultation and discussion among different ESA science directorates would be beneficial to all parties and in particular could have a positive effect on scientific and financial optimisation.**

Relations with EC and Horizon 2020 programme

- **The ESSC highlights that areas of common relevance between ESA and EU (e.g. data management, Space Situational Awareness, health, technology development) would benefit from better 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.**
- **The ESSC highlights that the ESA-EC *Joint Statement on Shared Vision and Goals for the Future of European Space* signed on 26 October 2016 should be used a basis for a stronger European space sector. It urges Member States not to underestimate the relevance and importance of space sciences and space research in achieving the objectives and goals announced for Earth observation and space exploration.**

International collaboration and competition aspects

There is strong consensus on the importance of international cooperation in space missions as having both potential and, often, concrete benefits to the participants.

- **The ESSC recognises that ESA needs to establish a leading role in the space exploration landscape by developing and operating ESA-led missions. At the same time, the current portfolio in ESA's programme contains a large number of missions and concept studies that are performed in collaboration with other space agencies, essentially NASA but also JAXA and CAS. 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.**
- **The science community urges ESA to envisage scientific exchanges and discussions with potential partners at the beginning of a mission's definition phase so as to ensure an optimised return of the mission within a bottom-up approach.**

Space technology and relations with European industry

In space sciences, as well as in 'mainstream' science, the development of innovative technologies is of the utmost importance, as it opens new fields of research and provides sophisticated new tools for scientists.

- **The ESSC recommends that ESA continues to work towards a better synergy between space and non-space technology, identifying and putting forward best practices and promising technology transfer mechanisms in both sectors through a combined effort of interested parties in ESA, the Member States and the EU.**
- **The ESSC recommends using the stable and ambitious technology 'Overwhelming Drivers' throughout ESA's Directorates as a novel categorisation of programme concepts and useful**

common strategy to guide reflection on future missions and related technological maturation.

- **In order to keep control over the risks of financial cost and science loss in the period of a mission development, the ESSC recommends that ESA be vigilant in its relationships with industrial partners in order to share the risk appropriately between contractual partners.**

Overall recommendation

In order for Europe to maintain and enhance its position as a key player in the international space arena, to be competitive via excellent scientific and technological achievements and to maximise the return on investment into European society, economy and education, ESA needs to receive full support from its Member States at the level of resources requested on the occasion of the Lucerne 2016 Ministerial Council meeting.

1. Introduction

The ESSC-ESF has been invited to attend the ESA Ministerial Council as an observer representing the European space science research community since 1999. The ESSC-ESF will also be attending the upcoming Council at Ministerial level to be held in Lucerne on December 1-2, 2016.

This document highlights the position and recommendations on four ESA programmes that are proposed to ESA member state delegations on the occasion of the 2016 Council:

- Mandatory science programme
- European Exploration Enveloppe Programme (E3P)
- Earth Observation programme
- Space Situational Awareness Programme

The ESSC position on these programme proposals – which were provided to the ESSC initially in draft form - has been developed over the August-October 2016 period and involved interaction between members of the committee and ESA executives, allowing us full insight into the programmes proposed. Furthermore, the ESSC Chair has represented ESSC's position via participation in the ESA advisory structure (SSAC, HESAC and HiSPAC) meetings or through direct interactions with ESA representatives.

The thorough analysis of past achievements and breakthroughs since 2012 as well as of the content and objectives of the science-related programme proposals submitted to the ESA ministerial council 2016 led the ESSC, representing the European space sciences community, to have a positive perception of ESA's capability and ambitions in space sciences.

Overall, the ESSC strongly supports the scientific programmes proposed to the ESA Ministerial Council 2016. In a situation of global economic torpor, it urges Member State delegations not to overlook or underestimate the unique potential space science has on triggering not only socio-economic benefits and wellbeing for European citizens as well as industrial innovation processes and growth, but also on inspiring interest, enthusiasm and vocations in its citizens. Space science is not a cost, it is a high-return investment with a broad and exciting leverage effect on people and the economy.

While the ESSC supports the programme proposals as they are put forward to the ESA council, the committee will also follow up and monitor how these programmes are implemented. As representatives of the European space sciences community, **the ESSC will be vigilant on the programmatic and budgetary decisions and arbitration that will be made in the months and years to come; it will provide informed independent statements and recommendations to ESA executives and the ESA advisory bodies in order to support the achievement of the excellent scientific return sought.** The Committee is particularly interested in the implementation of the novel programmatic approach proposed by the E3P; it will endeavour to provide advice to ESA and to the programme board on how best to keep a balanced approach and fulfil all the ambitions of this innovative programmatic setting.

2. ESA Programmes Achievements and Perspectives

2.1. Scientific achievements since 2012

ESA space science, via its three main components (mandatory scientific programme, European Exploration Envelope programme (E3P-related) and Earth Observations programme) is at the forefront of scientific and technological breakthroughs. ESA's portfolio of missions and activities tells an impressive tale of successes, engaging the public and boosting industrial and economic benefits.

Space science is a unique tool possessed by humanity to study fundamental science tracing back to the origin and evolution of our planet, of our neighbourhood in the solar system and beyond to the entire universe.

The ESSC recognises the growing strategic importance of ESA in shaping space science at a global level and the overall success of the missions flown: from science, technology, and programmatic points of view.

Successes in the Sciences programme:

The themes put forward in the Cosmic Vision programme to define ensuing calls for missions comprised many, if not all, of the great intellectual challenges and fundamental questions on the origins and properties of the earth, of the solar and planetary systems; on the emergence of habitable environments; and on the way our universe works and evolves. Thanks to the selections made during the various calls, ESA is firmly established as one of the leading worldwide actors in the various scientific disciplines. On top of this, by fostering a globally competitive European space sector, engaging the public interest and feeding the imagination of the young generation, ESA delivers tangible and unique benefits to European industry, economy, and society as a whole. It will undoubtedly lead to the creation and maintenance of unique skills and capabilities, including advanced technologies, in Europe.

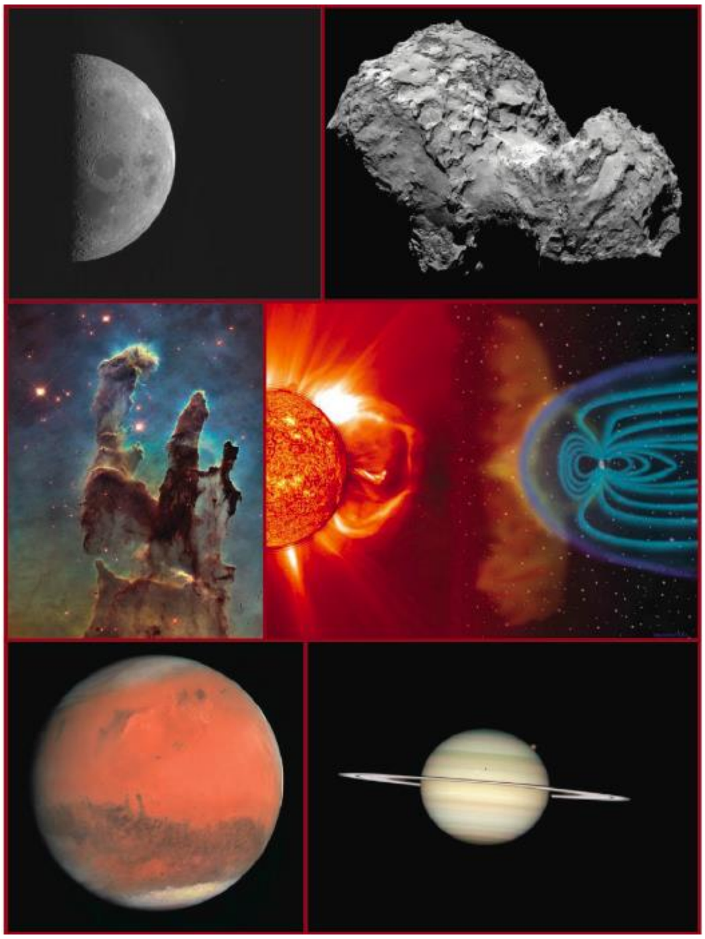

Fig. 1: Some of the scientific successes of ESA in the past years dealing with comets, the Sun and its magnetosphere, the Universe, Mars, Saturn, and the Moon (image credit: ESA/NASA)

Among the notable scientific results produced from current and post-operational astronomical missions since the ESA Ministerial Council 2012, the following can be mentioned in particular:

- *Herschel* which has provided unique insights into star formation processes in our own Galaxy to the distant universe,
- *Planck* has measured the age of the Universe and other cosmological parameters to an unprecedented level of accuracy,
- The *Gaia* astrometric mission, launched in 2013, is mapping our galaxy in exquisite detail with 10 billion spectra already acquired,
- The extraordinary measurements by *Lisa Pathfinder*, launched in December 2015, exceed all expectations and establish Europe's leadership in the technology needed for gravitational wave astronomy from space; the data will be used for future investigation of this important and "hot" science theme,
- Continuous phenomenal discoveries by the *Hubble Space Telescope* are the result of considerable contributions to the mission provided by European scientists.

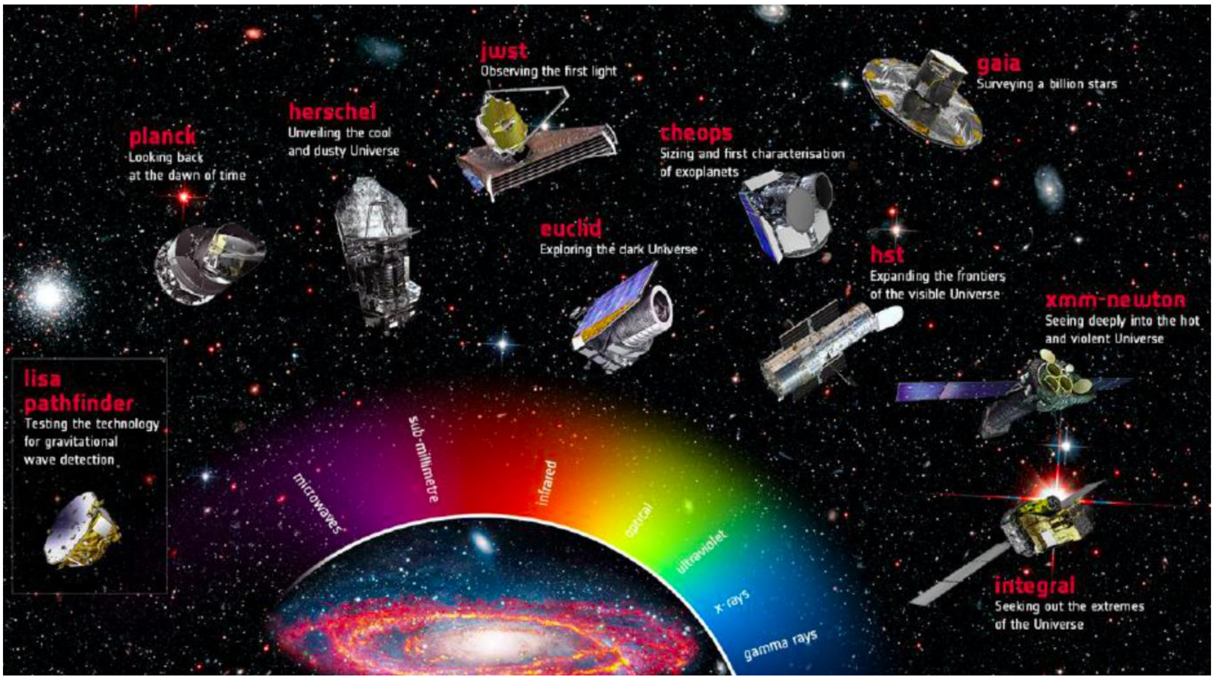

Fig. 2: ESA's fleet – Astronomy missions (Credit: ESA-SCI)

ESA and the European Solar and Planetary science community run and coordinate activities and missions that provide excellent science such as:

- *Mars Express,* a very successful mission in orbit around Mars since the end of 2003 and still delivering data while collaborating with MAVEN and soon with TGO, the first coordinated multi-satellite effort at another planet than Earth;
- *Venus Express*, which ended its mission in December 2014, leaving a wealth of data for ongoing science efforts;
- *SOHO*, our permanent eye at the Sun at L1 for more than 20 years, triggering over 5,000 publications and giving rise to the birth of Space Weather as an autonomous research field, currently still augmenting science return from NASA's Stereo & SDO missions with unique coronographic data;
- *Proba-2*, although within the technology demonstration programme, has provided important inputs on the understanding of solar activity;

- *CLUSTER*, which after successful collaboration with Double Star from China, is now exploring new regions in near-Earth space together with the ESA EOP SWARM mission, studying the Earth's plasma and magnetospheric environment.

More recently, and after a journey of 12 years, with several important discoveries on the way, *Rosetta* has completed its mission after one of the most scientifically compelling and widely-advertised rendezvous with the comet Churyumov-Gerasimenko, on which the module Philae landed in the midst of general community and public acclaim in November 2014. Our understanding of cometary science has dramatically increased thanks to this mission and new pieces were added to the puzzle of the formation of our Solar System. Furthermore, the technological achievement was unprecedented, ESA being the first space agency to have accomplished the feat of landing a probe on a comet's surface to date.

Also worth mentioning is the *Cassini-Huygens* mission, in which ESA is a major actor, having provided the Huygens probe and contributed to several of the orbiter's instruments. Since 2004, this mission is delivering amazing new daily insights into the Saturnian system and its satellites, like Titan and Enceladus, and more generally into the formation of our Solar System. Before ending its 13-year extended mission in 2017, Cassini-Huygens will have produced more than 3,600 peer-reviewed articles, many of which have been led by European scientists.

The ESSC highlights that the science programme of ESA has been the pride of the European astronomical and planetary community and is increasingly a benchmark for other space agencies now looking to mimic its successes. The science programme proposed aims at maintaining and reaping the benefits from current strengths and big successes. It plans to pursue efforts in science and technology excellence by augmenting the portfolio and the scientific themes represented with new calls and opportunities.

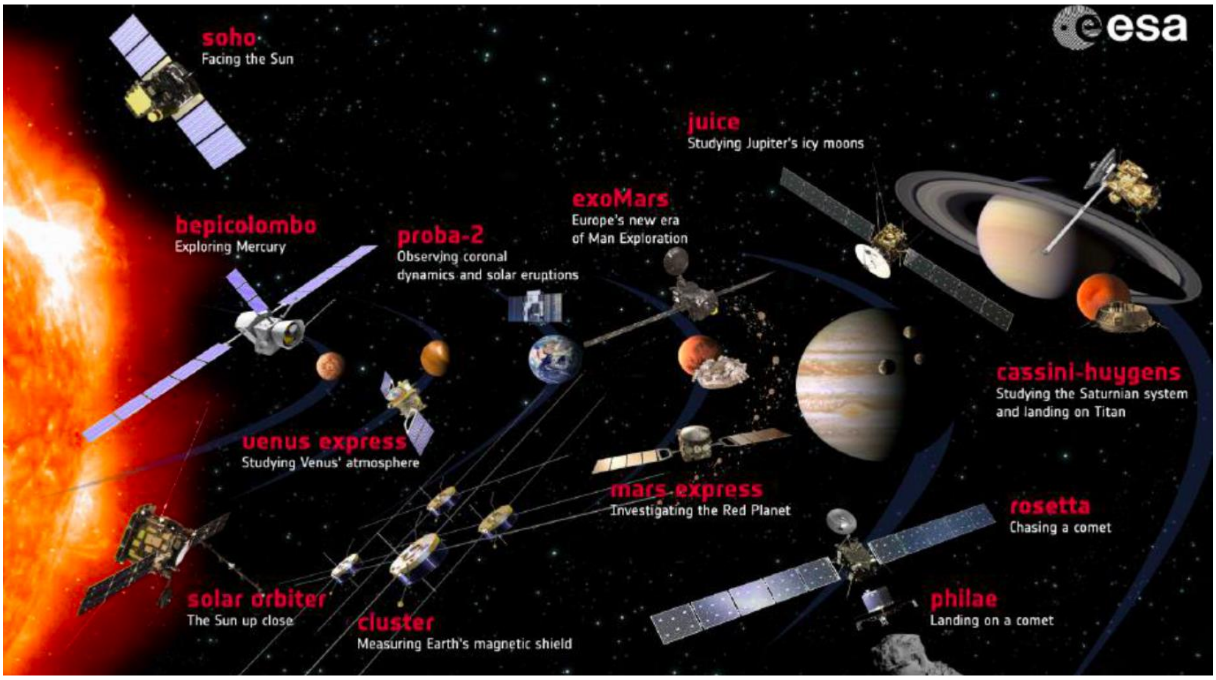

Fig. 3: ESA's fleet – Solar and planetary missions (Credit: ESA-SCI)

Successes in the Life and Physical Sciences programme:

In planetary sciences or astrophysics, a very significant portion of microgravity research is curiosity-driven fundamental science, especially in physical sciences (even with an application-orientated background such as material physics). Results of experiments on ISS (and on other platforms) have changed our understanding of the role of gravity in physical and biological processes. New paradigms have been established in human physiology, improving health on earth to the benefit of (ageing and sedentary) societies. Also, numerous parameters and processes elaborated in microgravity have advanced sciences of fluids and solids, making European industry more competitive on a global scale.

The ESSC highlights the outstanding outcome of the ELIPS programme in increasing European knowledge, capacity and capability in fundamental and applied sciences (life and physical) as well as on exploration-related research.

The ESSC perceives the current ELIPS pool of experiments (selected through high quality peer review) as being well balanced between fundamental science, applied science and exploration preparation. The programme ensures excellent science return and the significant number of very high quality experiments still to be implemented guarantees an excellent and efficient use of space infrastructures.

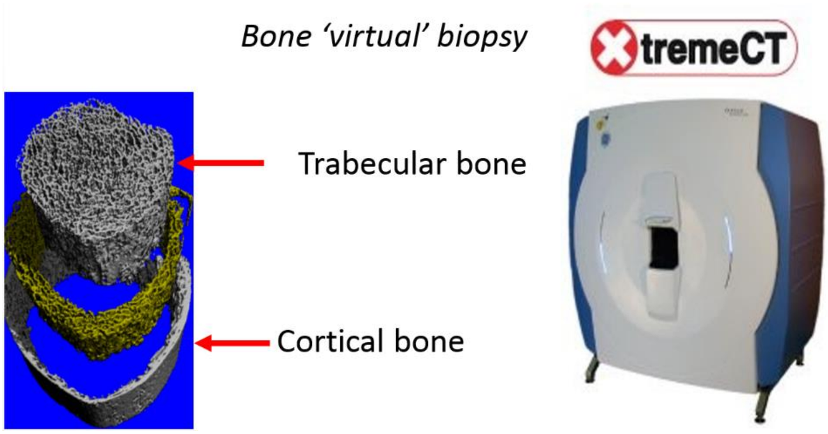

Fig. 4: Picture of the 3D CT scan initially developed for space studies (used for pre and post-flight measurements); this device is now also used for terrestrial health applications (osteoporosis). (Photos credit: Scanco Medical)

Six new astronauts have been operating in space, ensuring not only excellent science return from the various experiments but also very successful education and public outreach activities with strong public engagement. The achievements in life sciences have been exceptional, in particular for brain and cognition in space and novel insights into autoimmune diseases. Important results have been obtained in the study of bone mass and structure in space and during long-term recovery: bone loss and recovery processes are still major concerns for astronauts as they entail the risk of bone fracture. Very significant variability in bone change has been observed between individuals, with some of them not experiencing bone changes at all, while others display severe bone fragility. Understanding the related underlying mechanisms is necessary not only to ensure efficient astronaut recovery but also to better address health issues on earth such as ageing, immobilisation or osteoporosis.

ISS has also provided exceptional opportunities to improve scientific knowledge in physical sciences. The instrument DECLIC (Dispositif d'Étude de la Croissance et des Liquides Critiques) has provided important results on how heat propagates in microgravity environments where convection is absent. DECLIC was launched back to the ISS on 17 October 2016. Purely diffusive colloidal aggregation was studied using the instrument SODI (Selectable Optical Diagnostics Instrument) and for the first time it was possible to experimentally relate the strength of attraction between the particles and the structure of the aggregates. Yet to come are the experiments with cold atoms (PHARAO), set to improve present time standards.

One of the most important achievements was with Complex Plasmas (PK Laboratories) allowing macroscopic insights into microscopic processes such as crystal physics (at the individual particle level), fluid physics (including the onset of self-organisation and turbulence), nonlinear systems (in particular strongly coupled systems), coagulation and particle growth (with applications in astrophysics). Additionally, the results from the ISS were able to establish complex plasma as a new state of soft matter. The knowledge gained during the technology development for space has been transferred to the new and fast growing field of plasma medicine.

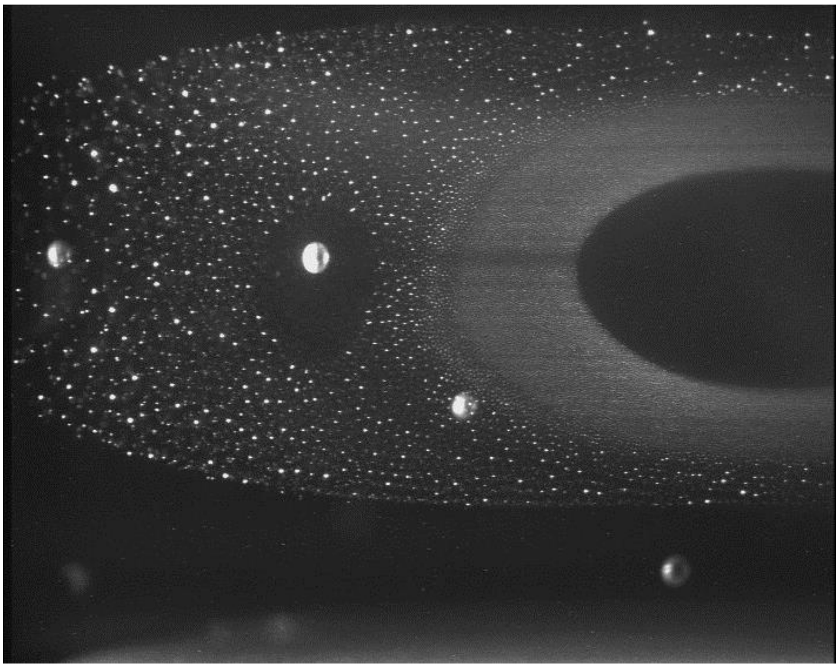

Fig. 5: This picture was taken during the last experiment with PK-3 Plus on the ISS. One can see some "large" particles of about 1 mm in diameter, which are moving through a cloud of "small" particles of about 1 µm in diameter in a background of cold low-pressure plasma. The interaction of the charged particles leads to strong coupling phenomena, interesting from a fundamental physics perspective. (copyright MPE)

Successes in the Earth Observation programme

The ESSC highlights that the period since the ESA Ministerial Council 2012 has seen impressive engineering and scientific advances within the Earth Observation (EO) programme.

With the launch of the *Sentinels* 1A/B, 2A and 3A, an important part of the unique Copernicus space component has been achieved. The vision and excellence of these platforms is widely acknowledged and the scientific community is enjoying unprecedented access to operational datasets.

Fig. 6: ESA's ADM-Aeolus wind mission (planned launch 2017) will provide timely and accurate profiles of the world's winds and further information on aerosols and clouds. (Copyright ESA/ATG medialab)

The *Earth Explorers* (EE) have continued to produce excellent data for scientific research. ESA continues to drive innovation with the EE, enabling European scientists to design instrumentation that answers fundamental questions on our planet and its climate. Future EE missions such as ADM-Aeolus (2017), EarthCare (2019), Biomass (2021), Flex (2023) and EE9 are strongly anticipated. These are original and ambitious missions that raise the profile of European excellence in science and engineering.

The successes of the ESA Earth Observation programme are evidenced by the growing use of satellite data for scientific studies and the reach of EO beyond specialist users. A record number of abstracts and participants at the 2016 Living Planet Symposium demonstrates the strides ESA EO is making and the progress ESA has made in democratising EO.

Successes in the Space Situational Awareness programme

Over the past years, ESA has carried out an excellent analysis of space weather monitoring needs and gaps by a thorough user-and-need assessment and consequent establishment of end-user requirements. This effort has led to the creation of a number of key Expert Service Centres (ESCs) on some of the most important and most urgent space weather monitoring needs, like solar conditions, ionospheric conditions and geomagnetic conditions. Also, ESA has made valuable progress in identifying the need for continuous space weather monitoring from space. This effort is going in the right direction, as are consolidating efforts between ESA Member States contributing to the Space Situational Awareness (SSA) optional programme.

Considering Near Earth Objects, the activities ESA has initiated to investigate the feasibility of deflecting a threatening NEO should allow Europe to gain important knowledge and develop new and critical techniques and technologies. This is particularly visible with the Phase A/B1 study for the Asteroid Impact Mission (AIM) developed in collaboration with NASA. Also, some new Space Surveillance and Tracking assets are being validated in Europe (e.g. monostatic and bistatic breadboard radars and robotic telescopes). Technologies for efficient networking are being developed to optimise the use of national and ESA facilities.

2.2. Looking to the future

Mandatory Activities - Science, Research and Development

In the years to come, among the science missions already in the pipeline, the ESSC notes a broad spectrum of large, medium size and small missions composing a diversified and coherent portfolio which allows ESA to cover all important science domains.

Planned for 2018, *BepiColombo* is a joint mission between ESA and the Japan Aerospace Exploration Agency (JAXA), carried out under ESA leadership and designed for an in-depth study of Mercury, the planet closest to our Sun, where the harsh environment will constitute a technological challenge. The mission comprises the ESA MPO (Mercury Planetary Orbiter) and the JAXA MMO (Mercury Magnetospheric Orbiter).

CHEOPS, the first small mission within the Cosmic Vision programme, was selected in October 2012 and will be launched in 2018 to perform ultrahigh precision photometry on bright stars already known to host planets. It will provide accurate radii and precise densities for a subset of those planets.

In the medium class range (M missions), the M1 mission is *Solar Orbiter*, a mission intended to produce images of the Sun at an unprecedented resolution and perform the closest-ever measurements of local, near-Sun phenomena. Solar Orbiter was carried over from Horizon 2000 Plus and is due for launch in 2018. The M2 mission selected is *Euclid*, destined to map the geometry of the dark universe, measuring the distance-redshift relation and the growth of structure by using two complementary dark energy probing methods, baryonic acoustic oscillations and weak gravitational lensing. The launch is anticipated in 2020. Finally, *PLATO*, selected as ESA's M3 mission, will detect and characterise the systems of small planets (mass, radii, density, age) as far out as the habitable zone around sun-like stars.

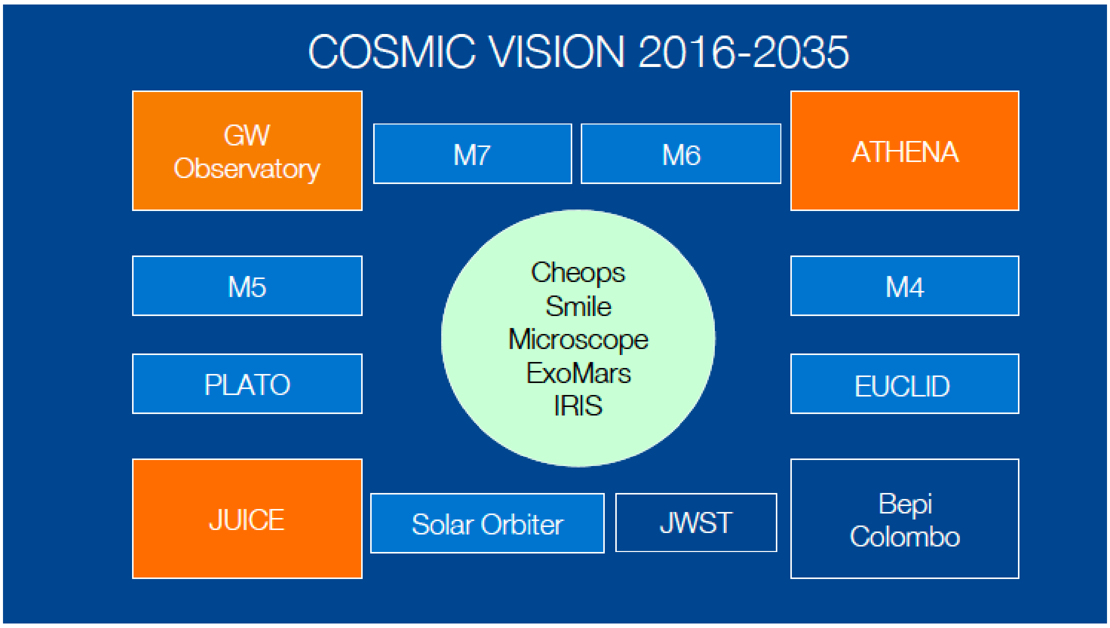

Fig. 7: The COSMIC VISION programme (Credit: ESA-SCI)

The first Large Mission foreseen, *JUICE*, is designed to explore the Jupiter system, with a focus on its satellites like Ganymede and Europa and the emergence of habitable worlds around gas giants. The science questions related to this ambitious mission also have direct implications on our understanding of waterworlds among the exoplanets. The launch is foreseen in 2022.

The science themes defined for the next two large missions within the Cosmic Vision programme include a large X-ray telescope, *ATHENA,* for L2 to study the hot and energetic universe and a space-based *gravitational wave observatory* for L3. These missions are to be developed for launches in the 2028 and 2035 timeframes, but there could be accelerated technology developments permitting the L3 'hot topic' to be carried out sooner than originally planned.

Following the M4 call for missions, three concepts were selected for study: *ARIEL*, an observatory performing exoplanetary spectroscopy in the infrared from an L2 orbit to characterise transiting planets; *THOR*, aimed at understanding turbulent fluctuations in plasmas from high elliptic orbit; and *XIPE*, which would measure the polarisation of X-ray sources from a Low Earth Orbit. The recent M5 call will certainly return many other proposals with various scientific objectives.

The broad range of science themes covered by these missions engage the European community and are valued in particular by early-career researchers and students in the field of space research. To ensure that this engagement pays off, the scientific programme needs to proceed in a timely manner with the current cadence. Furthermore, new ideas for science themes and fast missions have materialised in the form of interesting responses from the community to very recent ESA calls, and are now part of the proposed Science Programme. At the same time, the technological challenges posed by the ESA science programme will allow us to develop new key technologies.

Human Spaceflight and Robotic Exploration

The *ISS* was built over a period of more than 10 years. Only recently has full return on investment started in terms of results and achievements. Most, if not all, the initial problems have been resolved and high level scientists and institutions are now involved. The research, based on best science practice, is multidisciplinary and multiscale, ranging from small experiments to multiuser facilities.

Future activities include continuation of advanced science performed by ISS, with operations covered until 2019; finalisation of Orion ESM-FM1; procurement, assembly and testing of ESM FM 2 (barter element); initiation of the complementary barter on Deep Space Habitat. Finding additional and new ways for ISS exploitation, in addition to the classical scientific applications, particularly in the exploration domain (e.g. end-to-end validation of human-robot collaboration as planned for future missions) could further substantially raise the justification for an extension beyond 2020.

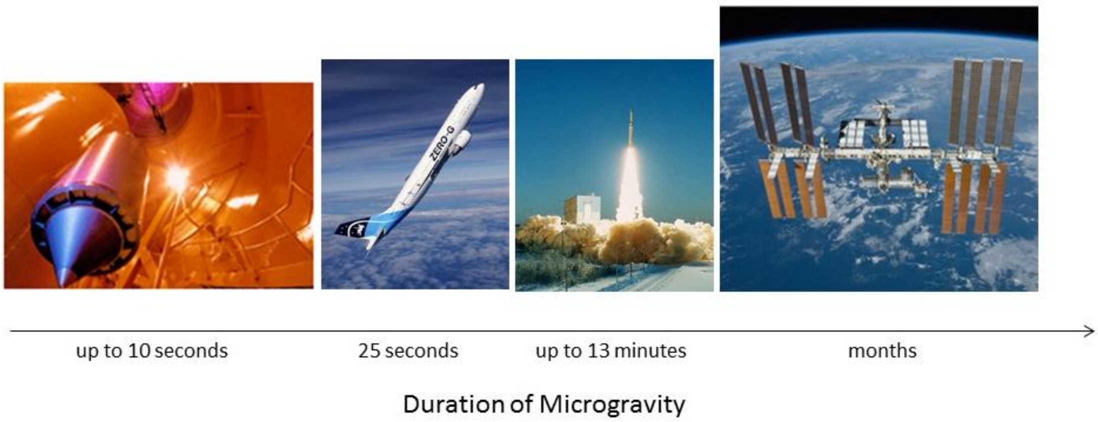

Fig. 7: Various microgravity platforms provided by ESA (Image credit: ESA)

The Science in Space Environment (*SciSpacE*) proposal for the next years (period 1 of E3P) is structured following thematic roadmaps and considers projects and experiment proposals for which implementation is compatible with the short time frame covered. **SciSpacE has not only the capacity to bring new and outstanding achievements in fundamental science, but it can also create important**

textbook knowledge (beneficial in particular for European industry) and lead to important outputs for human health and sustainable development.

For SciSpacE science support activities (Topical Teams, Application promotion) are envisaged, along with the development of ISS experiment facilities, instruments, cartridges, inserts, as well as the hardware and mission cost for non-ISS platforms including ground-based facilities, parabolic flights, sounding rockets and ESA participation in BION-M2.

The *ExoMars 2016* mission has safely arrived at Mars and the Trace Gas Orbiter (TGO) has been successfully inserted into orbit on 19 October. The EDM demonstration Schiaparelli model entered the atmosphere but did not achieve safe landing, but monitoring measurements should allow to determine the failure causes. The 2016 TGO science operations and the full implementation of the 2020 mission (development, integration, testing) are included in the E3P proposal. The 2020 mission is currently under development and the ESSC notes that there are elements of the mission that will produce excellent new science (such as, for instance, the capability to drill two meters deep and explore terrain more ancient and pristine than ever before).

For the *Luna-Resource* Lander it is planned to complete the implementation of Phase C/D/E of PILOT, the implementation of Phase C/D/E of PROSPECT, and the implementation of Ground operation support.

For *ExPeRT,* mission studies (up to Phase B1) with focus on Mars Sample return and Phobos Sample Return would be performed along with technology preparation for human and robotic missions within the framework of current and new international collaborations. One or more commercial partnerships would be envisaged and, in addition, the spaceship EAC /Harwell Robotics and Autonomy Facility would be studied.

Earth Observations

It is clear that the very successful ESA Earth Observations (EO) programme(s), designed with coherency and consistency, has acquired a strong international reputation and *Earth Explorers* (EE) will continue to produce excellent data for scientific research. Several more original and ambitious Earth Explorers missions are in the pipeline (ADM-Aeolus, EarthCare, Biomass, Flex and EE9) to satisfy the growing need for and use of satellite data for scientific studies. **The fifth Earth Observation Envelope Programme (EOEP-5) will consolidate European EO capability by continuing the EE programme and enabling new climate monitoring datasets as well as by complementing and expanding the well- established *Climate Change Initiative* (CCI) portfolio.**

With the launch of the *Sentinels* 1A/B, 2A and 3A, an important part of the unique Copernicus space component has been achieved, but the communities look forward to even more excellent opportunities within the programme with the advent of the Sentinels 2B and 3B and with EOEP-5. The stability of the programme appears secure with data continuity until 2030+.

The ESSC recognises that the ESA CCI has been very successful in producing world-class data from ESA Earth Observation missions, and highlights the relevance of this programme in the context of the COP21 policy decisions, an essential element of the current scientific, societal and political situation.

Fig. 8: The of SENTINEL-2 mission will contribute to ongoing multispectral observations and benefit Copernicus services and applications in areas of land management, agriculture and forestry, disaster control, humanitarian relief operations, risk mapping as well as security (Credit: ESA).

In the future, the addition of the development of the ten new *Essential Climate Variables* (ECVs) as well as the additional R&D on existing ECVs would provide unique insights into climate change studies in Europe.

Space Situational Awareness

On Space Weather, the third period of the SSA programme plans to initiate the development of a space weather mission to Lagrange (L1 and L5). This effort is expected to be coupled with ongoing and planned initiatives in the USA. In addition, ESA plans to focus on a coordinated and complementary approach with international partners, where possibilities for Europe's participation in Space Weather instrumentation on US platforms will be sought.

In the same way, ESA will develop satellite-based NEO observations as hosted payloads. It will also test and validate the NEO Fly-Eye automated survey telescope and deploy a telescope in the Southern hemisphere.

The SSA programme's third period also includes the development of Space Surveillance and Tracking (SST) technology and studies towards the creation of a European SST system. Finally, the programme will initiate development of small satellites in the NEO, SWE and SST segments.

Maintaining and developing ESA capacity in Space science

Within a rather morose international context, where space agencies struggle to secure financial support for their programmes, the long line of European successes led by the European Space Agency and the ambitious activities envisaged should convince stakeholders to join the scientific community in supporting the maintenance and further development of the SCI, HSRE and EO directorate programmes.

3. The European Landscape in Space Science and Beyond

3.1. European Leadership in Space Science

Several scientific areas in space study are being led by European teams. Some of the most prominent examples are included hereafter.

Astronomy and Fundamental Physics

Gaia Mission**:** Gaia is a space mission acquiring parallax data with precision at the level of microarcsecond for a billion stars. The thermal and mechanical stability required, the accurate data processing, the volume of data (of the order of 1 Petabyte) and other particularities make Gaia unique. Gaia is now operational to the end of 2018-2019 and the release of the archive is anticipated for 2022-2023, with intermediate data releases during mission operation (the first of which was already accomplished in 2016). Europe has been leading the research in space astrometry since ESA's Hipparcos mission, and Gaia has no competitor in the world. The European community around Gaia is extremely large as is demonstrated by the large number of scientists involved in i) the Data Processing and Analysis Consortium (more than 400 people from 18 countries), ii) the European Science Foundation Research Networking Programme Gaia Research and Astronomy Training (GREAT - more than 200 people from 12 countries) and, iii) the development of the Gaia archive to be delivered to the community (more than 200 people from 9 countries). Developing such a high level of consolidated expertise in the field of space astrometry requires time and investment; it can therefore be expected that Europe will keep its leadership in the field for years to come.

UV Astronomy**:** The UV is a powerful region of the electromagnetic spectrum for a very wide range of astrophysical topics ranging from the observation of diffuse gas being lost from exoplanets - revealing their composition - to observation of material falling into supermassive black holes. UV astronomy has been remarkably productive and informative, with the NASA/ESA satellite International Ultraviolet Explorer (IUE, 1978 - 1996) being among the most cost-effective missions ever carried out. The Hubble Space Telescope has continued and expanded on the IUE's UV astronomy legacy, and has inspired unrivalled enthusiasm for science among the peoples of the world. Europe has been fully engaged with IUE and Hubble science, and European researchers regularly lead high profile UV science. In particular, Europe was a clear leader in UV spectroscopy of objects in the distant early universe.

Exoplanets**:** coupled with the European leadership in asteroseismology and in ground-based high-precision radial velocity measurements, the CHEOPS and PLATO missions will consolidate Europe's expertise and eventually allow Europe to lead the search for and characterisation of earth-type planets around close-by bright stars. The latter are the best targets for the search of biosignatures with the NASA/ESA James Webb Space Telescope (JWST) or the future European Extremely-Large Telescope (E-ELT).

Gravitational Wave Astrophysics**:** LIGO (Laser Interferometer Gravitational-Wave Observatory, USA) and its European counterpart VIRGO (situated in Italy), as well as the ESA LISA Pathfinder technology space mission are three key platforms that give Europe by far the most advanced scientific and engineering communities in Gravitational Wave (GW) detection, follow-up of the GW counterparts by detection of their electromagnetic radiation and in GW astrophysics as an entirely new discipline of physics. This exciting new area in technology and astrophysics paves the way to a timely implementation of ESA's L3 GW mission to study the early universe in the 2035 timeframe.

Earth Sciences

Atmospheric Chemistry: European research institutes have made a significant and well-recognised contribution to this important research worldwide due to the large success of the ERS/ENVISAT/METOP platforms since the 1990s. European scientists are well represented in international associations and organisations like the International Association of Meteorology and Atmospheric Sciences (IAMAS) or the Scientific Committee on Oceanic Research (SCOR).

Observing Systems: Europe has an acknowledged leadership in suborbital observing systems. European scientists occupy leading positions in monitoring networks like WMO's Global Atmosphere Watch (GAW), Global Terrestrial Observing System (GTOS), Global Climate Observing System (GCOS) or Network for the Detection of Atmospheric Composition Change (NDACC). Europe is also a pioneer in scientific ballooning and in routine aircraft measurements. It also has a long-term expertise in the coordination of field campaigns, of observing systems (e.g. GMES/GATO, CEOS, GCOS) and of operational monitoring (GMES services, ESA DUP and GSE, EUMETSAT SAFs...). Another advantage of Europe is that several coordinating units are located either in the EU (e.g. EORCU in UK, SAFs in various countries) or in Switzerland (WMO, GEO).

Life and physical sciences in space

Infrastructure: The European Life and Physical Sciences in Space has reached a high level of excellence in the last decades. The availability of short time microgravity environments (sounding rockets, parabolic flights, drop towers) has meant that ISS experiments have been prepared in good conditions and contributed to this success. In some cases, the available time for these additional facilities was sufficient to obtain valuable results. Outstanding scientists became involved, resulting in European leadership in the field.

Human Physiology research in space: Space physiology research covers a wide spectrum that is much broader than the topic of space exploration, as it encompasses, for example, muscle, bone, nutrition, vestibular conditions, psychology, neuro-sensory conditions, heart and vascular system, immunology, lungs, environmental physiology, ageing, sports/training and other disciplines. Europe's role in Human Space Exploration has always stood in the shadow of the more ambitious US and Russian programmes. However, Europe is currently on the verge of taking a leading role in human space (physiology) research. There is a high level of expertise and the European scientific community is very well organised and networked.

Space Weather and heliophysics

In the field of **Space Weather**, Europe currently leads in many subtopics such as auroral research, global modelling and particularly in the top-end high performance computing effort, radiation belt forecasting. There are many new opportunities in combining subfields - e.g., space weather effects on controlled deorbiting of large bodies, necessitating in particular real-time modelling and information on ionospheric environment and atmospheric drag. Europe could readily take the lead in such new combinations if sufficient resources could be appointed.

In **heliophysics,** Europe has strong leadership in large observatories, with complementary and exhaustive instrumentation for solar and heliospheric research. Europe has been on the forefront of the solar physics field for a long time thanks to SOHO and Proba-2. Both missions are still world-leading in particular concerning coronagraphy. Solar Orbiter will further increase Europe’s knowledge in the field.

3.2. Stimulation of the European (space) economy

The coming years are full of promise for the European and international space sector. The domain of space remains, and is poised to become even more a unique opportunity for fundamental science and basic research, but increasingly also a vital component for technological innovation in numerous areas. **The space sector now offers several key solutions to challenges our modern society is facing. Furthermore, it provides a significant amount of high-technology employment in Europe.**

	Upstream	Midstream	Downstream	TOTAL
Satcom	10 250	4 600	200 000	~215 000
EO	4 900	5 100		~ 10 000
Satnav	2 500	50	Not quantified	> 2 500
Launchers	6 500	315	No downstream activities	~ 6 800
Space Exploration	2 870	Not quantified	No downstream activities	~ 3 000
Space Science	2 350	Not quantified	No downstream activities	~2 500
TOTAL European Space Industry	~ 36 000	> 5 000	> 205 000	> 246 000
Indirect Employment	72 000	Not quantified		> 72 000
Agencies & Institutions	~ 7 500		Not quantified	> 7 500
TOTAL European Space Activities Employment	~ 115 000	> 5 000	> 205 000	> 326 000

Table 1: Employment derived from space activities in Europe (FTE, 2009-2012 average - Source: [1])

Space activities such as telecommunications and navigation, operational earth observation services and security, space engineering and space technology are deeply rooted in the lifestyle of European citizens. In return, European societies and economic welfare are increasingly dependent on these services and activities. This intertwining of space activities with our technology-driven societies and economies can also be transposed to research performed in space. Space science (including research done in space) covers an extremely wide range of scientific disciplines. Space science is everywhere and has relevance and impact on many scientific disciplines: health research (i.e. ageing, immunity, stress-related responses and cardiovascular diseases), life and environmental sciences, physical and material sciences, to name but a few in addition to astronomy and planetary science.

Looking downstream, numerous space-based investigations have direct relevance to technology development (e.g. telemedicine, biomedical research, material engineering, energy production, communications, information technology, robotics, sensors and automation). **Acknowledging and catalysing the role and potential of space science on innovation in Europe would strengthen these links between research and application and facilitate industry uptake and appropriation of investigations performed in and from space.**

Fundamental Space research provides answers to some of mankind's most important questions: What environment do we live in? Why do we live here? How did the universe and our (and other) solar system(s) develop and how will it (they) evolve? Additionally, fundamental science brings surprises. It is not possible to plan how it will benefit society, but experience shows that it always does. For example, at CERN the need to coordinate between many different machines and experiments, hardware and software, support systems and beam lines, led to the development of HTML. This enabled the World Wide Web, an essential part of our modern society.

Studies that measure the socio-economic impact of space activities in Europe have shown that there is a positive return on investment for states that fund such areas. Some key results from two recent studies on the socioeconomic benefits of space [1,2] are summarised here:

- The *ISS* development programme represents a multiplier of 1.8 for ESA investments (1.8 Euro return for every Euro invested in by ESA) with a job multiplier of 1.9 (100 jobs in the space sector supported an additional 90 jobs in non-space sectors).
- The *Ariane 5* development programme represents a multiplier of 2.2 for ESA investments, with a job multiplier of 2.
- *Copernicus* represents a multiplier of 1.4 for ESA and EC investments.
- A cost/benefit analysis of the space weather and space situational awareness programmes indicated a positive 6.5 ratio for ESA investment, with the added value of reducing dependency on the USA for surveillance of space debris.
- *Earth Observation* services and activities is a very fast growing sector, with a projected return on investment of 5 to 6.
- *ARTES* Integrated and *Satcom Space Applications and Services* programme has a ratio of 3.2 to 1 for revenue versus initial ESA funding. This is projected to grow significantly (close to 13) for 2020.
- *ARTES competitiveness and Growth* products are estimated at a factor of 2.2 return on investment, with prospects of growing to a factor of 7 by 2020.
- *ARTES Public-Private Partnership* programme has a ratio of 1.3 to 2.6.

For the domains of science and exploration, a return on investment ratio is perhaps difficult to estimate, but some key factors showcase the world-class output of the programme:

- Space science has generated the publication of 140,000 scientific papers in Europe over the period 1996-2011. In the same time frame, 90,000 scientific papers in space science were recorded for the United States.
- The ESA Earth Observation Envelope Programme has resulted in 2,000 peer-reviewed publications in international journals by ESA PIs for 2015.
- In 2015, a total of 1,870 refereed papers were published based on data from ESA-led missions, 11% higher than for 2014.
- An estimated 13% of all astrophysics papers published worldwide in 2015 are based on data from ESA- or partner-led Science Programme missions.

The era of 'New Space'

Space is fast becoming a dynamic field where private companies - different in nature from the traditional space companies - compete to offer new services in the fields of research, earth observation, transport and even exploration, with the main economic activity of these enterprises taking place in the USA (space related 'start-up' companies). The main reasons for the high growth of USA-based companies seems to be the easier access to funding, both from governmental (NASA) and private sources, with Silicon Valley venture capitalists funding a significant number of start-ups. Another often cited reason is the business-friendly legislation in the USA along with a more risk-tolerant operational environment.

At the global level, the actual results of new space companies remain to be seen, as we are still in the early phase of this entrepreneurial transformation. Nevertheless, great strides have been made by private companies in domains that were previously government monopoly markets. It is thus paramount that Europe remains at the forefront of space development, maintaining and strengthening its position as a major space power and key international partner in all space matters.

According to ESA, 'New Space' is a crossroad of sectors, resources and people, open to a broader community. **The ESSC notes with interest that ESA is open to developing further activities in collaboration with European industry and society. The development of 'New Space' activities is viewed positively as it may open the way to faster and cheaper access to space and thence for the monitoring of systems, experiments and humans in space. Eventually these new actors may lead to a more diversified set of opportunities for the European space science community and the European private sector**. ESA's recent plans to use Sierra Nevada Corporation's Dream Chaser spacecraft and to develop the Space Rider reusable spacecraft are also seen as valuable first steps to increasing European access to space opportunities.

Although limited to human spaceflight and microgravity research, ESA's recent *Space4Inspiration* initiative is seen as a positive move towards the development of new partnerships and activities. ESA is already forging new partnerships with the private sector and planning new ways of working together. The *Space4Inspiration* event in London 14-15 September 2016 assembled a large number of people from different fields and companies, ensuring the success of ESA's purpose for this event: to forge new partnerships with the private sector and plan new ways of working together. The success of this meeting demonstrates the high interest among the public and private sectors.

3.3. Space science as an opportunity

The scientific and technical challenges posed by space science represent a great opportunity for European industry and citizens. Technologies related to reduction of mass, resilience of space infrastructures, deployment and operation of large-scale orbital infrastructure (rigid or free flying), robotics and autonomous systems (including human-robotic partnerships), life support systems, telemedicine, telecommunication, human-machine interfaces, in-orbit servicing, space debris reduction as well as power generation are key enablers of future world class scientific achievements

On a different note, space has been an inspiration for young people ever since the beginning of the space era. As in the first golden age of human space exploration, recent planetary science highlights (in particular NASA's Curiosity rover landing, ESA's Rosetta mission and most recently ExoMars starting with its 2016 launch and the safe arrival in orbit of the TGO) have drawn huge public attention, including that of the younger generation. Space science and space exploration are of the very few disciplines able to draw immense interest and enthusiasm. **In this context, the ESSC recognises and commends the continuous improvement in ESA's public relations over the past years and urges ESA to pursue its effort in this domain.**

Additionally, students and post-doctoral fellows having worked in a space mission environment have learned how to work within international teams, to manage a complex project, to cope with diverse requirements and interfaces and to work within the disciplines of science and engineering. This is an excellent preparation for industry, a sector that most space graduates choose to enter, not only in large space companies but increasingly in small SMEs or start-up companies. **Considering the current shortage of graduates in engineering, mathematics and physics in Europe, ESA (with other stakeholders) should use the interest raised by space activities as a tool to channel and build capacities in graduate STEM education and inspire young students to follow such a career, with specific attention to gender and minority groups.** In this context, the ESA educational programme for 2015 has reached approximately 5,800 primary/secondary teachers, 174,000 pupils and 16,000 university students, with 950 directly involved in hands-on activities.

4. ESSC Positions and recommendations on ESA Science programme proposal

A very successful programme bringing Europe to the forefront of space science

The ESSC recognises the structuring effect of ESA's scientific programme on the European scientific community and the involvement of this community in defining science priorities. The ESSC considers the fact that ESA is effectively pursuing the guidelines of the Cosmic Vision 2015-2035 programme as very positive; these are aimed at addressing fundamental scientific questions concerning planetary system formation and evolution, emergence of life, solar system, origin of the universe and its fundamental physical laws.

The ESSC recommends that ESA continues to develop the scientific programme along the fundamental science questions of the Cosmic Vision programme. This would ensure continuity of the space programme in these areas while at the same time paving the way for new fields and new ideas to emerge within the European scientific community.

Portfolio, continuity and cadence of missions

The ESSC underlines the fact that a wide palette of satellite classes will better serve a wide variety of science fields covered by the ESA mandatory programme - and even cater for new emerging communities. The Committee recognises that the science programme involves a significant element of risk. This is necessary and even welcome in order to lead to exciting new science. However, risk on mission completion and cost overruns should be managed so as not to jeopardise the programme's cadence or successes. In particular:

- The ESSC supports the approach of using a good mixture of strategic theme-based L-class missions and open M-class missions in the ESA science programme.
- The ESSC notes that L-class missions are important for tackling complex scientific problems and/or studying far-away worlds, ensuring the scientific excellence and visibility of Europe. The L2 and L3 science themes assessment and selection process by a senior ad hoc committee following an open competitive call is considered appropriate. It has permitted the communities involved in these topics (hot and energetic universe and gravitational waves) to gain a wider perspective and better visibility on the timeline of the space missions that will acquire the data necessary to their research. However, a strategy allowing ESA to react swiftly to major discoveries, without seriously affecting the schedule of other missions in development, should be considered (e.g. gravitational waves astrophysics).
- The ESSC recommends that the cadence of open full-cost M-class missions within the Cosmic Vision programme be kept as constant as possible, with the possibility of backup solutions or substitute implementations in case of the programmatic failure of a planned mission.
- The committee's view is positive towards the concept of the new type of F(ast) missions, which offers a solution to the important need for fast response in some cases of space science, in order to keep enthusiasm and teams engaged on a focused objective. The higher cost cap for F missions than that of small missions is viewed positively for new science opportunities.
- The new call for science ideas is considered an excellent move for increasing interaction with the scientific community in areas that are not currently in the pipeline. The ESSC considers that the ESA follow-up, with studies on these ideas to check feasibility and technology assessment, is also an excellent opportunity for young researchers to become involved in the space business.

- New technological developments are essential for the advancement of European industry, and missions requiring technological development should be positively considered in the selection process.

The ESSC recommends maintaining a regular cadence of small, medium and large missions. It also recommends supplementing this cadence by investing in the technologies required to meet new challenges associated with promising emerging science concepts. This would ensure Europe's competitiveness and open new perspectives in the different space research areas.

It should also be possible to maintain a fair frequency of space missions through astute and enhanced international collaboration, thus optimising the efforts and the science return on a global scale (see Section 8.4 on International collaboration). However, concerns from the science community and in particular from space-related laboratories, about too-strong demands on their financial and manpower resources should be taken into consideration in the cadence of the calls. Support from ESA for managerial and payload development aspects (as foreseen in the programme if a 2% increase is granted) would be highly appreciated by the European space institutions.

Enhancing efficiency and scientific return of the programme

The ESSC recommends that long-term strategic vision and planning of the scientific programme be further developed. Such strategic vision, also addressing the risk element and developed in consultation with the scientific community, would complement and/or update the Cosmic Vision programme.

Beyond further defining scientific priorities, such strategic vision would provide better visibility on the programme's progress and its impact on the disciplinary fields and their communities. Providing a longer-term perspective, this approach would facilitate international cooperation by identifying and potentially mitigating out-of-phase decision processes as well as duplications.

Continuity of competence and competitiveness in the various and complementary areas of space research is not only ensured by a regular cadence of missions in a variety of frontline research fields, but also by the extension of successful space missions such as SOHO, Mars Express or Cluster. **The committee highlights ESA's efficient approach to increasing the science return over investment ratio via mission extensions.** Through mission extensions, new ideas, new partnerships and new synergies with (complementary) missions can bring new life to ageing mission concepts and eventually result in valuable new knowledge. For example, the partnership of SOHO with Stereo and SDO or the new opportunities for Mars Express to operate in concert with Maven or TGO demonstrate that, through efficient coordination, multiple missions can produce qualitatively different and often better science.

Overall, different possibilities to enhance the scientific return on the investment in space missions include:

- '2nd life' of satellites after the nominal or even real end of the mission (nominal + extension) for new and/or updated science objectives,
- Envisage different science objectives (and corresponding payload) for the extension phase of the mission (once the primary mission objectives of the mission are completed), as early as during the preparation of the mission.
- The possibility to add components (payload) on a satellite for activities that are trans-programme,

- Cubesats opportunities: While they seem to be better suited to national agencies or even individual institutes and university groups, there is still a broad interest in scientific applications: Astronomy, Solar System exploration, Earth Observation technology developments etc. There is indeed a wide variety of possible usages: while smaller agencies could mainly make use of Cubesats as independent satellites, ESA could consider adding Cubesats as student-probes, or as sacrificial engines (in dangerous high risk environments). Also, the concept of fleets of Cubesats could require ESA as mission operator,

The ESSC recommends that such possibilities to increasing the scientific return on missions after nominal completion be considered as early as mission definition and design.

Level of Resources request

The ESSC recognises the need to provide the mandatory science programme with adequate means for the continuation of successful exploration *en route* and to allow for the forecasted new possibilities to be offered to the science community.

The ESSC notes that the level of resources requested in the mandatory programme proposal (increase of 2% on top of constant purchasing power) is fully consistent with its successful furtherance and ambitions. The Committee recommends that the Member States fully subscribe to the budget requested.

Undersubscription will inevitably impact the programme in a negative way and would prevent the inclusion of new and exciting concepts and fast missions.

The ESSC highlights that strengthening the level of control on the expected cost and schedule of missions, in particular during the study phases, would permit better management of the (financial) risk associated with any given mission and eventually protect the mandatory programme and its outcomes.

The ESSC views the preliminary cost and technology assessment of M missions as a good way to optimise efficiency during the proposal and selection process. Indeed, assessing the programmatic feasibility of a mission is essential in preventing cost overruns and other damaging impacts on the overall programme and its cadence.

The ESSC supports the programmatic and feasibility pre-assessment of proposals submitted in response to a call; however, it recommends that the preliminary cost and technology assessment procedure be made more transparent and more independent and encourages ESA to pursue a more interactive approach to ensure that all stakeholders involved are convinced of the robustness of the process and produce better proposals in follow-up calls.

5. ESSC Positions and recommendations on the ESA E3P proposal

5.1. The Envelope Approach

A coherent programme design

The new approach to addressing human and robotic exploration in the same programme is ground-breaking.

The ESSC strongly supports the concept of an envelope programme for European robotic exploration and human spaceflight in LEO and beyond. The ESSC particularly welcomes the coherent long(er)-term vision of the E3P approach, as it is forward-looking, integrative, adaptive and well balanced.

The envelope approach should mean getting the most out of each individual programmatic element and help to make E3P a highly competitive programme overall on the international scene.

The precedent was set with the introduction of the Earth Observation Envelope Programme (EOEP) in 2000; over its successive phases, the EOEP has been a robust and flexible backbone for European Earth science, whilst providing scope beyond its main envelope for nation-led collaborative ventures with ESA.

The various science-orientated programmatic elements (ISS exploitation, ExoMars, SciSpacE and ExPeRT) would benefit from the increased flexibility and adaptability offered by the E3P approach by:

- reaping benefits from potential synergies appearing during programme execution,
- acquiring more flexibility for the ESA in managing E3P, including financial flexibility
- gaining improved efficiency in ESA management,
- strengthening the position and visibility of exploration within the overall ESA Programme

Integrating and organising them, the envelope approach should provide maximum return on investment for each individual programmatic element and contribute to making E3P a highly competitive programme overall on the international scene.

Furthermore, this approach will enable countries not historically involved in the full spectrum of activities covered by the E3P proposal to engage in all programmatic elements, thus expanding the human spaceflight footprint and robotic exploration in Europe.

A programme for science and exploration

The ESA exploration strategy [3] is well reflected in the E3P proposal. Overall, the programme proposed is well balanced in terms of scientific content, as well as in science, technology and exploration-driven activities.

The programme proposed builds on current strengths and big successes and coherently connects the continued efforts on ISS with a promising exploration programme going from the Moon (including CisLunar Space) to Mars (and its moons). In effect, its coordinated approach bridges the gap between the current status and the future, when human and robotic exploration of our nearby Solar System will be further interlinked. As proposed, in the long term the E3P will contribute greatly to three priority scientific objectives: (a) sample return from Mars, (b) human presence beyond LEO and (c) exploitation of the space environment for fundamental scientific research and societal benefit on earth.

Fig. 9: The European Columbus laboratory visible in the reflection of ESA Astronaut Luca Parmitano's helmet. (Credit ESA)

Being science- and technology-driven, the European Exploration Envelope Programme is likely to deliver world-leading scientific return and keep the European community on a firm internationally competitive footing.

The implementation of the E3P programme should be supported by a clear and ambitious data strategy. Although this aspect cuts across all ESA scientific programmes, adopting a ground-breaking approach for human spaceflight and robotic exploration presents a unique opportunity to innovate on the issues of data longevity, access and proprietary periods. The ESSC recommends that a novel data policy be implemented in the E3P programme. Such a policy should be discussed and designed with input from all stakeholders and interested communities (beyond the traditional microgravity, radiation and exploration communities).

An appropriate request for resources

The ESSC notes that the level of resources requested in the programme proposal is fully consistent with the ambitions it carries. The requested funding should permit implementation of the scientific and technology-driven elements of the programme proposed while providing adequate resources to plan and properly prepare for future achievements.

There is no apparent leeway – any overruns, overspends or under-subscriptions would seriously impact the E3P programme delivery and scientific return.

The ESSC therefore recommends that the participating Member States subscribe to the E3P at the level of resources requested in the programme proposal.

The ESSC notes the considerable differences between the E3P seven elements budgets and acknowledges the fact that these elements all have a different budgetary critical mass. As a consequence, the leverage effect of budgetary decision differs substantially from one element to another and individual elements may be impacted by events and/or decisions that are independent of them. Therefore, programme prioritisation and budget arbitration (e.g. in the case of under-subscription) may result in significant impact on the viability of individual elements and therefore on the overall programme coherence and consistency.

The ESSC recommends that the overall programmatic balance, philosophy and diversity (at programme completion) be preserved; in this context the interplay of budget decisions and their consequences should be carefully considered. The ESSC also recommends that budgetary decisions on any of the science-orientated programmatic elements be governed by scientific excellence based on a transparent and independent (peer) review process, as is expected of a science-led programme.

5.2. SciSpacE - Science in Space Environment

The ELIPS heritage

The SciSpacE element puts European exploitation of space environments (radiation and microgravity conditions) in a connected state and on a firm world-competitive footing. It builds on the strengths and outstanding successes of the ELIPS programme across all research domains exploiting space and ground infrastructures.

In order to facilitate achievement of the SciSpacE ambitions, the ESSC supports the ISS Extension to 2024 and the two long-duration ESA astronaut missions proposed in the E3P programme.

The ELIPS programme was very successful in optimising the European share in the ISS programme while also providing access to very high quality ground infrastructure and suborbital platforms. Through the provision and exploitation of a coherent set of research infrastructures, ELIPS enabled European scientists to be world-leading in the research domains covered by the programme. Furthermore, European astronaut flights drew massive attention from the general public; efforts in education and outreach should be pursued.

A novel and balanced approach

The SciSpacE element is well integrated within the ambitions of the E3P programme. The ESSC recognises that, if supported at the adequate level, it will become a strong and leading pillar of this programme.

The ESSC welcomes the balanced share of experiments within the proposed SciSpacE (1/3 application orientated, 1/3 exploration orientated and 1/3 fundamental research) and strongly recommends that this balance be kept as a bottom line and guiding principle in the years to come.

Preserving such a balance may require dedicated competitive call topics with dedicated funding and an adapted infrastructure strategy for each.

By making SciSpacE one of the elements of an integrated human and robotic exploration programme also aimed at exploring space beyond LEO, European researchers in fundamental science and basic life and physical sciences will have the opportunity to access novel space environments and conditions (duration, microgravity quality, radiation environment). **Bringing new horizons for space and physical sciences in space, this is certainly considered by ESSC as a novelty in the ESA programmatic landscape and one of the strengths and added values of the E3P programme.**

In this context, the ESSC strongly recommends to start preparing for the future and in particular for the post-ISS era. It would be sensible to develop prioritised scientific roadmaps that will take into account key scientific challenges and objectives as well as the platforms (including commercial) and technology required to meet these.

Such prioritised roadmaps would then represent a backbone for the SciSpacE element as well as a programme implementation and management tool. SciSpacE being science-led, it is critical that these prioritised roadmaps be defined in an independent and transparent manner with the active contribution and participation of the European scientific community at large.

Science for Earth

The SciSpacE element clearly links space research to the Global Goals for Sustainable Development adopted by the United Nations in 2015. This is a good illustration of the positive impact space research can have on Earth's population and ecosystems. Exploiting this link represents a new and potentially efficient opportunity to foster exchange of knowledge as well as to widen the community of investigators and final users benefiting from ESA investment in space. It is seen by ESSC as a good way to initiate collaborations with teams, educators, institutions and companies not historically interested or involved in research in space environment. Finally, the linking of SciSpacE also provides a structuring element that will help ESA in reporting on the societal impact of the research it funds.

Bridging the past with the future

The ESSC notes that currently 152 experiments have been selected by ESA for implementation in the ELIPS (and successor) programme. These experiments (2/3 for the ISS and 1/3 for other platforms) were all peer-reviewed and selected based on their scientific excellence, and significant work and investment has been dedicated to them.

In order to reap the full scientific benefits of the efforts and investment made in ELIPS, as well as to maintain the knowledge capitalisation and transfer processes, the ESSC recommends that all possible effort be made to implement the experiments currently in the pool, ensuring continuity of the programme.

Besides the implementation of experiments already in the pool, the ESSC is concerned by the lack of a SciSpacE Announcement of Opportunity in the period covered by the E3P proposals. This is seen as a block to exploiting new and promising ideas and to seeing new groups emerging (e.g. via the Topical Team scheme).

The ESSC recommends that an Announcement of Opportunity be issued in the E3P period and that the Topical Team scheme (as a vector to define, develop and mature new innovative concepts) should be continued.

If both the completion of the current pool experiments and the opening of a new Announcement of Opportunity is not achievable, **the ESSC recommends that the current pool be independently assessed for its excellence against the priorities identified, investments made and expected science return listed in the roadmaps mentioned above.** Should the critical review of the pool result in the de-selection or re-scaling of some experiments, this could then potentially open the way for a new Announcement of Opportunity.

5.3. Exploration

Mars

ExoMars is the first astrobiology programme to the red planet and an important milestone in performing science operations on the Martian surface. The 2016 mission has witnessed the impeccable orbit insertion of the Trace Gas Orbiter (in October 2016) and the entry and descent phases - but not a successful landing - of the Schiaparelli module.

The ESSC is convinced that both missions (2016 TGO and 2020) will produce exciting and excellent new world-class science. The postponement of ExoMars 2018 to 2020 is fully understood and appreciated by ESSC; the rationales and justifications given by the Tiger Team are sound.

The ESSC commends ESA, and in particular ESOC, for the successful injection of the ExoMars Trace Gas Orbiter (TGO) into Martian orbit on October 19, 2016. The Committee is also convinced that the data collected by the sensors and studied in terms of the loss of the Schiaparelli lander during its landing will allow Europe to further develop its knowledge of Entry, Descent and Landing (EDL) systems for the future 2020 mission. In fact, from recent information acquired, it seems clear that ESA and Thales Alenia Space have validated the entry and descent phases, and that only the landing phase on an airless body has failed. The technologies used for entry and descent are therefore mastered with a real gain in competences. ESSC also notes that ESA has already achieved a successful landing on Titan with the Huygens probe in 2005. **In spite of the mishap with the Schiaparelli element, the Committee highlights the strategic requirement for European non-dependence to continue developing Europe's capability in EDM technology, building on lessons learned from the 2016 EDM failed last stage.**

The European scientific community is committed, engaged and involved in making ExoMars 2020 a true success and a landmark in the European space exploration history.

The ESSC considers it critical that funding decisions be made during ESA Ministerial Council 2016 to remove any remaining uncertainty on the mission implementation. It urges participating Member States to fully fund the 2016 TGO operations and the ExoMars 2020 mission.

***Mars Sample Return* is definitively considered by the ESSC to be a longer-term investment, with the highest value in scientific, technological and cooperation levels.**

Europe should try to keep on track and contribute its core technology and science approaches, finding appropriate partnerships in order to be a major player in such an endeavour.

Although Mars Sample Return and *Phobos Sample Return* missions are very different, the latter would be an important test case for the final preparation of MSR. Both missions are expected to produce a very high level of scientific output in combination with technological capability advancement. Phobos SR builds upon recognised Roscosmos experience and provides a solid cornerstone for further Mars exploration endeavours. ESA should also seek support for Phase A/B studies of the proposed Phobos Sample Return and *Lunar Polar Sample Return* missions (also in collaboration with Russia). These are key elements of ESA's developing exploration strategy, and are fully consistent with the aims and aspirations of the ISECG Global Exploration Roadmap [4]. **In addition, and also in the spirit of the Global Exploration Roadmap, the ESSC suggests that ESA explore additional opportunities for international cooperation in the field of space exploration (for example with China, India, Japan and the United States).**

The ESSC emphasises the great scientific value of programmes that will prepare and position the European Planetary Science community at the forefront of sample *curation*, data exploitation and archiving in relation to future sample return missions from the moons, asteroids and Mars. Due to the complexity of technological requirements and the mandatory involvement of different international and national regulatory institutions and the general public, a necessary step for a Mars sample return mission is the timely design, building and commissioning of a sample receiving facility.

The ESSC strongly supports further development of the *MREP-2* programme as it can provide the technologies necessary for Europe to play a major role in the future sample return programme, with the ultimate goal of Mars Sample Return including the timely design, building and commissioning of sample receiving and curation facilities.

Moon

The continuity between Rosetta, ExoMars and Luna Resource Lander in fostering specific European technology and science elements (precise and safe landing, end-to-end sampling including drilling) is considered a sustainable and efficient approach by the ESSC. Although Luna Resource Lander is a technology-driven mission, the ESSC is convinced that valuable science can be achieved through this cooperation. The Committee recommends that the mission's detailed and achievable scientific objectives be discussed and defined with the scientific community.

The ESSC supports efforts by the ESA Executive to secure funding for Europe's continued participation in the Luna-Resource and Luna Glob missions. These, along with the proposed Lunar Polar Sample Return (and Phobos Sample Return) mission with Russia should be an integral part of ESA's wider exploration strategy.

The ESSC also recommends widening collaboration in this area to include other international partners with expertise in lunar and other small body exploration, in the spirit of the recently formulated Global Exploration Roadmap.

As for the new concept of the Moon Village, the ESSC considers that the science return, the cost and trade-offs of such an ambitious project should be better defined and discussed with the scientific community before the value of such a project *vis a vis* others can be evaluated.

ExPeRT

The approach proposed in the Exploration Preparation, Research and Technology (ExPeRT) element is considered valid and promising in providing a coherent longer-term planning, well integrated and incorporated into the broader human space and robotic exploration programme.

The mission studies proposed in this part of the financial envelope, regarding Mars Sample return and Phobos Sample return, as well as in general technology preparation for both robotic and human missions, are essential for the successful development of the programme.

Although the named missions have not yet been fully committed to by national representatives and ESA, such a mission-driven approach will better focus resources and streamline cooperation aspects between the new technologies required. It also represents a sensible approach to gain momentum and prepare decisions to be taken at the next ESA Ministerial Council.

6. ESSC Positions and recommendations on the ESA Earth Observation programme proposal

The ESSC commends the achievements of the ESA Earth Observation programme as well as its coherency and consistency. This programme has delivered a large number of original and ambitious missions, including the unique *Copernicus Sentinel Satellites* that produce excellent data for scientific research. Moreover, there is a large number of Earth Explorers and Sentinels in the pipeline.

The community of users of ESA EO data is growing strongly. This has resulted, for example, in a record number of abstracts and participants at the ESA Living Planet Symposium in Prague in 2016.

The EOEP-5 programme is built upon the success of previous programmes. With the launch of the Sentinels 1A/B, 2A and 3A, an important part of the unique Copernicus space component has been achieved, and with Sentinels 2B and 3B and EOEP-5 in the pipeline, the stability of the programme is secure with data acquisition until 2030 and beyond.

The ESSC therefore strongly endorses the EOEP-5 envelope programme and recommends that it be fully supported by the EOEP Member States.

Several of the societal challenges that the EO programme addresses, including climate change, require high-quality long-term datasets. The strategy to continue the observations developed in the EOEP Copernicus programme, to derive *Essential Climate Variable (ECV)* data sets, is therefore very important. Because the satellite time series often span more than one mission, special attention has to be given to calibration and validation (CAL/VAL), to the development and evolution of the ECV datasets and to long-term data preservation.

CAL/VAL is an essential activity in assessing the quality of the EO data products and long-term data records. For Earth Explorers, CAL/VAL is usually started through campaign activities, whereas for Sentinels, continuous and timely validation data should be available throughout the lifetime of the missions. CAL/VAL often relies on scientific networks of instruments of which several have been under threat in recent years. The CAL/VAL activities for Earth Explorers is addressed by EOEP-5. In the Long-Term Data Preservation, CAL/VAL activities are also an important component for delivering high-quality ECVs.

For Sentinels, the ESSC recommends that ESA discuss the bottlenecks for validation of the Sentinel Satellites with the European Commission in order to come to a sustainable programme covering all scientific and operational requirements.

The *ECV (CCI)* programme has been extremely successful and several of the developed algorithms have been transferred to the Copernicus Climate Changes Service (C3S) programme for large-scale production of ECV data sets. The CCI+ programme extends this with new ECVs and further development of specific aspects of ECVs developed in the CCI programme. In addition to developing new ECVs we recommend sustained funding for further development of the CCI ECVs, which will allow for continuous improvements of the data sets and to extend the ECVs with data from new missions.

The ESA Earth Observation programme is producing very large data sets. In addition to improving fast, reliable and easy access to Level 1, Level 2 and higher level data products, new platforms should also be created where users can directly interact with the data sets. **'Bringing the users to the data, instead of the data to the users' is an important concept that is part of EOEP-5, and the ESSC supports this approach.** Such platforms will increase usage of the data and will attract new users from outside the traditional communities. All EO data should become part of these platforms, including all the Earth Watch data.

The ESSC recommends implementing these platforms as a continuous activity that starts small but with a scalable design. Furthermore, users should be actively involved from the beginning in the development of the platforms.

The observation of long-lived greenhouse gases, such as CO_2 and CH_4, is very important in understanding the main drivers of climate change. Whereas CH_4 will be measured by Sentinel 5 Precursor and Sentinel 5, there is currently no European mission in development for observing CO_2 with the required accuracy. Because of the long-lived nature of CO_2 in the atmosphere, the requirements are extremely challenging. Therefore, the observing system should consist of a combination of ground-based and space-borne observations. We recommend using the existing GOSAT and OCO-2 data to develop scientifically mature algorithms and methods, and to further study the observational requirements.

For implementing a Sentinel CO_2 precursor around 2025, the ESSC recommends developing a small mission to demonstrate the technology.

Experience from GOSAT and OCO-2 shows that scattering particles by aerosol is a leading source of uncertainty for the CO_2 observations. It is therefore recommended to fly such a small mission in (loose) formation with a mission that contains a dedicated aerosol instrument.

The Altius mission in the Earth Watch programme is important for the continuation of occultation and limb measurements of the stratosphere, which has been identified in several gap analyses. Because of the urgency of the stratospheric observations, the ESSC recommends following the timeline with a delivery in 2020 and actively investigating a launch opportunity.

With the increasing CO_2 levels in the atmosphere, we may encounter unforeseen processes in the climate system, for which observations from space are urgently needed. On the other hand, the development time of satellite missions is usually more than 10 years. For rapid response to observational needs, this development time should be reduced significantly.

ESSC therefore recommends designing a strategy for developing satellite missions in less than five years and demonstrating this strategy using micro satellites and/or high-altitude platforms.

The Earth Watch Altius mission could serve as a demonstrator; in addition, the HAP (High Altitude Platform) developments in EOEP-5 could have rapid response as an objective.

7. ESSC Positions and recommendations on ESA Space Situational Awareness programme proposal

7.1. Space weather

In the last two decades the awareness of the scientific community, and in turn of society, of the significant impact of solar activity on the heliospheric as well as earth's environment has greatly increased, thanks to the continuous monitoring of the Sun and the unprecedented sensitivity of the coronagraphs operating on board the Solar and Heliospheric Observatory (SOHO), the first European space solar observatory. Such observations have permitted the identification of sources of high and low speed solar wind streams that continuously sweep the heliosphere and have given us an opportunity to relate the solar activity phenomena to their effects on the near-earth space environment. This has given a new name to this new applied science 'Space Weather' (SW), i.e., 'meteorology of space'.

ESA and NASA are contributing to the future developments of the underlying science in this field with two major future missions: Solar Orbiter and Solar Probe Plus which will share phases of simultaneous operations. These challenging missions are, however, mainly aimed at advancing the science underlying the understanding of solar and space weather and will not be able to permanently monitor the Sun and its atmosphere, which would be needed for SW forecasts. Future perspectives to renew the ageing fleet of space-based instrumentation, dedicated to monitoring solar activity and the corona, are at the moment mainly in the programmes of countries such as India and China, which are envisaging a clear path of SW missions. New monitoring missions to ensure SW coverage at L1 are being prepared by NASA and NOAA with clear roles and responsibilities for these two agencies. Internationally, SW activities are loosely coordinated in the framework of the COSPAR space weather roadmap.

Both particle and electromagnetic radiation emerging from solar activity have significant effects on the extravehicular activity of astronauts and in the perspective of human exploration of the solar system. Particle radiation has effects also on space systems and star trackers and electromagnetic radiation, for instance on the signal transmission through the ionosphere. The impact of a coronal mass ejection, containing strong magnetic fields and a huge amount of energetic plasma and hitting the earth's magnetosphere at 1,000-3,000 km/sec, produces a violent perturbation of the earth's magnetosphere and induces large current systems. These can, for instance, damage power-network transformers and significantly increase electro-corrosion in oil pipelines.

Ironically, the more dependent our civilisation becomes on the availability of navigation, Internet, and other modern amenities, the more vulnerable we are becoming to what occurs in space. Improving our understanding of these effects and improving our resilience to them is thus crucial to modern society. Consider, for example, the case of driverless electric cars and the resulting chaos should communication and navigation be lost for even a few seconds. **Prediction of space weather, therefore, must be made to allow engineering solutions on earth, as well as to predict or forecast short-term effects and to issue reliable warnings.**

ESSC recommends that in order to safeguard the European technological systems in space and on the ground, and in order to ensure the highest level of safety for human flight and exploratory human missions, Europe and ESA cooperate and participate in the global/international development of a coordinated and robust space system of sun-heliosphere monitoring, in order to acquire exhaustive real-time data sets and improve space weather understanding and predictions.

These data together with insights from the basic science missions will be essential to improving our understanding of the physics behind space weather and its effects not only on the earth and human society, but also on planned extravehicular activity and human exploration of the solar system.

Planetary space weather studies have already commenced and are exploited in view of such an endeavour.

These data are furthermore important in order to feed the various operational space weather segments, which are under development within the Space Situational Awareness programme of ESA. The production of reliable forecasting and now-casting tools will become important to protect the technological systems, to plan extravehicular activity and to carry out human space exploration missions.

ESSC recommends that Europe participate in the global space weather monitoring effort by providing a spacecraft system composed of two or three elements, strategically distributed in space, to monitor solar activity, solar eruptions, and their effects on earth.

As spelled out in the SSA plan for period three, this can be accomplished by a European mission to either L1 or L5 (depending on the plans of other participating agencies) and hosted payloads on suitable missions to observe the sun, solar wind and the near-earth geospace. This idea of a mission to L1 or L5 is excellent, but it needs to be aligned with other global activities if it is to be the most effective and be able to position Europe as an important partner on the international scene.

In this scenario, the ISS and other existing spacecraft could also play a role by providing critical high-energy particle monitoring if the radiation monitoring data became publically available.

The ESSC recommends that the "space weather enabling science" be preferably part of the science directorate activities within the normal background of the Cosmic Vision programme and in competition with other fields, based on scientific excellence.

In contrast, the 'space weather monitoring', i.e. 24/7 missions observing the sun, the heliosphere between sun and earth and the terrestrial magnetosphere and ionosphere, should rather be carried out within the ESA SSA programme in collaboration with interested and capable member-states (in an optional programme), providing the necessary and mature hardware for such missions. ESSC would like to see that ESA SSA programmes and activities on mission and payloads are closely matched to the global plan for space weather activities, as also formulated in the recent COSPAR ILWS Roadmap for Space Weather [5].

When it comes to predictive services and a value added combination of space weather data for European end-user needs, **ESSC highlights that a broader European approach should be handled by the EU within the H2020 programme.** An optional ESA programme can by definition neither embrace, involve, nor cater for all European interests and needs.

ESSC also points out that many of the required and outlined predicting activities are still in urgent need of a better scientific understanding of space weather processes. The ESA science programme, the SSA programme (and even the EU H2020 programme) should enable the scientific use of present day scientific missions for such directed 'space weather enabling research', also in preparation for future scientific and monitoring missions.

7.2. Near Earth Objects

The near-earth space harbours natural near-earth objects (NEOs) in their voyages through the inner Solar System, and space-debris objects (SDOs), which are leftovers from artificial earth-orbiting satellites. Both NEOs and SDOs pose a threat to humans and our space-based and ground-based assets. From a purely scientific point of view the primitive NEOs are also most interesting targets for exploration, as they contain key information on chemical and physical processes pertaining to the early solar system.

The NEO population is composed of asteroids and comets, in proportions varying as a function of size. Towards the smaller sizes (km-size and smaller), the asteroid component is increasingly dominant, originating from the main belt of asteroids between the planets Mars and Jupiter. These NEOs have typical lifetimes of less than a few tens of millions of years, and are removed from the population by impacts and/or close approaches to the sun, injection into hyperbolic orbits by gravitational interactions with Jupiter, and impacts with terrestrial planets - in particular, the earth.

Towards the larger sizes (10-km size and larger), the long-period comet component becomes dominant, originating in the Oort cloud, a region located in the distant space between the sun and the nearest neighbouring stars. It is widely agreed that the most significant impact-hazard comes from earth-crossing asteroids, whereas more rare but even more severe catastrophes are caused by the cometary component.

The SDO population is composed of objects varying in size from the mm-scale to the 10-m scale. The numerous small SDOs are primarily debris from satellite-satellite or debris-satellite collisions, whereas the large SDOs are defunct satellites. Whereas the SDO population is diminished by the shrinking orbits, resulting in SDOs being destroyed during atmospheric re-entry, the population is constantly replenished by collisions among its members. It is widely agreed that the increasing SDO population poses a threat to the human space-based assets and sets challenges in finding safe launch windows for new missions (even un-controlled Cubesats will contribute to SDOs - see above).

In addition to the two main considerations given above (i.e. impact hazard, science), the NEOs also constitute possible valuable future mineral resources that are relatively easily accessible because of the low relative velocity difference between the earth and many of the NEOs. It is, however, evident that measures must be taken to minimise, beforehand, the chances for any mining mishaps or other unintentional activity resulting in impact threats on the earth.

ESSC recommends focused research on the physical and chemical properties of NEOs and SDOs in the near-earth space, increasing our knowledge-based preparedness for mitigating the threats posed by these objects. An increased understanding of science and resource potential of NEOs as a result of these investigations would be an added benefit.

8. Transversal issues

8.1. Data archiving, exploitation and dissemination

Data dissemination, exploitation, and long-term conservation are well-recognised issues of critical importance for the scientific community.

There are different data management approaches across the various ESA programmes.

The ESSC strongly recommends that data produced by all ESA missions be made openly available in a fast and efficient way; a cross-directorate data policy should be established.

Investing in novel solutions for data usage is an important priority, especially for the data intensive Sentinel mission. ('Bringing the user to the data, instead of the data to the user'). This has the potential to increase scientific data usage and for applications.

The same holds for the Earthnet and LTDP (Long-Term Data Preservation) programmes that are also proposed in the framework of the level of resources of the general budget.

Greater consideration should be given to the possibility of compiling data from different missions and to recompile available (archived) data.

8.2. Cross-talk between science directorates

It is the ESSC's belief that enhanced consultation and discussion among different ESA science directorates would be beneficial to all parties and in particular could have a positive effect on scientific and financial optimisation. For the former (science), bringing life, physical and planetary sciences around common themes (like radiation, astrobiology and studies of extremophiles) could generate, among other things, new ideas and more efficient interpretation of data. For the latter (budget), learning from successful approaches and financial aspects in one directory, applied to a different one, could only be positive. In addition, sharing vehicles for cross-cutting science or technology objectives would be a positive and optimised use of the budget.

8.3. Relations with EC and Horizon 2020 programme

Some benefit 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 2020 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 (e.g. Met. Offices).
- Considering the relevance of life science research in space to contemporary health issues (e.g. ageing) the Horizon 2020 Health programme and E3P SciSpacE elements should envisage stronger interactions. Likewise for 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 2020.
- 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.

The ESSC highlights that these areas of common relevance between ESA and EU 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.

In this context, the ESSC warmly welcomes the recent 'Joint Statement on Shared Vision and Goals for the Future of European Space' [6] between ESA and the European Commissioner on 26 October 2016. This statement, signed in conjunction - and in line - with the presentation of the new European Commission Space Strategy for Europe [7]:

- acknowledges European *successes from breakthrough science and exploration missions,*
- envisages *fostering a globally competitive European space sector by supporting research, innovation, entrepreneurship*
- addresses the need for *European autonomy in accessing and using space in a safe and secure environment, and in particular to consolidate and protect its infrastructures*

It concludes that common ESA-EC goals *should rest on the solid foundation of excellence in science, technology and applications, expressed through an environment of outstanding education and skills and a thorough knowledge base.* This statement is fully consistent with the ESSC contribution to the European Space Strategy discussion [8].

The ESSC highlights that this joint statement should be used as a basis for a stronger European space sector. It urges Member States not to underestimate the relevance and importance of space science and space research in achieving the objectives and goals announced for earth observations and space exploration.

8.4. International collaboration and competition aspects

There is strong consensus on the importance of international cooperation in space missions as providing both potential and often very concrete benefits to the participants. Furthermore, the current economic situation everywhere in the world does not allow for duplication of efforts and waste of resources and instead encourages combining means and manpower behind large- or medium-sized space missions and activities. 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.

There are many examples where international collaboration has been critical to mission success: the Cassini-Huygens mission is still delivering amazing results to date, having started and evolved as a very successful collaboration among ESA, ASI and NASA. This is a large mission that has delivered to date 3,616 science papers, involved 27 nations and, perhaps even more importantly, was the research basis for more than 200 PhDs. Space programmes like HST, Hayabusa, Planck, Herschel, SOHO, Hinode and LISA, as well as ground-based programmes that come in support of space missions (like ALMA, for instance) 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 exploration landscape by developing and operating ESA-led missions. At the same time, the current portfolio in ESA's programme contains a large number of missions and concept studies that are performed in collaboration with other space agencies, essentially NASA but also JAXA and CAS. 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.

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 on board 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 Europa mission study.

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. Mission of Opportunity possibilities 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 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 collaborations 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 actively pursue 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 science community also urges ESA to envisage scientific exchanges and discussions with potential partners at the beginning of a mission definition phase so as to ensure an optimised return on the mission within a bottom-up approach. This could lead to optimisation of the science return.

In a situation where a mission selected by a foreign agency overlaps with strong interest from European scientists, ESA should facilitate and promote the participation of European laboratories in that mission. The possibility for a sharing of the financial burden could also be discussed after the selection of a space mission either by ESA or by a foreign agency.

Scientific conferences, meetings, symposia and more targeted communication between scientists from all over the world have the potential to help ESA and its international partners identify avenues for collaboration and strengthen ties. Strengthening networks and exchange of knowledge would lead to improved foresight studies that can feed into sound roadmaps and eventually increase the robustness of international collaboration.

8.5. Space technology and relations with European industry

In space science, as well as in 'mainstream' science, the development of innovative technologies is of the utmost importance as it opens new fields of research and provides sophisticated new tools for scientists. However, the experience of the past decades of space research has demonstrated that a conservative approach to technology is too often followed, due for instance to the very long development times in that domain. As a result, ESA may have to deal with obsolete technologies in a fast developing field, losing competitiveness and leadership, while Europe looks to ESA for innovation in space.

A way of removing blocking factors and enabling scientific breakthroughs in space could be spinning-in advanced technologies that are not developed for space. Improving the situation therefore requires the development of synergies between space and non-space technologies. For this purpose, it seems important to make use of the classification of thematic disciplines outside the space sector under the broad headings of 'Key Enabling Technologies (KETs)', as identified in 2009 by the European Commission, and in particular Nanotechnology, Micro- and Nano-electronics, Photonics, Advanced materials and Biotechnology. These KETs are indeed expected to be the driving forces behind future European developments. Other areas critical to space, e.g. energy, robotics, biomimetics, or advanced propulsion, should also be included. The infusion of the best technologies to achieve scientific breakthroughs requires interaction between space and non-space communities and the establishment of mutually beneficial partnerships.

The ESSC recommends that ESA continue to work towards a better synergy between space and non-space technology, identifying and putting forward best practices and promising technology transfer mechanisms in both sectors, through a combined effort by interested parties in ESA, Member States and the EU.

In a recently concluded foresight exercise commissioned to the ESF by ESA [9], the identification of technological problems and solutions specific to the space area led to a focus of the discussion around the concept of 'Overwhelming Drivers' for space research and exploration, i.e. long-term goals that can be transposed into technological development objectives. The Drivers suggested in this study are (1) Reduce mass, maintain stiffness; (2) Build a spacecraft that can last 50 years; (3) Deploy a 30m+ telescope into space; (4) Autonomous geophysical survey of planets; (5) Enable humans to stay in space for more than two years.

The ESSC recommends using stable and ambitious technology 'Overwhelming Drivers' throughout ESA's Directorates as a novel categorisation of programme concepts and useful common strategy to guide reflection on future missions and related technological maturation.

The ESSC also recommends further identifying and developing technologies that will be critical for future scientific missions, using a bottom-up approach (with direct input from the scientific community) and strongly connected to the long-term strategic planning. Such technologies could include large deployable mirrors, flight formation, IR detectors, nuclear power generation, laser metrology, coronagraphy, remote sensing magnetography or novel sterilisation techniques.

As to (contractual) relations with the industry, several space missions have recently suffered from delays in completion due to test failures or other technical problems. The science community feels that industrial partners should assume their share of responsibility so that the overruns in delays and hence in cost and science reduction do not affect ESA alone.

In order to keep control over the risks of financial cost and science loss in a period of mission development, the ESSC recommends that ESA be vigilant in its relationships with industrial partners in order to appropriately share the risk between contractual partners.

9. Concluding statement

In order for Europe to maintain and enhance its position as a key player in the international space arena, to be competitive via excellent scientific and technological achievements and to maximise the return on investment into European society, economy and education, ESA needs to receive full support from its Member States at the Level of Resources requested on the occasion of the Lucerne 2016 Ministerial Council meeting.

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