European Space Sciences Committee

REPORT AND RECOMMENDATIONS TO THE EUROPEAN SPACE AGENCY MINISTERIAL COUNCIL 2022

"On a finite planet, only human ingenuity is unbounded"

Observations from space and access to space in a safe and reliable manner have never been more important. At a time of growing global complexity and daunting societal and environmental challenges, knowledge from the vantage point of space underpins key capabilities as well as evidence-based and reasoned decision-making. It attracts, inspires, and motivates new generations of engineers and scientists on their journeys of discovery and exploration. Meanwhile, humanity is at the threshold of an historic new era; the establishment of a permanent presence off-planet, extending from Low Earth Orbit to the Moon and Mars. Those nations that lead in this endeavour will reap the greatest benefits. Europe is privileged to host the European Space Agency (ESA), which for nearly five decades has been a world leader advancing the cutting-edge of space science and technology. In our role as a representative voice of the European space sciences community, we strongly endorse the science-related programme proposals submitted to the CM22 delegations. However, we wish to express deep concern at the financial outlook for the mandatory science programme. Declining purchasing power threatens harsh consequences for the scale, scope and overall coherence of the programme relative to plans, needs, capabilities and ambitions, especially in the longer term. We note too that any reduction of the optional programmes would have disproportionate impacts, given their tightly integrated natures. Coupled with the effects of European reliance on international partnerships that are now cancelled, the health of the European space-based scientific enterprise is at risk. Notwithstanding these caveats, the proposed package of activities offers the means for Europe to take its next steps as a leading spacefaring entity, reinforcing the foundations already established to contribute to an intellectually vibrant, well-governed, and prosperous European society. Our strong recommendation is that the programme should be supported in full, and that the budget for science should be uplifted at the earliest opportunity.

1 Introduction

The **European Space Sciences Committee** (ESSC) was established in 1974. We strive to be Europe's reference body for independent expertise on matters of space science, acting as a representative voice of the community. As scientists we believe that evidence-based reason lies at the heart of wise decision-making in a healthy and prosperous society. We regard space science as pivotal in opening new fields of scientific, technological, and commercial progress, whilst providing inspiration for all. We consider Europe's impressive history as a world leader in the space arena as the foundation from which, if nurtured and accelerated, even greater accomplishments and rewards will accrue.

1.1 Strengths, Opportunities, Aspirations, Results (SOAR) Analysis

We have studied the ESA programme proposals pertaining to science and have worked with representatives of the European space science community and with ESA to produce the analysis and recommendations provided here. We focus on the scientific **Strengths and Opportunities** of the package, and identify its forward-looking **Aspirations and Results**, whilst offering some **Observations** and specific **Recommendations**.

Through this approach, **we seek to express the community's views**, and to set the ESA programme in the **broader context of its value** for **science**, the benefits to **European society**, and the expediency to sustain and extend **Europe's front-ranking global standing** in the field.

1.2 Key Messages and Recommendations

- ESA has a distinguished track record of world-leading scientific and technological breakthroughs.
- This is especially impressive given the relatively modest size of its budget and the complexity of managing the interests of 22 partners to achieve such technologically challenging goals.
- A pivotal feature since its inception has been a 'science-led' approach, relying at its core on the creative interplay between scientific and technical advances.
- The implementation of the programme has been enabled by a highly effective combination of the skills and efforts of the academic community and industry throughout the member states, and ESA's internal technological and programmatic expertise.
- This has proved to be a potent wellspring of collective success, and a powerful means to stimulate fruitful cooperation across all member states.
- The CM22 proposals comprise a continuation and expansion of the community's ambitions and goals, encompassing fundamental science, the next phase of human and robotic exploration, and crucial inputs to the study and monitoring of the Earth's climate system.
- Recent geopolitical events and their consequences have highlighted the programmatic vulnerabilities of European dependency on the capabilities of other nations for access to space and for key technologies.
- These events, combined with the acceleration of climate change and other environmental impacts, and the demonstrated value of space data in helping manage societal crises such as COVID-19, underscore the necessity to boost European autonomy in critical space systems and future missions.
- Our concern is that budgetary constraints, especially for the mandatory core, will limit the scope and scale of the science programme, and hence its ability to act as a key driver to maintain and develop critical space systems capabilities and future missions, and to deliver their associated cultural, technical and commercial benefits.
- Hence, we strongly encourage financial interventions at the earliest opportunity, and certainly at the next CM, to boost the science programme so that the Voyage 2050 plan can be delivered as envisaged.
- We note too that any reduction of the optional programmes would have disproportionate impacts, given their tightly integrated natures, and so should be resolutely avoided.

- The role of commercialisation in space exploration is an emerging issue, including the extent to which, and mechanisms by which, commercial activities in and beyond Low Earth Orbit (LEO) can and should be both catalysed and regulated to allow the development of positive synergies between the public and private sectors, whilst promoting and protecting the joint interests of science and of society.
- These are pressing issues which require early resolution to ensure that European space activities remain on a firm footing for the future, recognising that at times of geopolitical and economic stress, nations that invest in forward-looking science and technology are better positioned to prosper.
- **With these provisos, we strongly endorse the programme and recommend that it is funded in full.**

Strengths, Opportunities, Aspirations, Results (SOAR)

STRENGTHS

- A legacy of scientific and technical excellence in fundamental and applied space science.
- Wide ranging scope supporting a diverse and intellectually vibrant European space science community.
- Inspirational to new generations of STEM students AND to the general public.
- 'Soft Power' projection makes Europe an attractive destination for scientists and engineers worldwide.
- International partner of choice.
- Through collaboration with the EC, world-leading delivery of services and societal benefit addressing the climate and environmental crises, with flexibility to respond quickly to unanticipated challenges such as the COVID pandemic.

OPPORTUNITIES

- Serve society's urgent need for actionable information to improve the quality of life and wellbeing of European citizens and peoples worldwide.
- Build on established scientific, technological and programmatic expertise and leadership to sustain and enhance future outcomes and prestige.
- Facilitate Europe's transition to a new era of human and robotic space exploration, including active efforts to achieve the optimum balance between public and privately funded enterprise.
- Respond to current geopolitical disruptions to achieve greater European autonomy and resilience in the space arena.

ASPIRATIONS

- To capitalise on established strengths and experience to remain at the forefront.
- To be, and to be recognised as, the most visionary, intellectually vibrant, scientifically, technologically, programmatically competent, and cost-effective global space agency.
- To achieve the optimum balance between the public and private sectors in the developing 'New Space' era.

RESULTS

- High value scientific knowledge, technical know-how and technology capabilities, fostering spin-offs
- Answers to fundamental societal questions about the universe, helping understand biological and physical processes on Earth
- Contributions to the foundations for a prosperous, modern, and vibrant 'evidence-based' society
- Enhanced social capital and offer greater return of investment to Europe
- Excellent results from international partnerships and recognized leadership in key fields.
- Successful climate mitigation and adaptation efforts in Member States
- A sustainable Space European autonomy and sovereignty in all space strategic domains.

2 The ESA Science Programme

"Now is the time to understand more, so that we may fear less."
(*Marie Curie*)

2.1 Strengths

The ESA mandatory Scientific Programme forms the **backbone of the Agency** and of **related activities of the national agencies of the member states**. The programme has a **legacy of scientific and technical excellence** and **leads the world in key areas of space science** with many **historic firsts**, having produced a **cornucopia of new knowledge and understandin**g about the Universe we occupy.

Examples include:

- Pioneering research in studies of the X and gamma-ray sky, opening up new windows on the high energy Universe (EXOSAT, XMM-Newton, INTEGRAL)
- The first ever flyby encounter with a comet (Giotto) and the first cometary soft landing (Rosetta Philae-lander)
- The first landing on Saturn's moon Titan (Cassini-Huygens)
- The mapping and understanding of the primordial cosmic microwave background radiation (Planck)
- Laying foundations of European planetary science via Mars Express and Venus Express
- The pioneering development of space astrometry (Hipparcos) leading to the revolutionary mapping of the three-dimensional structure and evolution of our entire Galaxy (Gaia)
- Advances in understanding of the interaction between our Sun, the surrounding heliosphere and the Earth (Ulysses - which uniquely operated out of the ecliptic, providing a new view of the Sun, SOHO, Cluster, SWARM, Solar Orbiter). These missions together provide Europe's central underpinning of the scientific basis of Space Weather
- The first space-based measurements of stellar seismology and Exoplanet transits (CoRoT) and the Exoplanet observatory CHEOPS, positioning Europe at the forefront of Exoplanet research
- The demonstration of technology enabling a gravitational wave detector in space (LISA pathfinder)
- Frontiers of astronomy (Hubble and James Webb Telescope)

A measure of the **scientific productivity** and **accelerating impact** of the ESA science missions is provided by the ~3,500 directly associated scientific publications in 2021, and the 55% increase over a 5-year period.

The symbiotic relationship between **science 'pull' and technology 'push'** is a fundamental feature of the programme. Exploiting such interplay, whilst at the same time managing the ***'juste retour'*** principle amongst member states to achieve the balanced and **successful delivery** of hugely **technologically challenging missions** is an **unrivalled feat**.

The established **excellence of ESA basic activities** (technology and programmatic development; front-ranking infrastructure such as major test facilities) are **enablers** which provide the foundation on which the programme's scientific success rests.

Several missions in the Programme have been operating for more than twenty years - well beyond their design lifetime, and often serving science not envisaged at the programme outset. **Mission longevity** thus provides an excellent return on investment to the Member States and ensures enduring **long-term scientific continuity and productivity** and **enables new uses of existing resources**.

The programme is **founded on a 'bottom up' basis**, drawing on the expertise of **Europe's world-leading community of space scientists**. This is achieved via the advice and decision-making of the Science Advisory structure, including the **Space Science Advisory Committee (SSAC)** and related **Working Groups**, as well as via input from the community at large. The approach **ensures that the best ideas are identified**, and forges a **unity of purpose** between the European space science community and the Agency.

The community is **world class, numerically large**, and **capable in all aspects** from **transformational instrument development** to the **front-ranking analysis of results**. Its breadth and depth are exemplified by the **nearly 100 diverse and ambitious proposals** submitted in response to the **Voyage 2050** open "call" for ideas. Similar strong responses to Announcements of Opportunity are the normality.

The programme's objectives are fully consistent with the **Voyage 2050** plan, which provides a blueprint for the future. It rests on a **balanced portfolio of Large, Medium and Fast missions**, delivered in a cadence to match previously anticipated funds and technological and programmatic realities. This provides the community with a **clear map** regarding existing commitments, and a **sound understanding of the pathway open for future opportunities**.

It also allows **coherency** with the programmes of other major **national programmes**, such as those of NASA and the Chinese National Space Agency, and the growing community of new nations engaging in the field.

Given the necessary funding, the programme would also be consistent with the '**Exploring the Icy Moons of Jupiter and Saturn Inspirator'** of the **Matosinhos Manifesto,** endorsed by all 22 ESA member states.

The ESA brochure "**Space economy – Creating value for Europe**" (ISBN 978-92-9221- 119-6; ISSN 0250-1589) states that **€1 invested in ESA science missions generates €1.6 in the wider European economy**. A variety of other studies estimate that, over time, investments in space activities generate **even greater multipliers** – with one example[1] concluding that support for ESA programmes can achieve a factor 3-4 return on investment, or even more.

The **"soft power" projection** of the science programme missions contributes to making Europe a **highly attractive destination for scientists and engineers worldwide**. It also creates recognition and **sense of pride amongst European citizens** of the scientific achievements and capabilities of European society. With its achievements and high visibility, the programme plays a key role in continuing to **inspire a flow of students in STEM disciplines**, necessary to ensure a healthy pool of talent and skills to support European academe and industry.

2.2 Opportunities

To **continue at the forefront of fundamental astronomy and astrophysics**, with the **Voyage 2050** ground-breaking L-class missions: to investigate the first instants of our Universe, the observation of the Universe from temperate exoplanets to the Milky Way, and a pioneering venture to study the "Icy moons of the giant planets", which will also **exploit the investments made** in **key technologies** developed by **European industry** for the **JUICE** mission (such as heat and power sources, radiation-tolerant / radiation-hard systems).

To **maintain and enhance Europe's leading role** in the field of **Exoplanet studies**, with missions under preparation such as **PLATO and Ariel** and complemented by access to the ground-breaking NASA-led **James Webb** telescope.

Similarly, the fleet of missions **BepiColumbo, JUICE, EnVision, and Comet Interceptor,** along with the **Rosalind Franklin and Mars Sample Return Missions** being implemented by the Human and Robotic Exploration Directorate, will open up new windows on Solar System bodies, including their evolution, and possibly finding unequivocal evidence of biosignatures on Mars.

To continue making **use of the stream of invaluable data and new science** that the fleet of **operational missions** continue to provide. The ability to maintain such missions, given that the cost savings of termination are marginal, will require careful consideration, especially given the growth of **'multi-mission science'** in which **originally unplanned combinations** of mission data are **opening up new scientific benefits**.

---

[1] https://www.gov.uk/government/news/the-wider-benefits-of-space-investments-for-the-uk-economy

To play an **enhanced role as a 'partner of choice'** in **key missions of the next decades on the international stage**, taking advantage of the excellent **international cooperation** record and the fact that International Flagship missions (especially NASA's) are currently being defined.

To **enhance European autonomy and deliver a more robust and resilient programme,** by taking stock of the **financial and geopolitical challenges** ahead and delivering the necessary financial and programmatic initiatives and optimisations to meet those challenges. The **ENDURE** programme to develop independent European **space-qualified nuclear power sources** provides a key example. Such technology is pivotal for future missions across the Agency that operate at large distances from the Sun or in extended periods of solar night.

To **open up the path** to the challenging scientific missions of Voyage 2050, with the development of **new enabling technologies** (such as cold atom interferometry, X-ray interferometry, cryogenic sampling and return capability and solar sails), together with intermediate technology **demonstrator missions**.

2.3 Aspirations

To **push forward the frontiers of science**, driven by human curiosity and the thirst for new knowledge and understanding, both for their own sake and because **"Today's science is tomorrow's technology, prosperity, wellbeing and power".**

To **provide opportunities** to the scientific community and industrial entities of smaller member states through F mission profiles (smaller, more diverse missions, with the aim of a shorter turnaround from concept to flight), helping to **increase the diversity** of the programme and to **maintain a healthy pool of world class researchers and technologists.** The F1 **Comet interceptor** mission, which builds on ESA's rich history in the field, provides the first example of this new degree of **flexibility**, with a planned launch of 2029.

To **nurture a competitive European commercial space ecosystem**. Commercial space is a reality, and a transformation is taking place in the way traditional space operates across the world. The definition of an ESA-wide **approach to commercialization** is timely and necessary.

To establish **European autonomy** in key technological areas. This is a paramount objective given recent examples of vulnerability to dependence on international collaborations for space access and other capabilities.

2.4 Results

New insights into the **nature of the Universe**, providing a pathway to the **astronomy and fundamental physics of the future**. NewAthena is the only **'next-generation' X-ray observatory** currently planned, and LISA aims to be the **first ever orbiting gravitational observatory**.

Europe at the global scientific leading edge through mission such as the EUCLID dark energy explorer, the Jupiter system probe JUICE, EnVision, the Venus mapping orbiter, and SMILE (in collaboration with Chinese Academy of Sciences) studying the interaction between the Earth's magnetosphere and the solar wind.

Globally front-ranking scientific output: as exemplified by the 3453 unique refereed scientific publications published in 2021 based on data from ESA science-led missions, 55% more than 5 years ago.

Substantial contributions to European **economic prosperity**, both in terms of **economic multipliers** propagating through to increased GDP, and the potential uptake of new technologies. in the future, but more directly in the development of **social capital**, in catalysing **international relationships**, and in **making European 'hi-tech' industry ever more competitive** on the world stage.

The **preparation of the workforce of tomorrow** is the result of young engineers and scientists entering STEM education now, inspired by the scientific and technological accomplishments of today.

Job creation, technological knowhow, and enabling scientific knowledge initiated from the engagement of European companies in ESA missions.

2.5 Observations and Recommendations

- We submit that the ESA mandatory programme is a **high-prestige gem** of **scientific and technical co-operation** in which **Europe** can take much **pride**.
- This is despite its relatively **modest budget** in comparison, for example, to that of NASA (~1/4), and despite the **complexity of 22 entities working together** to achieve such a **technologically challenging outcome.**
- Given this solid foundation and the rapidly evolving space ecosystem, with new national and commercial actors entering the field, we believe that this is the moment to **build upon past and current achievements** to **sustain and grow Europe's role and capabilities in the field**.
- This is especially the case given the impacts on the ESA science programme in general of the Russian invasion of Ukraine regarding **access to launchers and key technologies**. In this regard we welcome and applaud the measures being taken by ESA to mitigate those impacts.
- We note also that at times of **geopolitical and economic stress**, nations that **invest** in **forward-looking science and technology** are **better positioned to prosper**.
- With these issues in mind, we **greatly regret the declining purchasing power of the Scientific Programme, which, taking into account inflation, corresponds to a reduction in scope and scale.**
- In our view, the **erosion of the budgets** for both the Basic Activities and the Scientific Programme since 2016 is placing at risk **the ability of ESA to sustain its fundamental contribution to the scientific and industrial community,** as well as to fulfil the **justified ambitions of European leadership**.
- Specifically, whilst the **momentum of existing investments** will maintain a **core of exciting new projects over the remainder of the current decade**, the proposed CM22 settlement **places at risk the ability to maintain a full programme of L, M and F missions in the longer term**.
- In doing so, it exacerbates the natural tension in the Programme between the wish to implement **ambitious, innovative, and world-leading mission**s (such as **NewAthena and LISA**), that require very significant resources (and thus commensurate Programme budget) and **frequent smaller Programme elements** (less complex but ensuring diversity and flexibility to the Programme and its launch cadence).
- In addition, it will **place at risk** key **international cooperations** and the **extensions of longstanding missions** which continue to produce **invaluable science**.
- Regarding the latter, we are **deeply concerned** about the possibility of **not extending** the missions of **Mars Express, CLUSTER, INTEGRAL and Mars TGO (science),** since these all continue to provide **cutting edge science** at **modest cost**.
- **Consequently, we recommend that the mandatory programme as proposed should be funded in full.**
- **In addition, we strongly encourage financial interventions at the earliest opportunity, and certainly at the next CM, to boost the science programme, so that the Voyage 2050 plan can be delivered as envisaged, with all the associated scientific, technical, programmatic, economic and societal benefits.**
- **Additional national investments via the PRODEX (PROgramme de Développement d'Expériences scientifiques) mechanism offer one means to achieve that outcome.**

3 The ESA Human and Robotic Exploration (HRE) Programme 'Terrae Novae' Period 3

"Man cannot discover new oceans unless he has the courage to lose sight of the shore."
(André Gide)

3.1 Strengths

The programme builds on and expands **50 years of rich history** in ESA Low Earth Orbit and Solar System human and robotic exploration, independently and with international partners, from Spacelab to Columbus and the Cupola, and now I-Hab and ESPRIT, and from Mars and Venus Express, Huygens and Rosetta (executed under the science programme), to ExoMars and the Mars Sample Return mission.

The four cornerstone campaigns - **Humans in Low Earth Orbit (LEO)**, **Humans beyond LEO, Lunar Surface Activities**, and **Mars Robotic Explorations** - provide a **well-crafted foundation** for **enhanced ambitions** as **humans embark on extending their permanent presence** at the three exploration destinations; **LEO**, the **Moon** and **Mars**.

Previous **astute commitments** include the provisions of the **European Service Modules** for the US Orion crew vehicles, major components of the **Lunar Gateway** and the **partnership with NASA on the Rosalind Franklin and Mars Sample and Return missions**. These have ensured that Europe is a **fully integrated and indispensable partner** in the vanguard of the international commitment to a '**New Era**' of human exploration in space.

In the longer term, new infrastructure assets such as the Lunar **Moonlight** communications and navigation system, and the multi-application **European Large Logistics Lander** (EL3 now **'Argonaut'**) will provide a pivotal capability to **open up Lunar access** to both robots and humans for **exploration and science**, whilst confirming Europe as a valued international **service provider**.

More specifically, Argonaut, over and above its **science and technological** value, has the **strategic goal** of securing the first **European on the Moon by 2030,** in co-operation with NASA, as foreseen in ESA's **Agenda 2025,** with **powerful potential for engaging public interest and support.**

Whilst **exploration** is the programme driver, **science plays a central role**, both as an **enabler** and as an **opportunistic beneficiary**. The **interplay of exploration, science and technology** is well organised and managed within the programme by the transversal activities **SciSpacE**, which provides the science framework and programme detail, and **ExPeRT** which identifies and develops the necessary frontier technology. Examples of science as an **enabler** include the **understanding and securing of crew health and performance**, and the development of **technologies to sustain long-duration missions beyond LEO**. The question of **radiation protection** is paramount in this context and deserves special mention.

The programme of opportunistic science reflects the **longstanding European excellence in the domain**. It covers **fundamental research** in physics, biology and planetary sciences, as well as **applied sciences** such as health research, energy transfer and materials processing.

Recent successes in these areas include advances in the understanding of **fundamental processes** in multi-phase systems such as **foams, granular materials and complex plasmas**, diffusion and solidification processes in **molten alloys,** and a better understanding of **quantum systems** (Bose-Einstein condensates), as well as **plant growth, signal transduction in plant and animal cells, physical and (mal)-adaptation of organ system functions when exposed to the extremes of the space exposome (***i.e. the measure of all the exposures of an individual in a specific time frames or in a lifetime and how those exposures relate to health***),** and **heat transfer in capillary systems**.

An example of **benefits to society** is provided by the GRIP experiment investigating the effect of weightlessness on astronauts' **ability to regulate their fine grip force**, which is casting new light on **muscular dystrophy**, whilst the Atomic Clock Ensemble in Space (ACES) experiment illustrates **ground-breaking science at the most fundamental level.** By using a **new generation atomic clock** to synchronise atomic clocks worldwide, it will be possible to test both **special and general relativity** to new levels, and to contribute novel insights into **dark matter**.

The programme science content is based on a **'bottom up' approach** drawing on the expertise of the **Human Spaceflight and Exploration Science Advisory Committee (HESAC)** and the supporting **Science Working Groups**, as well as close collaboration with the community via workshops, Announcements of Opportunity, White papers and Topical teams.

The **SciSpacE** strategy provides a **comprehensive, well laid out** and **understandable plan** to build on the established programme of HRE-supported research, whilst transitioning to a programme that will support and take full advantage exploration beyond LEO to the Moon and Mars. The new concept of **"Spotlights"** is clear and compelling, with a **well-defined scope and range**, supporting both **exploration and fundamental science** in an **interdisciplinary manner**.

The combination of ground-based, aircraft-borne, sounding rocket-borne, LEO and more distant platforms for research experimentation provides a **comprehensive range of opportunities** for a **broad multiplicity** of scientific investigations and discoveries.

The proposed programme shows a strong commitment to **diversity and opportunity**, including the study of potential adaptations to enable an astronaut with a physical disability to fly to space. We congratulate ESA for the appointment of Samantha Cristoforetti as the **first European woman astronaut in command of the International Space Station**.

3.2 Opportunities

To enter a **new era of a permanent human presence** in the Low Earth Orbit, and on the Moon and Mars. The **USA and China** are both committed to such a presence, with other international actors entering the field, and Europe needs to increase its capabilities to avoid being left behind. The programme and its **close alignment with NASA exploration objectives** reflect a pragmatic approach to this endeavour.

To **engage at the forefront and reap the greatest benefits**. The **New Space Economy** is currently one of the leading factors driving growth in space exploration. A well-funded and secure ESA exploration programme will generate **investor confidence**, and allow European Industry to take advantage of the **new opportunities** that exist in the **Global Space Ecosystem**.

To **ensure access to space** platforms for fundamental research. For example, **biomedical research** (and its developments) are not only key activities enabling humans to **safely operate in** space, but also open up the future of **new inventions** or **game-changing technologie**s that have the potential to bring **significant advancements and benefit back to Earth**.

To **foster synergie**s **between science and commercial space applications** such as spacecraft autonomy, power conversion and storage, automation and robotics, in-space assembling, data processing and Artificial Intelligence.

To secure **new return samples from the Moon and Mars** for the European science community. As a signatory to the Artemis Accords and an active participant, ESA is in a strong position to facilitate access of new (volatile rich) samples from the polar regions of the Moon that will be returned through Artemis missions. We are also pleased to note the **guaranteed access to samples** returned by the Mars Sample Return campaign. In this respect we **welcome** ESA's agreement with NASA as an **equal partner** in the curation and analysis of returned samples.

Although, the provision of sample **curation facilities** for **planetary samples** is formally not ESA's responsibility, the Agency could play an important role in supporting the development of technologies for equipping the Sample Receiving Facilit(ies)y (i.e. when the samples are still quarantined). However, developing a **European sample curation facility** is a non-trivial endeavor, work for which must begin now so that it is ready in time to receive and curate samples that will be returned by upcoming missions to Mars, as well as to the Moon and asteroids.

To utilise the Moon and Mars as **science destination**s, providing opportunities for **scientific synergies between HRE and the Science Programme**. The co-operation on Mars Trace Gas Observer to provide both science and data relay for surface robotics is an excellent example.

For the European **astronaut corps** form a 'celebrity' group with a **powerful voice** to **promote the excitement and value to society of science in general and space technology and science in**

particular. The very high degree of public interest is reflected by the 22,523 applications in response to the 2022 recruitment call.

3.3 Aspirations

To lead **Europe's human journey into the Solar System** using robots as precursors and scouts.

To lead **trailblazing research** on and around Earth, the Moon and Mars and use the unique environment of space to further the understanding of the impact of the force of gravity and radiation on life and matter, with science priorities being underscored by six 'Spotlights', namely **Humans Living on other Worlds, Astronauts 2.0, Space Travel and Transport, Origin, Evolution and Protection of Extra-terrestrial Life, Exploring the Principles of Nature exploiting the Exploration Destinations,** and **The Nature of the Exploration Destinations.**

To create new opportunities in LEO for a sustained European presence in the post-ISS era, to enable **the first European to explore the Moon's surface** by 2030 as a step towards sustainable lunar exploration in the 2030's, and to prepare the horizon goal of **Europe being part of the first human mission to Mars**.

To **open up and exploit new enabling technological frontiers** and to **stimulate commercial opportunities** for European Industry to contribute to the growing LEO economy.

To **ensure the safety, health, and performance of humans in deep space**, to be in the vanguard of the **search for life in other worlds** and to enhance the **enduring habitability** of space.

To **return the benefits and spin-offs of the exploration programme back to society.** The new medical insights alone offer a compelling return on investment.

To **increase** further the level of **interest, engagement and support** of the European public for ESA and space science, technology and commerce.

3.4 Results

Scientific discoveries (fundamental and applied) which will both **enable the ongoing safe development of the exploration programme**, and open up **new frontiers** not possible from an Earth-based location.

New **opportunities for cis-lunar and lunar surface science** (including the return of new lunar samples) will be possible as a result of the expanded range of missions and research platforms now becoming available within the programme. These include international partnership on lunar surface missions of opportunities, Gateway, and Artemis. ESA's EL3 (Argonaut) will **enable large European-led surface science missions**.

The Mars robotic element of the programme continues to invest in the realization of longstanding sciences objectives, such as **searching for signatures of past and present life** and will subsequently provide **novel opportunities for Mars science**, including the ability of **European scientists to analyse returned Martian samples** in the next decade.

The maintenance and enhancement of a **large and productive scientific community**, with **high international standing**. The new research opportunities available in the coming programme period P3, provide the means to **grow this critical mass of European expertise**.

Deeper understanding of the impact of low gravity which will **create new insights in human physiology,** as well as for a wide variety of **biological and physical processes.** Apart from being of high fundamental interest, this unique category of research offers many economic and societal benefits, such as for health research and industrial processes.

New scientific knowledge and the development of **new instruments and diagnostic tools**, all of which **contribute to the progress of medicine and its reach in remote areas**. Also the development of individual measures and progress in **precision medicine,** and to **develop secure and efficient human-robotic interactions**.

Educational activities that promote Europe as a **knowledge-based society** and enhance the **appeal of STEM education** for young students. Enhanced **media coverage and public interest**.

3.5 Observations and Recommendations

- Terrae Novae Period 3 (TNP3) will deliver **continuity** for the **highly successful and productive** ground-based and LEO/ISS programme of work that has evolved over the past decade. The **proposed ambitious programme** is well-crafted to exploit the **scientific and technological opportunities of the rapidly evolving 'new era' of human and robotic space exploration.**
- With this in mind, we strongly recommended that Europe / ESA **takes full scientific advantage** of the ISS and future substitutes, the lunar gateway and Moon surface operations, as these are key elements of an **interdisciplinary endeavour**. Earth analogues for exploration will also play a pivotal role.
- Regarding the exploitation of the Moon and Mars as science destinations, ESSC **recommend**s **strengthening of existing inter-agency platforms**. The TNP3 proposal offers new perspectives in shaping **stronger linkages between European infrastructures and national programmes**, including, for example, the development of curation and analysis facilities for future sample return missions.
- In this context, we point out the benefits of **close coordination and collaboration** between the ESA directorates for Science and Exploration, noting the existing active liaison between the two Directors, and between the associated elements (e.g, HESAC, SSAC) of the ESA science advisory structure. As an example, the '**Inspirator' mission concept for an icy moon sample return** could be tested by targeting the south polar region of the Moon for cryogenic sampling.
- The European heritage is acknowledged and **close alignment with NASA exploration objectives** reflects a pragmatic approach. This is extremely important in the present context where dependency and collaboration with other spacefaring nations are uncertain or being withdrawn (e.g., ESA-Roscosmos collaboration on ExoMars). Given recent uncertainties about the future of cooperation with Russia on the ISS, in ESSC's view it is prudent to also review the current relationships with other international partners to **manage and minimise risk** to future ESA programmes.
- We recommend and applaud ESA efforts to increase the **self-reliance and sustainability of European capabilities**, which are considered critically important for the success of future missions. The combination of the geopolitical context and the ESA's strategic long-term objective to "launch and deliver payloads to LEO, the Moon and Mars", call for **increased European autonomy and capabilities.** The proposed plan should be strongly supported and even accelerated by **filling European gaps in critical systems and technologies**.
- The geopolitical circumstances that resulted from the invasion of Ukraine by Russia forced the cancellation of ESA-Roscosmos cooperation on missions to the Moon (Luna 27) and Mars (ExoMars). We welcome the arrangements for the European payload developed for Luna-27 to be redeployed and the ongoing activity to **secure the future of ExoMars rover (Rosalind Franklin Mission – RFM)**. Because it is the **only rover able to investigate organic molecules at depth**, the Rosalind Franklin rover is **singularly suited to discover signs of extra-terrestrial life**, a finding of such **scientific and societal importance** that it would **change the way we as humanity perceive our position in the Solar System and Universe,** and would pave the way for future planetary exploration. **No other mission, presently in operation or in planning, can offer these capabilities and with a very significant and enhanced role of Europe in exploring life on Mars.**
- We also strongly support the ongoing actions by ESA to address the impacts of the cancellation of the **Sample Fetch Rover** from the **Mars Sample Return campaign**, and fully endorse ESA's continuing central partnership role through the proposed provision of the mission critical **Sample Transfer Arm** for the lander, and of the **Earth Return Orbiter (ERO).**
- We note and encourage the power of **European astronauts as 'celebrity voices**' to promote the ESA programme in particular and space science, and technology in particular.
- **Given the above, and noting the closely-integrated nature, international importance and exceptional timeliness of the Terrae Novae proposal, we recommend support in full.**

4 The ESA Earth Observation Programme

"Man must rise above the Earth, to the top of the atmosphere and beyond, for only thus will he fully understand the world in which he lives."
(*attributed to Socrates*)

We live in a rapidly changing world. Climate change and the biodiversity crisis threaten the natural systems upon which we depend. The evidence that this is so, and that human activities are the cause, has derived from a combination of theory, modelling, and a multitude of observations, both *in situ* and from space. But it is the **vantage point of space** that has transformed our ability to observe the planet as a complex, unified, interconnected whole. **Geostationary and low-orbiting satellites** provide the bedrock upon which the understanding of the Earth system, the monitoring of its behaviour, and the management of human affairs to mitigate and adapt to climate disruption, rely.

4.1 Strengths

ESA identified Earth Observation (EO) as a **priority** in the early 1980s. Its current **Earth Explorer** programme capitalises on a **distinguished heritage and established expertise**, originating with the pioneering ERS-1/2 missions and Envisat, followed by the GOCE gravimetry mission, SMOS, which focusses on the water cycle, Crysosat-2, which has transformed the radar measurement and monitoring of Arctic sea ice and ice sheet mass balance, and the SWARM magnetospheric constellation. The most recent addition, ADM-Aeolus, has revolutionised operational weather forecasting. **The record of innovative, game-changing missions is unarguable.**

This rich foundation is extended by the programme of **planned Earth Explorers**, including EarthCARE, which will characterise aerosols and clouds (the latter recognised as one of the key uncertainties in climate change science), Biomass, which will address the carbon cycle and forest ecology, FLEX, a biology mission which will measure the chlorophyl content of terrestrial vegetation, FORUM, which will measure the crucially important outgoing infra-red emissions which balance the Earth's energy budget, and Harmony, which will open up new windows on the coupling of the ocean and atmosphere, as well as measuring global surface motions of relevance to the study of topics as widely separated as ice sheet mass balance and earthquakes.

It is supported by the flexibility, low cost, and rapid turnaround of the recently introduced **Scout missions,** with CubeMAP (a constellation of CubeSats that focus on understanding and quantifying atmospheric processes in the upper troposphere and in the stratosphere) and HydroGNSS (providing hydrological measurements using Global Navigation Satellite System (GNSS) reflectometry) as the first two examples.

For the longer term, there is no shortage of innovation, with four cutting-edge prospects under study for the **11th Earth Explorer** opportunity, and a host of new ideas being fostered under the **NEOMI (New EO Mission Ideas)** initiative.

By demonstrating and proving new instruments and observing techniques, by developing their exploitation to generate **actionable knowledge and information**, and by nurturing and growing the pool of related expertise in European academia and industry, the Earth Explorer satellite series, along with national programmes and international collaborations, has **laid the foundation for the Copernicus operational Sentinel constellation**.

The Copernicus constellation, comprising Sentinels 1 - 3 and 6, provides a **comprehensive data stream covering the atmosphere, oceans, land and ice**, which supports a huge variety of **scientific applications, operational services** and a vast **user base.** This close coordination of the **ESA Future EO Earth Observation Envelope Programme** with the **European Commission** has established **European global leadership in Earth Observation**.

The future of the Sentinel constellation is bright, with **six 'Expansion' missions** planned, all drawing on the scientific, technical and programmatic capabilities developed under the ESA Earth Explorer series.

The ESA and EC missions constitute fundamental components of the **global Earth Observing System,** contributing to regular **IPCC (Intergovernmental Panel on Climate Change) syntheses** and yearly reports on the **State of the Global Climate** by the **World Meteorological Organization (WMO)**, which in turn address the pressing need for **evidence-based decision making** regarding the climate and the environmental crises, and service development in ESA Member States.

The **ESA and EUMETSAT close coordination** on **meteorological satellites** in Geostationary Earth Orbit (GEO) and Low Earth Orbit (LEO) has a long heritage of successes contributing to day-to-day citizen life. ESA's technology developments in cooperation with EUMETSAT provide the critical foundation for the **'Next Generation'** of GEO and LEO operational meteorological satellites.

The ability of ESA to contribute in this manner, has been made possible by the highly successful, decade-long **ESA Climate Change Initiative (CCI).** The CCI involves world-leading experts drawn from across the ESA member states. It generates global multi-mission, long time-series data sets that address 21 of the Essential Climate Variables (ECVs) defined by the **Global Climate Observing System (GCOS)** working with the United Nations Framework Convention on Climate Change (UNFCCC). The CCI is the source of nearly 1000 peer reviewed publications. It's proposed extension, **CLIMATE-SPACE** builds on this exemplary and unique foundation.

The scientific underpinning of the programme derives from a **'bottom up' approach,** drawing on the expertise within the ESA formal science advisory structure, notably the **Advisory Committee on Earth Observation (ACEO),** supported by the **Science Working Groups** and enhanced by close collaboration with the research community through Announcements of Opportunity, calls for ideas in the form of White papers, Topical teams, and wide consultation at events such as the **Living Planet Symposium** (the most recent in 2022, attended by ~5000 participants).

The overall outcome of this rich history is an **integrated, balanced, and forward reaching package of proposals** for CM22, constructed around a core of **FutureEO** and ESA's 'basic activities' (that ensure competence and capability in the field), and including **ClimateSpace**, support for the **Sentinels and meteorology**, with the additional innovative elements **Digital Twin Earth** (exploiting AI to simulate the Earth system), **TRUTHS** (to address new levels of calibration and validation, and commercialisation (**InCubed**).

The EO proposal components supports key European strategic challenges and priority policies addressing the Climate Crisis and the implementation of Conference of the Parties of the UNFCCC (COP) agreements, the European Green Deal, and the Decarbonisation of Europe.

The proposal also aims to further reinforce **European autonomy** in terms of **EO data access** and **EO technology**.

4.2 Opportunities

To nurture, strengthen and deliver **FutureEO**, to ensure a community of **intellectually vibrant and scientifically and technologically capable researchers**, to deliver the **planned programme** of Earth Explorers, Sentinels (in collaboration with the EC), and meteorological missions (in collaboration with Eumetsat), and to develop the levels of maturity of **front-ranking options** from which to select candidate missions for the future.

To ensure that the **FutureEO programme**, combined with the **Climate-Space initiative**, support the ongoing needs of climate science, whilst addressing society's urgent need for **actionable information** on the changing climate system, disasters, global anthropogenic changes, issues of food security, and in particular support for mitigation (i.e., agriculture, forest, land use and greenhouse gas emissions) and adaptation (to the changing environment) at both the national (via the **Paris Agreement's enhanced transparency framework**) and international levels (via the **Global Stocktake**). With this in mind, to **extend the 'reach'** of EO space data to achieve an even greater delivery of **societal benefit**.

To enhance th**e continuity of the Copernicus Space Component (CSC) infrastructure**, in order to meet the needs of current and prospective users. The Sentinel missions of the Copernicus project are crucial for monitoring changes of the Earth System in response to natural phenomena and anthropogenic forcing factors, hence increasing scientific knowledge on how our planet is functioning. They also provide essential support to decision-makers in their efforts to reach carbon neutrality and achieve sustainable life on Earth, as well as increasing societal resilience through adaptive pathways.

To lay the foundations of the **Space for a Green Future (S4GF) accelerator** proposed by the ESA Director General's High Level Advisory Group and endorsed by the 22 ESA delegations in the **Matosinhos Manifesto**, with the commitment to "***To tackle the urgent and unprecedented societal, economic and security challenges faced by Europe and its citizens***".

In addition, to underpin the **Rapid and Resilient Crisis Response Accelerator** to support stakeholders to decisively act on crises facing Europe, at a moment when it is urgent and relevant for Europe to have the necessary toolsets at hand for taking effective decisions and actions within the field of **defence and security**.

Where appropriate, to increase **cooperation with other space entities**, including those currently entering the field (internationally in both the public and private spheres) to explore possibilities of mutually beneficial joint projects and missions.

To expand the **development of small satellite missions**. SmallSats provide more flight opportunities and faster access at a lower cost for a broad variety of science applications. This is particularly the case in several domains in Earth sciences (e.g., oceanography, meteorology, hydrology, disaster assessment, etc.) which may benefit from higher spatio-temporal resolution from **SmallSat constellations** (e.g., several satellites on the same orbit or in different orbital planes).

To collaborate on the next generation gravity mission **MAGIC**: this joint mission with NASA has strong support from the whole EO community considering its multidisciplinary applications (climate and cryospheric sciences, oceanography, hydrology, geophysics, etc.) and continuity with the previous GRACE-type missions.

4.3 Aspirations

To contribute to solving the **most urgent environmental problems** of this Century – **climate and global environmental change**.

To anticipate **extreme hydrometeorological events** by accelerating the development of new Satellite and instrument solutions **enabling improved forecast** and **early warning** accuracy.

To identify, prepare, develop and operate **unique new science demonstration missions**.

To ensure **socio-economic benefits** both directly and via synergy with the worldwide efforts to understand, monitor and predict the trajectory of the Earth system

To perform the R&D necessary **to maximise the value of information** from European satellite infrastructure in supporting Member States' needs, and in collaboration with partner space agencies to act as a **focal point** for the climate science and service community, bringing users and data producers closer together and extending the 'reach' of earth observation data and services deeper into society to achieve even greater value and benefits.

To Support the **UNFCCC Paris Agreement** and efforts to achieve **Net Zero** by 2050.

To ensure the successful exploitation of the Aeolus success through the transformation of meteorological forecasting by the **Aeolus follow-on mission**.

4.4 Results

Improved knowledge on the **Global Cycles (Energy, Water and Carbon), Tipping Points, and Climate Sensitivity**. These are **major objectives** as currently highlighted by the EO community and recent IPCC reports.

ClimateSpace will also respond to new requirements for EO to **support the UNFCCC Paris Agreement**, in particular, providing information and support for **mitigation** (i.e., Agriculture, Forestry and Land Use (AFOLU) and greenhouse gas emissions) and **adaptation** to a changing environment at both the national (via the Paris Agreement's enhanced transparency framework) and international levels (via the Global Stocktake). This is a very important objective for climate research, as highlighted by the EO community during the ESA CCI Mid-Term Review.

High-quality **climate data records** (CDR), responding to and driving **international standards**, as the excellence **base that underpins all further activities** towards addressing the effects of climate change.

Global wind velocity measurement notably through the Earth Explorer Aeolus mission being adopted as the operational mission **Aeolus 2.**

Climate related financial risk assessment supported through the development of climate variables informing on climate risk, exposure and vulnerability, supporting investors, regulators, central banks and governments to address the significant financial challenges that climate change presents.

Improved **automated generation of geo-information products and services** for **climate resilience** and provision of better estimates of the **economic impact**, as well as publicly available, consistent, and comparable asset-level datasets for actors across the financial system, supporting equity and capacity building towards developing countries.

Quantification of greenhouse gas (GHG) budgets through (i) top-down monitoring of atmospheric GHG concentrations and associated anthropogenic emission fluxes, (ii) bottom-up estimates of GHG sources and sinks from AFOLU, and (iii) information to support the quantification of national emissions inventories. This is a much needed, and timely contribution to a major problem.

Preparing the ground for climate research through Earth System Science as well as developing applications to address adaptation and resilience to a changing climate, **providing actionable information to policy makers**.

Use in the context of **humanitarian aid and security**, including food and civil security, sustainability of societies and migration, building local capacity in developing countries to address the effects of climate change.

Continued and expanded R&D activities on satellite-based CDRs to enlarge the portfolio of **Essential Climate Variables** (ECV)s and their thematic variables being delivered, improve the quality of existing CDRs, and integrate data from new instruments (e.g. Copernicus Expansion missions);

4.5 Observations and Recommendations

- The Earth Observation (EO) programme consists of a package of optional elements built around the **FutureEO** core. ESSC judges the package to be well formulated, rates its scientific, technological and programmatic bases as **excellent,** and considers that it **rises effectively to address the challenges to society** presented by the **climate and environmental crises**, and **extreme hydrometeorological events**, whilst at the same time laying **new scientific and technological foundations** for **understanding the Earth system**.
- The programme provides a sound basis to contribute to the proposed European **Space for a Green Future (S4GF) accelerator** and the **Rapid and Resilient Crisis Response Accelerator** adopted in the **Matosinhos Manifesto,** each of which seeks to achieve the **deeper penetration** of Earth Observation data into **societal decision making** to enhance the creation of **'Agency to Act'**.
- ESSC observes that **even small cuts to the programme** would have **profound implications** for its delivery and implementation and the provision of **vital information for society** in its day-to-day life.
- **Given the above, ESSC recommends the ESA Member States to provide funding in full, stressing the importance of supporting the complete integrated package of activities.**

5 Transverse Issues

"Everything Is Connected to Everything Else"
(Barry Commoner)

5.1 System Science

A growing feature of space science is the use of launched assets to support **'System Science'** in which data from a **multiplicity of instruments and spacecraft** are combined to **synthesise results** that are '**greater than the sum of the parts**'.

A particularly important example is the "**Grand Heliospheric Orchestra (GHO)'**, comprising a suite of widely distributed instruments that provide the means to study the interactions of Solar Activity as they spread throughout the Solar System. This new capability is critical to the needs of predictive capabilities for **Space Weather** of importance in managing and protecting vulnerable terrestrial and off-planet infrastructures, and to the safety of humans in space. We welcome the establishment by ESA of the **Heliophysics Working Group** to coordinate the associated cross-Directorate planning and activities.

Both for the GHO, and more generally, System Science has implications for decisions on **mission extensions**, which need to take into account the **consequences for science and services beyond those originally anticipated**.

5.2 Enabling Technologies

The emergence of **innovative technologies,** some with **broad application** across the ESA programme, can **significantly enhance European scientific capabilities,** as well as **boosting autonomy, prosperity and competitiveness**.

A prime example is the development of **large, reliable low-cost launchers**, which would enable a transformative increase in the **size and mass of scientific payloads**, opening up **entirely new observational windows**. **Human rating** would provide critical **European autonomy** at a time when being in the vanguard of off-planet exploration would ensure the ability to **influence future developments** and to be party to **ensuing societal benefits**.

At a more granular level, past ESA Missions have achieved **outstanding scientific results** thanks to a combination of **leading-edge spacecraft technologie**s and **highly innovative instrument concepts.** With this in mind, specific **strategic technologies** that we **highlight for attention** include:

- Advanced RF and optical instruments, spacecraft autonomy and proximity operations, new power conversion and transmission, energy storage, automation and robotics, in-space assembling, ultra-high speed data processing and Artificial Intelligence,
- Quantum technologies for fundamental science, sensing, communication, and generic components such as photonics, nanoelectronics, and new materials.

To make these advances happen, the ESSC recommends efforts to continue to increase the R&D coordination and harmonisation between ESA, Member States, National Agencies and the EC. We recommend a substantial increase in spending on such game-changing technologies and on enhancing in-orbit demonstration and validation opportunities.

5.3 Citizen Support

Finally, whilst applauding the **impressive efforts of the ESA communications team**, both in the realms of traditional and social media, we **recommend** that ESA, the European space science community, and all related government, commercial and NGO actors, work together to **even better articulate to European citizens and decision-makers the value of space science, and the outstanding success of ESA and of the European space science enterprise**. The voices of the **European astronaut corps** provide a **powerful resource** to be deployed for this goal.

"When you have a great story to tell, use a megaphone!"

6 European Space Science Committee Membership

Role	First name	Surname	Affiliation	Country
ESSC Chair	Chris	Rapley	University College London	United Kingdom
AFPP Chair	Nabila	Aghanim	Institut d'Astrophysique Spatiale	France
ESP Chair	Anny	Cazenave	LEGOS, CNES	France
LPSP Chair	Alexander	Choukér	Ludwig-Maximilian University Hospital	Germany
SSEP Chair	Mahesh	Anand	The Open University	United Kingdom
Treasurer	Marc	Heppener	Consultant	Netherlands
Senior Tech Advisor	Serge	Flamenbaum	Consultant	France
ASTRONOMY AND FUNDAMENTAL PHYSICS PANEL - AFPP				
Member	Xavier	Luri	University of Barcelona	Spain
Member	Manolis	Plionis	National Observatory of Athens	Greece
Member	Floris	van der Tak	SRON	Netherlands
Member	Fabrizio	Fiore	INAF, Astronomical Observatory of Trieste	Italy
Member	Saskia	Hekker	Heidelberg University	Germany
Member	Ravit	Helled	University of Zurich	Switzerland
EARTH SCIENCES PANEL - ESP				
Member	Yann	Kerr	CESBIO	France
Member	Sindy	Sterckx	VITO	Belgium
Member	Michaela	Hegglin	University of Reading	United Kingdom
Member	Gustau	Camps-Valls	University of València	Spain
Member	Jonathan	Bamber	University of Bristol	United Kingdom
LIFE AND PHYSICAL SCIENCES PANEL - LPSP				
Member	Kai	Bongs	University of Birmingham	United Kingdom
Member	Luca	Cipelletti	University of Montpellier	France
Member	Marc	Heppener	Consultant	Netherlands
Member	Ann-Iren	Kittang Jost	NTNU Social Research	Norway
Member	Zita	Martins	Instituto Superior Técnico	Portugal
Member	Nicola	Montano	University of Milan	Italy
SOLAR SYSTEM AND EXPLORATION PANEL - SSEP				
Member	Christina	Plainaki	ASI	Italy
Member	Nicole	Schmitz	DLR	Germany
Member	Mauro	Messerotti	INAF, Astronomical Observatory of Trieste	Italy
Member	Vinciane	Debaille	Université Libre de Bruxelles	Belgium
Member	Sonia	Fornasier	Université Paris Cité	France

ESSC Secretariat

Executive Secretary	Emmanuel	Detsis	European Science Foundation	France
Administrator	Mariette	Vandermersch	European Science Foundation	France
Science Officer	Jonas	L'Haridon	European Science Foundation	France
Project Officer	Mari	Kolehmainen	European Science Foundation	France

ESSC