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Optimising Human Space Exploration Policies and Strategies

Serge Plattard[a]*, Alan Smith[b]

[a] *UCL Space Domain, Department of Space and Climate Physics, University College London, Mullard Space Science Laboratory, 3 Taviton Street, London WC1H 0BH, UK, s.plattard@ucl.ac.uk*
[b] *UCL Space Domain, Department of Space and Climate Physics, University College London, Mullard Space Science Laboratory, Holmbury St. Mary, Dorking, Surrey, RH5 6NT, UK, alan.smith@ucl.ac.uk*
* Corresponding Author

Abstract

The key protagonists of human space exploration are pursuing different strategies. Yet in this international environment one would imagine cooperation rather than competition to be the most affordable. The long-term objective of the US/NASA is to reach Mars and set up a sustained human presence. A Lunar Orbital Platform-Gateway (LOP-G) would ultimately become a springboard to the Red Planet. This is consistent with a privatized/or deactivated ISS starting in 2025, freeing NASA to concentrate on human space programmes beyond LEO. SpaceX would create the capability of direct access to Mars, enabling regular shuttling from Earth. Asteroid mining retains some commercial interest and would piggy back the above. The Chinese will continue to gain additional LEO experience by establishing a larger space station, Tiangong-3, in the next decade - with the possibility of hosting European astronauts. Later, China would deploy a permanent infrastructure on the Moon to explore and exploit local resources. Russia wished to continue its ISS/LEO programme as long as possible. Funding, a constant hurdle for the Russian space programmes, and the lack of reliable heavy lift capability remain challenging issues in their preparing for human exploration beyond LEO. ESA plans are not yet formalised: the Aurora programme of Lunar/Mars exploration appears to be running out of strategic vision with ExoMars probably the culmination rather than the first step; the Moon Village is still a concept and while it may materialise, the European lunar presence needs to be worked out. Since ESA will be without the independent means to put humans on the Moon for decades to come, its Member States are destined to fit into non-European strategies, seeking to capture specific niches, and more so to be on the critical paths of major projects. Yet, it remains to be seen if such a demarche is acceptable by all, or any of the players. Japan and Canada, partners to the ISS, will have to find their place alongside other emerging space nations in the developing landscape of strategies laid out by US, China and ESA. After analysing these different strategies, the paper will propose some scenarios based on a more holistic approach where the different players, including private entities, could contribute in a more synergistic mode, reducing costs, engaging throughout an improved path for a sustainable human space exploration. The outcome of the 2nd ISEF will be taken into account in building the different scenarios.

Acronyms/Abbreviations

BFR: Big Falcon Rocket
CSS: Chinese Space Station
GEO: Geosynchronous Equatorial Orbit
HSE: Human Space Exploration
ISECG: International Space Exploration Coordination Group
ISEF: International Space Exploration Forum
ISRO: Indian Space Research Organisation
ISS: International Space Station
LEO: Low Earth Orbit
LOP-G: Lunar Orbital Platform-Gateway
NASDA: National Space and Astronautics Development Agency
OPSEK: Orbital Piloted Assembly and Experiment Complex
SLS: Space Launch System

1. Introduction

Space exploration started with the launch of Sputnik in 1957 and has made tremendous progress since, pushing the outer space frontiers to the limits of the solar system, travelling beyond Pluto, *en route* to the Kuiper Belt with the New Horizon probe, and even entering interstellar space with Voyager 1 and, eventually, 2. Only a relatively few counties have participated in this robotic exploration, led by their space agencies and the European Space Agency. Overall, these far-from-Earth endeavours have been undertaken largely under the leadership of the United States of America.

Conversely, human space exploration (HSE) has remained confined essentially to the immediate Earth vicinity, i.e. Low Earth Orbit (LEO) operations, with the exceptional American excursions to and on the Moon in the late 60s' and early 70s'. The reasons for such a limited exploration of outer space by humans are well known: the further astronauts are from the Earth, the higher the risk; increasing costs to ensure better spacecraft safety within increasingly unknown environments; increased complexity (and therefore, cost) when moving to the next generation of launch vehicles, in-orbit activities and return-to-Earth systems; challenges posed by microgravity; living in confined and isolated environments; radiation and longer exposure times; increasing data volumes and telemetry demands; etc.

For more than 50 years, humans have lived in LEO, albeit intermittently, carrying out human space flight related scientific experiments, preparing for long and distant journeys in space, study the effects of microgravity and radiation not just on human physiology, but also biology, materials, and electronics. From components through units to system, equipment has been tested in space for future space use or, indeed, Earth-based application. To that end, the Soviet Union and the United States began this endeavour, followed by the contribution of ESA Member States and Japan. Later, China also became an active player.

Since the retirement of the Space Shuttle in 2011, these activities have taken place mainly on the International Space Station (ISS), and to a significant lesser extent on the Chinese orbital outposts Tiangong-1 and-2, although some limited use of free-flying satellites has taken place. Nevertheless, HSE activities have been very focussed mainly on the ISS.

Presently the US is considering a possible withdrawal from the ISS in 2025, the NASA project of a Lunar Orbital Platform-Gateway (LOP-G) is gaining momentum, China space station, Tiangong-3, continues with a planned deployment in LEO in the early 2020s', Elon Musk's has declared a project to fly-by Mars during the next decade and land humans 10-15 years later. In summary after half a century of stagnation in LEO activity HSE is set to enter into a new phase in which humans begin the real exploration of the Moon and Mars, using public and private means. HSE will move further away from Earth, aiming at cislunar orbits and possible outposts on the Moon, preparing eventually for settlements on Mars

Given the above proposed undertakings, some legitimate basic questions need to be asked and answered, viz:

- Why is it timely to go beyond LEO now?
- Do we share a common vision for HSE? How much diversity exists in this vision?
- Can the current approach be made less expensive?
- Is accountability properly ensured?
- Can the decision process be sped up and be resilient to political changes?
- Is immunity from national changes in direction (cancellation-proof) a legitimate reason for international cooperation?
- How optimal is the current approach, in particular when considering the recent International Space Exploration Forum (ISEF-2) joint statement? [1]

In terms of how to pursue HSE, we stand at the cross roads: do we continue the prevailing model consisting at having a national or bi-national actors maintaining leadership in HSE, aggregating international cooperation and involving the participation of commercial space contributors, or do we engage in a major paradigm shift in which HSE is seen as a collective, inclusive humankind endeavour supported worldwide by policy decision makers at the highest levels of governments, involving a wider range of contributors (with contributions currently at differing levels of technological maturity) agreeing to a common governance scheme. We argue here for the latter, recognising that while an extremely daunting challenge, it is necessary to achieve humankind's ambitions for HSE.

The aim of this paper is not to justify HSE but rather to explore how it can progress as much as possible in an effective and sustainable way.

2. HSE shaped by the space race

The space race that was a manifestation of the Cold War, triggered human space flight. While the Soviets set the early pace the US established dominance after President Kennedy in his famous 1961 speech to the Congress, delivered the month following Yuri Gagarin's successful flight: "Americans should be the first to land on the Moon and return by the end of the decade" [2]. This enormous (and extraordinarily ambitious, given the US poor track record of failed Lunar exploration up to that time) challenge (at its peak in 1966, the Apollo programme represented about 4.5 % of the US federal spending) was met in July 1969 and repeated five more times in rapid succession. This rivalry, an attribute of two socio-economic models fighting for geopolitical influence and domination, shaped the developments of HSE from the 70's to the early 90's (with the exception of the joint Apollo-Soyuz flight symbolic of the nascent détente), America went on to develop the Shuttle programme (initially also called the space logistics vehicle by NASA) based on a reusable vehicle with a maximum crew of 7. However, the shuttle did not meet its expectations in terms of cost-effectiveness in two key aspects; the launching rate was about five times slower than initially expected; and the cost of delivery for satellites in GEO could not compete with Russian and

European launchers prices. Reconditioning costs between two Shuttle flights had been vastly underestimated due to the increasing safety concerns. On their side, the Soviets / Russians continued to develop their own orbital outposts transitioning from the Salyut, Almaz to the Mir stations.

Following the termination of the Apollo programme, NASA operated Skylab during 1973-79, its first continuously crewed space station, while the Shuttle programme was under development. Under thawing Cold War tensions, President Reagan in his 1984 address on the State of the Union directed NASA to "develop a permanently manned space station and to do it within a decade" and to "invite other countries to participate" [3]. The space station Freedom went through seven redesigns between 1984 and 1993 where the Clinton Administration announced the transformation of the NASA project into an International Space Station as the result of merging the American endeavour with the Russian NPO Energia Mir-2 project. During the late 80's, the European Space Agency (ESA) and the Japanese NASDA agreed to provide one module each to the station Freedom, respectively named Columbus and Kibo.

After 30 years of rival national HSE endeavours, attitudes had changed; nations were now more ready to consider cooperation on a larger scale, while sharing costs, management and procedures for sustainable activities in a large LEO outpost.

China for its part joined the HSE club in 1992 by developing the Shanzou capsule, very much inspired from the Soyuz and with early on technological assistance from Russia. The first taikonaut flew in October 2003 and the first Chinese space station was orbited in 2011, capable of supporting a crew of three. With the launch of Tiangong-2 in 2016 and the successful mastering of its new cargo resupply vehicle Tianzhou-1, the CNSA is now getting ready to begin assembling the Chinese Space Station (CSS) by this decade's end.

Table 1 lists the costs, of several major HSE programmes.

Table 1. Estimated costs of major human space exploration programmes

Activity	US$ (Billion)
Apollo	> 107 (FY-16)
Space Shuttle	> 190 (FY-10)
ISS	> 150 (FY-14)
Humans to Mars and Return	100-1000?
Global Space Economy (2017)	330
World Defence Expenses (2016)	1800

3. Setting the scene

The International Space Exploration Coordination Group (ISECG) has released in February 2018 its third edition of a Global Exploration Roadmap (GER) reaffirming "the interest of 14 space agencies* to expand human presence into the Solar System, with the surface of Mars as a common driving goal", underlining "the coordinated international effort to prepare for space exploration missions beginning with the ISS and continuing to the lunar vicinity, the lunar surface, then go to Mars" [4]. These agencies highlight the importance of international cooperation for achieving individual and common goals and objectives.

There is growing interest in HSE within the private sector both as an opportunity to contribute to national and international programmes through contracts, and in its own right recognising its commercial potential.

There are a number of aspects of the 2018 GER (Fig 1) that deserve particular attention:

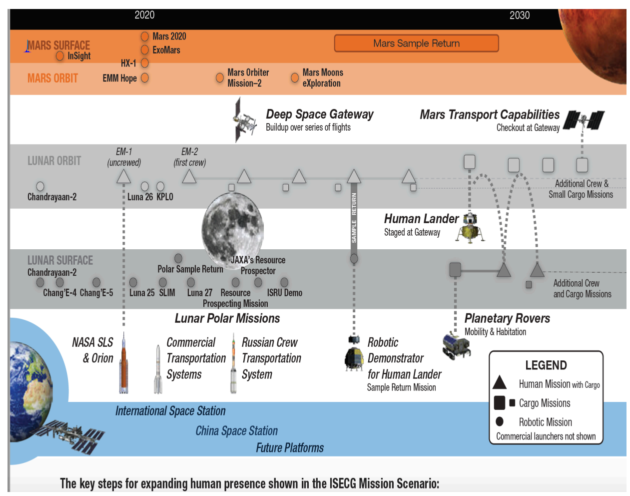

Fig. 1. Expanding Human Presence following the latest ISECG Mission Scenarios [4]

- In the next 10 years or so, most HSE will be focussed in two areas i) LEO with the expected ISS scaling down by the mid-2020s' and the deployment of the CSS ready for a 20-year service and, ii) cislunar activity (see next bullet) supported by robotic missions.
- A cislunar / lunar activity driven by a US initiative currently called the Lunar Orbital Platform-Gateway (LOP-G). This activity is most likely to comprise an internationally funded, inhabited platform (proposed crew of

* ASI, CNES, CNSA, CSA/ASC, CSIRO, ESA, ISRO, JAXA, KARI, NASA, Roscosmos, State Space Agency of Ukraine, UAE Space Agency, UKSA

4) from which robotic landers would be deployed to and operated on the lunar surface with some elements returning to the LOP-G. This platform would be assembled in a near-rectilinear Lunar halo orbit using NASA's Space Launch System (SLS) to transport the different components, while commercial transportation systems and Russian crew transportation systems would also be involved in in-orbit assembly and servicing. The LOP-G is seen as a precursor to a human return to the Moon before 2030.

- Elon Musk plans to send humans on a Mars fly-by during the next decade and intends SpaceX to land humans on there in the 2030s'. Both of these programmes will use a new Big Falcon Rocket (BFR) that will be a fully reusable launcher and considerably reduce costs. NASA's plans for Mars exploration are matured, but the possibility to use the LOP-G as a springboard for astronauts to reach Mars is being carefully studied. It appears entirely feasible technically and is likely to be significantly less costly than a Mars-direct mission using conventional launchers such as the SLS. To this end, NASA proposes the Deep Space Transport, a reusable vehicle that uses electric and chemical propulsion, specifically designed for crewed missions. . For returns from Mars, the LOP-G could also act as a docking harbour, reducing the speed of astronaut re-entry and so minimising life-threatening risks.

Given the relatively long timescales, international dependencies, technical challenges and cost, it is essential that programme elements are underpinned by robust visions fed by high-level political commitments together with scientific endorsement and public support. In the case of Apollo only 8 years passed from start to delivery. The programme involved a tremendous national effort across a range of disciplines including technical, managerial, scientific and logistic. It left a legacy for the US, which probably exceeds even President Kennedy's highest ambitions, yet it is hard to imagine a similar endeavour today given the current landscape of space actors internationally.

We now consider the current visions and drivers of the national players in space..

As for the *United States,* President Trump has announced on two occasions the willingness of the US to engage in a new step for HSE. In March 2017, when signing into law the NASA Transition Authorization Act, calling for human missions beyond Earth orbit, including Mars, he said "Today we're taking the initial steps toward a bold and brave new future for American space flight" [5]. Elements of the bill called upon NASA to draw plans to send humans to Mars by 2033.

In December 2017, Donald Trump signed the Space Policy Directive 1, formally directing NASA to send humans to the Moon [6]. It replaces one paragraph of the current 2010 Space Policy enacted by President Obama, and read as follows: "Lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations". NASA, also in 2017, announced its plans for a Deep Space Gateway as described above.

The message is explicit and unambiguous: the United States will continue to lead HSE in its move beyond LEO.

The drivers for this US-led new frontier are multiple. Politically the US intends to reinforce its status as leading technological nation, in particular vis-à-vis the challenging capabilities of China, considering that such an advantage will spring benefits across the board, including on Earth-bound activities. It also considers this new step in HSE as an indispensable key to master capabilities to harvest resources from celestial bodies, be it to support exploration, or to be used on Earth. Moreover, as it has been the case so far in any type of exploration that new capabilities / opportunities in security and defence may be also contemplated thanks to this new frontier endeavour.

Russia, for its part, considers that there are still valuable scientific results and applications that can be harvested from an inhabited LEO station, advocating a continuation of the ISS after 2024, or contemplating the development of its own station, a project Roscosmos had in the past with Mir-2 or even earlier with OPSEK. Three Russian modules are still slated to join the ISS: the Multi-purpose Laboratory Module (MLM), the Node Module (UM), and a new-generation laboratory and power supply facility dubbed NEM-1. The Head of Roscosmos mentioned in 2016 the possibility of having these three modules upgraded to form parts of a Russian LEO space station if the ISS is deactivated after 2024.

Because of the limited successful experience Russia has gained in cislunar / lunar activity, together with recurrent long-term uncertainties regarding space funding, (in particular a significant budget squeeze over the 2015-25 period and economic sanctions that are still in force), Moscow is not in a position to lead innovative HSE around the Moon or on its surface. Nevertheless; Russia is definitely willing to partner with the US in a lunar initiative. Despite its inclination for LEO human activity, Roscosmos understands the necessity to move to lunar exploration, being part of the NASA-led project. To that end, a joint statement between NASA and Roscosmos was signed in September 2017 during Adelaide's IAC-17, supporting research that could lead to a cislunar habitat, and reflecting a common vision for human exploration. The Russian communiqué added "the future elements of the station will be created on the basis of Russian developments, as well as the standards of life support systems".

Yet, a Moon landing remains a strategic goal of the Russian human space flight, with a tentative launch date in 2030, five years beyond the current 10-year Federal Space Programme.

More fundamentally, the Russian vision calls for a twin track approach to HSE: remain as long as possible in LEO, and be an indispensable partner in a future lunar outpost, if possible on the critical path and so able to have a major influence.

China, who joined human spaceflight more than forty years after the USA and the USSR, currently focuses its HSE activities to LEO, i.e. the CSS. The fourth version of the White Paper on space entitled "China's Space Activities in 2016" was released by the Chinese government in December 2016 [7], exemplifying space as a "strong support for the realization of the Chinese Dream of the renewal of the Chinese nation". The Chinese objectives for the next five years are to "acquire key technologies and conduct experiments in such technologies to raise our manned spaceflight capacity, laying a foundation for exploring and developing cislunar space". In this White Paper, there is no formal plan or timeline to send humans to the Moon, although this is evidently a long-term objective. China considers that it still has a lot to experience and master before moving to manned cislunar space.

China's general motives for space activities including HSE are:

- National prestige- mastering the complete panoply of space engagements is an attribute of a world power;
- Science and exploration;
- Development enabling the control of spacecraft in deep space;
- Exploitation of the Moon's natural resources.

As for *Europe,* the vision for HSE is still very much in the hands of the European Space Agency (ESA) and its Member States since the European Union (EU) in its Communication on a European space strategy released in October 2016 focuses on space-based applications, and environment monitoring tools [8].

The catchword for the next HSE step is the "Moon Village", a concept floated by ESA's Director General in 2015, gaining maturity year after year, and that may be an after-ISS guideline for the Europeans, opening new technical and scientific challenges. This is an area where Europe can contribute to some LOP-G components, robotic and crewed missions to the lunar surface, and to elements of a lunar ground segment.

European aspirations for HE were not helped by the selection of Ariane 6 as the next European medium-heavy lift launcher given its lack of suitability for lunar exploration. However, as was the case with the provision of the Columbus module for the ISS and the creation of an Astronauts Corps, ESA will remain in a position as a necessary partner to the NASA project, seeking to capture niche responsibilities, and to be on the critical paths of major undertakings. Already responsible for the service module of the Orion spacecraft, ESA should and could play a significant role in the deployment of the lunar ground segment, a relevant test bed for the development and validation of key capabilities that will be needed for future missions on Mars.

The visions for both *Japan and Canada*, already partners to the ISS, are to build upon their expertise acquired over the last 20 years to contribute to the US initiative developing new tools serving the LOP-G project for cislunar activity as well as for *in situ* missions. Tokyo has still embryonic thoughts about what would be its most relevant contribution to the LOP-G assembly and missions, wondering how and when the US lunar project will unfold.

In 2007 the *Indian* Space Research Organisation (ISRO) took the first steps towards HSE by adding a crewed spacecraft capability to its space programme. It is currently gearing up for a maiden flight of the manned Gayanyaan capsule in December 2021, and in the more distant future, looking at docking capabilities to LEO space stations.

As one of the two largest continental Asian powers, India's HSE drivers are first of all national prestige considerations. Having sent successful probes to the Moon and Mars, it now aims at entering the human space flight capability.

4. Towards a sustainable HSE

From the above it is evident that we have two visions extant for future HSE. One involves mainly national interest in LEO while the other sees a move to cislunar orbit, the lunar surface and Mars. The latter being an endeavour that is too expensive and diverse to be accomplished by a single nation.

Fig. 2 shows the interactions of some mission objectives that would lead to Human Exploration of Mars.

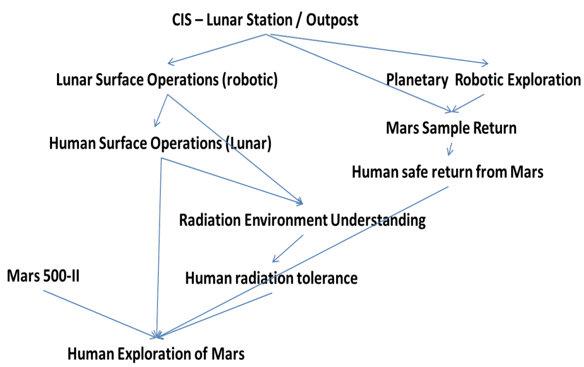

Fig. 2. Human Exploration Diagram

Somehow these visions must be realized within the context of increasing participation from commercial (at least independent) players and the current funding, political and governance infrastructures. Is such a situation sustainable? Taking the view expressed in the 1967 Outer Space Treaty that space is for the benefit of all mankind, we argue that the next steps in off world living and working should be a humankind endeavour. It will be necessary to increase funding (and value for money), and secure against dependency risks without the need for duplication. A new paradigm may be required.

The need for a new rationale supporting space exploration, including HSE, has been identified early in this decade, crystallising at two International Space Exploration Forums (ISEF), i.e. those in Washington DC (January 2014), and in Tokyo (March 2018) that produced a series of recommendations. Participants to these forums were members of governments and heads of space agencies; more than 40 countries and international organisations attended ISEF-2 in Tokyo. Here are a few points from the Joint Statement issued on the occasion of the Tokyo Forum [1,9]:

- Exploring new frontiers and expanding areas of human activity in outer space are an important challenge for humankind;
- Exploring the solar system is a common endeavour;
- The importance of investments in space exploration will contribute to economic growth and societal well-being;
- Activities can be strengthened through international cooperation, looking for synergies based on shared vision and goals to enhance effective and efficient space exploration activities;
- Wider opportunities for innovative partnerships involving public and private partnerships from all continents must be encouraged;
- The importance of building HSE as well as robotic by making the most of it (robotics preparing for HSE, and vice-versa, HSE setting new challenges to robotic exploration);
- The latest GER released by the ISECG is recognised as a guiding path to be followed;
- Principles of international space exploration is a basis for governments to engage a dialogue to promote international cooperation and long-term space endeavours to deliver benefits to humankind

While ISEF-2 demonstrated a positive and constructive spirit under which future international HSE should progress, it is silent about how the Joint Statement recommendations be progressively implemented. No *modus operandi* is suggested presumably because complex political, financial, and governance issues have yet to be sorted out. Considering the difficulties and the benefits of a more collaborative approach to HSE, enabling innovative actions should be explored.

First of all, a more global political approach to HSE is now needed. This will mean agreeing a common and consensual long-term vision and strategies that avoid redundancies and excessive duplication while privileging fail-safe approaches in international cooperation, i.e. in case a partner defaults at some point, for any reason, the overall project should not be jeopardized. As a general guideline national contributions that are a distinct and coherent part of an international programme should be recognised as such, with consequential national responsibility, and should not be branded within an international umbrella. If a nation defaults then that should be evident.

Second, the paradigm for cooperation needs to be changed: i) moving from "traditional" cooperation to a more holistic approach from the outset; ii) organise HSE as a humankind venture based on a common and shared project rather than on a pre-formatted cooperation scheme, e.g. ISS international treaty; iii) to that end, create an International Council for Space Exploration (ICSE) and an international entity responsible for the completion and delivery of HSE projects (agency type to be defined); and, iv) pursuing this logic, put HSE on the agenda of G8 / G20 meetings signalling the strong support and commitment of major world Heads of State / Governments. One can imagine that a major HSE programme would be endorsed / launched on the occasion of such Summits, as the Human Frontier programme was at the 1987 G7 in Venice.

The ICSE, as a proposing and coordinating entity, would include representation from all actors groups: governments, space agencies, industry, experts, and academics. Council members would elect the chair. The Council's main role would be to endorse / agree guidelines, set priorities, advise for efficient governance, and ensure resilience of its recommendations.

The international entity responsible to conduct HSE programmes could be an agency set up for this purpose, a consortium bringing national space agencies / ESA together, a public / private agency, or something different and to be defined.

The main purpose of this entity would be to deliver the desired HSE outcomes, carry managerial and programmatic responsibilities, and facilitate the smooth functioning of international cooperation mechanisms, probably the most delicate task.

This entity could also address issues common to all HSE missions, mainly: microgravity environment, psychological effects tied to long duration missions in isolated habitats, sustainable and safe life support systems, and radiation effects. Indeed, rather than having few national space agencies working on these issues for their astronauts, a single body would help in setting agreed standards and rationalise the required studies relevant to specific journeys.

5. Conclusion

While there is a lot of consensus around the objectives of HSE that begins with a cislunar orbit platform and progresses eventually to Mars, there is currently no truly credible and realizable strategy to ensure the necessary international cooperation. We propose a new paradigm shift that sees this programme as a humankind endeavour and which puts national agendas and prestige to one side, instead creating an international agency that will deliver what is agreed in terms of objectives. A political sustainable long term commitment of governments at the highest level is necessary to maintain momentum in keeping HSE high in the international agenda and to make progress. Just as climate change, environment protection or biodiversity have permeated the international agenda, the rising expansion of humankind throughout the solar system deserves the same kind of attention. While politically challenging, Space is one area in which international cooperation is part of its DNA, but the way that it is entrenched in policy decision-making will have to change.

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