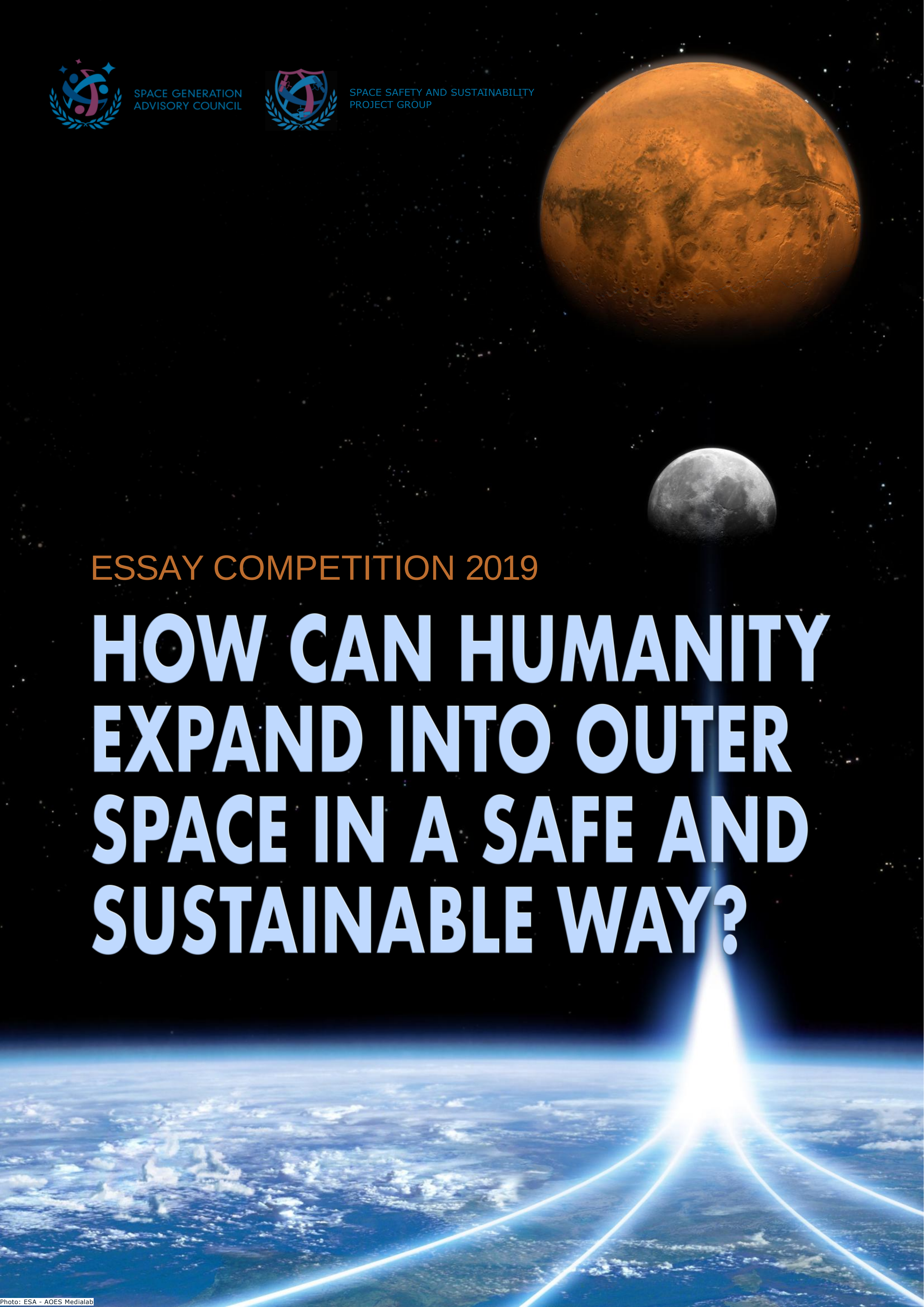
SPACE GENERATION ADVISORY COUNCIL

SPACE SAFETY AND SUSTAINABILITY PROJECT GROUP



ESSAY COMPETITION 2019

HOW CAN HUMANITY EXPAND INTO OUTER SPACE IN A SAFE AND SUSTAINABLE WAY?

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FOREWORD

Congratulation to the winners and thanks to all participants in our essay competition “How can humanity expand into outer space in a safe and sustainable way”! We were overwhelmed by the dedication of so many young people and the number of essays that we have received. We have read them with great pleasure and want to encourage the participants to work on the realization of their ideas.

This publication is composed of the top ten essays that were chosen by our jury.

The organization team is thankful for the sponsorship from the European Southern Observatory (ESO) and especially to Dr. Andy Williams, External Relations Officer at ESO, for his kindness and support.

We also thank the Co-Leads of the Space Safety and Sustainability Project Group Jessica Creech and George-Cristian Potrivitu for the help and confidence and everybody else who was involved and supported us. Thanks for all the effort and energy to make this happen!

On behalf of the organization team,
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Best Practice Environmental Impact Assessments Guide Safe, Sustainable Space Development

Introduction

Governments should adapt the terrestrial environmental impact assessment (EIA) process to the space environment to promote human expansion into space in a safe and sustainable manner. Developing a stellar economy presents a unique opportunity to develop a sustainable industry now before unforeseeable risks of new technology permanently damage irreplaceable resources and locations. EIAs can manage human expansion into outer space by providing robust, transparent consideration of potential impacts before they occur, while not directly regulating space activities.

What are EIAs?

EIAs are a proven technique in national and international law to evaluate and understand the environmental impacts of proposed actions. The foundational environmental law in the United States, the National Environmental Policy Act (NEPA), provided a framework that other States soon followed. NEPA requires federal agencies to conduct an environmental impact statement of "major federal actions significantly affecting the quality of the human environment."[1] The process forces agencies to consider and incorporate the environmental impacts of their normal activities into their decision-making process. NEPA is not a substantive statute. It does not prescribe a particular outcome. Rather, it creates a process that enhances understanding and transparency of impacts.

There are two primary advantages to space EIAs.

First, EIAs or similar processes are common in national laws globally. According to U.N.E.P. (2018): "Environmental Impact Assessments (EIAs) are the most commonly known, used, and globally widespread, environmental planning and management tools."[2] Further, EIAs are established in international law; forty-four countries participate in the Convention on Environmental Impact Assessment in a Transboundary Context[3].

Second, an EIA process can scale depending on the activity being examined. This right-sizes regulatory burden to match policy requirements. Using EIAs for space applications is innovative because they offer a demonstrated technique to gauge, evaluate, and understand environmental harms in a new context. Through transparent processes, EIAs encourage public engagement and participation. They can inform and address the primary threats to space safety and sustainability. Space EIAs can thus create the social license necessary for expansive government and commercial space operations.

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1 42 U.S.C. § 4332

2 United Nations Environment Programme (2018). *Assessing Environmental Impacts-A Global Review of Legislation*. Available at https://europa.eu/capacity4dev/unep/documents/assessing-environmental-impacts-global-review-legislation

3 Convention on Environmental Impact Assessment in a Transboundary Context. Multilateral treaty. 25 February 1991. Available at: https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-4&chapter=27&lang=en https://www.unece.org/env/eia/eia.html

They are also compatible with international space law, particularly the Outer Space Treaty's Article VI requirement that States authorize and oversee space activities. EIAs can act as part of authorization and oversight, while informing policy for both. However, EIAs need not be limited to government activities. Kramer (2014, 2017) identifies an industry-led EIA process as facilitating private space actions within the international nature of space activities.[4,5]

Considering the Space Environment

The space environment is inherently hazardous. Vacuum, large temperature swings, microgravity, and radiation threaten both crewed and uncrewed missions. However, the most hazardous part of human activities exploring space may be human activity itself.

Space debris is the primary near-term environmental problem facing the space sector. Along with micrometeoroids, orbital debris is the number 1 safety issue facing human spaceflight[6]. In 2009, two satellites, one a decommissioned Soviet nuclear reactor, collided and caused a radioactive debris cloud, illustrating limits in existing liability provisions[7]. Worryingly, catastrophic space debris chain reactions (Kessler Syndrome) could limit human access to LEO in the mid- to long-term[8].

Industry, national, and international actors are working to address the debris problem. EIAs would neither duplicate nor replace this effort but rather inform it. This is a strength as EIAs require consideration of impacts at the point of the decisionmaker but leave potential restrictions to other policies. They also provide public documents that States can use to understand other State's activities and to inform their own space due diligence.

Beyond space debris, emerging NewSpace activities pose many space environmental risks including biotic and abiotic contamination of celestial bodies, radioactive pollution from space nuclear power, interference with radio astronomy, and worsening space traffic. EIAs are advantageous because they can address each of these human impacts on the space environment to inform future regulation and industry practice, if necessary.

In early 2019, Israel's Beresheet lander crashed during a landing attempt on the Moon. Unknown to the launching states and spacecraft team, part of the payload sponsored by the Arch Foundation contained 'smuggled' tardigrade life[9]. Although the illicit nature of the payload is problematic there was a process issue. FAA launch licenses treat payload review and EIAs separately[10]. Including payload review within the EIA would require disclosure of such potential impacts and enable countries to make informed authorization decisions.

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4 Kramer, W.R. (2014). Extraterrestrial environmental impact assessments – A foreseeable prerequisite for wise decisions regarding outer space exploration, research, and development. *Space Policy*, 30, pp. 215-222.

5 Kramer, W.R. (2017). In dreams begin responsibilities – environmental impact assessment and outer space development. *Environmental Practice*, 19(3), pp. 128-138.

6 NASA (2015). *NASA Engineering & Safety Center Technical Update: 2015*. Available at https://www.nasa.gov/sites/default/files/atoms/files/techupdate-2015-onepage.pdf

7 Weeden, B (2010). *2009 Iridium-Cosmos Collision Fact Sheet*. Secure World Foundation. Available at: https://swfound.org/media/6575/swf_iridium_cosmos_collision_fact_sheet_updated_2012.pdf

8 La Vone, M. The Kessler Syndrome: 10 Interesting and Disturbing Facts. *Space Safety Magazine*. Available at: http://www.spacesafetymagazine.com/space-debris/kessler-syndrome/

Like any policy solution, environmental assessments are no panacea. There are limitations to what space EIAs could accomplish because they:

- Do not impose substantive restrictions
- Can be susceptible to political considerations
- Face uncertain or unknown space environmental impacts
- Must address low risk but high impact activities, like space nuclear reactors

However, the last two factors are the point of the EIA process; by identifying potential impacts, they can inform both science and subsequent policy decisions. The process itself becomes self-reinforcing; already, scientific analyses are beginning to address the scope and scale challenges of space EIA[11].

For example, a space EIA for lunar mining might identify impacts like regolith disturbance, landing risks, or toxic chemical leaks. Despite uncertainty, the space EIA would inform government of potential policies and industry of best practice. As Moon mining grows, new concerns might emerge, like the discovery of life, interference with other lunar surface activities, or risks from growing orbital traffic. The space EIA process can be iterative by identifying risks, providing a mechanism to study and understand those risks, and providing options for risk mitigation.

A Policy Pathway: Space EIAs for the U.S.

Due to established policy designs, EIAs can begin making space development safer and more sustainable almost immediately. Although all countries could benefit from including outer space, the original NEPA in the United States presents a near-term opportunity. The U.S. hosts many NewSpace activities, including space resources, space nuclear power, space tourism, and satellite constellations.

Under existing agency-level interpretations, NEPA does not require analysis of the outer space environment[12]. This is based, in large part, on Executive Order 12114 which advises that NEPA applies to the "global commons (e.g. Antarctica or the High Seas)."[13] NASA, FAA, and DOD interpret "e.g." as excluding outer space.

No court has yet addressed whether NEPA applies to outer space[14]. Several factors indicate agency interpretations may be wrong and NEPA should apply to the space environment:

- A plain reading of NEPA, a broad statute focused on the "human environment," finds its goals expansive and focused on managing the impacts of new technologies
- Extensive studies by US space agencies on elements of the "space environment" indicate it is a "human environment"
- Case law from *EDF vs. Massey* and other extraterritorial NEPA cases[15]

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9 Johnson, C.D., Porras, D., Hearsey, C.M., O'Sullivan, S. The curious case of the transgressing tardigrades. *The Space Review*, August 26, 2019. Available at: http://www.thespacereview.com/article/3783/1

10 Ken Wong. *Regulating and Licensing Commercial Space Transportation.* Presentation. October 17, 2018. Available at: https://www.nesdis.noaa.gov/CRSRA/pdf/FAA_COMMERCIAL_TRANSPORTATION.pdf

11 Mustow, S.E. (2018). Environmental impact assessment (EIA) screening and scoping of extraterrestrial exploration and development projects. *Impact Assessment and Project Appraisal*, 36(6).

12 The National Science and Technology Council on Transportation Research and Development (1995). *Interagency Report on Orbital Debris 1995*. Available at: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20000011871.pdf

NEPA could thus apply to U.S. and U.S.-authorized activities in outer space if a future Administration updates E.O. 12114, someone brings a successful lawsuit, or Congress clarifies Congressional intent.

Conclusion

Environmental impact assessments offer a potential comprehensive solution to guide human expansion into space in a safe and sustainable way. They provide an internationally recognized process that can inform both future activities and policies. They can also be a tool for States to meet their international obligations under the OST and other treaties. By making sure that all nations and peoples are 'looking before they leap', we can all leap safely together.

[13] Exec. Order. No. 12114, 3 CFR 356 (1979).

[14] Gerrard, M.B., Barber, A.W. (1997). Asteroids and Comets: U.S. and International Law and the Lowest-Probability, Highest Consequence Risk. *NYU Environmental Law Journal*, 6(4).

[15] Klick, K.A. (1994) The Extraterritorial Reach of NEPA's EIS Requirement after *Environmental Defense Fund v. Massey*. *The American University Law Review*, 44, pp. 292-322

How Can Humanity Expand Into Outer Space in a Safe and Sustainable Way?

The prioritization and improvement of ethics, planetary protection, and safety standards in the astro-sciences is the most critical priority as our scientific and exploratory capabilities progress, both within government agencies and the private sector. Given the inevitability of the private sector in influencing future crewed missions both in and beyond low-Earth orbit, it is essential to the science community to agree on universal standards of safety, mission assurance, planetary protection, and especially anti-colonization. The existence of oversight bodies to enforce planetary protection and communication between public, private, and academia is necessary. Delegation of power and strict communication standards not only to protect the lives of the explorers, but protect the environments of wherever humanity decides to venture. Opening up the multidisciplinary approach of space exploration to international law and governance regarding planetary protection, safety, mission assurance, and creating comprehensive and ethical standards across all space faring institutions is needed for the future of space exploration. Ultimately, moving international space law and domestic space policy from a reactive nature to a proactive one will ensure the future of space exploration is one that is sustainable and safe.

While planetary protection standards are mandatory for all exploration missions, it is rare that scientists, scholars, and scientific policy writers actively integrate these standards in a mission. NASA has protectionary standards set in place for robotic missions, but a 2018 NAS report describes these standards as "inadequate". For crewed missions, standards are non-existent and will be the most difficult to create and implement due to the human body's physiological limitations. Additionally, the new and quickly evolving private industry and non-federal space actors largely experience regulatory gaps when it comes to protection standards, adherence to international space customs, and subsequent bioethical standards. With inevitable exploration of other bodies in the solar system, regulatory entities such as NASA and international partners must lead the effort to create and enforce planetary protection standards, cultivate a pathway with delegated authority for crewed and uncrewed space exploration, including tourism and commercial activities. In addition, all participants in space exploration must also adopt anti-colonization standards and protocol to ensure equal and fair participation in space. By actively implementing strict safety customs from the individual level, the proper chain of command via the respective government can ensure enforcement of standards in the form of an independent and strengthened planetary protection office (PPO).

Universalization of standards is heavily reliant upon building and maintaining a regulatory and communicative global infrastructure. Delegation of safety procedures would be best executed by a PPO, active ad-hoc committees, and other representatives involved in mission communication and enforcement. Implementing this infrastructure would bridge the regulatory gap between private and public sectors. Without the implementation of practicing safety norms and customs from mission management bridging public and private, any formal establishment of law will not have a solid practical foundation. Therefore, actions must be taken by governments ultimately responsible for these exploratory actions to allow the authority of the agency to constantly monitor, communicate, and enforce safety and protectionary regulations including private sector partnerships.

Mission safety can also be improved by working with the astronomy community to research potentially hazardous environmental concerns, such as quantifying and mitigating radiation exposure during long-period spaceflight, the effects of planetary regolith on mechanical systems and human health, potential in-situ equipment failures, and detection of potential life forms. This is also crucial in changing reactive policy to proactive – rather than wait for tragedy to strike, all areas of safety are heavily accounted for via collaboration with scientists and policy makers alike. However, such collaborations between members of the space science community and the private sector aren't limited to planetary missions. The recent launch of SpaceX's Starlink satellite constellation raised concerns among the astronomy community due to the effects of an artificial constellation on ground-based astronomy. The public outcry could have been avoided with an ethical/communicative oversight body working from mission conception to not only mitigate the constellation's effects on observing efforts, but to assess the impact of Starlink on all stakeholders. This would allow for innovation and competition from the private sector to continue to flourish while holding private science to the standards used by government agencies and public science.

Furthermore, having highly collaborative and communicative leadership between public institutions, private industry, and academia can help in ensuring safety on Earth. For example, an inter-agency framework with respect to the safety and biothreat control of spacefaring missions can prove to be another method of creating proactive public health policy. In the United States, partnership with the Department of Energy, the National Institutes of Health, and relevant agencies on comprehensive study and assessment of microbiome survivability in closed systems such as the ISS not only helps relieve NASA of studying these effects alone, but helps build an intellectual framework that is transparent and sharing in nature that all parties can benefit from, and that can be used for other matters, such as the United States National Biodefense Strategy, or future space tourism safety procedures.

Safety and international cooperation meet at the intersection of sustainability and ethics in exploration. "Seeking to prevent a new form of colonial competition" was the very premise to the OST. It is important for space-faring nations to remember that colonization is a structure; an institutionalized virtue stemming from exploitation of (often native) populations to preserve a central selfish ideal of preserving the way of life as seen by the colonizing nation. It is paramount that the astro-community not only recognizes colonialism and imperialism in the premise of settling other planets/celestial bodies and their orbits, but also work together to prevent further colonialism on Earth. A proper check to colonialism from the astro-community takes the example of the Thirty Meter Telescope (TMT) in Mauna Kea, Hawaii. Ground-based observing, as well as other astro-science related developments, cannot and should not take precedence over lands belonging to Native populations, and the environment.

Because space exploration is an extremely large, global, and mostly unified effort, governments will be at the helm of exploration and ensuring updated and proactive exploration policies for the foreseeable future. In this light, all levels of every science mission are encouraged to actively participate in effectively creating the norm of checks and balances. Never before has a space agency asked for reviews of ethics and safety in a mission. Minding other cultures and ensuring space for all, even as just a practice, would solidify peaceful relations in space, safety of all astronauts and all spacecraft, and preservation of resources. As the world progresses in technological and scientific advancement, policy and safety standards must also remain transparent and adequately communicated across all agencies and governments. Thus, it would benefit governments and their respective agencies to utilize true terra nullius law. Rather than protecting state interests in space, space is to be protected by all states in collaboration for peaceful exploration and scientific advancement to allow for sustainability that does not benefit one agency or state. This works to further ensure that space remains international, collaborative, and cooperative, and avoids unnecessary conflict.

In this case, sustainability and safety in space is reliant upon ensuring peaceful purposes in space via international collaboration. Avoiding conflict, or one-party “domination” in space, serves to protect non-Earth environments, resources, and future astronauts and rovers.

Applications of synthetic biology in biosafety and planetary protection

Synthetic biology is a rapidly emerging field combining advances in life sciences with an engineering approach. It is based on the idea that biological systems, like genetic circuits, biochemical pathways, and whole organisms, can be designed and constructed in the same manner as electrical or mechanical systems. Innovations in this interdisciplinary area hold great potential to revolutionize numerous branches of the industry, including agriculture, energy, manufacturing, and pharmacy, improving the lives of millions of people. Novel, sustainable biological technologies are particularly important in space exploration, due to its many limitations, for example extremely high cost and limited payload volume. Among proposed applications of so called space synthetic biology are biopolymers synthesis, food production, *in situ* resource utilization, propellant generation, and waste management (Menezes et al., 2015).

However, progress in this field raises a wide range of issues, like concerns about physical harm, legal complications, and social implications. Although many of them are shared by both Earth-based and space-applied synthetic biology, some are specific to the latter. One of them is planetaty protection policy that aims to prevent biocontamination of both Earth and other celestial bodies. Microbes are particular object of interest, as they are able to survive in unexpectedly extreme conditions on Earth and possibly beyond. Ethical, legal and societal implications of so called space synthetic biology were discussed in detail by Race and colleagues (Race et al., 2012).

It should be noted, though, that synthetic biology offers us not only new production techniques, but also multiple ways to ensure biosafety. Bioengineered organisms have substantial advantage, because they can be made more predictable, reliable, robust, and safe than many natural systems. Synthetic biology itself might resolve at least some of the raised issues and enable us to expand into outer space in accordance with the principles of biosafety and planetary protection.

One of the earliest and most well-established biocontamination strategies is the construction of auxotrophic strains that are unable to synthetize particular compounds essential for their survival. These compunds must be provided externally in the culture medium, which prevents microbes from growing outside the strictly controlled environment. Method dates back at least as early as 1977, when Curtiss and colleagues developed *Escherichia coli* strain χ1776, that has dependency on diaminopimelic acid (DAP) and thymine or thymidine supplementation. Since then, systems based on auxotrophy have been improved and are still in use (Whitford et al., 2018).

Even though auxotrophy can be sometimes introduced by a single point mutation, e.g. in the promoter region, it might be easily overcome by a reversion. Complete deletion or replacement of a gene responsible for biosynthesis of specific compund is much safer approach. An example of this is project of biosafety system for cyanbobacterium *Synechocystis* sp., presented on iGEM by team Amsterdam 2015. In order to contruct stable carbon producing strain, the team has developed an algorythm called "Auxotrophy Sniper", which was used to find optimal ways to create such an organism (Vecchini et al., 2015). This particular microbe is important, as it was proposed by Menezes and colleagues as a promising candidate for sufficient acetaminophen production during space missions (Menezes et al., 2015). Acetaminophen, also known as paracetamol, was examined in inflight and ground-based studies in simulated microgravity (Kast et al., 2017).

Redundancy, which is commonly used to increase spacecraft safety, may be applied to build more reliable biological systems too. Triple auxotrophic mutant of multidrug-resistant *Mycobacterium tuberculosis* was suggested as safer candidates for the studies on tuberculosis – disease that caused around 1.6 milion deaths in 2017 acording to WHO's report (Vilchèze et al., 2018; WHO, 2018).

Most bioengineered strains have auxotrophy for aminoacids or vitamins, but there are many possible dependencies for substances that do not occur naturally, like unnatural amino acids. This might be vital for astrobiology and space synthetic biology, because some organic compunds can be synthesized abiotically. For example, aspartic acid was succesfuly produced in both Miller–Urey (Miller & Urey, 1959) and H_2S-rich spark discharge experiments (Park et al, 2011), so it should be excluded as a potential target. Auxotrophy-based systems for properly selected, synthetic compunds might be in the future the most basic form of built-in protection from bioconatmination of other celestial bodies.

Auxotrophy prevents microbes from survival beyond very specific enviroment, but to immediately eliminate an organism, kill-switches might be applied. In essence, kill-switch is biosafety strategy based on gene circuit, that blocks the expression of essential genes or induce synthesis of toxins, both of which lead to death. Activation occurs in the presence or absence of specific signal, often chemical in nature. An example of a kill-switch is the construct consisting of the gene hok, encoding membrane-depolarizing lethal toxin, and tryptophan-repressible promoter, that controles it. In case of lack or low concentration of tryptophan, which has to be supplied in the growth medium, bacterium would produce toxin, effectively killing itself (Simon & Ellington, 2016). This bears similarity to mechanism of action of auxotrophy-based systems and those two can be combined. Modern kill-switches are more advanced, offering higher stability and robustness through the deployment of various solutions. For example, "Passcode" microbial kill-switch uses simple logic gates – organism survives only in the presence of inputs called a and b and absence of input c (Chan et al, 2016).

Kill-switches can be designed to efficiently work in many different conditions. "Cryodeath" switch, based on cold-inducible promoter, responds to changes of enviromental temperature, allowing bacteria to grow at 37°C and significantly reducing survival ratio below 22°C (Stirling et al 2017). Temperature-sensitive switch may be introduced into the DNA of organisms destined for Mars as additional safeguard. Among other potential activation signals are ultraviolet light and components of martian regolith.

Many kill-switches depend on the external signal, but there are alco ciruits that activate in response to the internal cell state. Team LMU Munich 2012 presented a kill-switch for *Bacillus subtilis* at iGEM competition that eliminates germinating spores (Team LMU Munich).

Genetic tools dedicated for this species are of great importance for several reasons. Firstly, it is model organism in space microbiology. Its spores possess great resistance to extreme conditions and are able to survive even in extraterrestrial environment, being a serious threat to planetary protection. At the same time, *B. subtilis* is efficient cell factory for many proteins and at the time it was resposible for production of about 60% of the commercially available enzymes (Westers, Westers, & Quax, 2004). This makes it a promising candidate for further research.

Auxotrophy and kill-switches are only two of many potential biocontamination strategies that can be applied in space synthetic biology. This field was described as being in an embryonic stage and much more attention should be paid to its further advancement. Although we already have some basic technological solutions that can be applied as a part of more sophisticated systems, in order to ensure biosafety of space missions and planetary protection.

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How Can Humanity Expand Into Outer Space in a Safe and Sustainable Way?

There is no doubt humanity has already started on the journey of expansion into outer space-whether one considers outer space to be earth orbit, Moon, Mars, our solar system or beyond (or all of these), human beings or our robotic assistants have extended:

(a) our knowledge and awareness;

(b) our presence (temporary in the case of the Moon, permanent in the case of low earth orbit with the ISS); and

(c) (to a much less extent and only in earth orbits) our control and use.

Indeed, with our decades of experience with the early attempts at unlocking the space age, we do have a number of lessons and ideas which we would do well to retain as we chart the next steps. This essay attempts to record five key points, with a focus on a safe and sustainable expansion of (a) to (c) above into outer space.

(1) "Humanity" as a (increasingly) united global community

While international competition may spur innovation and funding commitment, outright global conflict would be counterproductive for sustainability. For example, a war in space would set us all back in terms of space infrastructure and potentially destroy the relevant environment in space (be it the orbits or other planetary bodies).

Although several decades of space utilisation has left only the least jaded hypothesising that the space age would herald greater harmonisation and convergence of human societies, it bears remembering that we expand into space as a single humanity and not as disparate arbitrary nation states. If policymakers and diplomats can dedicate themselves to this cause as humanity expands its existential reach into outer space, idealists have reason to be hopeful.

(2) "Step-by-step" incremental approach

We have learnt that few grand one-off space projects have tangible outcomes and most play minor roles in the expansion story (except as increasingly faded inspirational memories). In contrast, the less sensational and more practical, incremental advance of remote sensing, communications and (to an extent) geo-positioning satellite systems now pervade our immediate orbits with no slowing down. We must therefore be wary of headline-grabbing projects (especially those which are patently unsafe) and focus our energies on more practical, sustainable efforts.

The incremental approach would also allow us to slowly make technical and tactical corrections to our course, increasing safety of the participants (both physically and economically) and the space environment (be it orbits, asteroids or planets). There would be no greater disaster than a reality-showesque destruction or irreversible depletion of the lunar surface by early settlers who are sent there on a one-off fantasy project. Going step-by-step steadily might allow us to consider more comprehensively. Robotic pilot projects would conceivably be helpful.

(3) Finding and sharpening the economic spur

Of the three categories of expansion listed in (a) to (c) in the first paragraph above, the greater value of the space age would likely derive from (c) control and use. The global community is currently engaging in an unprecedented contest to find the best ways to privately fund infrastructure, logistics and projects beyond our orbits, and invariably most business cases would revolve around monetising (c).

Humanity would have to solve the international space law questions relating to control and use of space resources – humanity's expansion into space would be derailed if satisfactory resolution is not forthcoming.

Inevitably, the lobbying for state subsidy (in terms of funding, tax breaks), protection (in terms of security in space or economic contracting and monopolies) of commercial foray into outer space would intensify. One may even argue that the space industry today remains buttressed by state support. Yet, if such state support is sustainable there is no reason to deny entrepreneurs of the state as a customer (or potential customer). Policy-makers have a role to play to ensure economic sustainability of government space projects, and impose compliance requirements around health and safety of human participants.

(4) Global technical standards and sharing of know-how

From the engineering and technical angles, the expansion of humanity (be it through human beings or robots) into outer space would be facilitated if global standards (from the plug and socket types in a moon base to the docking mechanism of spaceships) are agreed upon and accepted. This is not impossible to achieve, given that even the Cold War opponents could agree on compatible rendezvous and docking systems in space and deliver the Apollo-Soyuz Test Project in 1975.

It would avoid duplication if scientific data and know-how can be shared and it would reduce wasted time and funds if academics can develop upon each other's research findings and experience gained from projects. It bears noting that current efforts are possibly duplicative and wasteful, and wastefulness would reduce the degree of sustainability. However, this issue is connected to point (1) above and hopefully there is a potential of greater sharing of technical data and know-how if the global community is able to steer itself towards greater unity (at least in the domain of space).

(5) A focus on the long term

If humanity's expansion into outer space is to be safe and sustainable, actors must as far as possible abandon short-termism and dedicate themselves to keeping a long term view. In terms of actual usage of space resources for example, this would mean not overusing/depleting resources or polluting the environment (i.e. unlike the case with the deforestation of, and industrial pollution on, earth). In terms of use of orbits and space environments for example, this would mean not creating or leaving man-made debris that will endanger or threaten the safety of future use.

If the market fails to incentivise responsible behaviour by economically and profit-driven actors, policy-makers would have to step in to impose compliance requirements which are in line with such long term thinking. In designing such international compliance mechanisms, policy-makers should also maintain a long-term view and refuse short-term political influences.

Conclusion

As humanity readies itself for the next phase of the space age, it needs to do better in terms of galvanising all of its members and consolidating its knowledge domains (scientific, technical, engineering, business, finance, legal etc) to make a concerted advance. Humanity would have to, as a planet, think long term, involve all stakeholders, share and collaborate and build on all mankind's strengths and knowledge, to push the envelope on all fronts and usher a period of safe and sustainable expansion into outer space.

TAT-mediated Protein Transduction as A Method for Increasing Intracellular Glutathione Levels in Astronauts

21th century comes along with great challenges and prospects for humanity. A major vision of our species, in this context, is the expansion in outer space and the exploration of cosmos. However, as space is a tramontane and adverse environment for a human being, much effort and research have to be accomplished, in order to secure the safety of the future, extending space travels.

Irradiation is a contributory factor regarding the inhospitable conditions of space. On Earth, living organisms are protected by mutagenic radiation due to planet's magnetic field and atmosphere's ozone layer. Because of the absence of these factors in outer space, astronauts are exposed to extremely high levels of ionizing radiation. Furthermore, microgravity constitutes a great and insinuating enemy for space travelers, as human bodies and metabolism are evolutionarily supported to be maintained on Earth's 1G gravity. Cosmic irradiation and microgravity are considered as the main factors responsible for the significant and uncontrolled production of reactive oxygenated species, like hydrogen peroxide and superoxide anion, which leads to the pathological situation called oxidative stress (Goodwin & Christofidou- Solomidou, 2018; Blaber, Pecaut & Jonscher, 2017; Crucian et al., 2018). Oxidative stress is a phenomenon that causes a variety of problems to astronauts. Indicatively, abnormalities in immune activation and inflammation processes (Crucian et al., 2018), alterations on skeletal system and osteogenesis (Alwood et al., 2017) and impacts on cardiovascular system (Tahimic & Globus, 2017; Takahashi, Okumura, Guo, Naruse. 2017) and liver (Blaber et al., 2017) are only some of them. Thus, it is clear that combating oxidative stress and its effects is a necessary condition, if we really want to materialize long and distant space explorations.

The tripeptide glutathione, known as GSH, seems to play a key role, in order to achieve this goal. GSH is the most important and potent antioxidant found in cells (Forman, Zhang & Rinna, 2008). It is synthesized in cytosol in virtually all cells (Meister & Anderson, 1983), including two ATP-requiring enzymatic steps. The first one is considered rate-limiting (Dalton, Chen, Schneider, Nebert & Shertzer, 2004) and is catalyzed by the enzyme glutamate cysteine ligase or GCL (Lu, 2008). GCL is formed of a heavy or catalytic (GCLC) and a light or modifier (GCLM) subunit, which are encoded by different genes in humans (Huang et al., 1993; Meister, 1974). GCLC subunit is the relatively heavy one and can be feedback inhibited by GSH (Huang et al., 1993). As the lower molecular weight subunit, GCLM regulates the activity of the enzyme by reducing the inhibition by GSH (Huang et al., 1993; Choi et al., 2000). The second step of GCL's biosynthesis is catalyzed by the enzyme GSH synthase (GS), which is not able to regulate GSH's intracellular levels in a significant scale (Lu, 2008). Glutathione's powerful antioxidant action is based on its ability to be oxidized to glutathione disulfide (GSSG), while the corresponding oxidative molecule or ion is suffering reduction and inactivation. GSSG is then reduced back to GSH, forming a redox cycle (Lu, 2008). However, despite its great antioxidant role, GSH is not synthesized in large quantities by the majority of human cells (Backos, Brocker & Franklin, 2009). So, by the fact that notably increasing levels of oxidative stress and damage on astronauts during long and remote space missions require even stronger antioxidant responses in order to keep their homeostasis, raising GSH's intracellular levels may be a decisive step for astronaut's health and safety securing.

But, how could we increase GSH biosynthesis in astronaut's cells in a safe way? A variety of methods have been developed and tested aiming to GSH's levels increase, mainly involving transgene expression, both viral and non-viral (Backos et al., 2009). However, these approaches conceal plenty of possible dangers, especially for cosmonauts and the extreme conditions they are going to expose to, regarding toxicity and proinflammatory responses (Schwarze & Dowdy, 2000; Wadia & Dowdy, 2005). In contrast, a method that is evolving during the last decades, called TAT-mediated protein transduction seems to be the most appropriate and safe one for the special case of astronauts. This process is based on a transduction domain found in HIV-TAT protein, called TAT-domain (Becker-Hapak, McAllister & Dowdy, 2001). This sequence has the capacity to transduce in cytosol full-length proteins, independently of protein's length, weight or largeness, via a receptor-independent mechanism and most importantly, in a safe way, as TAT-domain does not get involved in HIV's infectious materials (Becker-Hapak et al., 2001). Procedures include the construction of TAT- GCLC and TAT-GCLM fusion proteins from bacterial expression plasmids and then their isolation from the bacterial culture via centrifugation and sonication (Backos et al., 2009; Becker-Hapak et al., 2001). Afterwards, fusion proteins are able to penetrate, *in vivo*, in a living organism and its cells, via injections (Schwarze & Dowdy, 2000). TAT-mediated transduction especially for the raise of GCL's intracellular levels has been developed only once *in vitro*, but with at least remarkable results (Backos et al., 2009). Transduction of TAT-GCLM or TAT-GCLC only resulted to a significant elevation of both GCL and GSH, while co-transduction with TAT-GCLM and TAT- GCLC fusion proteins increased even more cellular GCL activity, raising GSH by 75% (Backos et al., 2009).

The advantages of this approach for astronauts are numerous. First of all, TAT-fusion proteins have the ability to transduce into the smashing majority of cell types, including those present across the blood-brain barrier (Schwarze et al., 1999; Schwarze & Dowdy, 2000). This capacity is extremely important for space travelers, as the total of their bodies and, consequently, their cells (involving brain's ones) are going to be exposed to cosmic irradiation and present oxidative stress. Thus, a treatment which is applied in the ensemble of cells is judged as requisite, in order to successfully protect the crew. Furthermore and as mentioned before, phenomena like toxicity and immunological reactions, which would cause severe problems for both the astronauts' wellbeing and mission's completion, are avoided, because there is no use of infectious sequences. Moreover, the main method which is proposed to storage the purified fusion proteins until their use is freezing at -80 degrees of Celsius with the presence of glycerol (Becker-Hapak et al., 2001), something very easily applied in extremely cold temperatures of space. So, the necessary quantities of TAT-fusion proteins could be produced from bacterial cultures and get purified on land and then be saved on the spacecraft, in order to be used by astronauts via injections in the most suitable parts of their bodies.

In conclusion, TAT-mediated protein method seems to be an effective and safe approach, so as to achieve an increase in intracellular GCL’s levels and activity and by this way gain at maximum point the benefits of glutathione’s protective, antioxidant action. Thereafter, a new field for innovating and extended capabilities and opportunities is coming up, in our effort to make the future, long and distant space travels a safe and realizable case.

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How can humanity expand into the outer space in a safe and sustainable way?

The safe and sustainable exploration of the outer space is an important step forward for humanity. Such an achievement requires advanced technological development and the critical consideration of different aspects of the exploration. Human safety and sustainable progression towards this goal is a topic to debate for the future of humanity. In addition to technical capability, peace policy and law should be emphasized for a safe exploration. Similarly, much should be done on the ethical exploration of outer space to ensure the preservation of human values in outer space. The main idea of this work is to use our Earth experience to learn from our well established and functioning law and policies, as well as, our challenges on peaceful law and technological agreement to anticipate challenge/conflicts in the outer space human expansion.

Space exploration presents several advantages to humanity namely the understanding of the universe, the space pioneered technologies used on Earth, and STEM (science, technology, engineering and mathematics) work force empowerment through space mission challenges. The space pioneered technologies has led to the innovation of solution that arise on the Earth. Among these technologies is the memory foam, developed by NASA 1970s and is used to improve seat cushioning and crash protection for airline pilots and passengers. We can also cite the digital image processing developed by the Jet Propulsion Laboratory as to allow computer enhancement of Moon pictures. These technologies are inspired from the outer space challenges and have been used since for several applications on human health science, technology, and transport.

Referring to Planet Earth can inspire us for the proper implementation of sustainable law and policy to avoid similar current Earth issues on other planets to explore. The Planet Earth human damage on the nature such as deforestation, plastics use, and climate change can be avoided on the other planet by an early implantation of the proper policies. On Earth, years of work by the United Nation and similar organization have led to the establishment of policies that are mitigating anthropogenic and natural disaster activities that are affecting the Earth. These policies have been polished and can be used to the outer space in a safe and sustainable way.

Among the policies of the planet Earth to implement for a safe and sustainable exploration of the space, one finds the use of biodegradable and the reusable materials in mission, such as, shuttle mission, waste and water recycling. The reuse of materials, to which reference can be made to green space exploration, can be encouraged to reduce space debris as well as the financial cost. On the other human side, the UN-SDG (the United Nations Sustainable Development Goals) can be a framework for guiding the outer space human habitat, which we refer to the UN-SDG Framework for space exploration (UN-SDG FSE). The UN-SDG is designed frameworks consider all the aspect of human dignity, development and health, hence their re-use in the outer space can ensure human civilization sustainable exploration.

Similarly, a policy on the ethical exploration of outer space must also be anticipated. Technological advances in robotics and artificial intelligence will make space exploration possible. However, without appropriate limits to the use of these technologies, human ethical values may be at risk. Therefore, ethical law should also be included in space mission policies. These ethical laws should be limited to the proper adjustments so that human values and dignity are preserved. These ethical laws can also regulate human and trans-human social interaction prior to the establishment of human settlement in space.

The peaceful and sustainable human expansion in the outer space establishment requires the global agreement for space law and regulation. On Earth, difficulties on the climate change agreement and application can imply that much effort would be required for nation on the human expansion, and land distribution agreement etc.

Besides, the choice of technology regulation and policy would also be a challenging issue to probably anticipate. The current 5G (5 generation of mobile telecommunication technology development) capability on Earth inspires the importance on technological regulation for the safe and sustainable human expansion in the outer space. Its development, installation and data access capability can lead to security issues to anticipate. The earlier technology regulation and policy are a necessity so that technological provider would have sufficient time to elaborate proper measurement to addresses issues. However, the collaboration of space agencies on different mission and projects such as the International Space Station is a sign of human potential and capability for a global action on the space exploration.

The space exploration and human expansion in the outer space have several advantages for humanity. However, to achieve this goal in a safe and sustainable way, it is necessary to critically examine the key elements to be taken into account. By learning about the Planet Earth global challenges, this goal can be achieved through green space exploration, UN-SDG Framework for space exploration, and the ethical exploration of outer space. An exhausted list can be described, however, we believe that these three essential elements are a fundamental for a safe and sustainable human expansion in the universe.

How can humanity expand into outer space in a safe and sustainable way?

During the past 200,000 years, mankind has been adapting to the terrestrial ecosphere[i], which has now become essential for its survival. Colonizing and expanding into outer space regions safely and endurably necessarily leads to obtaining independence from Earth. Such autonomy can only be achieved through the foundation of a new self-sustaining environment that may satisfy the physiological needs of human beings, described by Maslow's *Hierarchy of Needs*[ii]. At the basis of any living carbon-based life form, there is liquid water[iii]; this one has already been found on the Moon[iv], on Mars[v] and other celestial bodies[vi]. Prior to settling in deep space territories, it is mandatory to establish the presence of a nearby water source through the several technologies that have already been developed and used in the cases previously mentioned. Henceforth, it is possible to pursue the main idea behind this essay: the constitution and evolution of an extraterrestrial ecosystem that includes the indispensable fauna and flora for future outer space human settlements.

With regards to the latter one, there are several benefits that encourage its development as “plants can metabolize carbon dioxide in the air to produce valuable oxygen, and can help control cabin humidity”[vii] as well as potentially representing unlimited nutriments. However, it has already been taken into consideration by several organisations such as NASA[viii] and ESA[ix] which are currently investigating the feasibility of this project. I will therefore mostly dwell on the former aspect of such an ecosystem.

Animals were first sent to space in 1947, more than a decade earlier than humans, starting with fruit flies, monkeys and then dogs[x]; the initial flights showed that animals could survive weightlessness and the effects of high gravitational forces[xi]. In the mid-‘70s, thanks to the Skylab space project, further research was led on different species and it emerged that they adapted “amazingly […], within 5 minutes, (they) are floating in their living spaces, grooming themselves, and eating, just as they would on Earth” [xii].

According to the Earthwatch conference: “Which is the world's most invaluable species?”, that took place at the Royal Geographical Society on 20th November 2008[xiii], scientists and professors discussed the five most important species to human survival[xiv]. For the purpose of this essay, I will abide by such results and briefly assess the following species’ suitability and adaptability to space – In order, starting from bees, plankton, bats, fungi and then primates.

“Without bees, humans would starve. These industrious little insects are the world's greatest pollinators, carrying a dusting of pollen from flower to flower as they gather nectar for their hives. Millions of years of evolution have seen many plants become almost entirely reliant upon bees to help them breed.”[xv] Experiments performed on 3400 worker bees and one queen bee, during the 1984 Space Shuttle Challenger mission, “showed complete adaptation to microgravity […]; the bees were even able to produce honeycomb and the queen laid around 30 eggs”[xvi]. Their presence would be exceptionally valuable to humans in space by sustaining entire crops and guaranteeing their maintainability.

Another fundamental organism for humans is the plankton; they are the main producer of atmospheric oxygen as well as the primary element of the whole food web[xvii]. These organisms can also withstand extreme temperatures "being encased in ice in our Antarctic and Arctic oceans and surviving near-boiling water during the spring"[xviii], making them an ideal candidate for a space ecosystem. In fact, in the presence of water, they would be able to generate great quantities of oxygen for future colonies. Vladimir Solovyev - Head of the Russian ISS orbital mission – found plankton in 2014 on the outside of the International Space Station confirming that they can live "amid factors of a space flight, such as zero gravity, temperature conditions and hard cosmic radiation. Several surveys proved that these organisms can even develop (in outer space)".[xix]

As regards to bats, they perform essential ecological roles in our ecosystem, most of which might potentially be advantageous in an extraterrestrial environment. They seed-disperse as well as pollinate a wide variety of flowers and "improve the genetic diversity of cross-pollinated plants"[xx]. These mammals, in addition to being mostly insectivores and fructivores, have been very successful at adapting to extreme habitats; they are nocturnal animals that master echolocation and that by nature have light skeletons[xxi]. Unfortunately, there currently is no experiment that shows bats behaviour in orbit, but their adaptability suggests the possibility of a future space contestant.

Fungi are one of the most important organisms of our planet. They are responsible for the recycling of organic material which returns dead material to the soil and for the growth of most plants, including crops, through the development of mycorrhizal associations[xxii], which are essential for the productivity of the land. These organisms can also be extremely useful in biocontrol to monitor insect pests and animal diseases. Directly useful to humans, some fungi are even edible and may provide substantial nourishment[xxiii]. Furthermore, they can be utilized in the medical field through the production of antibiotics; the discovery of the penicillin is an example. Surprisingly, fungi would easily live in space, as it happened in 1997 onboard the MIR when it was noted that they "have an abundance of radiation-shielding antioxidants containing positively-charged manganese"[xxiv] protecting them from cosmic radiations as well as reproducing faster than on Earth due to the absence of friction caused by gravity[xxv].

Finally, primates "provide ecosystem services we all depend upon – especially absorbing carbon while releasing oxygen through photosynthesis and pumping water into the atmosphere through evapo-transpiration"[xxvi]. During the space age, the United States, the Soviet Union and other countries performed several orbital flights on apes to successfully prove that they could survive[xxvii]. Additionally, monkeys have a similar physiological and anatomical structure to that of humans, meaning that they would adapt positively to an alien territory.

Reproducing a safe and autonomous ecosystem in an unfamiliar world represents an arduous challenge. It would be vital to devise an enclosed greenhouse with liveable humidity, temperature and pressure ranges. Animals and plants would breed and increase exponentially. Some new species might form and evolve. Some others might even adjust and survive exposure to the vacuum of space, as *tardigrades* have shown[xxviii]. Humans will eventually expand permanently into outer space and survive. In the words of Charles Robert Darwin, "it is not the most intellectual of the species that survives; it is not the strongest that survives; but the species that survives is the one that is able best to adapt and adjust to the changing environment in which it finds itself"[xxix].

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How can humanity expand into outer space in a safe and sustainable way?

Throughout the last few decades, thanks to the development of space technologies, humanity could have expanded their activities into space and established the general principles governing space activities in accordance with international treaties and regulations.

Since 1960s, the international community has sought to regulate space activities within the framework of international treaties. Now, all space activities will be governing under the legal framework of outer space activities consisting of five international treaties; the 1967 Outer Space Treaty (OST), the 1968 Rescue Agreement, the 1972 Liability Convention, the 1975 Registration Convention, the 1979 Moon Agreement, resolutions of the General Assembly of the United Nations, and the national space legislation of space faring countries.

According to Art 1 of the 1967 Outer Space Treaty, the exploration and use of outer space should be regarded as the ‘province of all mankind’ regardless of economic or technological developments of states. Thus, the usability of outer space should be free remaining accessible for all states. However, the freedom of outer space is not limitless (Popova, R. Schaus, V. 2018) and ensuring the sustainability of outer space activities not only in the short-term vision, but on a long-term basis should be taken into consideration because human's dependency on outer space is growing every day. One of the limitations which is relevant to the sustainable use and exploration of outer space and celestial bodies would be the environmental protection of outer space. Taking measures to preserving the outer space environment would definitely ensure the sustainability of outer space. Article IX of the OST as the basis for the environmental protection of outer space highlights the importance of preventing space activities to pose a risk or harm other states. This article provides that states parties shall conduct all their activities in outer space, including the Moon and other celestial bodies, with due regard to the corresponding interests of all other states, and conduct exploration avoiding harmful contamination of outer space and celestial bodies and adverse changes in the environment of the Earth.

The main space environmental concern-space debris- could pose challenges to the safety and sustainability in outer space. As a consequence, accessibility and usability of outer space require long-term actions through which states are responsible to apply mitigating and remediation measures to preserve space arena for future generations. There is no reservation that space faring countries particularly emerging space countries and private sections are responsible for their activities which mirrors in protecting the safety and security of space environment avoiding risks which can be resulted from their activities. For instance, it is obvious that activities such as irregular increase of small satellites in orbits which is cost- effective could pose a danger on space environment. This is mainly because after launching, states will not have a constant supervision on those satellites, and do not have appropriate technologies to remove debris remained as space objects in orbits.

On international level, long-term sustainability of outer space activities and space debris issue (UNOOSA, n.d.) have brought into attention by the UN Committee on the Peaceful Uses of Outer Space (UNCOPUOS, U.N. Doc. A/AC.105/2017/CRP.26, U.N. Doc. A/AC.105/2018/CRP.20) in the light of setting guidelines for states. Since these guidelines are not legally binding instruments would mean that other certain measures shall be taken to address space debris as an environmental hazard issue. Reviewing of legal frameworks makes the lack of ensuring safety and sustainability measures thoroughly clear. To put it other way, space law treaties neither prohibited the creation of space debris nor imposed obligations on states to accept the consequences of their activities regarding to removing space objects from space orbit. Removal of space debris and mitigation measures have so far been adopted in the frame of soft law as non-binding instruments. In addition to that, high risk activities have been adopted by some states in their national laws. Due to deficiencies in space law treaties in defining concepts such as launching state, the space object, the necessity of registration and license of small satellites to secure safety of operations as well as space environment, space international community will be encountered with probable challenges raised from space actor's activities.

It seems that, on one hand, the registration of all satellites even the small ones should be the responsibility of states which can be defined by international community as an indispensable commitment to states, and co-operation of developed countries to sharing advanced technologies so as to enable emerging space countries to apply removal debris measures could be a crucial step forward on the other.

Due to the lack of legal and structural framework for ensuring the safety and sustainability of human activities in space, this essay is inclined toward providing some main ideas as solutions.

On international level, development of systems such as space traffic management strategies by establishing an international organization could ensure the secure, safe and sustainable future of space activities. On the other hand, presenting an idea of the national independent authority to secure space sustainability codifying space safety regulations on national level to be compatible with international regulations would be an effective solution by which humanity will be able to expand into outer space in a safe and sustainable way. The establishment of an institution which is capable to serve as a centralized model would be required. This step should be taken as the responsibility of states. An increasing number of States are adopting measures so as to minimize debris creation which can be an obvious threat to sustainability and space environment. However, significant importance is placed on state's responsibility to establish a way forward through best practices. A creation of such a new national space organization would be an opportunity to assure space operations by creating an effective collaboration between emerging space countries and developed ones in this industry to address the necessity of needs on risk mitigation resulted from space activities which can reflects the real meaning of space sustainability which is ensuring the safety of this arena so as to humanity can continue to use space environment for numerous peaceful purposes and benefit from its potentials ranging from Earth observation, telecommunications, navigation to national security intentions in the long term.

The development of safe, secure and sustainable human activities in space would require a coherent structure, uniform international law regulations and standards. As a consequence, what makes these ideas innovative might be a comprehensive outlook toward other legal regimes such as national and international air law which could play a pivotal role to determine the most effective and practical regulation as well as aiming at guaranteeing sustainable operations in space arena through independent authorized organization ensuring the safety and sustainability of space for all humankind.

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COSMIC ALGACULTURE: Harnessing Spirulina power towards safe and sustainable human space colony

Who would have thought that a man and even a monkey could go beyond the Earth? From the momentous journey of the Russian cosmonaut Yuri Gagarin who became the world's first man to reach the outer space and the pioneering animal spaceflight of the Rhesus monkey Albert 1, space colonization seems to be feasible.

With the ceaseless boom of 7.6 billion people in the world and the massive degradation of the environment, survival proves to be the biggest challenge for mankind. Thus, the quest for a safer and sustainable human space colonization idea of survival is initiated. This article will unveil the potential of the Spirulina or blue-green algae to sustain life into the outer space and show it can make useful energy for the Controlled Ecological Life Support System (CELSS). This will be seen, initially by discussing the characteristics of Spirulina, probing its life efficiency in space colonization, and then the milestone it can bring to mankind.

Spirulina can aid people in outer space by making oxygen they need. While the notion of space colonization might seem ferocious to any life form, one study states the Spirulina has withstood Earth's harshest conditions ever since 3.5 billion years ago (Vidalo, 2008). The study moreover insists 90 percent of the world's oxygen, accounting to around 330 billion tons, comes from the blue-green algae. These primordial organisms play a vital role in creating the Earth's atmosphere and UV Shield (Ozone Layer) through endless photosynthesis. If Spirulina did battle Earth's early floods, fires, and freezes, so will it in a closed vessel like CELSS. A group of Asian researchers likewise launch their 32-day gas closed experiment on three live Tilapias, a tropical freshwater fishes which flourish incessantly by obtaining oxygen gas from the Spirulina (Oguchi, Otsubo, Nitta, & Hatayama, 1987). The experiment boosts sustainability since both Tilapias and Spirulina benefit from their gas exchange. Spirulina collects carbon dioxide from Tilapias to make their food while Tilapias breathe in oxygen to live longer. In a closed vessel like CELSS, the use of Spirulina to produce a sufficient amount of oxygen for humans can be critical for space colonization.

Despite its nano-sized look, Spirulina can bring colossal nutrition to humans in the space colony. One research affirms Spirulina has been the food source of cosmonauts for long spaceflights (Edwards, 2008). Moreover, the study asserts that blue-green algae carry greater nutrients, vitamins, and minerals than land plants. True to its edible content, Spirulina will unlikely be intoxicated because its medium is heavily alkaline. If the Spirulina cultivation is eyed to halt global hunger, so is it in the CELSS which will serve some people first. Keeping in mind that Spirulina requires no time to boom exponentially, hunger might never be felt in a space colony.

Possessing its huge amount of biomass, Spirulina can form biofuels, sustainable for a space colony. In the modern world, skyrocketing power firms produce massive energy for society through burning non-renewable materials, specifically, fossil fuels and coal as their power machine's fuel. Aside from a long time it will take to replace non-renewable materials, burning it will surely annihilate the environment.

The use of Spirulina as fuel causes no pollution at all (Edwards, 2008). It otherwise converts light, water and carbon into oily compounds called lipids. The lipids can now be extracted and decayed into usable jet fuel and green diesel. Through the voracious appetite of Spirulina for carbon dioxide, the proliferation of carbon footprint across the space colony will come to an end. Aside from the Spirulina's natural way of making oxygen, the CELSS can also have its oxygen generator system to produce breathable gas (National Aeronautics and Space Administration [NASA], n.d.). The oxygen generator system will only run when filled with fuel, which can be derived from the biofuel of Spirulina. As the generator system starts to run, it will combine the water from Spirulina and the electricity generated from its fuel cells by the process called electrolysis. The combination of water and electricity reclaims oxygen for humans to breath and hydrogen to be released overboard. The chemical equation of electrolysis can be shown as ($2H2O + \text{electricity} < 2H2 + O2$). The integration of the fuel-powered oxygen generator system and algaculture will surely yield a massive reserve of oxygen for the space colony. Meanwhile, NASA is optimistic that people can have potable water to drink by executing the method called Sabatier Reaction. In this method, the hydrogen by-product of electrolysis will be combined with the carbon dioxide gas exhaled by people and the smoke itself from the CELSS machines. The products of the reaction are water for drinking and methane for overboard release. A chemical equation of Sabatier Reaction is provided ($4H_2 + CO_2 < 2H_2O + CH_4$). Through a safe and sustainable power system of Spirulina, darkness may never be seen in the space colony.

Endeavor to space colonization may surely bring economic snag, but when the regime, scientists and people across the world unitedly back the cosmic algaculture and its ways of 3R: Reduce, Reuse and Recycle to promote safety and sustainability, nothing seems impossible to attain. As the Spirulina persists to grow, the endless possibility for scientific breakthrough remains on hand. For with every sheet of blue-green algae, the future of the world unfolds.

Who would have thought that a man and even a monkey could stay and live beyond the Earth? Cultivate Spirulina to know the answer.

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From the Earth to the Moon and beyond: Ensuring safety and sustainability in the era of Space (Tele)medicine

Back in 1865 Jules Verne narrated the story of three individuals who travelled to the Moon and back in a cannonball. From the 19^{th} to the 21^{st} century and from fiction to reality many challenges have appeared. The effect of spaceflight on health represents one of the most challenging ones. So far it is well known that spaceflight affects all body systems. Fluids balance is altered resulting in a puffy face. Vision may be blurred. Mental afflictions occur. Bone architecture is altered. Numerous risk factors await out there with radiation and super resistant bacteria being the most prominent ones. To maximize safety and to make long term missions sustainable, astronaut's health-and hence, space medicine-ought to be a priority.

Space medicine combines aspects of preventive medicine, emergency medicine and rehabilitation. However space medicine is predominantly telemedicine. Flight surgeons hold regular checkup interviews with the astronauts working in the International Space Station (ISS). They are trained and they train astronauts to manage various emergencies from infections to trauma. This virtual tie between earth and space contributes to astronauts' safety but at the same time it has the potential to skyrocket terrestrial healthcare (Buckey, 2006; Hamilton, 2008).

Evidence suggests that advances in space telemedicine have the potential to be implemented on earth. This suggestion is based on the similarity of a space mission and remote terrestrial communities (Comtois. 2007; Hamilton, 2008).

What do a spacecraft and a remote village in Kilimanjaro have in common? Isolation, unbearable distance to tertiary care centers, resource scarcity, difficult (and expensive) emergency transfers. In both cases physicians may be absent and whenever they are present they have limited equipment, limited sources, lack of specialist consultation and limited – if existent - auxiliary personnel (Bellavance, 2004; Comtois, 2007).

Space telemedicine is based on direct communication and real time transmission of biometrical data. Besides the evaluation of the results, efficient guidance for various procedures including Cardiopulmonary Resuscitation (CPR) and minimal surgical interventions are performed by the spacecraft's crew under the guidance of terrestrial space surgeons. (Jadad, 2004; Wooton, 2009) Elevated cost and physical obstacles towards the transportation of a severely diseased patient to an adequate terrestrial facility underline the need for direct communication. In terrestrial settings this feature will may be possible through 5G internet applications. The ultimate goal is to have interventions that need second's accuracy performed from a remote center either if the patient is in Madagascar or if the patient is rotating near Mars. (Summerer, 2009) Of course the application of 5G on earth has already been widely discussed and transferring this discussion in space will add even more controversy. However addressing the matter of 5G in both terrestrial and extraterrestrial context will possibly boost innovative solutions. (Etzkowitz, 2000; Martin, 2012)

In spaceflight a crewmember is usually appointed as Crew Medical Officer (CMO). This individual receives hands on training in fundamental healthcare according to Advanced Trauma Life Support standards. The concept of Crew Medical Officer could make a blast in terrestrial communities. Individuals capable of detecting life threatening conditions, assisting in a wide range of medical procedures and of performing such procedures under guidance could save many lives. (Jadad, 2004; Wooton, 2009)

Telemedicine can also have an educational dimension in such settings. Training courses could be delivered to enhance the skills or even train further terrestrial medical officers and local General Practitioners or auxiliary personnel. Lifelong learning appears as a key feature in space and terrestrial telemedicine and can definitely facilitated by its means. Making this training as interactive as possible and assessing the level of practical skills acquisition is pivotal in both cases. (Bellavance, 2004; Jadad, 2004)

Although many new skills can be taught and obtained, other skills such as conducting and interpreting an echocardiogram or leading a needle require long time training and specialization. It is a challenge for space and terrestrial telemedicine to enable remote specialists to conduct such procedures regulating every single parameter and angle as they wish instead of guiding inexperienced user. Time and even lives could be saved this way! (Martin, 2012; Browman, 2019)

Nowadays, space telemedicine is expected to push the limits towards safety and sustainability. Encompassing terrestrial health needs will not only relieve those in need on Earth but will also provide space telemedicine with a huge pool of evidence and feedback. Although (tele)medicine is at stake this adventure is shared by many fields and professions. Engineers, Computer Scientists and health professionals to name only a few are already sitting down together to make what already exist and what should exist happen. Except from its interprofessional character telemedicine is also calling upon international collaboration. Just like in the ISS scientists and stakeholders from the EU, the USA, Russia, Australia, India, China and Japan need to work together to achieve the expected results. Besides these, national agencies ought to cooperate with academia and with the private space sector in order to transport, test or further develop the applications of space telemedicine. In the end of the day, safety will have been maximized. (Martin 2012; Browman, 2019)

Besides safety many Sustainable Development Goals will have been addressed. Good Health and Wellbeing (SDG3), Innovation and Infrastructure (SDG9), Peace and Justice (SDG16) and of course Partnership for the Goals (SDG17) are only few of them.

Joint space and terrestrial telemedicine research can reach innovative outcomes with a positive impact on earth and who knows where else. From 21st century to the next decades, who knows what will be fiction and what will be reality.

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