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# Gateway Earth: A Pragmatic Modular Architecture for Space Access and Exploration

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**Abstract**

Gateway Earth is proposed as modular space access architecture, operating a combined governmental space station and commercial space hotel located in the geostationary orbit [1, 2]. This location, close to the edge of the Earth's "gravity well", is ideal for robotic and crewed interplanetary spacecraft to dock as they depart for, or return from, any Solar System destinations. Additionally, assembling interplanetary craft, almost certainly including in-situ (additive) manufactured components, at this location would avoid these vehicles having to withstand the rigors of launch and re-entry through Earth's atmosphere. Moreover, space tourism revenues will provide a significant part of the funding needed to both build the complex and supply the regular reusable tug service via low-earth orbit [3]. Various elements of the architecture are being developed independently by a whole range of different space engineering firms and national and international agencies; some large, and others small and entrepreneurial in nature. Our aim is to synthesize all these disparate activities, and have them focus on making the overall Gateway Earth concept possible and deliverable in the mid-term future [4]. This paper is providing a status update on Gateway Earth Development Group's progress to date and invites feedback on key modules of the architecture as well as Gateway Earth's overall development and operational strategy.

**Keywords:** Space Access, Modular Architecture, Future, Space Exploration

## 1. Introduction

Since the end of the Apollo era it has been difficult to put in place an approach for continued and sustainable space exploration, particularly with regards to crewed spaceflight. This has been due to a number of factors, including changes in the geopolitical factors which created the original impetus for what became known as the space race. During the 1960's, in an urgent national focus on competing with the Soviet Union, the USA spent annually almost 5% of GDP in achieving the lunar landings. Political and financial commitments on such a scale are not possible over the long term [5], however, and nowadays NASA operates with budgets that are only about one tenth of what they were during the early years of space exploration [6].

The Space Shuttle replaced the Apollo capsule architecture, but did not achieve its hoped-for economic goals, and that system too has been abandoned [7]. Now, the US is in the early stages of introducing a new reusable and commercially-operated taxi-like system for getting cargos and crews at least into low Earth orbit []. But what of the more distant goals of true space exploration? If we cannot any longer use the Apollo approach, what can replace it, and provide a way forward that is financially and politically sustainable, and uses a technological approach which takes advantage of twenty-first century techniques, rather than the system of a half century ago?

In this paper we propose the Gateway Earth approach as a candidate architecture for achieving the goal of sustainable space access and exploration, we describe the steps we have in place to demonstrate its feasibility, and we urge governmental and commercial space entities to consider its merits.

## 2. Current and Future Space Travel Outlook

Why do we need to undertake space travel at all? There are of course the scientific and human reasons; humankind must explore. And there are commercial reasons; there is after all a lot of raw material out there, and dwindling resources on the Earth. It is important to review these elements. It is in part a failure to do so over the last half century that has led to the paralysis in terms of having a consistent space agenda that can survive multiple governments and administrations. If we don't know *why* we are doing it, then it is hardly surprizing that we cannot agree on *the way* to do it.

With regards to the *scientific and human aspects* of the space exploration endeavour, then we must recognize that we have barely scratched the surface in terms of accumulating knowledge of our fellow members of the solar system. Even with regards to our neighbour, Earth's Moon, six landings can hardly provide much more than a basic sampling of the body as a whole. And regarding more distant objects, such as Mars and its Moons, we have scarcely begun to characterize the celestial bodies. If we could afford to do it, then there are many gaps in our knowledge that we would want to attempt to close. We must also include asteroids and comets, the ways in which they could put Earth in danger in the long term, and so our ongoing engagement in trying to understand them, their properties and behaviours. This latter point is indeed an existential rationale every bit as real as the cause which ignited the space race in the 'sixties, but without the near-term urgency which fuelled the space program budgets back then. We owe it, nevertheless, to future generations to make steady progress in characterizing these objects, and developing ways to protect the Earth from the potential disaster they could inflict.

What of *the commercial rationale*? The US president (JFK) realized at the start of the program that exploring space would trigger new high-tech industries, and he was proven to be correct in so thinking [8]. It effectively created the micro-electronics business, which has provided much of what we now regard as essential parts of modern life. The subsequent development of the commercial space business has provided massive employment opportunities, international communications and broadcasting, superb weather forecasting capabilities, Earth resource monitoring, and navigation and precise location capabilities which on an ongoing basis are creating new business opportunities. The industry was worth $323 billion in 2015 [9]. And new sectors, such as space tourism, are about to add further growth sectors to this base. Beyond these established sectors, we are seeing the beginnings of the resource-extraction business being applied to space operations, with asteroid-mining being considered by various entrepreneurial firms and supported by the government of Luxembourg from a regulatory perspective [10]. Space settlement is also being discussed as a possible medium-to-long term aspect of space developments. Some have even described it as the ultimate purpose of space exploration.

So, we have offered a *smorgasbord* of rationales for why we want to go into space. What do they have in common? The need to make access to space *affordable*. The need for a basic *infrastructure* that can be used by all potential operators to allow for reliable, repeatable low cost, access to interplanetary space. Does this exist today? No. Is any government proposing to work towards making it happen? No. Are there any ideas being floated which could lead to this objective? None of which the authors are aware. The US is beginning to consider an architecture that is referred to as the Deep Space Gateway, in orbit around the Moon, but it is not intended to enable affordable repeatable access to interplanetary space [11].

We believe there is a way, however, which uses the combined best efforts of government and commercial motivations to resolve this half-century old problem, and we refer to it as the Gateway Earth architecture. It uses space tourism resources and revenues to make interplanetary space travel affordable and repeatable for all contemplated crewed and un-crewed payloads in the decades to come.

## 3. Gateway Earth Proposal

The basic ideas behind the Gateway Earth architecture have already been described in a series of earlier papers [1, 2 ,3, 4, 12, 13, 14, 15, 16], so we shall not here go into full detail, but merely state its main aspects. Fig 1 shows the basic elements of the architecture. It is designed to simultaneously solve a technological, funding and political problem. But it starts with physics.

When considered in terms of energy levels, all objects in the solar system – the Earth, Moon, Mars, its Moons, etc. – all may be represented as depressions, or "gravity wells" in the generally flat geopotential plateau of the interplanetary regions. Starting off from the Earth, once one has acquired sufficient energy to climb out of our own gravity well, it takes very little additional energy to travel the vast interplanetary distances to other celestial objects. It so happens that the Geostationary orbit (GEO) is near the edge of Earth's gravity well, which is one important reason why this location is proposed as the site for Gateway Earth. If one could have a government station there, equipped with a 3-D manufacturing facility, it would be possible to manufacture and assemble interplanetary spacecraft *in-situ*, ready for their ongoing missions. And such spacecraft would not need to be able to survive the rigors of either launch or return through the Earth's atmosphere. And they would need much lower energy propulsion systems than craft designed to go on interplanetary trajectories starting from Earth or even LEO. Consequently, they would be much cheaper craft than the alternatives which did *not* start from the GEO Gateway. Thus, we can already see the potential for substantial cost savings in this approach.

But there is more. By co-locating a space tourism hotel with the governmental station, then all journeys, of both crew and materials, both up and down to and from Gateway Earth can use the re-usable logistical tugs that the space tourists will use for themselves and their supplies to get to their space hotel. So government astronauts would be able to get all the way to their GEO station via rides on re-usable taxi craft. So, this also brings vast savings, provided that the commercial business is profitable, its infrastructure is installed, and

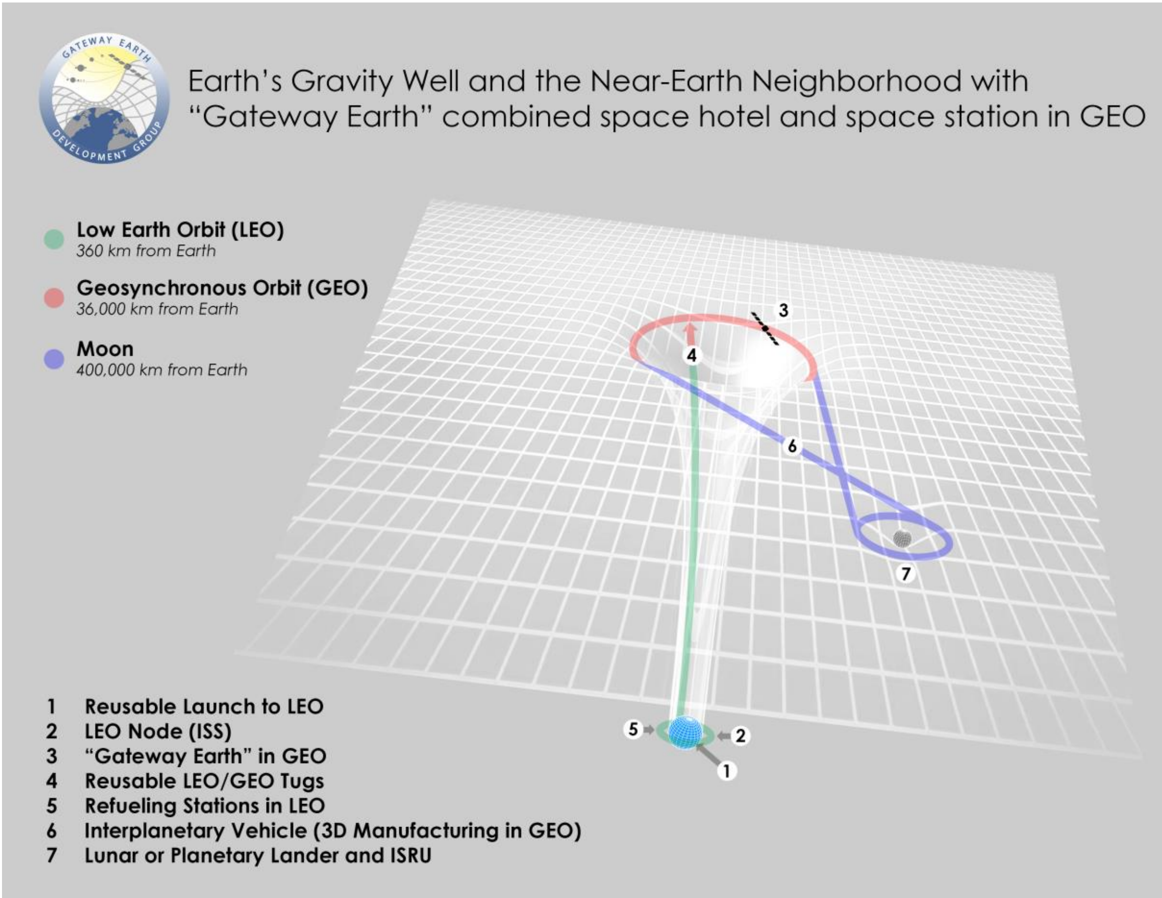


Fig 1. The basic elements of the Gateway Earth Architecture.

is operating on a regular basis. There could also be other commercial businesses operating at Gateway Earth, and thereby contributing funds to the operation and maintenance of the outpost.

There are, of course, a great many unresolved questions about the proposal which need work. For example, is there a market among space tourists, of folk willing to pay a premium to spend, say, two weeks in GEO – and how much of a premium would they pay over and above the price of a ticket to LEO? The market research needs to be conducted to find the answer. Who would provide the service for refuelling the fleet of tugs in LEO? We shall come back to discussing some of these questions later in the paper, but meanwhile will simply explain the seven steps described in the Figure 1 schematic. Note, however, that there is no implicit phasing or schedule in the numbering convention used in describing this proposal. The eventual schedule will rely on progress being made in parallel by both government and commercial entities, with their different motivations. Importantly, the proposal relies on the eventual success of an orbital space tourism business, first in LEO, and subsequently in GEO. This is not something which can be mandated by government, but depends on market factors and entrepreneurial offerings. The scheduling of activities may turn out to be the hardest of the planning aspects of the proposal.

The eventual success of the Gateway Earth proposal will depend upon a combination of monitoring of activities already taking place, some direction in terms of government expenditures (eg LEO refuelling work; additive manufacturing work, ISRO work), and some integration of planning activities between government and commercial agents. With those caveats having been stated, we summarize the seven steps :-

Step One is already taking place. Companies are working towards providing reusable vehicle delivery of cargos, both human and otherwise, to LEO.

Step Two refers to the need for a continuing presence in LEO of a human-rated habitat. At present, that need is supplied by the ISS. The implications of adopting the Gateway Earth architecture would be that there needs to be an eventual replacement for the ISS. And meanwhile, there would be a gradual change in the purpose and functions of the ISS. It is needed as a way-point for travellers, both governmental and space tourists, *en route* to and from the Gateway Earth station, 100 times farther out in space than the ISS, at GEO. In the case of government astronauts, they might even be returning from interplanetary journeys.

Step Three refers to the facility in GEO, partly governmental, partly commercial, with all of its life support and logistics functions. This would not, it is assumed, be built all at once. It can be gradually assembled. The commercial part is unlikely to be installed, for instance, until sufficient revenues have been made from the LEO orbital space tourism business. It would be important, however, to have an *a priori* understanding between government and commerce that there was a shared beneficial objective in creating the outpost, and an intention to work towards its assembly.

Step Four is a reference to the need for the logistical supply tugs to be operating up and down between LEO and GEO. The assumption is that the tugs would be built by the space tourism operators in order to service the needs of their customers, getting them, and their supplies, both up and down regularly between Gateway Earth and LEO.

Step Five points out the need for refuelling stations in LEO, being regularly topped up via tankers from Earth. This may eventually turn out to be a commercial operation in its own right, just like gas stations on Earth, or might be seen as part of the enabling infrastructure that government decides to provide in support of the proposal.

Step Six is the manufacture, assembly and eventual sending onward of the interplanetary vehicles from the GEO facility. It should be possible for these craft to be designed and built to be reusable. Additive manufacturing is the assumed technique, with some assembly supported by government astronauts at the complex.

Step Seven relates to the final stage when the destination object has been reached. This would be the inclusion as part of the interplanetary spacecraft payload of a destination-dependent lander and if needed the ISRU capability.

The ideas described above were first mooted in a 2012 paper presented in Naples [12]. What has been happening since then in terms of testing out the economics? A major step forward took place when the Gateway Earth Development Group was formed in 2015, and this group has been working towards obtaining acceptance of the architectural concept as a way of making future space exploration financially, technically and politically possible [4].

## 4. Gateway Earth Development Group

Gateway Earth Development Group (GEDG) was established at a fringe meeting at the 13th Reinventing Space conference held in Oxford in autumn 2015. As a group, we are seeking to promote research and development of a new modular space access architecture for maned and robotic Earth Observation, In-orbit Servicing, Interplanetary Exploration and Space Tourism based on inter-disciplinary, inter-organizational and international cooperation.

Specifically, the group is proposing to develop the Gateway Earth concept, as outlined in previous section of this paper. Our goals can be best summed up as:

*"Gateway Earth Development Group seeks to develop a technically and economically viable architecture for interplanetary space exploration. We are proposing to utilize space tourism as an enabler for the development of a space station in (Earth's) geostationary orbit (GEO), at which interplanetary spacecraft could be built and serviced to take astronauts on missions across the Solar System. Access to this space gateway will be provided by deploying re-usable vehicles, which will in stages (through Low Earth Orbit - LEO) deliver goods and people to the station." [17]*

Hence, the group sees as its mission to influence the development and integration of various aspects of the Gateway Earth Space Access Architecture though a set of work areas (Policy, Technology, Economics/Market, and Membership/PR) and specific tasks within each of the areas, which are led by Area Leads [4] and briefly summarised in the next section.

Currently, the main activities concern formulating detail solutions to technical, political and economic challenges to Gateway Earth's implementation. This work is leading towards a full white paper proposal, currently scheduled to be published in 2020 [18].

## 5. Our Objectives and Role(s)

As mentioned above, the key objective of the Gateway Earth Development Group is to develop a consistent and comprehensive solution for modular space access and ensure its consideration by key international players in this arena. The key to this process is to carefully consider the emergent development trajectory for the future of Space exploration and to identify its gaps and pressure points. We further attempt to link on a global level current actors and their existent and proposed visions for the future of space access by examining synergies amongst them and to influence their conversion. Hence, our Policy Lead is very actively engaging with a variety of stakeholders and fora to create a network of awareness and interest around Gateway Earth.

Additionally, we are developing a detailed business case for Gateway Earth, considering detailed costings and different investment and revenue streams, led by our dedicated Economics Lead. The main commercial revenue currently tabled is space tourism, as operating a Space hotel at this location could result in an estimated annual turnover of $4.5bn [3]. We have also recently investigated generating additional revenue from in-orbit satellite construction, servicing (more details below) and disposal, and exploring design solutions for the Gateway Earth complex which include antenna farm(s) and other EO/comms/navigation capabilities.

In order to propose stare-of-the-art technological solutions for bespoke challenges of a GEO station, our Technology Lead is tracking technology development in a variety of Space Industry sub-sectors, in particular (reusable) launch vehicles and tugs, orbital station modules design (in particular inflatable modules and fuel depos), ISRU and propulsion technologies, and in-orbit 3D additive manufacturing [4]. What we are finding through this work is that pretty much all of the different components of our architecture are being advanced by many different companies and research organisations and their technology readiness levels (TRL) are now by-and-large reaching demonstrator phase (TRL 5-6).

Hence, we are moving into the crucial phase of our Group's work, which is to coalesce the various interests in the industry and research spheres to converge on Gateway Earth project. To do so we are engaging space professionals and the wider public in discussion surrounding the future of space exploration and specifically access to space and space resources. We are also recruiting new individual members to the larger development group, with sign up now available on-line through our website:

**http://www.gatewayearth.space/join-us**

## 6. Key Current Projects

In the Summer of 2017, GEDG ran a series of student research projects at leading UK universities to further the technical and business model integration of the Gateway Earth proposal. Not all projects are yet completed and they will be presented in more detail later this year. However, some of the key preliminary findings are summarised below.

### Gateway Earth GEO Station Design

In a project organised and led by Cranfield University and Airbus Defence and Space (UK), a Masters students, Frank Augrandjean, was examining detailed designs for the GEO Gateway Earth Complex, focusing on radiation protection, mass/power budgets, internal architecture and facilities. The resulting station can be seen at Fig 2, consisting of separate quarters for tourists and crew, living and service modules, science

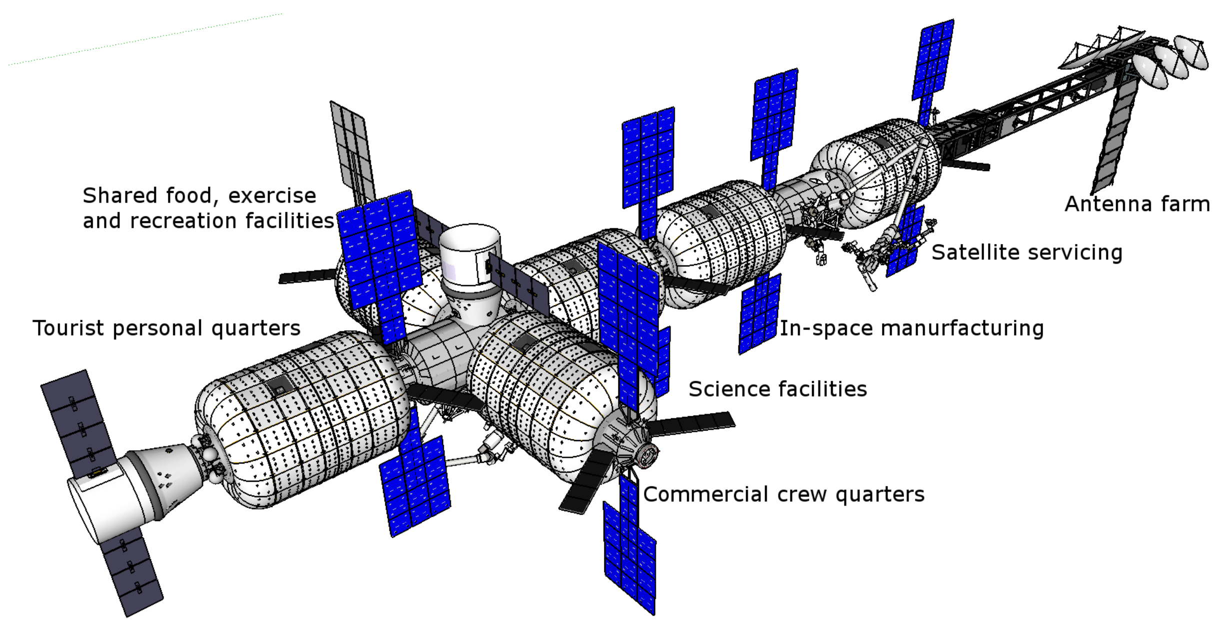


Fig 2. The basic elements of the Gateway Earth Complex as proposed by the Cranfield/Airbus project.

and engineering facility and the antenna farm. Central nodes are modelled after ISS equivalents, whereas the larger modules are extrapolated from an inflatable design of Bigelow B330.

Analysis yielded good performance with respect to functionality, activities separation and crew and tourists protection. Several additions, such as viewing platforms (cupola) or semi-EVA environments for space tourists has also been studied.

GEO Station Assembly and Operational Logistics

Another student on the above Cranfield/Airbus project, Solène Doublet, was looking at assembly and operational logistics, in particular launchers, tugs and journey modelling for construction, resupply and operations. Whilst we have no concerns over technical availability of most architecture components within the proposed time frame, their operationalisation and deployment with this specific architecture needs further examination. The findings of the project in particular pointed to issues of re-supply propulsion and orbital dynamic efficiency. More detailed findings and proposed next steps are being examined.

In-orbit Satellite Servicing: Technical and Economic Feasibility

In a summer project at the University of Edinburgh's Institute for Astronomy, Physics student Maureen Cohen, was investigating the feasibility of providing a geostationary satellite repair and refuelling service based at the Gateway Earth station to remedy the problem of space debris in GEO and generate a funding stream for the space station's operating costs. Her findings estimate that a significant revenue could be generated from such operations, with predicted market size the range of $20bn per year by 2040 [19], and made even more significant due to (current) limitations of GEO slots licensing.

Debris Detection and Management on Architecture Level

Funded by UK's Engineering and Physical Sciences Research Council Summer Bursary, another Physics student, Angus Millar, also worked at the University of Edinburgh's Institute for Astronomy examining the space debris detection, management and removal, which

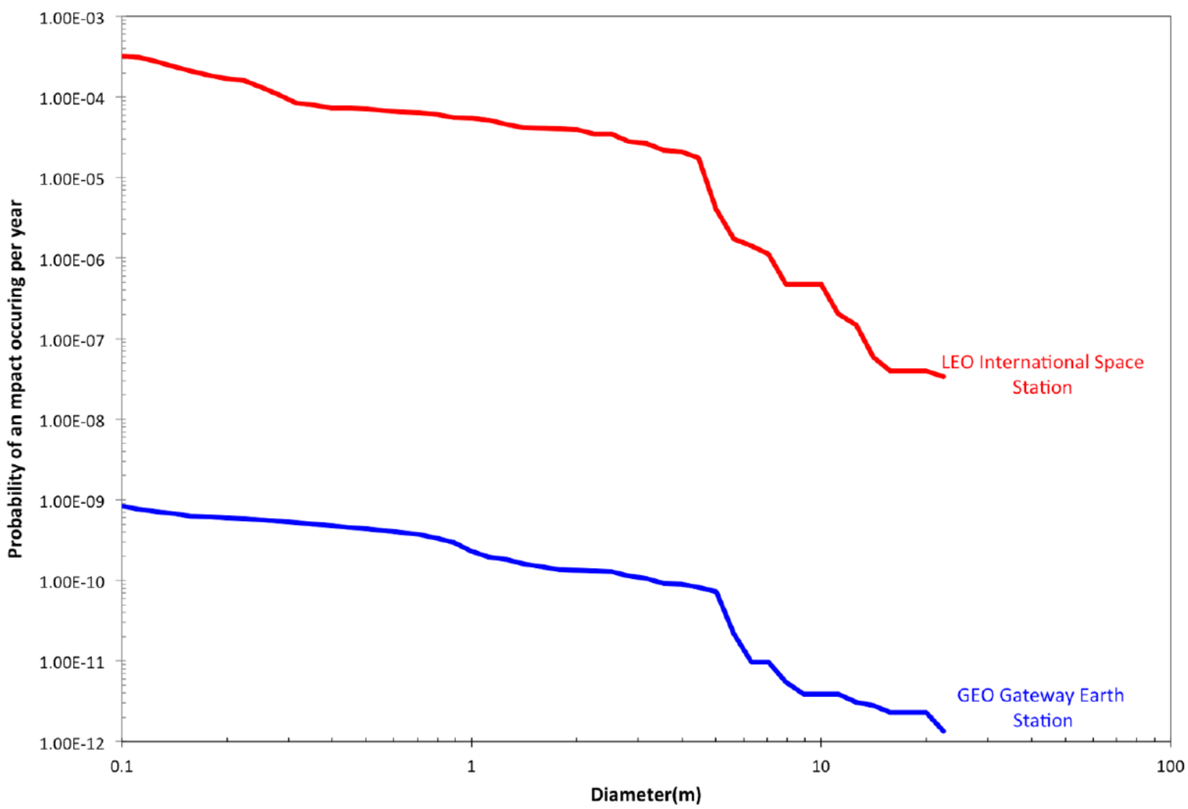


Fig 3. MIDAS predicted probability of an impact occurring per year vs diameter (logarithmic) of impactor for LEO and GEO stations [20].

is one of the first architecture-level studies of this type. Fig 3 is showing the probability of impact per year versus size (logarithmic) for LEO and GEO Gateway Earth nodes.

Findings suggest that LEO protection will be paramount, whilst in GEO the need for protection is significantly lower. As a solution, better detection, tracking and active debris removal solutions are recommended. However, for architecture level protection, political and legal solutions for debris regulation are also needed to ensure smooth operation [20].

## 7. Next Steps

We are hoping the research endeavour outlined above will continue to produce concrete solutions for technical, political, legal and operational challenges of such a complex mission. These efforts are leading towards a fully costed and detailed white paper proposal, which is scheduled for completion in 2020. At that stage, we will be looking to form and steer a group of internationally significant stakeholders who are to build, launch and operate this architecture.

New updates, including more detailed results of our current research projects will be published later this year as part of the 15th Reinventing Space conference in Glasgow (24th – 26th October 2017). New work packages and new Area Leads will also be announced there.

As mentioned previously, we are actively recruiting new members, hence we are calling on all readers with an interest in space access architecture development or with a stake in any of the relevant technology, science, policy or legal fields, to get in touch and join our newsletter subscription via our website: **http://www.gatewayearth.space/join-us**

We are hoping you will be joining us on our space adventure!

## Acknowledgements

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