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Transformational Release of Scientific Payloads From the Apex Anchor – Any Size, Every Day, Anywhere

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Abstract: This research will describe the remarkable transformational characteristics of the Release from the Space Elevators Apex Anchor for Solar System Science Missions. Two main strengths enable the claim – Scientific Payloads, any size, any day, and anywhere in the solar system. The first is the ability to raise massive cargo against the Earth's gravity while being friendly to our environment. The beauty of the Space Elevator is that it raises massive cargo with electricity [hence – "The Green Road to Space"]. [1] The initial operations maximum capability of a Galactic Harbour could be as much as 30,000 tonnes per year. As the capacity matures, the yearly number increases to 170,000 tonnes. The second operational capability is that it may release the scientific spacecraft as frequent as each day towards solar system bodies with great velocity (minimum 7.76 km/sec). This article will describe advanced releases that greatly increase the initial velocity to include escape from the solar system. To set the stage, research within Arizona State University shows one example which explains the new conundrum quite well: Traditional launches from Earth to Mars are 8-month trips each and are separated by 26 months until the next opportunity, with delivery to the surface of about 1 percent of the mass on the pad. When looking at releases from the Space Elevator Apex Anchor (at 100,000 km altitude) the release towards Mars could be every day. In addition, it can send massive amounts of cargo and has a spectrum of possible travel times – shortest from a normal release from the Apex Anchor is approximately 61 days. [2]

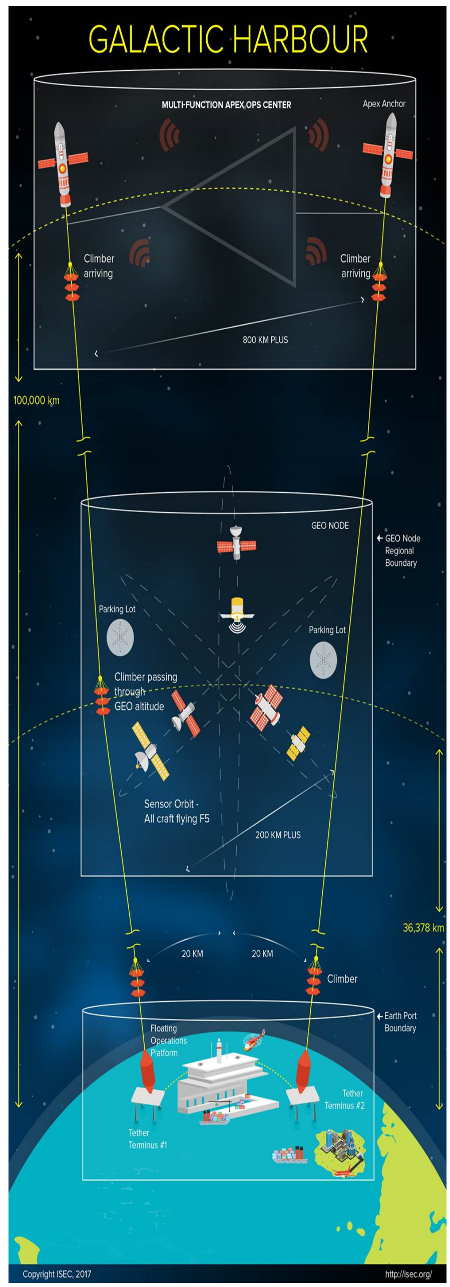

Figure 1: Galactic Harbour

1.0 Introduction:

The science community is excited now about future space missions around the solar system. There is excitement building about our near-term visits to the Moon and Mars by government and commercial actors. This pivotal point in the exploitation of space has remarkable events occurring in parallel and providing excitement across the globe. This paper will address the next two phases of excitement for these missions. The first is a near term leveraging of the remarkable lift capability, expected turnaround times, and price of lift with the Starship. The second is the projected operational capabilities of the Space Elevator in the late 2030's. The Space Elevator Transformational characteristics will enable planetary scientists to achieve "so much more." The current rocket limitations, in payload mass and solar system orbital insertions, will be thrown away when the scientist is allowed any size experiment, to be released any day of the year that can reach all

** This work was done as a private venture and not in the author's capacity as an employee of the Jet Propulsion Laboratory, California Institute of Technology. William Page, William.e.Page@jpl.nasa.gov solar system destinations rapidly. But first, the remarkable expansion enabled by the Starship revolution will open the dreams of planetary scientists with far more capability than today. This will be occurring over the next decade or so and will stimulate new visions of science across the solar system. Next comes the transformational space access capabilities of Space Elevators which will be beyond the expansion of larger rockets. With these capabilities, mission support leads to: Scientific Payloads, any size, any day, and anywhere in the solar system can be tossed from the Apex Anchor. This vision is explained in the next session as it breaks the paradigm by building your huge space systems above the gravity well.

1.1 Assembly at the Top of the Gravity Well:
One of the basic problems with our science missions of the past (and near-term future) is that they had to be built on the ground and then tremendous resources had to be expended to reach our destinations fighting gravity all the way. Can you image robotic assembly at 100,000 km altitude after the segments of the payload, spacecraft and rockets have been raised by electrical energy? This concept is the essence of the permanent space access infrastructure called the Space Elevator. There are two parts to this transformational concept:

- Beat Gravity for assembly at essentially the Sphere of Influence altitude. This means that the Green Road to Space lifts all the components of huge science missions destined throughout the solar system to an assembly plant on a daily schedule in a routine, inexpensive and safe operational approach. When the segments reach the Apex Anchor, they have gained tremendous potential energy (associated with a height of 106,378 km) and kinetic energy (associated with a velocity of 7.76 km/sec) allowing them to race across our solar system.
- Release towards any destination daily. This statement is supported by the fact that the speeds at release are impressive (7.76 km/sec) with alignment towards any solar system object each day. The key here is that additional rocket motors can be raised and assembled to adapt to the inclination differences, additional speeds for gravity assists timing, and rendezvous slowdowns as appropriate at destinations.

When the science spacecraft leaves the Apex Anchor, it has been prepared for its mission with the transformative strengths of Space Elevators. This technique will indeed allow any size payload to be mounted on the appropriate spacecraft with proper rockets enabling it to be released any day towards any mission destination.

In a parallel mission assembly facility at the Space Elevator GEO Region, similar transformational strengths will allow almost any size antenna or science instrument to be assembled with appropriate spacecraft to be "floated" by robotic tugboats to any GEO node for Earth science missions. In addition, this assembly plant would have the capability to maintain, replace, repair, refuel or re-engineer these valuable assets above the gravity well. All of these raised on the Green Road to Space.

1.2 Current Mission Excitement:
There has been much excitement with the release of the latest Decadal survey, "Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032 (2022)" [3]. It was released earlier this year and it identifies the highest priority NASA missions for the next Decade 2023 – 2033 and beyond evaluated to help answer the science communities' highest priority questions. The study was sponsored by NASA and the National Science Foundation and performed by a committee organized by the National Academies of Sciences, Engineering, and Medicine. The Academies conduct Decadal Surveys for all five of NASA's science disciplines — astrophysics, biological and physical sciences in space, earth science, heliophysics, and planetary science. This decadal survey identified, evaluated and prioritized over 50 different projects/missions (not all were selected). The board evaluated their ability to address key questions and their feasibility based on required technology maturity level, risk, and cost in order to prioritize them. "This Survey confirmed earlier decadal studies' recommendations to pursue the Mars Sample Return (MSR) and the Europa Clipper missions currently being developed by NASA's Jet Propulsion Laboratory, Pasadena, CA, and its partners." The recommendations of the survey will help us to better understand our gas giant planets by visiting Uranus and one of Saturn's moons Enceladus to gain insights into that icy ocean planet [13]. Matt Williams, from Universe Today summarizes the report best, "Looking to the coming decade, there is no doubt that there is tremendous potential for exciting

missions and investigations. Even more exciting is the potential scientific discoveries these missions could reveal. These range from revelations about the history of the solar system, the formation and evolution of the planets, and enduring questions surrounding the emergence of life (and what forms it might take). But perhaps the most exciting thing is how these missions could enable the next generation to explore even farther, possibly to the edge of the solar system" [4]. However, the majority of the analysis relied on the historic approach for launch- government, rocket equation delivery statistics, and similarities in the cost equations.

1.3 Near Term revolution in mission support: We are on the edge of an incipient revolution in the amount of volume and mass which can be launched into orbit with a corresponding revolution in the size and shape of the payloads that can be sent into space. In addition, the remarkable growth of commercial launch availability will enable less expensive missions, more launch opportunities, and larger space system capacity. The drivers which will enable greater volume and mass to orbit for the scientific and spacefaring community will be supported by the SLS and the SpaceX Starship. The SLS will be able to send increased mass and larger payloads to the ends of the solar system but will have limited availability and is very expensive [5]. The Starship will be able to send 100 plus ton payloads into orbit for the lowest projected cost to space. Combine this with the ability to refuel in orbit and it unlocks access to the solar system with significantly larger and heavier payloads "You could get a 100-ton object to the surface of Europa, "Space X's CEO Elon Musk said in a public meeting of the National Academies in November 2021" [5]. Starship will have an unimaginable impact on scientific space exploration and the ability to maintain a human presence on both our Moon and Mars.

1.4 Mid-term revolution in mission support – Beyond SpaceX with Space Elevator: For the movement off planet, the Space Elevator Apex Anchor has many inherent strengths, deriving from its permanent space access characteristics, which will transform the future mission scope for off-planet. Three interplanetary strengths will enhance our reach beyond GEO and are important to understand as revolutionary steps:

1. Assembly at Apex Anchor (100,000 km altitude) enables the mission hardware to be almost any size. Adding large rocket motors to significantly sized spacecraft with desired size shape and complexity mission payloads will enable missions not even dreamed of yet. Figure 2 estimates the mass capabilities across the next 30 years for Space Elevators. [Initial Operational Capacity – 30,000 tonnes per year growing to Full Operational Capacity – 170,000 tonnes per year] [2]

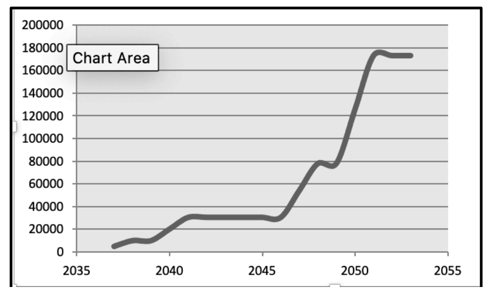

Figure 2: Massive Cargo Movement by Space Elevators[1] (tonnes/yr) [2]

2. Inherent velocity (7.76 km/sec) enables the huge space systems to reach beyond Mars and then allows them to use gravity assist and extra rocket motors to reach beyond Pluto in any inclination plane. This series of strengths negates the restrictions such as Hohmann ellipses of "minimum energy."

3. Daily release assures mission flexibility to any solar system object – essentially every day. Some trips would be more rapid (i.e., 61 days to Mars), but all planets can be reached with tremendously flexible release dates from the Apex Anchor. This capability can leverage the concept of "just in time delivery," a logistician's core belief.

These three strengths were recognized within the multiple year research conducted at the Arizona State University with the International Space Elevator Consortium. From their study report, "Space Elevators are the Transportation Story of the 21st Century,"[2] three points were emphasized

[1] Swan "Dual Space Access Strategy Minimizes the Rocket Equation," Space Renaissance International 3rd World Congress 2021 – Congress Theses, Final Resolution and Papers. Pg 254-255.

[2] Swan, P, Swan C, Fitzgerald, M., Peet, M, Torla, J, Hall, V., "Space Elevators are the Transportation Story of the 21st Century," ISEC Study Report, www.lulu.com, 2020.

for the trips to Mars, as shown in Figure 3. The students at Arizona State University even developed a "bus schedule" for their research timeframe of 2035 missions to Mars [2]. These inherent strengths derive from the transformational characteristics of the Space Elevator and its Green Road to Space approach.

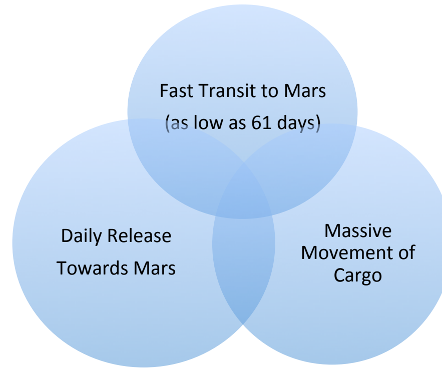

Figure 3, Strengths of Interplanetary Space Elevators.

1.5 Transformational Strengths: During this research, a series of space elevator transformation strengths became obvious. These permanent infrastructure impacts will be revolutionary as space elevators join advanced rockets in a Dual Space Access Architecture strategy enabling massive missions to GEO and beyond. The seven strengths are shown in Table 1.

Table 1: Space Elevator Transformational Strengths

Transformational Strength	Short Explanation (For further information see section 4.0)
Daily, routinely, safely, and inexpensive	An example can be the trips to Mars when Space Elevators enable logisticians to send a 14 tonne payload daily. This routine would be revolutionary as an Apex Anchor release to Mars any day of the year on different paths, eliminating the two + year launch window for Mars with Earth alignments necessary for advanced rockets.
Transforming the economics towards an infrastructure	This economic strategy helps transition the thinking from the early century's discussions of rocket vs Space Elevator towards what can be enabled by development of permanent space infrastructures. Mr. Barry stated: "The economic paradigm of building Space Elevators needs to shift from a focus on cost to the consumer to focusing on its value to the investor."[3] [6]
Massive movement (30,000 tonnes/yr vs. approx.. 26,000 tonnes over 65 years by rockets)	Rocket equation reality is catastrophic when the realization dawns on the dreamer – "How much mass do I need?" A chart showing the natural growth of Space Elevator capacity is shown in Figure 2. [2]
This Green Road to Space ensures environmentally neutral operations	As a Green Road to Space[4], it ensures environmentally friendly operations: Solar energy to the tether climber motors ensures that there is no combustion within the atmosphere and no hardware left along the way in low Earth Orbit. [1]
High velocity (starting at 7.76 km/sec at 100,000 km altitude) enables rapid transits	High velocity (starting at 7.76 km/sec at 100,000 altitude enables rapid transits to the Moon, Mars and beyond):[5] The Apex Anchor is rotating at high rotational velocity sufficient for spacecraft to reach Mars in as little as 61 days, with a range of trip durations depending on planetary orientation. [2]
Reduction of the need for Rocket Fairing Design limitations	The shake, rattle, and roll of rocket propulsion is very stressful to the designer of payloads. Their extraordinary set of requirements (including faring size) inhibits the design of space payloads and restricts design flexibility. The extra volume from the Space Elevator Tether Climber and the soft ride enables far more design flexibility.
Assembly at the top of the Gravity Well	The concept is simple, raise payloads with solar power to 100,000 km altitude and then assemble any size space system needed for solar system missions.

3 Barry, K., Eduardo Pineda Alfaro, "Changing the Economic Paradigm for Building a Space Elevator," 71st International Astronautical Congress, 2021, Paris.
4 Eddy, et.al., "Space Elevators are the Green Road to Space," ISEC Report, Lulu Publishers, April 2021

5 Swan, P, Swan C, Fitzgerald, M., Peet, M, Torla, J, Hall, V., "Space Elevators are the Transportation Story of the 21st Century," ISEC Study Report, www.lulu.com, 2020.

1.6 The Future is Brilliant: Historically, the scientific community has been identifying missions based upon launch constraints that include: cost, mass, and volume limitations. The Starship will be the next step in reducing these limitations and will provide greater access to space. Their ability to share space on flights to the Moon and Mars will ensure early delivery of science payloads along with exploration. It would seem reasonable that any flight to the Moon and Mars could fit a few science payloads with later dedicated missions. The next step – transformative in nature, - will be adding a Space Elevator architecture to complement the Starship. These characteristics of Space Elevators will tremendously reduce the rocket limitations and widen the scientific community's aperture of what is in the realm of the possible. These possibilities will be pursued in section 5.0 after the expansion on the Space Elevator strengths and characteristics.

2.0 Needs of the Planetary Scientists over the next 10 - 30 years: When looking at the remarkable future lift capabilities, the science community can dream "bigger" than before. The 2022 decadal study identifies NASA's robotic and human scientific exploration projects over the next three decades. The projects are categorized according to cost with the largest identified as Flagship missions which cost multiple Billions of dollars ($3.5 – 5.5B), New Frontier missions that cost up to $1.65B, Discovery missions that each have a cap of $.8B and finally SIMPLEx missions that can cost up to $80M. In addition to re-affirming the Mars Sample Return and the Europa Clipper missions which were already in work, the new decadal survey identified two new Flagship missions, three New Frontier missions, four Discovery missions and five SIMPLEx missions to be executed over the next couple of decades [3]. Based on the prioritized science questions and technology constraints the decadal survey identifies two Flagship projects to Uranus and Enceladus and recommends that three of the following nine missions be selected: Comet Surface Sample Return, Enceladus Orbiter, Lunar Geophysical Network (LGN), Saturn Probe, Venus In-Situ Explorer (VISE), Enceladus Multiple Flyby (EMF), Ceres Sample Return, Centaur Orbiter and Lander (CORAL) and the Titan Orbiter missions. In addition, there are 5 Discovery and 4 SIMPLEx missions nominated for execution as well. Outside of these missions, the survey also identifies missions within other established programs, for example, the Endurance-A mission consists of a rover to collect samples across the lunar south pole which will then be retrieved by Artemis astronauts when complete. For Mars Life Explorer (MLE), the survey recommends a mission for in-situ resource utilization (ISRU) of water to demonstrate and learn about the ability to use water from the moon [3]. In the area of planetary defense, the Double Asteroid Redirection Test (DART) mission is planned to understand how much an impact to the asteroid will actually move its trajectory. The Near Earth Object (NEO) Surveyor is an earth defense mission consisting of a mid-IR space based telescope to help in early warning and there is a larger NEO rapid redirect mission recommended [3]. In addition to the numerous interplanetary missions described by the survey, there are other initiatives underway to expand human influence and science in space over the next decade or so. NASA's Artemis program initiative plans to return man to the moon with regular access and ultimately to build a permanent human presence and this experience will inform and guide NASA's and Elon's plans to send people to Mars. There are many exciting missions supporting science for the next 30 years and ambitious crewed missions to the Moon and Mars. These are just the starting points when one includes the Dual Space Access Strategy.

2.1 Future plans are constrained to current launch limitations: All of the missions described in the survey over the next 20 - 30 years were evaluated and selected based on an inherent mindset of existing "launch constraints" on the mass and volume of payloads and the cost to get them there. There are many constraints which limit the number of selected missions based on funding, state of technology (realm of the possible) and the few organizations able to manage the projects. There are also constraints driven by launching these systems on rockets. Those constraints include mass limitations, challenging environmental factors during launch and space, weight and power restrictions which drive system cost to design, develop, procure and test. The rocket equation dictates that it takes most of the launched mass to get a very small portion of it where you want it to go – less than 2% of the rocket mass on the ground is usable payload to any planetary destination. The Starship approach recognizes the rocket equation by using another Starship to refuel one that is in orbit to achieve its tremendous capabilities for delivery. Currently, because of the mass limitations, the payload instruments must be designed and selected based on their mass and ability to fit into a volume constrained payload fairing. For example, Ariane 5's fairing is 56 feet (17 meters) tall and measures 17.7 feet (5.4 meters) in diameter. This may seem large, but it can be very difficult to fit into that space, for example the James Webb Space Telescope (JWST) observatory had a 6.5-meter (21.6-foot) primary mirror and a sunshield the size of a tennis court – it was 22 meters by 12 meters (69.5 ft x 46.5 ft). The JWST had to fold the entire observatory and sunshield into the Ariane 5 payload fairing which drove the most complex set of deployments ever required by a space system in a place where it would have been impossible to fix if there was an issue [5]. The scientific instruments which are just part of the payloads must compete for limited space available and fit within size, weight, and power (SWAP)constraints. Designers now must evaluate trades between one instrument and another to be able to decrease their mass by almost insignificant margins, a couple of grams potentially, which drives greater cost in designing these systems. In addition, the space payload developers are driven to design and procure more exotic solutions, which are more expensive, to be able to fit SWAP requirements. Based on evaluation of these factors, the instruments are priority ranked and only the most important make it onto the payload. The planning for these missions is based on current launch capabilities, which includes the Falcon Heavy and the Space Launch System (SLS). There will be so much more possible in the near term than anticipated by this survey.

3.0 Starship Impact The planetary science community has been noticing the development of these systems, but the realization of the full impact has not surfaced yet. It will!

3.1 Starship capabilities: Future Starships will revolutionize access to space by increasing overall mass to space, the size and shape of the payloads and the cost to get them there. The Starship is a beast! It will be able to get 150 tons to LEO – the payload fairing is 9 m (27 ft) in diameter and 18 m (54 ft) high, which will be the largest operational payload volume of any current or in development launcher. The estimated low cost of the Starship is based on being re-usable, flying frequently and having the ability to be refurbished cheaply between flights. The initial cost of building Starships gets spread over many missions making the initial investment almost negligible. Longer term, Elon Musk said "SpaceX's Starship launches will cost less than $10 million within 2-3 years." [7] He went on to predict that one Starship rocket launch could cost a few million dollars in the future [8]. The Starship will positively affect the launch limitations discussed earlier. The mass and usable launch volume will be greatly increased enabling more massive payloads and greater variety of shapes. The JWST example used earlier to illustrate how to fold and fit a much larger payload into a small fairing is an excellent example of this. With the Starship, the developers would have been able to build the JWST and launch it close to its final configuration eliminating the costs and time associated with designing, building and testing the most complicated unfolding deployment structure yet attempted [5]. The ability to launch greater mass into orbit means the space payload developers don't have to spend as much time and money to develop exotic technologies that utilize extremely efficient SWAP technologies and solutions. The Starship will be a huge boon to the scientific community because it will directly impact the mass. size of the payloads while providing more launch opportunities and will allow the focus to be on conducting the best science vs making their payloads fit launch "packaging" constraints.

3.2 Perpetual Concerns with Rockets. The downside of rockets lifting massive payloads to orbit and beyond has two continuing limitations.

- Delivery Statistics: The Tsiolkovsky rocket equation is still in play and is dominating when rockets lift off against gravity. Even with massive Starships and Space Launch Systems capabilities to move large payloads, the ratio of delivery to pad mass is still penalizing low. The delivery to LEO is still less than 4% when the rockets are designed to be reusable (extra mass must be lifted to return the stages, thus lowering the delivery statistics) while to GEO or Lunar trajectories the numbers are less than 2% and landing on the Moon or Mars will be less than 1%. These numbers are crippling (of course it is the only way to achieve our space missions today and must be tolerated).
- Pollution (atmospheric and debris): These new massive rockets will also burn more rocket fuel inside our atmosphere and leave more parts along the mission trajectory. The specifics on

this topic are starting to surface across the industry with the frequent question – no one knows the impact on our atmosphere of massively increased launch rates. [9, 10, 11]

These two limitations of rockets are significant, but have to be accepted while we explore our neighborhood. However, a combined dual space access strategy could leverage the Green Road to Space characteristics of Space Elevators and their large delivery statistics (reaching 70% of liftoff mass to mission destination). This collaborative approach would benefit both approaches to space while achieving far more missions.

3.3 Emerging Capabilities with Starship: The emerging capabilities initially provided by Starship will enable already allocated funds to go farther. In the short term it will likely be difficult to obtain greater funding levels for scientific exploration, but with the following cost savings it should be able to buy more science. With these new commercial launch capabilities and costs – the assumptions used in the recent survey about what missions could be funded and launched over the next couple of decades could be expanded. Space vehicle and payload developers will not have to expend the effort and funds to develop more complex ways to package payloads and to address all the payload complexities driven by launch [12]. It would even open the door to utilizing much cheaper off the shelf components. In addition, the cost of launch itself should drastically decrease. There will be ample rideshare opportunities available where multiple scientific missions are combined on a single rocket manifest or there is space available on a different mission with the extra space that can be taken advantage of. Payload developers could also include in their design space the idea of developing a cheaper payload to do the mission because if it fails or does not last as long as desired it can just be replenished. [off the shelf components] With these savings there should be ample funds to select additional missions – maybe another Flagship or two could be included at least? Or maybe three or four more Discovery missions could be funded vs only three. In addition to Starship's described benefits, there will be operational benefits we are just starting to imagine. One of these alluded to earlier is the ability of Starship to be re-fueled in orbit which unleashes the full payload to be launched throughout the solar system. The first Starship, is planned to visit Mars in 2024 to prove itself and will likely not have sufficient time for "rideshare" opportunities. However, a follow up mission by 2026 would provide time for NASA and SpaceX to plan out science missions on those human pre-cursor logistics missions [15]. Scientists are just now beginning to contemplate the tremendous capabilities coming in the next couple of years.

3.4 What is needed? A different scientific/funding business model: With tremendous capacity available for space exploration there must be a corresponding scaling of NASA's payload selection and funding processes. NASA has had success with both the PRISM (Payloads and Research Investigations on the Surface of the Moon) and CLPS (Commercial Lunar Payload Services) programs to accelerate the speed of selecting scientific and commercial instruments and payloads bound for the lunar surface [12]. There is no corresponding program developed around Starships heading for the Moon and Mars to take advantage of Starship's capacity [12]. It is vital that NASA build corresponding programs of similar speed (but perhaps better funded) to ensure this does not become a wasted opportunity. Competing for Flagship or Discovery selection takes many years of planning, and as pointed out earlier not all of them are selected. Scientists could spend most of their career waiting to be selected for one of these missions [14]. With something akin to the PRISM and CLPS programs the scientist might get their science accomplished by just submitting an instrument proposal [14]. The time is now for NASA to start working to increase their budget in anticipation of the opportunities Starship will provide and it will need a corresponding process to be able to quickly select new missions to meet the increased capacities available. Maybe, the new funding can be derived from the cost saving of using the new commercial launch opportunities. The capacity available to go to the Moon and Mars with Starship will simply be unmatched by any other time frame thus far, and the business and selection processes must start in advance of this capability to be prepared!

4.0 Rocket Strengths inside a Dual Space Access Strategy: If the revolutionary capabilities driven by the Starship are this dramatic, imagine the future of mega rockets combined with the tremendous force multiplier the Space Elevator will be. The complementary benefits of having the Starship and the Space Elevator working together will drive capabilities we are just beginning to imagine. The mass and size of payloads and equipment that can be delivered across our solar system will be liberated by these systems! Rockets and the Space Elevator will be complementary systems with inherent strengths and weakness that the other system offsets. Rockets are tremendously successful, can reach any orbit and can rapidly move people through radiation belts and to other planets. Rockets are only able to launch a small percentage of their starting mass into orbit or other planets due to the energy required to get them there – Starship refueling in orbit emphasizes the extremely low delivery statistics to any orbit or destination. Once the Space Elevator investment has been made, Space Elevators will have the ability to move massive cargo into GEO orbit or to the planets on a daily basis within inexpensive and environmentally friendly operations. The Space Elevator will not be good at placing payloads into LEO or MEO orbits but lucky for us Rockets are. The observation here is that both systems are needed to be able to achieve the great visions of populating the Moon and Mars and beyond. We will need to get people there and there needs to be all the logistics in place with continual replenishment to make these concepts work. The main shortfall for Space Elevators is that their initial operations is not scheduled until 2037. This concept of Dual Space Access strategy will develop similar to the following:

Initial step: The space industry will support and enable Artemis project goals which will establish presence on Moon. In parallel, Mr. Musk's vision of establishing humanity on Mars will be initiated. These are two tremendous leaps forward for humanity and its ability to understand our neighborhood. These will be huge steps for humanity's ability to do colossal activities in space.

Next step: The support for development of the Space Elevator is a must for humanity for so many reasons to encourage the research community to start thinking out of the box. The realm of science fiction has been surpassed as the Space Elevator has entered the second phase of development – Engineering Validation [2]. There are so many missions screaming for more capability to orbit while the environmental community is concerned about thousands of launches around the globe per year. In addition, the Space Elevators are going to help these dreams become realized in dramatic fashion. Massive cargo to high orbits and beyond for solar power system in space, mining asteroids, and settlements beyond LEO are just a few.

The current scientific community's assumptions have always included the restrictions of rockets. This needs to be changed into an aggressive approach to mega-rockets for ride sharing and then the future Space Elevators opening up the universe with assembly of massive science spacecraft at the top of the gravity well. In addition, they must recognize that the commercial community will be a significant player in the future of space travel. The Science communities thinking has been stymied by our history with small mass capabilities for planetary missions. However, the future is bright and full of resources if we are bold and start recognizing the opportunities brought on by near term Starships and mid-term Space Elevators.

5.0 Space Elevator Transportation System (SETS) Characteristics and Strengths: The Time is NOW to develop Aggressive Plans for transformational capabilities with the planetary scientific community.

As discussed previously, advanced rockets will enable far more complex missions into the future. However, revolution is coming when you beat the rocket equation and the gravity well. Space access transformation will occur when a permanent infrastructure is developed – similar to replacing small boats going across a river with a bridge – enabling rapid, massive, inexpensive transport of goods to market. To fully understand the scope of this revolution the scientist needs understanding of the scope and reach of the Space Elevator as portrayed within its vision. This commercial transportation infrastructure will grow out to include three Galactic Harbours, each with two Space Elevators (up/down, principle/backup, both up for commercial reasons or mission interchangeable). The image is shown below in Figure 3, immediately followed by its vision (for all missions).

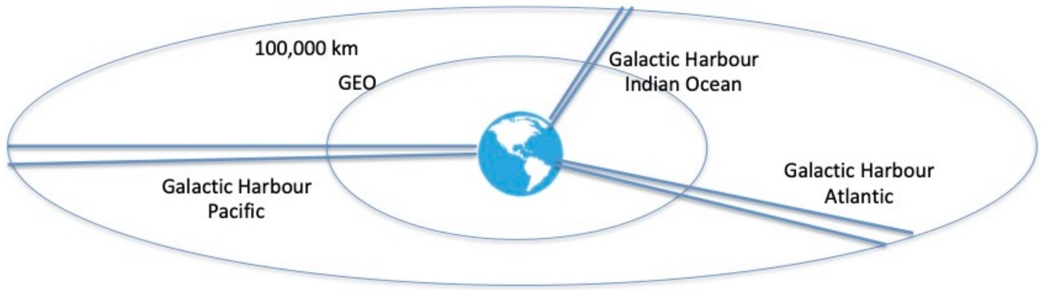

Figure 3, Three Galactic Harbours

VISION: Space Elevators are the Green Road to Space where they enable humanity's most important missions by moving massive tonnage to GEO and beyond. They accomplish this safely, routinely, inexpensively, and daily; while, they are environmentally neutral.

The following is an expansion of the analysis referencing the impact upon future interplanetary (and Earth based GEO) missions by the implementation of the Space Elevator architecture. These characteristics were in Table 1 earlier, but are shown here to emphasize the revolution within the Green Road to Space. Each will then expand on the specific impact upon Planetary science missions of the future.

- Planetary Sciences Impact from SETS Strength One (Daily, routinely, safely, inexpensively): The ability to do daily, routine, safe and environmentally friendly lifts to the assembly facility at the Apex Anchor will revolutionize the planetary science industry. Amazing – any size assembled outside of the gravity well (almost) with massive payloads, spacecraft and rocket support. Which planet? When? With how many payloads? At low cost!

- Planetary Sciences Impact from SETS Strength Two (Transforming the economics towards an infrastructure with access to more valuable, lucrative, stable and reliable investments): When cost was the driver of planetary science missions (driven by complexity of design driven by rocket limitations) very little could be accomplished. With a whole new paradigm of low-cost delivery to any solar system destination, science experiments will blossom from the science community.

- Planetary Sciences Impact from SETS Strength Three (Massive movement (Initial Operational Capability (IOC) at 30,000 tonnes/yr and Full Operational Capability (FOC) 170,000 tonnes/yr) [2]: The whole planetary science community has suffered over the decades because they have not had capability to send "all the science instruments needed to accomplish the mission." Most missions were restricted by size, shape, mass and electrical power over the years. With almost unlimited mass restrictions (from assembling as many segments as you desire at the top of the gravity well) the lifetimes of the missions can be expanded, the complexity of the science collected, and the number of missions can expand.

- Planetary Sciences Impact from SETS Strength Four (High velocity (starting at 7.76 km/sec) at 100,000 altitude enables rapid transits to the Moon, Mars and beyond): The ability to leave the Apex Anchor at 7.76 km/sec (or higher) ensures that the planetary spacecraft leave the Earth's sphere of influence and can go beyond Mars without chemical assistance. In fact, there are many advanced proposals to release space systems from Apex Anchors at greater velocities to include escape from our solar system. This capability will enable missions to all parts of our solar system with daily releases.

- Planetary Sciences Impact from SETS Strength Five (As a Green Road to Space, it ensures environmentally neutral operations): The impact to our atmosphere and low Earth orbits by rocket launches are being discussed currently and there is great concern for thousands of launches per year around the globe. [9, 10, 11] Raising payloads with electricity ensures the Green Road to Space.

- Planetary Sciences Impact from SETS Strength Six (Reduction of the need for Rocket Fairing Design limitations): Limitations from rockets have dominated the design of planetary space systems. By raising up to the Apex Anchor inside a 14 tonne (payload) tether climber and then assembly at the top of the gravity well ensures far less restrictions in design. Not only is the volume greater during transit, but the mass restrictions are reduced greatly and the concern for the "rock and roll" of the launch process is eliminated.

- Planetary Sciences Impact from SETS Strength Seven (Assembly at the Top of the Gravity Well): This capability to assemble at the top of the gravity well ensures science missions that will revolutionize the concept of planetary missions. How big? How heavy? Large rocket motors for rendezvous? These are all questions from the past, not the future.

5.1 Summary of Strengths: When one looks at the future missions that are being seriously considered, the worry is about capability to lift that amount of mass to the desired destinations. When one thinks of Mr. Musk, one thinks of 1,000,000 tonnes to the surface of Mars. The aggressive goal of hundreds of Space Solar Power Satellites around the GEO belt leads to 3 or 4 million tonnes to that altitude. Of course, there is the L-5 mission for Mr. Bezos and the National Space Society at 10.5 million tonnes. These desires have not emphasized the ability to lift those numbers out of the gravity well. The key is that if the advanced rockets and Space Elevators collaborated and cooperated, they could each leverage their strengths. Moving initial mass to initiate these dreams need rockets as they will be in the near term and they can achieve those limited visionary steps. A good example of this is the Space Solar Power mission to GEO. Many demonstrations will occur in low Earth orbit and then prototypes will be lifted to geosynchronous. However, the heavy lifting of 3 million tonnes to GEO seems like the perfect match for the strengths of Space Elevators – thus the dual space access strategy. The timing is about right for near term experiments and then operational heavy lifting in the second half of the 30's decade.

6.0 Conclusions and Recommendations

6.1 Space Elevators have remarkable transformational strengths that will enable the planetary science community to launch any size and any shape space system from the Apex Anchor to any location within our Solar System, daily. This set of transformational space access characteristics are centered around the remarkable concept that space science missions can be assembled at the Apex Anchor and then be released at great velocity daily, routinely, inexpensively, and environmentally friendly.

6.2 Enthusiasm will skyrocket through two major phases of space access capabilities. The opportunities for dramatic improvements in scientific missions will be evolving at a very fast pace. The initial leap in capability will be the improvements in advanced rockets (SLS & Starship) with the mid-term giant leap resulting from space elevator operations start.

- The initial growth in science mission spacecraft size and capability will come from the incorporation of the commercially available Starship series of rockets with their carry capacity, volume of payload bay, rate of launches and inexpensive rates leading to near term successes.
- The mid-term leap in capability will come from the incorporation of the Galactic Harbour architecture with its daily and routine massive lift capability. This will lead to a dramatic increase in capacity and destination flexibility not even dreamed of previously. In addition, the characteristics of environmentally neutral operations will ensure a main throughfare called the Green Road To Space.

6.3 Recommendation: Space Elevators, as a transformative agent, will grow within the Dual Space Access Architecture strategy while collaborating with advanced rockets. The concept, that both advanced rockets and space elevator were leveraging the strengths of their own approach with varied capabilities, will lead to phenomenal missions in the future for the scientific community. The time is NOW for both the scientific and commercial communities to start to aggressively think outside of the old launch and mass constrained mindset and visualize space projects, up to now unimaginable, that will benefit mankind.

References:

[1] Eddy, et.al., "Space Elevators are the Green Road to Space," ISEC Report, Lulu Publishers, April 2021

[2] Swan, P, Swan C, Fitzgerald, M., Peet, M, Torla, J, Hall, V., "Space Elevators are the Transportation Story of the 21st Century," ISEC Study Report, www.lulu.com, 2020.

[3] National Academies of Sciences, Engineering, and Medicine 2022. Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032. Washington, DC: The National Academies Press. https://doi.org/10.17226/26522.

[4] Williams, Matt. "Planetary Decadal Survey Says It's Time for a Mission to Uranus (and Enceladus Too)." PHYSORG, 25 Apr. 2022, phys.org/news/2022-04-planetary-decadal-survey-mission-uranus.html.

[5] O'Callaghan, Jonathan. "SpaceX's Starship and NASA's SLS Could Supercharge Space Science." Scientific American, 12 Apr. 2022, www.scientificamerican.com/article/spacexs-Starship-and-nasas-sls-could-supercharge-space-science.

[6] Barry, K., Eduardo Pineda Alfaro, "Changing the Economic Paradigm for Building a Space Elevator," 71st International Astronautical Congress, 2021, Paris.

[7] Maidenberg, Micah. "SpaceX's Elon Musk Expects Starship to Deliver Launches at Lower Costs." WSJ, 11 Feb. 2022, www.wsj.com/articles/elon-musk-expects-Starship-to-deliver-launches-at-a-fraction-of-current-costs-11644549926.

[8] Wall, Mike. "SpaceX's Starship May Fly for Just $2 Million Per Mission, Elon Musk Says." Space.Com, 6 Nov. 2019, www.space.com/spacex-Starship-flight-passenger-cost-elon-musk.html.

[9] Ryan, R. E. Marals, C. Balhatchet, S. Eastham, "*Impact of Rocket Launch and Space Debris Air Pollutant Emissions on Stratospheric Ozone and Global Climate*." Research Article Advanced Earth and Space Science, https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2021EF002612

[10] Piesing, Mark, "*Rocket Launches are an integral part of our 21st-Century world. But how do we stop their polluting exhausts accelerating climate change?*" BBC website "Future," 15 July 2022. https://www.bbc.com/future/article/20220713-how-to-make-rocket-launches-less-polluting

[11] O'Callaghan, Jonathan. "Emissions from Rocket launches could affect Earth's weather systems," NewScientist, Earth, 15 June 2022. https://www.newscientist.com/article/2324367-emissions-from-rocket-launches-could-affect-earths-weather-systems/

[12] Heldmann, Jennifer, et al. "Mission Architecture Using the SpaceX Starship Vehicle to Enable a Sustained Human Presence on Mars." Mary Ann Liebert, Inc., Publishers, Mary Ann Liebert, Inc., www.liebertpub.com/doi/10.1089/space.2020.0058. Accessed 6 Aug. 2022.

[13] Ralph, Eric. "SpaceX-Launched Uranus Mission a Top Priority of New Decadal Survey." TESLARATI, 20 Apr. 2022, www.teslarati.com/spacex-falcon-heavy-uranus-mission-decadal-survey.

[14] Scientific American. "The New Race to the Moon." Rebecca Boyle, vol. 327, no. 2, Aug. 2022, pp. 73–77.

[15] Berger, Eric. "Planetary Scientists Are Starting to Get Stirred up by Starship's Potential." Ars Technica, 1 Dec. 2021, arstechnica.com/science/2021/12/planetary-scientists-are-starting-to-get-stirred-up-by-starships-potential.