Interplanetary Mission Support from Galactic Harbour's Apex Anchor

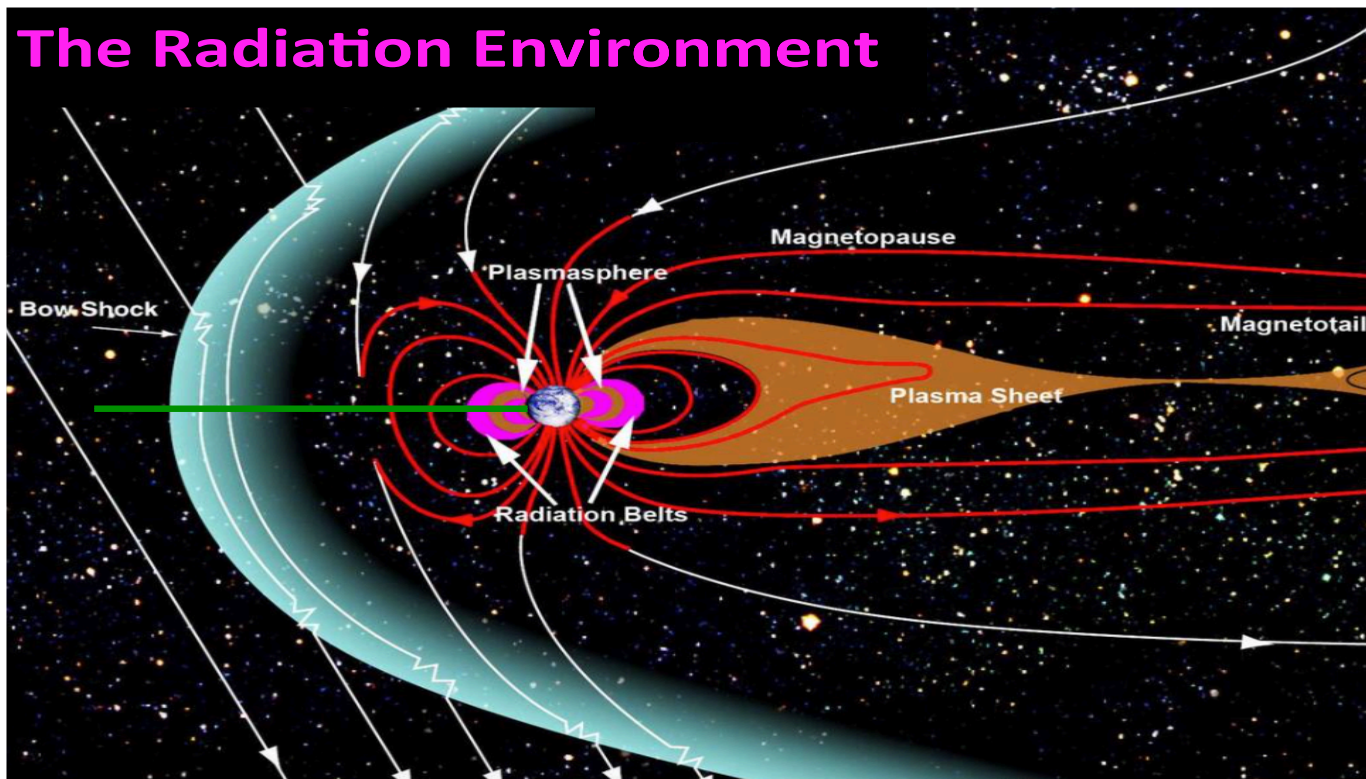
Peter A. Swan, Ph.D.
President, International Space Elevator Consortium
Member, Board of Directors
Past Industry Professor
Technical University of Delft and Stevens Institute of Technology
Member, International Academy of Astronautics
FBIS, FAIAA, MNSS

Michael Fitzgerald

Chief Architect, International Space Elevator Consortium Member, Board of Directors
Executive Vice-President, Galactic Harbour Associates

Earth Radius
6,378 Km

Space
Elevator
100,000 km
In green



9/28/17

Case for Space Elevators

Point One: Space Elevator Transportation Infrastructure - if you ship 100 tons of mission support equipment from the Earth Port; 100 tons show up in proper orbit. No rocket equation eating up launch pad mass.

Point Two: Interplanetary Mission Support - Departs daily from Apex to Mars (no 26-months wait between launch windows) with rapid transit (77 days best time) plus other solar-system destinations.

Point Three: Inexpensive, routine, and environmentally friendly daily departures from the Galactic Harbour's Earth Port.

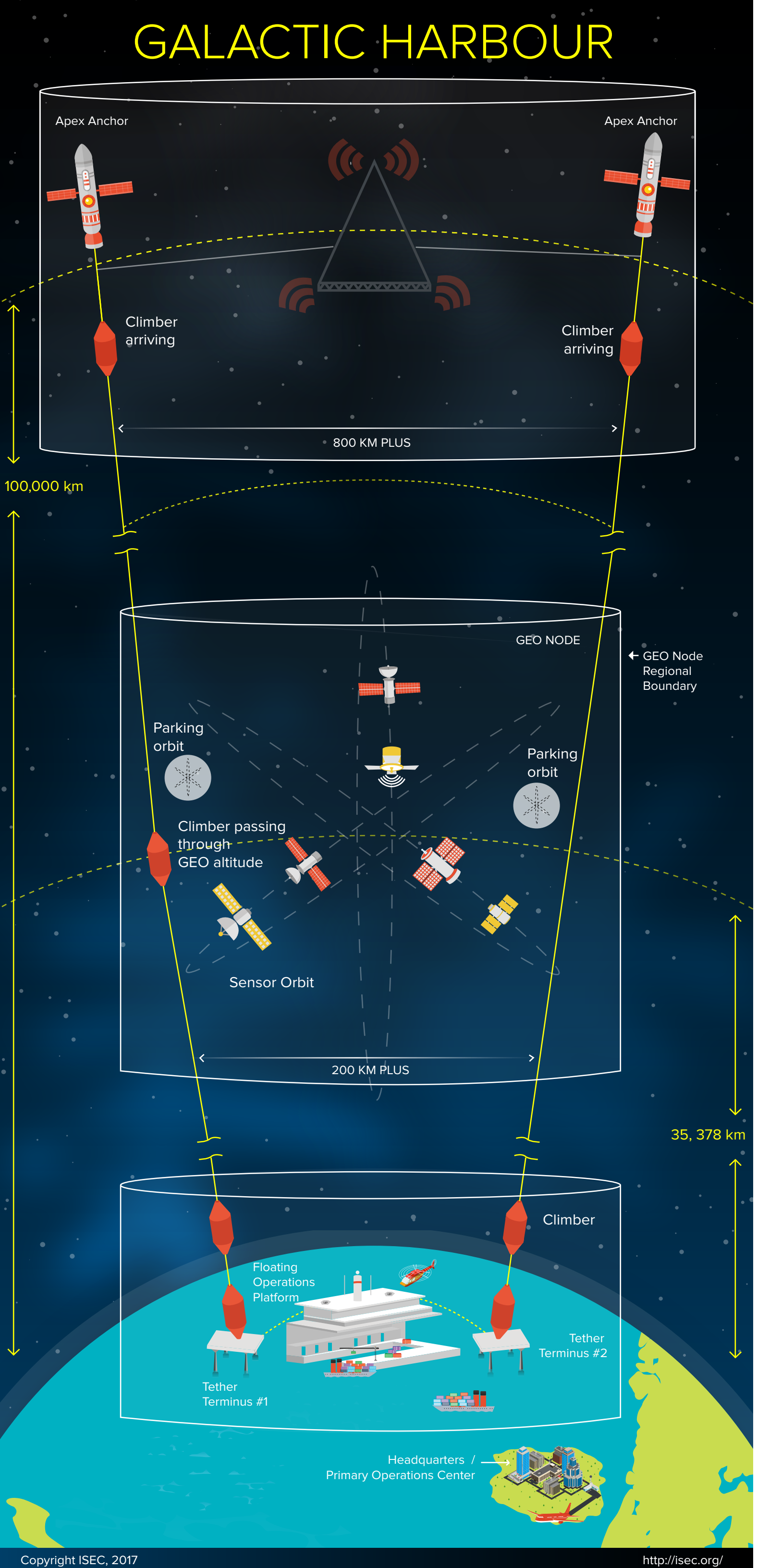
Point Four: Single Crystal Graphene shows remarkable potential as tether material, half meter single molecule already made in the lab in 2D form.

Basic Needs for Interplanetary Flights

- Massive Movement of Support Equipment, Food, and Fuel for robotic and human expansion.
- Rapid Transits – Minimum of 77 days to Mars
- Every Day lift-offs (no 26 month wait)

One Million Tons to Mars to Support my Colony!

Elon Musk, 21 July 2019, CBS Sunday Morning Interview

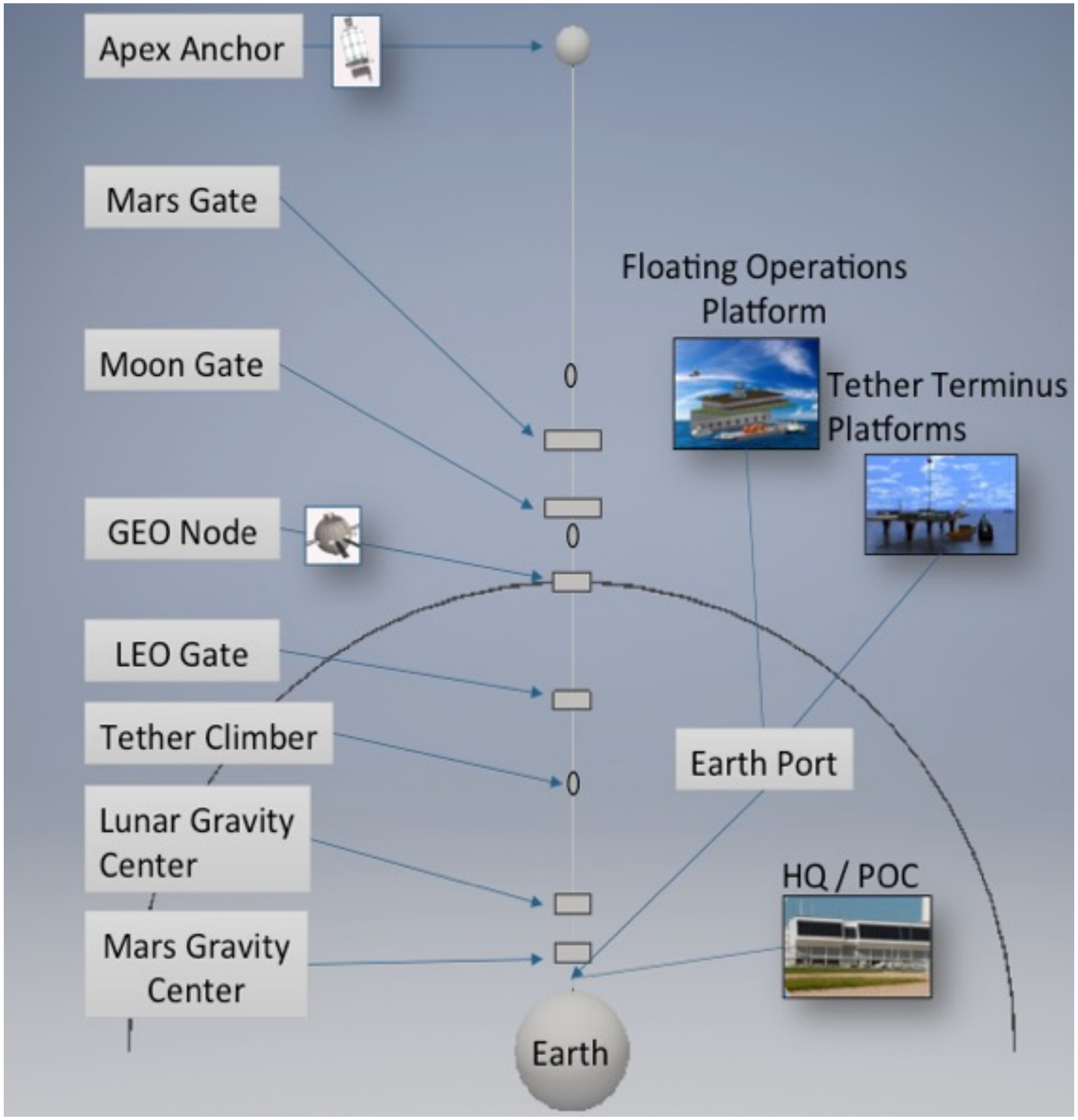


Today's Agenda

Introduction
Mission Support
New Concept supported by Apex Anchor
Numerical Analysis
Conclusion

Galactic Harbours will Unify Transportation and Enterprise Throughout the Regions.

Lexicon for a Space Elevator



Apex Anchor Node
Mars Gate
Moon Gate
GEO Node
LEO Gate
Lunar Gravity Center
Mars Gravity Center
Tether Climbers
Tether Structure
Earth Port
- Earth Terminus
- Floating Operations Platform

Headquarters and Primary Operations Center (HQ&POC)

Major centers of activity
Locations on tether
Tether Material in development

Space Elevator Strengths

- Routine [daily] access to space
- Revolutionarily inexpensive [<$100 per kg] to GEO and beyond
- Commercial infrastructure development similar to bridge building
- Permanent infrastructure [24/7/365/50 years]
- Massively re-usable, no consumption of fuels
- Environmentally sound/sustainable - will make Earth "greener"
- Safe (low risk) and reliable [no shake, rattle and roll of rocket liftoff]
- Low probability of creating orbital debris
- Redundant paths as multiple sets of Space Elevators become operational
- Massive loads per day [starts at 14 metric tons cargo loads]
- Opens up tremendous design opportunities for users
- Optimized for geostationary orbit altitude and beyond
- Co-orbits with GEO systems for easy integration

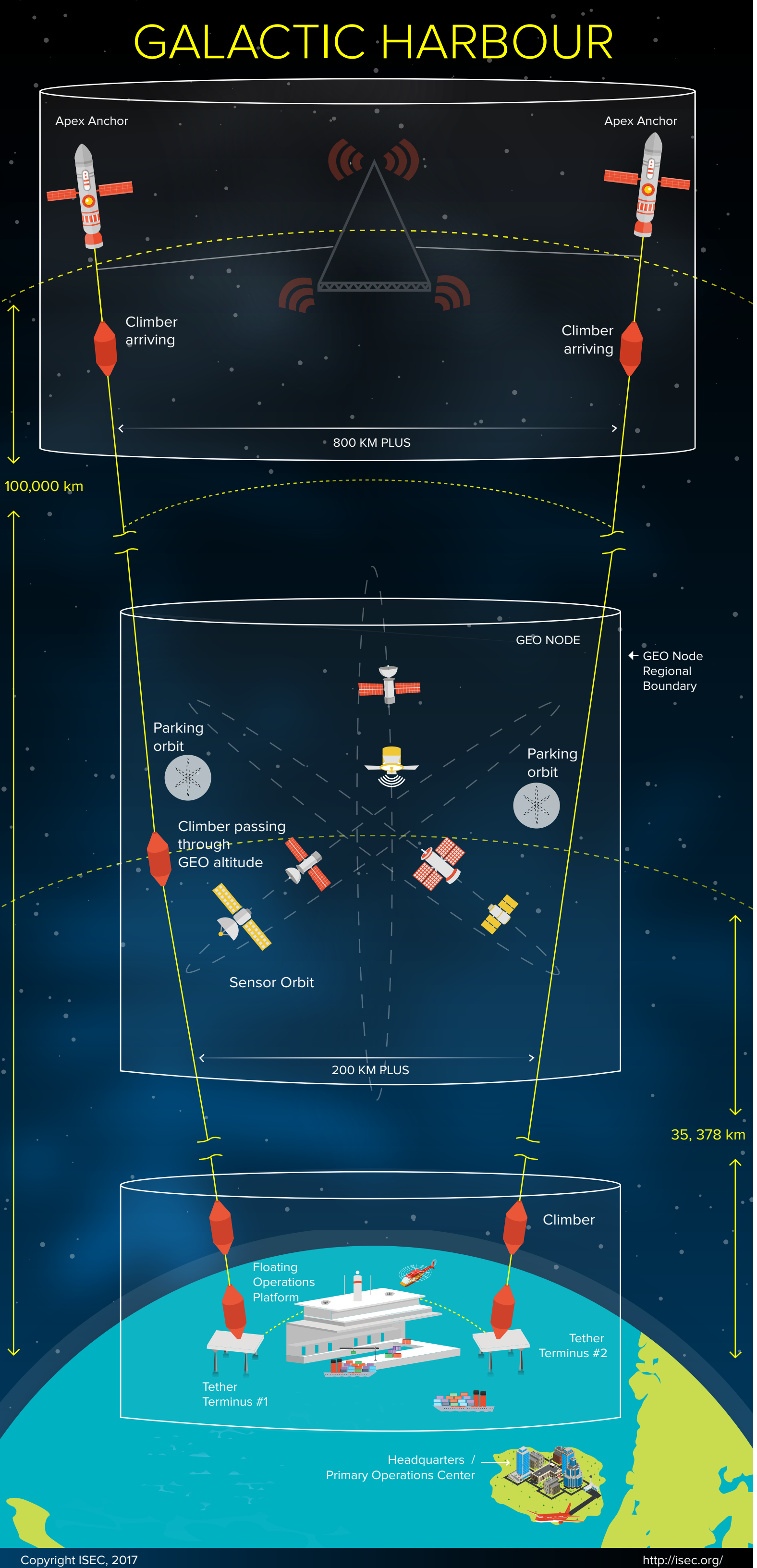
Reference Missions

- To Compare future loads with today's loads, three Reference Missions are identified:
  - GEO: Space Solar Power
  - Lunar: Moon Village
  - Mars: SpaceX's Colony
- Reference Missions must have support far exceeding current capabilities.
- Concept: Cooperative Infrastructures working together: Future Rockets and Space Elevators

Three Chosen Missions

- Space Solar Power – 80,000 MT – "Space solar power can solve our energy and greenhouse gas emissions problems. Not just help, not just take a step in the right direction, but *solve*."*
- Moon Village – XXXXX MT - European "togetherness" towards a Moon Village suggests a massive support effort required.
- SpaceX Colony – 1,000,000 MT** – Mr. Musk has stated that he needs that amount of mission support on Mars.

[*The Case for Space Solar Power by John C. Mankins](#)
**** July 21, 2019 Quotation on Sunday Morning TV.**



Today's Agenda

Introduction

Mission Support

New Concept supported by Apex Anchor

Numerical Analysis

Conclusion

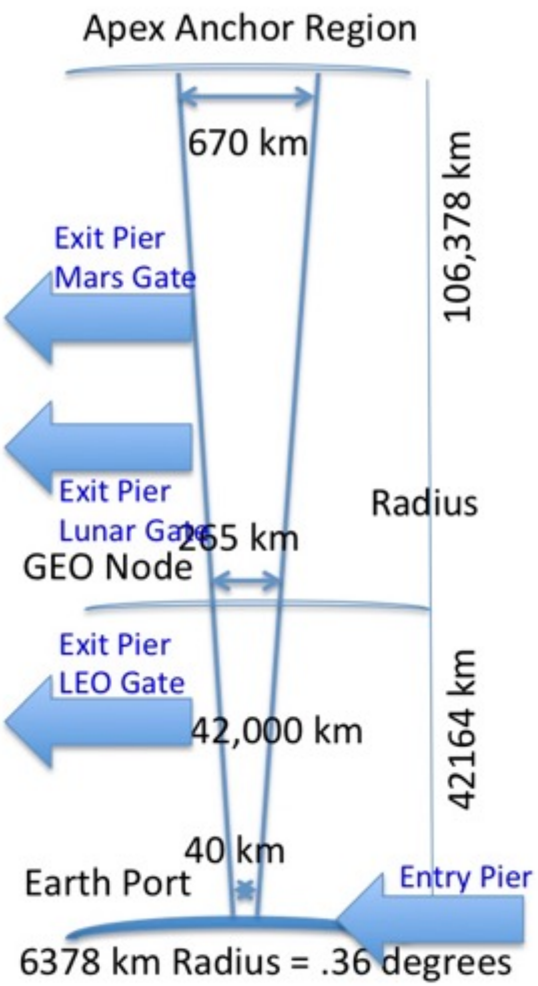
Galactic Harbours will Unify Transportation and Enterprise Throughout the Regions.

New Concept

- New Paradigm for Supporting Interplanetary Flights and Destinations
- Fast Transit -- as low as 77 days to Mars
- Everyday “tosses” – No 26 month wait
- Massive support -- support colonies and missions with 84 MT per day (14 x 6) for 365 days or 30,576 MT per year

Vision of the Galactic Harbour Piers

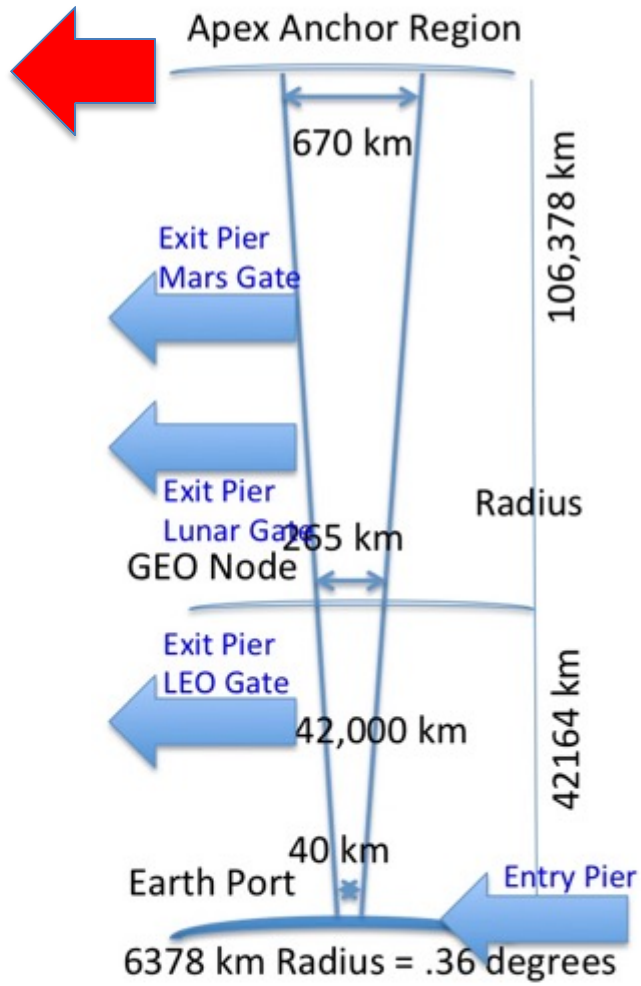
- *Space Elevator Transportation System serves as the 'main channel' in the Galactic Harbour.*
- *Businesses access the main channel from the Earth Port, the GEO Node, and the APEX Region.*
- *Businesses flourish as part of the Space Elevator Enterprise System*



Galactic Harbour The Unifying Vision

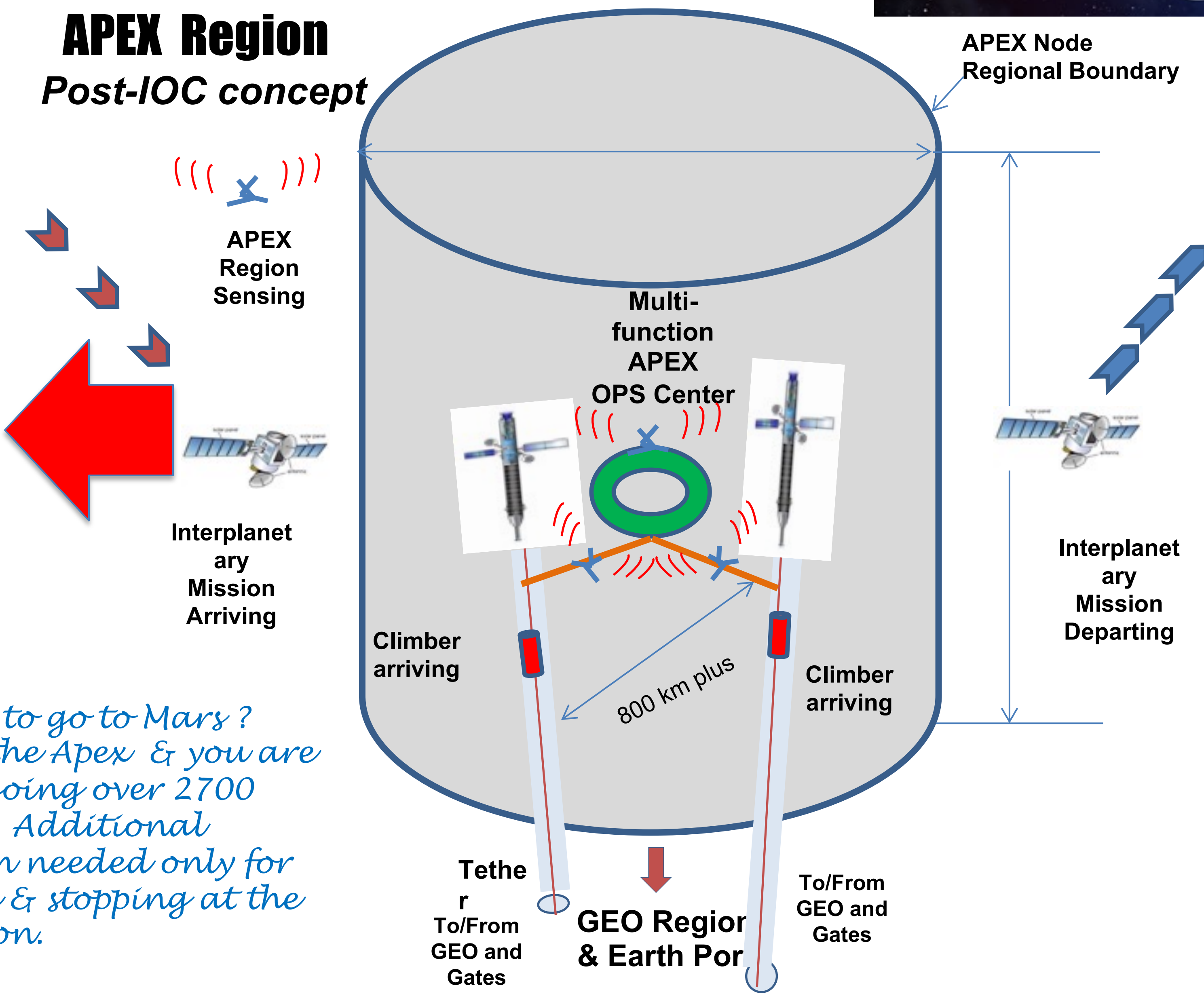
Galactic Harbour Fast Transit Pier

- *Space Elevator Transportation System serves as the 'main channel' in release towards interplanetary flights.*
- *Apex Anchor has great velocity.*
- *Release Once a day enables flights to full region of interest*



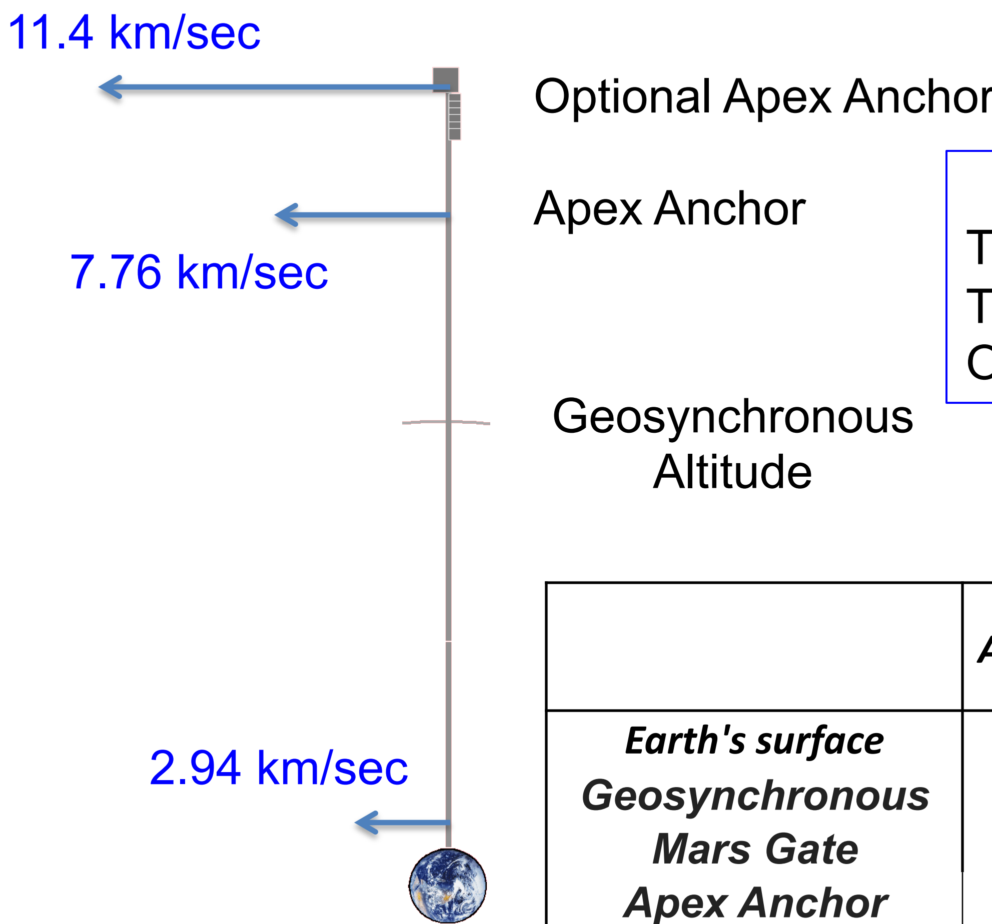
Galactic Harbour The Unifying Vision

SPACE ELEVATOR
APEX Region
Post-IOC concept



You want to go to Mars ? Jump off the Apex & you are already going over 2700 km/hour. Additional propulsion needed only for guidance & stopping at the destination.

Velocity at Sphere of Influence



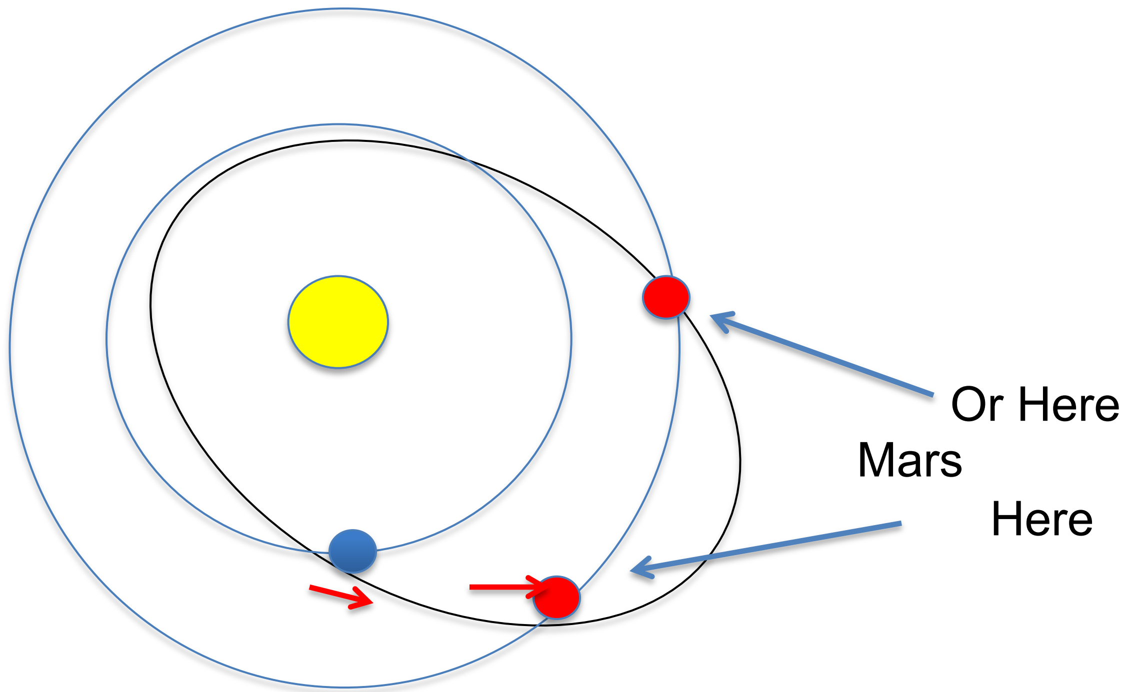
Three Release Locations

Traditional Hohmann Transfer (LEO)
Traditional Apex Anchor (100,000 km)
Optional Apex Anchor (150,000 km)

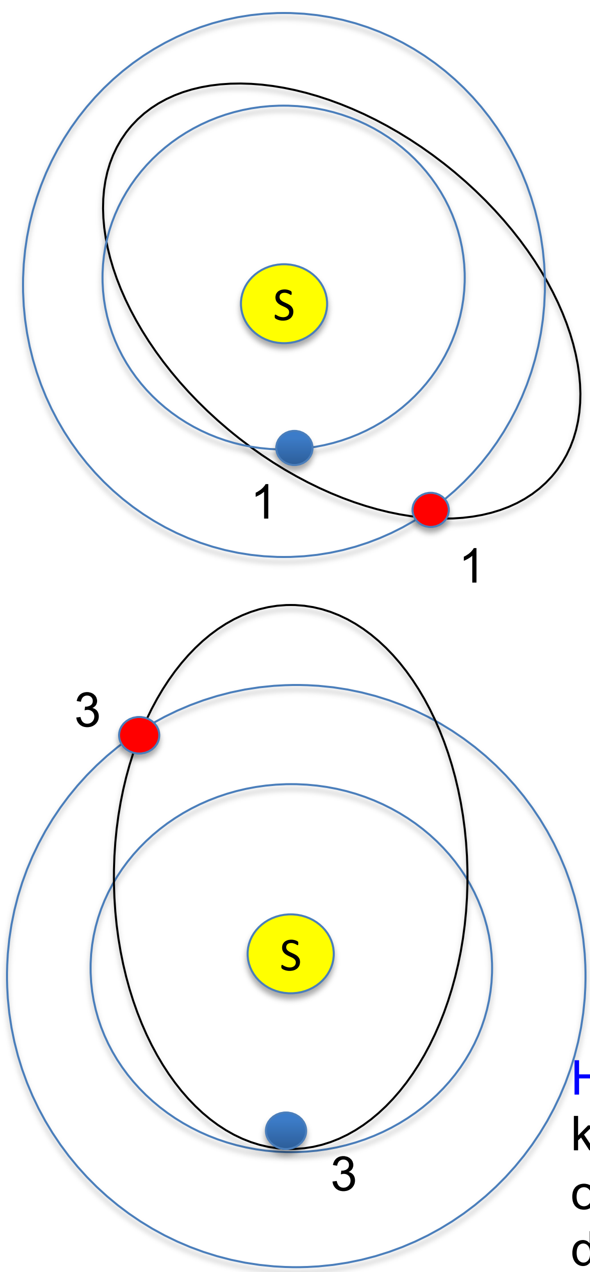
	Alititude (Km)	***Radius (Km)***	***Velocity (km/sec)***
Earth's surface	0	6378	0.465594
Geosynchronous	35,786	42,164	3.077972
Mars Gate	57,000	63,378	4.626594
Apex Anchor	100000	106,378	7.765594
Option Apex Anchor	150000	156378	11.415594

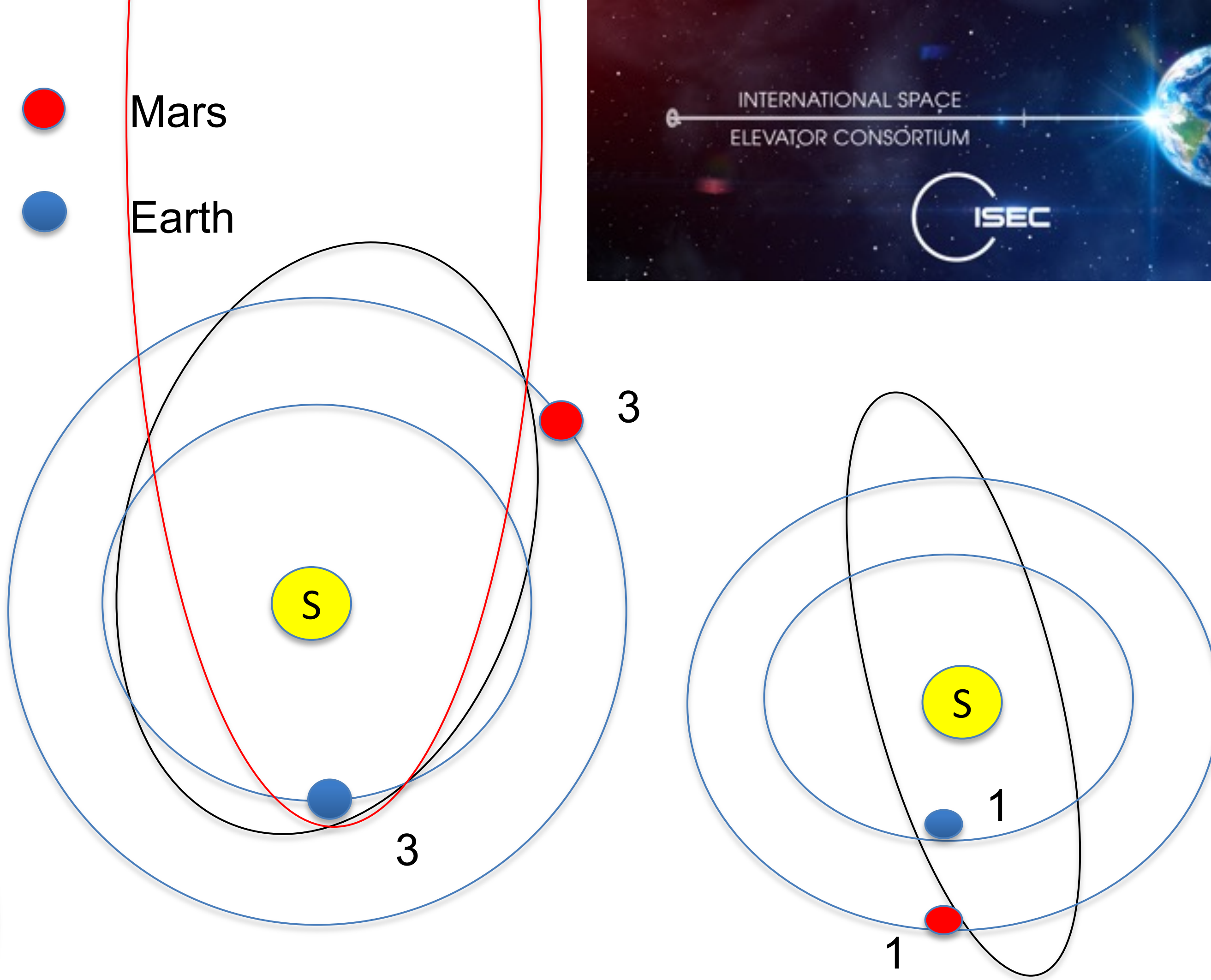
Every Day an Opportunity for Release

Case One: Fastest Approach



Concept: Our spacecraft enter the ellipse “not at perigee”
Ellipse is created by a velocity vector with one foci at the Sun
A later portion of the ellipse coincides with Mars with a rendezvous vector

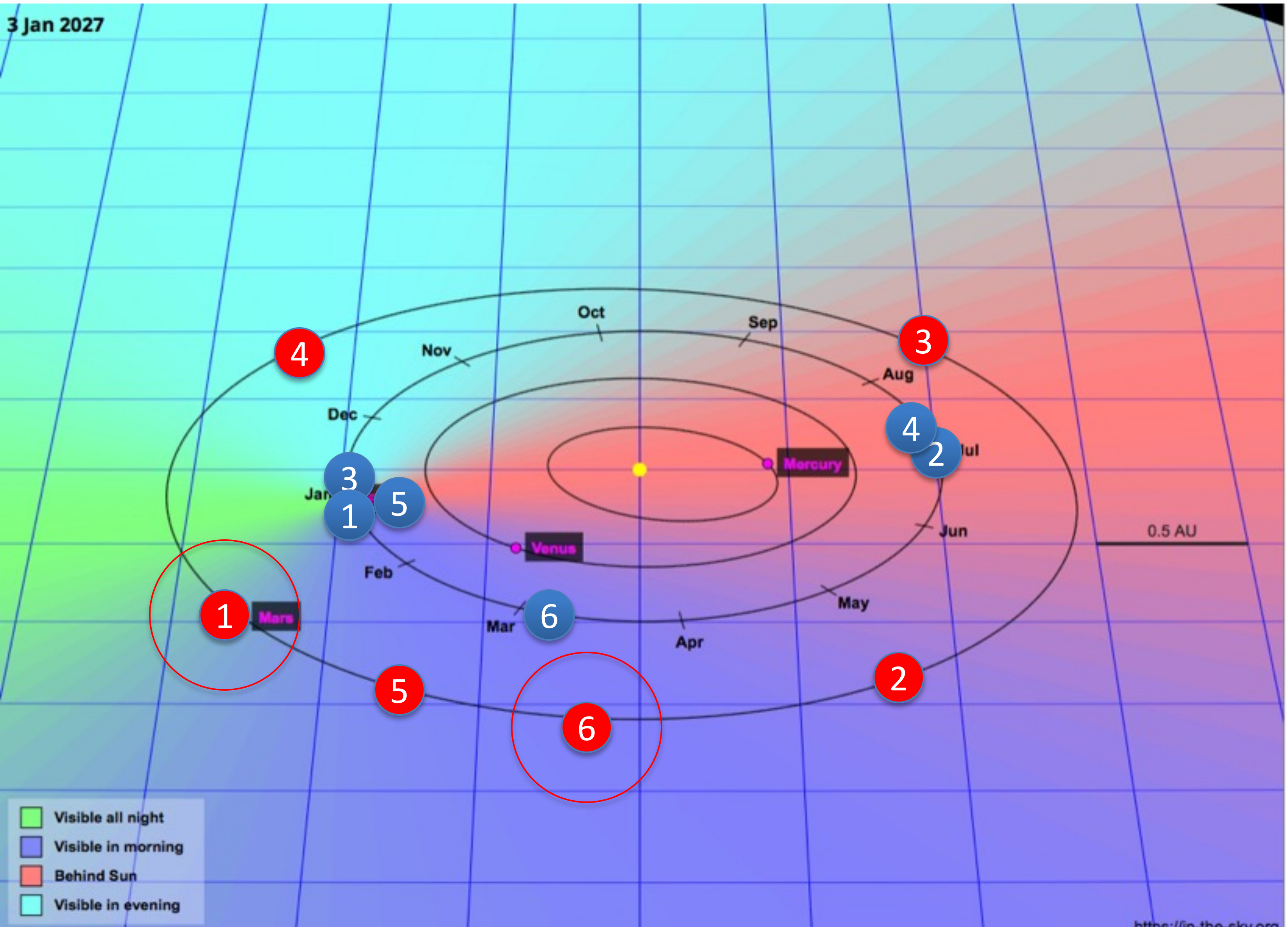




Hypothesis: With a departure velocity of 7.76 or 11,41 km/sec, added to the Earth's velocity in vector addition [not orthogonal vectors as is Holman Transfer], time of flight decreases and a plethora of launch windows appear.

Challenge: Show how Apex Anchor release improves Interplanetary flights and discuss impacts?

NASA Window to Mars Every 26 Months



Mars

Earth

1--3 Jan 2027
2--3 July 2027
3--3 Jan 2028
4--3 July 2028
5 --3 Jan 2029
6 --3 Mar 2029

Motion counter clockwise

This is the transportation story of the 21st century. Reliable, safe, and efficient access to space is close at hand. The Space Elevator is the Galactic Harbour, and an essential part of the global and interplanetary transportation infrastructure.

Bus Schedule for Interplantary Transportation
when departing from Galactic Harbour Apex Anchor

Bus Schedule to Mars

Bus Schedule, from Apex Anchor 2035

Date	Departure	Destination	Flight Time	Arrival	Comments
7/1/2035	Indian #1	Mars	87 days	9/26/2035	
7/1/2035	Pacific #1	Mars	86 days	9/25/2035	
7/1/2035	Pacific #2	Mars	84 days	9/22/2035	Fast

Bus Schedule, from Apex Anchor 2035

Date	Departure	Destination	Flight Time	Arrival	Comments
7/8/2035	Indian #1	Mars	81 days	4/14/2035	
7/8/2035	Indian #2	Mars	81 days	4/14/2035	
7/8/2035	Indian #1	Mars	80 days	4/13/2035	Fast

Bus Schedule, from Apex Anchor 2035

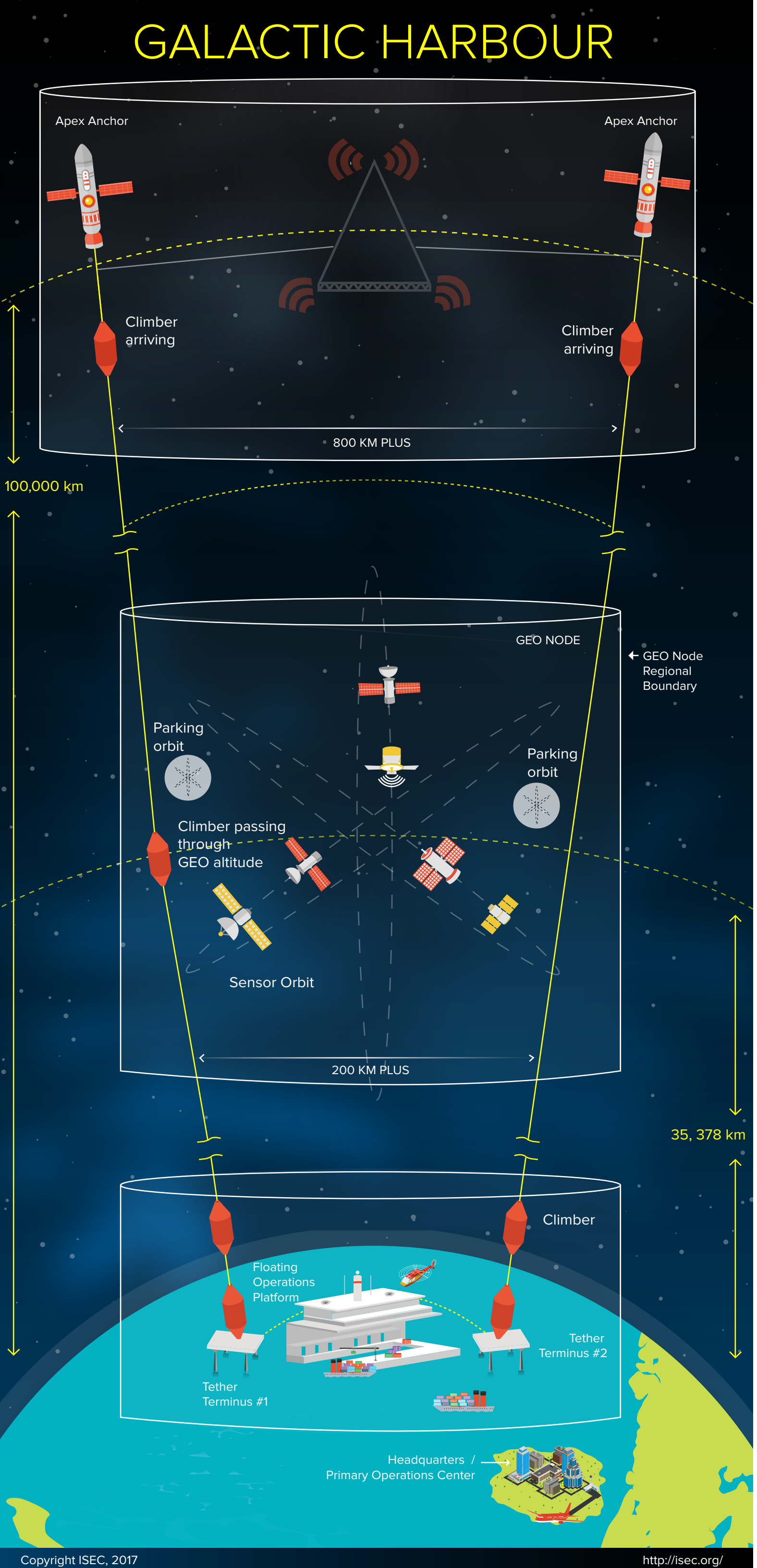
Date	Departure	Destination	Flight Time	Arrival	Comments
7/15/2035	Indian #1	Mars	79 days	10/2/2035	
7/15/2035	Indian #1	Mars	79 days	10/2/2035	
7/15/2035	Indian #2	Mars	79 days	10/1/2035	
7/15/2035	Indian #2	Mars	79 days	10/1/2035	
7/15/2035	Pacific #1	Mars	78 days	9/30/2035	Fast
7/15/2035	Atlantic #1	Mars	190 days	1/21/2036	
7/15/2035	Atlantic #1	Mars	182 days	1/13/2036	
7/15/2035	Atlantic #2	Mars	173 days	1/4/2036	
7/15/2035	Atlantic #2	Mars	164 days	12/25/2035	
7/15/2035	Atlantic #1	Mars	154 days	12/15/2035	

Bus Schedule, from Apex Anchor 2035

Date	Departure	Destination	Flight Time	Arrival	Comments
7/22/2035	Pacific #2	Mars	77 days	10/7/2035	Fastest
7/22/2035	Pacific #2	Mars	77 days	10/7/2035	Fastest
7/22/2035	Pacific #1	Mars	223 days	3/1/2036	

Bus Schedule, from Apex Anchor 2035 to Moon

Date	Departure	Destination	Flight Time	Arrival	Comments
every day	Indian #1	Moon	14 hours	+ 14 hours	
every day	Indian #2	Moon	14 hours	+ 14 hours	
every day	Pacific #1	Moon	14 hours	+ 14 hours	Fast
every day	Pacific #2	Moon	14 hours	+ 14 hours	
every day	Atlantic #1	Moon	14 hours	+ 14 hours	
every day	Atlantic #2	Moon	14 hours	+ 14 hours	



Today's Agenda

Introduction

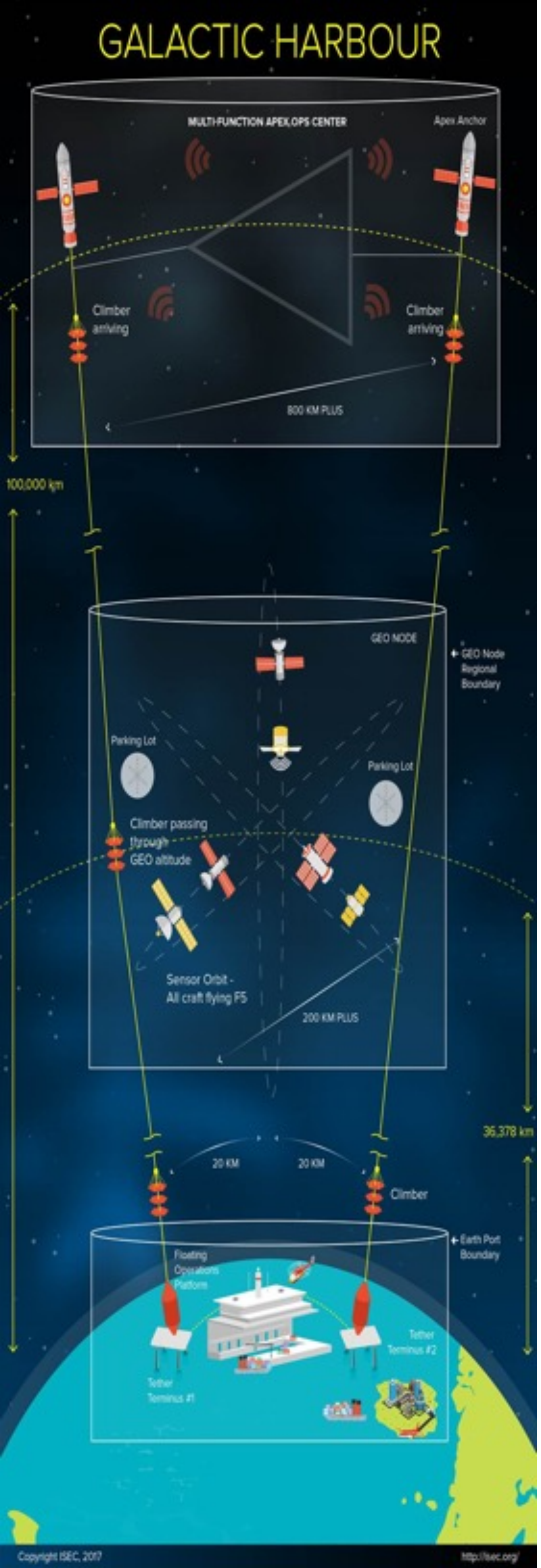
Mission Support

New Concept supported by Apex Anchor

Numerical Analysis

Conclusion

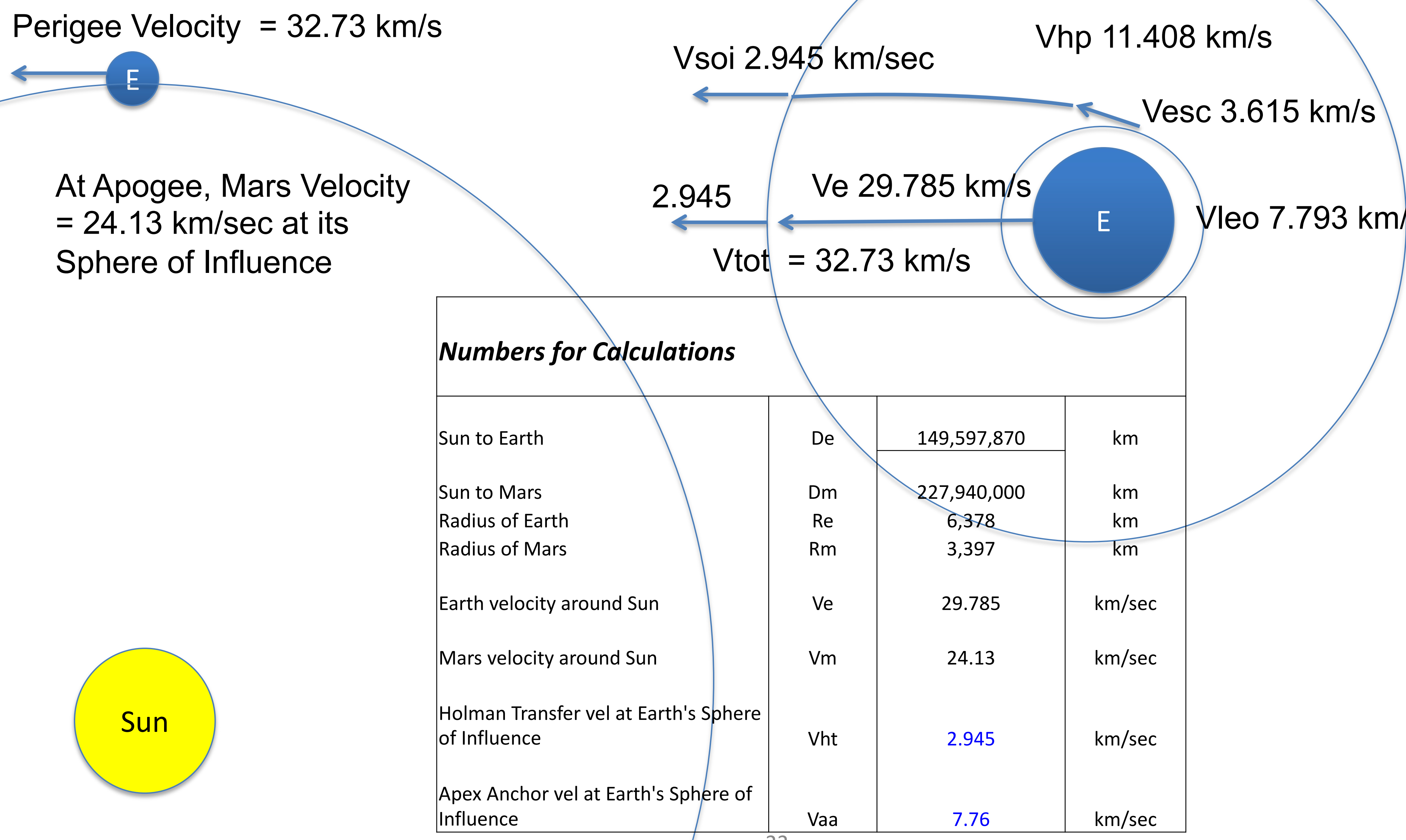
Galactic Harbours will Unify Transportation and Enterprise Throughout the Regions.



Challenge

- Challenge Question: How does Apex Anchor release improve Interplanetary flights? Example to use is Earth to Mars.
- Traditional Approach to Mars: Minimum energy Hohmann Transfer from ellipse perigee (Earth's orbit) to apogee (Mars orbit). Characteristics: time consuming (8 or 9 months), restriction of launch window only every 26 months, and historically, small payloads. The departure velocity is historically 2.9 km/sec added to Earth's velocity around the sun. Can go faster with shorter transit, but requires great fuel consumption.
- Hypothesis: With a departure velocity of 7.76 km/sec (or greater), added to the Earth's velocity in vector addition [not orthogonal vectors as is Holman Transfer], time of flight decreases and a plethora of launch windows appear.
- Project: Explain, and show with numbers, the advantages of leaving from Apex Anchor locations

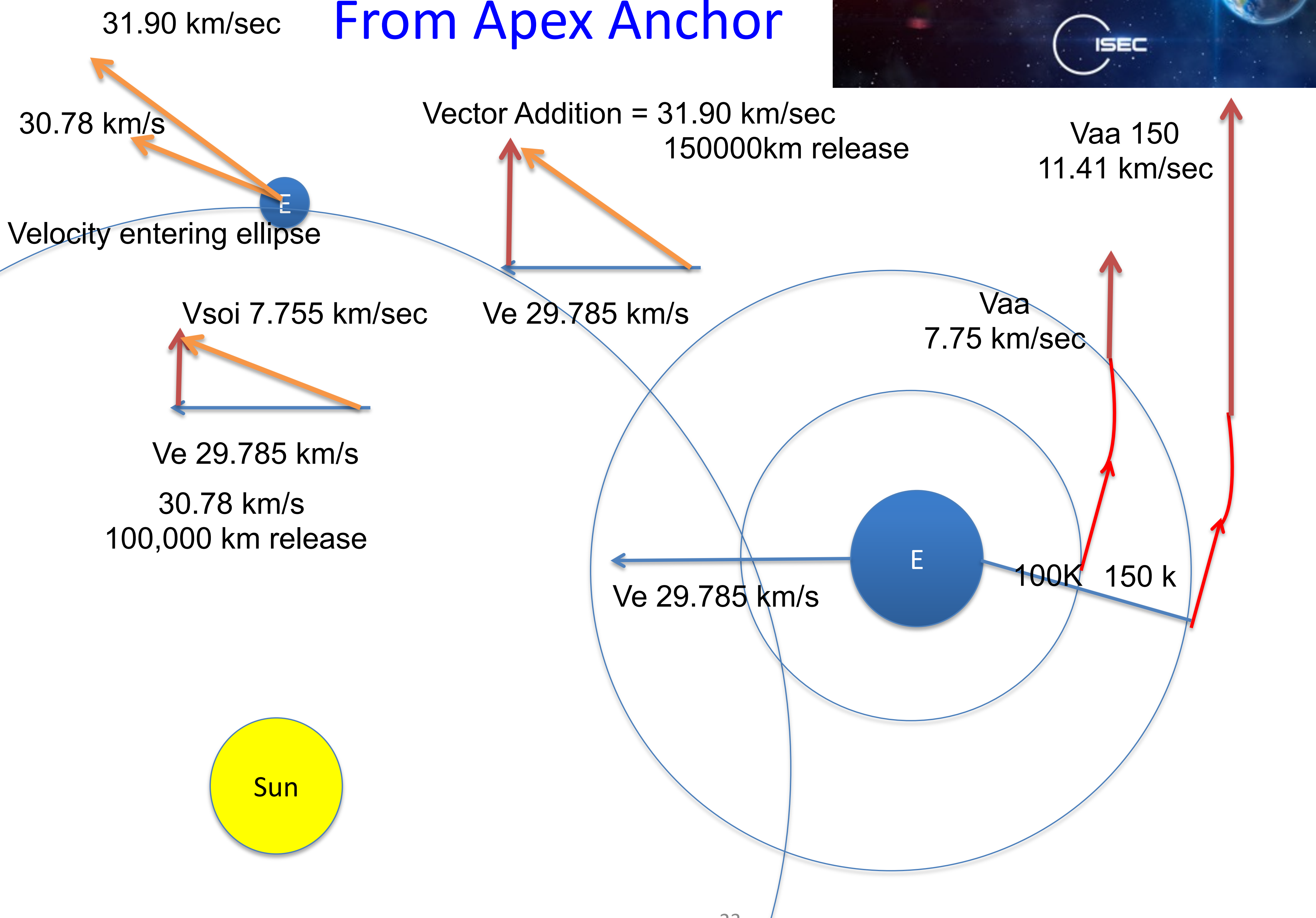
Hohmann Transfer
Patched Conic



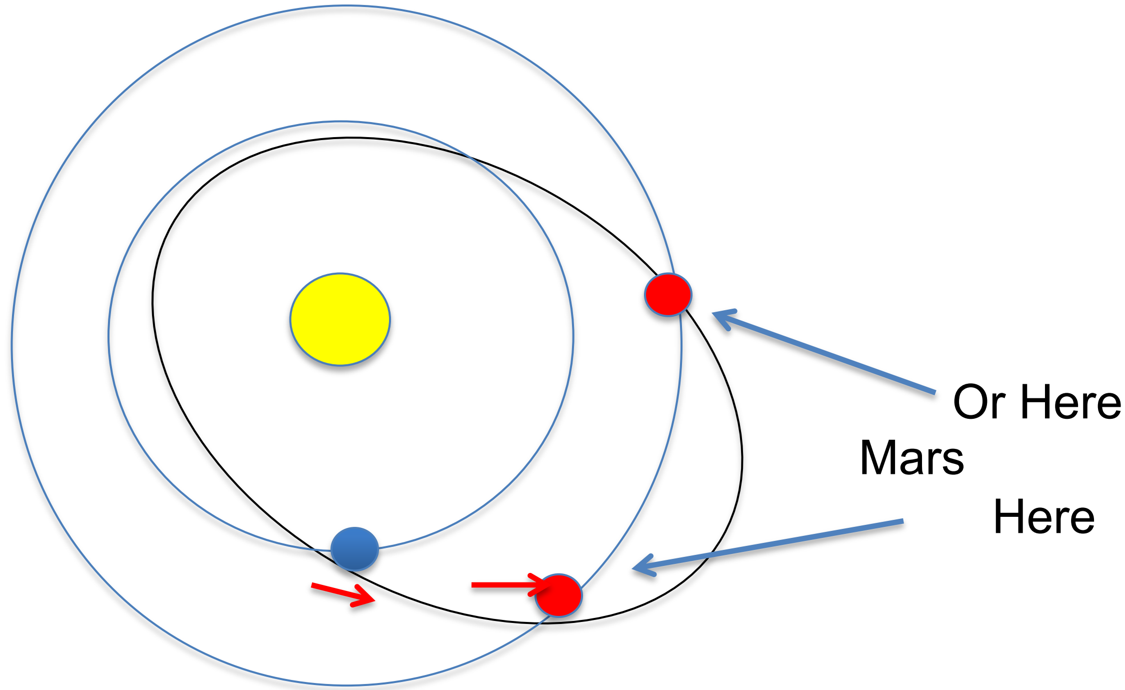
Numbers for Calculations

Sun to Earth	De	149,597,870	km
Sun to Mars	Dm	227,940,000	km
Radius of Earth	Re	6,378	km
Radius of Mars	Rm	3,397	km
Earth velocity around Sun	Ve	29.785	km/sec
Mars velocity around Sun	Vm	24.13	km/sec
Holman Transfer vel at Earth's Sphere of Influence	Vht	2.945	km/sec
Apex Anchor vel at Earth's Sphere of Influence	Vaa	7.76	km/sec

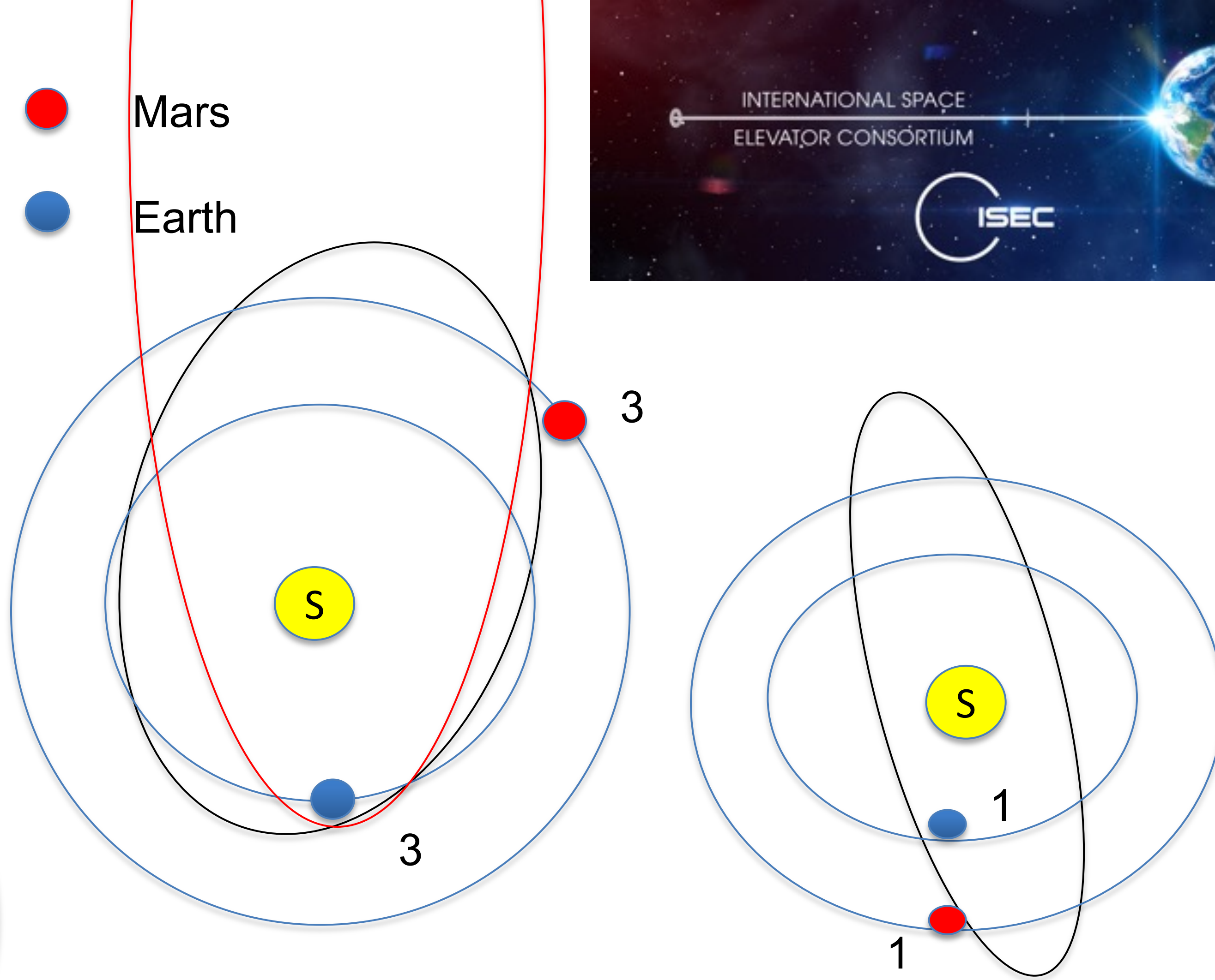
Rapid Transfer From Apex Anchor

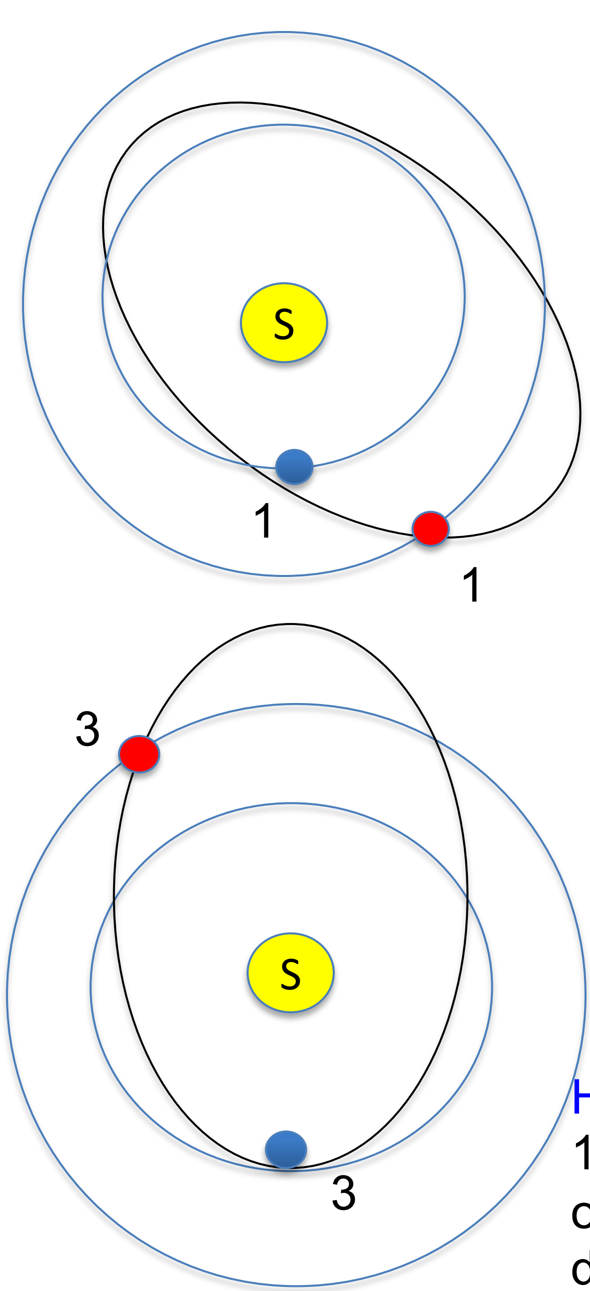


Case One: Fastest Approach



Concept: Our spacecraft enter the ellipse “not at perigee”
Ellipse is created by a velocity vector with one foci at the Sun
A later portion of the ellipse coincides with Mars with a rendezvous vector





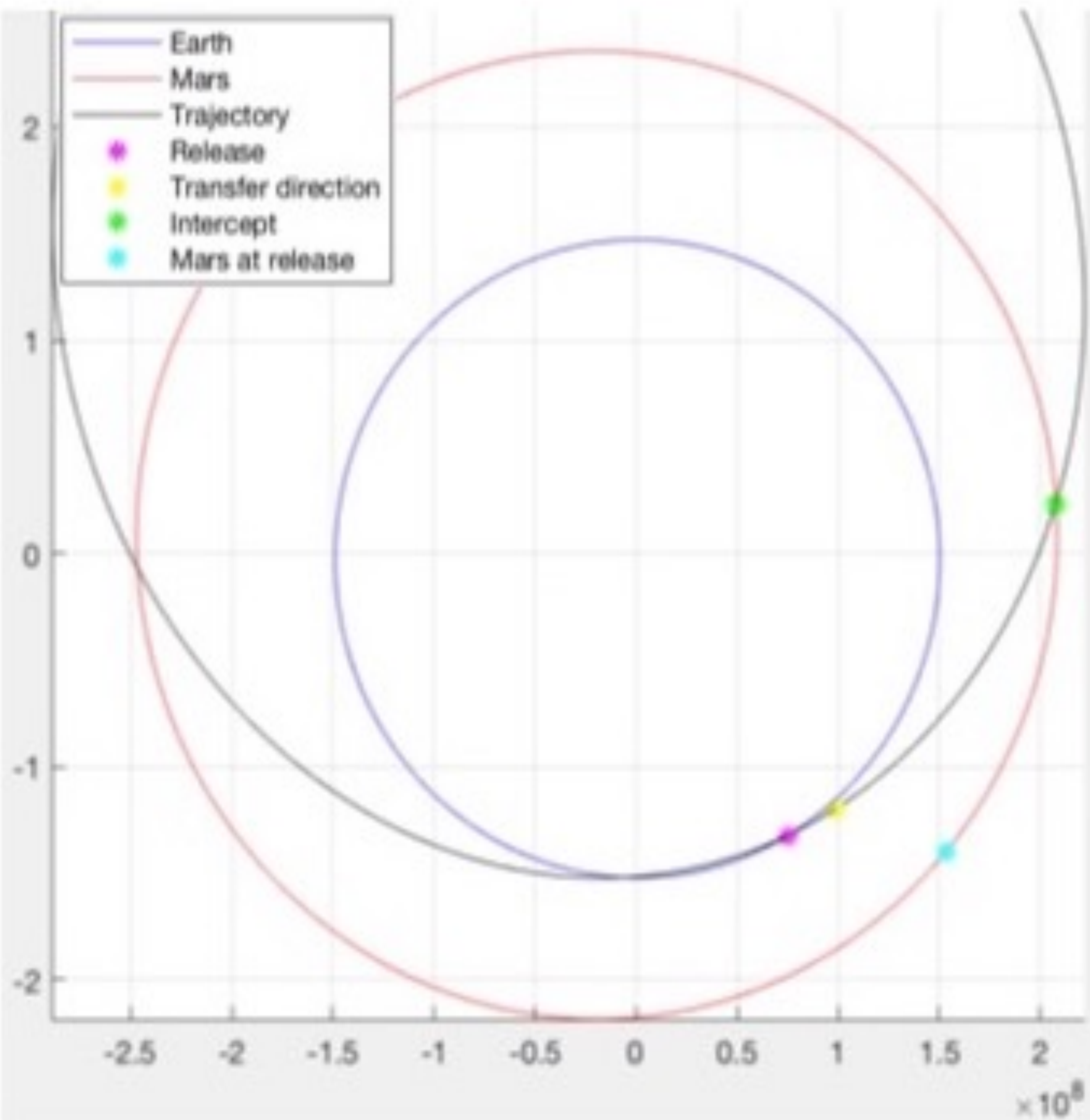
INTERNATIONAL SPACE
ELEVATOR CONSORTIUM
ISEC

Hypothesis: With a departure velocity of 7.76 km/sec (or 11.41) added to the Earth's velocity in vector addition [not orthogonal vectors as is Holman Transfer], time of flight decreases and a plethora of launch windows appear.

Challenge: Show how Apex Anchor release improves Interplanetary flights and discuss impacts?

Optimum Case 77 Days

INTERNATIONAL SPACE ELEVATOR CONSORTIUM
ISEC



Lambert Problem

Lambert's problem is a way to solve for the trajectory connecting two position vectors with a given time of flight. In Figure 1, $\vec{r}_0$ and $\vec{r}_f$ define the positions of the initial planet (P_0) at the time of departure and the final planet (P_f) at the time of arrival. With these positions and the time of flight, solving Lambert's problem will define the orbital elements of the transfer orbit. Once the orbital elements of the transfer orbit are computed, the velocities at departure and arrival may be found.

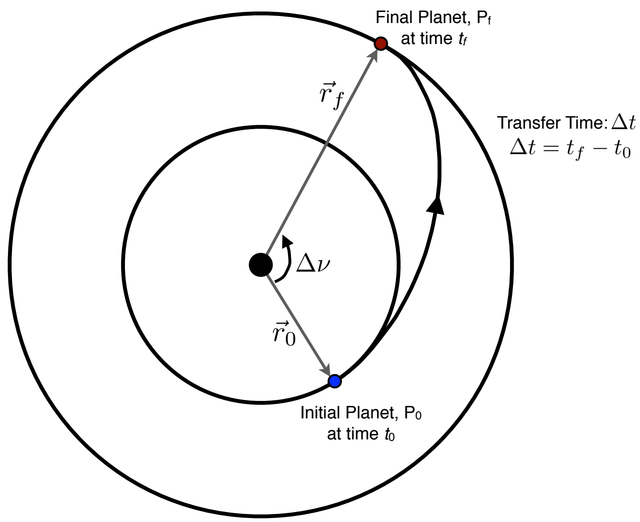


Figure 1. Lambert's Problem

According to Lambert's Theorem, the transfer time Δt from P_0 to P_f is independent of the orbit's eccen- tricity and depends only on the sum of the magnitudes of the position vectors, the semimajor axis a and the length of the chord joining P_0 and P_f.

David, Kate, "Lambert's Problem, Interplanetary Mission Design"

Comparison to Rockets - data varies greatly, only representative

Table 1: Launch Vehicle Delivery Percentages to GEO

Launch Vehicle	Pad Mass	To LEO (with % of pad)	to GEO (est.) (with % of pad)	to Moon surface (with % of pad)
Atlas V	590,000	18,500 (3%)	7,000 (1.2%)	
Delta IV H	733,000	28,770 (3.9%)	10,000 (1.4%)	
Falcon H	1,420,000	63,000 (4.4%)	26,000 (1.8%)	
Saturn V	2,970,000	140,000 (4.7%)		16,000 - 0.5%
average		4% of Pad mass	1.5% of pad Mass	

Note: data from web varies greatly - these numbers are representative only

Rough Numbers for Rockets:

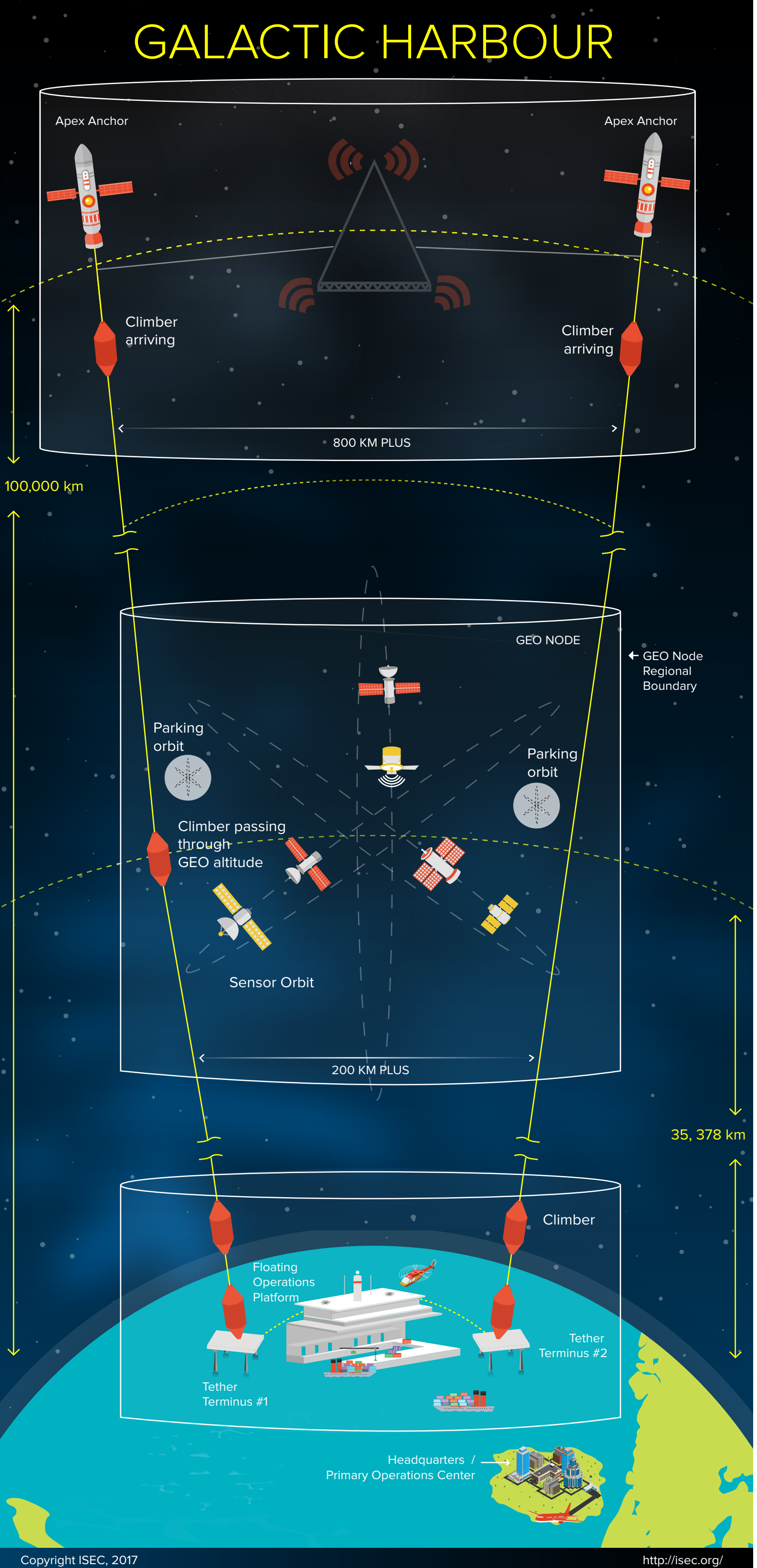
Mass on the Pad	3,000,000 kg
Mass to LEO	120,000 kg
Mass insertion to GEO	45,000 kg
Mass to Lunar Surface	15,000 kg

Rough Numbers for Space Elevators

Mass at Earth Port	20,000 kg (14,000 kg of Payload)
Mass upon release at Apex Anchor	14,000 kg
Mass approaching Moon or Mars	14,000 kg

Number of Rocket Launches per year = 91 average

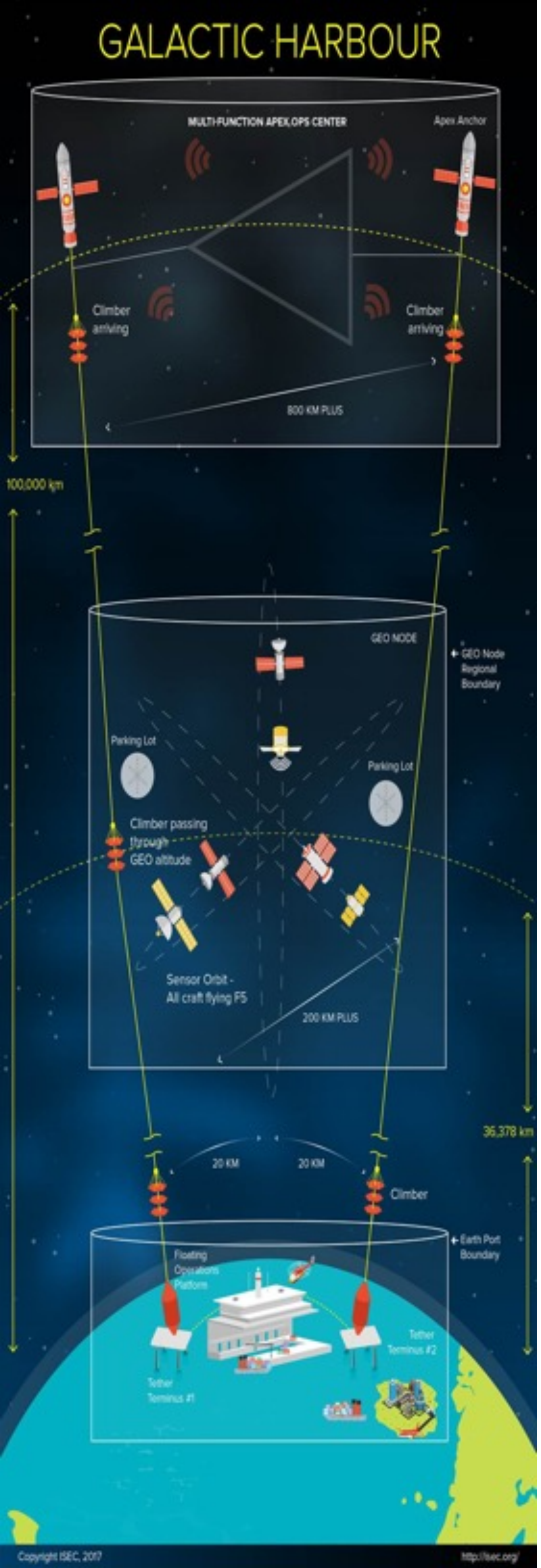
Number of SE Liftoffs in a year = 2190



Today's Agenda

Introduction
Mission Support
New Concept supported by Apex Anchor
Numerical Analysis
Conclusion

Galactic Harbours will Unify Transportation and Enterprise Throughout the Regions.



Conclusions

Can we do daily lift-offs with a variety of flight times to Mars?

Of course!

What type of massive support is there

30,576 MT per year

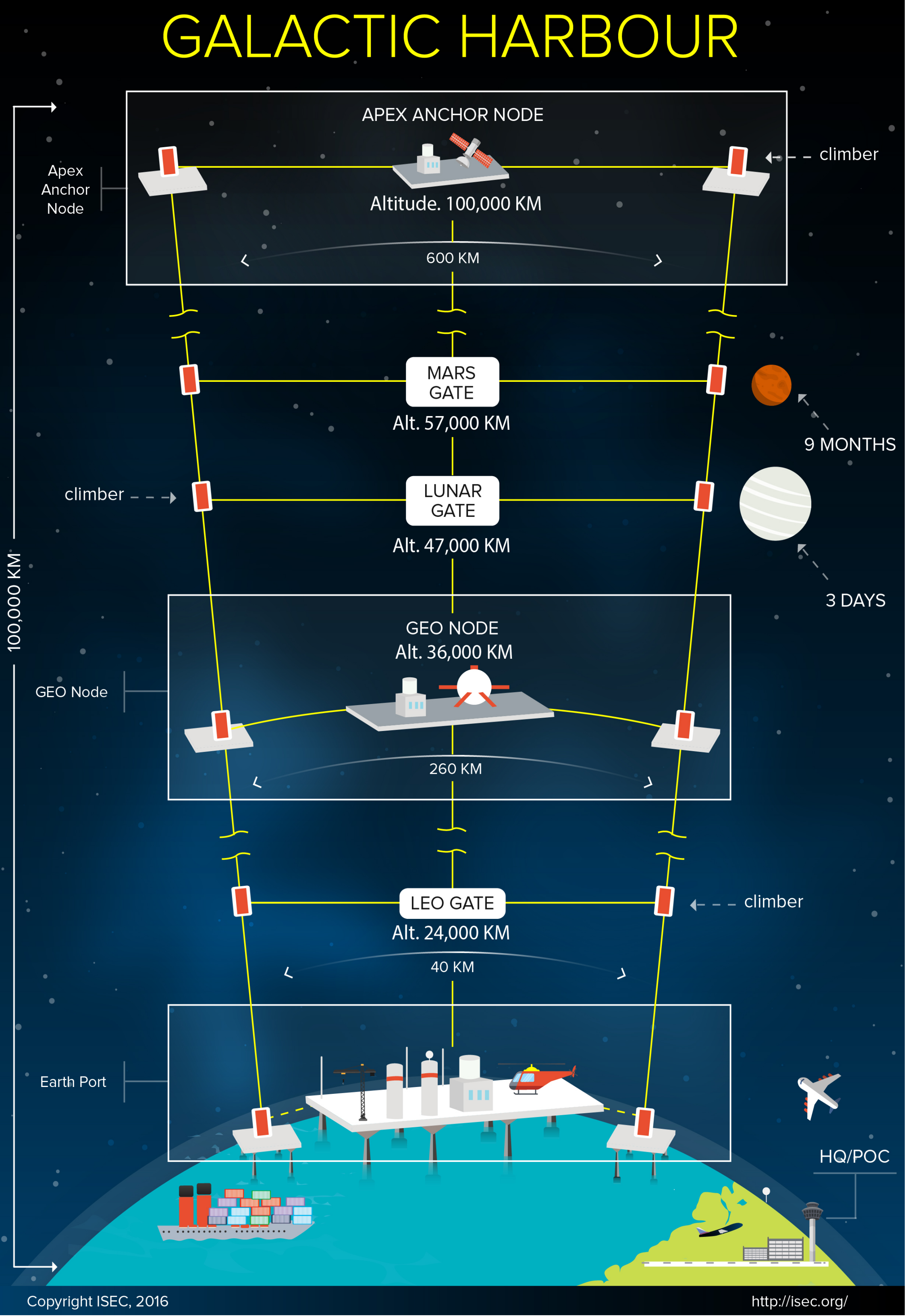
What type of launch windows are there?

365 days a year

What is Fastest Transit Time to Mars?

77 days

Reliable, daily, routine, safe and environmentally friendly movement off-planet towards the Moon Mars and asteroids.



INTERNATIONAL SPACE ELEVATOR CONSORTIUM

ISEC

Our Vision of Space Elevators is a Galactic Harbour

Galactic Harbour Mission Statement:

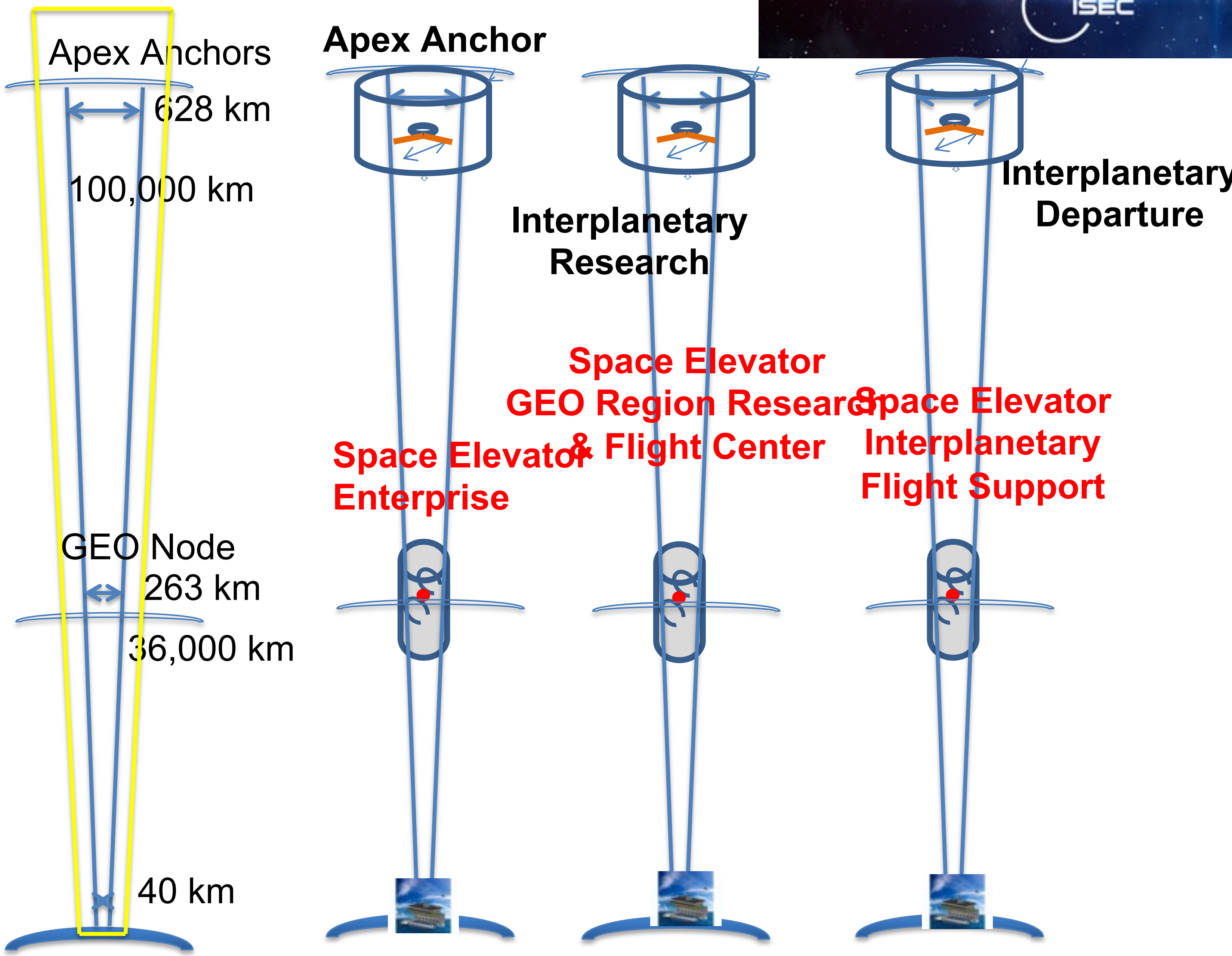
Importing needed commodities and exporting business and exploratory payloads.

Our "strategy" is to link the Space Elevator Transportation System to the Space Elevator Enterprise; within a Unifying Vision

… the Galactic Harbour.

Family Of Elevators

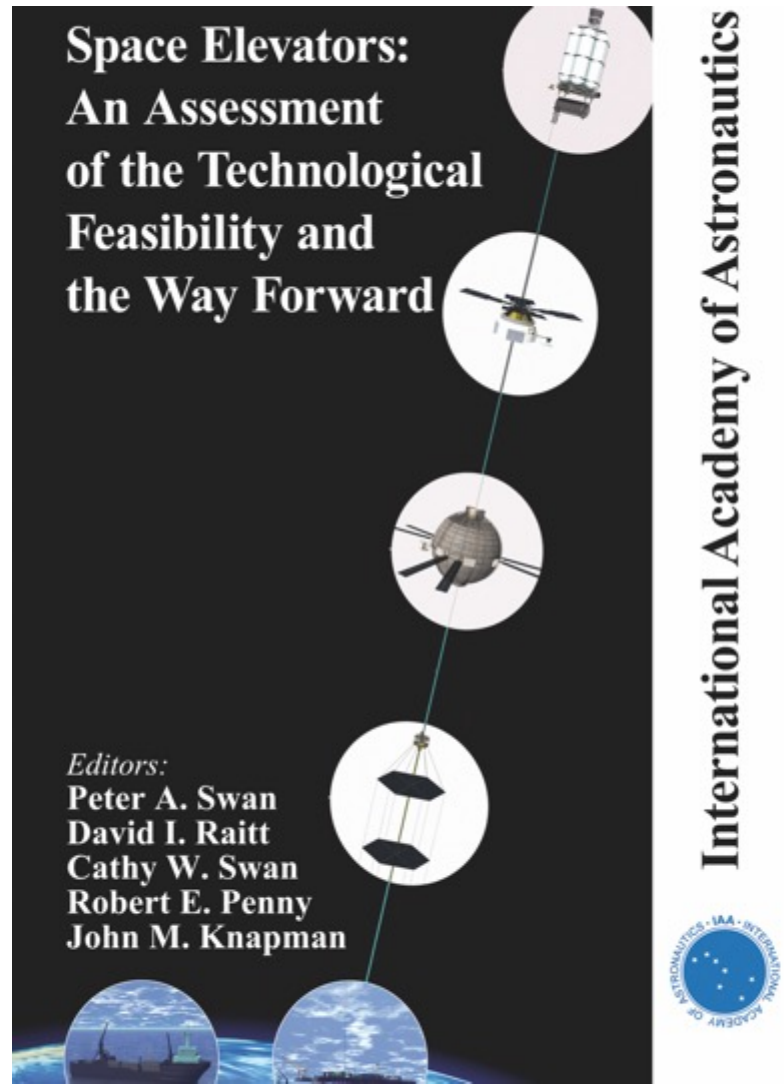
INTERNATIONAL SPACE ELEVATOR CONSORTIUM
ISEC



IAA Studies on Space Elevators

IAA Study One (2014) – Feasibility?
Conclusion: Space Elevators
Seem Feasible

IAA Study Two (2019) How To? Maturity?:
Road to the Space Elevator Era
Many global experts evaluating
critical technologies



ISEC Study Activities

Year	Study Title	Organization
2020	Interplanetary Mission Support (in development)	ISEC
2019	Road to the Space Elevator Era (four year long)	IAA
2019	Today's Space Elevator	ISEC
2018	Design Considerations for Multi-Stage Space Elevator	ISEC
2017	Design Considerations for Space Elevator Modeling and Simulation	ISEC
2016	Design Considerations for GEO Node and Apex Anchor	ISEC
2015	Design Considerations for Earth Port	ISEC
2015	Space Elevator: An Assessment of the Technological Feasibility and the Way Forward (four year long)	IAA
2014	Space Elevator Architectures and Roadmaps	ISEC
2013	Design Considerations for the Tether Climber	ISEC
2012	Space Elevator Concept of Operations	ISEC
2010	Space Elevator Survivability and Space Debris Mitigation	ISEC

Note: IAA - International Academy of Astronautics: ISEC - International Space Elevator Consortium

Notes: all completed studies on www.isec.org in pdf format for free **Study initiated August 2017 *Study being drafted

Recommendations

- *The vision of a Galactic Harbour should be enhanced as a unifying force for the space elevator community.*
- *Recognizing the strengths of space elevators leads one to realize that Movement off-planet will only happen when space elevators are supplying mission support within a cooperative arrangement with the future rocket infrastructure.*
- *Initiate a program soonest – while developing a Space Elevator Institute immediately.*

Final Thought

This could be the story of this century. Reliable, safe, and efficient access to space. This transportation capability is close at hand. Probably within 20 years. Space access without rockets! The Galactic Harbour opens the road, it opens the Heavens; it opens the way.

with the final realization:

The Space Elevator is Closer than you Think!

How the Space Elevator Grew into a Galactic Harbour?

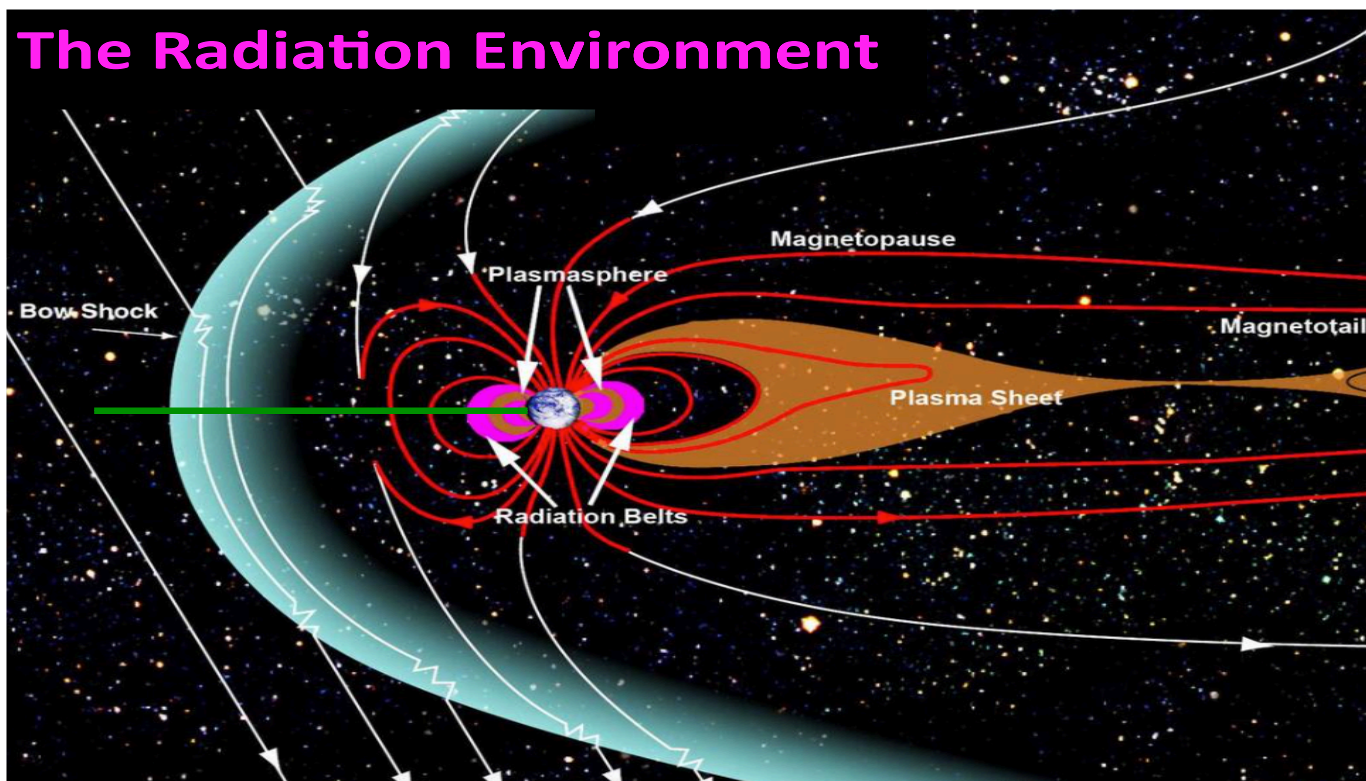
INTERNATIONAL SPACE ELEVATOR CONSORTIUM

ISEC

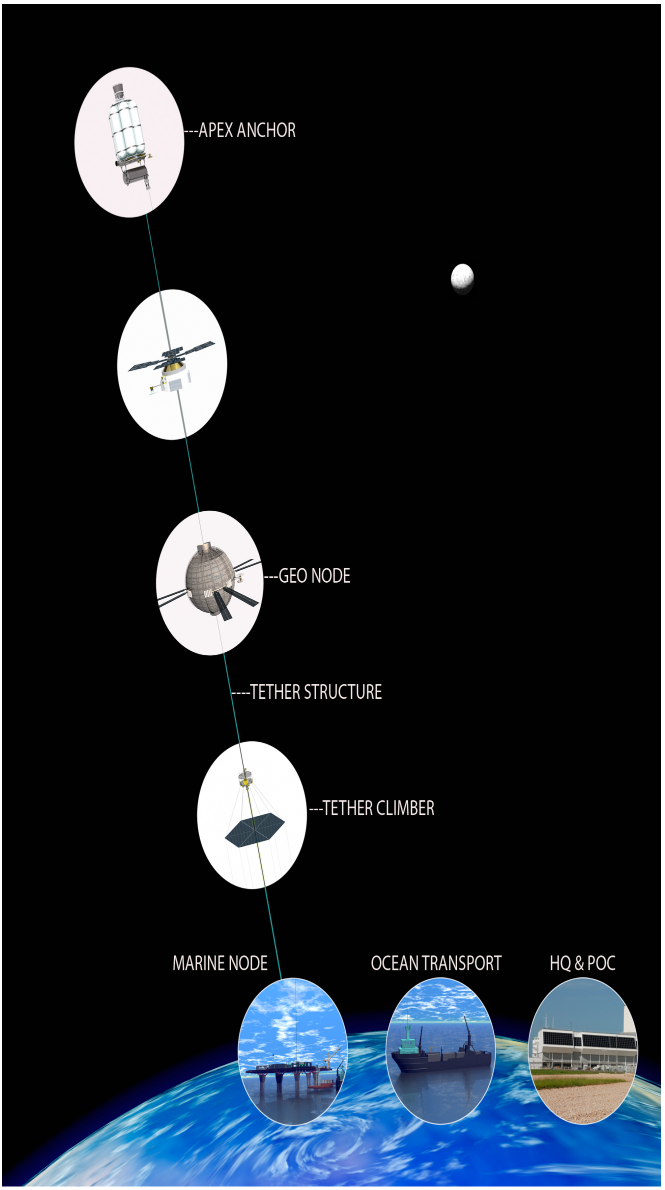
Backup Charts

Earth Radius
6,378 Km

Space Elevator
100,000 km
In green

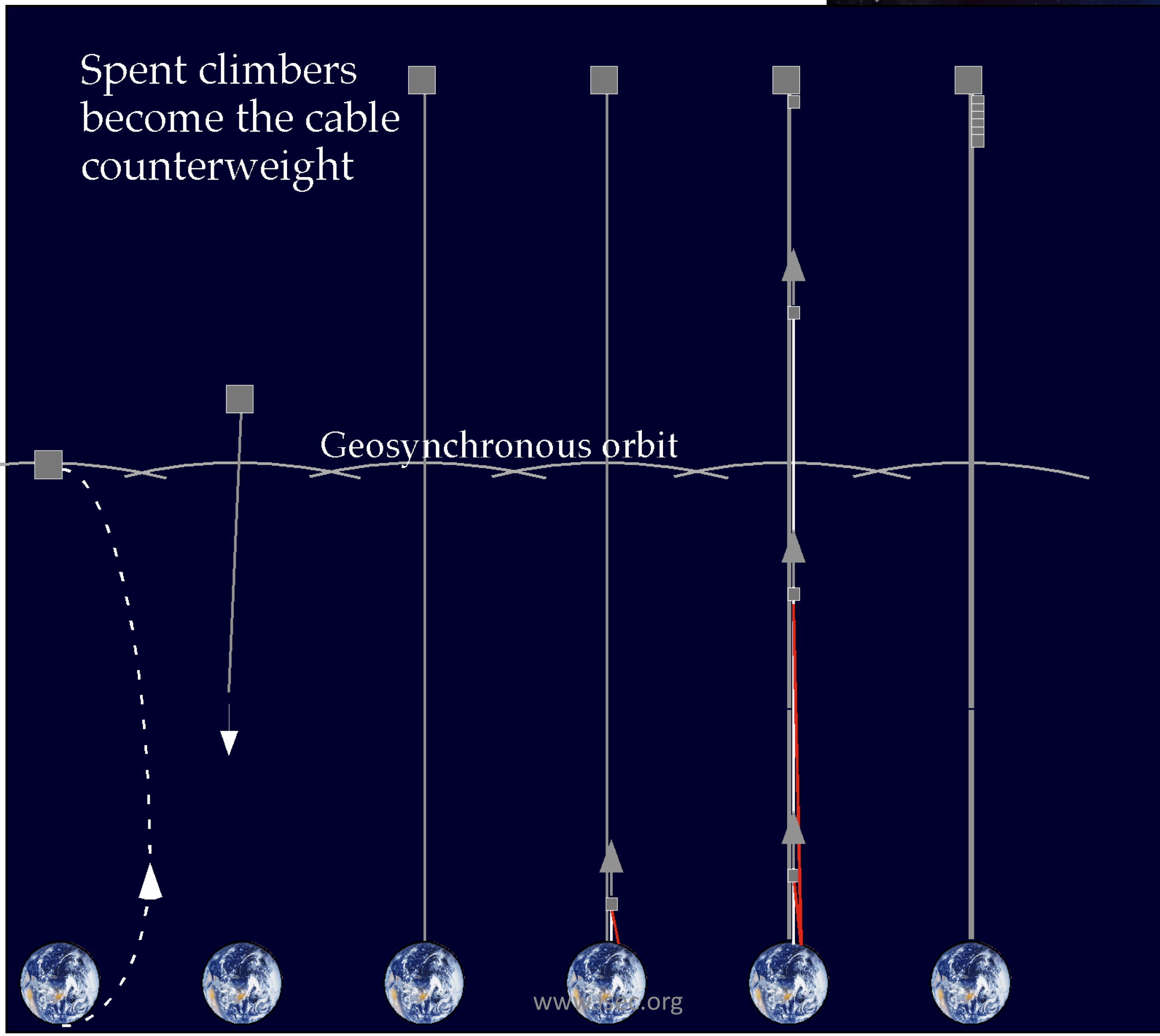


Second Modern Day Space Elevator International Academy of Astronautics (2013)



- Length: 100,000 km, anchored to floating Earth terminus, with a Marine Node connected to a large Apex Anchor.
- Ribbon: Width-One meter, curved;
- Design: Woven with multiple strands and curved;
- Material-Carbon Nano-Tubes with 25-35 MYuri at 1.3 gm/cm3
- Cargo: 14 metric ton payloads without humans [tether climber 6 MT]
- Loading: Seven concurrent payloads on the ribbon
- Power Source: Solar power after 1st 40 km
- Marine Node: Ocean going oil platform or retired aircraft carrier
- First 40 kms: box protection with power from an ultra-light cable.
- Alternant: High Stage One at 40 km altitude
- Apex Anchor: Based upon deployment satellite (with thrusters)
- Operations Date: The space elevator can, and will, be produced in the near future. [2035 operations start]
- Construction Strategy: The first space elevator will be built from GEO; then, once the gravity well has been overcome it will be replicated from the ground up.
- Architecture: Baseline is one replicating space elevator [used to produce all others] and then pairs sold to operating companies. Initial concept: three pairs operating around the world.
- Price: $ 13 billion for first pair, after replicator space elevator.
- Cost per kg: $ 500 USD

Deployment Overview

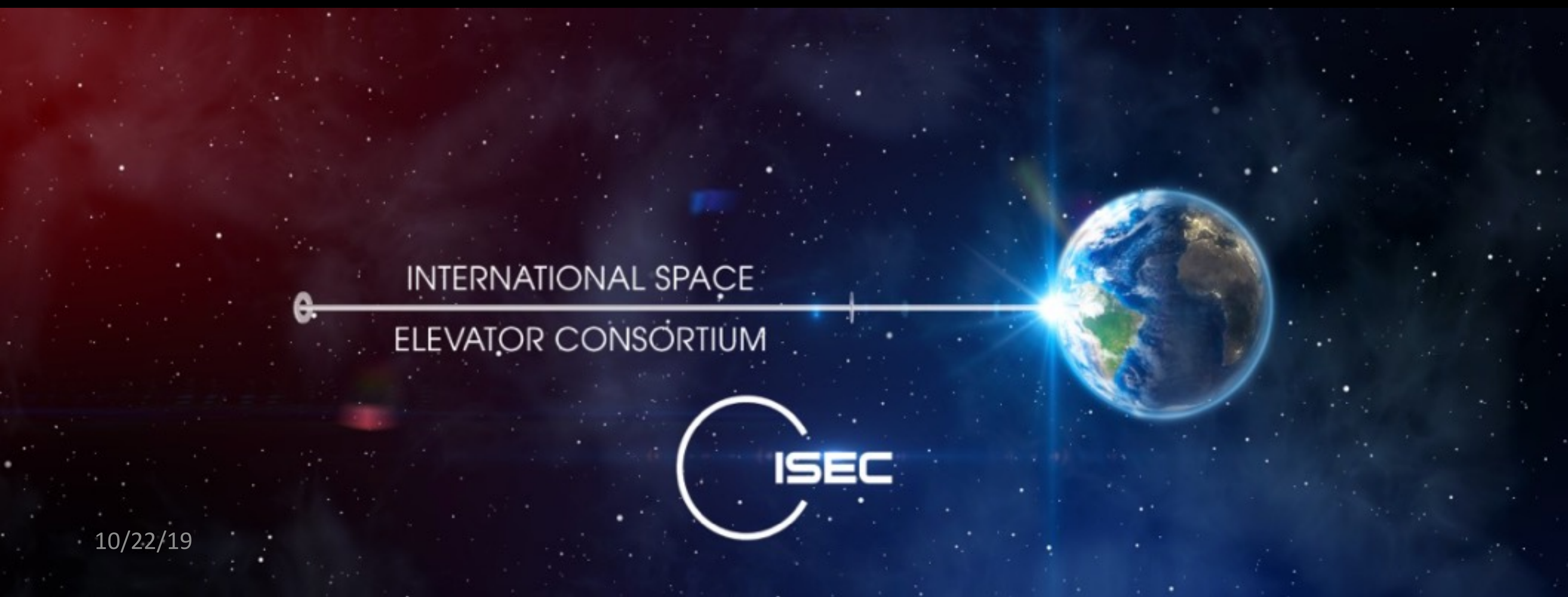


The last piece of the puzzle?

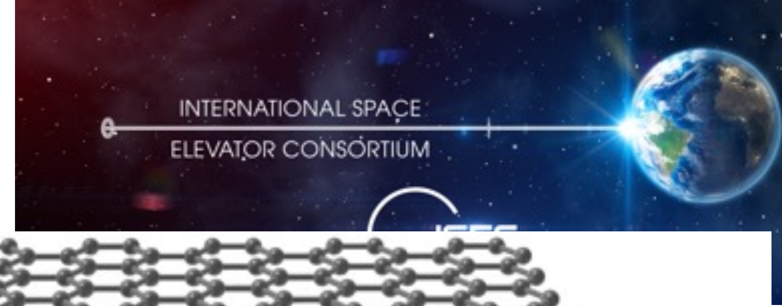
Graphene

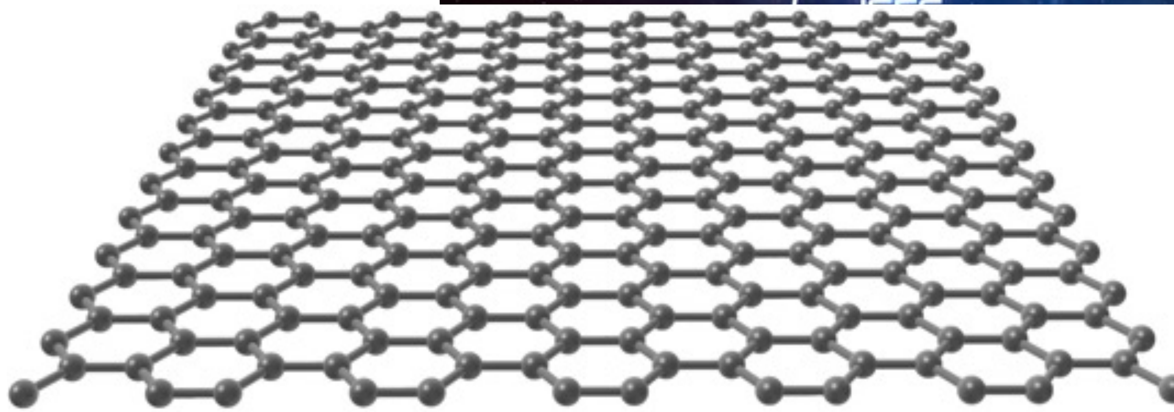
Adrian Nixon

15th June 2019

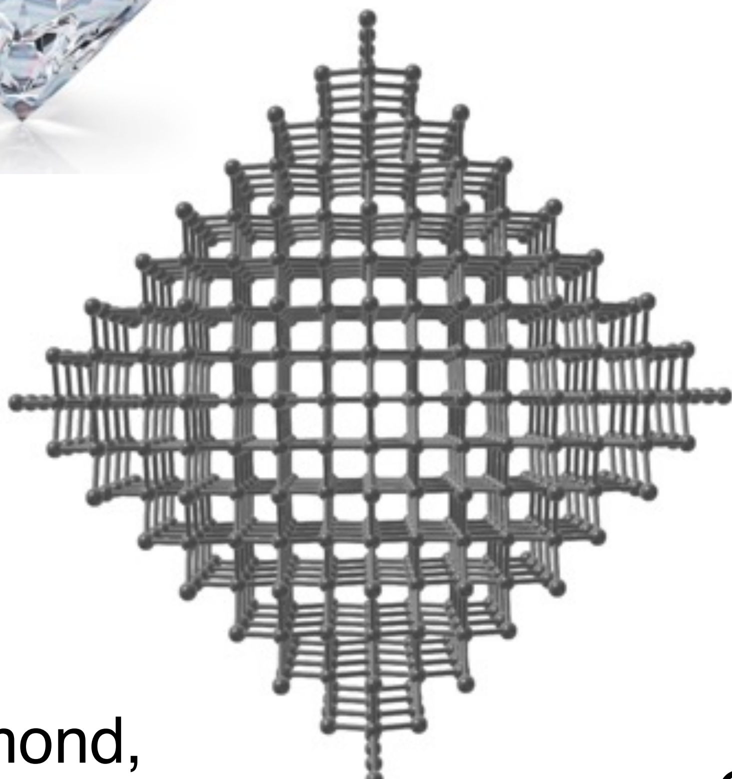


The carbon family

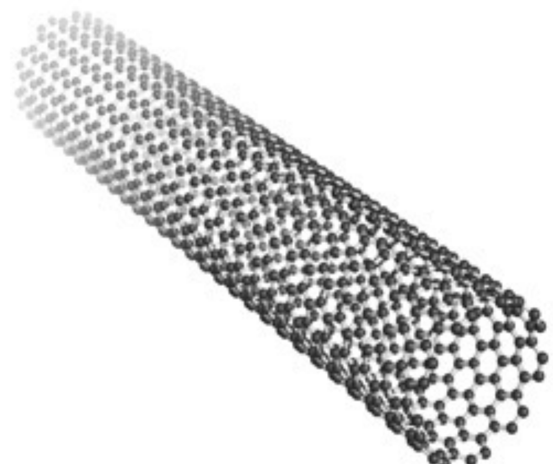




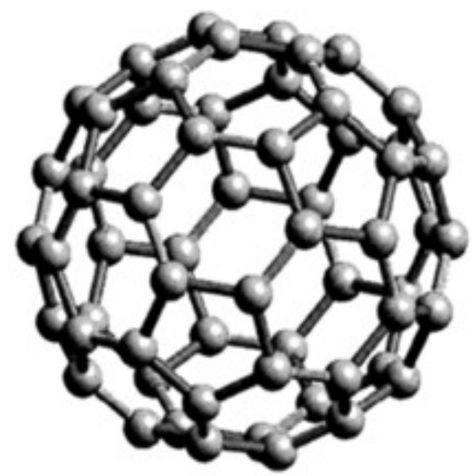
Graphene:
2D material



Diamond,
Amorphous Carbon:
3D material



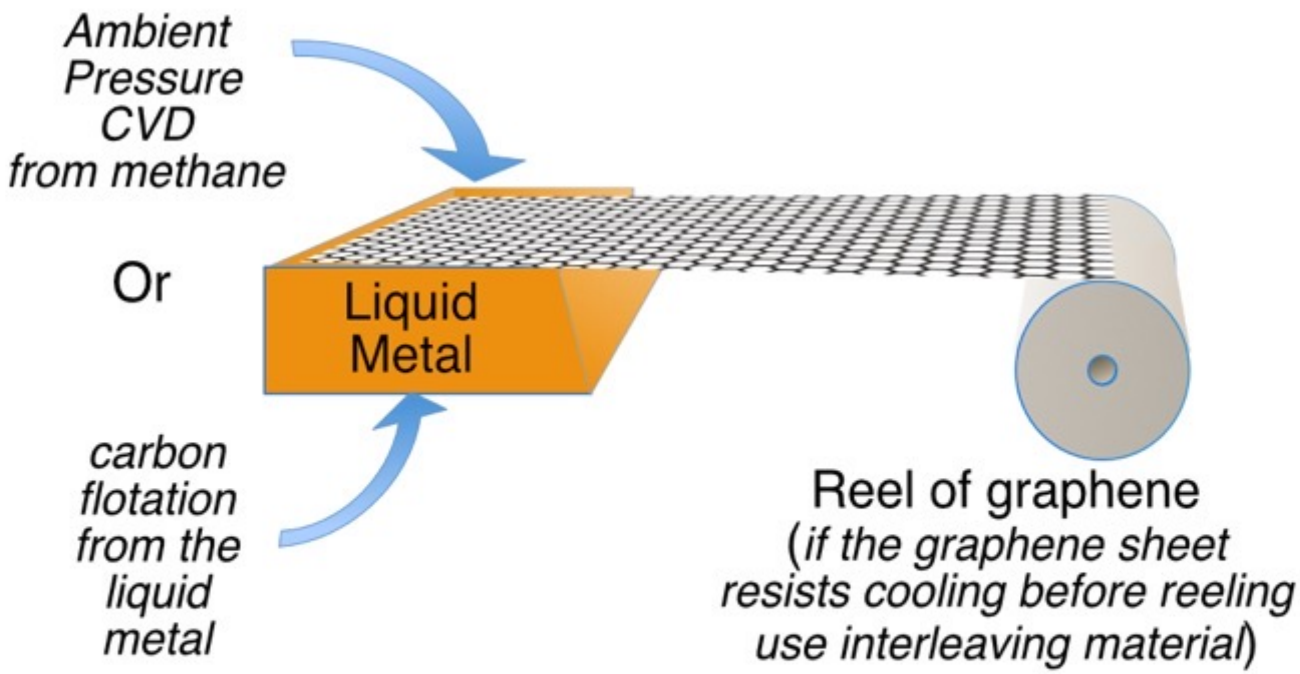
Carbon nanotubes:
1D material



Fullerenes:
0D material

Graphene: A new continuous process

Principles for making continuous single crystal sheet graphene



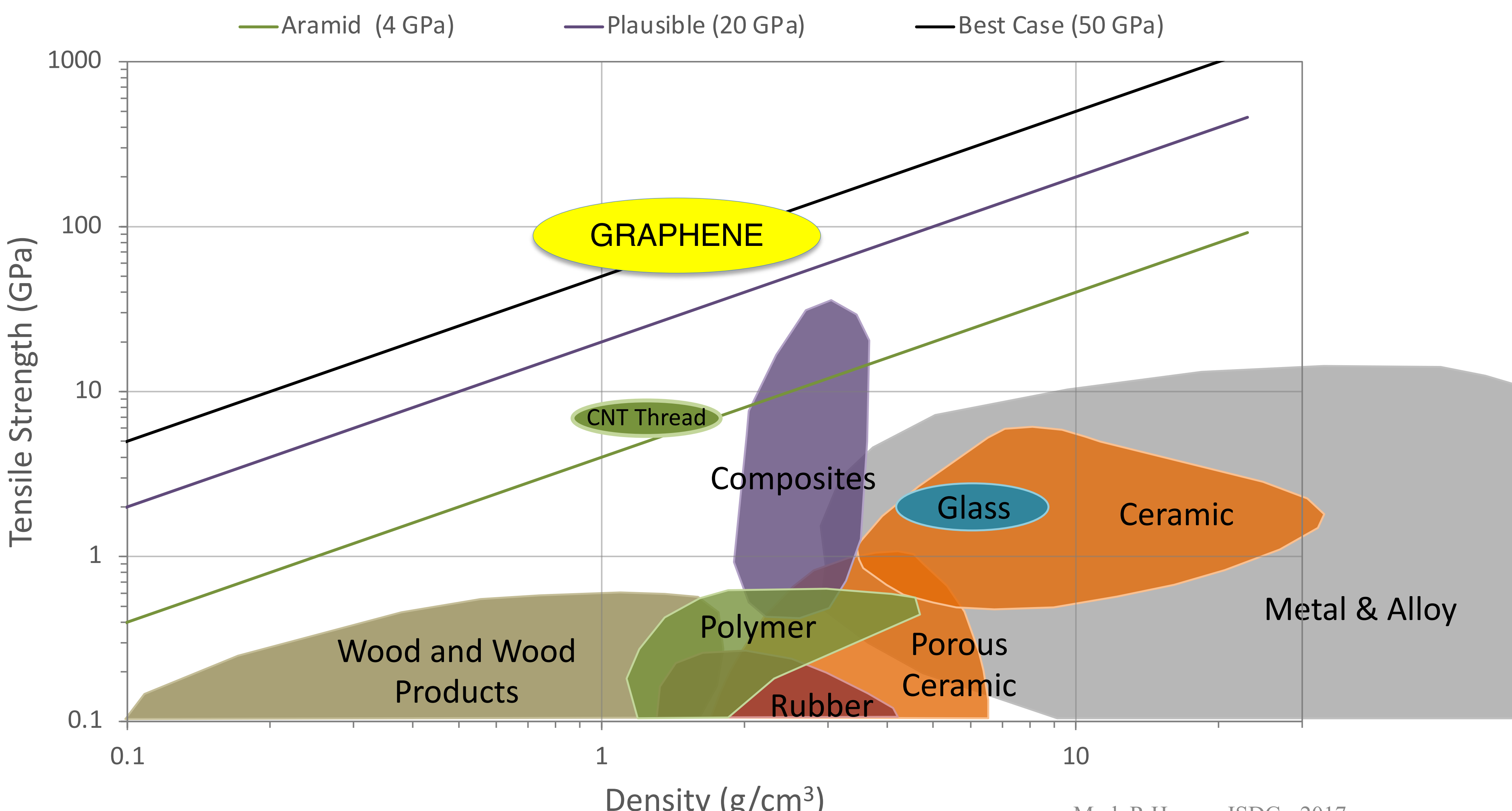
I published the hypothesis to test it amongst the world's top graphene scientists. (While retaining key intellectual property)

This hypothesis has not been invalidated to date.

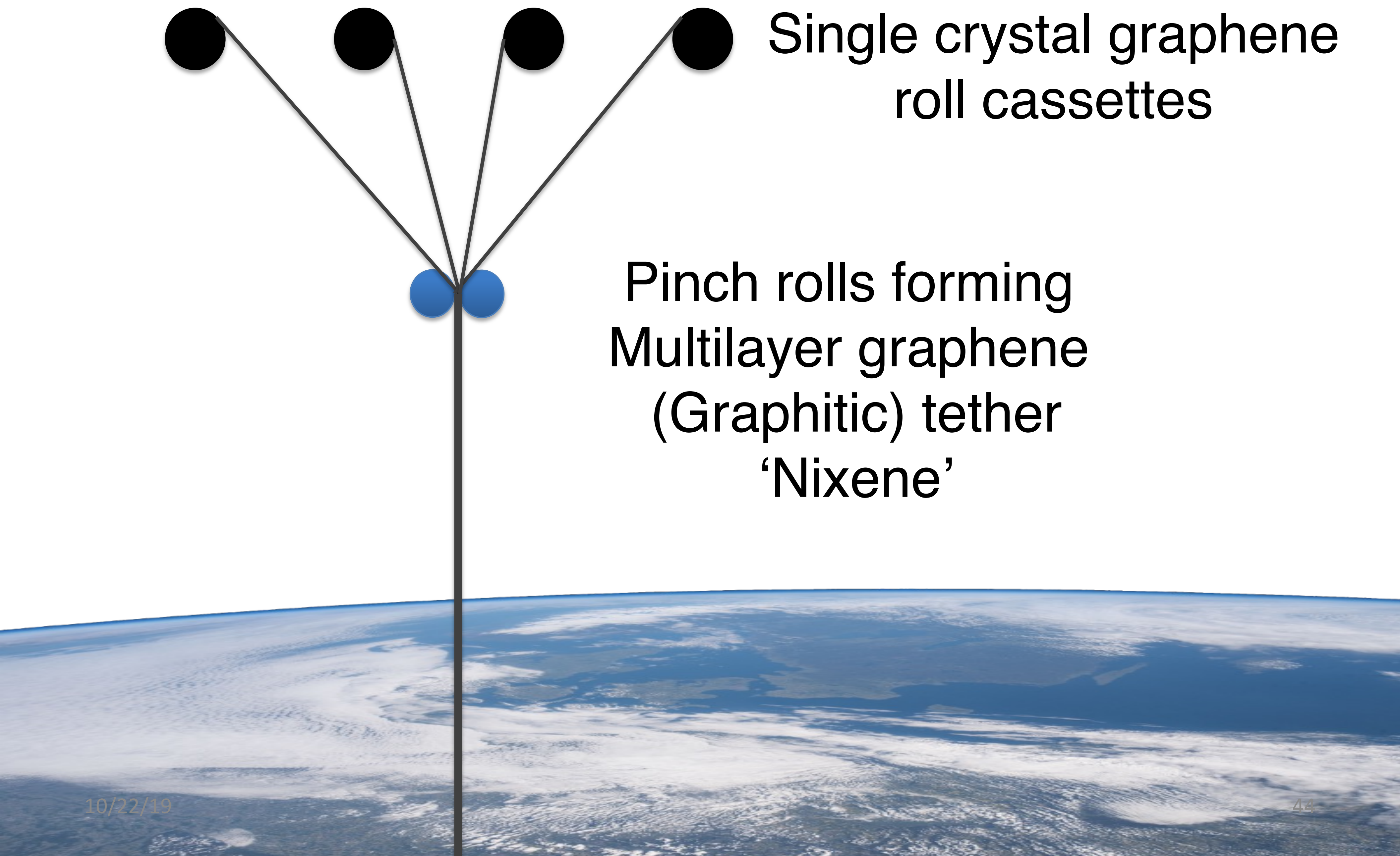
https://investorintel.com/market-analysis/making-graphene-2d-materials-liquid-

Tether candidate materials

YES: Graphene is strong enough to be a candidate tether material



Combine the tether layers in orbit…



Is a tether made from single crystal graphene feasible?

INTERNATIONAL SPACE ELEVATOR CONSORTIUM
ISEC

Current commercial nanoplate graphene cannot be used to make a tether.

However, 500mm of single crystal graphene has been made 13 years after graphene first isolated.

Layered single crystal graphene is yet to be made but we know how to do this and the material is already being called Nixene

YES

Graphene tether material really is possible within our lifetimes.

Space Debris is a Manageable Challenge for Space Elevators

TOPICS to be Addressed:

Debris alert ➔ Warning needs

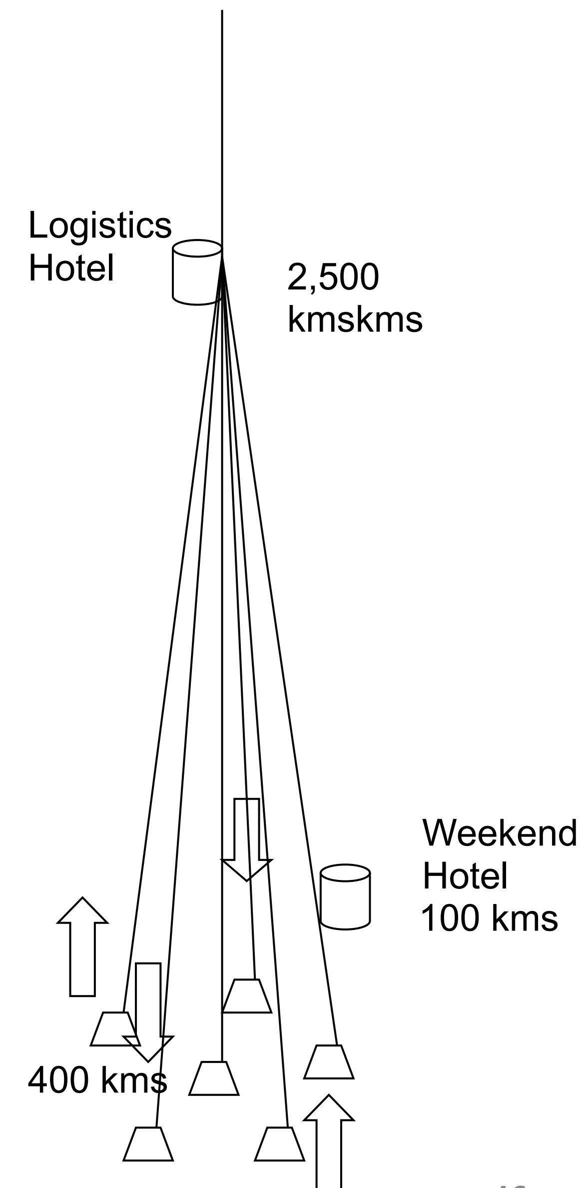
Debris sizing ➔ as a threat variant

Space Elevator Tether Movement ➔ passive defense

The Sentry System ➔ an Architecture adjunct for protection

System Recovery ➔ Post debris-event actions

Space Debris Adjunct (Mitigation) -- The Space Elevator will establish an op's relationship with space debris mitigation systems. The space debris "chair" will be charged with providing awareness, warning, active defense, passive defense, and (if needed) recovery after a debris event.

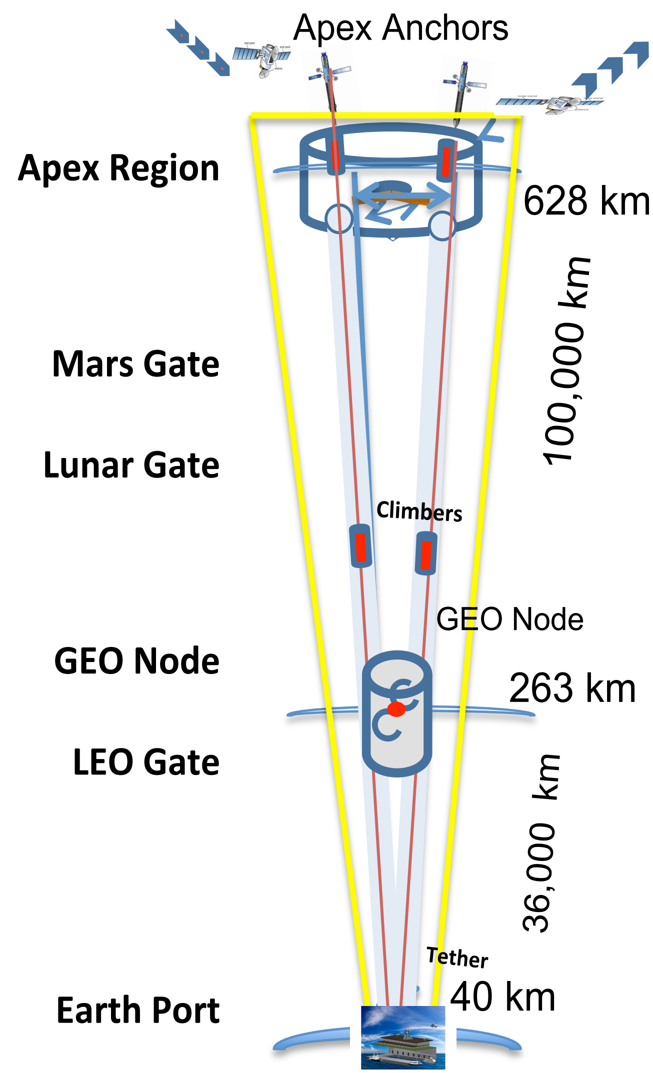


ISEC Approach

- Executive Summary of 2010 Report stated: To assess the risk to a space elevator, we have used methodology from the 2001 International Academy of Astronautics (IAA) Position Paper on Orbital Debris:
- "The probability (PC) that two items will collide in orbit is a function of the spatial density (SPD) of orbiting objects in a region, the average relative velocity (VR) between the objects in that region, the collision cross section (XC) of the scenario being considered, and the time (T) the object at risk is in the given region."

$$PC = 1 - e^{(-VR \times SPD \times XC \times T)}$$

- Using this formula, we calculate the Probability of Collision for LEO, MEO, and GEO. Our focus is on LEO -- as fully two thirds of the threatening objects are in the 200-2000 km (LEO) regime. Our analyses show:
- 2001 Position Paper On Orbital Debris, International Academy of Astronautics, supported by NASA, 24.11.2000. download for free from www.isec.org



Summary for Future

Item	*2010*	*2019*	*2030 Est.*	*Comment*
Total Tracked Debris by NASA	15378	19137	38,000	Assume comm constellations will add many space objects
Threats in GEO region	Not significant	Not significant	Not significant	Good operational proceedures a must.
Threat in MEO region	Not Significant	Not Significant	Not Significant	Good operational proceedures a must.
Untracked, small (<10 cm) debris will impact a Space Elevator in (LEO 200-2000 km), on the average;	Once every ten days	Once every 7.5 days	Once every 4 days	Design for tether anc movement planned to account for this - with continuous repair
Tracked debris will impact the total LEO segment (200 – 2000 km) if no actions are taken.	Once every 100 days or multiple times a year	Once every 75 days or several times a year	Once every 40 days or every two months or so	Note, this assumes there is no active movement of trackec objects or of the tether
Tracked debris will only impact a single 60 km stretch of LEO space elevator, on the average	Every 18 years with every 5 years in peak regions	Every 14 years with every 4 years in peak regions	Every 7 years with every 3 years in peok regions	Note, this assumes there is no active movement of trackec objects or of the tether

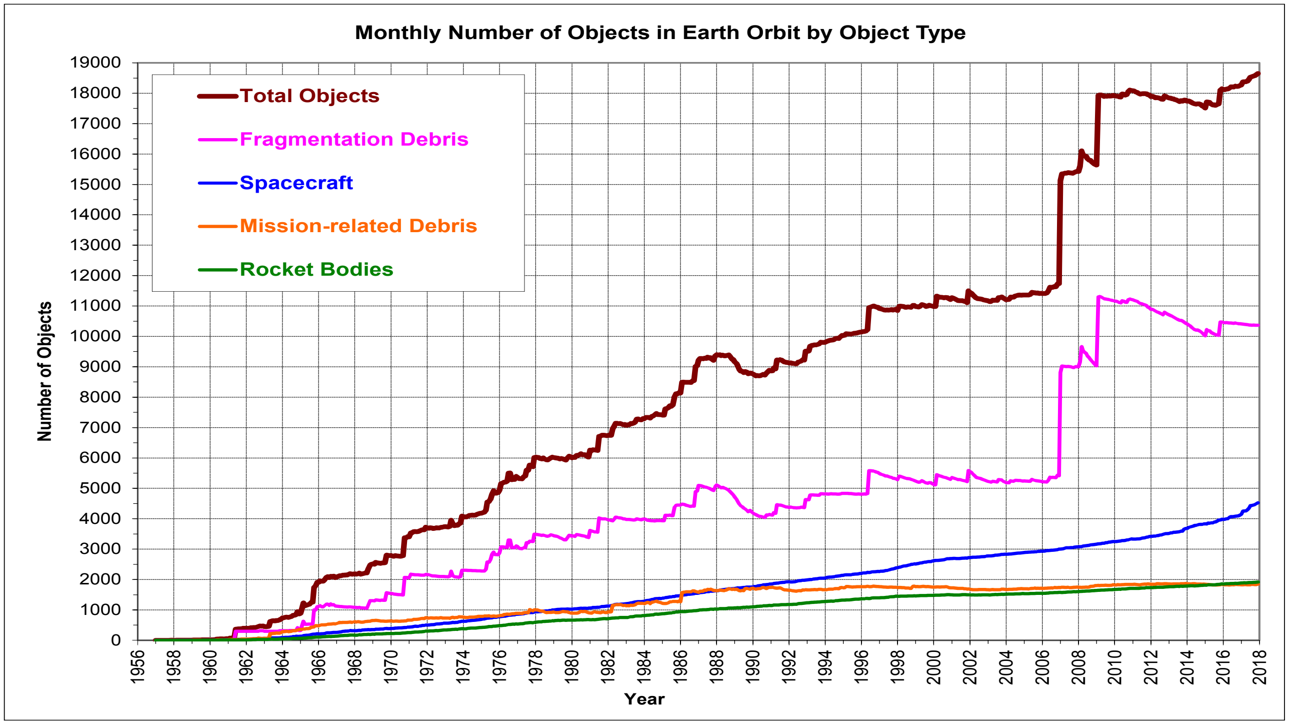
Conclusion

- As a result, the conclusion stays the same: - for 2009, 2018 and 2030
- Space debris mitigation is an engineering problem with definable quantities such as density of debris and lengths/widths of targets. With proper knowledge and good operational procedures, the threat of space debris is not a show-stopper by any means. However, mitigation approaches must be accepted and implemented robustly to ensure that engineering problems do not become a catastrophic failure event.
- And there are always the engineering solutions for some of the challenges. Many people have suggested architectural designs to help the issue. Here are some of them:
- Eliminate the major debris in orbit (this is a must - and there are many people around the world who believe this must be started soon to ensure no future challenges to normal spaceflight - this is NOT a space elevator issue alone, but one for all spaceflight.)
- design an emergency response that sends tether from GEO downward when the tension jump signals a major change resulting from sever.
- provide an emergency lowering of tether from 2,000 km upon sever in the highest probability areas (LEO high density orbits)
- provide multiple legs from 2,000 kms and below. [I actually like that one - see image below]

Space Debris Sept 2018

Sep 2018 Orbital Debris Quarterly News(NASA Johnson Center office)

Orbital Debris Quarterly News



Monthly Number of Cataloged Objects in Earth Orbit by Object Type: This chart displays a summary of all objects in Earth orbit officially cataloged by the U.S. Space Surveillance Network. "Fragmentation debris" includes satellite breakup debris and anomalous event debris, while "mission-related debris" includes all objects dispensed, separated, or released as part of the planned mission.

Item	***2010***	***2019***	***2030 Est.***	***Comment***
Total Tracked Debris by NASA	15378	19137	38,000	

SATELLITE BOX SCORE

(as of 04 July 2018, cataloged by the U.S. SPACE SURVEILLANCE NETWORK)

Country/ Organization	Payloads*	Rocket Bodies & Debris	Total
CHINA	312	3652	3964
CIS	1520	5069	6589
ESA	82	57	139
FRANCE	64	488	552
INDIA	89	117	206
JAPAN	173	111	284
USA	1663	4737	6400
OTHER	887	116	1003
TOTAL	4790	14347	19137

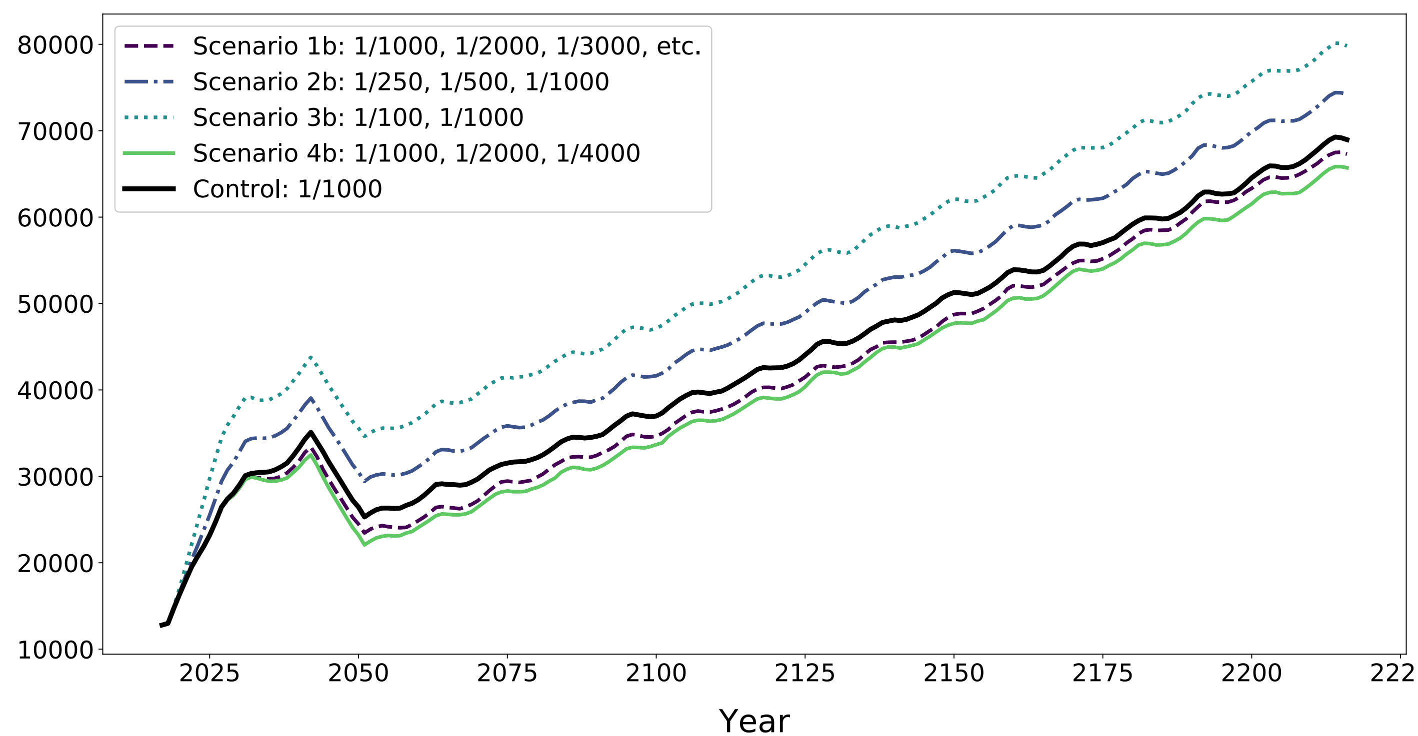
** active and defunct*

Effects of Large Constellations - NASA

"Therefore, constellation operators should design spacecraft to ensure an accidental probability of explosion of 1/1000 or better from the initial constellation deployment in

order to protect the future space environment."

An Extended Parametric Study of the Effects of Large Constellations on the Future Debris Environment
Oribital Debris Quarterly News, Vol 23, I 3, Aug 2019, pg 5-8



e 2. Effective number of objects projected to be in orbit after 200 years with varying explosion rates over each replenishment cy ulge represents the constellations deploying and the subsequent fall-off represents the end of the constellations lifetime, i.e., ti o additional constellations being added to the environment.