Multi-stage Space Elevator: Research and Development

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Topics

- Parallel, convergent tracks
- Dynamically supported structures
- Climbing the multi-stage space elevator
- Development activities
- The way ahead

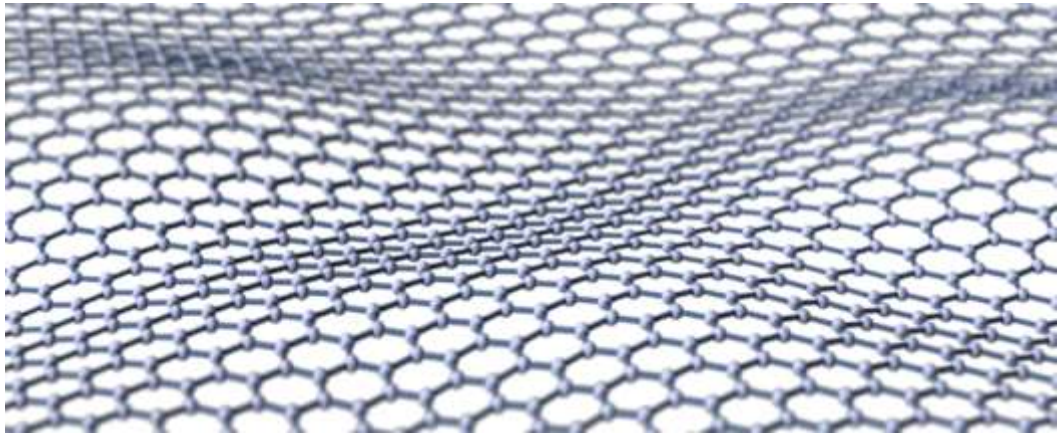
Two parallel tracks

- Light, long, strong materials
  - We are actively pursuing work on single crystal graphene
    - An excellent material with the right properties
    - Boron nitride and CNTs are also candidates
  - A team has been assembled, led by Adrian Nixon
- Using materials that are less strong
  - Multi-stage space elevator
    - A prototype is being built

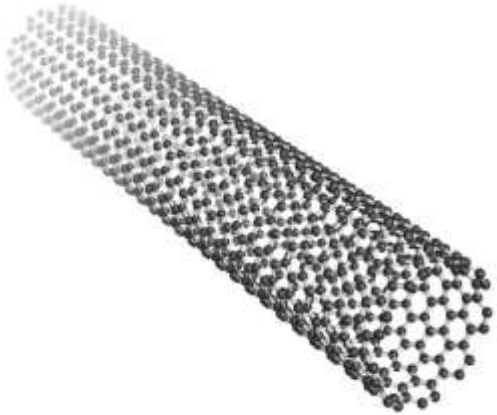
The carbon family: dimensions

Graphite, Diamond, Soot / Carbon Black: 3D material

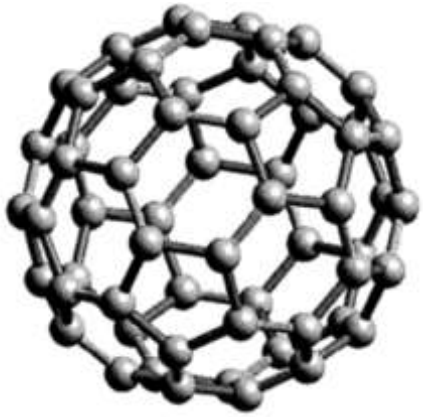
Source: Adrian Nixon



Graphene: 2D material



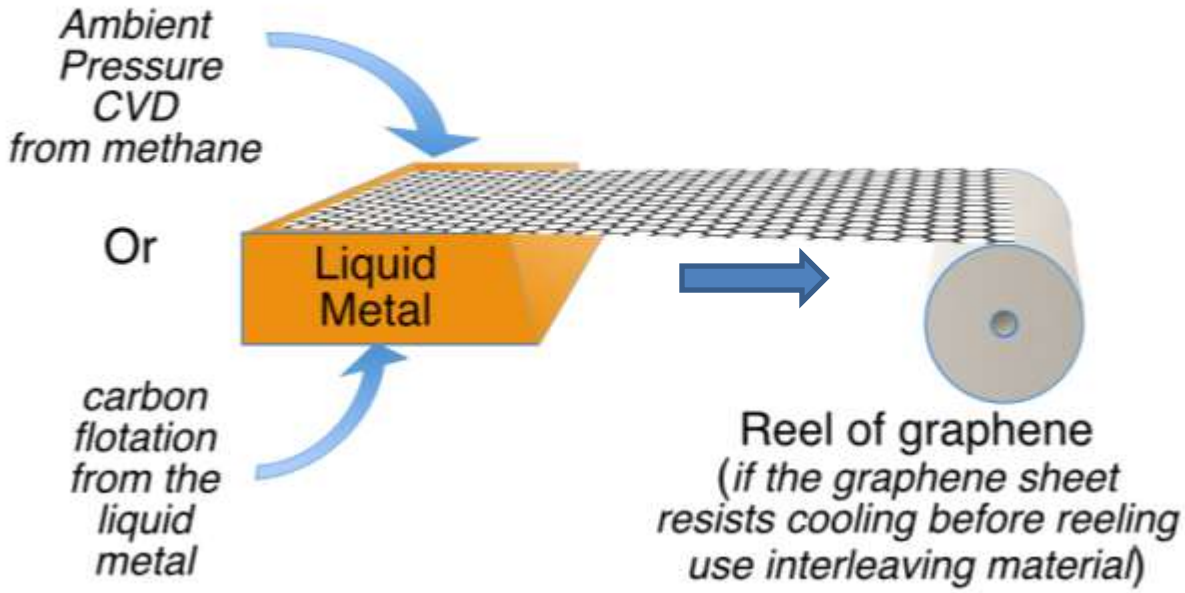
Carbon nanotubes: 1D material



Fullerenes: 0D material

Graphene: A new continuous process

Principles for making continuous single crystal sheet graphene



A team in South Korea has pioneered this technique with boron nitride

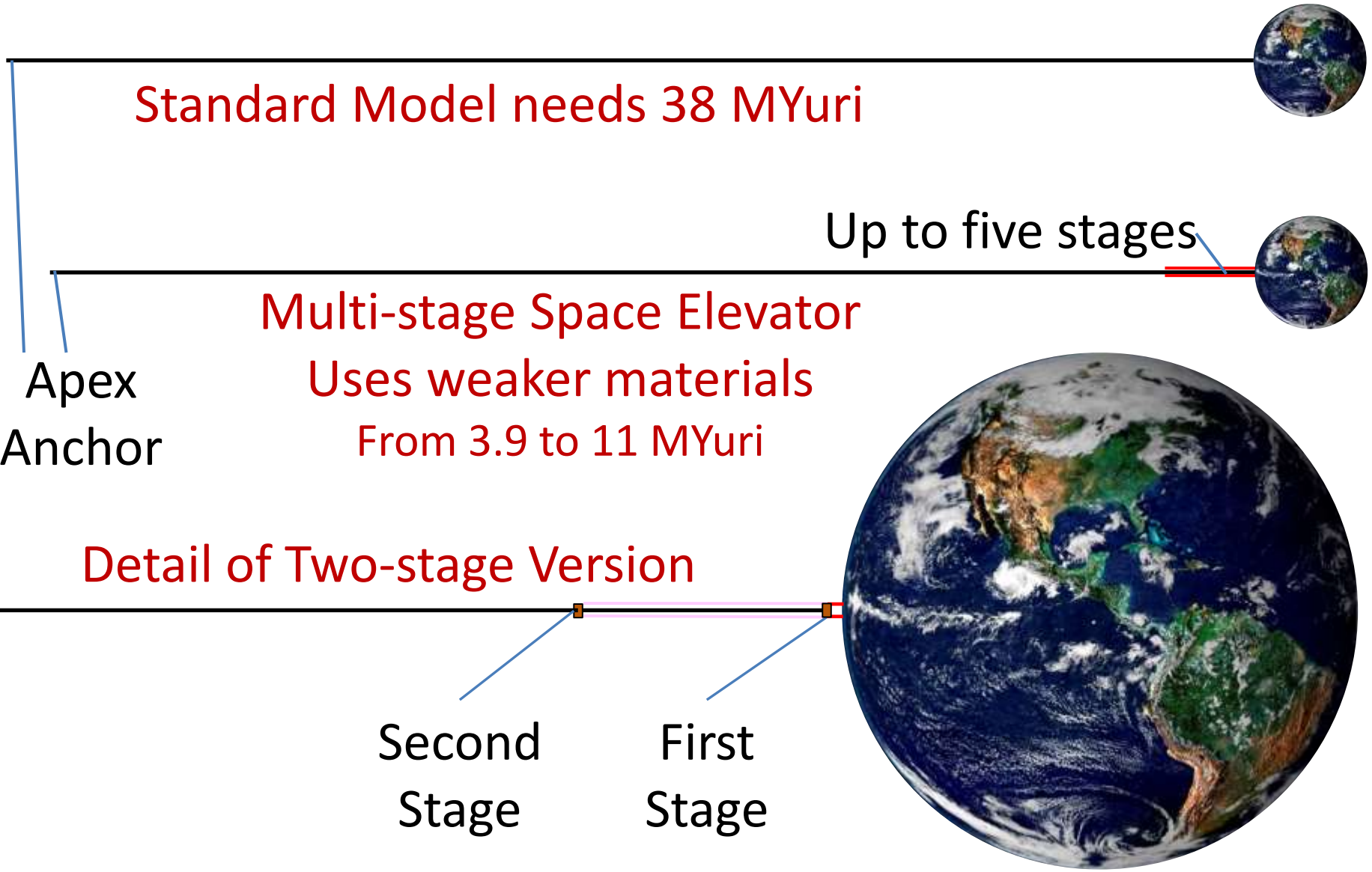
J S Lee *et al*, *Science*, 2018, **362**, 817 (DOI: 10.1126/science.aau2132)

Source: Adrian Nixon

Light, long, strong materials

- Single crystal graphene
  - Strength 130 GPa
  - Density 2.3 g/cc
  - Specific strength 130/2.3 = 56 MYuri
  - Length so far 50 cm (20 inches)
- Single crystal hexagonal boron nitride
  - Specific strength 100/2.2 = 45 MYuri
- Minimum strength needed 38 MYuri in standard model
  - Best available now: carbon fiber yarn 3.9 MYuri
    - Possible with multistage space elevator

Multi-stage space elevator



Multi-stage space elevator

- Reduces the strength requirement for the tether
  - It's even possible to use commercial carbon fiber
- Supports the part of the tether nearest Earth
  - Where gravity is strongest
- ISEC Report 2018
  https://www.isec.org/studies/#MultiStage

Question 1

- What do you think will be the tether material actually used in the first space elevator?

Tether material	
Carbon fiber	
Carbon nanotubes (CNTs)	
Single-crystal hexagonal boron nitride	
Single-crystal graphene	
Another material	

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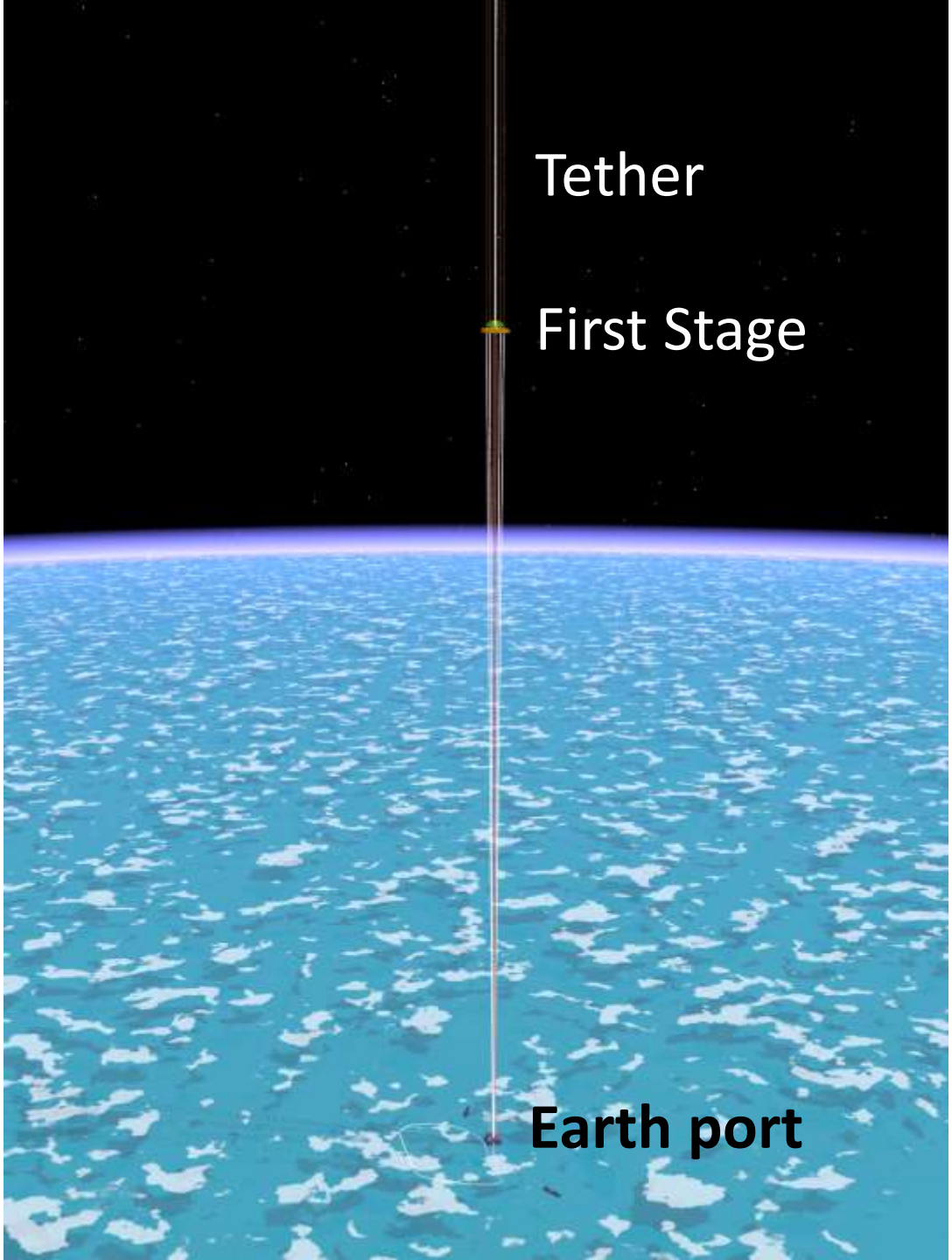
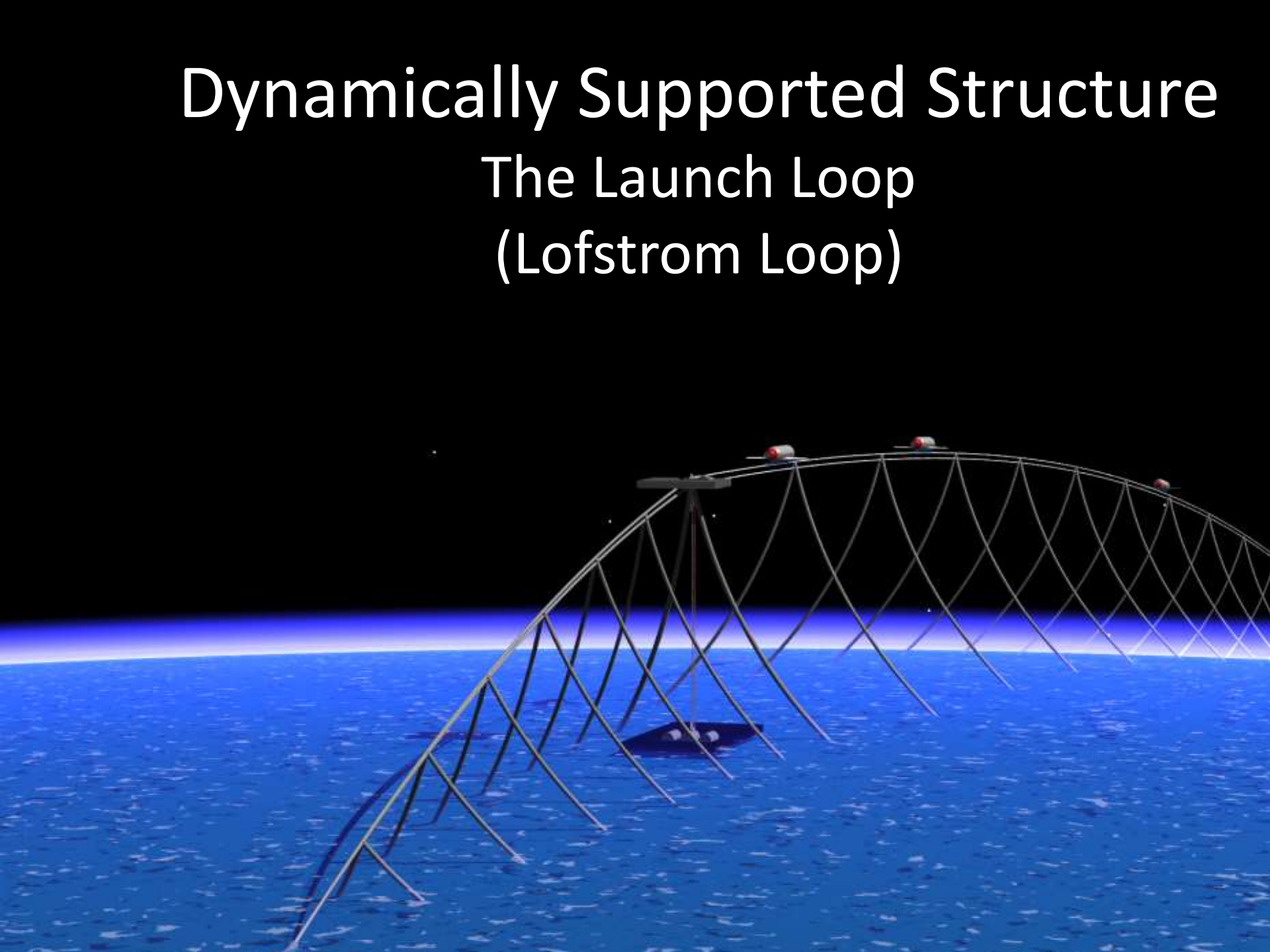
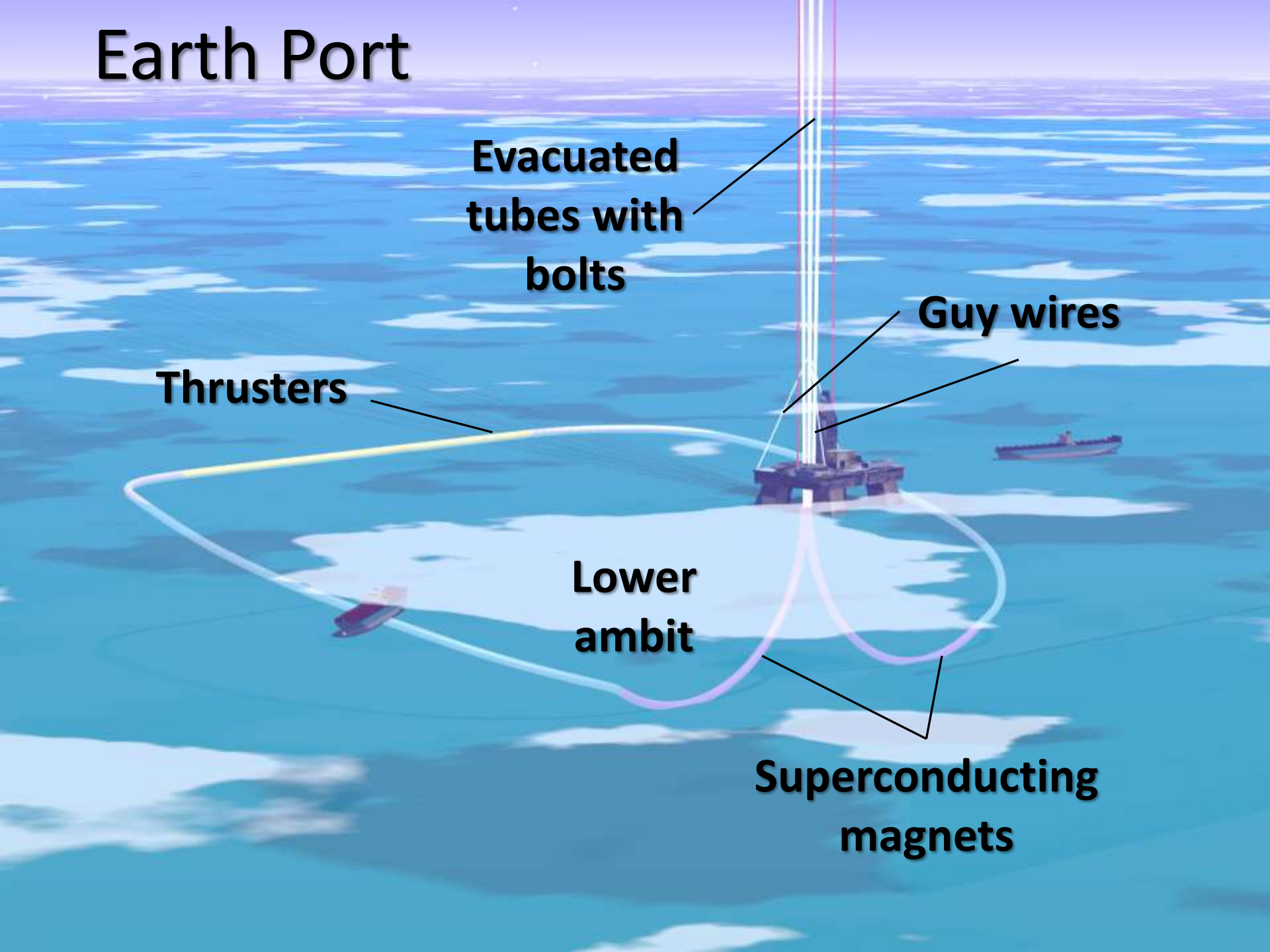

Tether
First Stage
Earth port

Dynamically Supported Structure

The Launch Loop
(Lofstrom Loop)

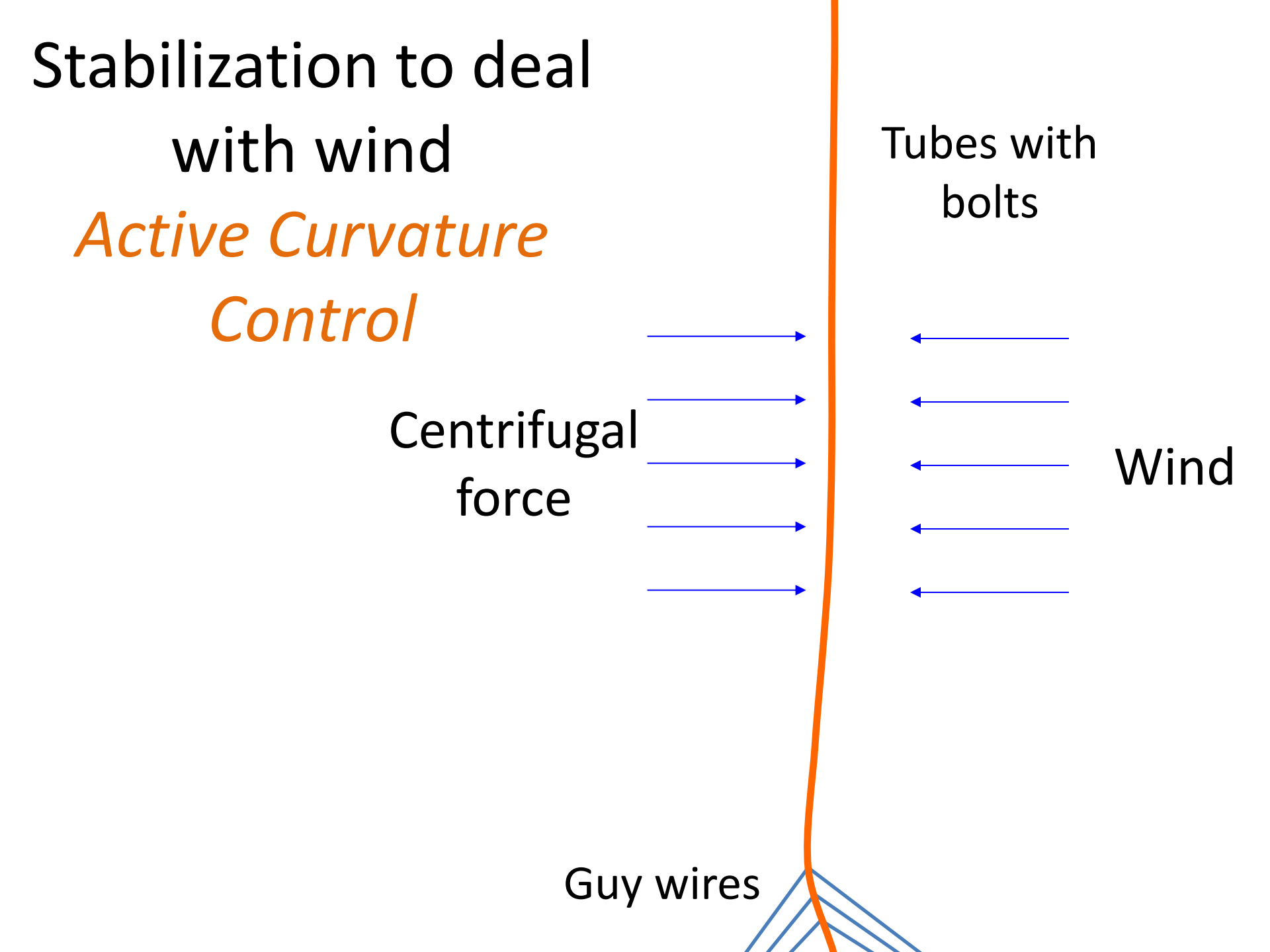


Earth Port

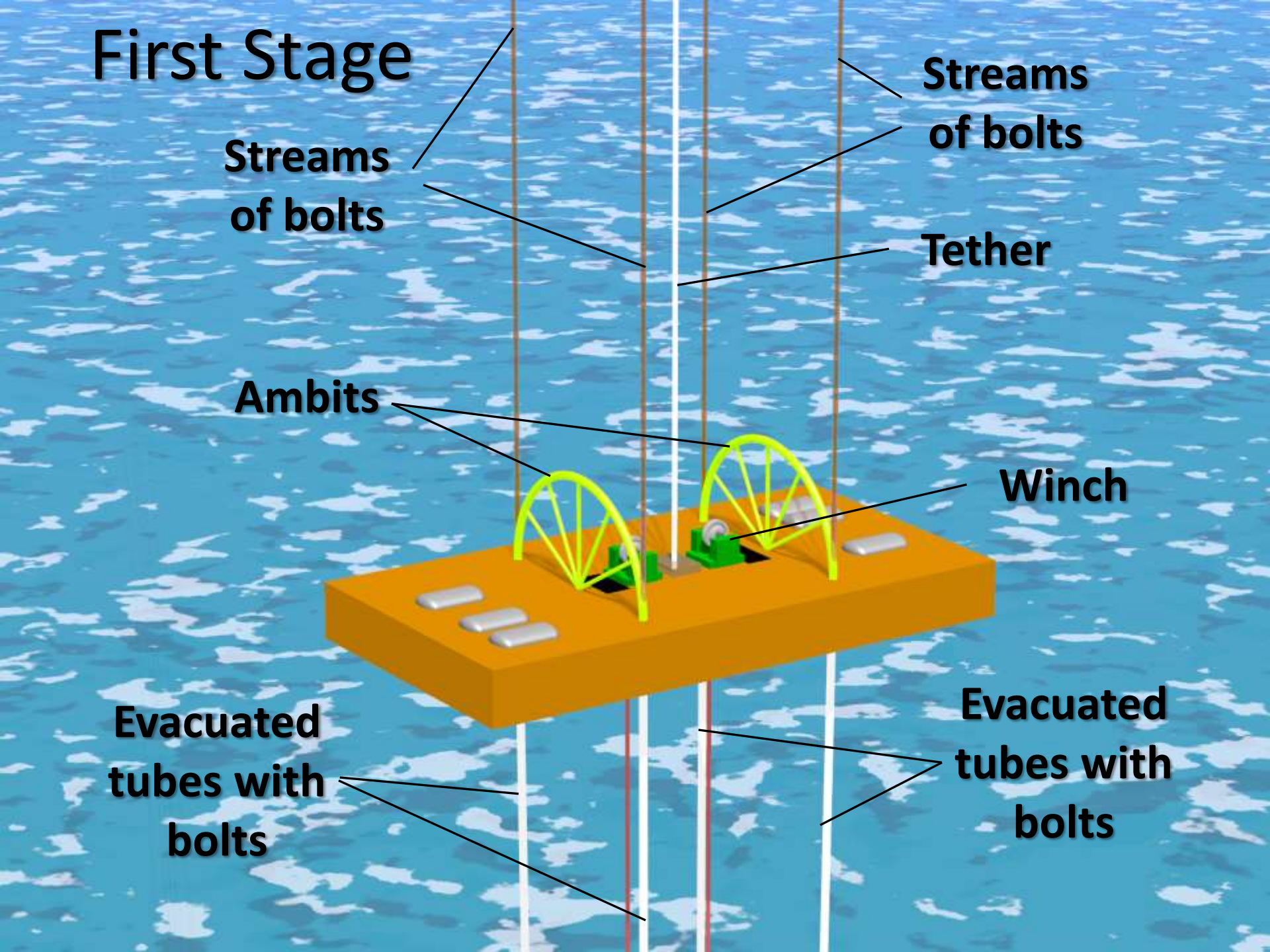

Evacuated tubes with bolts
Guy wires
Thrusters
Lower ambit
Superconducting magnets

Stabilization to deal with wind

Active Curvature Control



First Stage

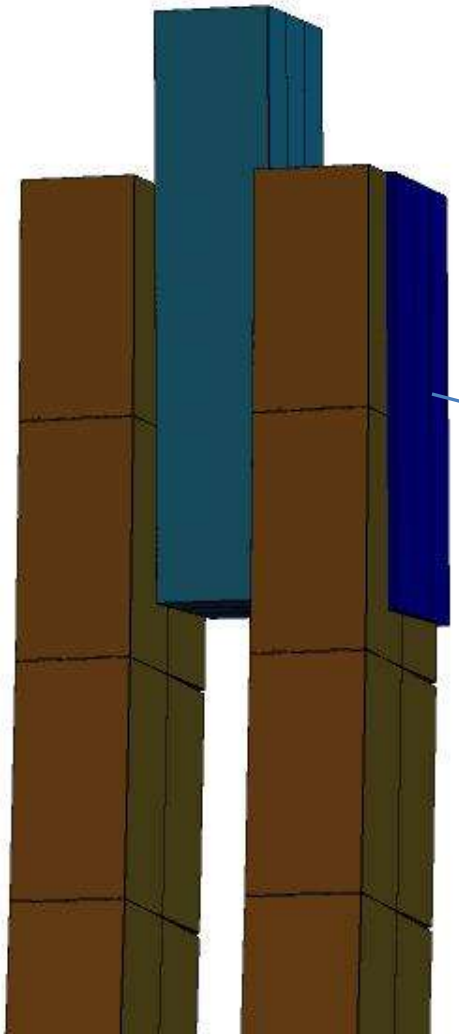

Streams of bolts
Streams of bolts
Tether
Ambits
Winch
Evacuated tubes with bolts
Evacuated tubes with bolts

Ambit Simulation

with high temperature superconductors (HTS)

Ideal temperature 50°K

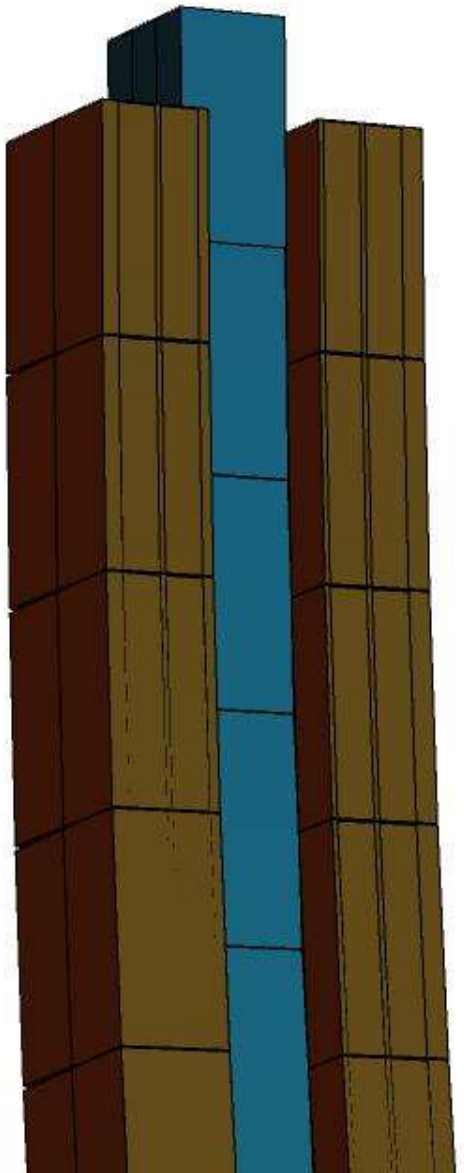
Actual temperature so far 86°K



Mirror field provides stability

Trapped Field

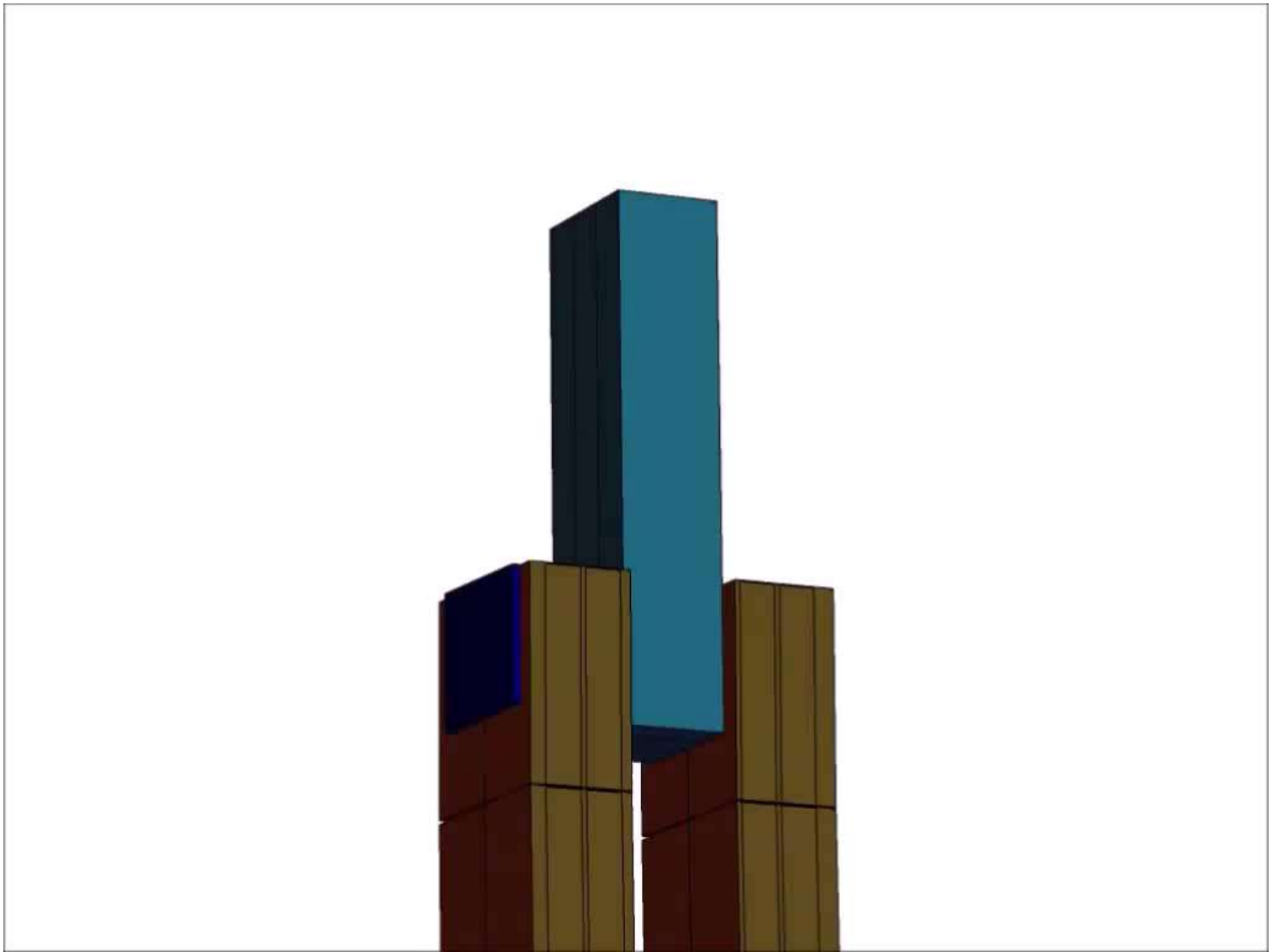
Trapped field is “frozen” in while HTS is being cooled.



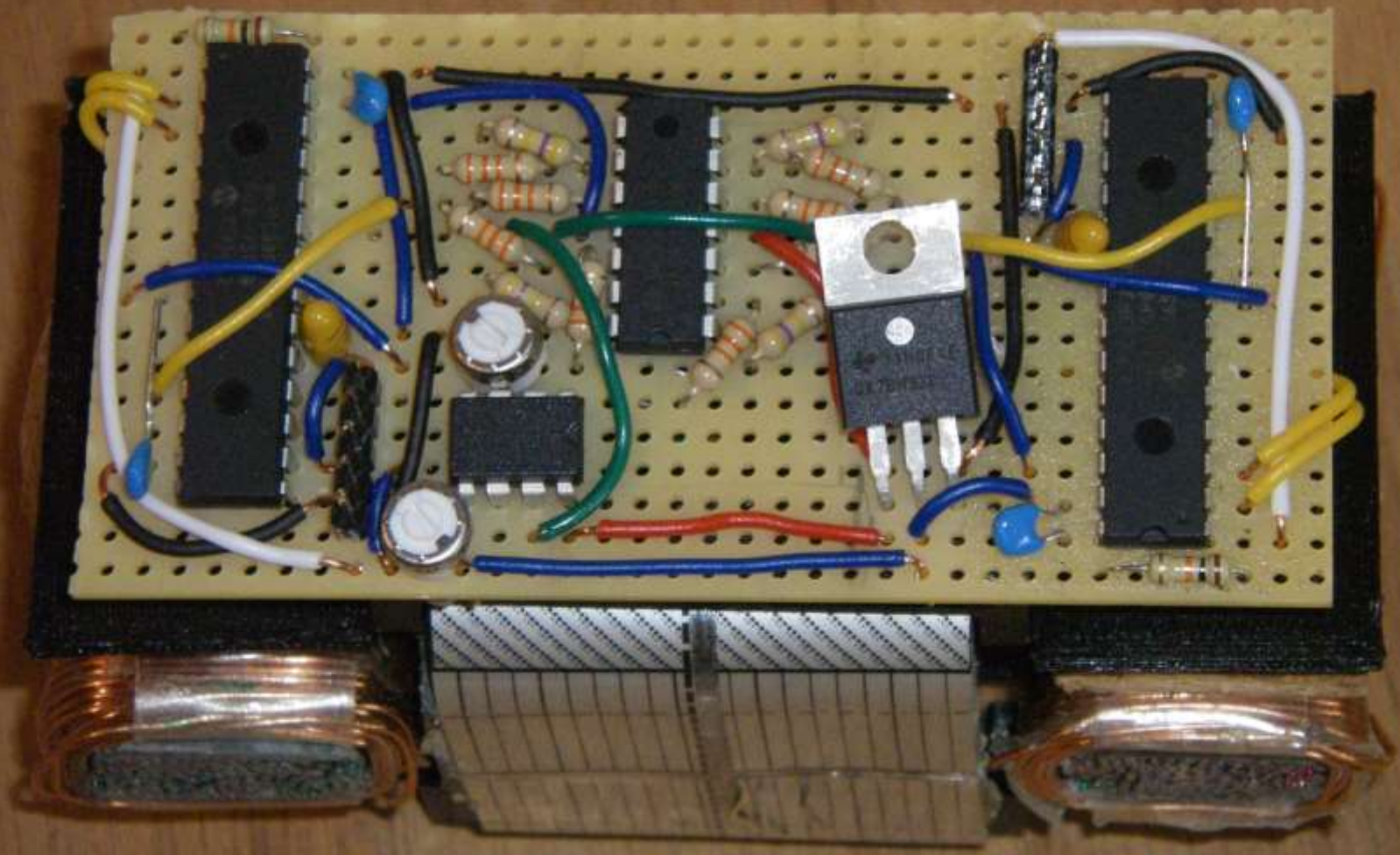
Trapped field provides levitation.

Ambit Simulation

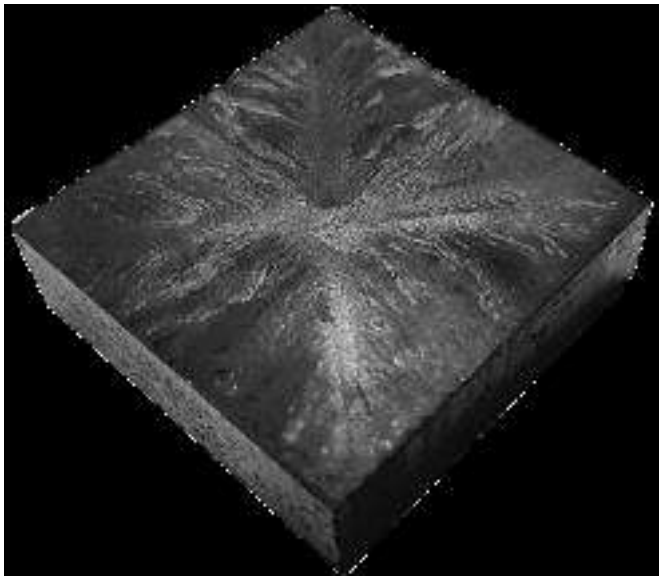
with HTS (YBCO)



Early Version of a Bolt

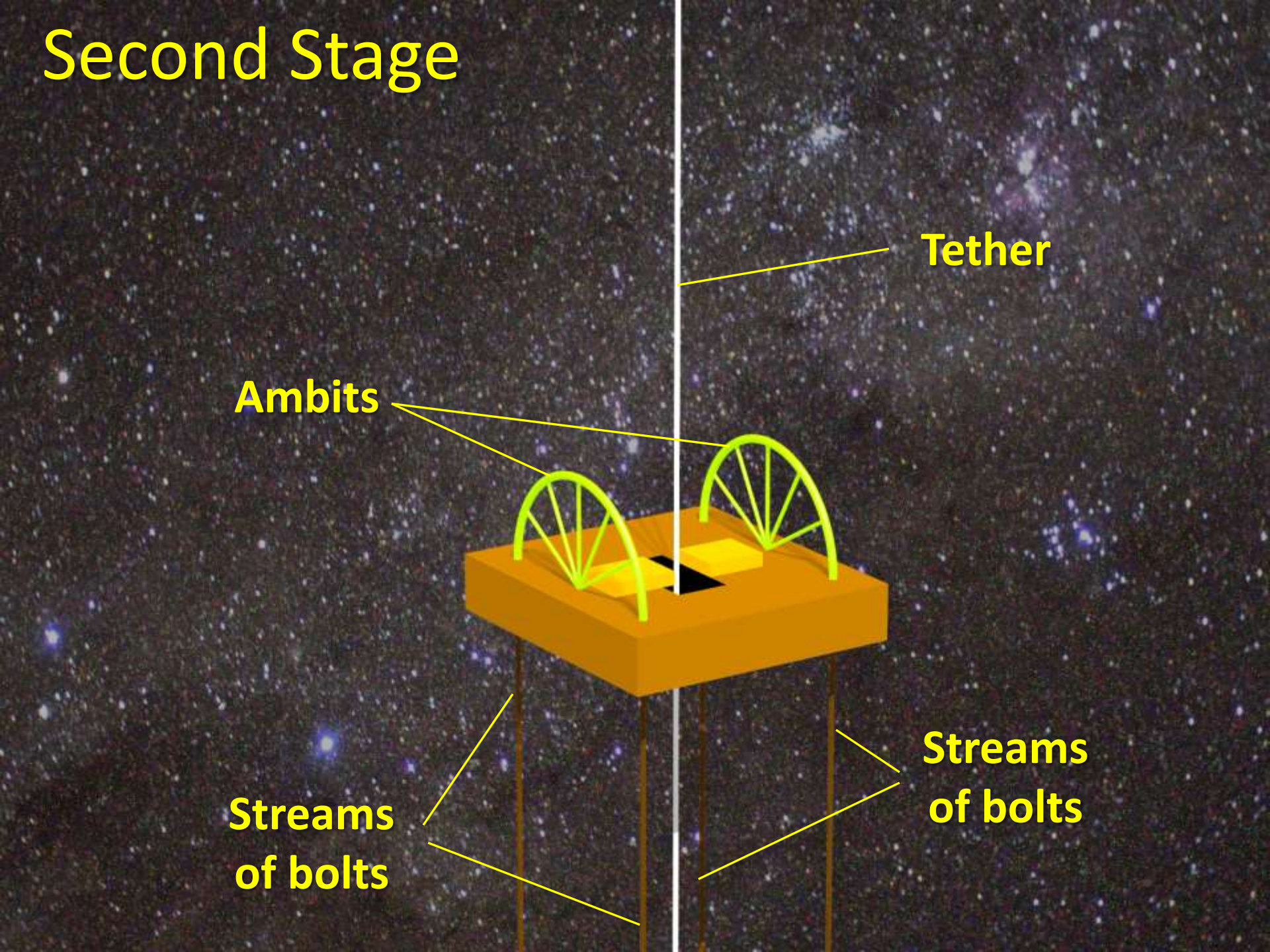


HTS bulk



Copper block for cooling

Second Stage



Question 2

- Do dynamically supported structures have a future?

Applications	
For space elevators	
In civil engineering	
For launching spacecraft	
Other applications	

Topics

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- Climbing the multi-stage space elevator
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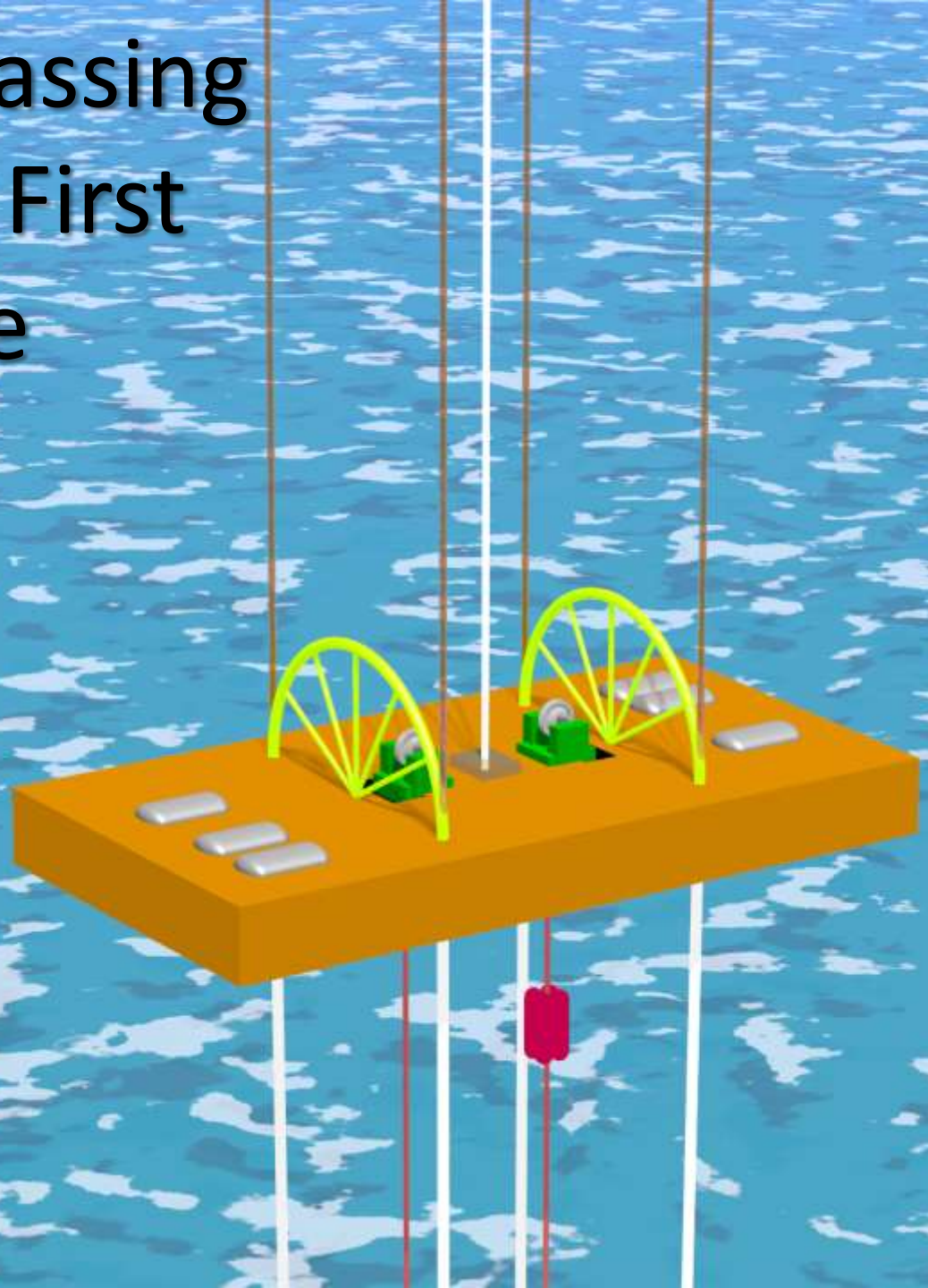
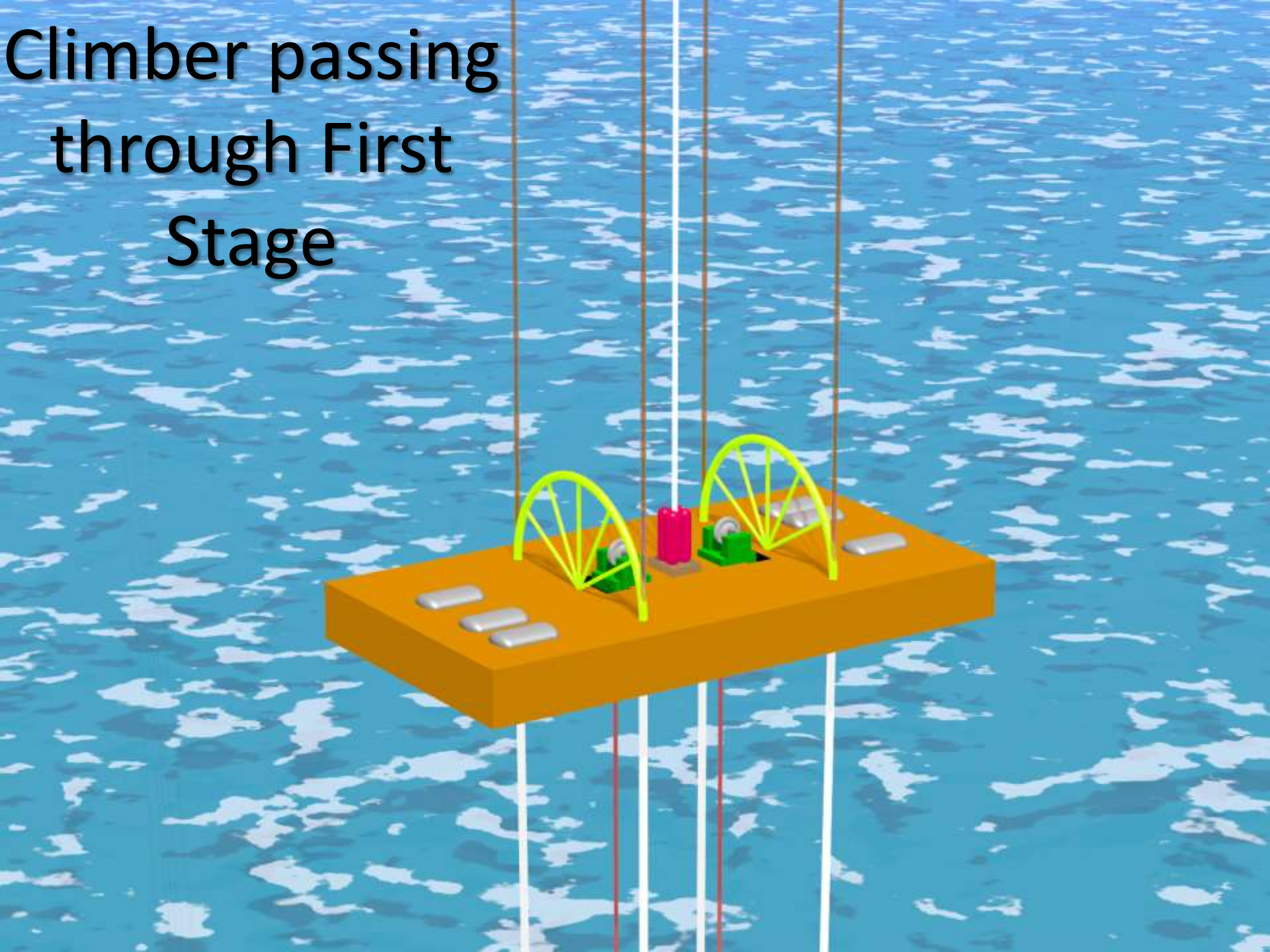
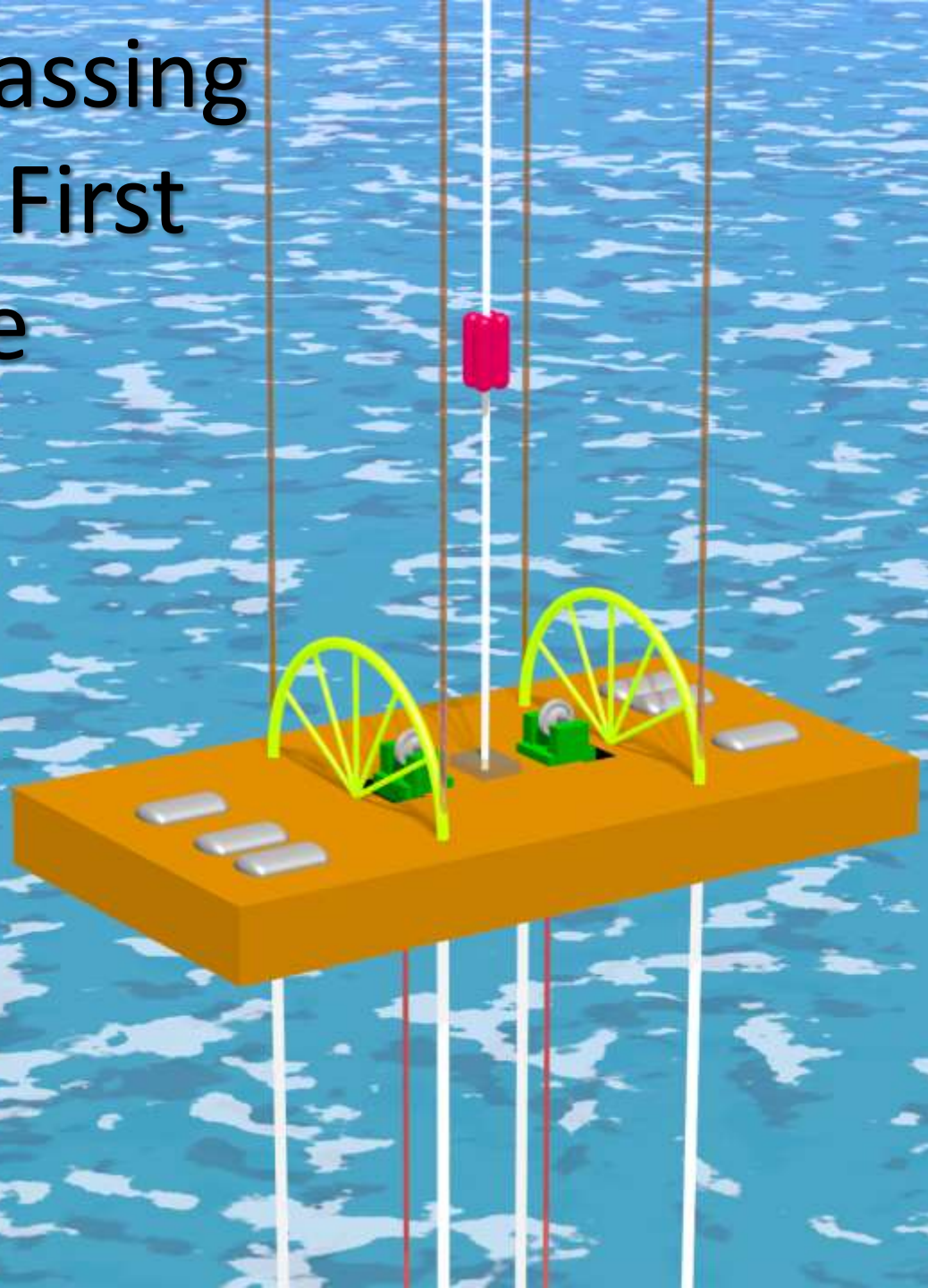
Climber passing through First Stage



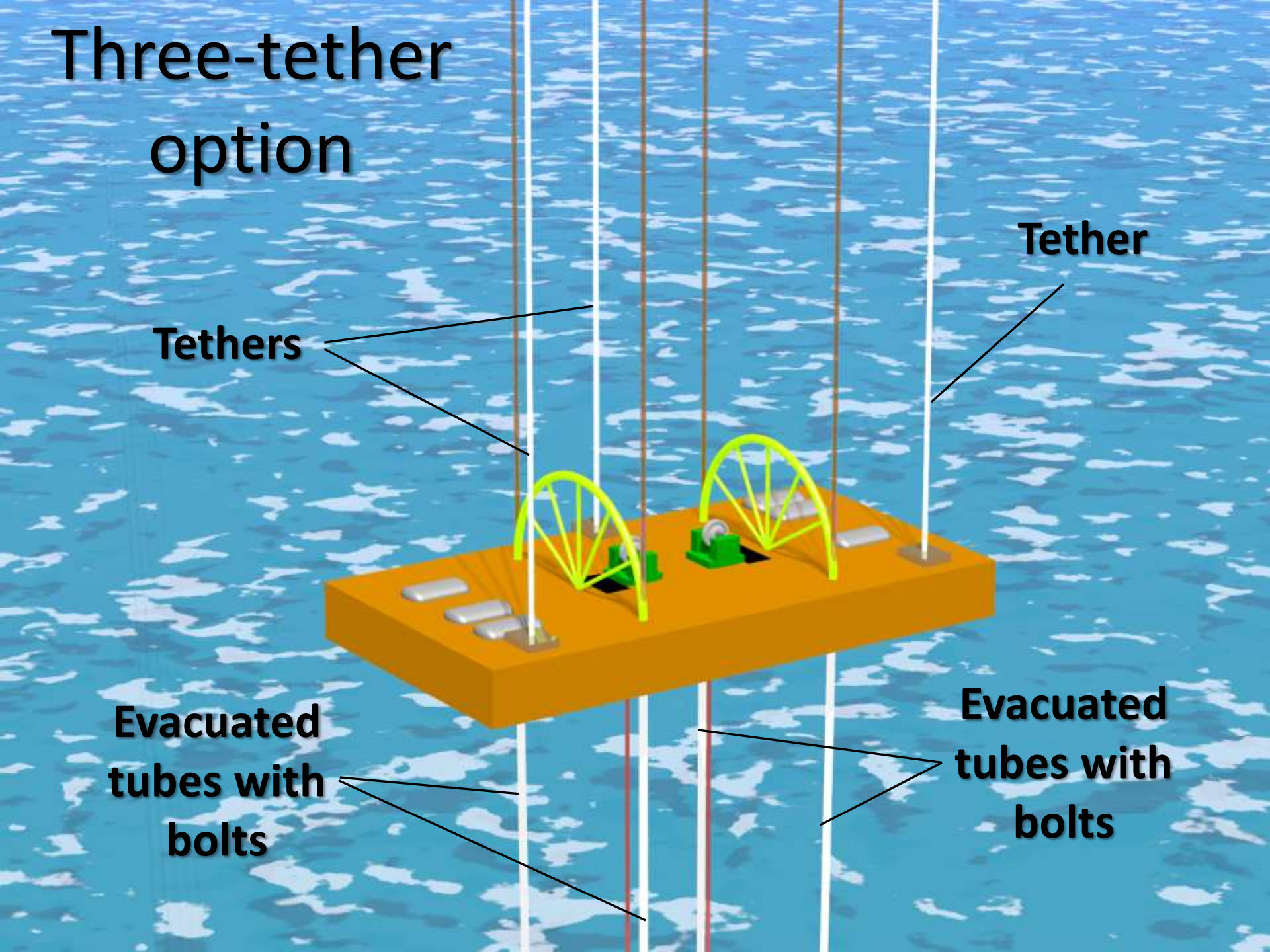
Climber passing through First Stage



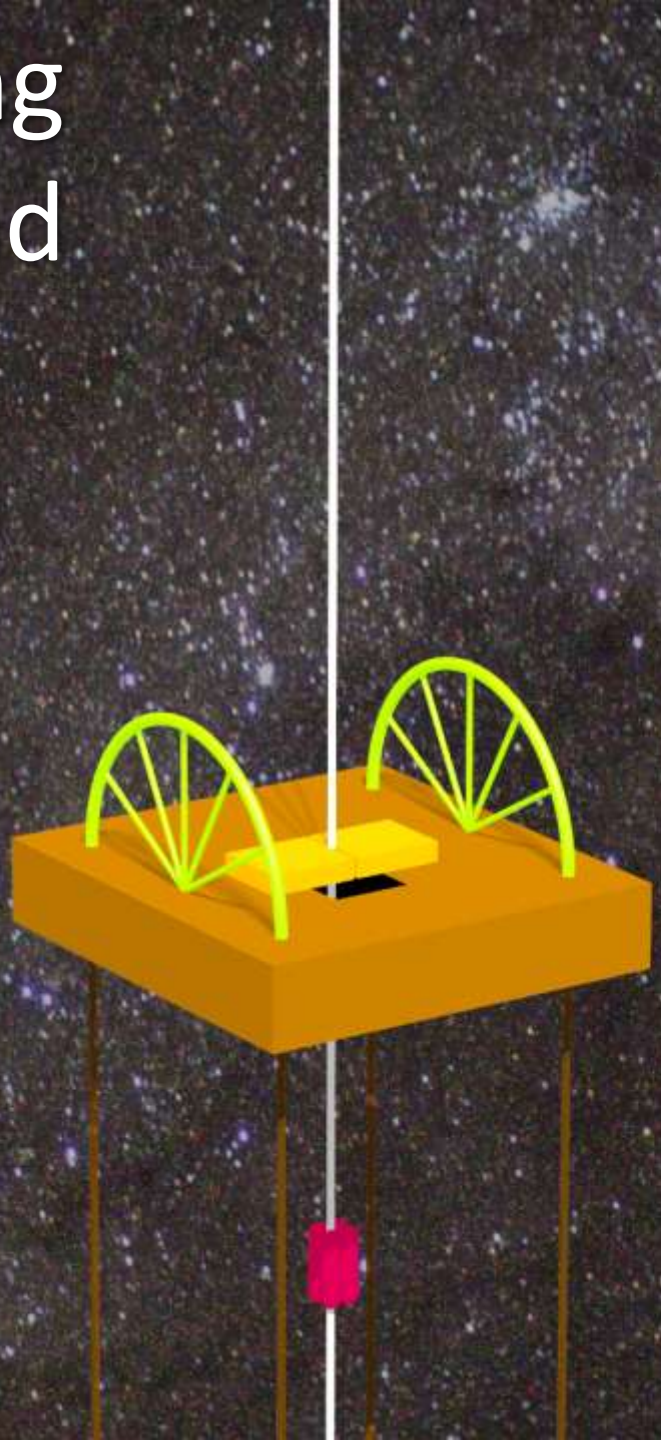
Climber passing through First Stage



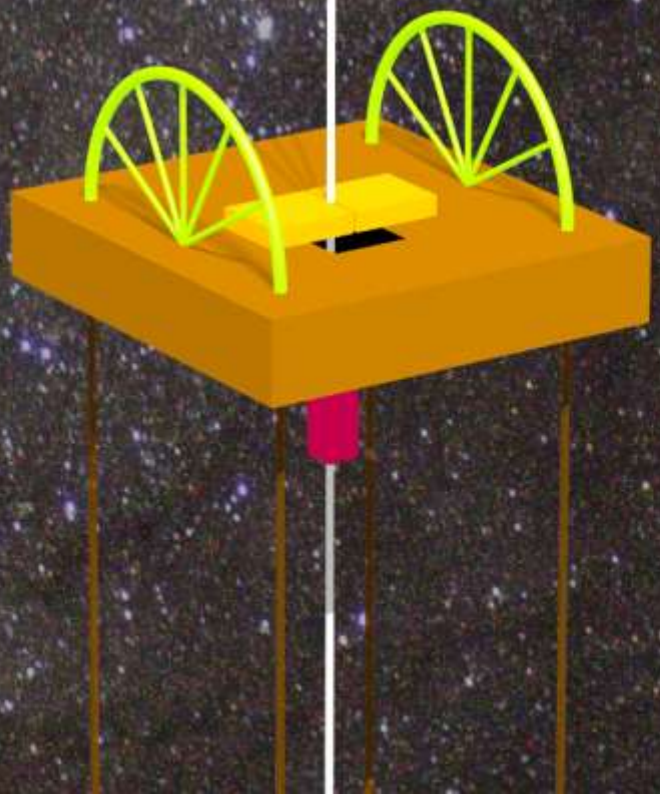
Three-tether option



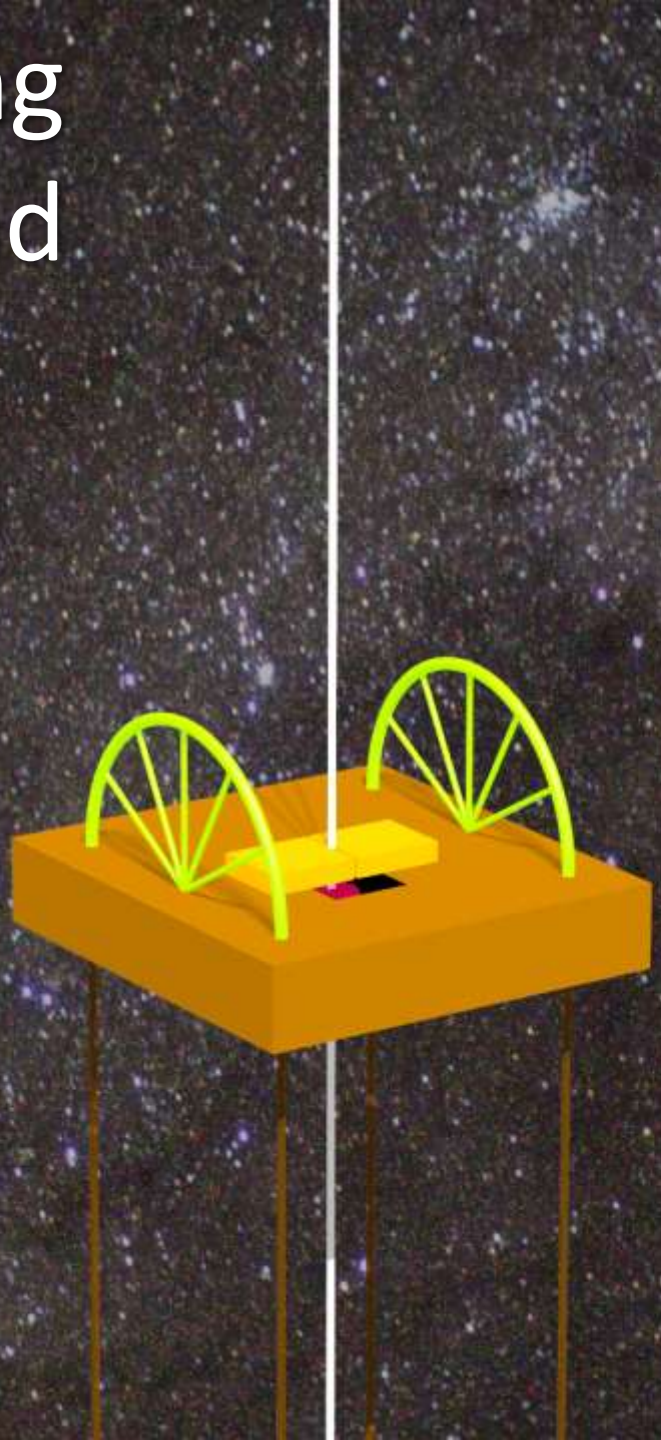
Climber passing through Second Stage



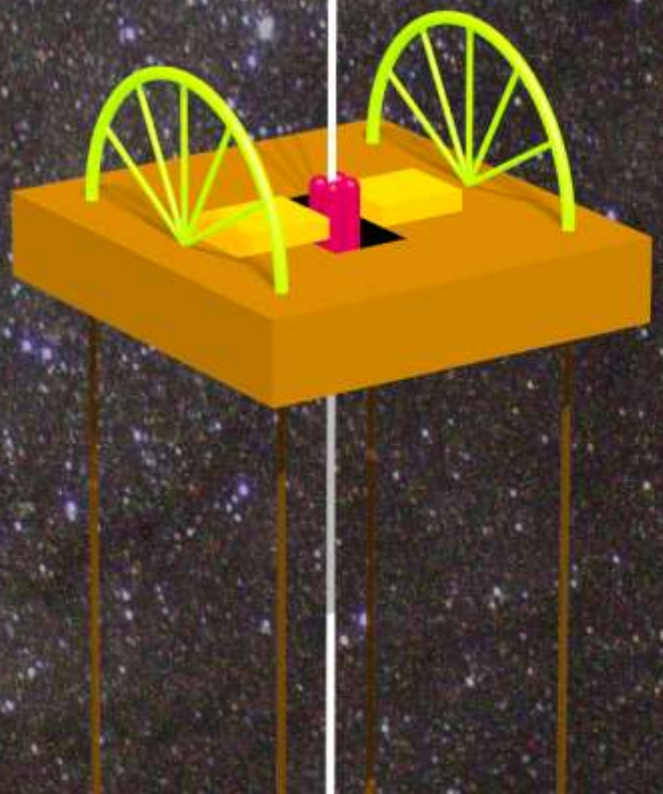
Climber passing through Second Stage



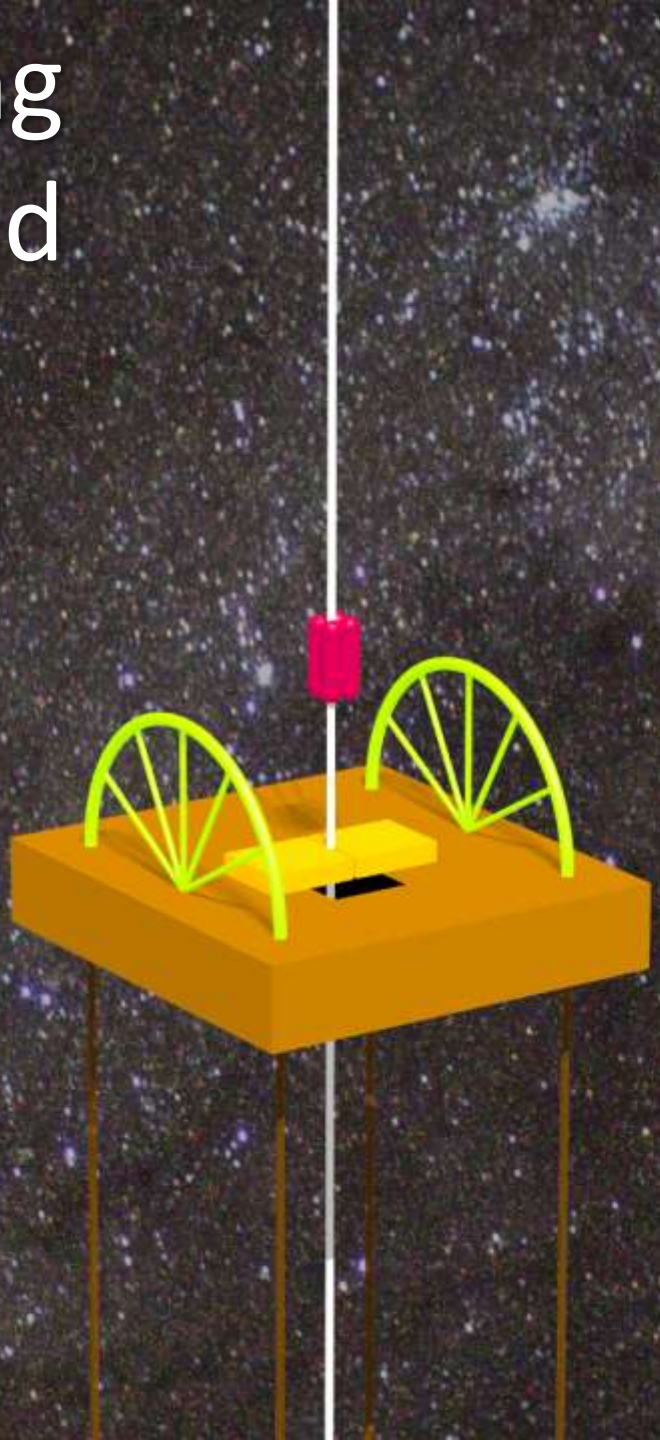
Climber passing through Second Stage



Climber passing through Second Stage



Climber passing through Second Stage



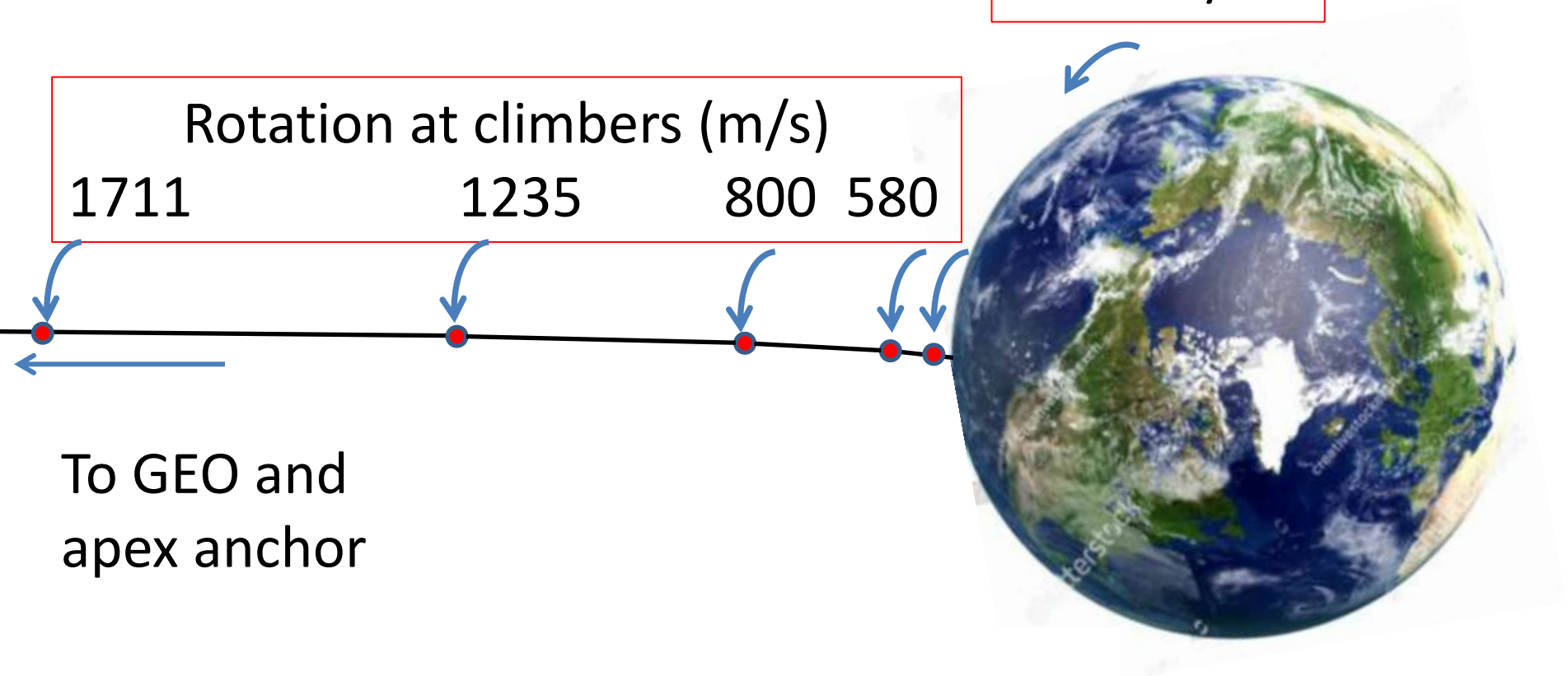
Coriolis Force in the Standard Model

Climbers accelerate in the orbital direction as they ascend.

Rotation at surface 465m/s

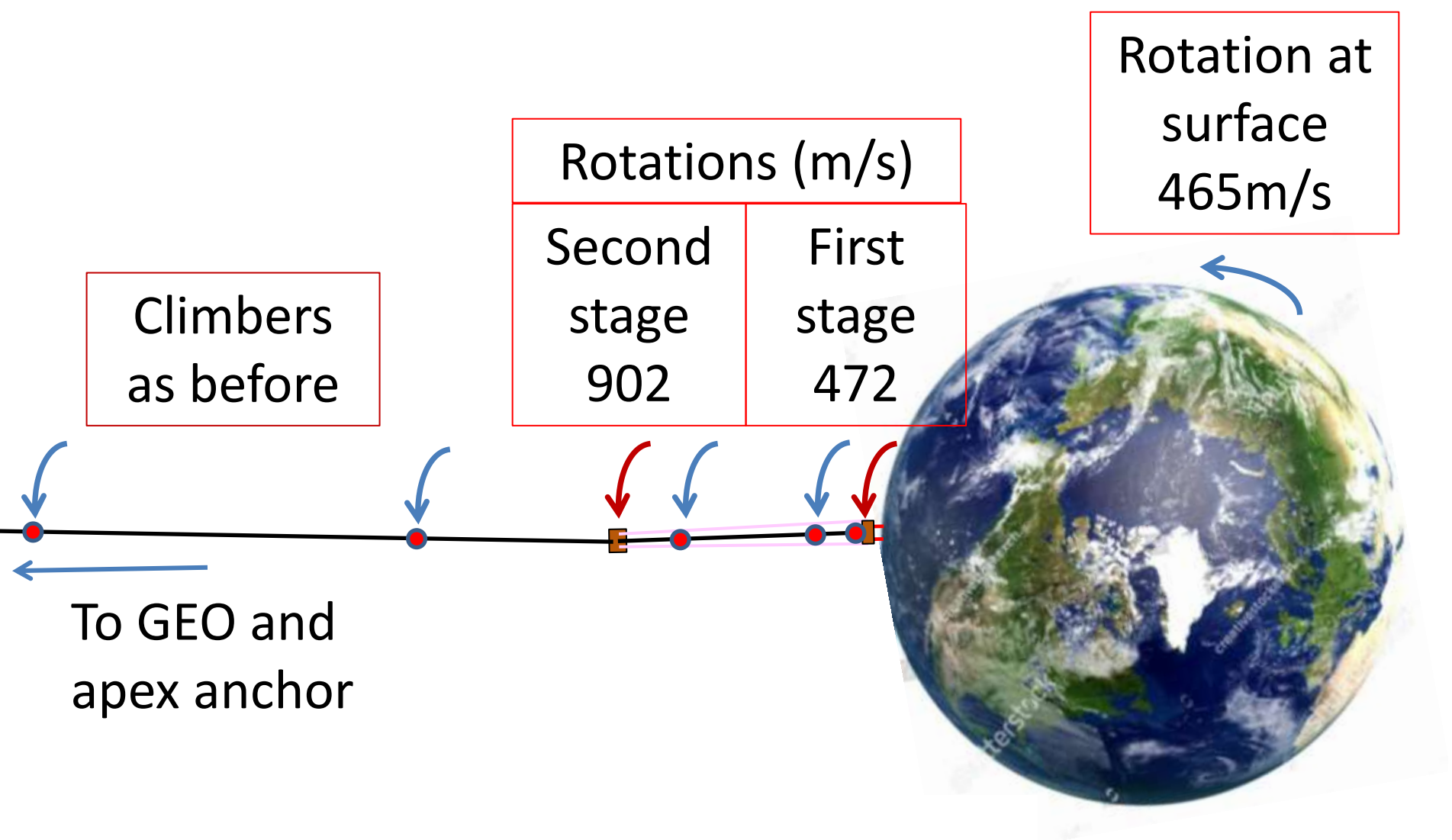
Rotation at climbers (m/s)

1711 1235 800 580



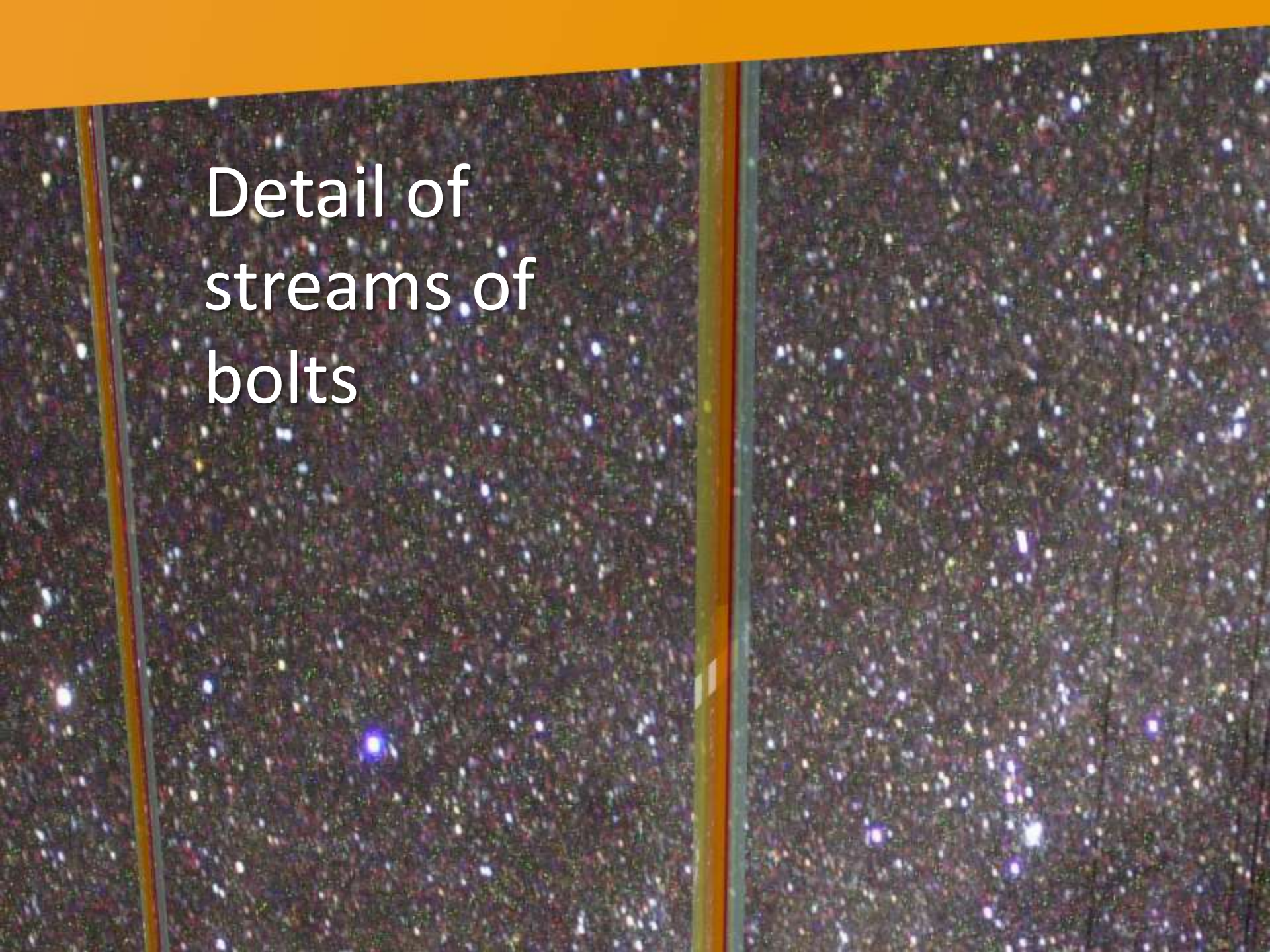
To GEO and apex anchor

Coriolis Force with Two Stages



Coriolis Force

- Bolts also accelerate as they climb
- Bolts decelerate as they descend
- Ascending and descending bolts exchange lateral momentum
  - They are magnetically connected and electronically controlled
  - Each bolt is a microprocessor


Detail of
streams of
bolts

Question 3

- Is it best to have the same climber mechanism throughout or should we change it?

Climber mechanisms	
Same throughout	
Winch to first stage, then climb the tether	
Change mechanism at first and second stage	
Other	

Topics

- Parallel, convergent tracks
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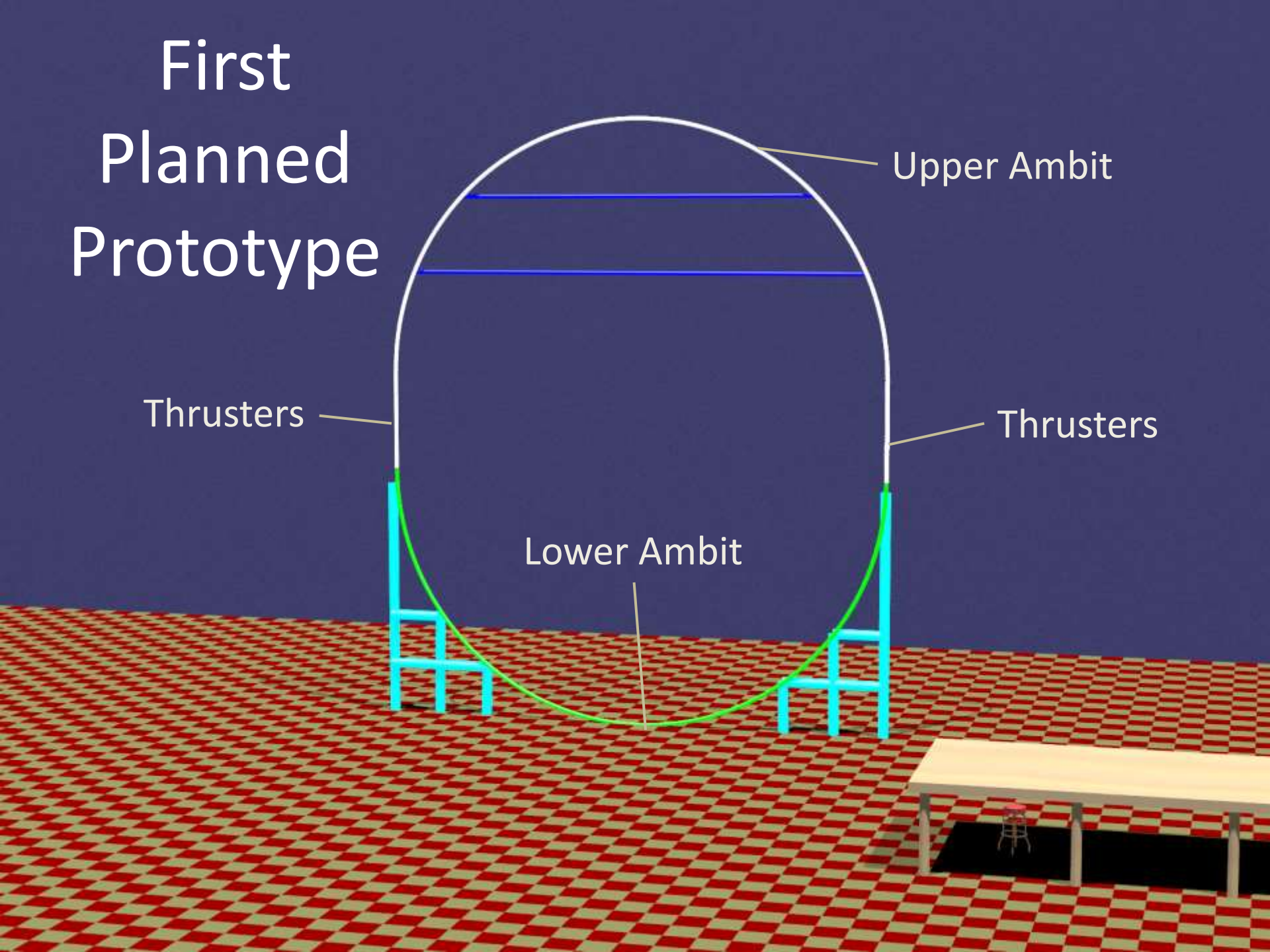
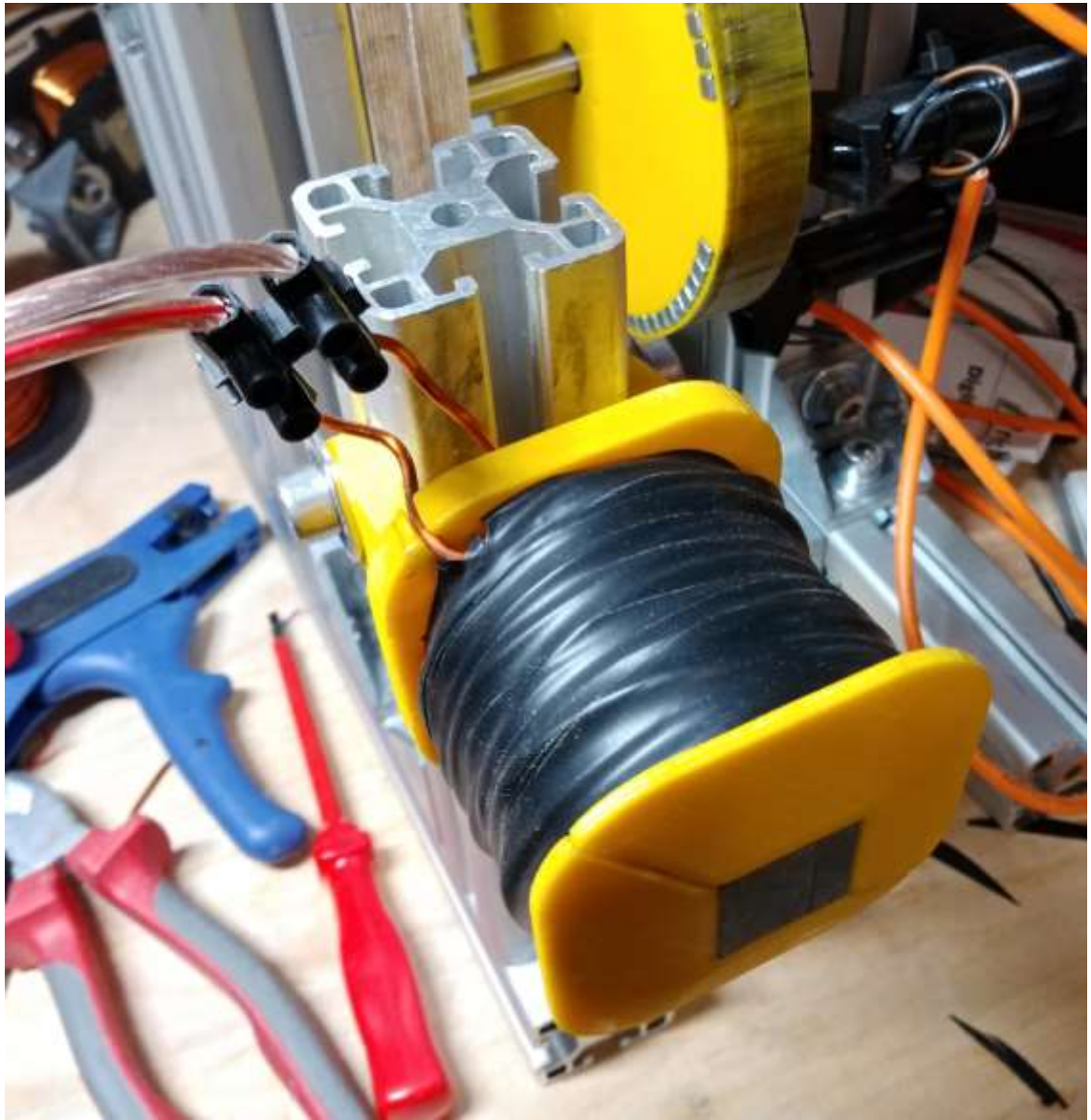
First Planned Prototype

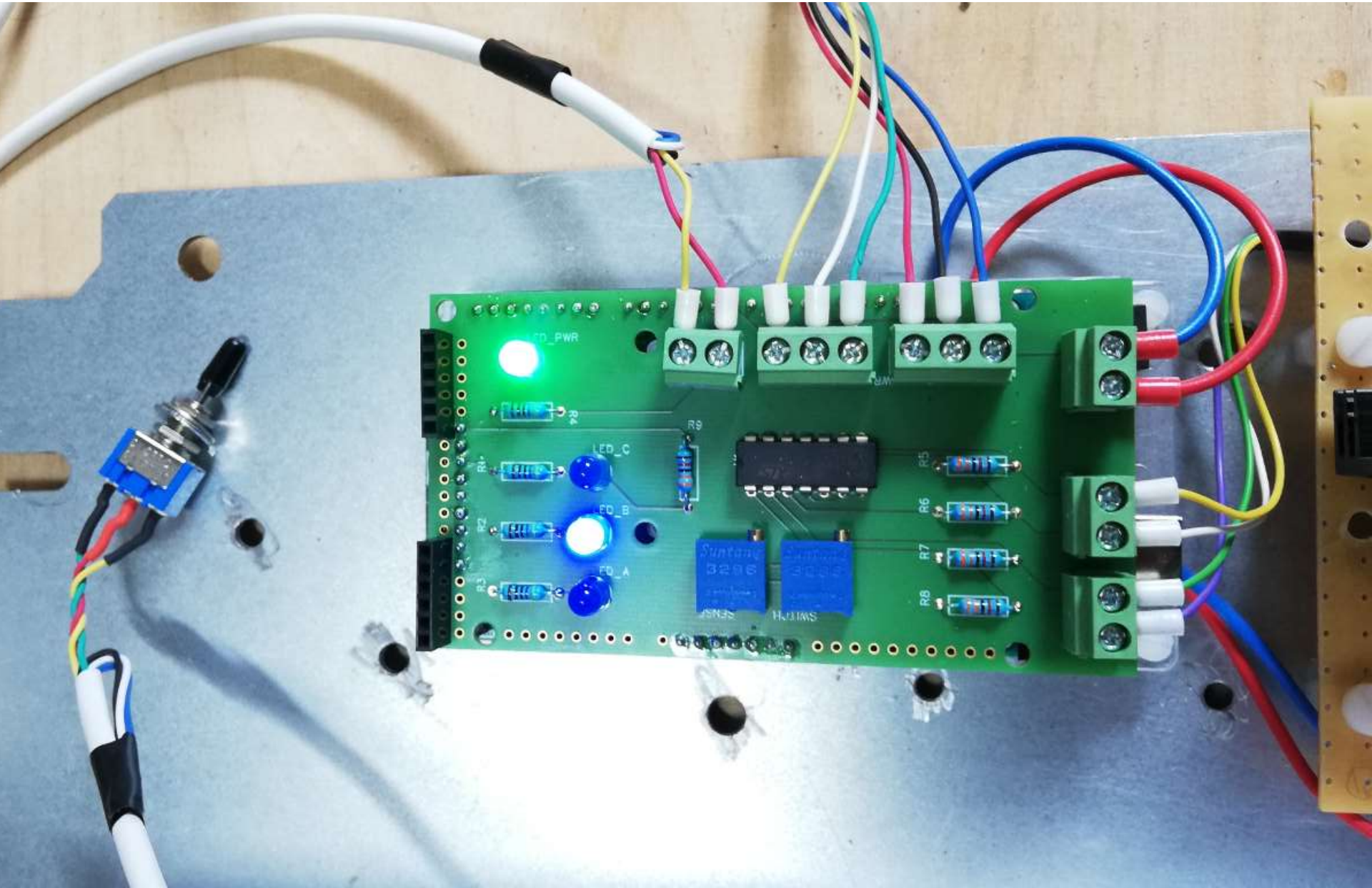


New Workshop

Thruster Coil



Recent Electronic Controls



Test Rig in Vacuum Chamber

Liquid Nitrogen Connections

Other topics

See ISEC Report 2018

https://www.isec.org/studies/#MultiStage

- Physics
- Space debris
- Stability in space
- Friction
- Magnetic levitation
- Linear propulsion
- Reliability
- Very high speed of the bolts
- Minimizing power consumption
- Maintenance
- Construction and erection

Topics

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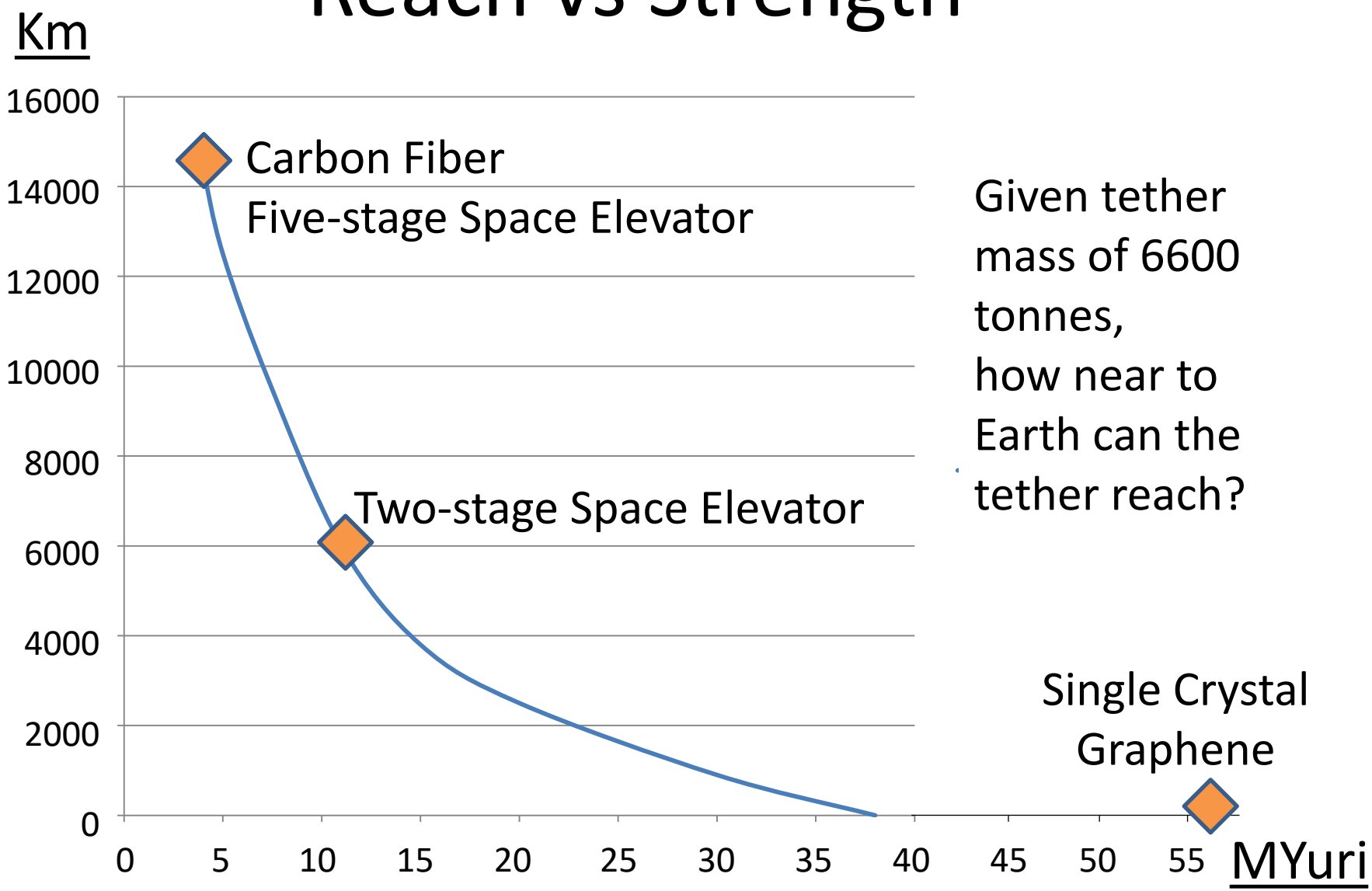
Convergence

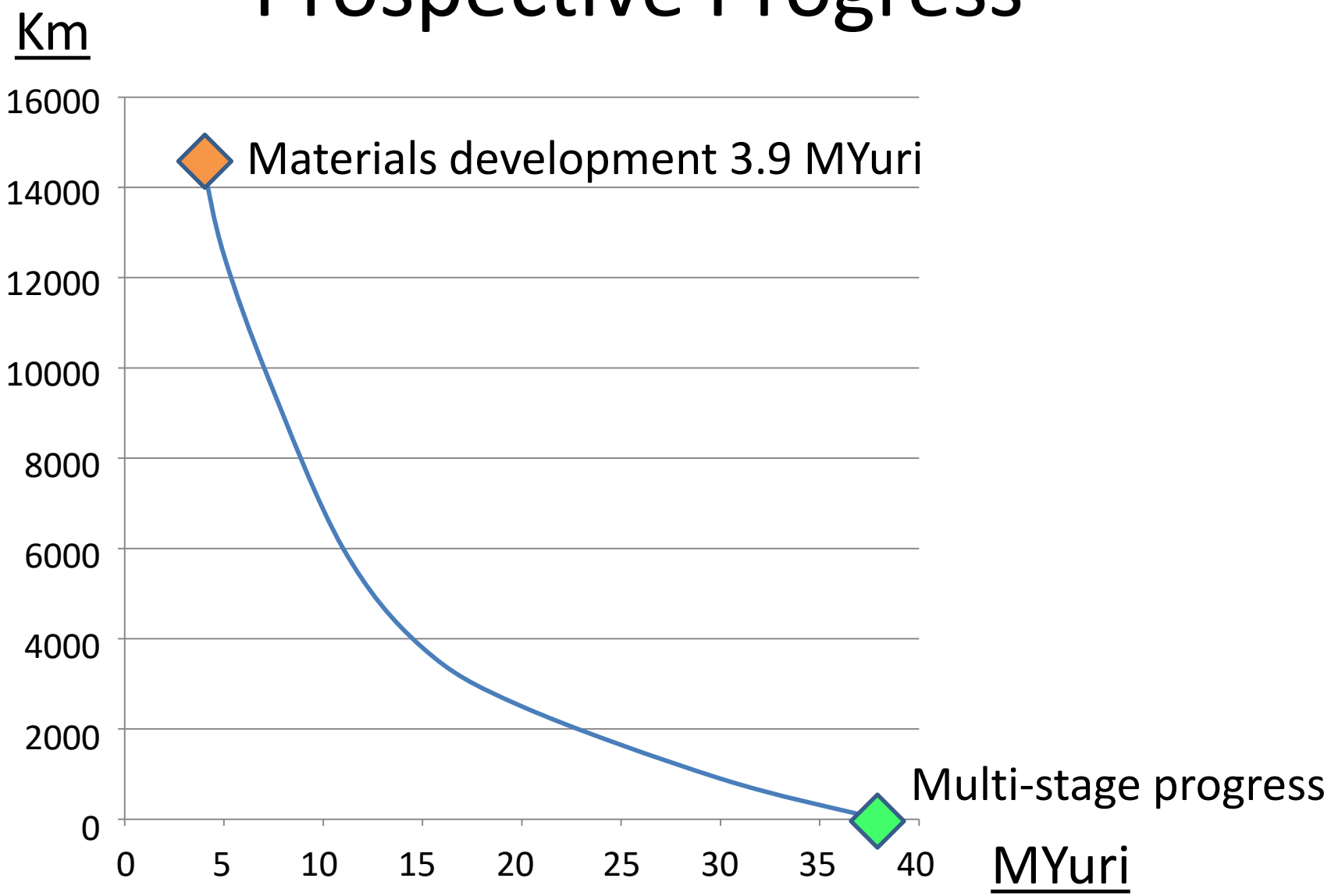
- Parallel tracks
  - Light, long, strong materials
    - Single crystal graphene
  - Multistage space elevator
    - Supporting the tether's weight near Earth
    - A more complex solution

Reach vs Strength

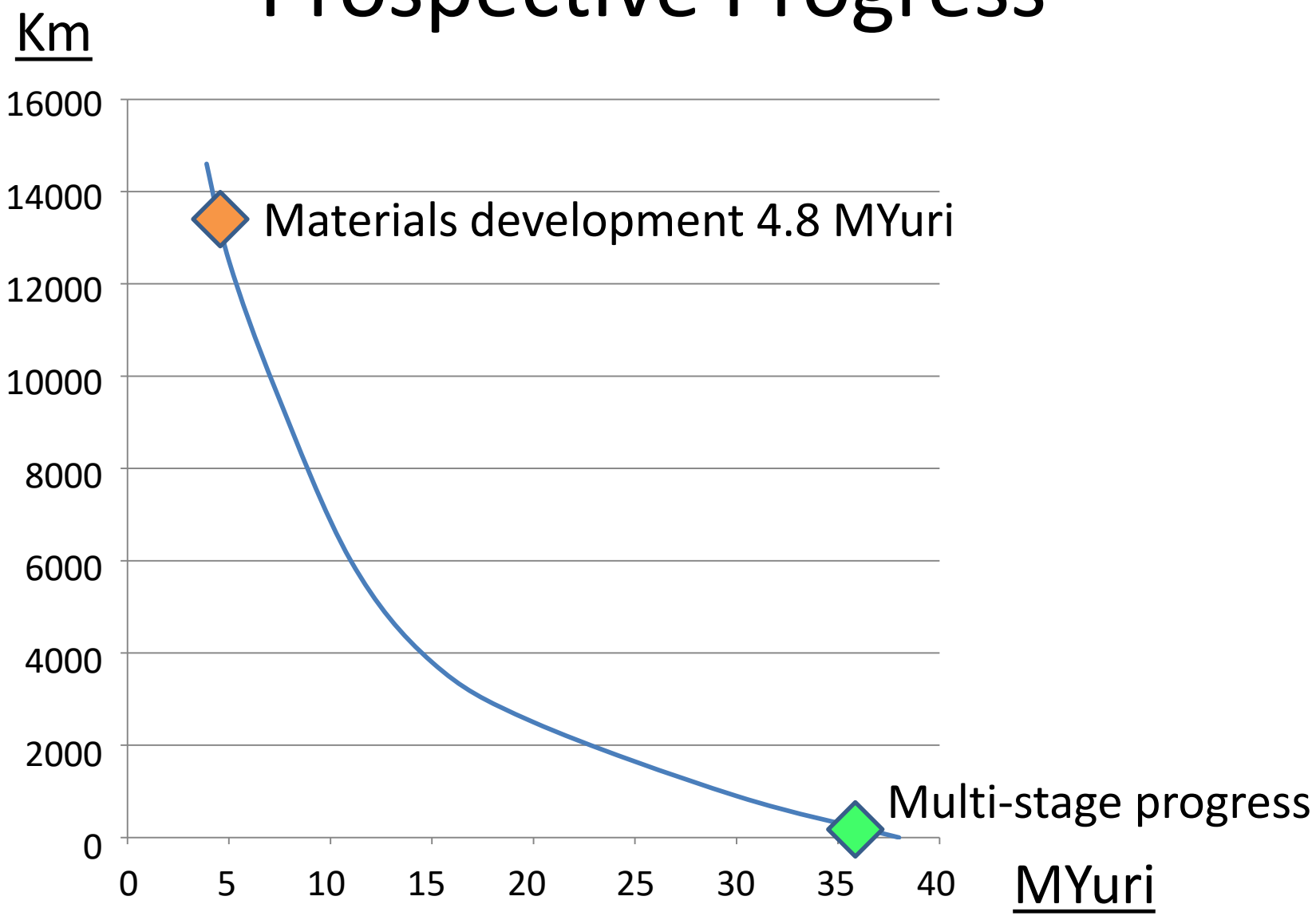


Given tether mass of 6600 tonnes, how near to Earth can the tether reach?

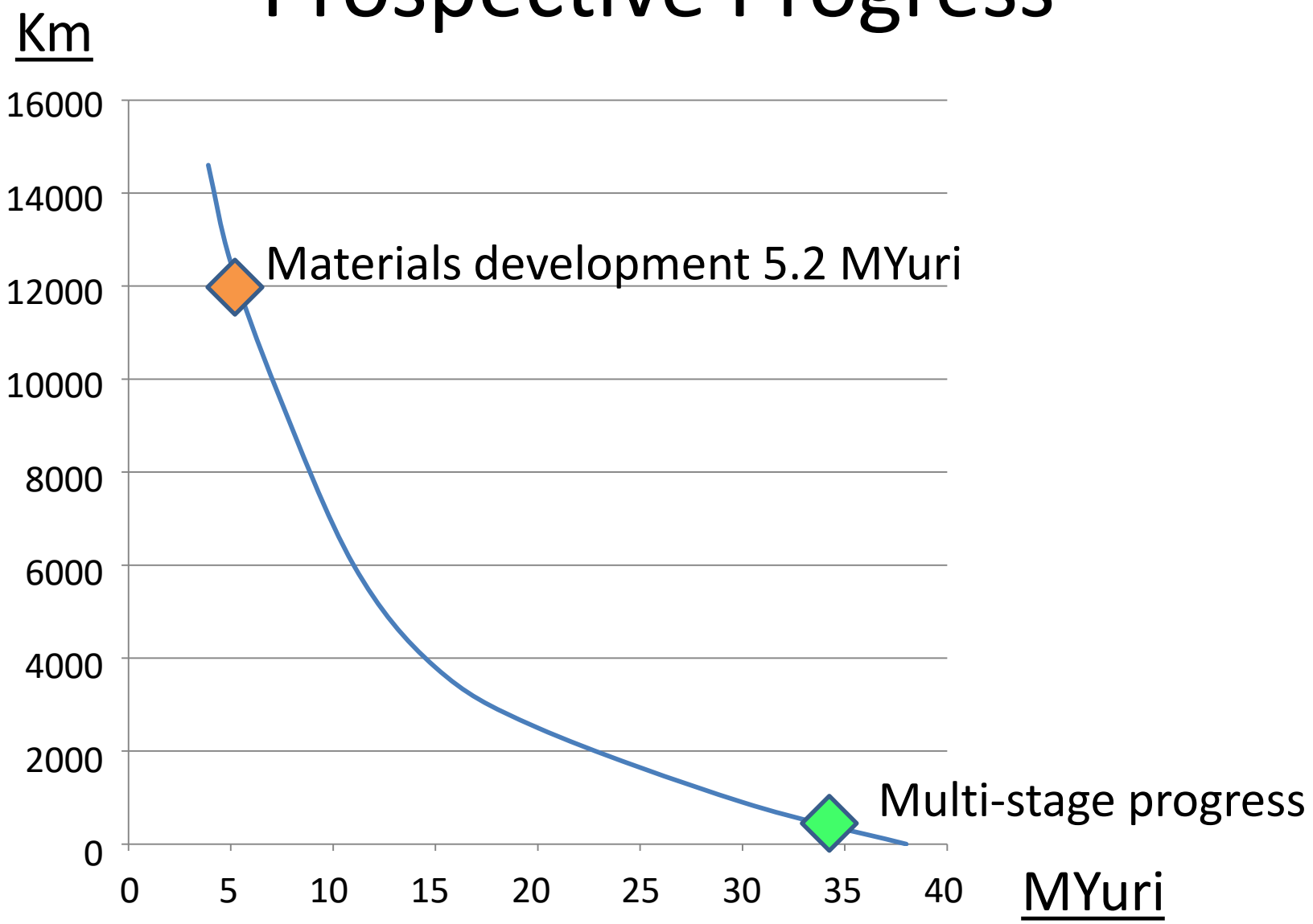
Prospective Progress



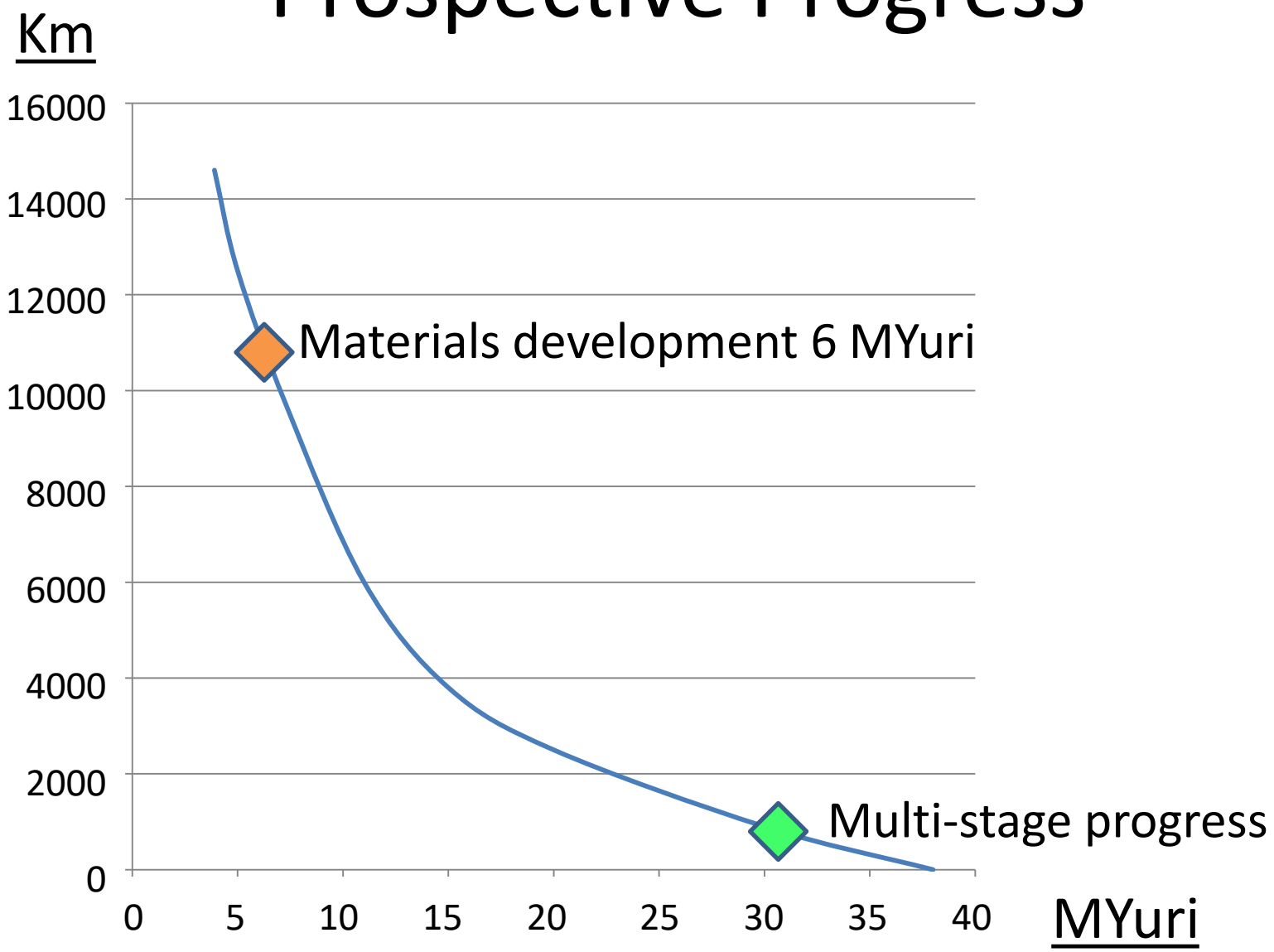
Prospective Progress



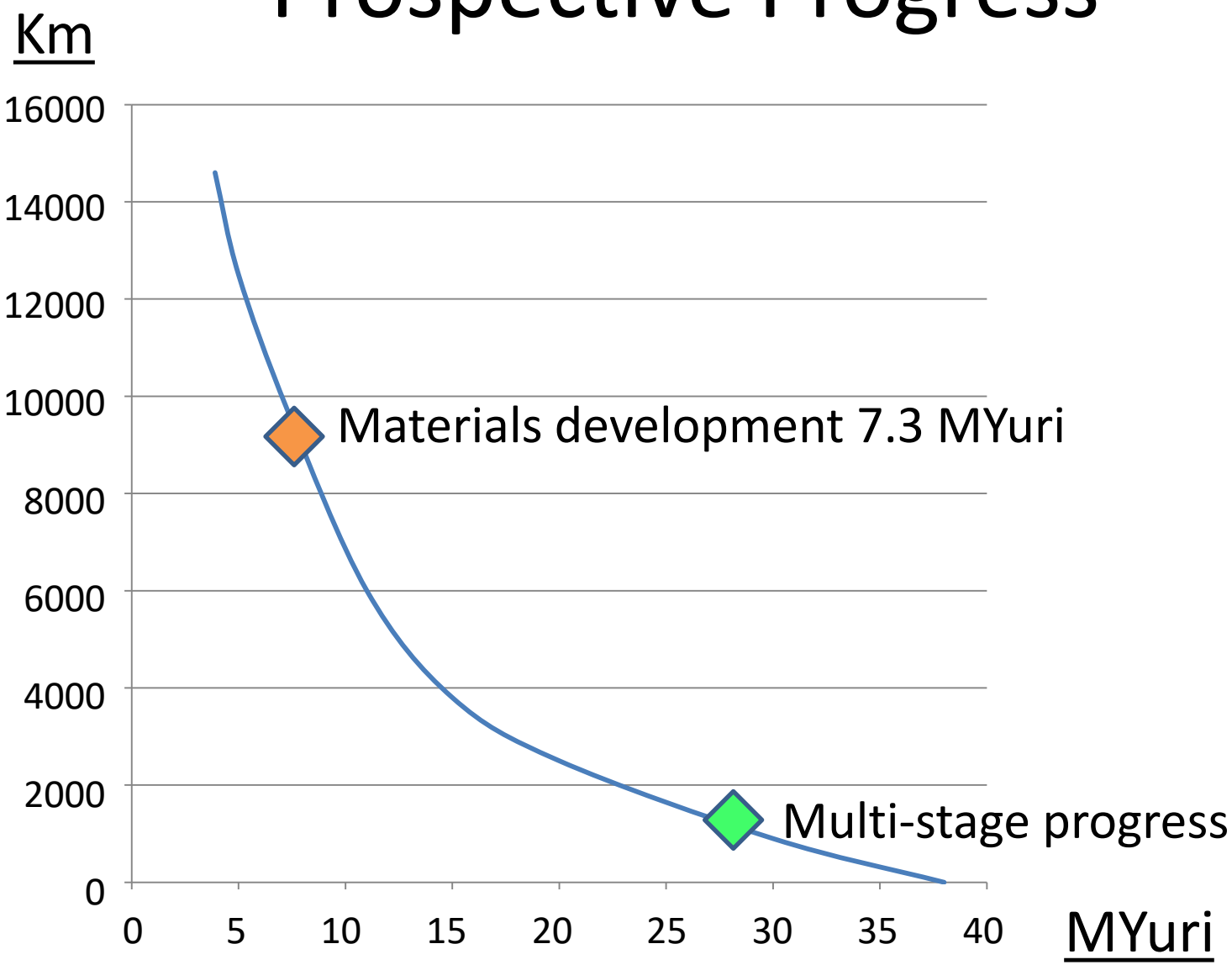
Prospective Progress



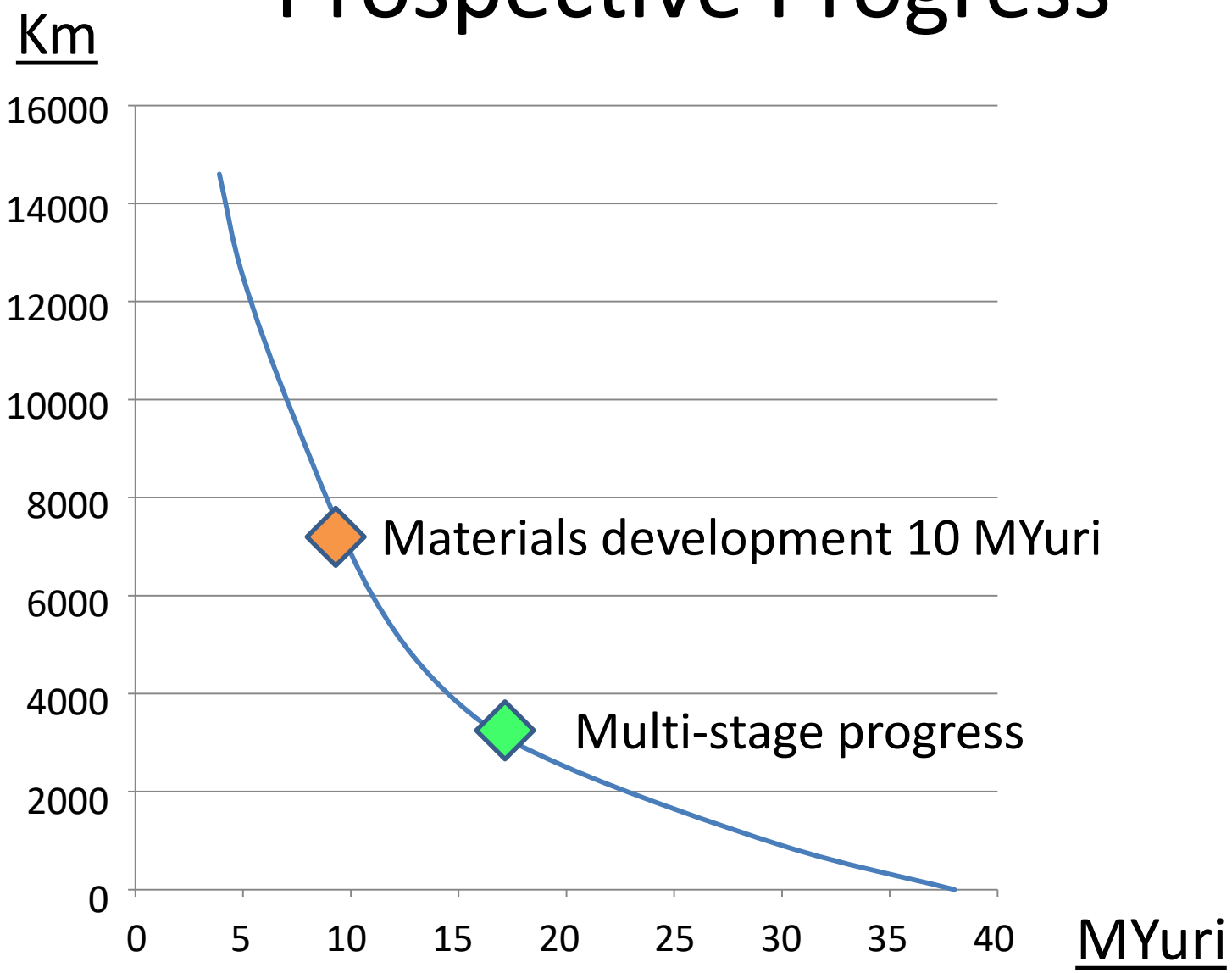
Prospective Progress



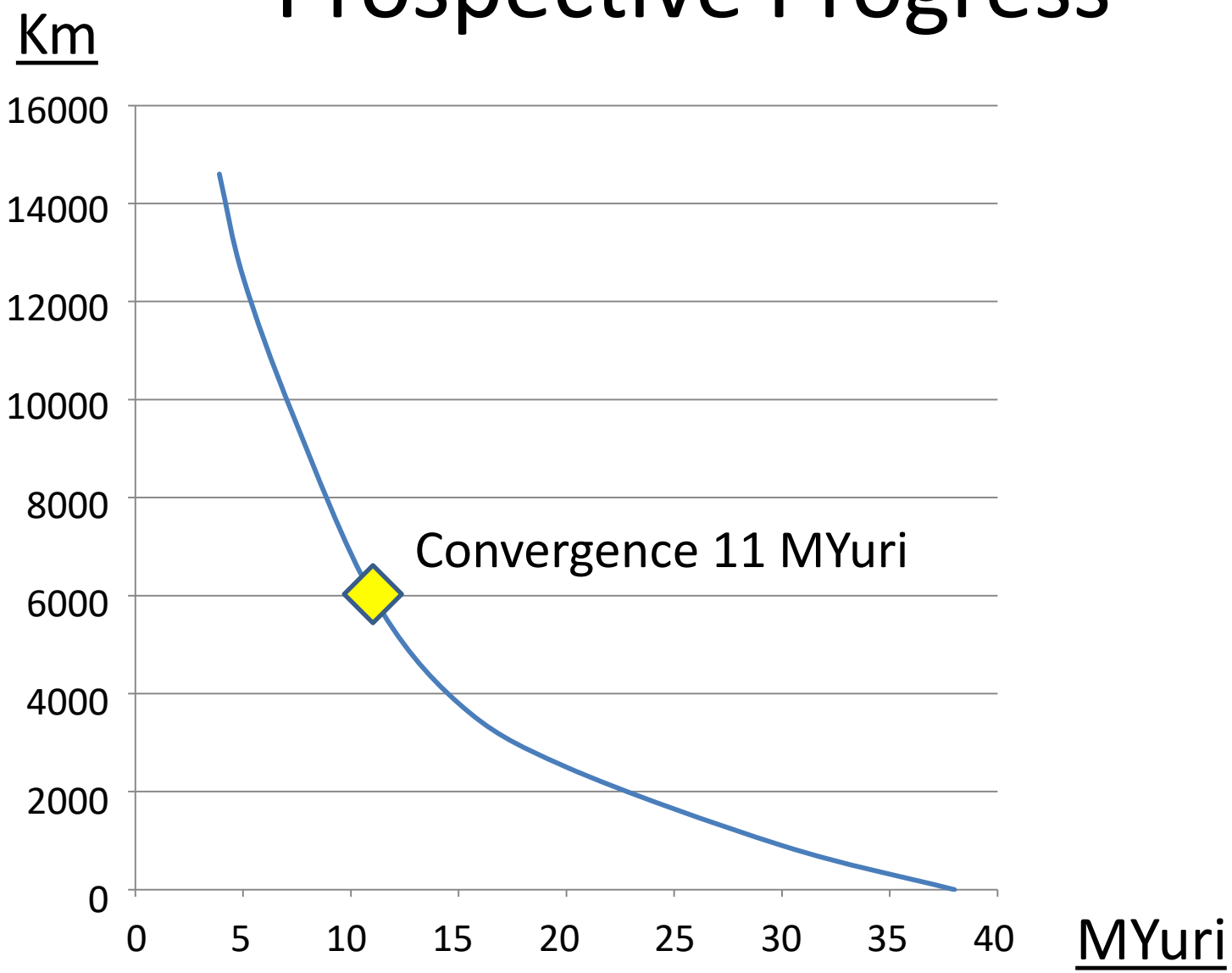
Prospective Progress



Prospective Progress



Prospective Progress



The Space Elevator

- To explore the solar system and beyond
- Enable colonization of the solar system
- Provide bulk lifting, complementing rockets
- Enable new industries such as space-based solar power

Question 4

- Are we likely to see a breakthrough or steady progress in these areas?

	Breakthrough	Steady progress
Dynamically supported structures		
Light, long, strong materials		