The Multi-stage space Elevator
ISEC 2018 Report

John M. Knapman, Ph.D., FBIS
Director of Research
ISEC

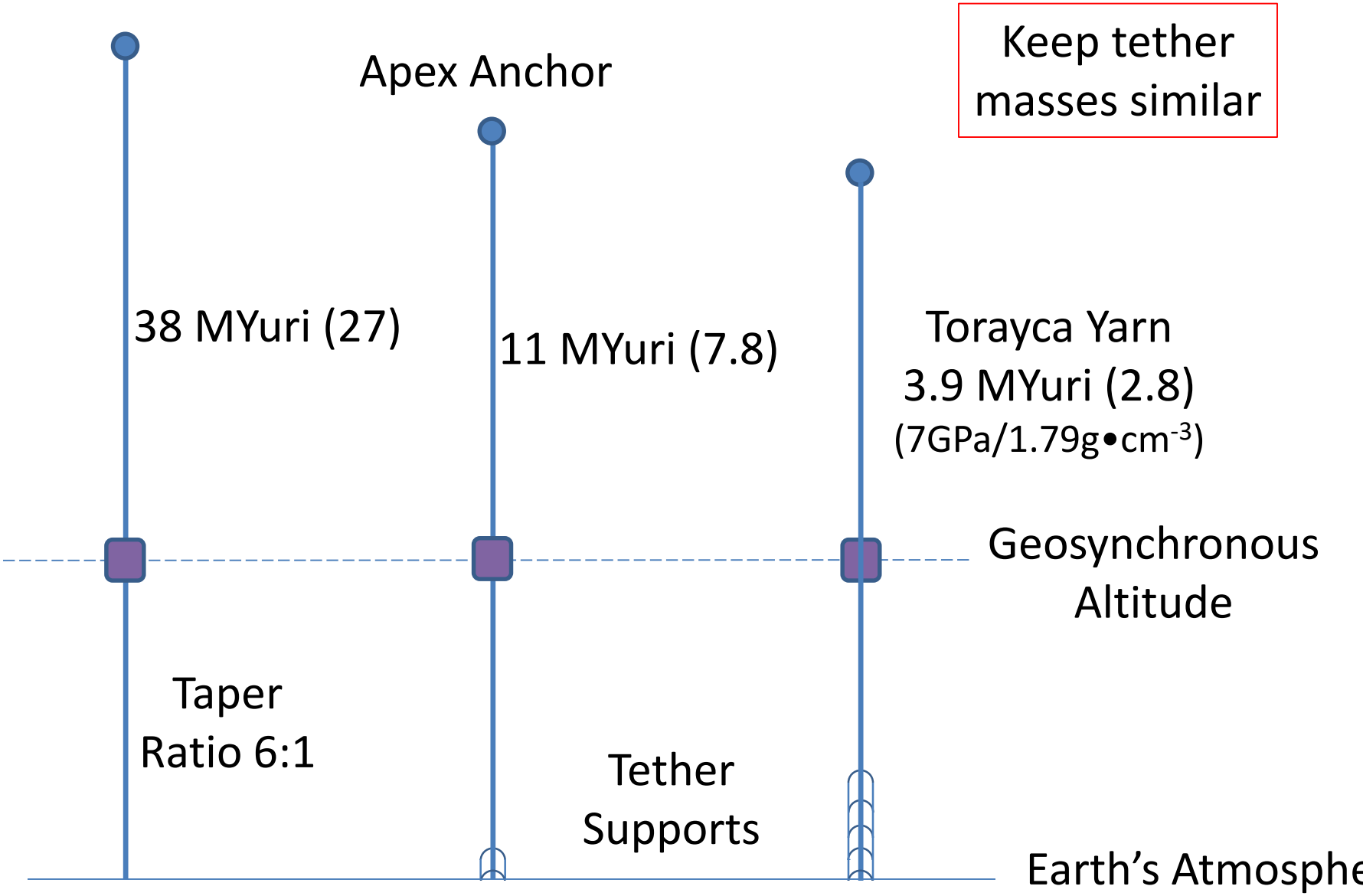
Purpose

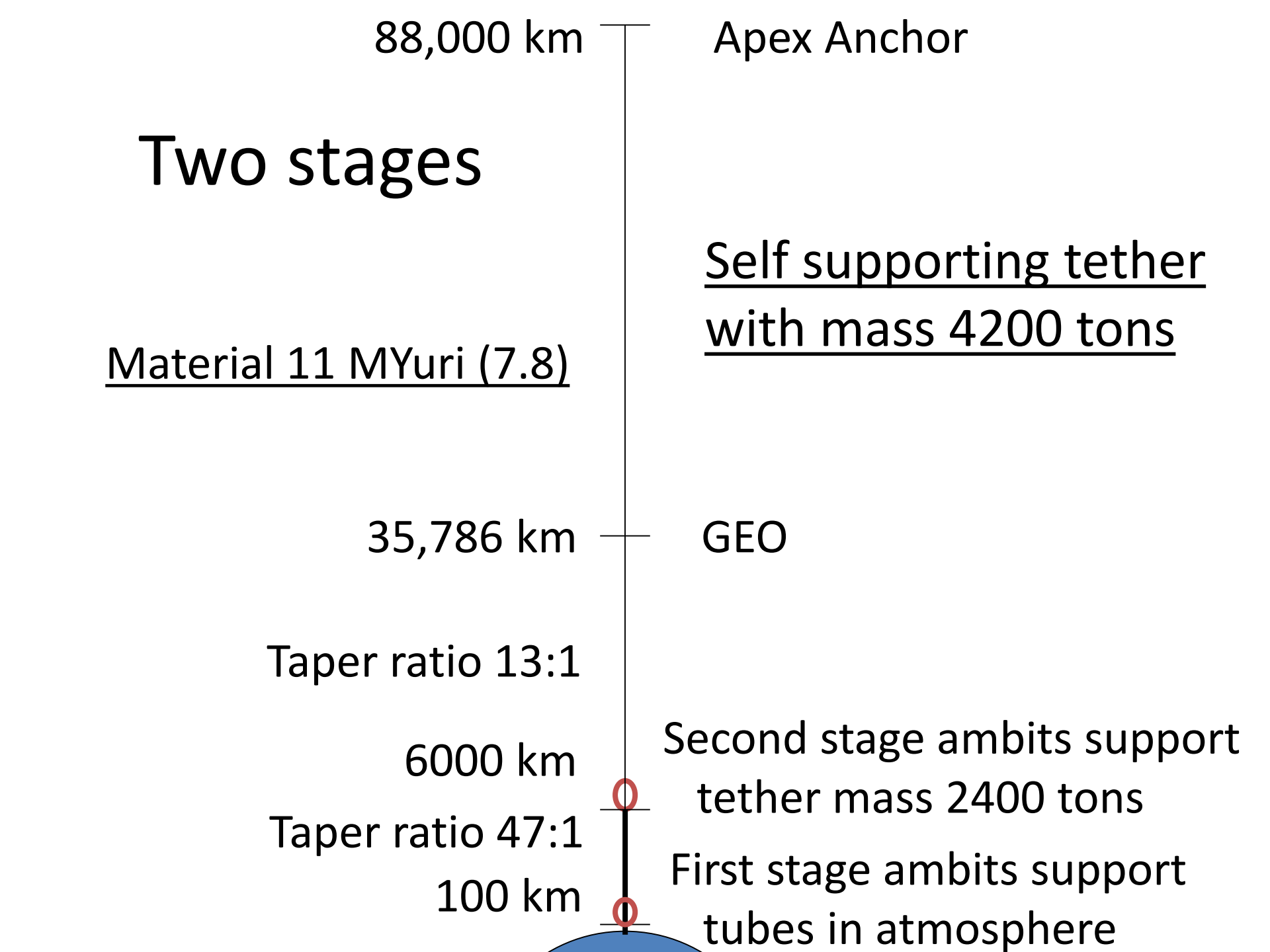
- To be able to use tether materials that are available now or likely to be available soon
  - Carbon fiber yarn
  - Improved graphene or CNTs
    - Beyond the small samples produced today
- To deal with Earth's turbulent atmosphere
  - Wind, ice, electric storms

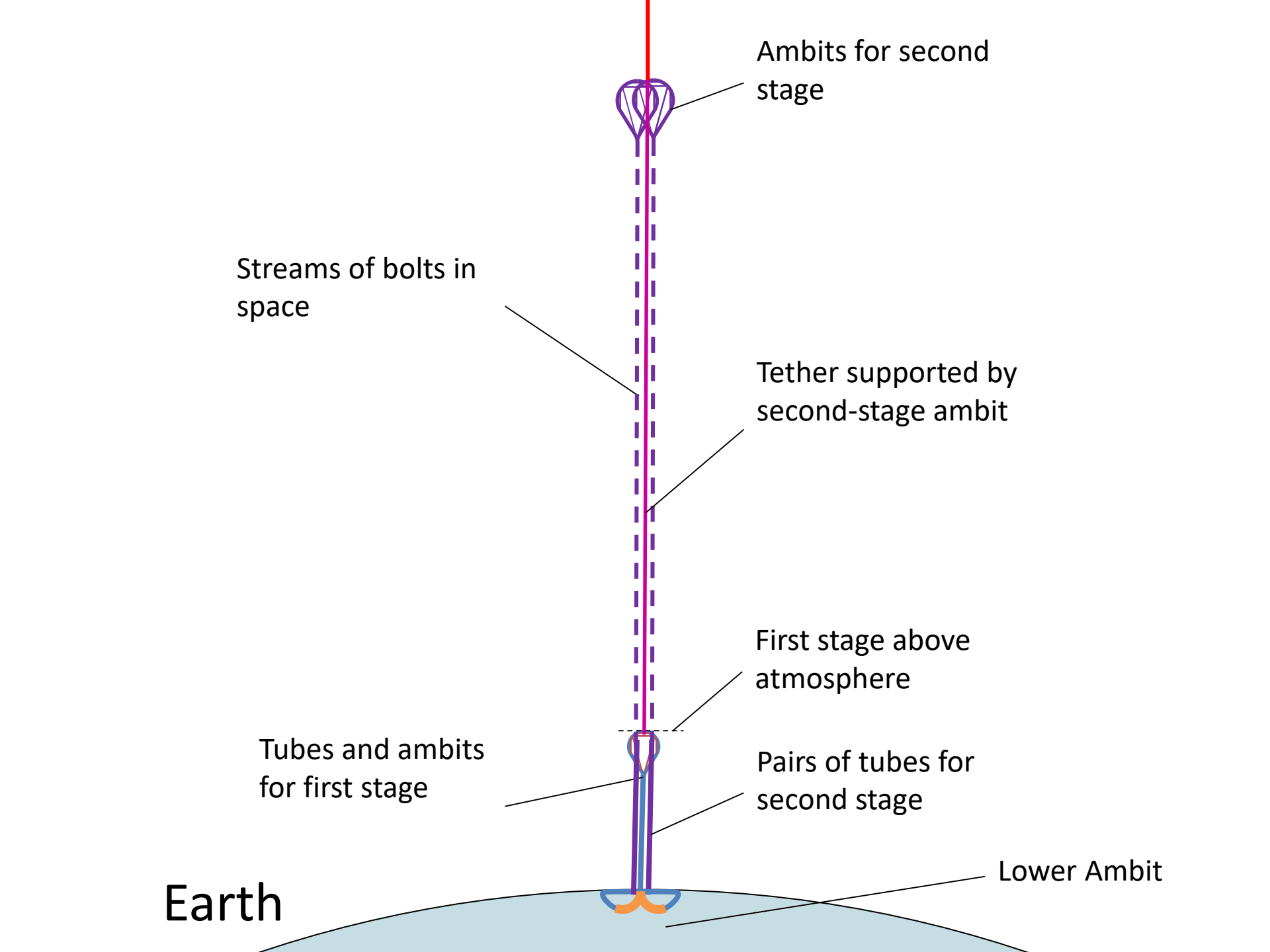
Topics

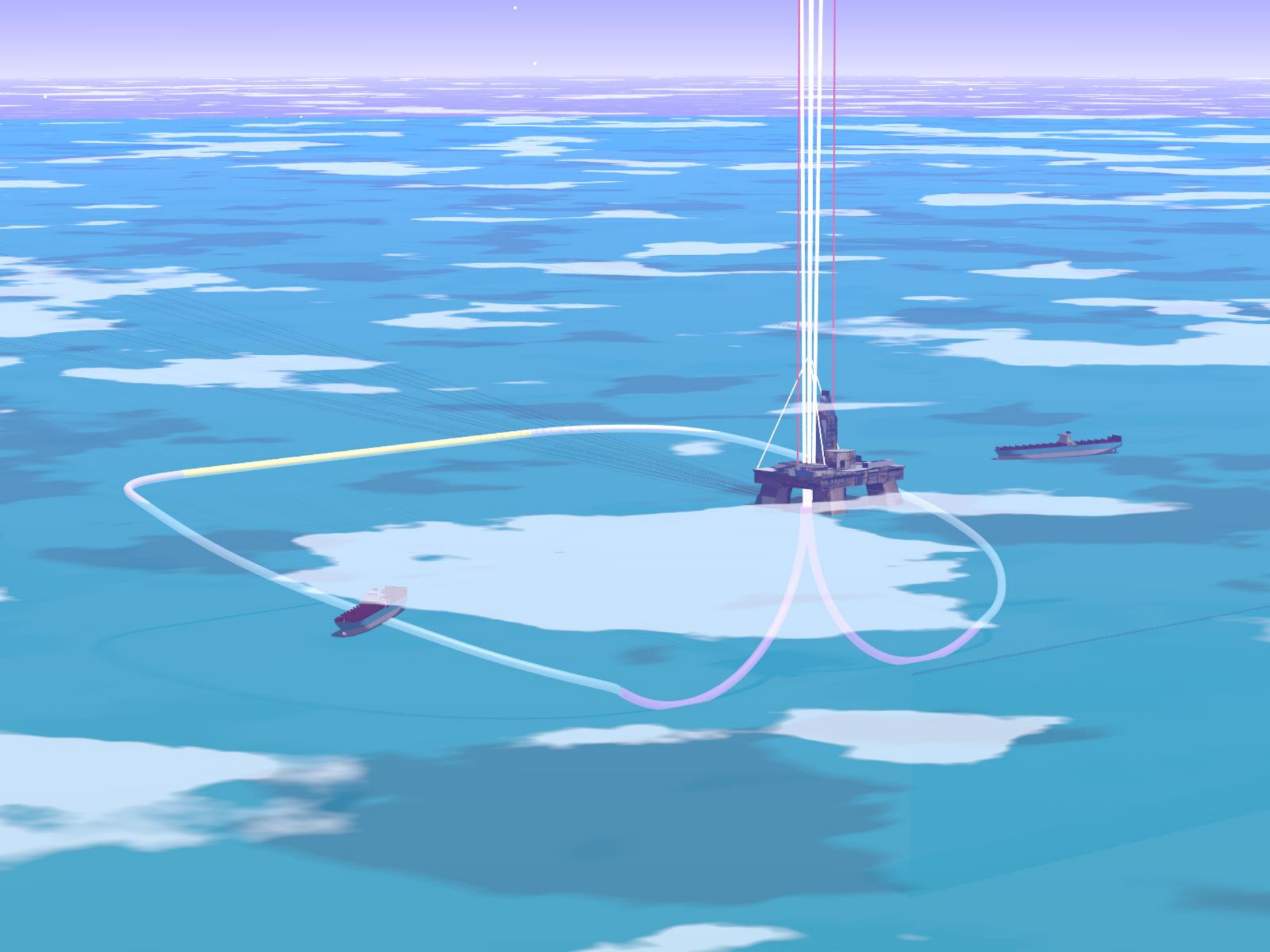
- Principles
- First Stage
- Upper Stages
- Resilience
- Prototype Work
- Mini Workshop Questions

How to use a weaker tether

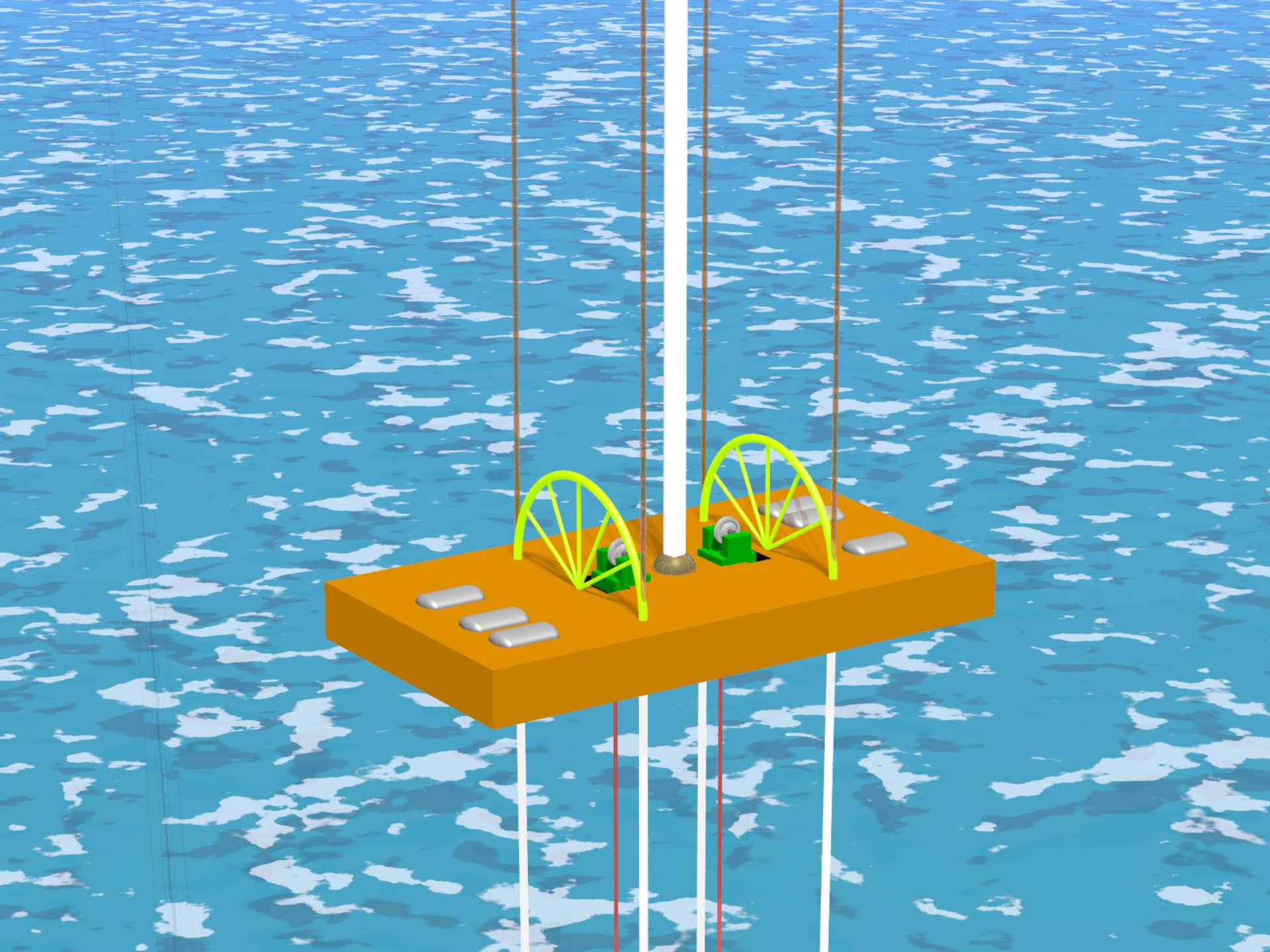


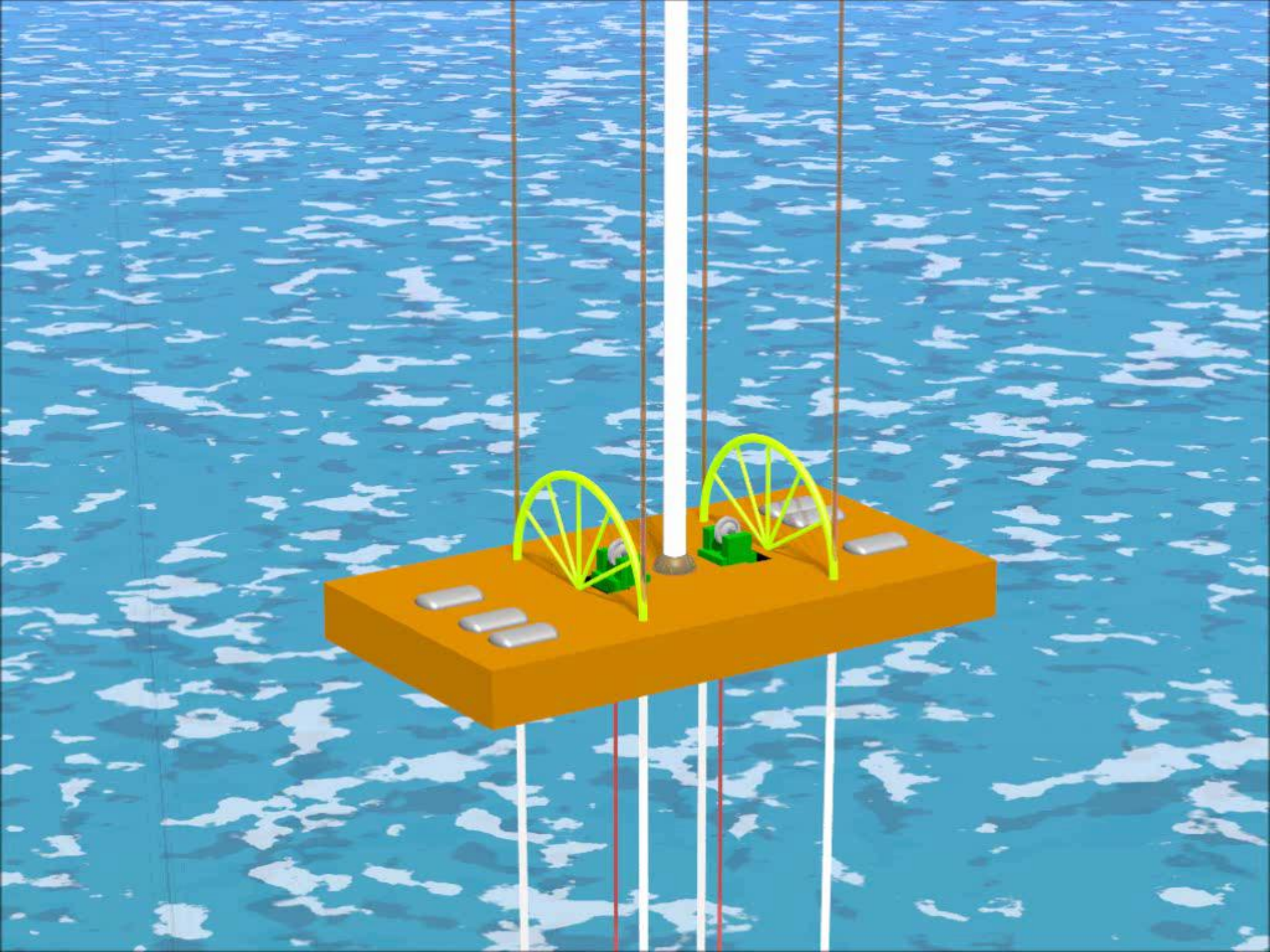

88,000 km
Apex Anchor
Two stages
Self supporting tether
with mass 4200 tons
Material 11 MYuri (7.8)
35,786 km
GEO
Taper ratio 13:1
6000 km
Second stage ambits support
tether mass 2400 tons
Taper ratio 47:1
First stage ambits support
100 km
tubes in atmosphere


Ambits for second stage
Streams of bolts in space
Tether supported by second-stage ambit
First stage above atmosphere
Tubes and ambits for first stage
Pairs of tubes for second stage
Lower Ambit
Earth



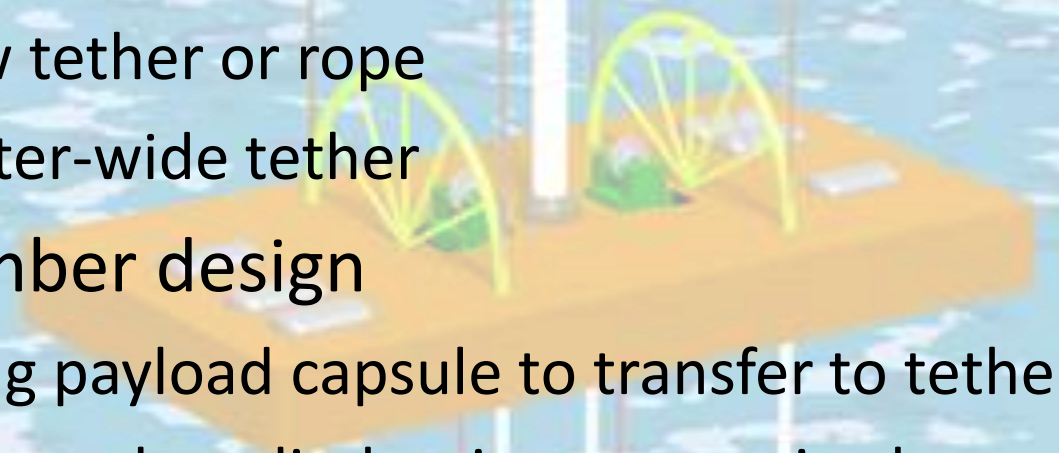
First Stage

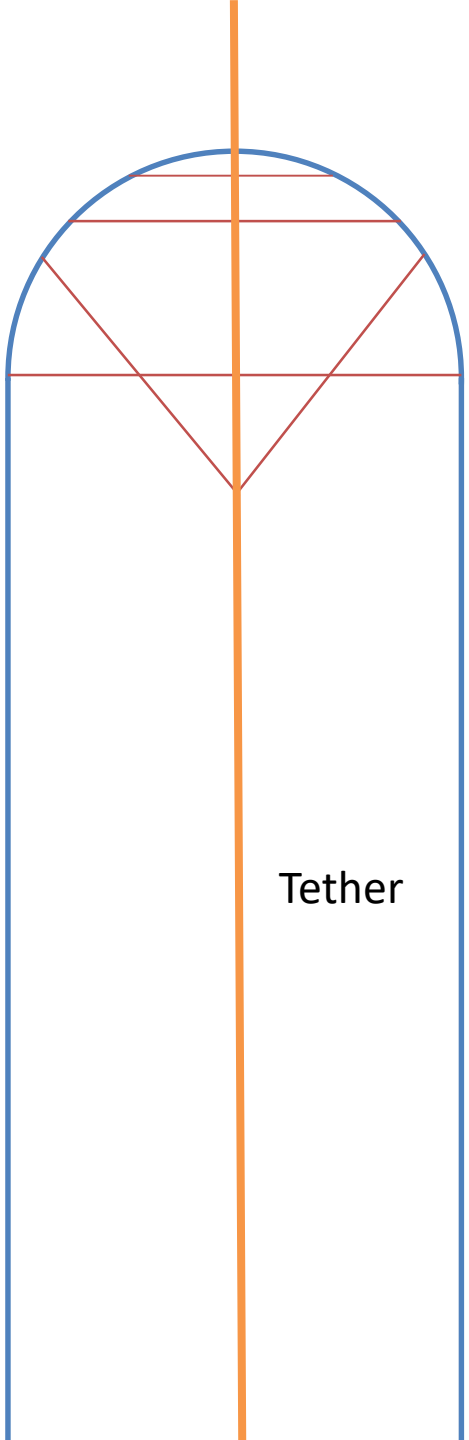




Design Choices

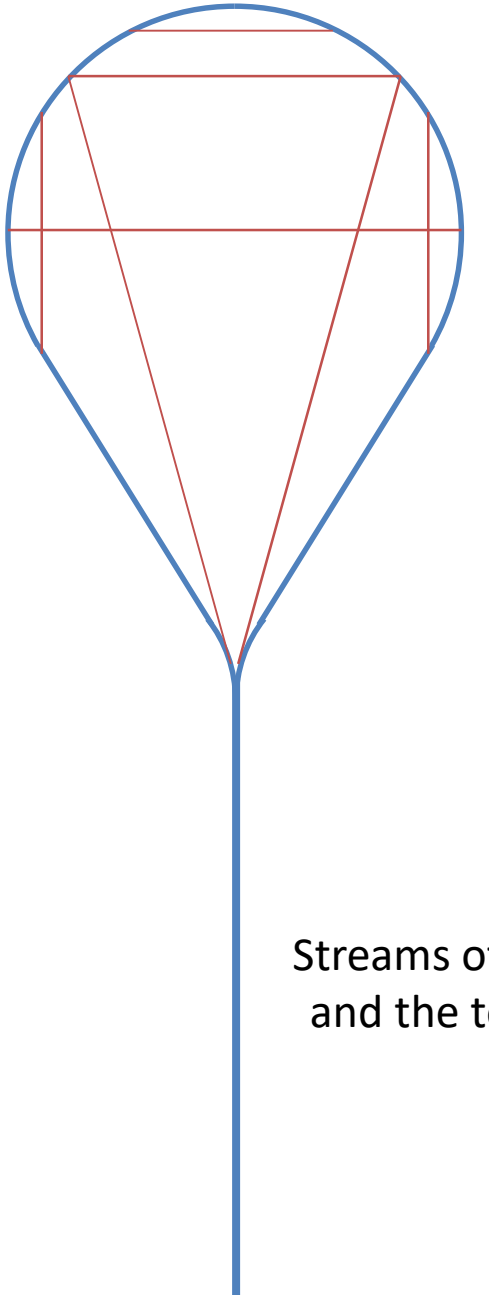
- Tube climbers in the atmosphere (up to 100 km)
  - Winch up to first stage
  - Climbing up the tubes
  - Narrow tether or rope
  - OR meter-wide tether
- Tube climber design
  - Carrying payload capsule to transfer to tether climber
  - Carrying tether climber in a protective box
  - OR same as tether climber





A group of bolt streams

A group of bolt streams



Streams of bolts
and the tether

First Stage Automation

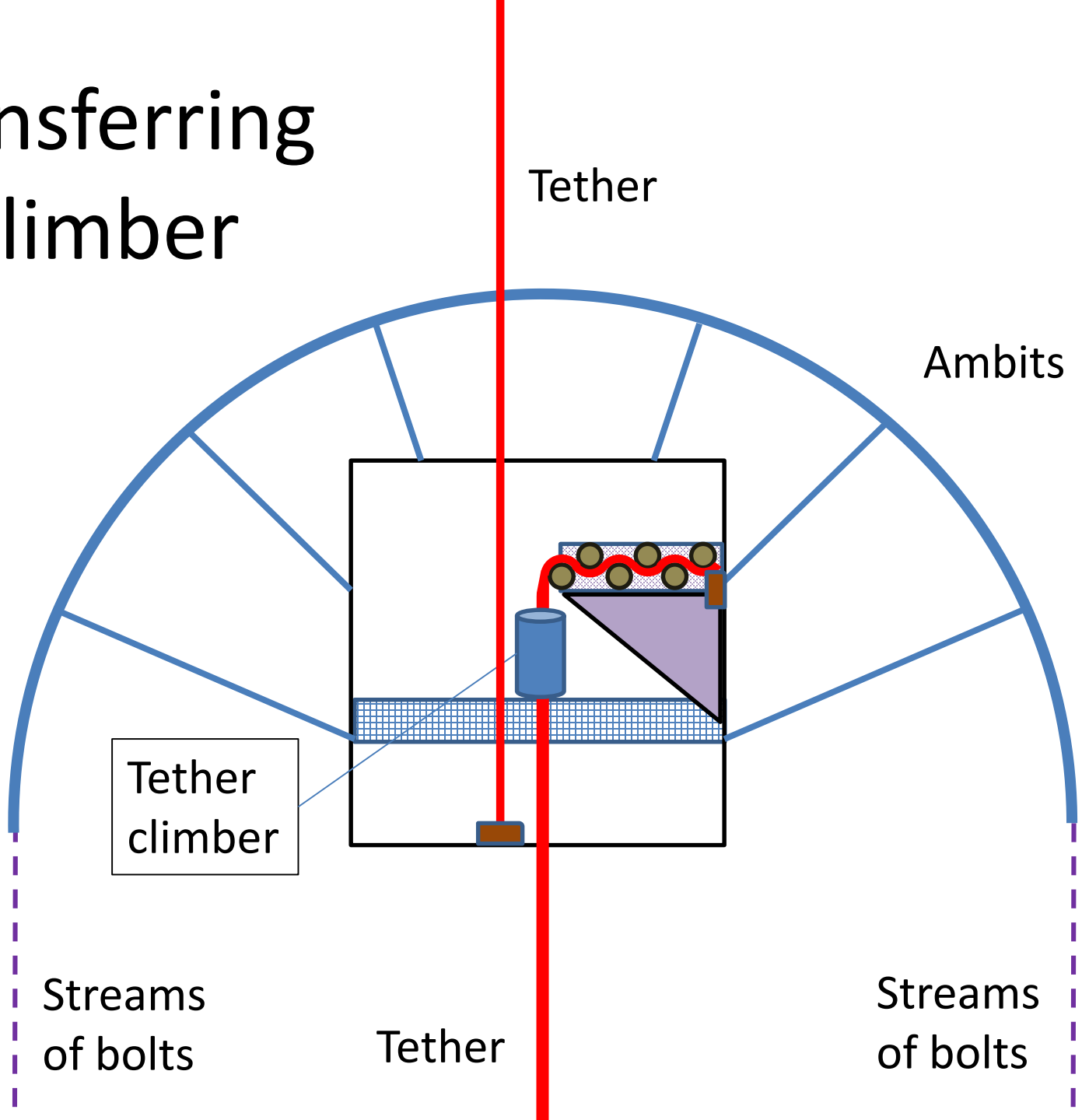
- Automate transfer of climbers to tether
  - First stage should not be manned continuously
  - Humans should only inspect and maintain
- At the first stage, tether climbers…
  - …grip the tether
  - …open their solar panels or laser receivers
  - …commence their ascent under their own power

Upper Stages

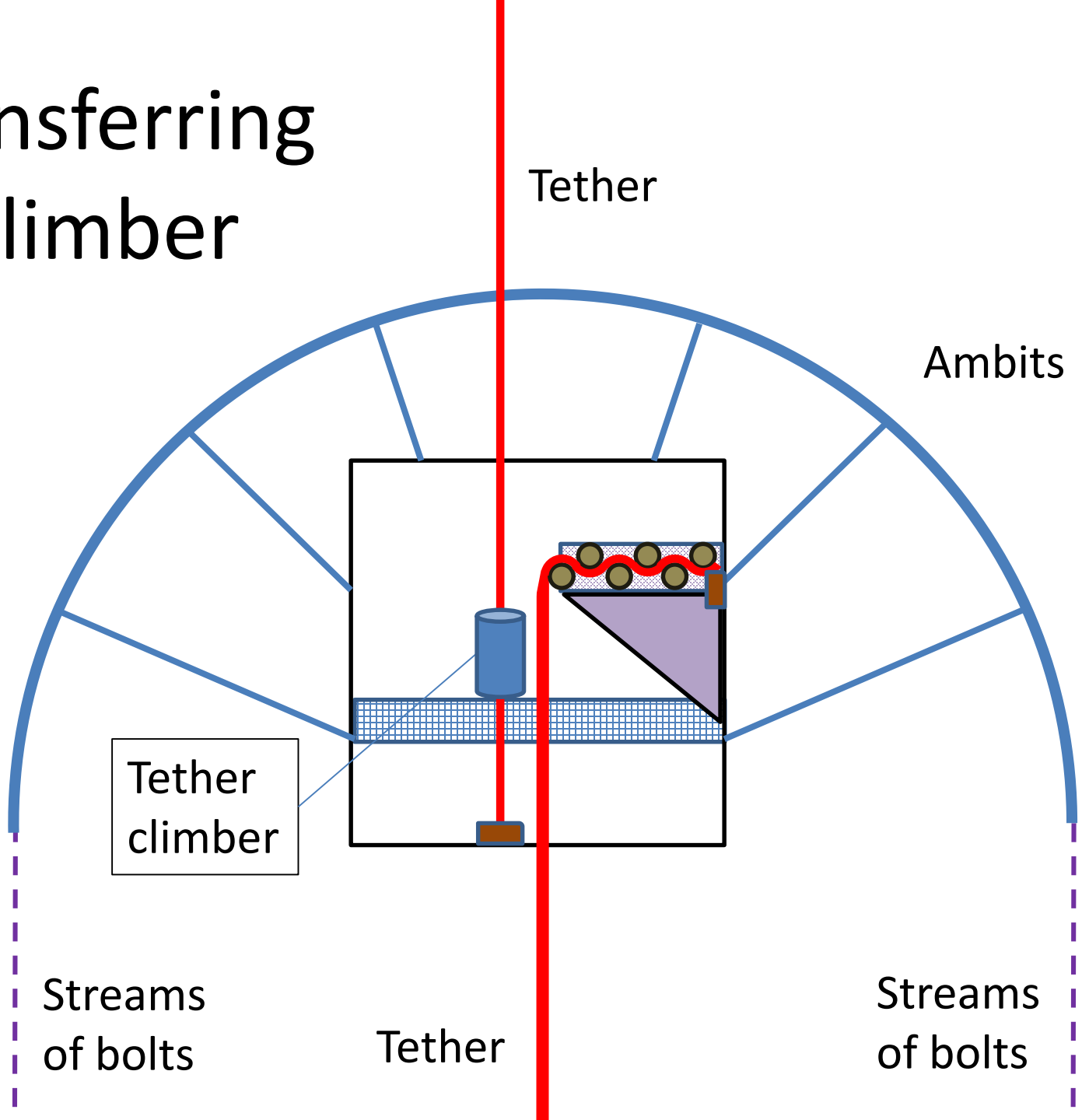
Passing through Upper Stages

- Second and higher stages support the tether
- Jump-over mechanism
  - Either transfer climber from one section of tether to the next
    - Climber must renew its grip on the tether
  - Or have the second or higher stage support the tether in two places
    - Remove supports in turn to allow the climber to pass
  - Process is fully automated

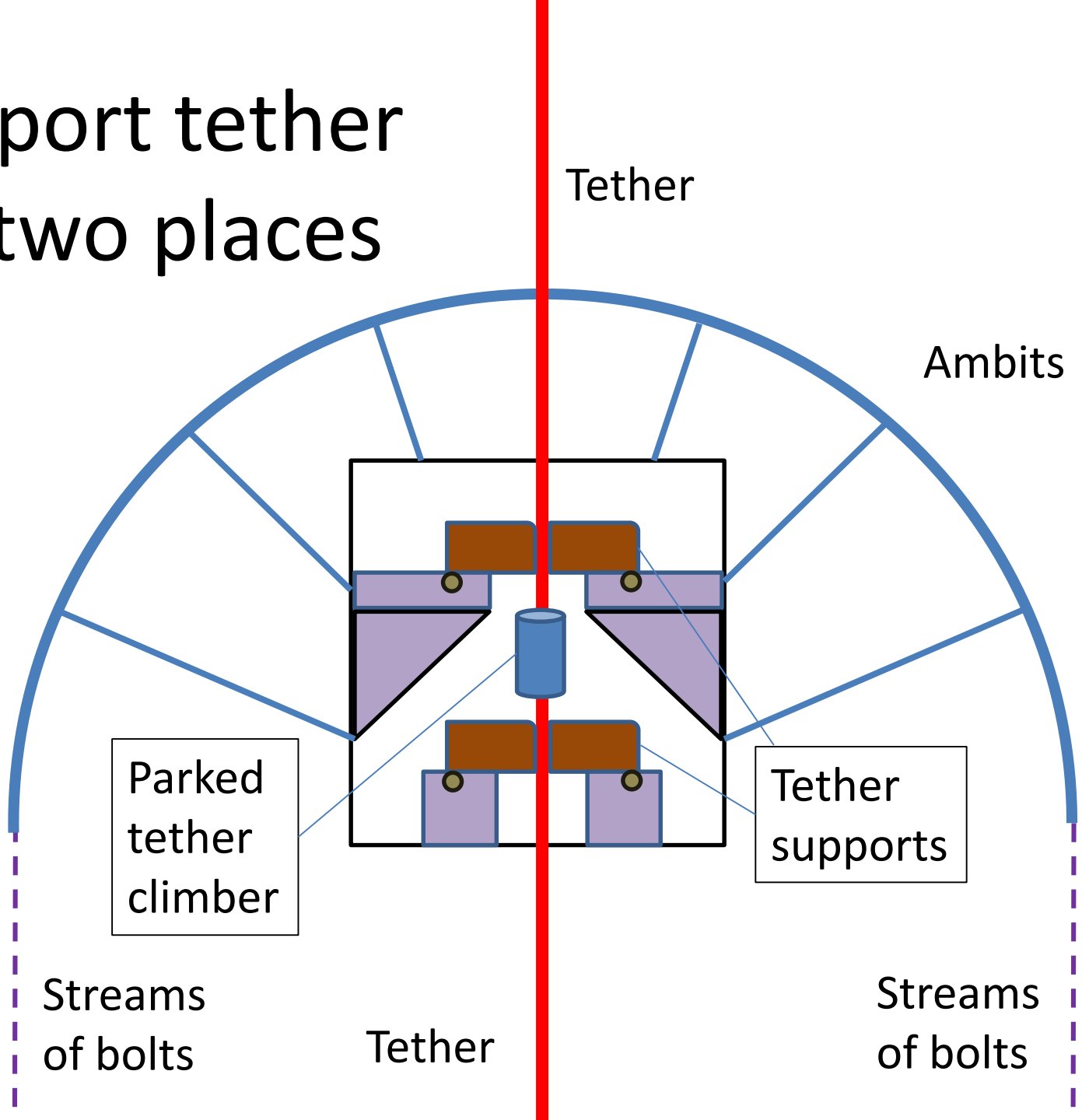
Transferring Climber



Transferring Climber



Support tether in two places



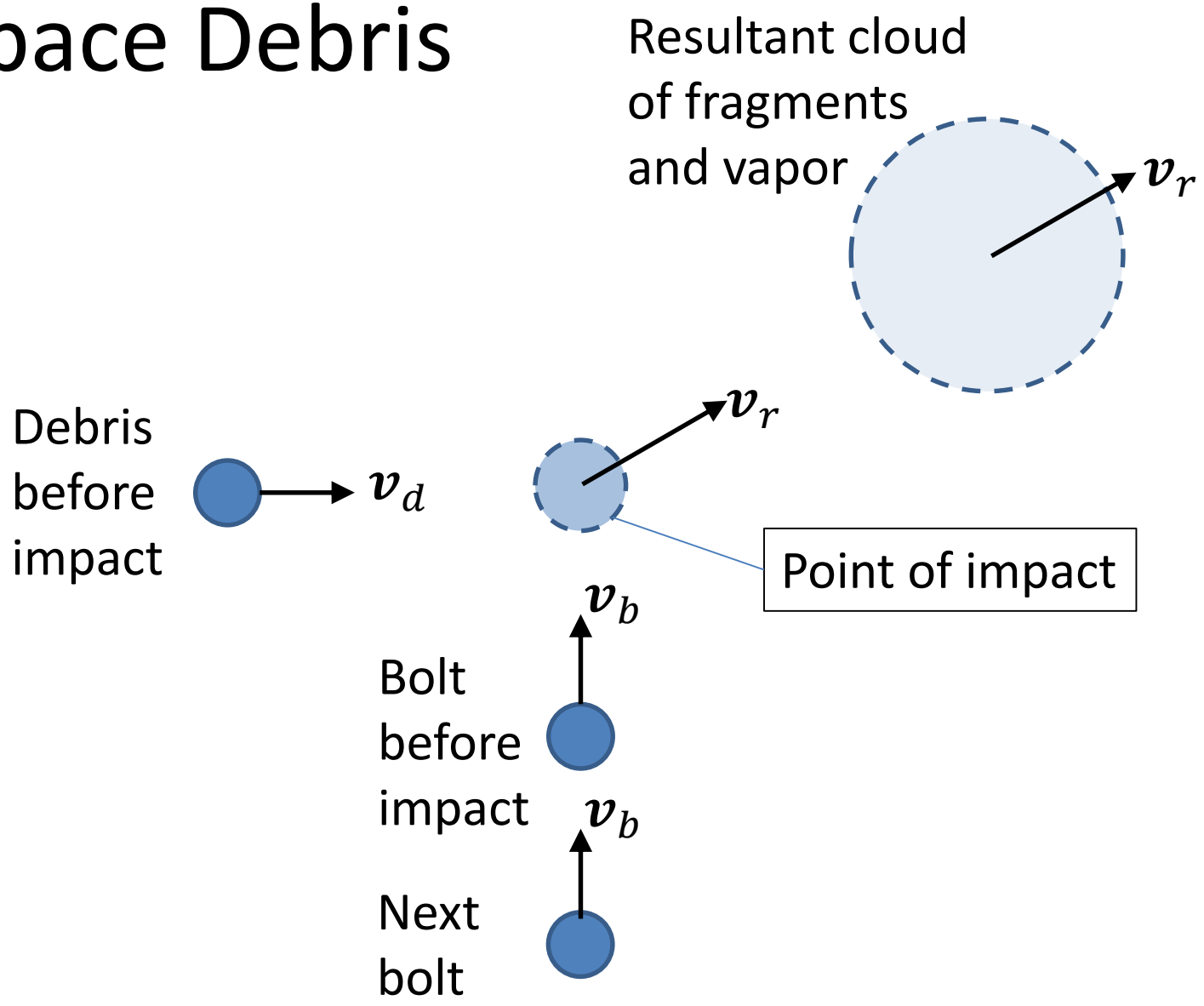
Resilience

- Power failure
  - Use the stored energy until power is restored
  - Ensure standby power always available
- Multiple tubes provide backup if one tube needs repairs
- Space debris
  - Structures in space need shielding
  - Bolts travel in vacuum of space without tubes

Space Debris

- Nylon is good for bolt construction
  - It vaporizes on collision
- Large incoming object smashes through
  - Carries vapor, dust and ejecta with it
- Small incoming object forms a crater on a bolt
- Bolt-size incoming object
  - Both objects vaporize or shatter
  - Resultant debris travels at 8 km/s
- Risk of cascade effect in unlucky cases
  - More work needed

Space Debris



Stability

- In the atmosphere, measure the wind force near each control point along the tube
  - Algorithm called “active curvature control”
  - The tubes bend so that the centrifugal force as the bolts pass the bend equals the wind force
- In space, measure the gap between ascending and descending bolts
  - Controls in the bolts ensure that they arrive at the ambits in the right positions

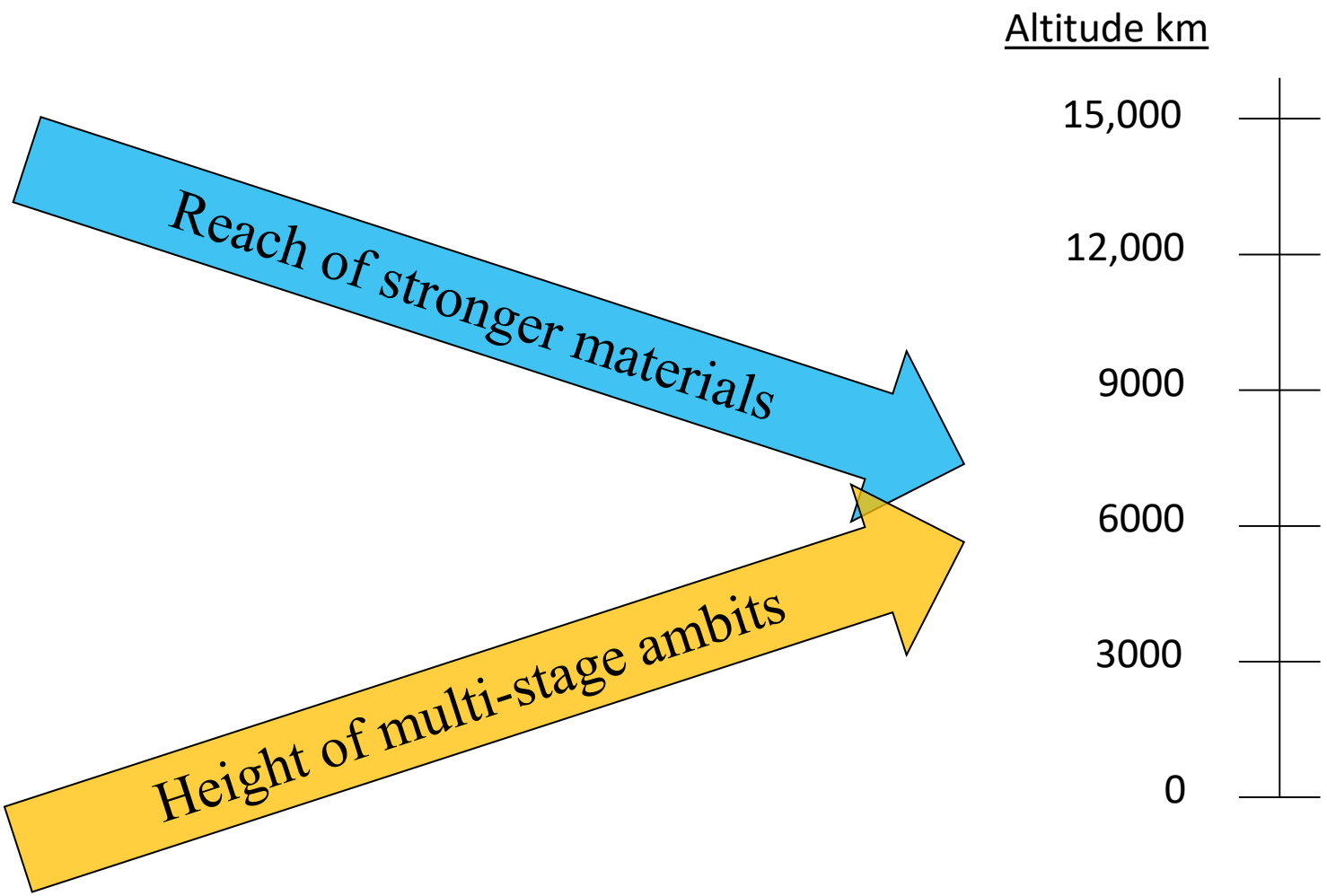
Topics

- Principles
- First Stage
- Upper Stages
- Resilience
- Prototype Work 
- Mini Workshop Questions

Prototypes

1. Circular loop 80 cm diameter
   - In vacuum chamber
   - Bolt speed 18-25 m/s
2. Circular loop 50 meters diameter
   - Evacuated tubes
   - Bolt speed 300 m/s
3. Raise the upper part of the loop
   - It becomes the upper ambit
   - Insert additional tubes

Technology Convergence



Mini Workshop Questions

- What prototype phases should we plan?
  - How big does a prototype need to be to be convincing?
- What should the funding balance be between strong materials and multi-stage technology?
  - Suppose we had $1 million, $10 million or $100 million.
- What are good methods of descent?
  - Falling, gliding, retro rockets?
  - Coming down the tether?
    - What about jumping or crossing over ascending climbers?
- Propose good operating procedures
  - Use automation and remote control as much as possible