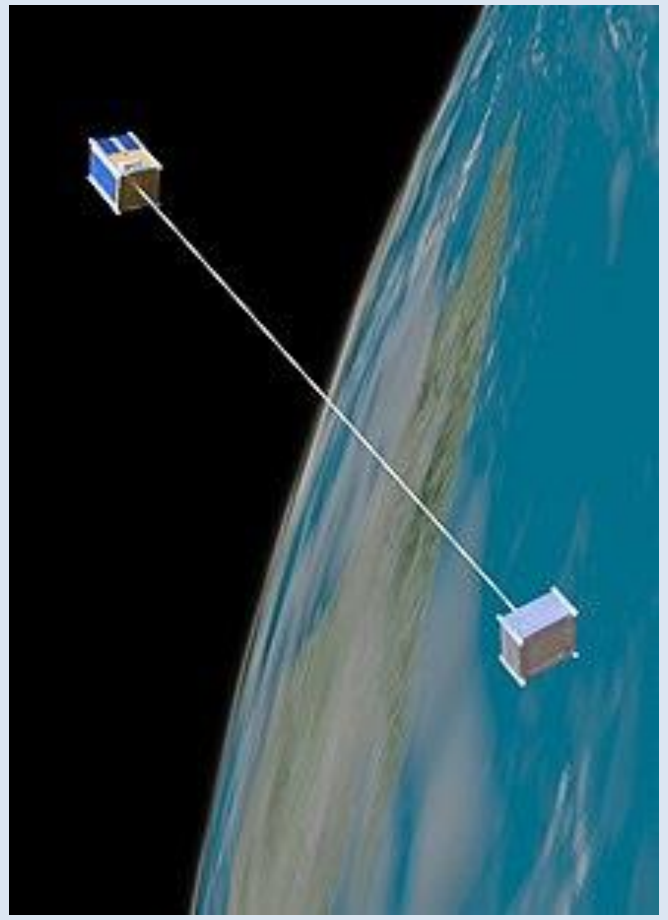

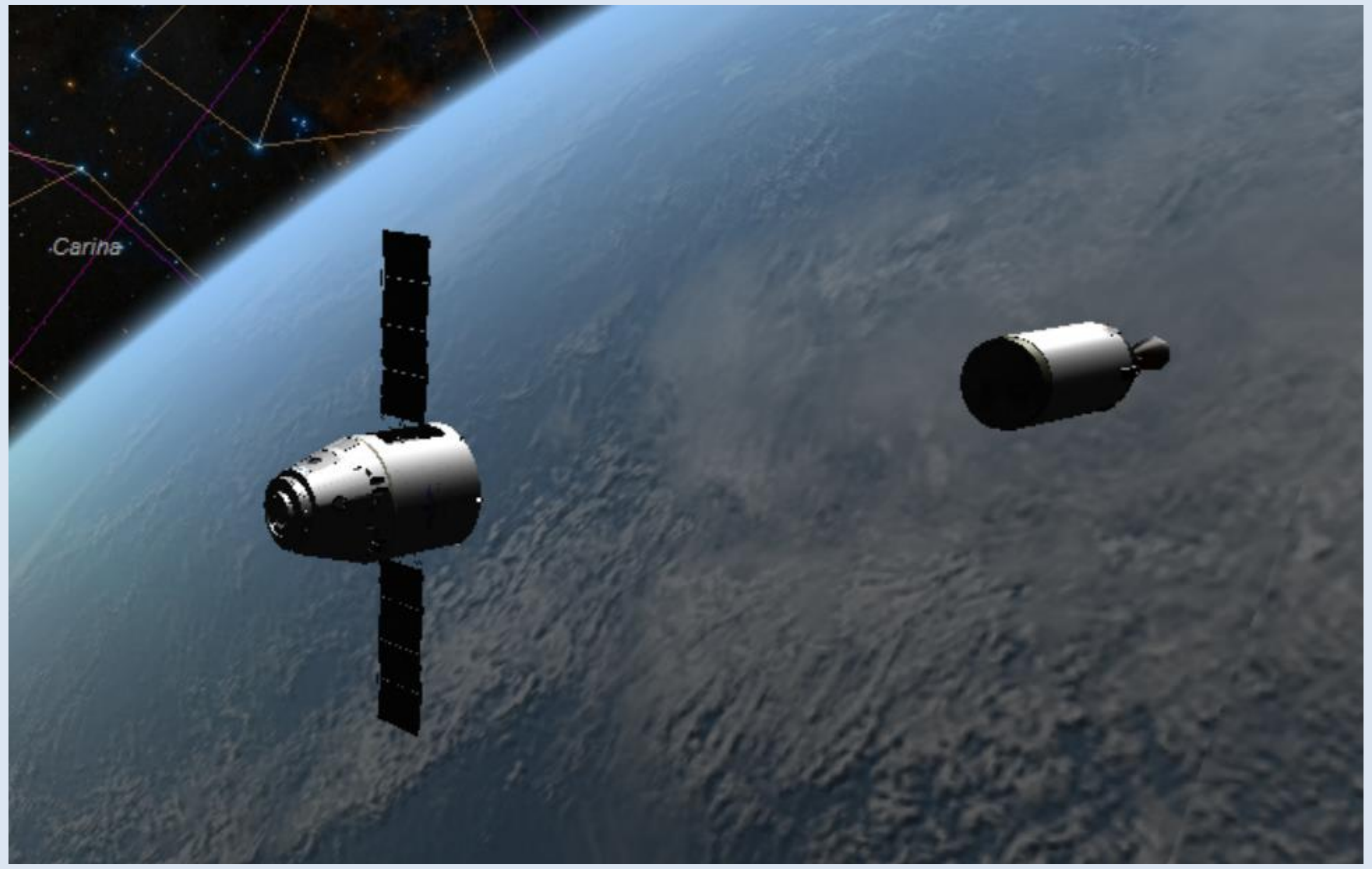


# Tethers and possible applications for artificial gravity production in space

Claude Nicollier

ESA and Swiss Space Center/EPFL

Credits: NASA

# Outline

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- Tethers in LEO
- Shuttle-based tether missions
- Do we need artificial gravity during long journeys of manned spacecraft in the solar system?
- Basic tether-based artificial gravity concept for interplanetary transits
- Alternative technique
- Conclusions

# Tether in space concept

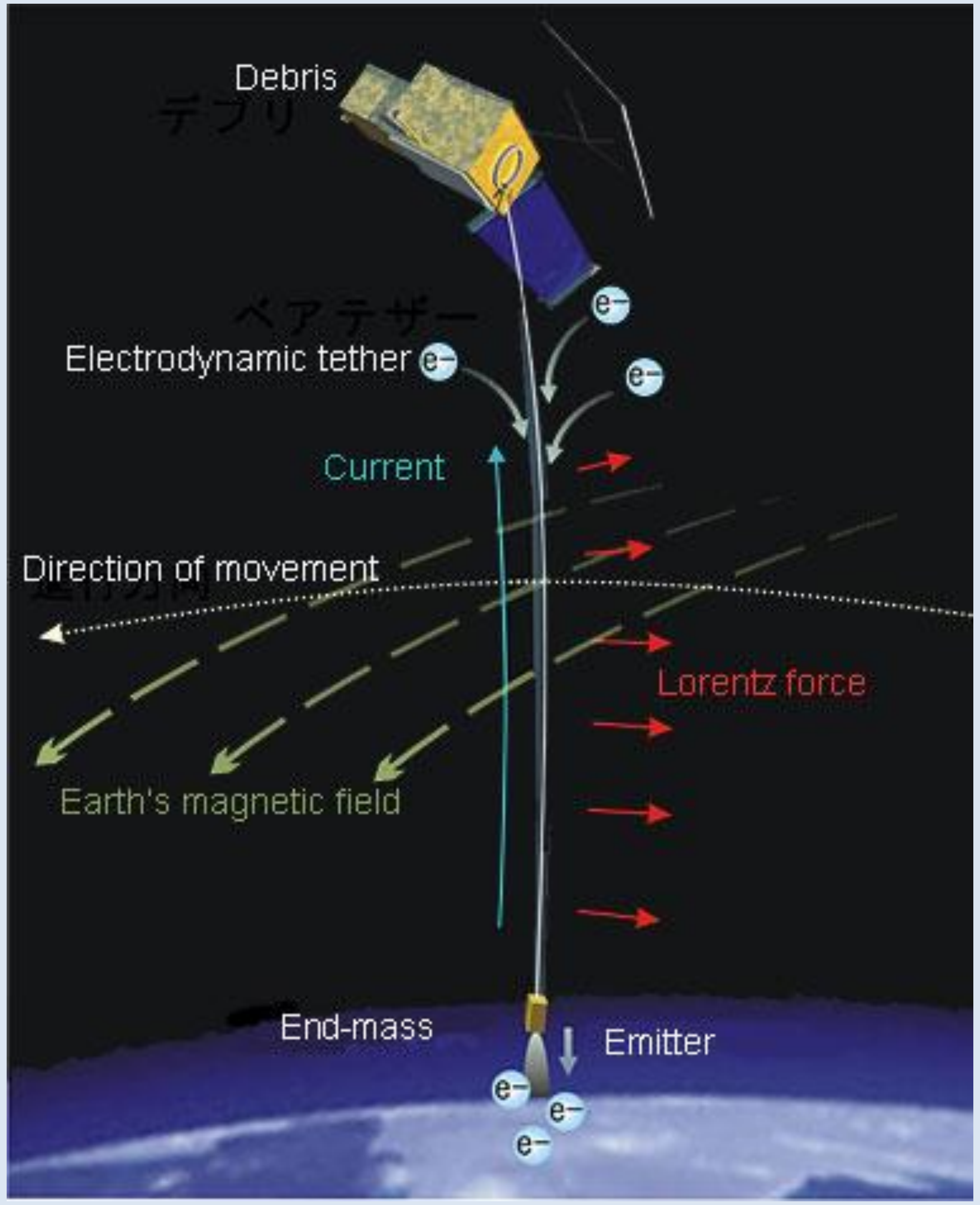
A space tether is a long cable which is used to couple spacecraft to each other or to other objects in space, like an asteroid or a spent rocket upper stage.

Tethers are usually made of a strong material like high-strength fibers or Kevlar, with or without an electrically conducting material in the core.

Space tethers have several useful applications listed here.

## Applications

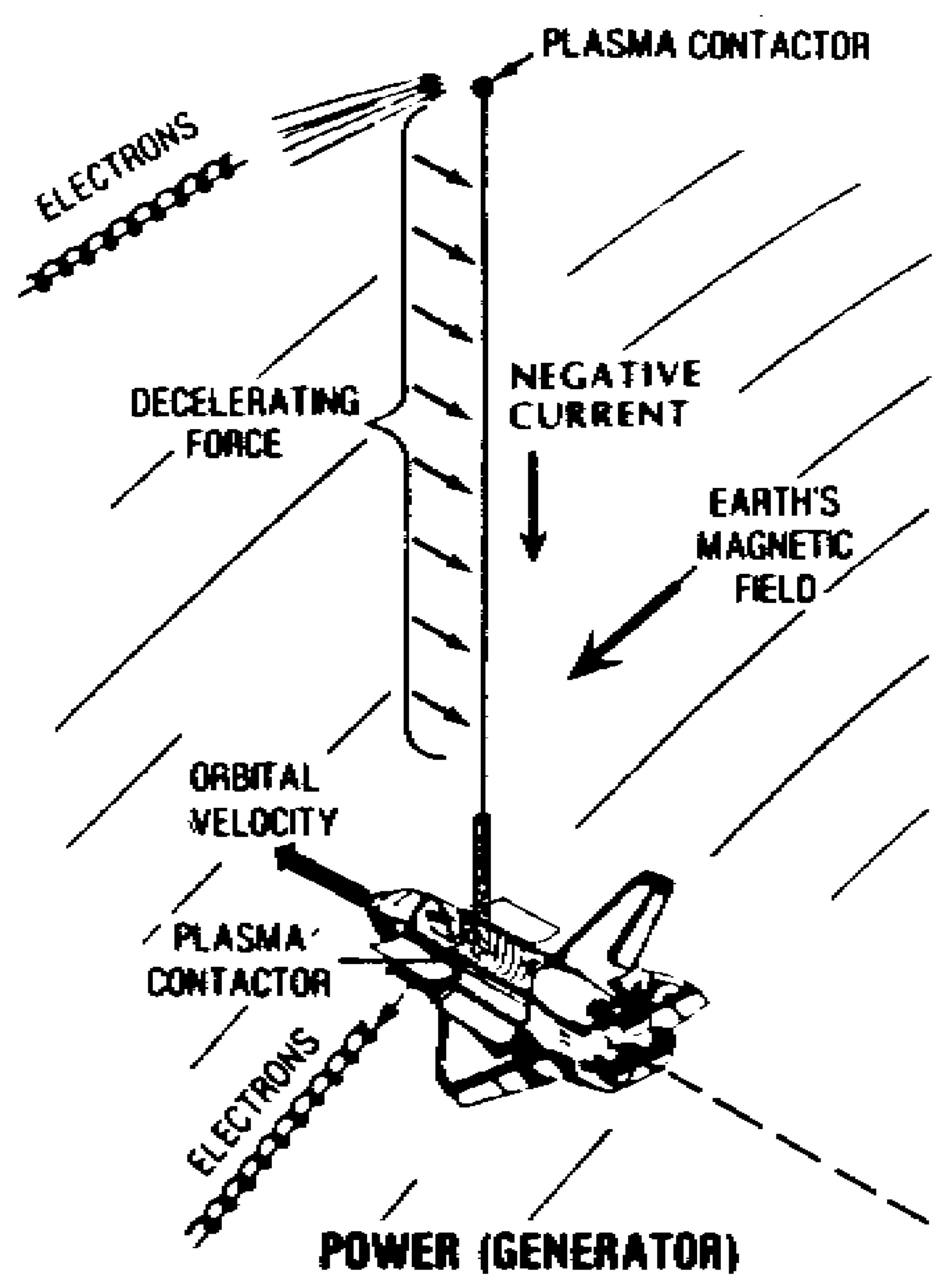
- Electrical power generation
- Orbit transfers
- Ionospheric studies
- Variable gravity research
- Space debris removal
- Provision of artificial gravity for long journeys in the Solar System
- Earth-Moon payload transfer
- Space Elevator




Tether in LEO

Credits: JAXA

# Tether as an electrical generator



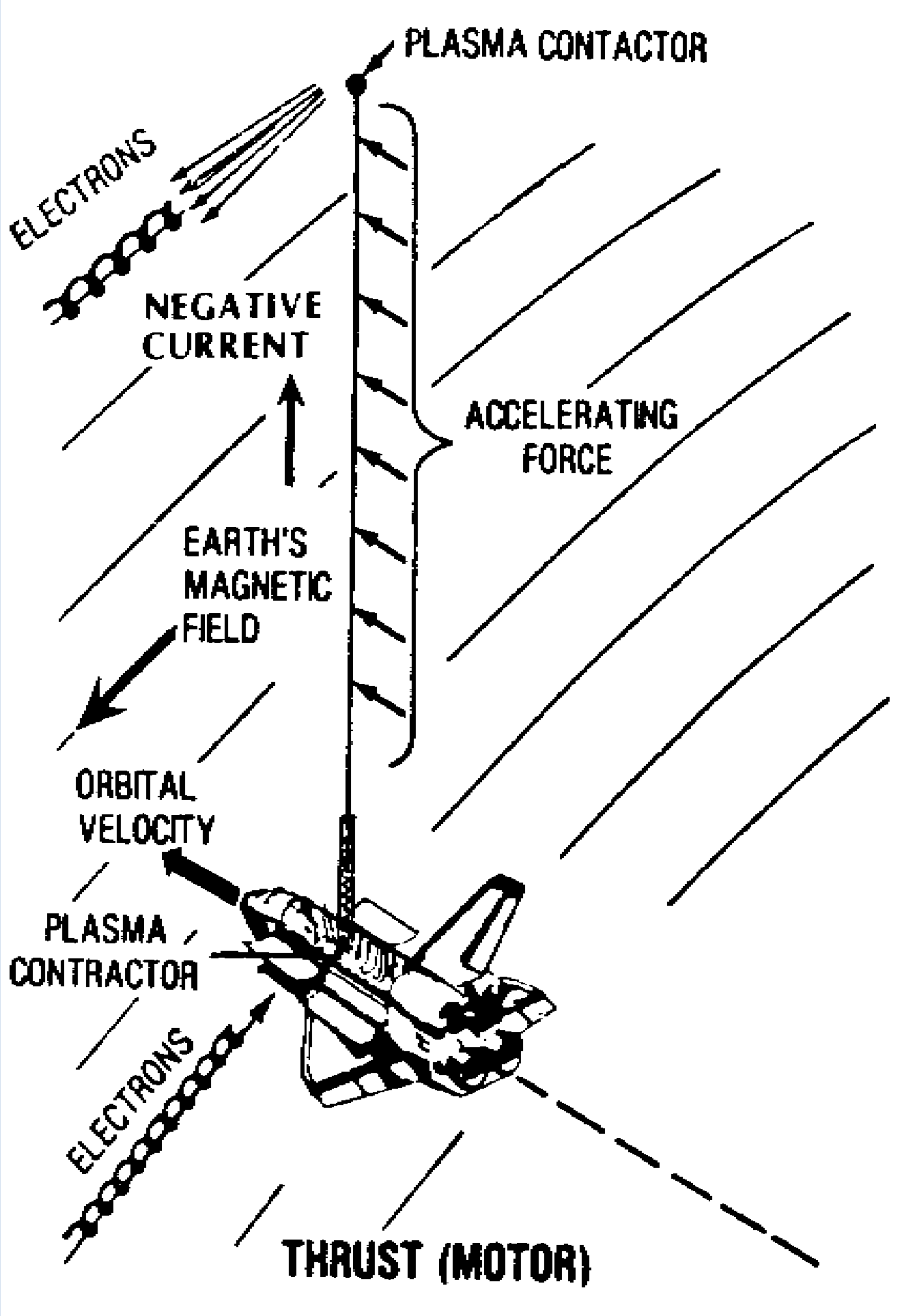

- Induced voltage caused by the motion of the tether in the Earth's magnetic field (Faraday's law of induction):

$$U_i = (\vec{V} \times \vec{B}) \cdot \vec{L}$$

- $\vec{L}$: Tether length (m) – a vector pointing in the direction of positive current flow.

Credits: NASA, MSFC

# Tether as an electrical motor




- Lorentz force resulting from the current flow in the tether (posigrade force or retrograde).

$$\vec{F} = \int (Id\vec{L}) \times \vec{B} = I \int d\vec{L} \times \vec{B}$$

- The integration is along the length of the tether.

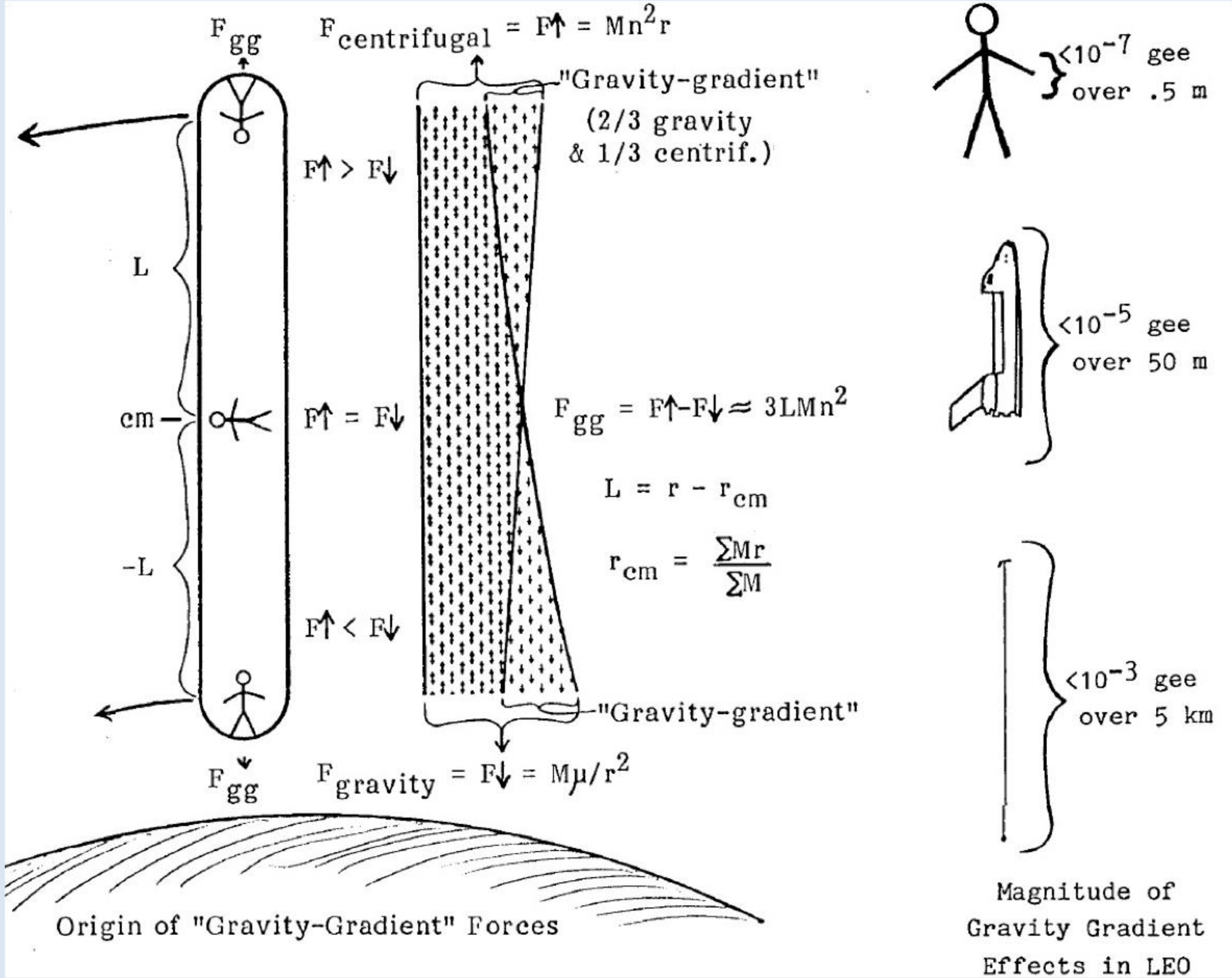
Credits: NASA, MSFC

# Gravity gradient effects

Forces inside a large orbiting cylinder oriented along the local vertical, without oscillations

M = element of mass in the cylinder

n = mean motion in Rad/sec




Credits: NASA, MSFC

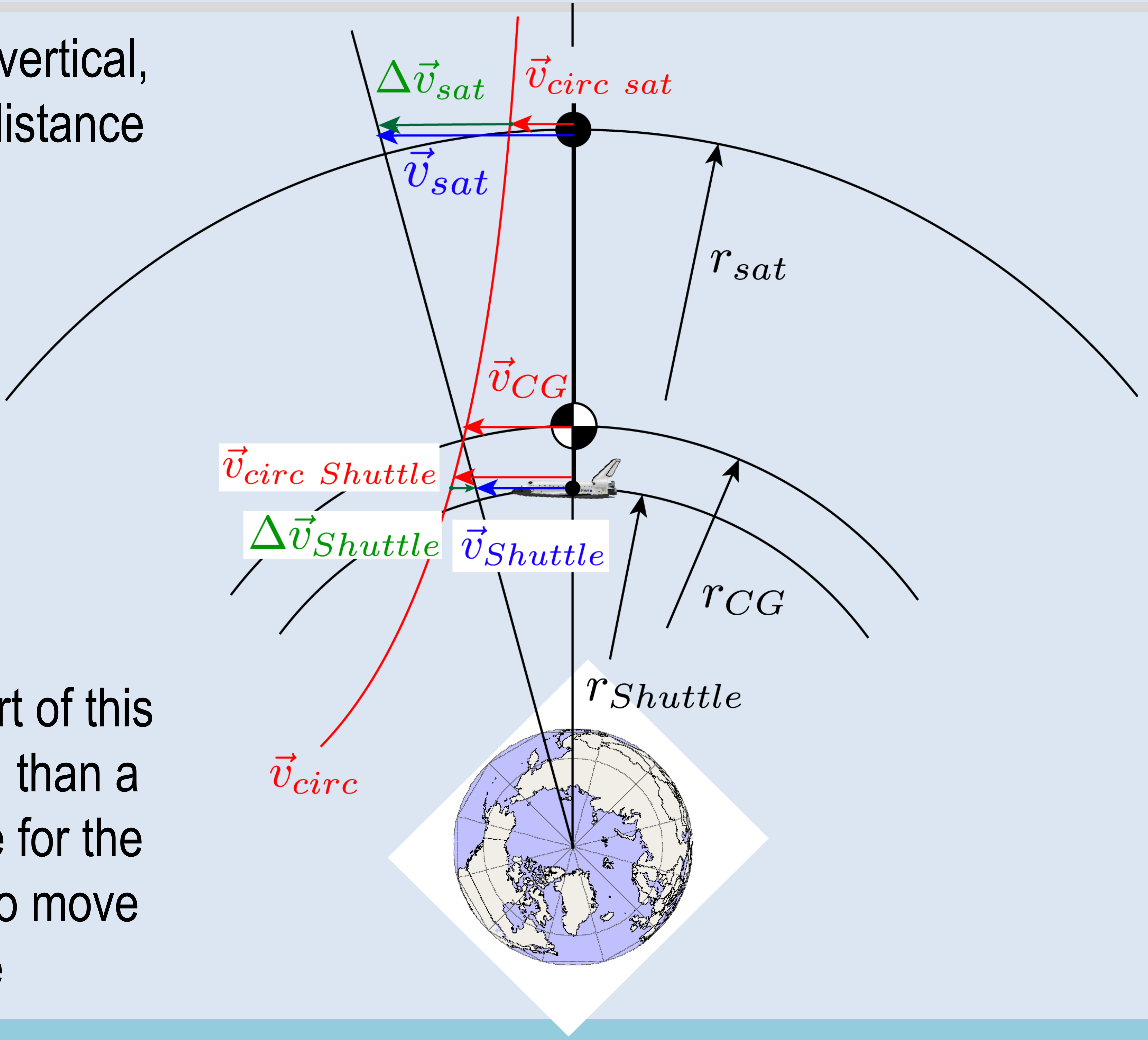
# Space tether–velocity profile

As the space tether remains oriented along the local vertical, all velocities along the tether are proportional to the distance to the center of the Earth

As the circular velocity along the distance covered by the tether is

$$V_{circ} = \sqrt{\frac{\mu}{r}}$$

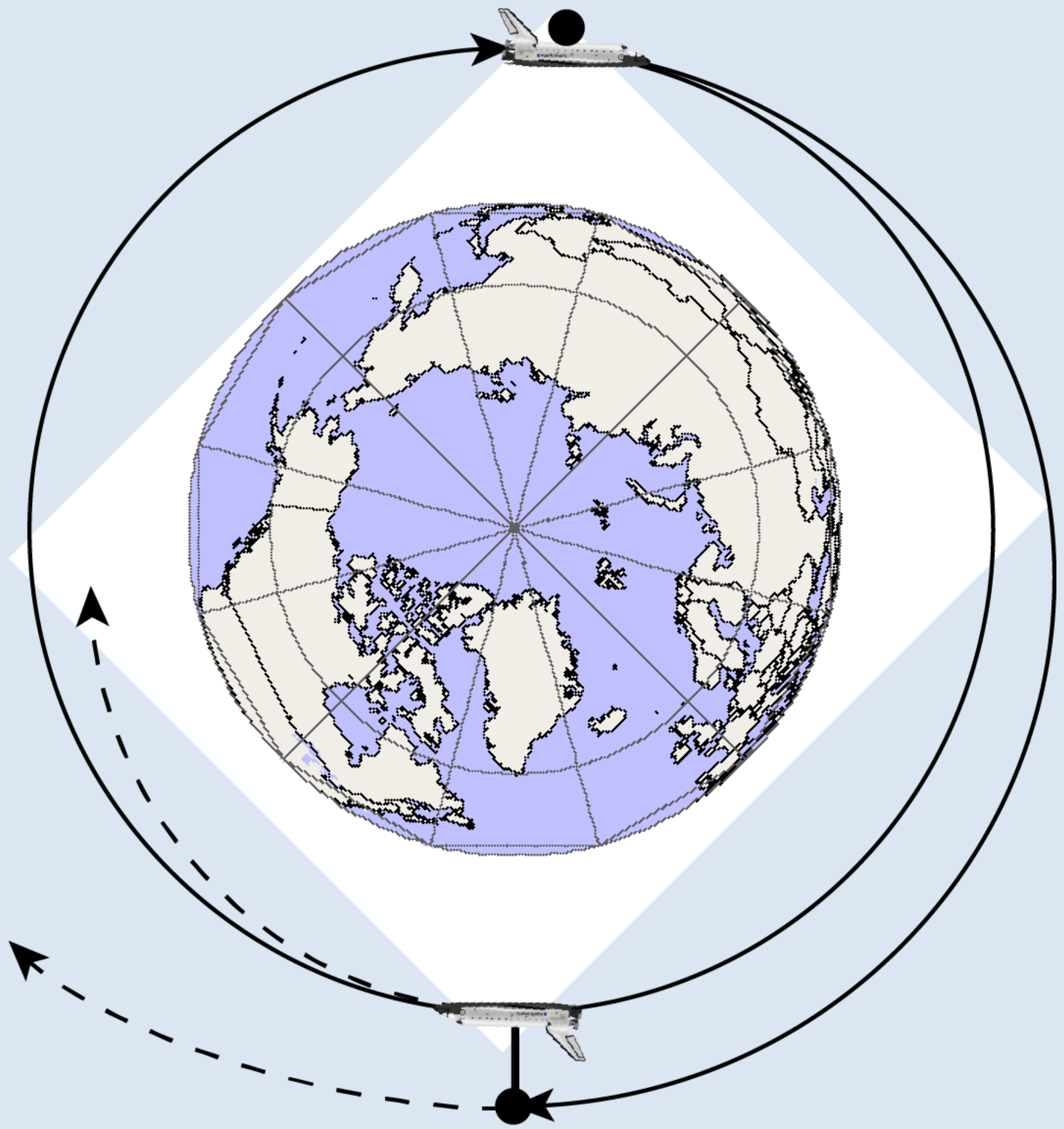
We see that in the upper portion of the tether, any part of this tether is forced to move faster, in the orbital direction, than a free satellite at the same altitude.  The reverse is true for the low portions of the tether, where the tether is forced to move slower than would a free satellite at the same altitude



# Tether boost/deboost scenario

Here we represent a tethered satellite deployed from the Space Shuttle upwards in the LVLH frame. After full deployment of the satellite (for instance at 20 km like for TSS-1R), a tether cut or break will cause the satellite to be injected into a significantly higher orbit, and the Shuttle to a slightly lower orbit.

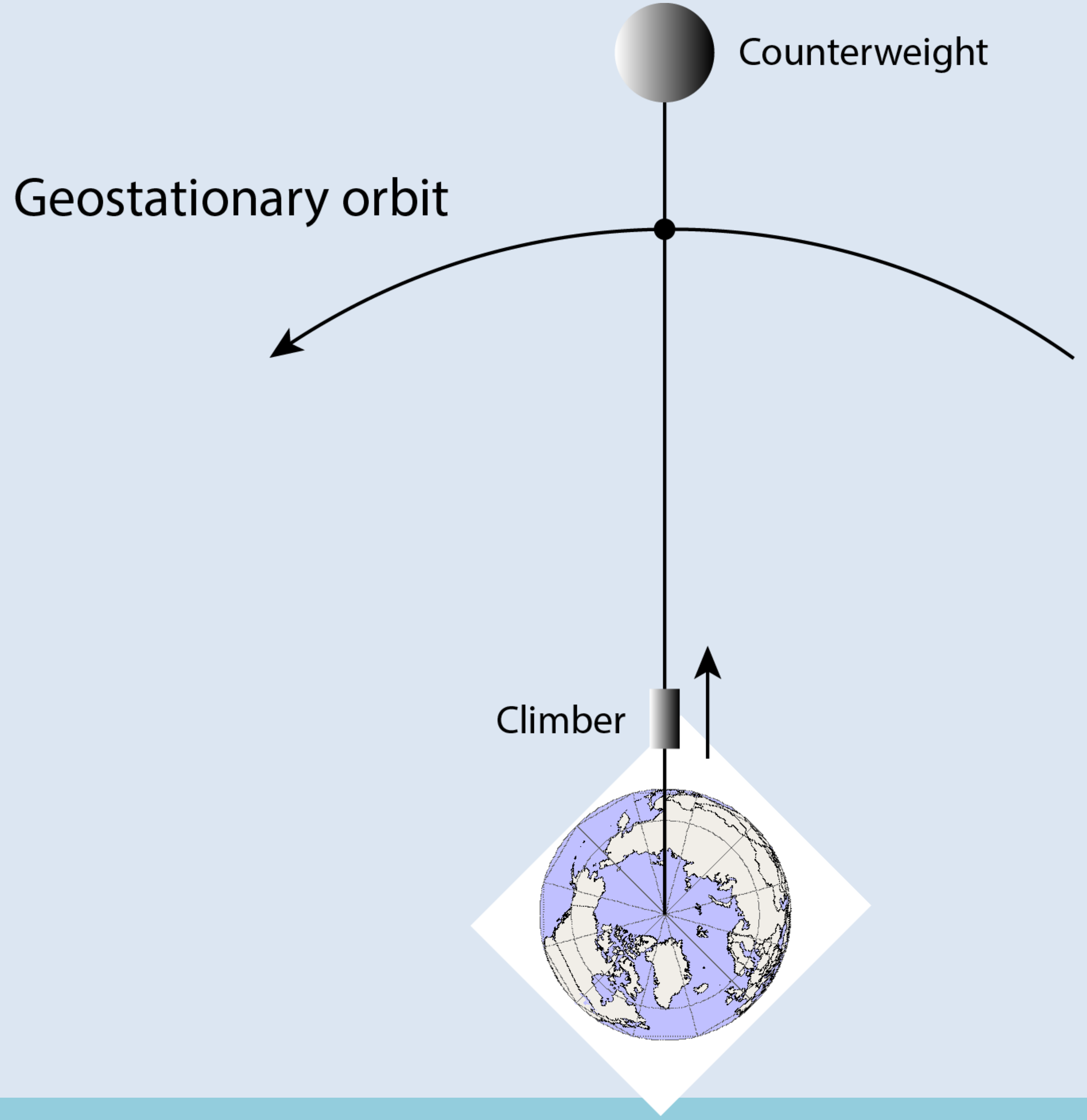
There is exchange of angular momentum, with useful consequence for both the upper and the lower body in this case.



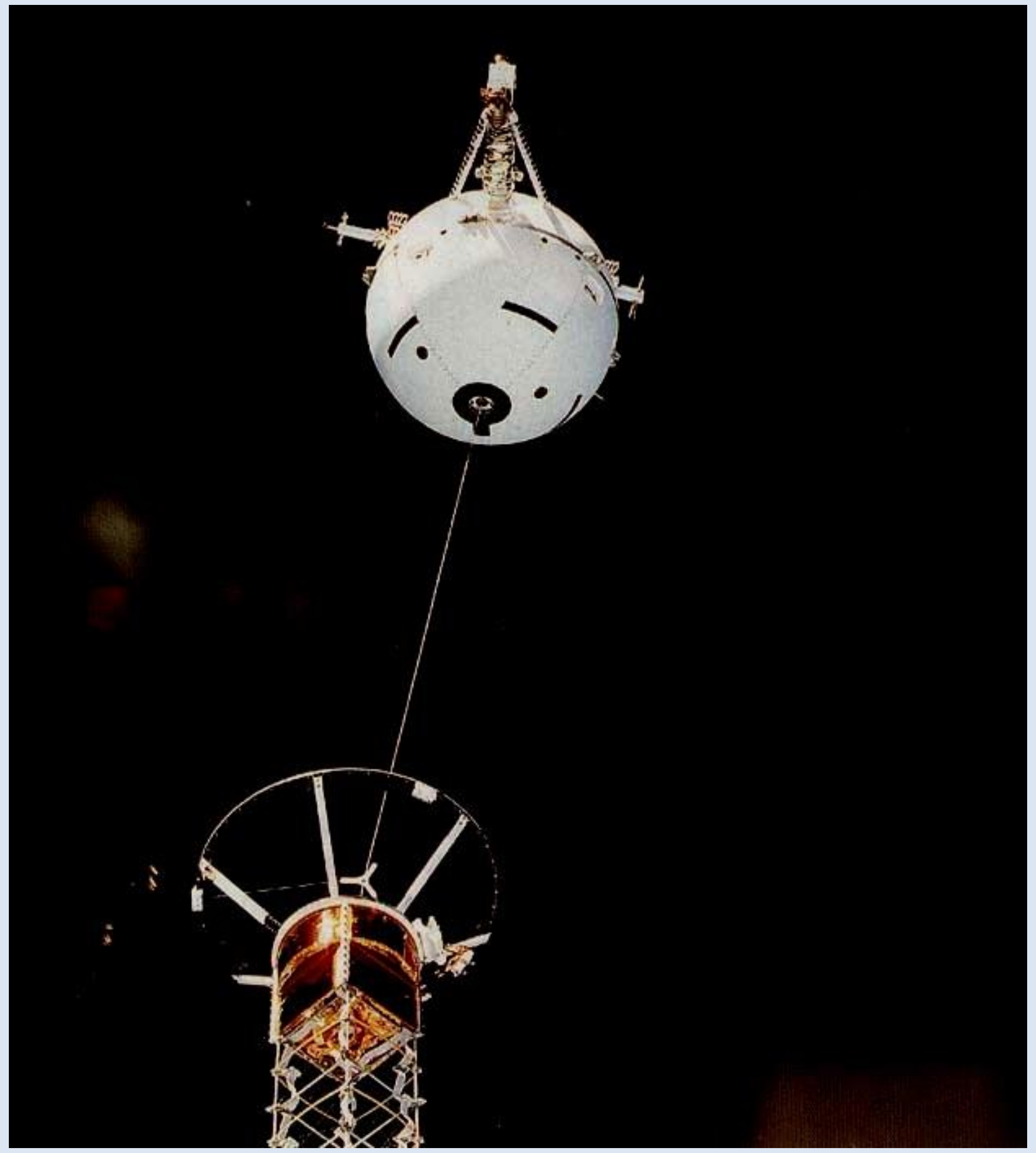
# Space elevator concept

Originally proposed by Tsiolkovsky, a space elevator consists in a cable anchored at a location on the equator, and longer than the geostationary distance, with a counterweight at the end, and a climber able to move upwards and downwards along this cable

It would allow access to nearby space without using a rocket!



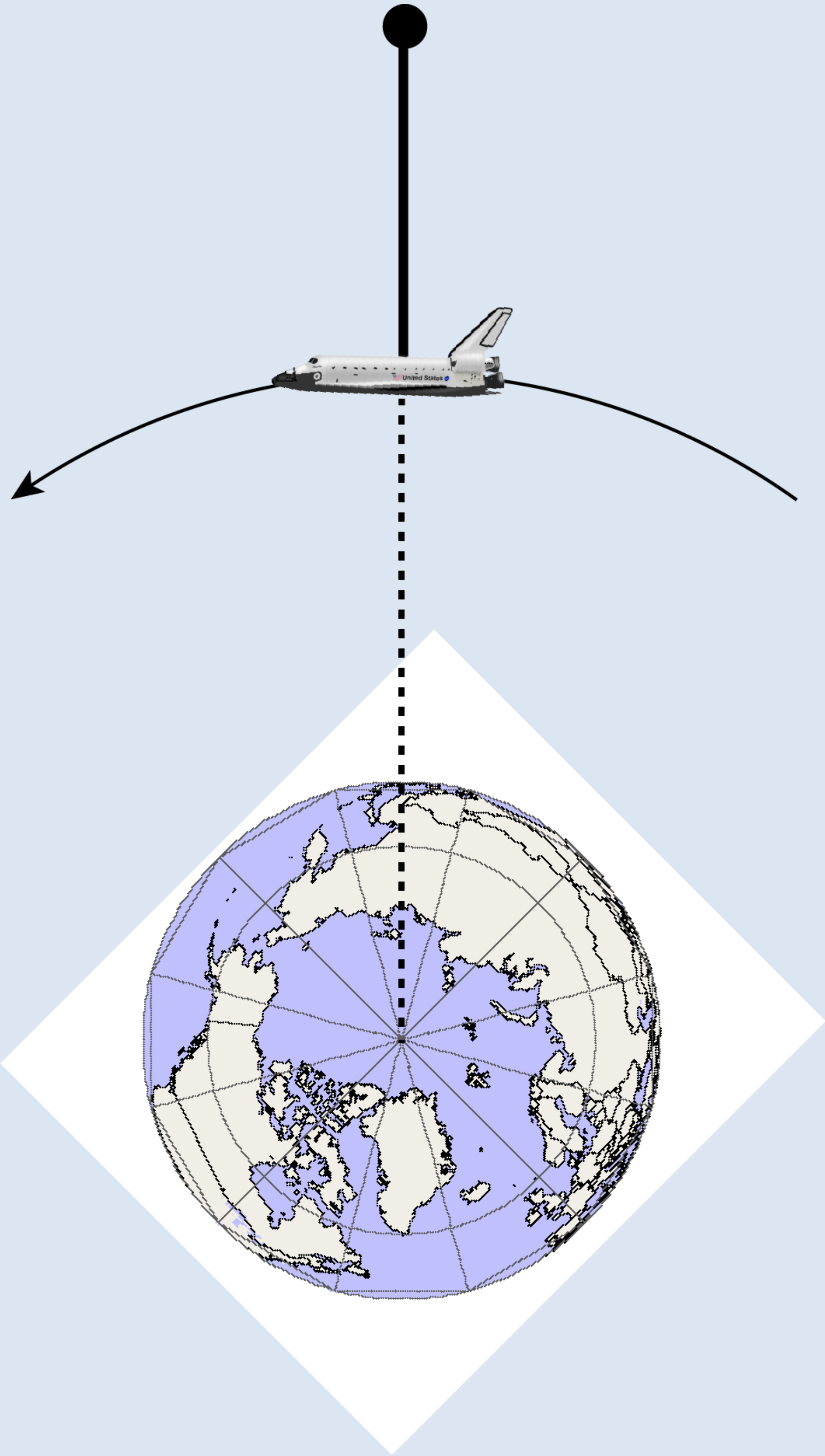
# Shuttle-based tether missions

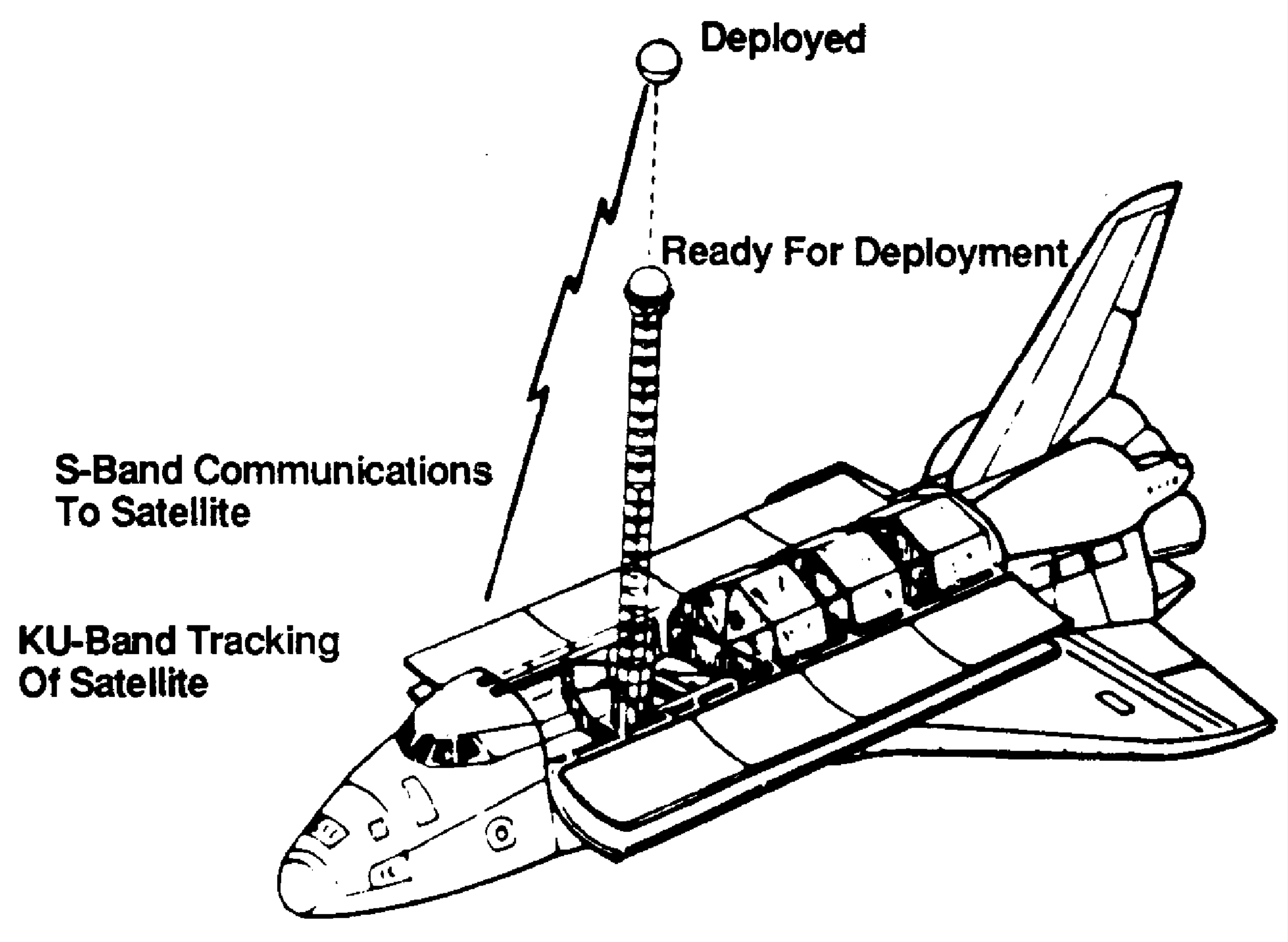


Credits: NASA

# Plans for a Tethered Satellite System (TSS) mission

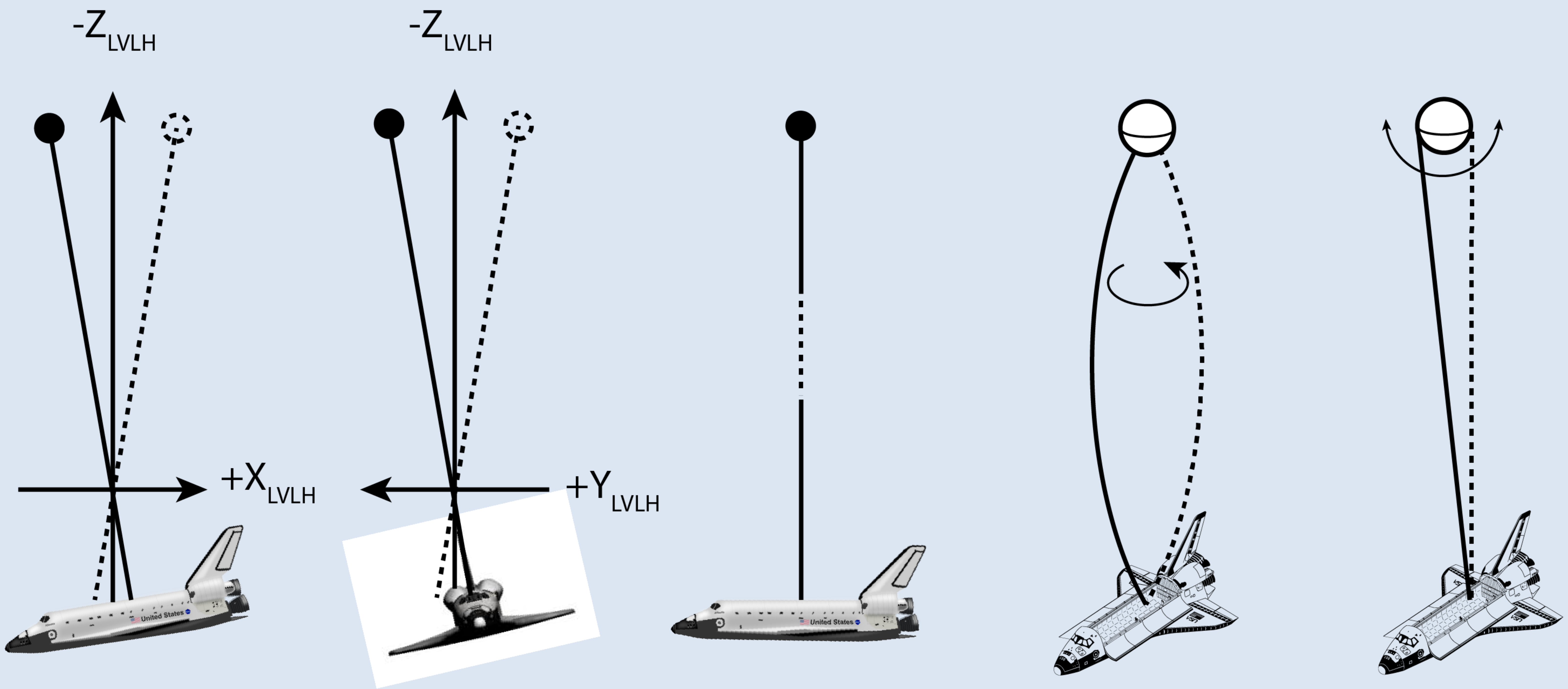
- Italian Space Agency and NASA joint project, initiated already around 1970.
- Later plans for a 20 km long Shuttle-based conductive tether.
- Mission objectives in tether dynamics and electrodynamics, and ionospheric physics.






Credits: NASA, MSFC

# The operational challenge of tether and satellite oscillations




IN-PLANE LIBRATION

OUT-OF-PLANE LIBRATION

LONGITUDINAL OSCILLATIONS

SKIPROPE OSCILLATIONS

SATELLITE PITCH & ROLL OSCILLATIONS

# EURECA & TSS-1, STS-46 – July 31- August 8, 1992

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Credits: NASA

# STS-46 – Satellite at 200 meters distance, deployer failure

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Credits: NASA

# TSS-1R, STS-75, February 22 - March 9, 1996 – Trying again!

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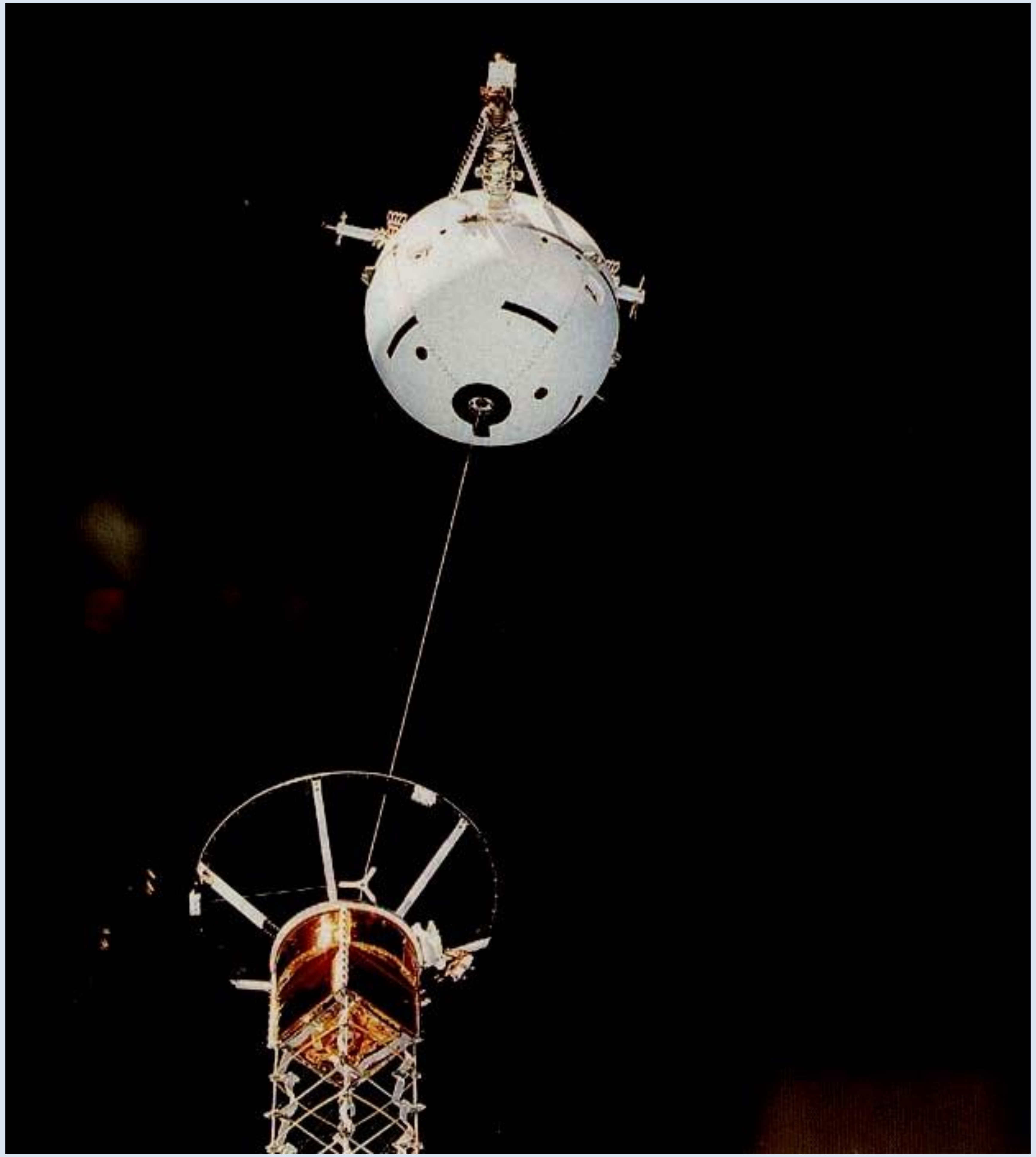


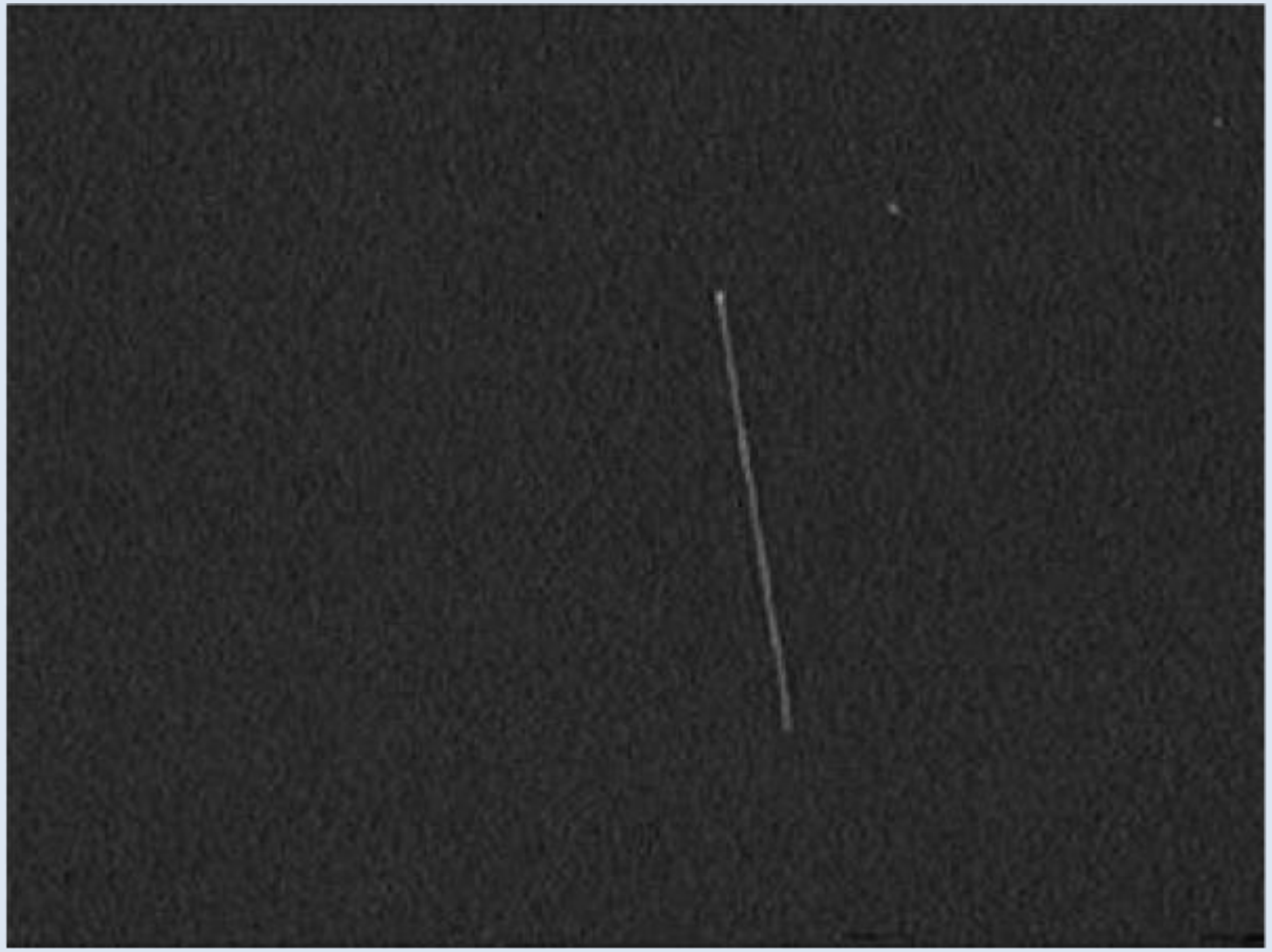
Credits: NASA

# STS-75 – Observing the tether from a crowded flight deck


Credits: NASA

# STS-75 – Four days after the tether broke

Visual observation and photography of the satellite and attached tether directed exactly along the local vertical – Gravity gradient forces at work!



Credits: NASA

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Credits: NASA

# Do we need artificial gravity during long journeys of manned spacecraft in the solar system?

# An old idea…


Credits: Tintin «On a marché sur la Lune»

# Artificial gravity needed?

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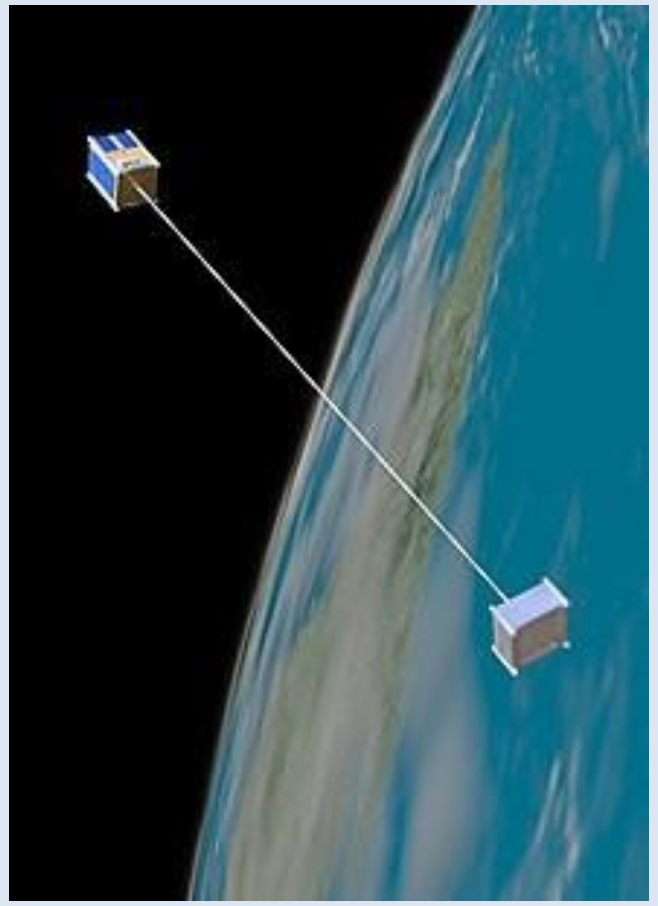
- Honestly, we do not really know , but it is likely that, for crew well being, and to maximize the likelihood of reasonably good physical condition of the crew upon arrival on the surface of the destination planet, some amount of artificial is desired during the transit period (typically several months).
- Artificial gravity level somewhere between 0+ and 1
- We know very little about living long time and working in these conditions, except some APOLLO program experience for Lunar surface g-level (0.165 g)
- My feeling is that, for a manned flight to Mars, the best would be to provide artificial gravity close to the level of the gravity on Mars (0.378 g)



Credits: NASA

# Basic tether-based artificial gravity concept for interplanetary transits

# Basic design

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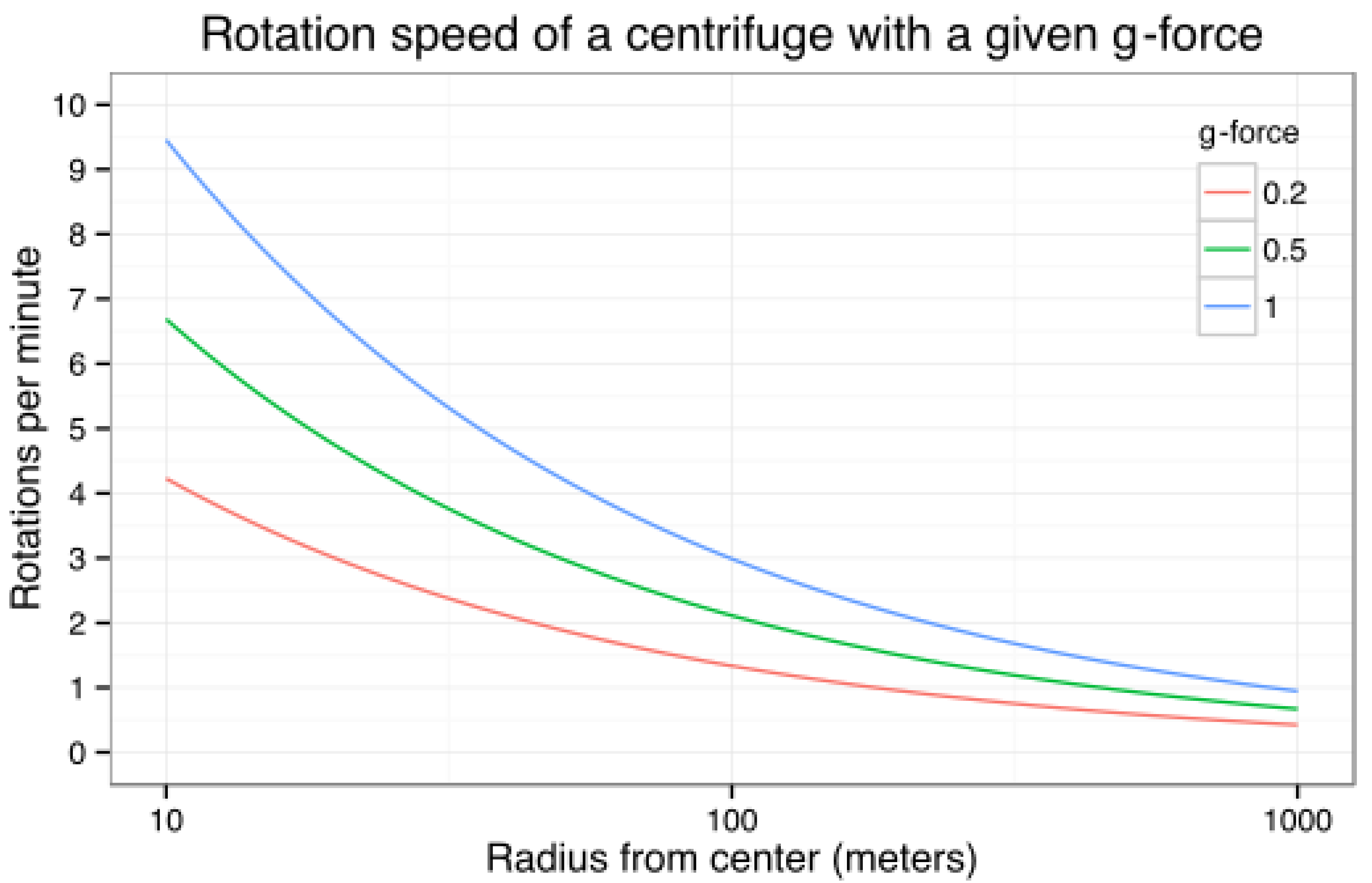
- A manned module or habitat linked to a counterweight by a tether in rotation with respect to an inertial reference frame.
- The counterweight would be separated from the manned compartment after the Trans-Mars-Injection maneuver.
- The rotation would be initiated by means of counterweight and/or manned compartment-based thrusters (example of TSS centrifugal retrieval)
- Tether tension should be maintained at all times during tether rotation initiation process, with possible help of in-line thrusters.

# Artificial g-force vs. radius from center and rotation rate




Credits: Wikipedia

# Issues with tether-based artificial gravity concept

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- The Coriolis force caused by crew motion (or just head motion) in an inertially rotating reference frame  can be disorienting for crewmembers and cause nausea. This is mainly for rotations rates beyond 2 RPM.  Restraining head movements helps!
- EVA strategies and techniques would have to be revised when performed in a rotating environment.
- Despite a very low likelihood with a relatively short and strong tether, tether break scenarios would have to be looked at carefully to insure crew safety.

# Test of artificial gravity in LEO

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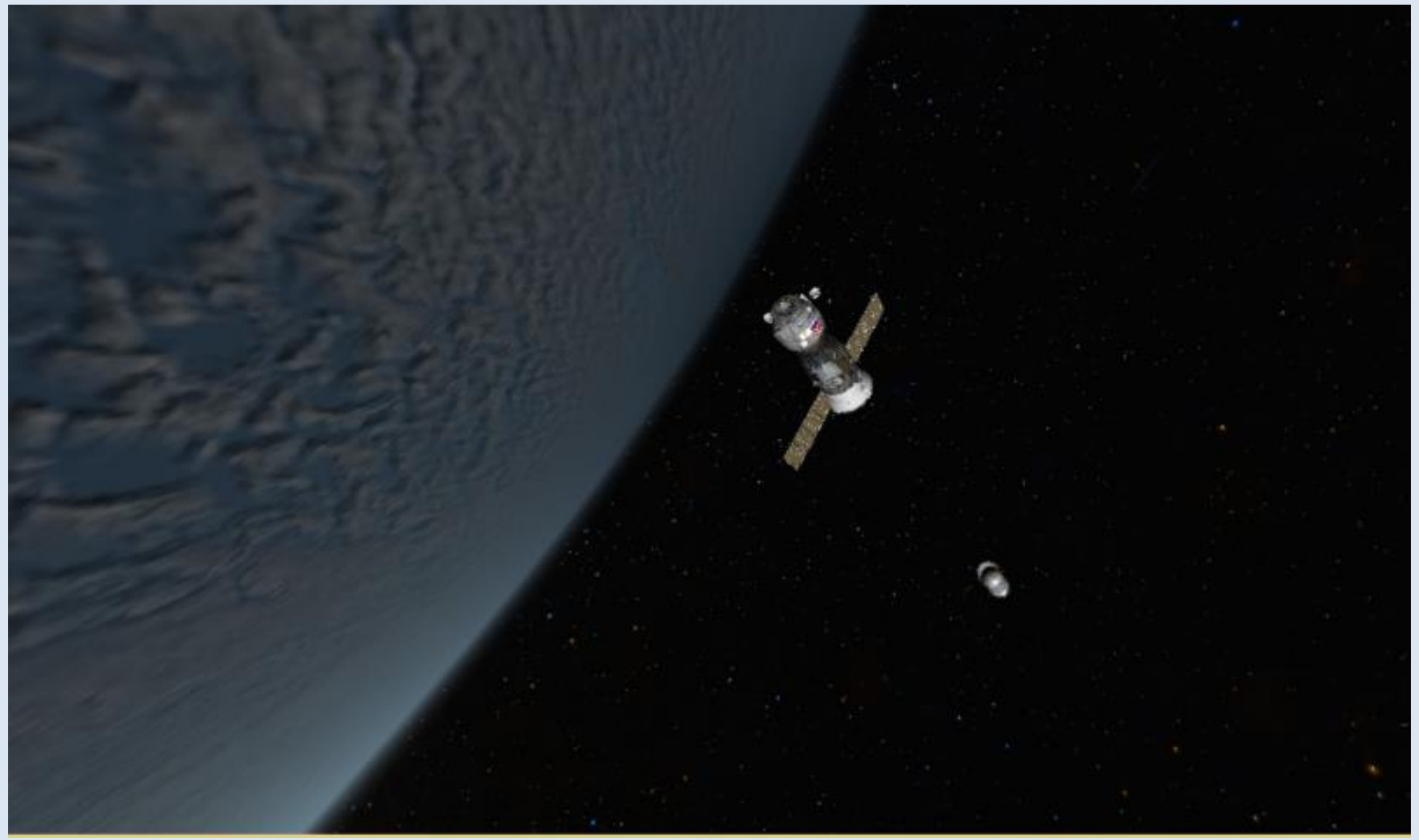
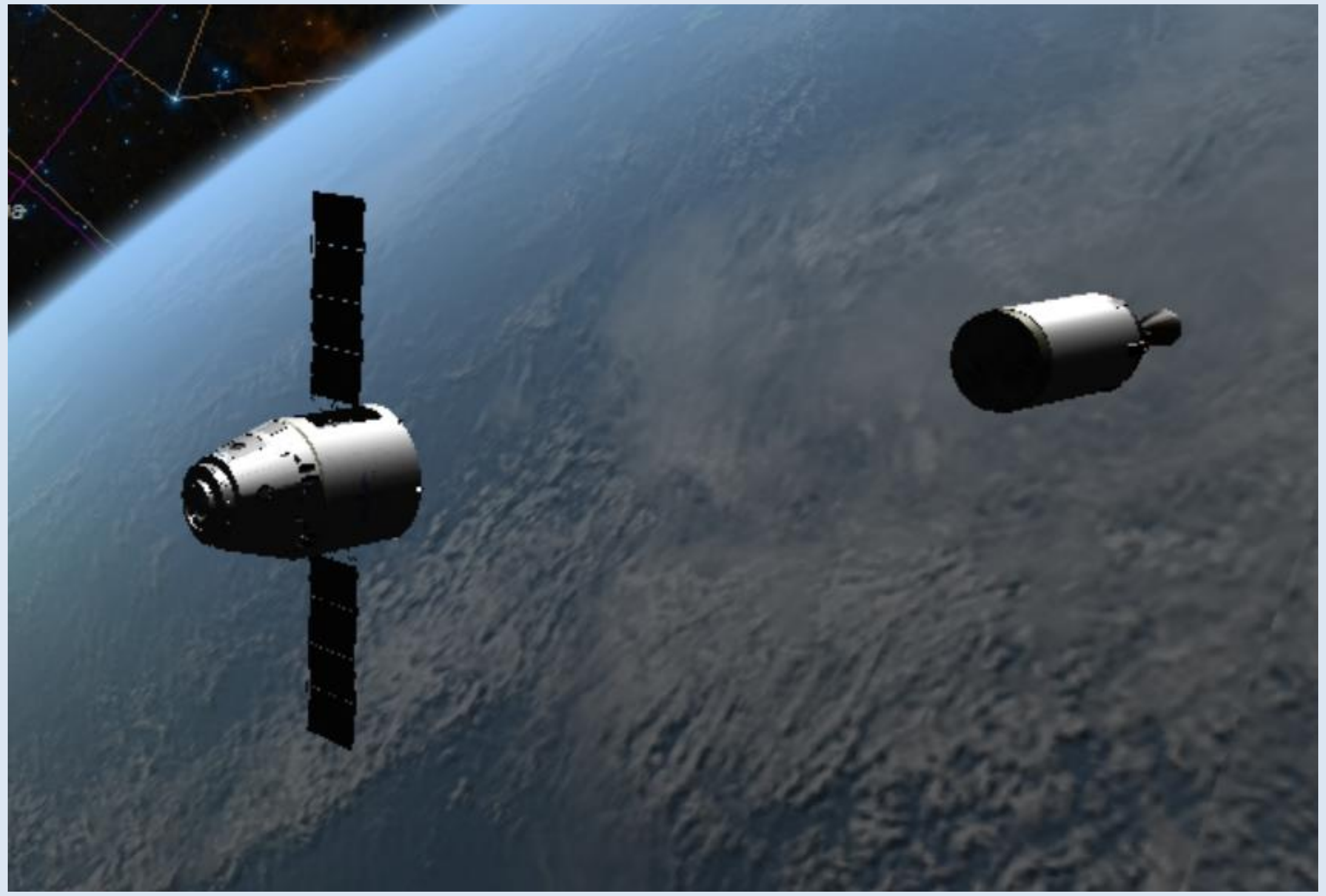
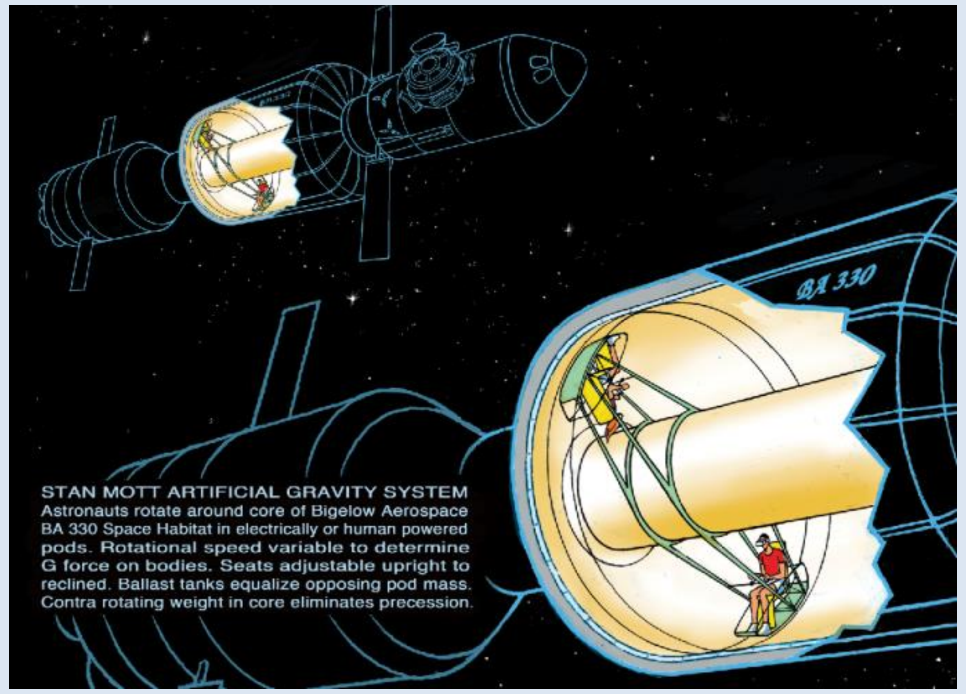
- Such tests have been proposed for Soyuz/Soyuz upper stage linked by a deployable tether set in rotation after upper stage engine cut-off.
- At the completion of the artificial gravity period, a reboost of Soyuz and deboost of the upper stage could be conducted by proper management of the tether cutoff process.
- This test would be better suited for an autonomous Soyuz mission rather than an ISS crew exchange mission.
- Such a mission could be done with Crew Dragon and Falcon 9 upper stage also.





Credits: NASA




# Alternative technique

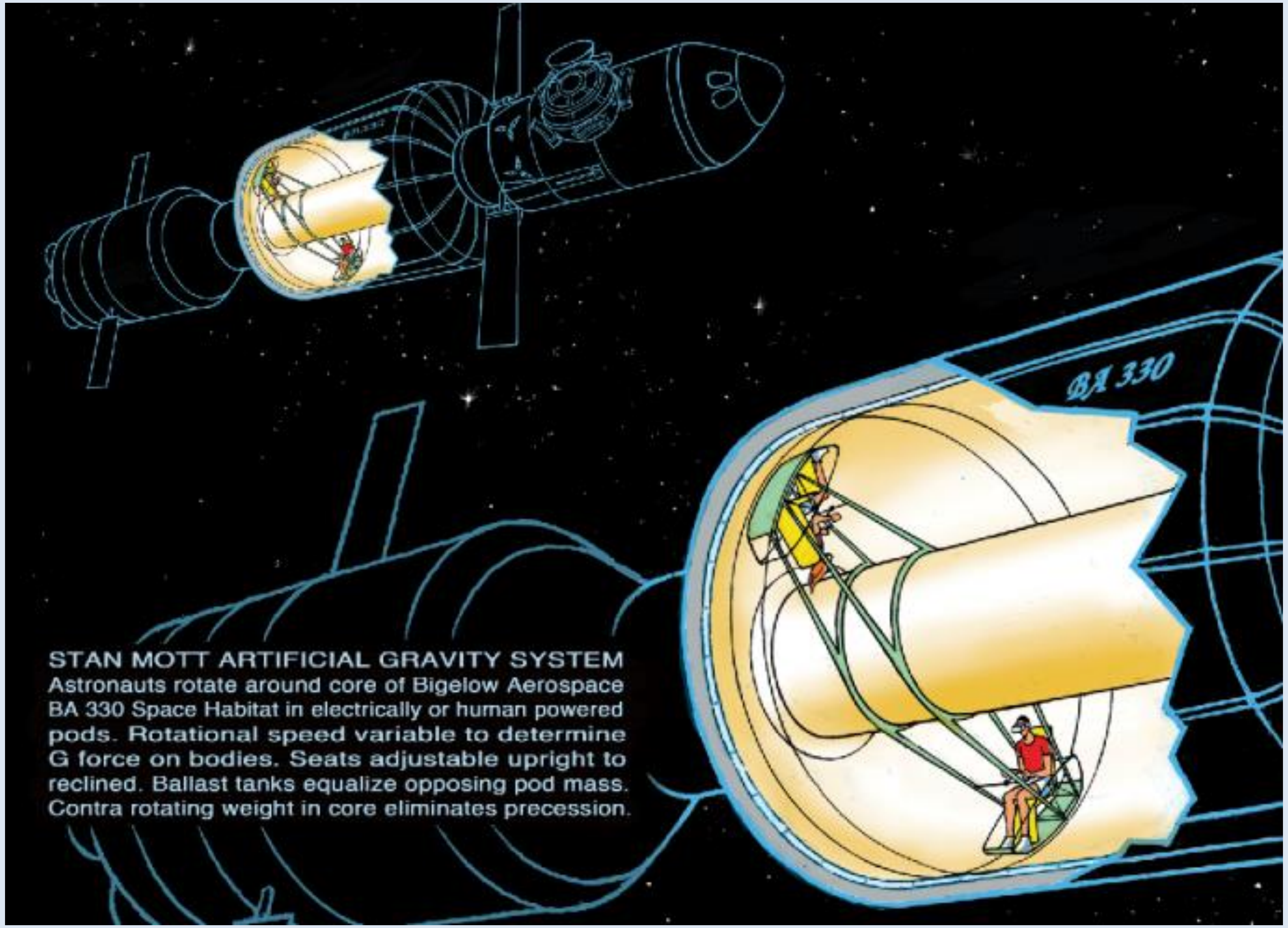
Credits: Stan Mott

# Alternative artificial gravity concept

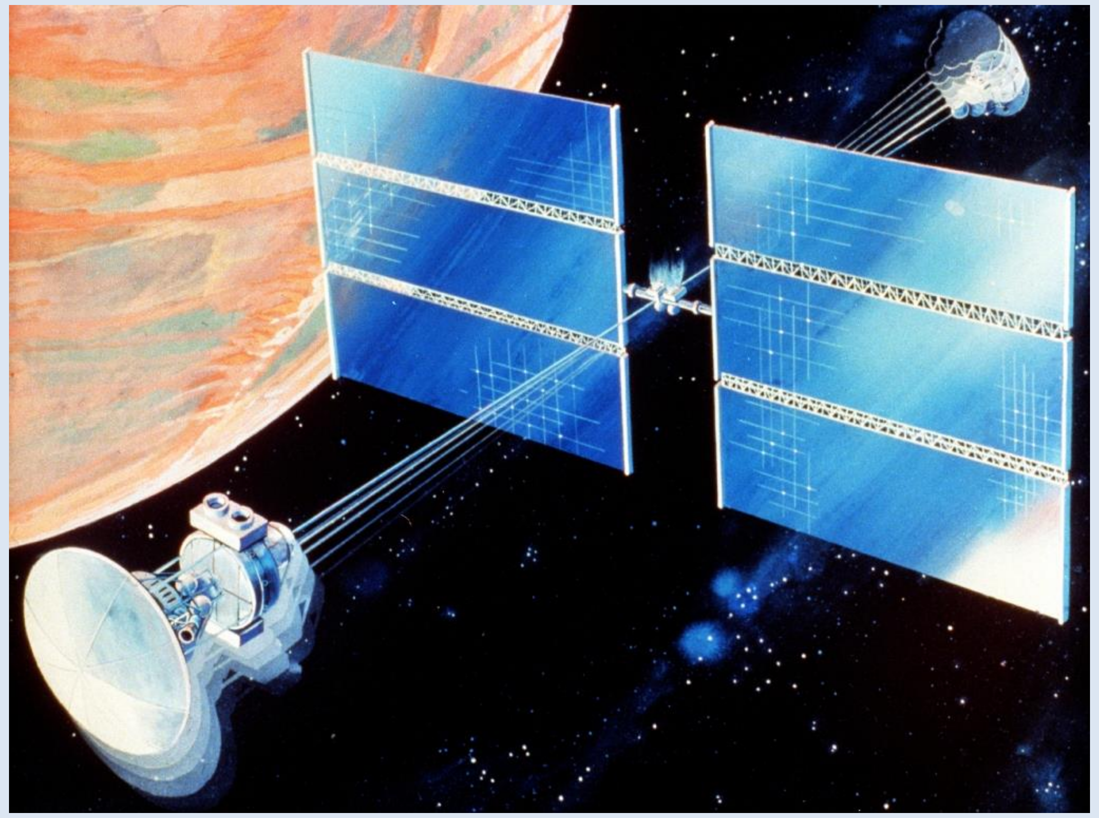
- Presented by Stan Mott in a Mars Society paper:

www.marspapers.org/paper/Mott_2017.pdf

- The concept is also centrifugal force based but with a rigid rotating structure, and adaptable to the Bigelow Aerospace BA 330 space habitat, with variations for the SpaceX BFR Mars spacecraft and the SpaceX Interplanetary Transportation System.




Credits: Stan Mott



Credits: NASA

# Conclusions

# Conclusions

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- Tethers are hard to control in the space environment at low tension values. A slack tether is space is a real nightmare!
- For a long duration manned mission to Mars, it would be very desirable to provide an artificial gravity value in the spacecraft equal to roughly 1/3 g during the whole transit time Earth to Mars.
- I recommend testing such a tether-based artificial gravity system in LEO using Soyuz/Soyuz upper stage or Crew Dragon/Falcon 9 upper stage linked by a tether. This would provide the added benefit of the rapid deorbit of the spent upper stage.