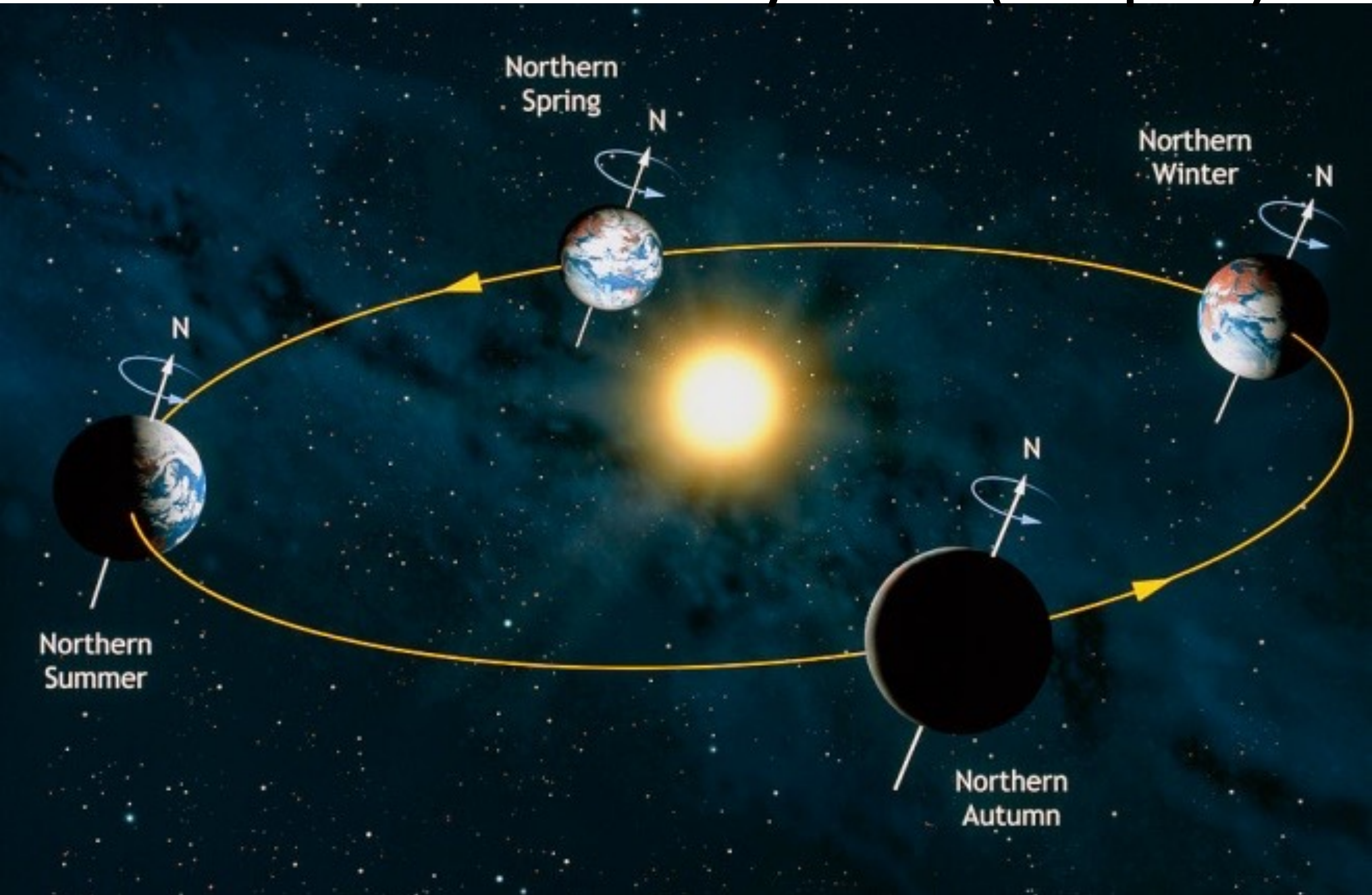
Secondary Tethers
for Interplanetary Travel

John Knapman, Ph.D.
Director of Research
Pete Swan, Ph.D.
President
International Space Elevator Consortium

Topics

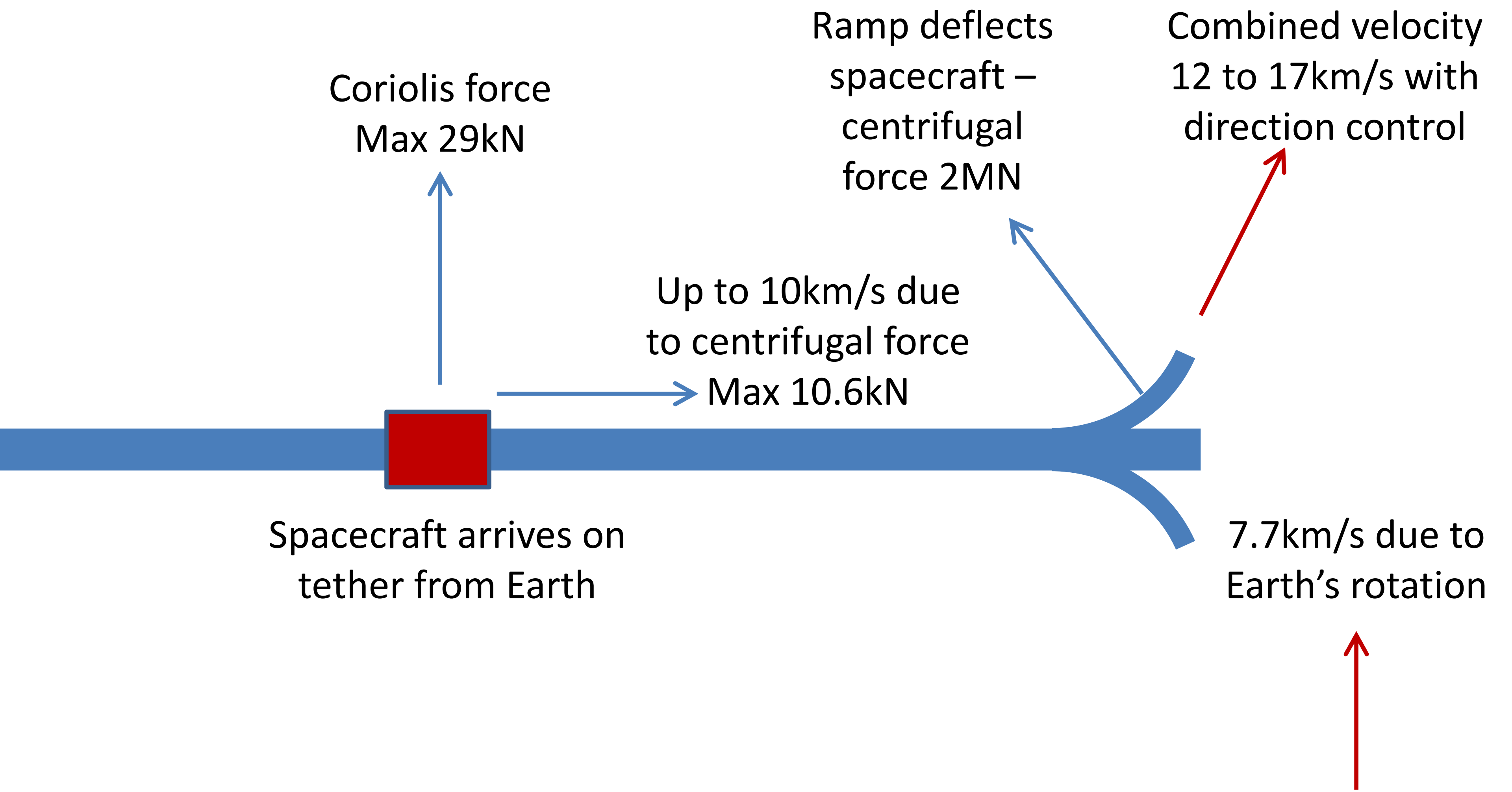
- Gaining speed and controlling direction
- Method of Matthew Peet
- Rotating tethers at the apex anchor
- Centrifugal and gyroscopic effects
- Action and reaction

Plane of the Solar System (Ecliptic)



One of Matthew Peet's Methods

Launching to the planets without propellant



Times of Flight

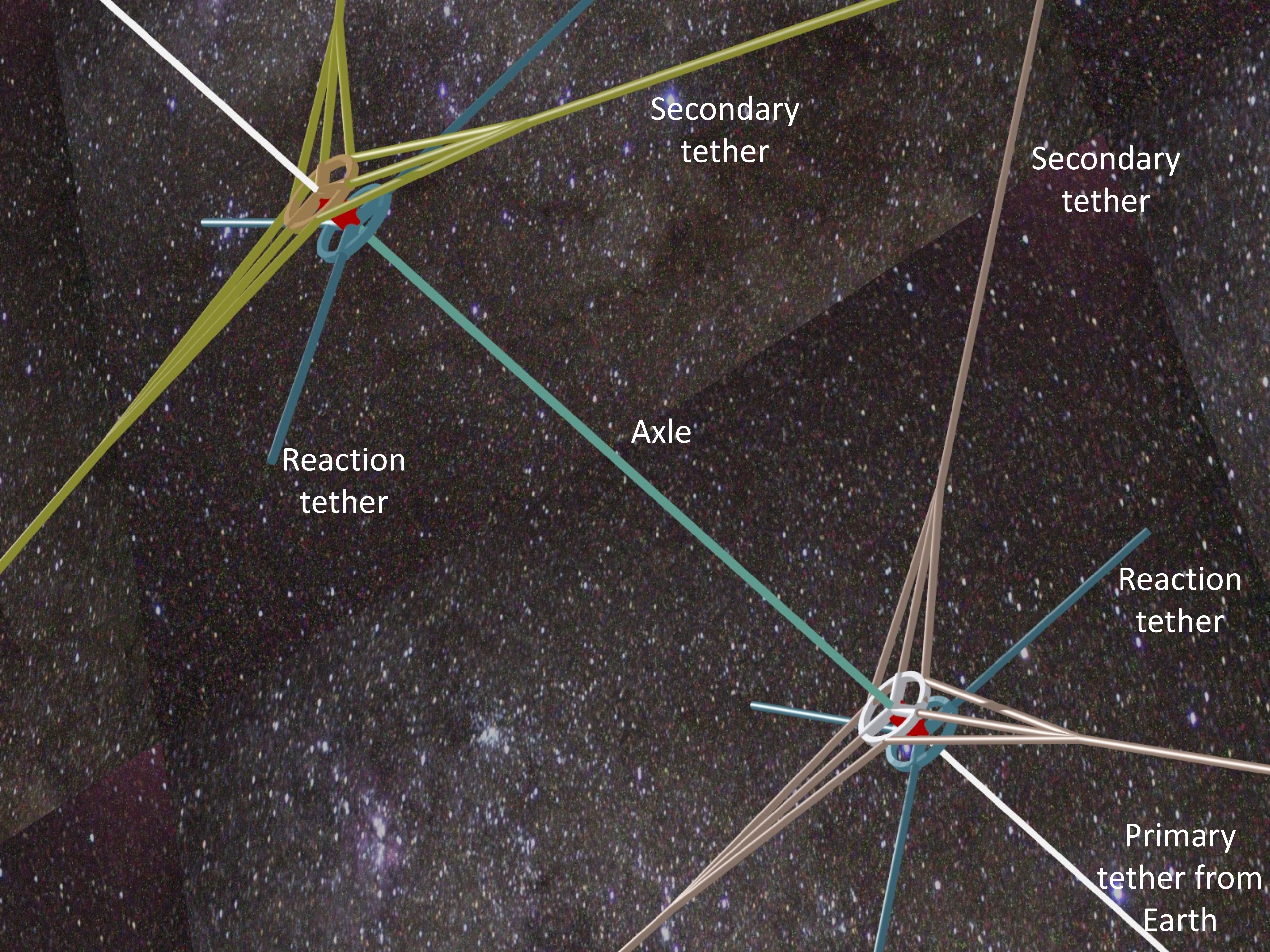
	Fastest time in days per synodic period*	Longest time≯	Synodic period (years)
Mars	60	800	2.1
Jupiter	450	850	1.1
Saturn	800	1165	1.0
Uranus	2000	2365	1.0
Neptune	4000	4365	1.0

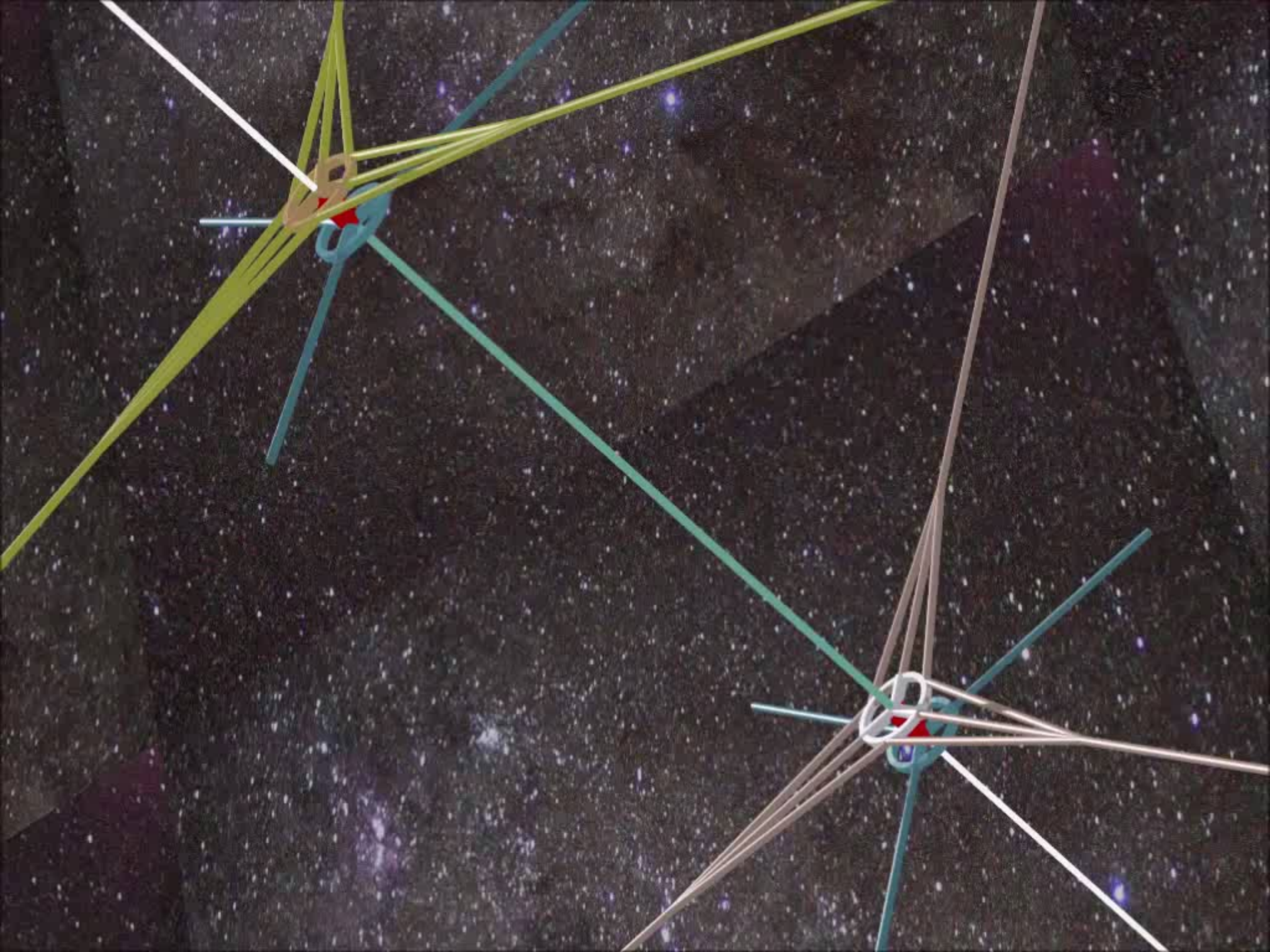
*Synodic period is the time required for a planet to return to the same position relative to the sun as seen by an observer on Earth.

≯Longest time assumes launching every day to Mars but waiting up to a year for the outer planets

Rotating Tethers

- At the apex anchor (100,000km from Earth)
- Secondary tethers rotate about primary tether
- Launching spacecraft in any direction on the celestial sphere
- Multiple tethers and reaction wheels
  - Stability and gyroscopic effects

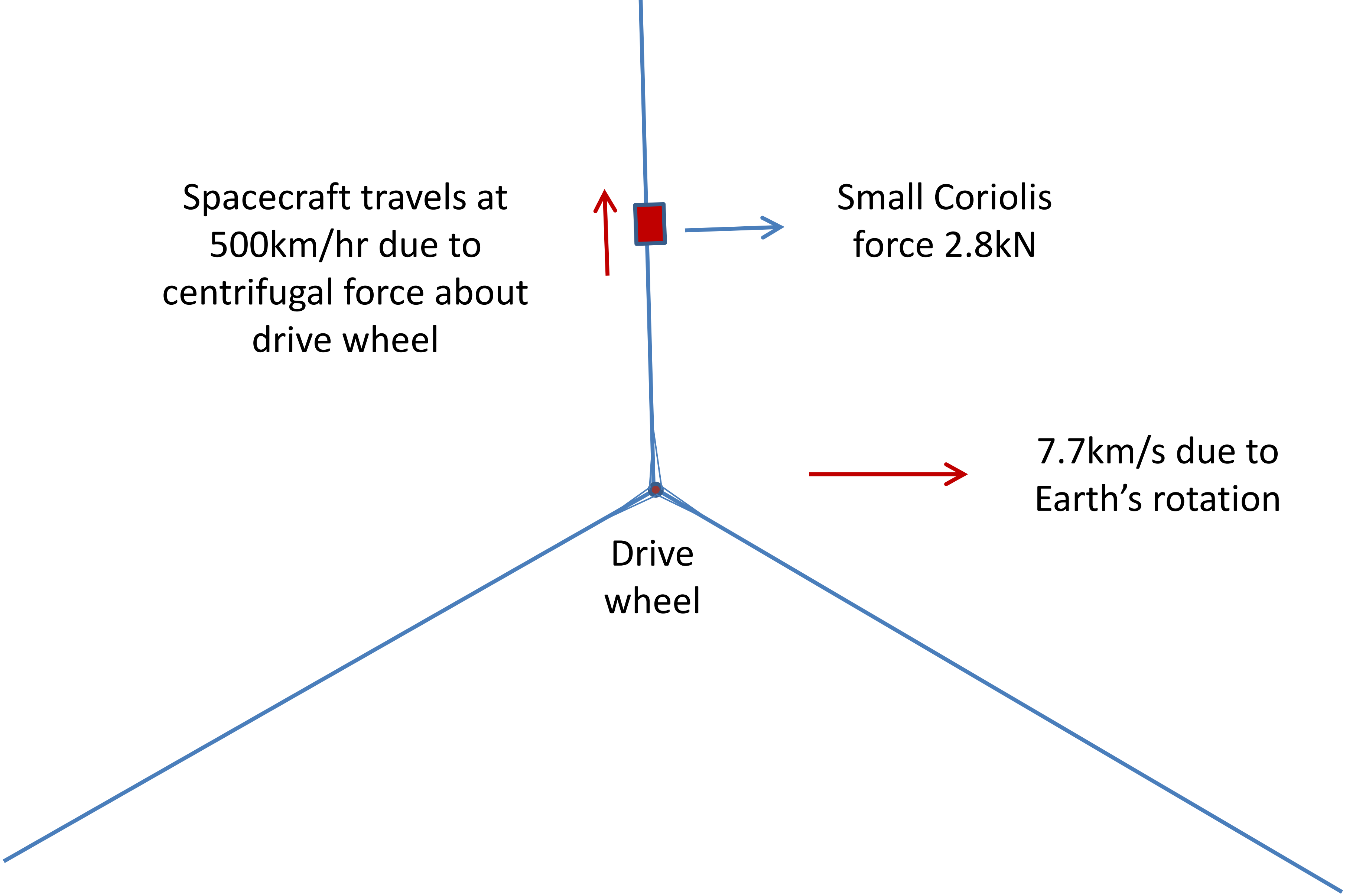

Secondary tether
Secondary tether
Axle
Reaction tether
Reaction tether
Primary tether from Earth



Secondary tethers

- Made of single-crystal graphene
  - Same as primary tether
- 10,000km long
  - Speed at tether's end: 10km/s
  - Centrifugal force equivalent to 1g
    - $10m/s^2$ same as Earth gravity
- Spacecraft will move along tether under centrifugal force

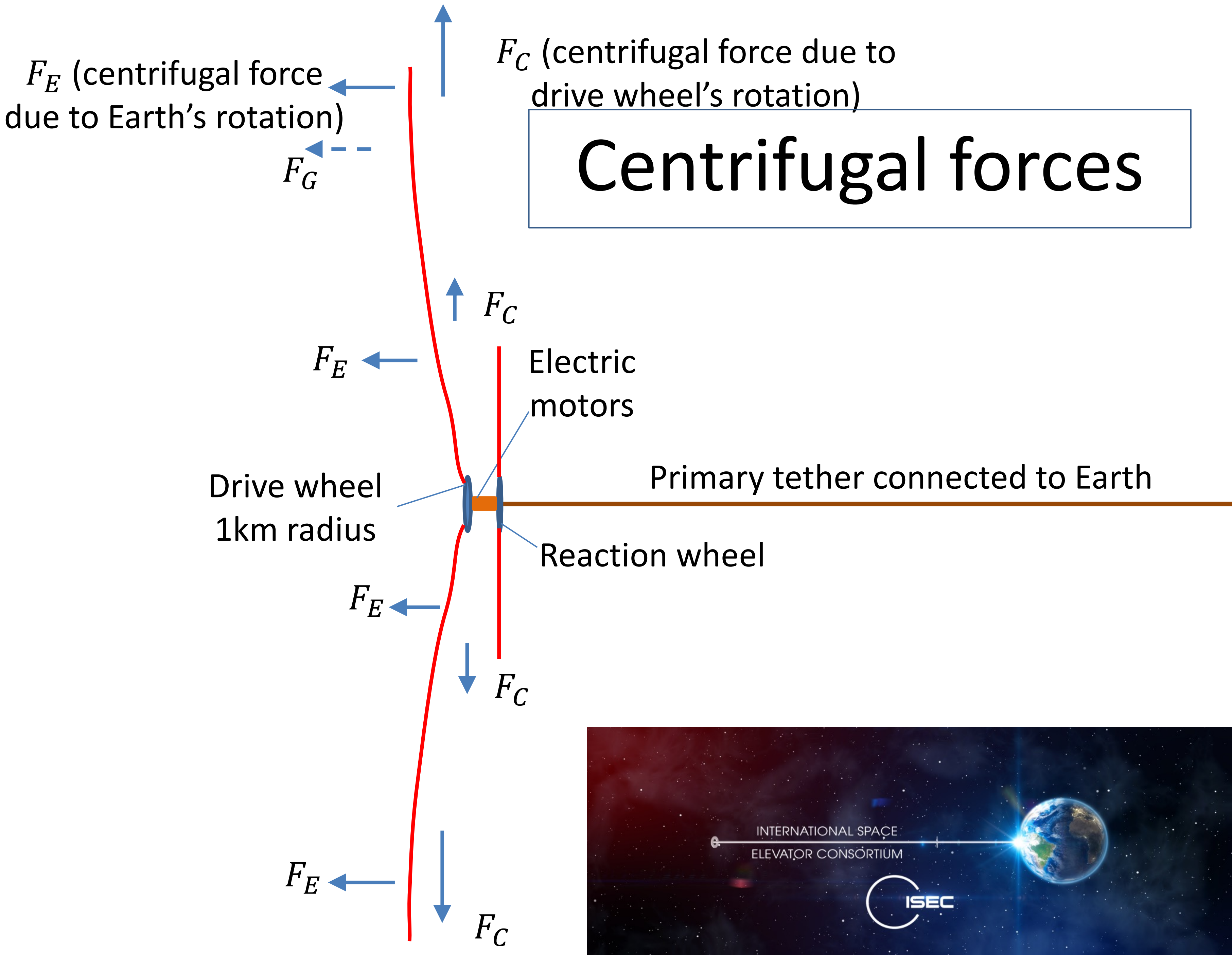
Gentle ride to tether's end



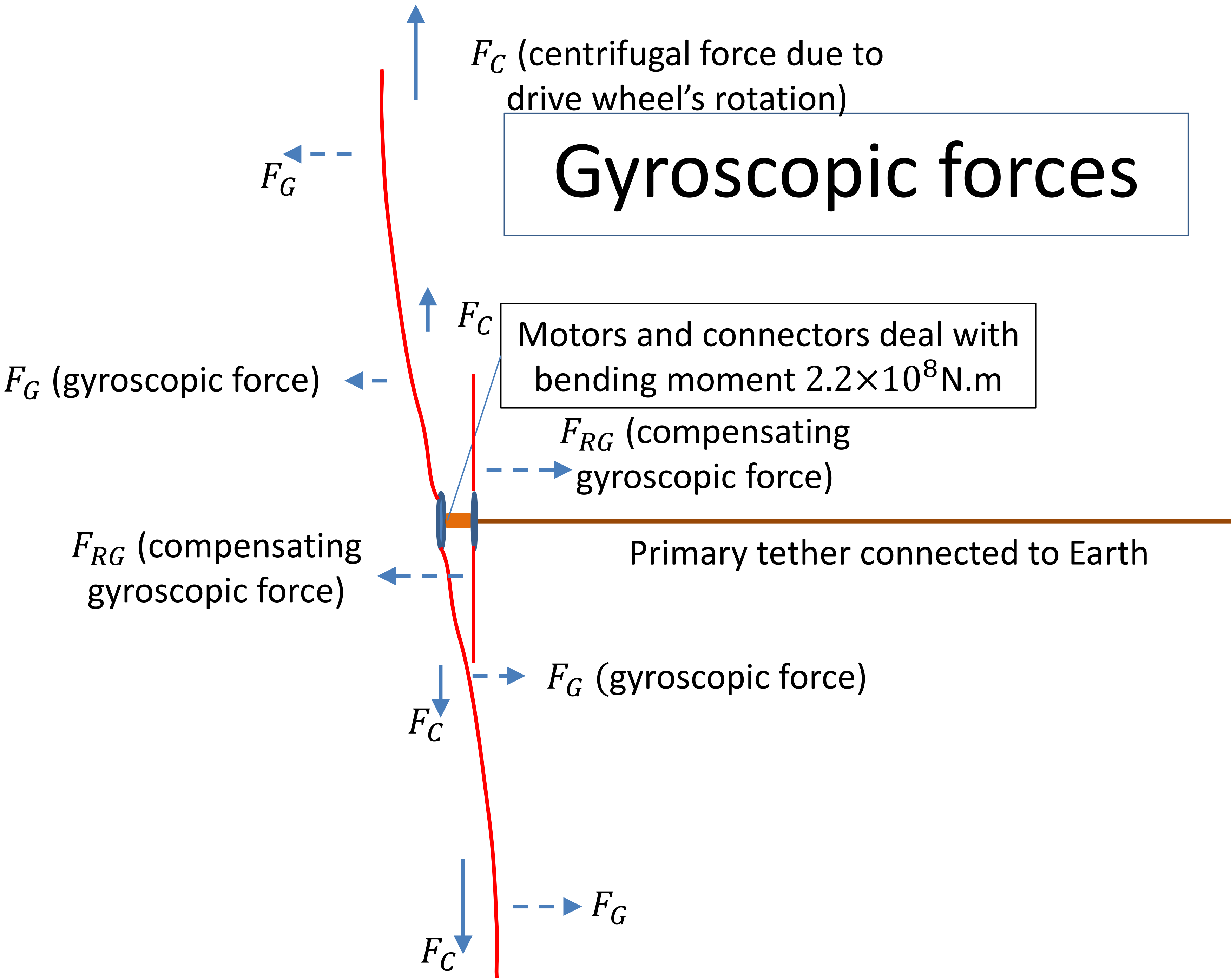
Launching a spacecraft

- At 500kph, spacecraft traverses tether in 20 hours
  - Faster is possible
  - Allow extra hour for acceleration and deceleration along tether
  - Enables daily launches
- Power from electric motors fixed to drive wheel accelerates 20-tonne spacecraft to 10km/s
  - 14MW required for 20 hours
  - More power is needed to drive reaction wheels and second system of tethers
  - Overall power 56MW

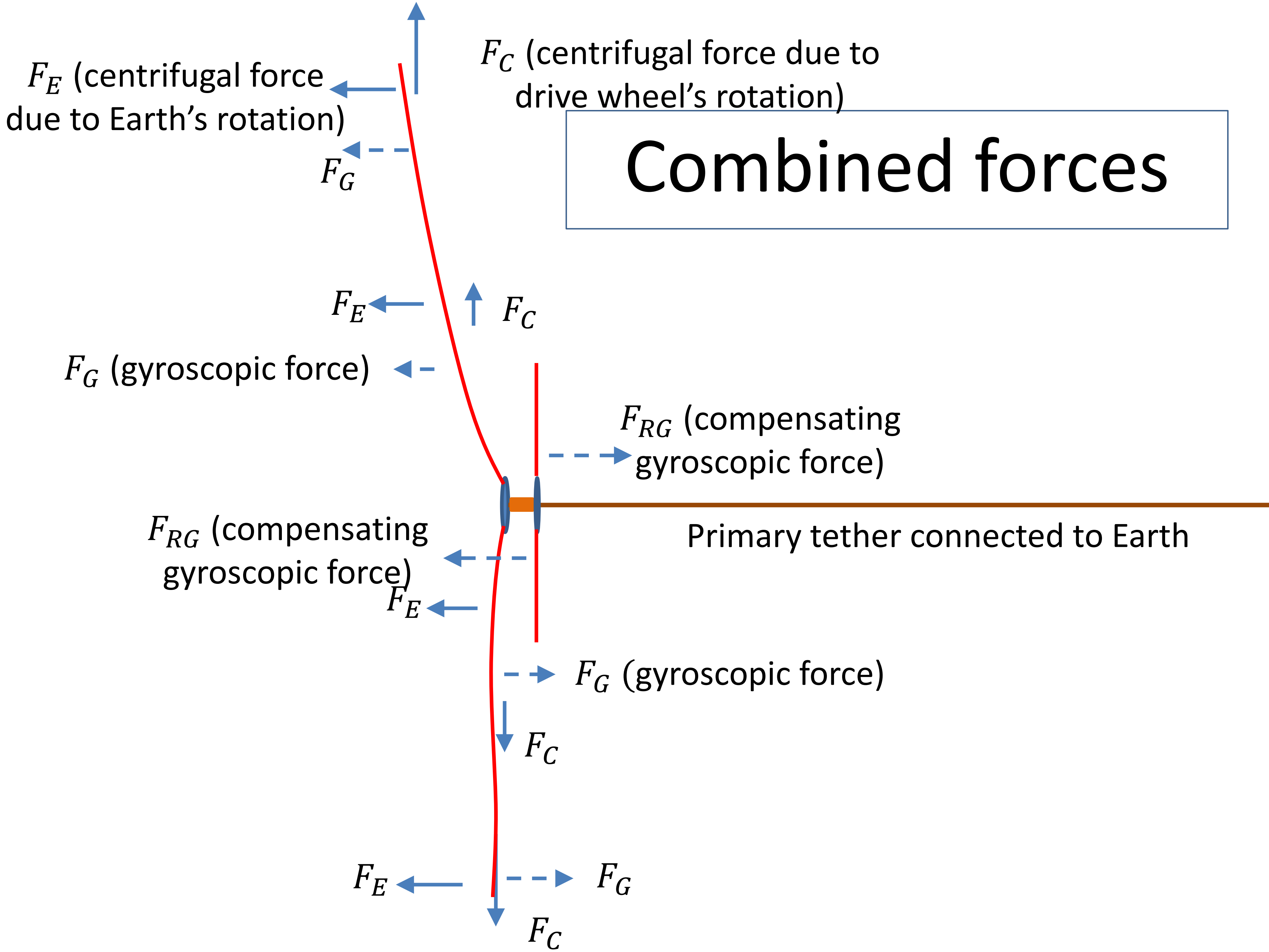
Centrifugal forces



Gyroscopic forces



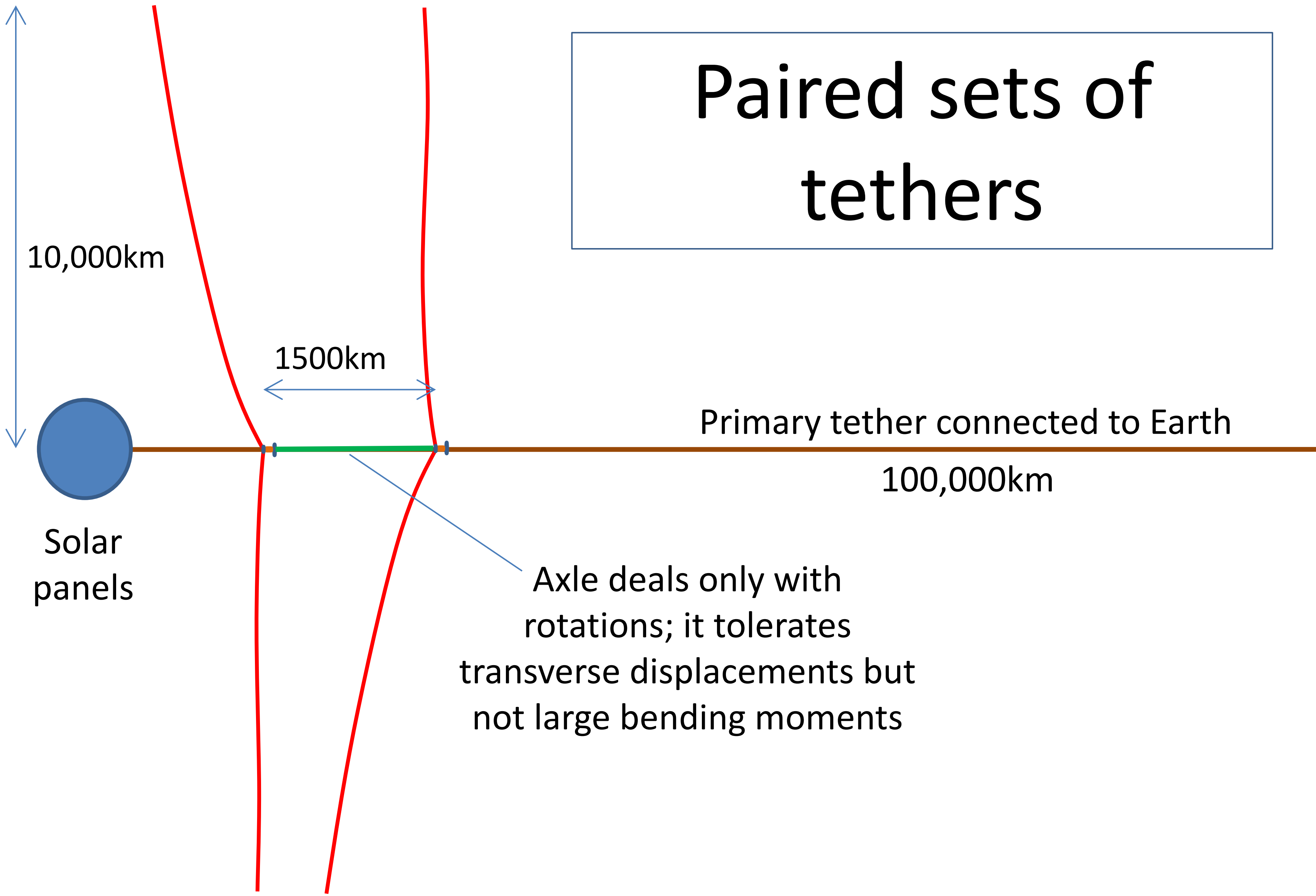
Combined forces



Reaction Wheel

- Drive wheel rotates once per 105 minutes
- Reaction wheel counter-rotates at 7.5 rpm
  - Reaction tethers are 20km long
- They balance the gyroscopic effects
  - 3-metre connector and motors are between the drive wheel and the reaction wheel
- Absorbs some of the angular momentum from the secondary tethers and their drive wheel
- A second set of tethers is needed with its own drive wheel and reaction wheel

Paired sets of tethers



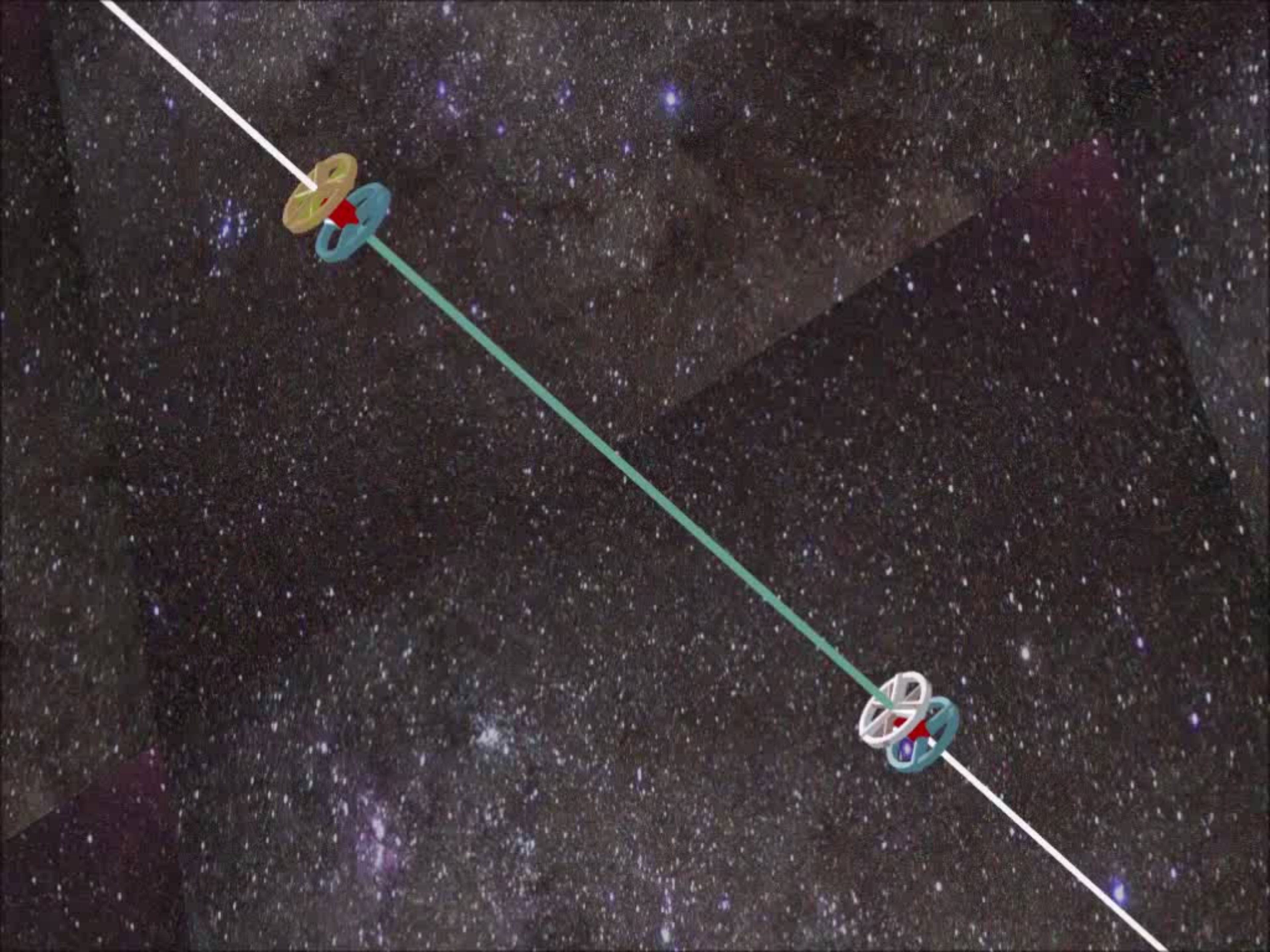
Mass budget

	Number	Each (tonnes)	Total (tonnes)
Secondary tethers	6	120	720
Drive wheels	2	20	40
Reaction tethers	6	120	720
Reaction wheels	2	20	40
Electric motors	2	75	150
Solar panels	2	20	40
TOTAL			**1710**

Available budget 1900 tonnes

Starting Up

- Get drive wheels up to speed (10^{-3} rad/s)
- Pay out tethers gradually
  - Pay out all tethers equally and simultaneously
  - Speed up reaction wheels in parallel
- Energy in operational system 4.2×10^{13}J
- 65 days is required for a stable startup
  - Power needed is 7.5MW



Stability

- System is naturally stable
  - But there will be oscillations when spacecraft are released
- Move counterweights along tethers to reduce oscillations
  - Can also partly retract and pay out tethers
  - More detailed work is needed
- To maintain balance, use all six tethers in turn to launch spacecraft

Speeding up and slowing down

- For exact control of the launch angle
  - To ensure a tether is at the required angle at the required time
  - At 24 hours notice
- Drive wheels and tethers rotate 13.7 times a day
  - For a 60^{o} delay, slow tethers down to 13.4 and back to 13.7 times a day
  - For a 60^{o} advance, speed up tethers to 14.0 and back to 13.7 times a day
  - Can be achieved by moving masses along the other two tethers

Conclusions

- Using the space elevator there is more than one way to send spacecraft to the planets
  - Fuel and reaction mass are only needed for course correction and deceleration at destination
- No need for time-consuming gravity assist manoeuvres
- Daily launches

INTERNATIONAL SPACE ELEVATOR CONSORTIUM

ISEC