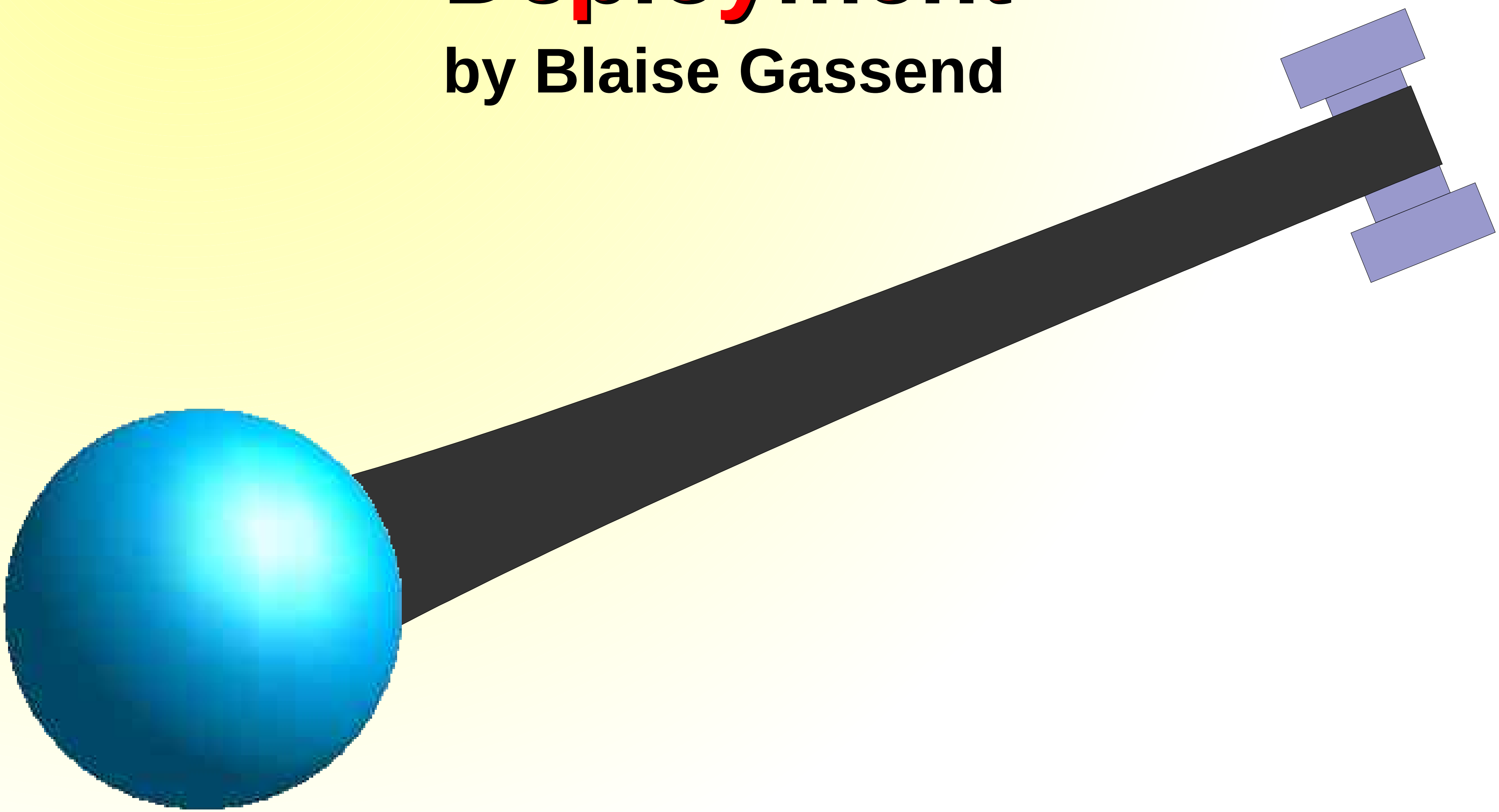
Exponential Tethers for Accelerated Space Elevator Deployment

by Blaise Gassend

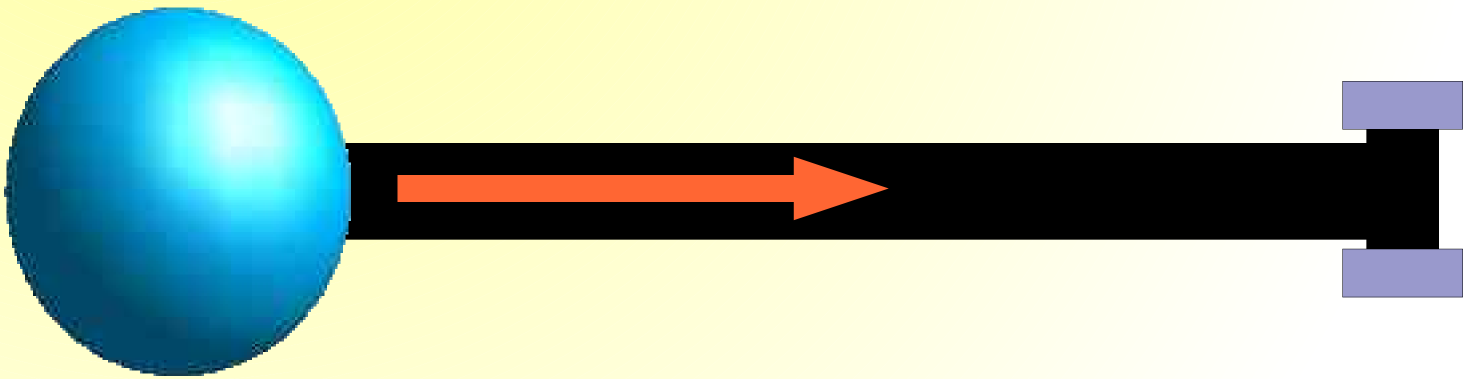


Introduction

- What is the best taper for a Space Elevator?
  - Uniform-stress taper, of course!
- How do you lift material with a Space Elevator?
  - With a climber, of course!
- What if you are trying to lift ultra-strong carbon nanotube tether material?
  - Don't waste the payload's strength!

Reeling Material into Space

- Feed out tether at the anchor station while reeling in at the counterweight.



- Faster than lifting with climbers.
- Not really possible with uniform-stress tethers, though.

Critical Strength

- If a tether is strong enough, it can support itself from GEO without any taper.
- Critical strength satisfies:

$$\sigma_c = \rho G M_e \left(\frac{1}{r_e} - \frac{1}{r_g}\right) + \frac{1}{2}\rho \Omega^2 (r_e^2 - r_g^2)$$

- For Earth, the critical strength is 63 GPa (assuming density of 1300 kg/m^3.)

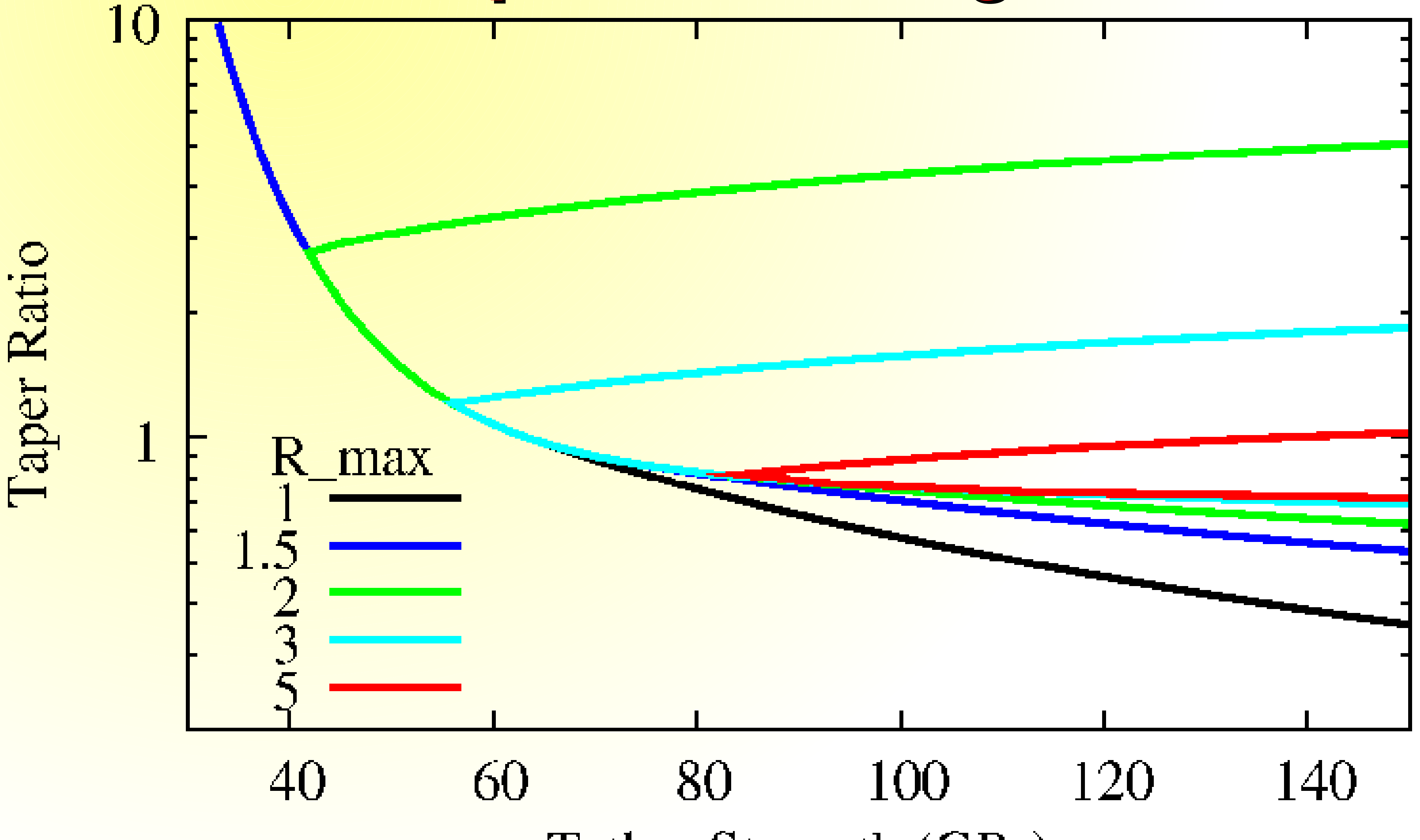
Exponential Tethers

- An exponential tether's cross section depends exponentially on altitude.

$$A(r) = A_0 e^{\gamma r}$$

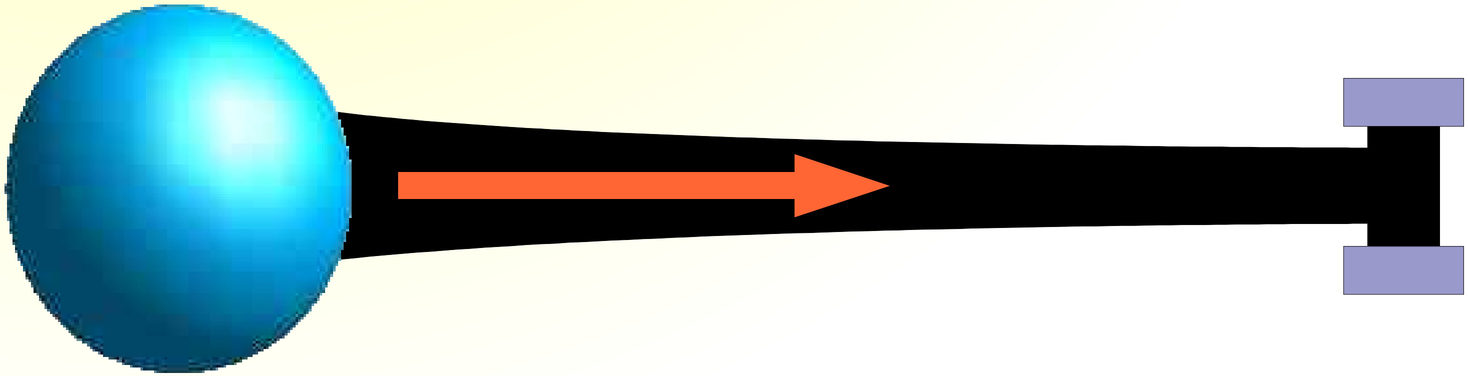
- Translation multiplies area by constant factor.
- $\gamma > 0$ ➔ Normal Taper, Taper Ratio > 1
- $\gamma < 0$ ➔ Inverse Taper, Taper Ratio < 1
- How strong does an exponential tether have to be?

Exponential Tethers – Strength, Taper and Length



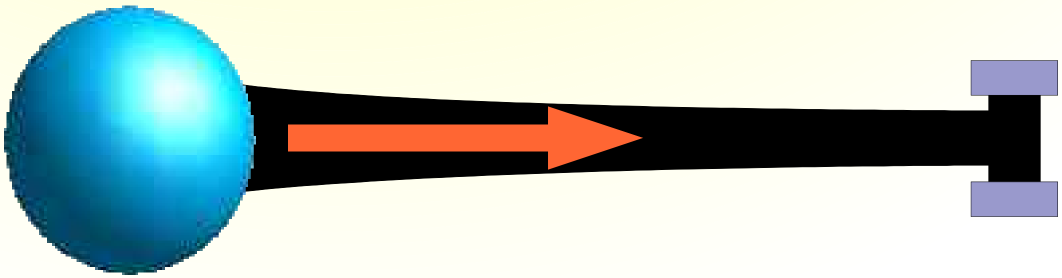
Reel-to-Reel Buildup - Concept

- Take a taper that is thicker at the base than at the top.
- Feed out tether at the anchor station while reeling in at the counterweight.
- Pull up a uniform-stress tether when desired cross-section is reached.



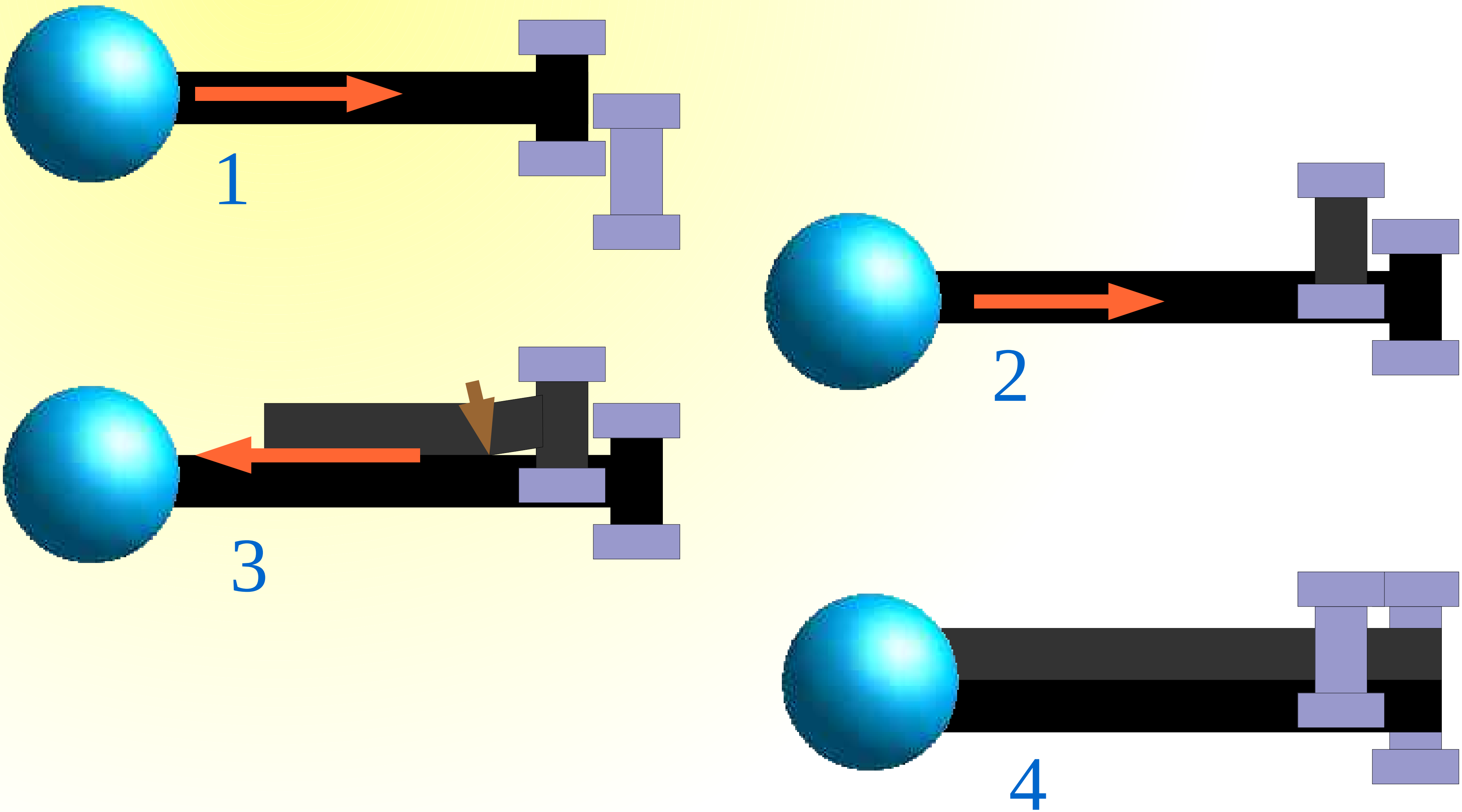
Reel-to-Reel Buildup
Good or Bad?

- Good
  - Fast
  - Simple
  - Easy to Repair
  - High Quality Ribbon
  - Eliminate Hundreds of Climbers



- Objectionable
  - Power use Location
  - Counterweight Reliability
  - Wind, Debris, Atomic Oxygen
  - Counterweight Growth
  - Ribbon Waste
  - Needs Inverse Taper

Redeploy and Splice - Concept



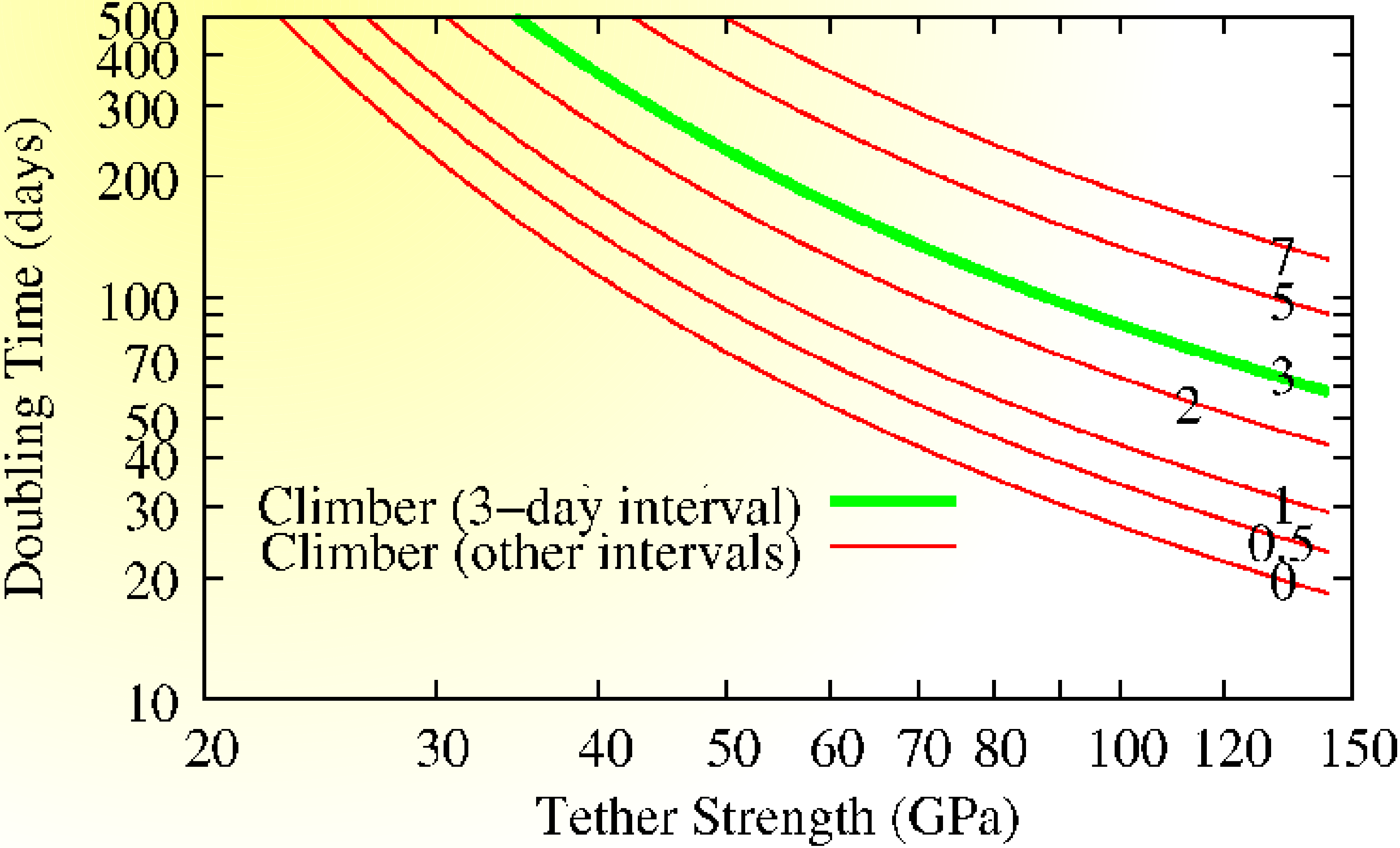
Evaluation

- We compare bulidup rates for climber based, reel-to-reel and redeploy-and-splice buildup.
- Assume same velocity and safety factor for all methods.
- Optimistic evalution for climber based buildup.
- Pessimistic evaluation for reel-to-reel and redeploy-and-splice buildup.

Evaluation – Climber Based

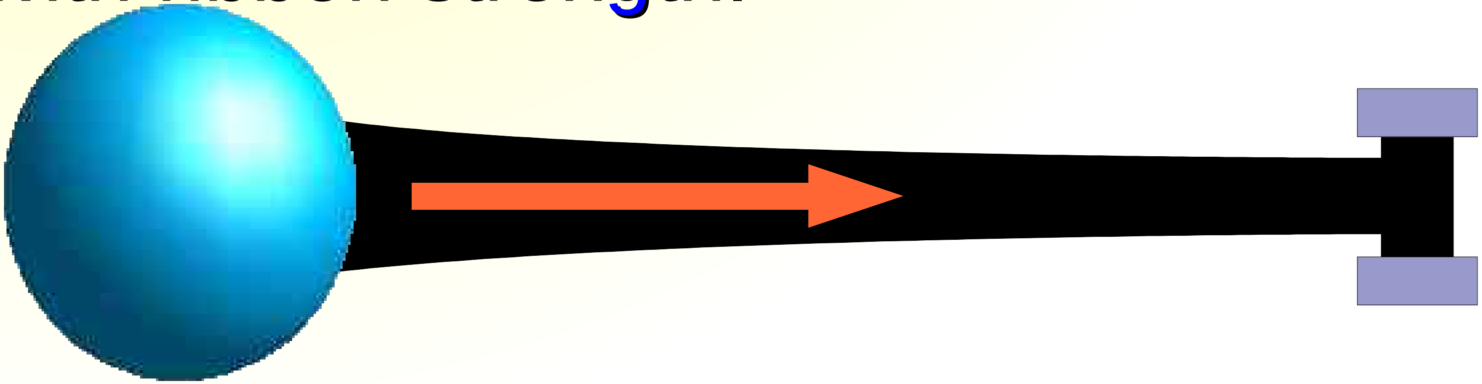
- Growth rate depends on number of climbers on cable at a time.
  - Edwards assumes 3 days between climbers.
- Assumptions
  - Infinite length elevator
  - Assume each climber adds infinitesimally to elevator.
  - Ignore climber mass.

Evaluation – Climber Based

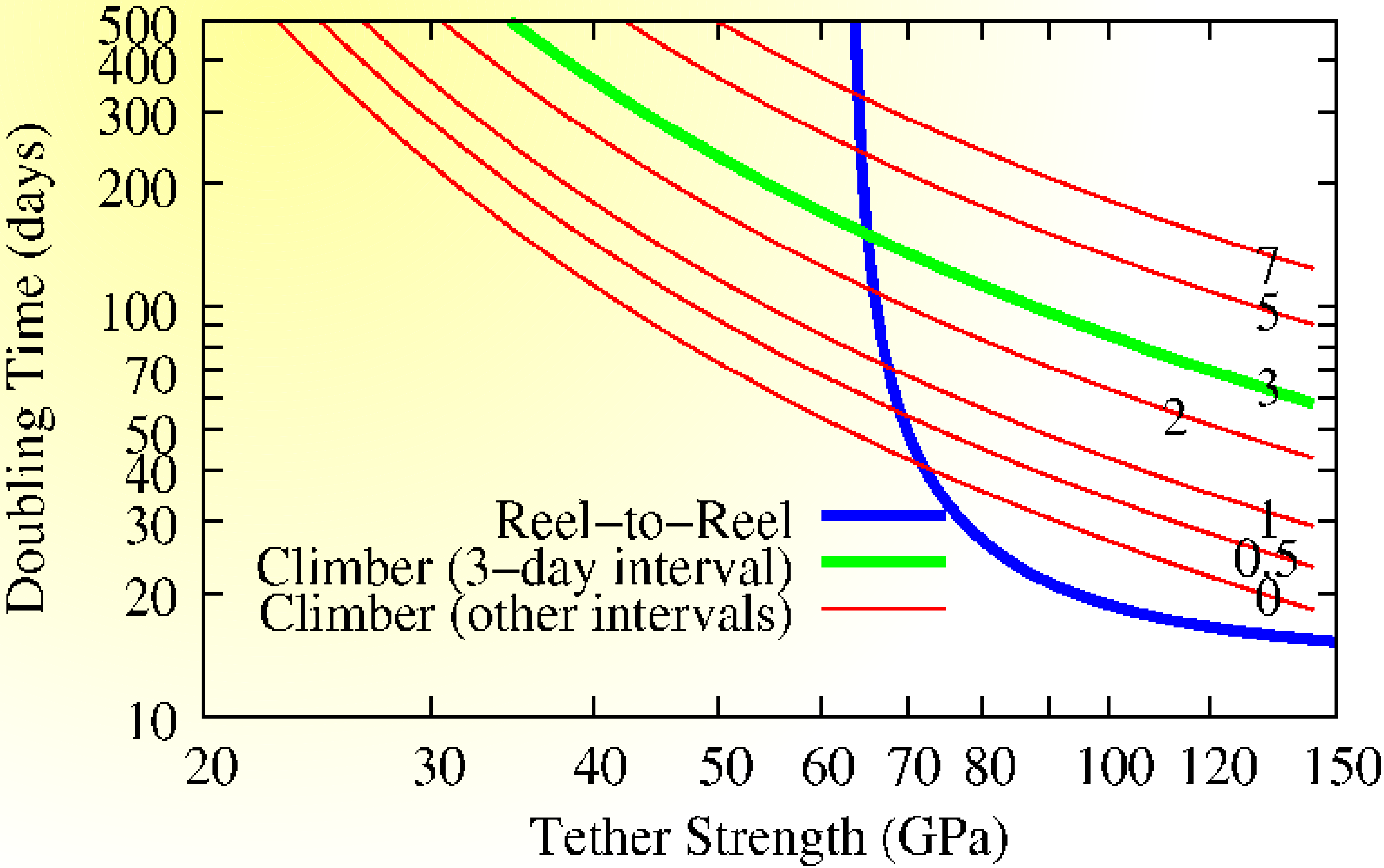


Evaluation - Reel-to-Reel

- Growth rate determined by taper rate and ribbon velocity: $-\gamma v$
- Assume counterweight altitude is selected so that counterweight grows at same rate as tether. $-\rho A(r_c) g(r_c) = T(r_c)\gamma$
- Pick largest inverse taper that is compatible with ribbon strength.

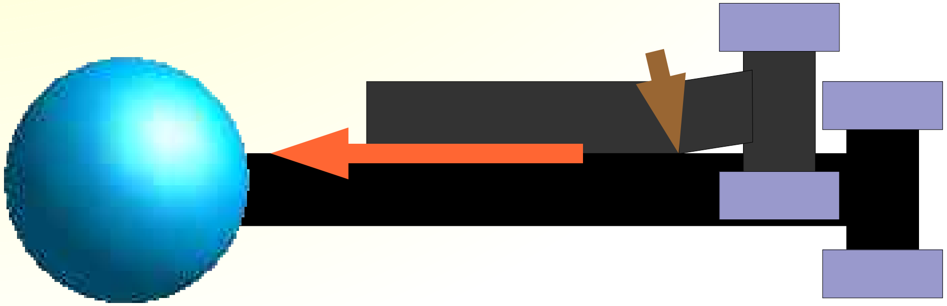


Evaluation Reel-to-Reel

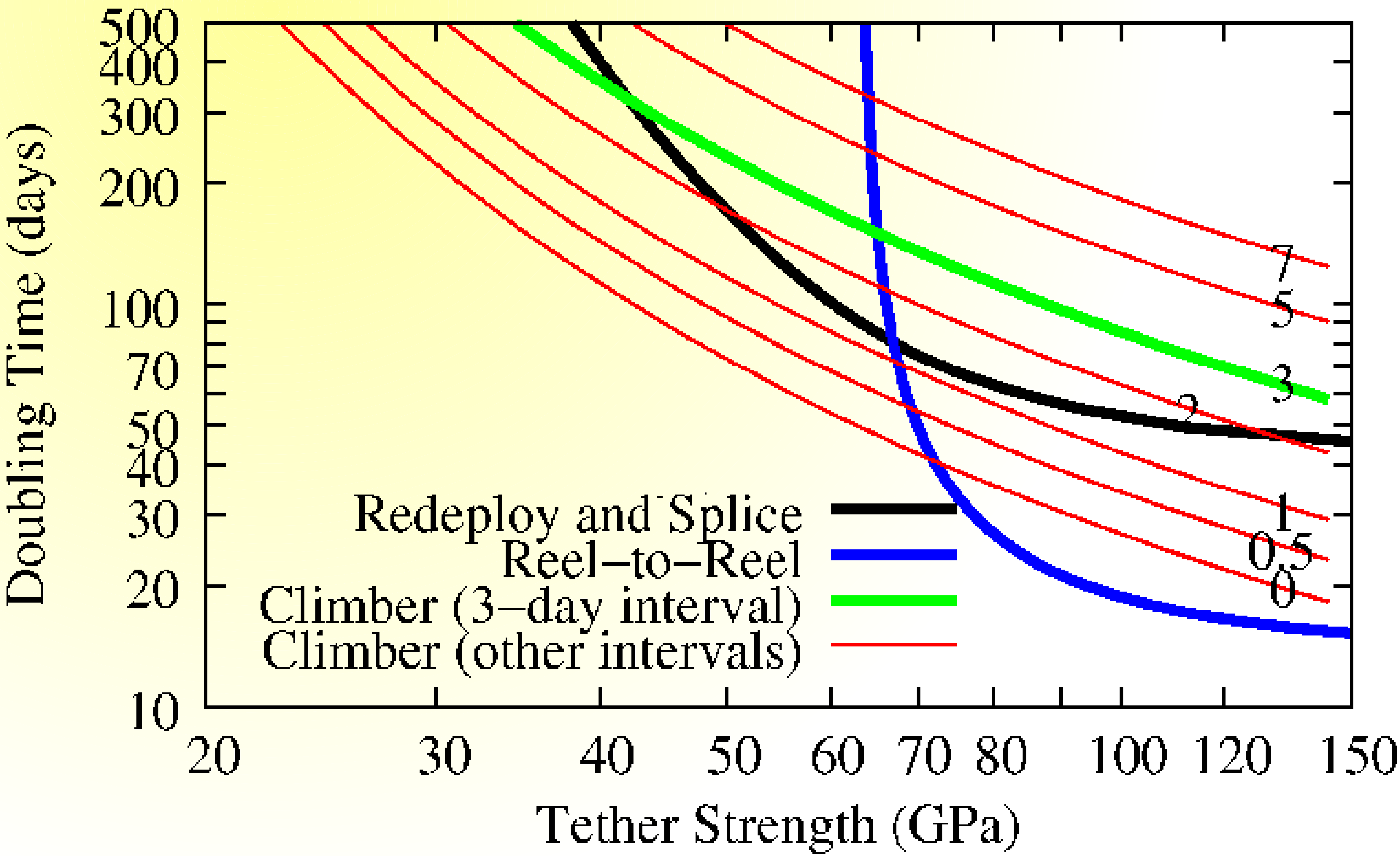


Evaluation Redeploy-and-Splice

- In one redeploy and splice cycle, tether grows by a factor: $e^{-\gamma(R_c - R_e)} + 1$
- Assume longest possible tether.
  - Minimizes total mass (reasonable choice).
  - Maximizes reeling time (optimistic assumption).
- Each cycle lasts: $3(R_c - R_e)/v$



Evaluation Redeploy-and-Splice



Conclusion

- Uniform-stress is not always best.
- Lifting tether material is faster with reeling.
- Buildup and cloning is often faster with exponential tether methods.
- What other similar improvements are we missing?
- Check out the paper for Breeder Elevators and Pull-Down Buildup.

THE END

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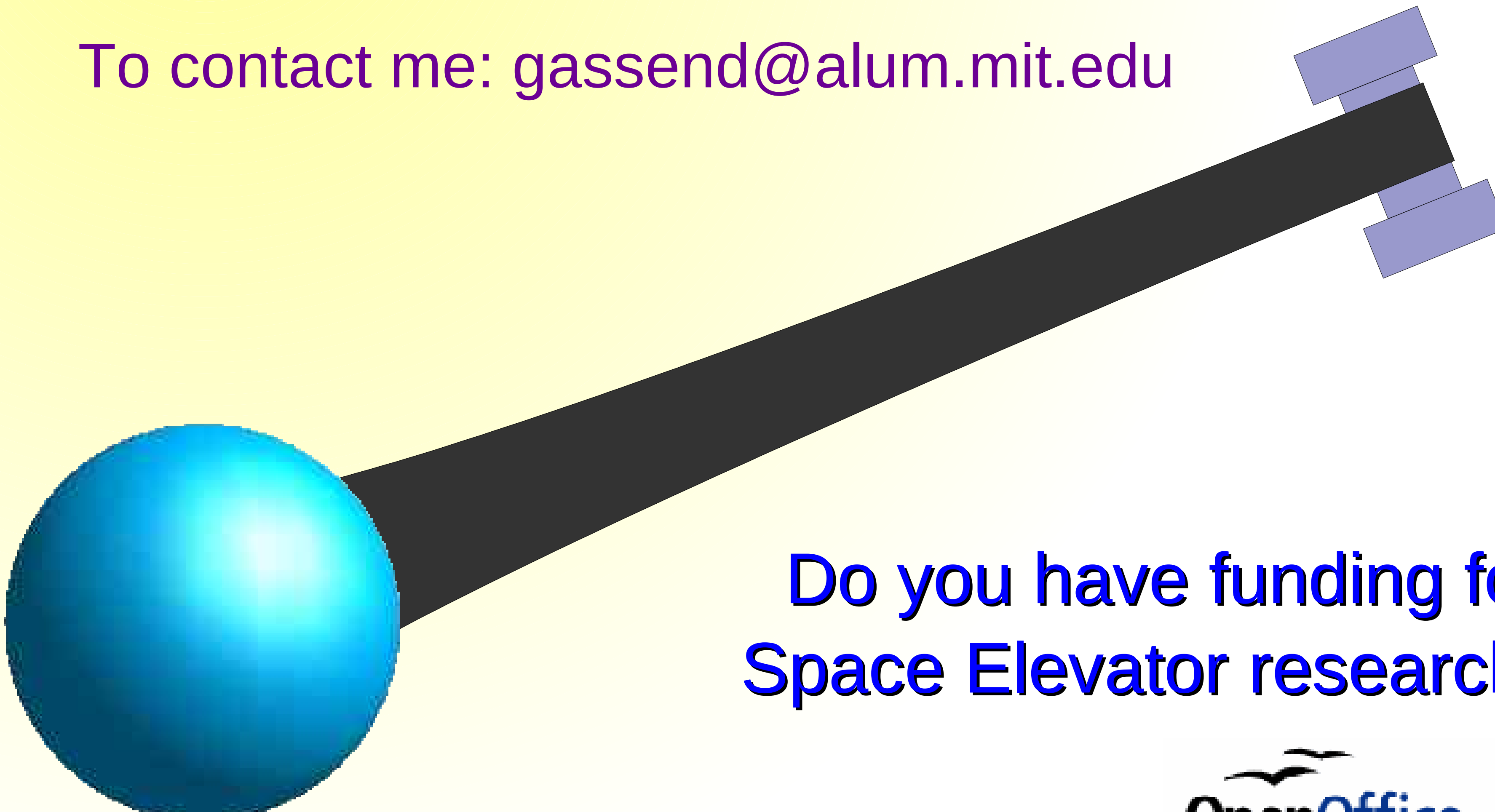

Do you have funding for
Space Elevator research?

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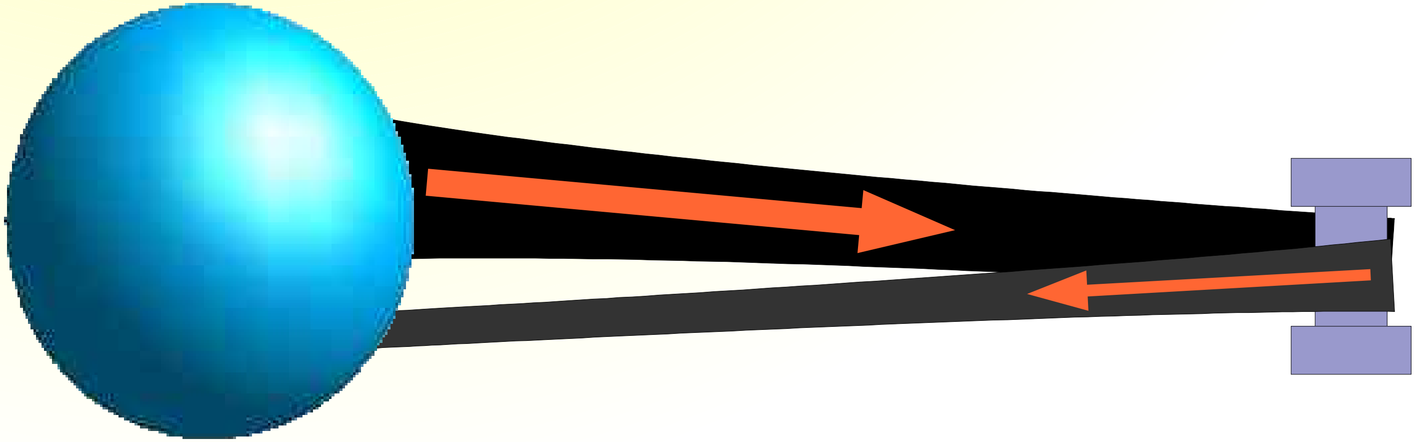
Outline

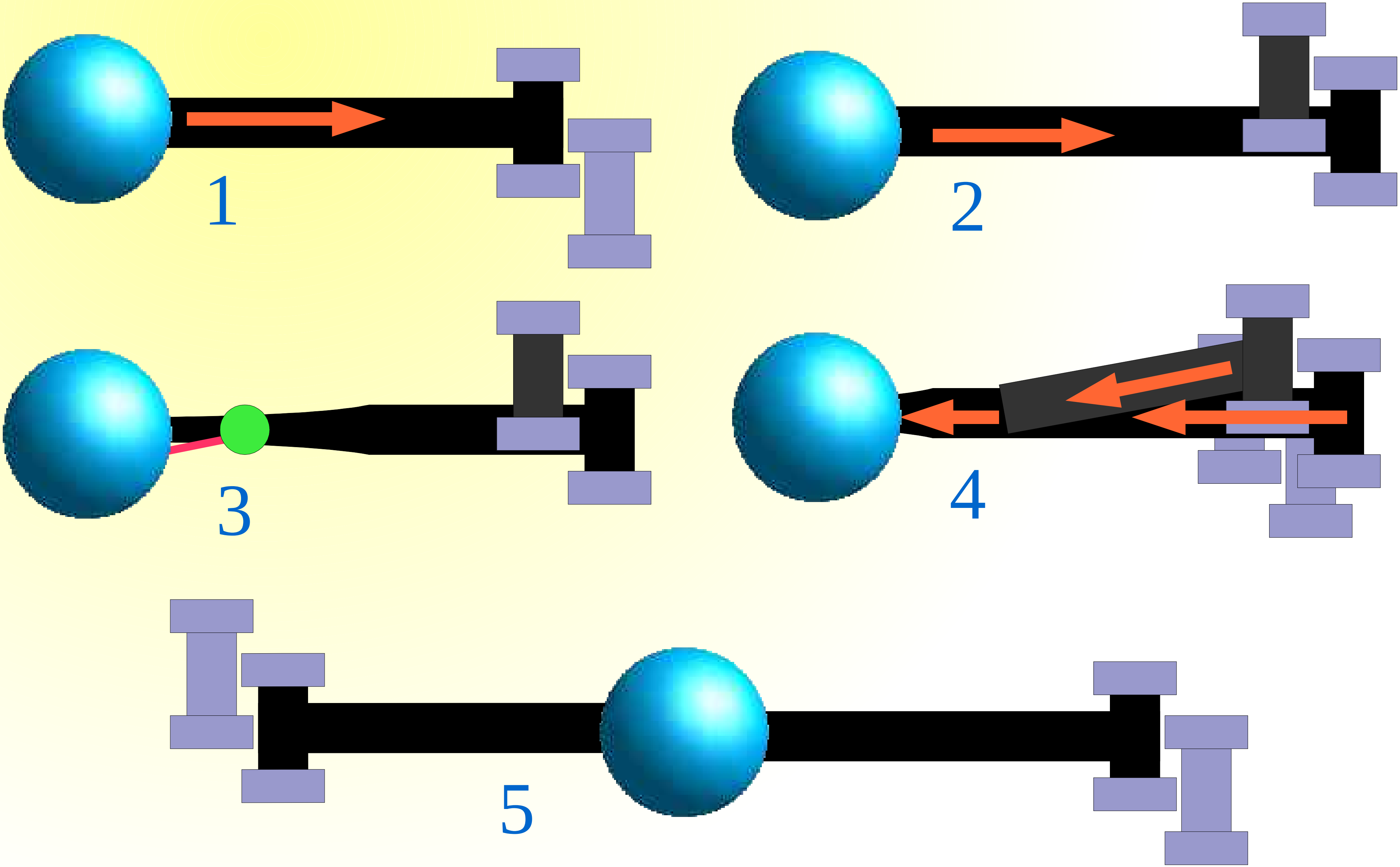
- Exponential Tethers
- Applications
  - Reel-to-Reel Buildup
  - Breeder Elevators
  - Redeploy and Splice Buildup
- Comparison of Buildup Growth Rates

Pull-down Buildup - Concept

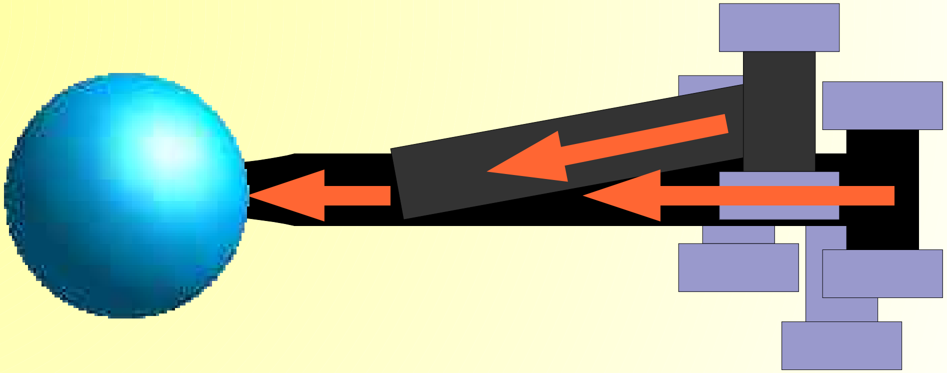
- Use the counter-weight as a pulley
- New problems
  - Tether tangling
  - Counterweight growth
  - Needs more analysis
- Solves many problems
  - Power Use Location
  - Ribbon Waste
  - Reliability



Breeder Elevators



Breeder Elevators



- Fast: Uses strength of material being lifted.
- Does not require inverse taper.
- Involves ribbon cutting. Scary!
- Many variants can be imagined.
- Idea: Why not stick the two tethers together?