The Space Elevator and Geant4

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27 August 2015

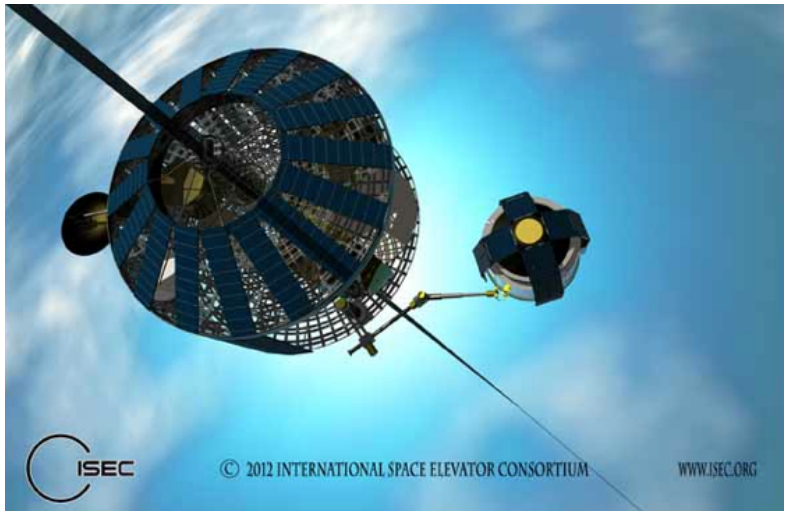
Geant4 Space Users' Workshop

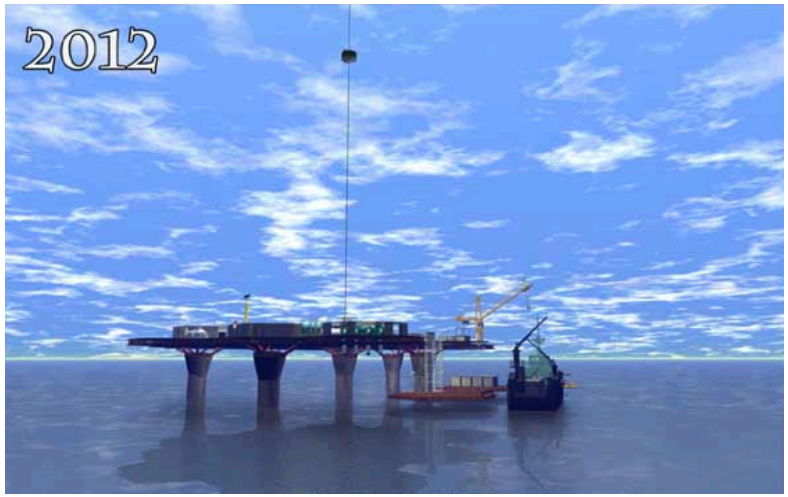
Outline

- A space elevator primer
- Critical technologies
- A space elevator simulator
- Current activity in the field
- Prospects

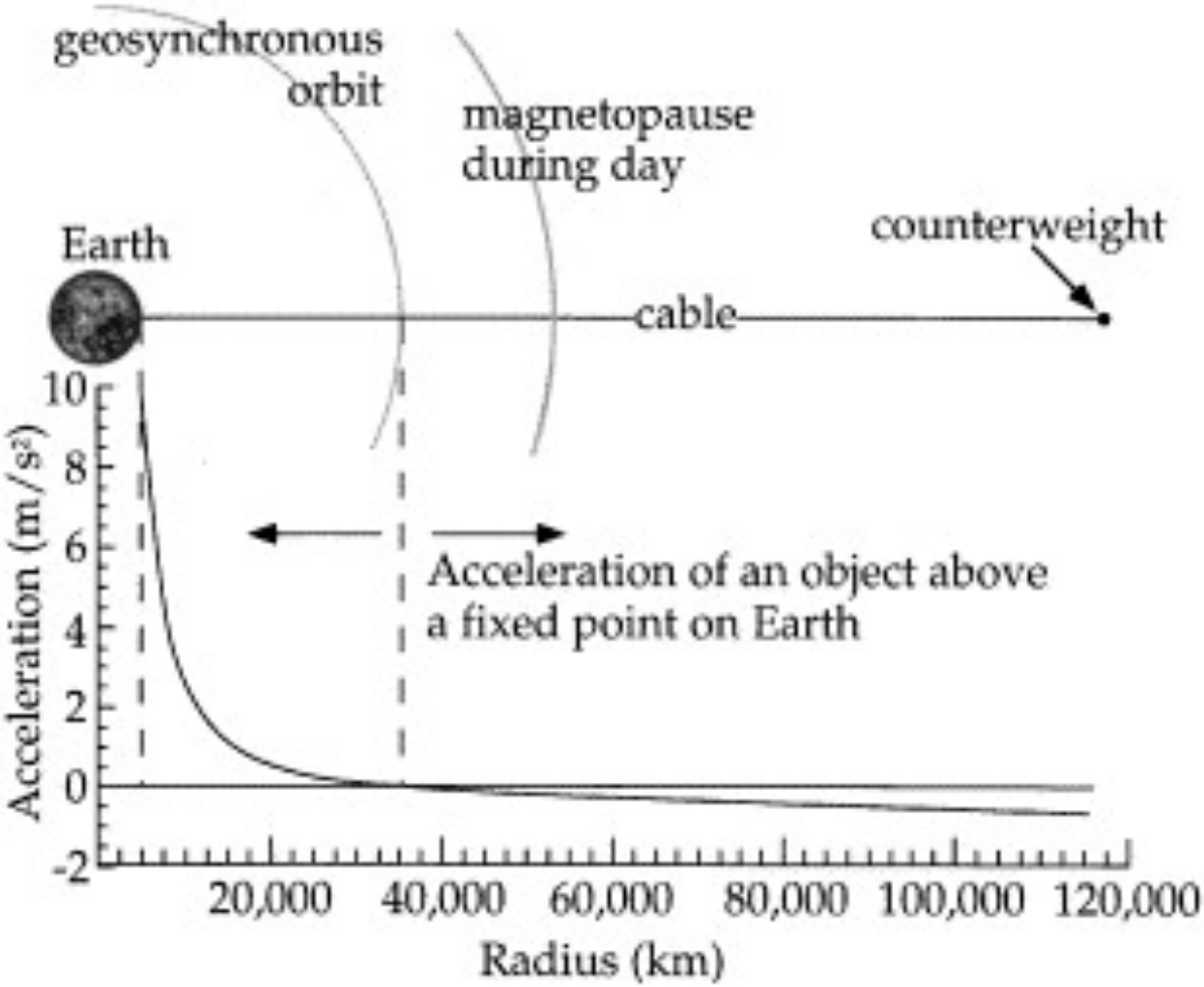
The Modern Space Elevator

- First scientific concept:
  - Tsiolkovsky, 1895
  - compressive tower
- Modern space elevator a tether, not a tower
  - tensile structure, gravitationally stabilized
- DARPA study (Edwards, 1983)
  - SE is feasible with strong materials
- Discovery of CNTs (Iijima, 1991)





Balancing the Forces



Deployment

a) Satellite at GEO with pilot strand

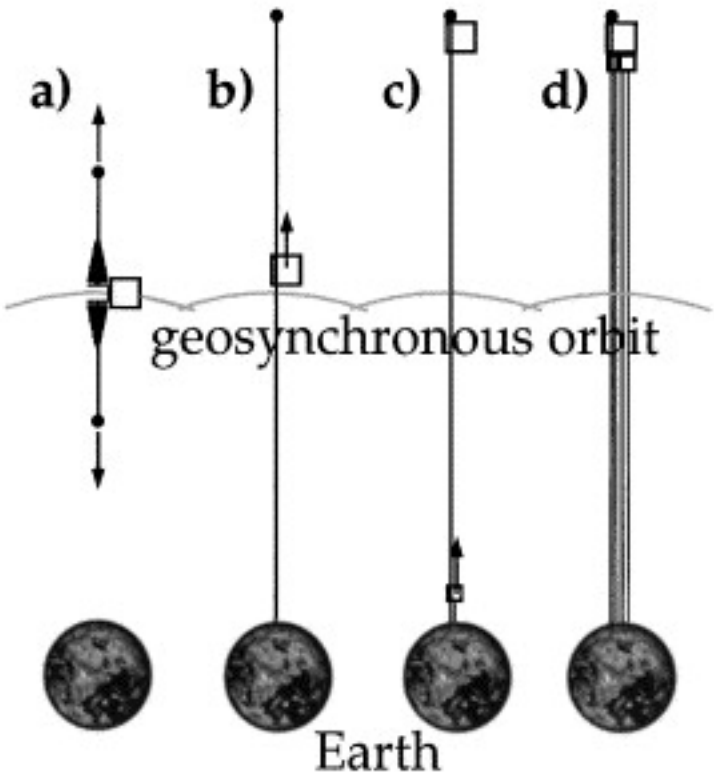
two deployment spools – one up, one down

b) deployment satellite to apex

c) first climber ascends tether with second strand

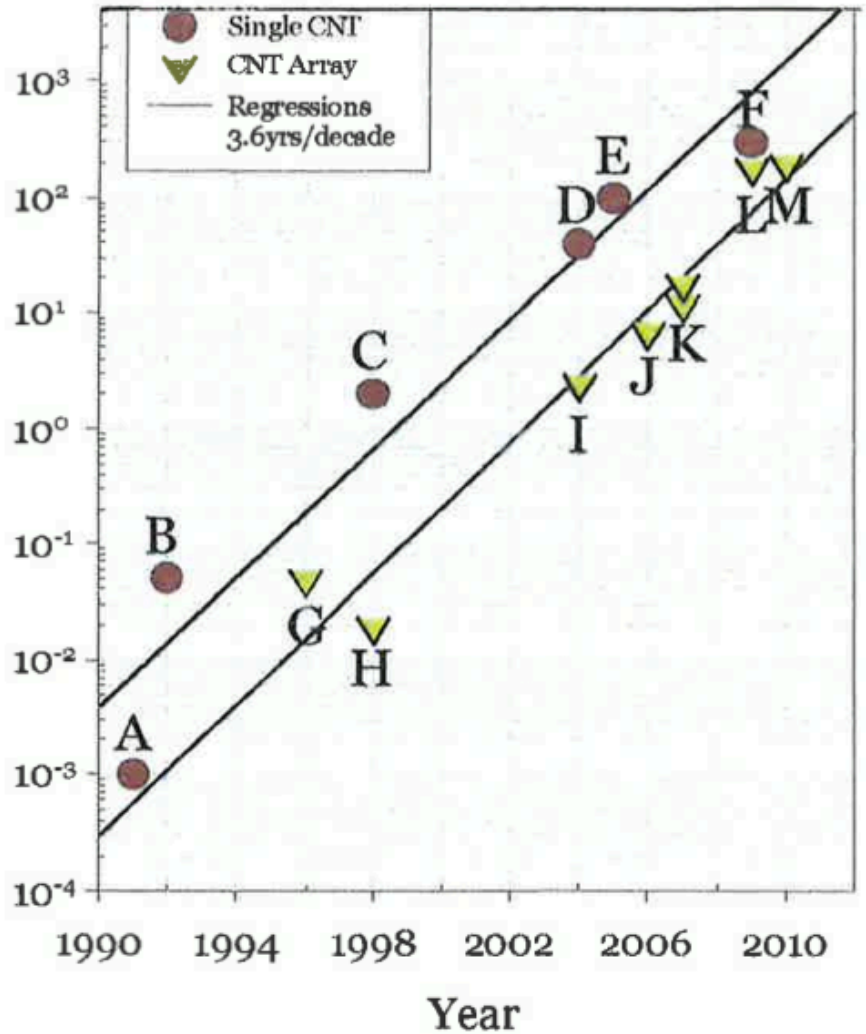
climber stays at apex as part of counterweight

d) subsequent climbers add strands and counterweight mass until design mass is reached



Strong Materials

- Carbon nanotubes
  - strong enough
  - long enough ?
- Climbers
  - rollers
  - maglevs
- Other materials
  - boron nitride
  - solar
  - already strong enough to build lunar elevator



Climbers

- Estimated speed 200 km/h
  - determined from likely power available
  - will arrive at GEO in 7 days
- Mass of first climber: 20 tons (14 ton payload)
  - later climbers will be bigger
- Crawlers
  - grip the tether with rollers and pull themselves up
  - problem: no currently designed bearing can survive the number of revolutions required for a single journey to GEO
- Maglev/linear induction motors
  - use tether to carry current, set up magnetic field

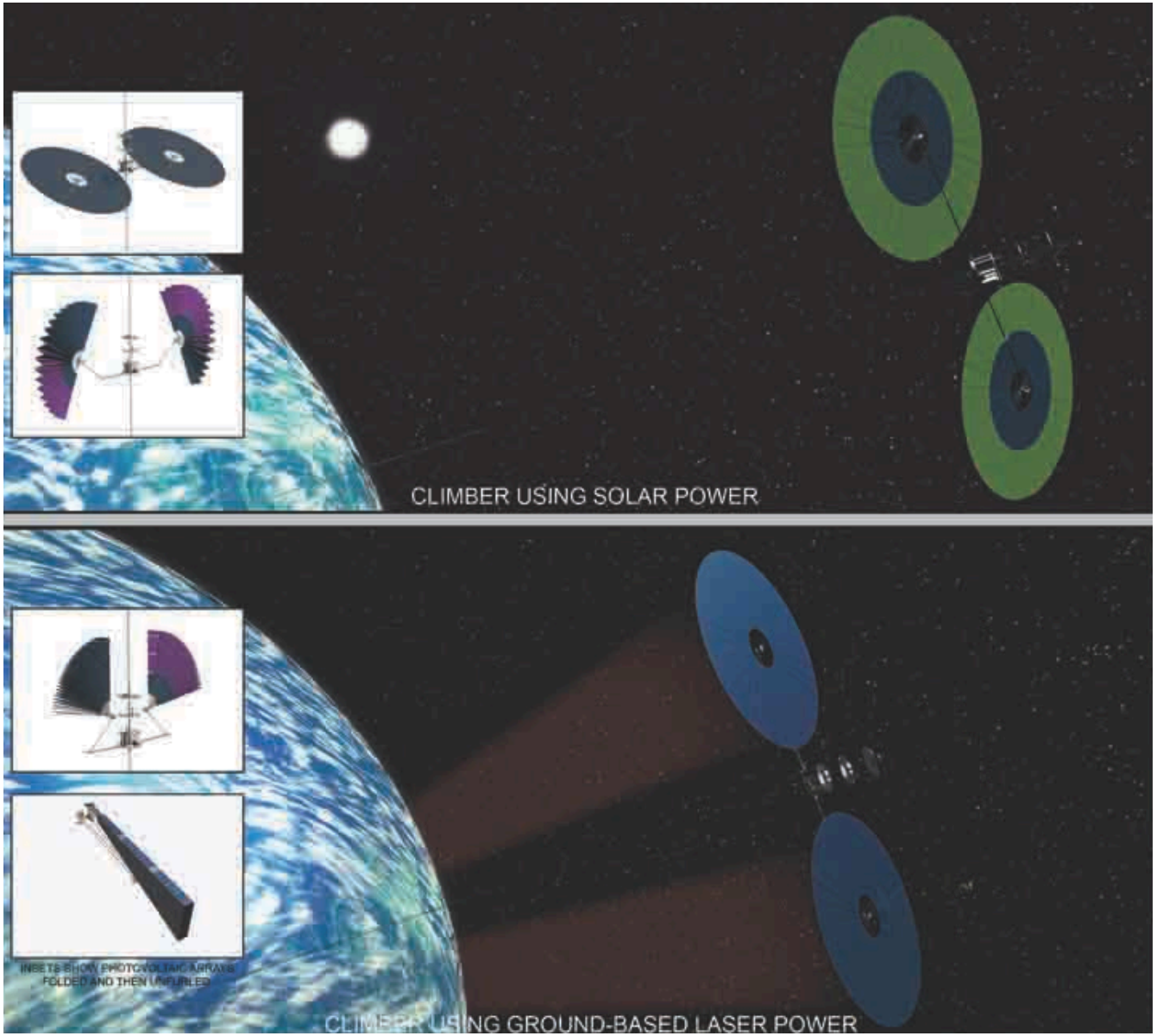
Power Transmission to Climber

- Solar power
  - for medium and high altitudes
  - should be more than adequate

- Beamed power
  - ground-based lasers or microwaves for low altitude
  - more problematic
    - deep in gravity well
    - atmosphere

- Tether as transmission line
  - could be configured as coax cable, or single strand with AC power

Solar and Ground-based Laser



A Space Elevator Simulator

- Major goal for ISEC: a software simulation of all aspects of space elevator operation
  - dynamics of tether and climber
  - electrodynamics
  - radiation effects

- Software framework to accommodate
  - different types of tether dynamics code
  - radiation simulation
  - magnetosphere models
  - databases
  - visualization
  - user interface

Dynamics

- Need to solve the equations of motion for
  - longitudinal and transverse oscillations
  - torsion
  - lunar and solar tides
  - moving loads (climbers)

- Example: transverse oscillations on tether in gravitational field

$$\rho \frac{\partial^2 \eta}{\partial t^2} = E\varepsilon_0 \frac{\partial^2 \eta}{\partial x^2} + \rho\Omega^2 \left[1 - \frac{R_G^3}{(R_E+x)^3}\right]\eta - E(1+\varepsilon_0)\frac{W^2}{12}\frac{\partial^4 \eta}{\partial x^4}$$

  - η is amplitude of transverse vibration, x distance along tether
  - R_G , R_E are geosynchronous and Earth radii
  - E, ε_0 , ρ are Young's modulus, longitudinal strain and density of tether

Dynamics

- Without gravity, previous equation is that for a stiff piano string
  - with gravity, no closed-form solution
  - equations quickly become non-linear when coupling to other oscillation modes
  - complexities mount up with moving loads, tides

- Numerical simulators needed (Runge-Kutta, etc.)
  - well-known problems with stability of solutions
  - discretized tether and finite element approaches being tried

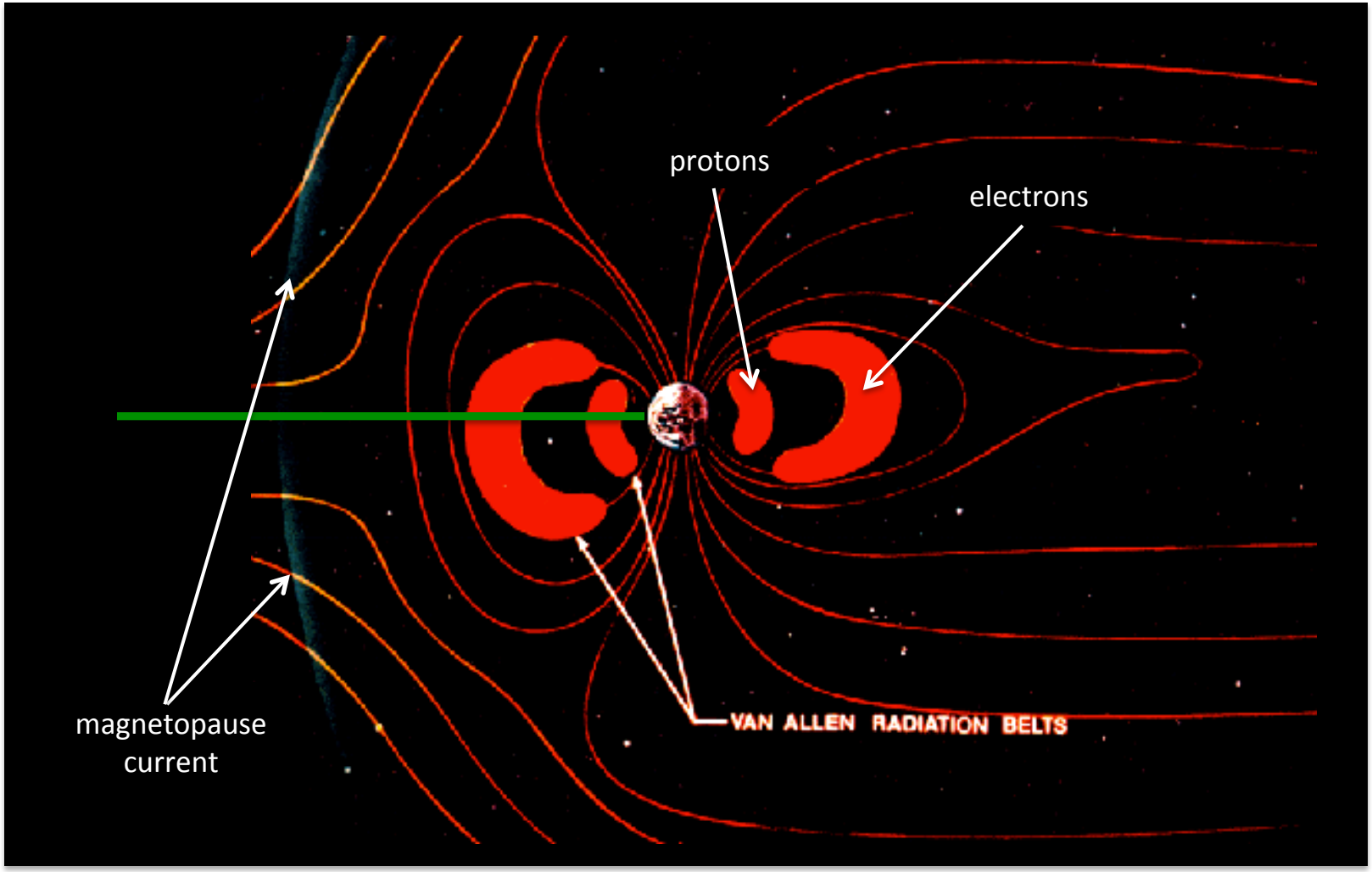
Geant4 Space Elevator Simulation Jobs

- Charging
  - accumulation of charge from space environment
  - spacecraft charging can be severe, especially if there are loose ends, sharp edges

- Radiation pressure (Compton, photo-electric, solar wind)
  - 1 m wide, 10^8 m long tether → huge solar sail, effects dynamics

- Radiation damage (CNTs, climber, passengers, …)
  - upper bound < 3 MRad/yr in radiation belts
  - trip to GEO takes 1 week, passengers require shielding
  - SEE in electronics
  - can DNA physics be applied to CNTs?

Magnetic and Radiation Environment



Geant4 Space Elevator Simulation Jobs

- Modeling the magnetosphere
  - augmented version of Planetocosmics?
- Micrometeorite and debris collisions
  - can treat as Geantinos passing through tether, scoring hits
  - use to design optimal tether cross section (curved, not curved, thickness, etc.)
- Monatomic oxygen
  - dynamics effect of 1 km/s particle impacts
  - simulate frequency of bonding with/breaking CNTs?

Current Activity in the Field

- International Space Elevator Consortium (www.isec.org)
  - a non-profit (501(c)(3)) group of engineers, scientists, writers and artists
  - yearly studies covering single aspects of SE development
  - annual meeting in August in Seattle

- Japan Space Elevator Association (www.jsea.jp)
  - also a non-profit
  - sponsored Space Elevator Games 2009 (climber competition)

- Obayashi Corporation
  - large general contractor company (Tokyo)
  - currently working on linear motor climbers

Prospects

- Schedules
  - ISEC (2035)
  - Obayashi (2050)

- Cost
  - $10 - $50 billion (< ISS: $84 billion from US and partners)
  - when SE in operation, $100/kg to GEO
    - $22,000/kg for Space Shuttle

Conclusion

- Arthur C. Clarke predicted that a space elevator will be built "about 10 years after everyone stops laughing."
  - most people have stopped laughing
- Space elevator research is going on now
  - Geant4 will play a significant role
- Plenty of work to do!
  - volunteers welcome
  - maybe even funding in the near future

Student Climber Competition