Paths to Space Settlement

Space Tourism -- Space Solar Power -- Planetary Defense

"For me the single overarching goal of human space flight is the human settlement of the solar system, and eventually beyond. I can think of no lesser purpose sufficient to justify the difficulty of the enterprise, and no greater purpose is possible," -- Michael Griffin

Al Globus

San Jose State University, NASA Ames

Chairman, NSS Space Settlement Advocacy Committee

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Space Settlement

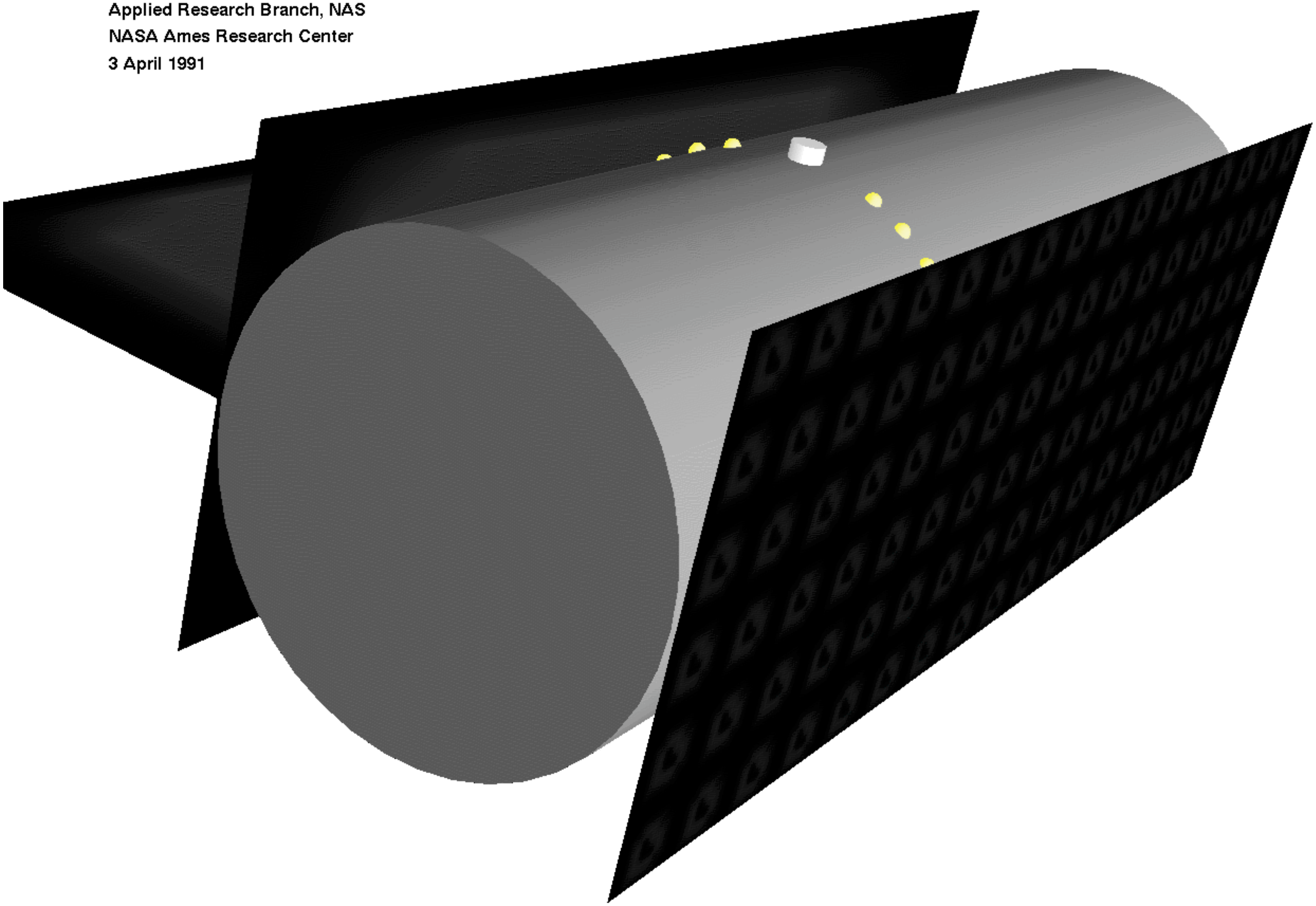
- Not just a place to go work or visit for a limited time
  - Not a space station like ISS
  - Not exploration
- A home in space
  - Hundreds or thousands of residents
  - Many space settlements (thousands)
- Some stay for life
- Some raise kids

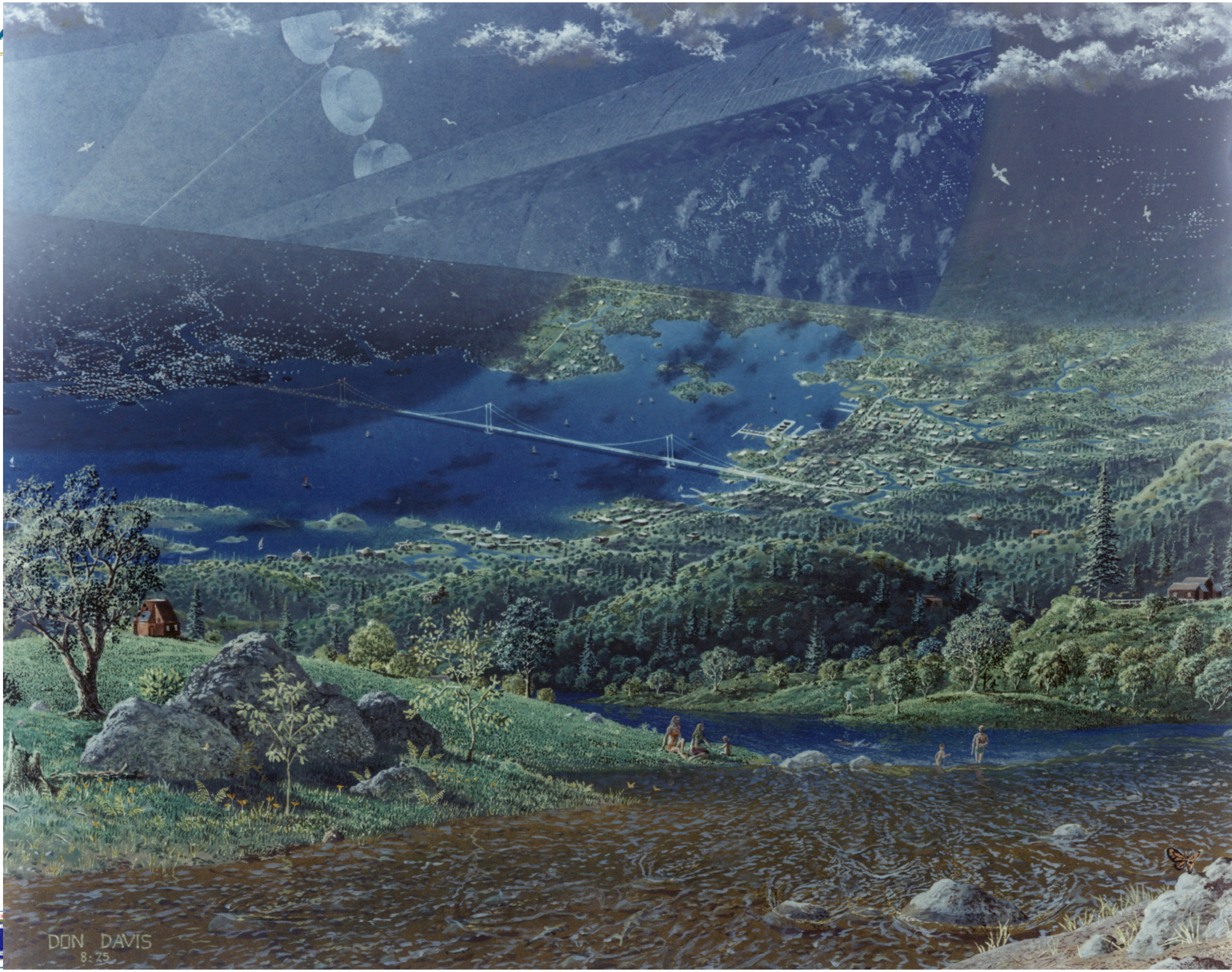
Where? Orbit

- To raise children that can visit Earth requires 1g
  - Moon 1/6g Mars 1/3g
  - Orbit any g, for 1g rotate at 2rpm = 250m radius
- Continuous solar energy
- Large-scale construction easier in 0g
- Short supply line to Earth (hours vs days/months)
- Greater growth (Moon/Mars 2x vs orbit 100+x)
- Orbital disadvantage: materials
  - Need millions of tons, mostly shielding and structure
  - Moon: metals, Si, O
  - Near Earth Objects (NEO): wide variety

Lewis One Exterior

Image: Al Globus, CSC
Software: Jeff Hultquist
Applied Research Branch, NAS
NASA Ames Research Center
3 April 1991

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Why

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Wealth and Power

- China's Ming dynasty
  - 1400-1450 ocean exploration
  - Pulled back, was colonized
- English 100 Year War 1337-1453
  - Failed military expansion in known world
  - Established empire overseas
    - English merchant marine, 1485-1509
    - 1550s Irish colonization
    - American colonies 1600s
- 625 million x energy on Earth
  - Total solar energy available
- One smallish NEO, 3554 Amun, contains $20 trillion materials.
  - There are thousands of such asteroids

What Do We Need?

- Earth to Orbit transportation
- Build really big things in orbit
  - Habitats, solar collectors, thermal rejection
  - Use local materials (ISRU)
    - Moon, NEOs
- Stay alive
  - small semi-closed plant-based ecosystem
- Pay for it
  - Unlikely fiscal 2010 line item
  - Piggy-back space tourism, SSP, planetary defense, (molecular nanotechnology)

Launch Problem

- Thousands of dollars per kg
- Failure rate about one percent
- Forces mass, power optimization
  - Leads to small margins requiring extensive analysis and testing
  - No repairman!
    - Redundancy expensive, particularly testing
- In man-hr/kg to orbit, Saturn V cheapest!
- Low volume (55 in 2005)

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Tourism = Launch Volume

Price/ticket	Passengers/year
$1,000	20,000,000
$10,000	5,000,000
$100,000	400,000
$250,000	1,000
$500,000	170

Crouch, G. I., “Researching the Space Tourism Market,” Presented at the annual Conference of the Travel and Tourism Research Association , June 2001.

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Tourism Path

- Sub-orbital tourism
  - Virgin Galactic ($200K)
  - XCOR ($95K)
- Orbital tourism
- Orbital hotels
  - ISS ($30M)
  - Bigalow (2011?)
- Low-g retirement
- Special group habitats
- General space settlement

Launch Prizes

- Pay to put people in orbit
- Pay for many launches
- Limit payout fraction to any one competitor
- Estimate $1 - 8 billion in prizes to get cost to $10,000/person
- Based on costs estimates by tSpace, SpaceDev
- Safety: key personnel on flights

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Launch Prize Schedule

Passenger	K$/Pass	Cost($M)	Comp. 1	Comp. 2
25	15,000	375	262	113
25	10,000	625	437	188
25	5,000	750	525	225
50	2,000	850	595	255
50	1,000	900	630	270
100	100	910	637	273
1,000	50	960	672	288
10,000	10	1,060	742	318

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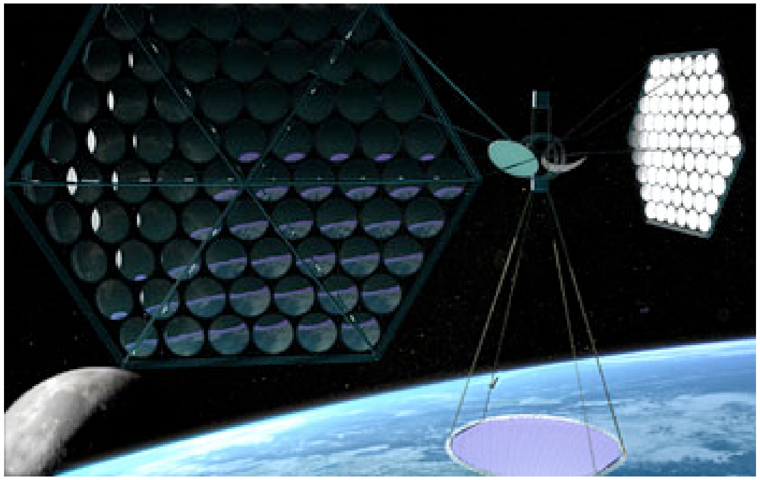
Floating to Orbit

- Airships (JP Aerospace)
  - Experimentalists
  - Vehicles
    - Ground to 120,000 ft
    - Floating base at 120,000 ft
    - Orbital vehicle constructed at base
      - Km scale
      - Floats to 180,000 ft
      - Low thrust engines
      - 1-5 days to get to orbit
      - High drag return

SSP = Launch Volume, ISRU

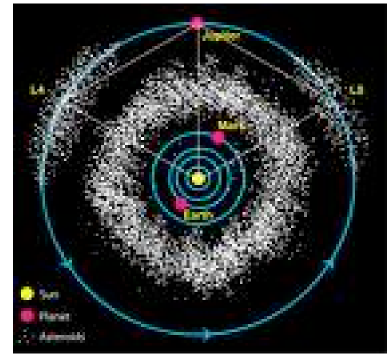
- Today's market 18 TW
  - $8Tr/yr @ $0.05/kw-hr
    - US Military $1/kw-hr remote regions
  - Tomorrow's market much larger
  - 18 Mtons sat @ 1kg/kw
    - 100,000 Ares V launches
  - Depose King Oil
    - Requires electric cars
- ISRU
  - Lunar Si and metals supply most mass
  - Extremely green



SSP Systems (60s)

- Sea Dragon Launch Vehicle
  - 150m tall, 23m diameter
  - Pressure-fed engines
  - 8mm steel tankage
  - Ocean launch, shipyard construction
  - 1.2 million lb to LEO @ $200/lb
  - 0.5 GW sat per launch
  - $27B development cost
- Solar-electric orbital transfer vehicle
- Teleoperated robotic assembly

Planetary Defense



- Thousands of dangerous NEOs
- Large fraction will impact Earth
- NEO detection identifies potential materials sources
- Deflection technology may be adapted for retrieval
  - Small NEOs (10-50m) for safety

- Modest cost for excellent program

Space Programs

- Constitutional (promote the general Welfare)
  - Earth observation
  - Launch
  - Planetary defense
  - Aeronautics
  - SSP
  - Science
- Space Settlement
  - Launch
  - Lunar/NEO mine
  - Material transport
  - In-orbit materials processing and manufacture
  - SSP
  - Large construction
  - Life support

Life Support 'Easy'

- Consider Biosphere II
- Six people in closed environment for over one year on first try
  - We know it was closed, ran out of oxygen
- Scientific failure hid engineering success
- Lots of species
  - Survival of the fittest
  - Make sure most are edible

Conclusion

The settlement of the solar system could be the next great adventure for humanity. There is nothing but rock and radiation in space, no living things, no people. The solar system is waiting to be brought to life by humanity's touch.

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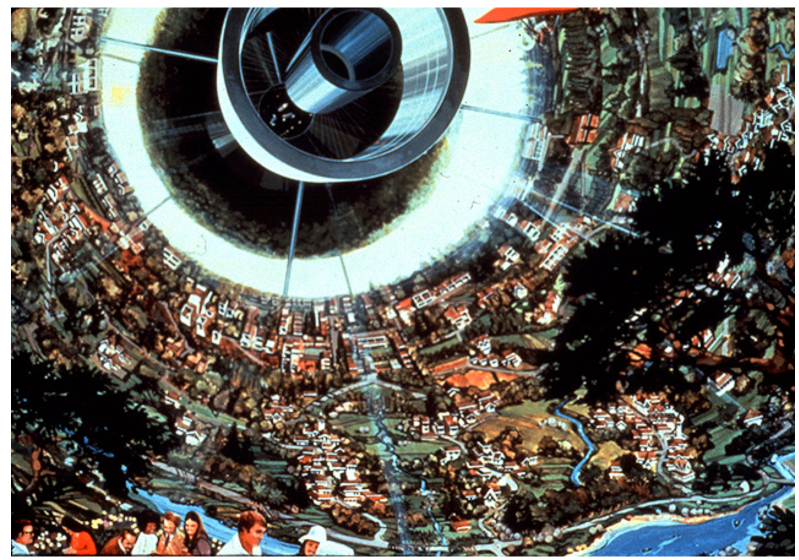
Nice Place to Live

- Great views
- Low/0-g recreation
  - Human powered flight
  - Cylindrical swimming pools
  - Dance, gymnastics
  - Sports: soccer
- Independence
  - Separate environment
  - Easy-to-control borders



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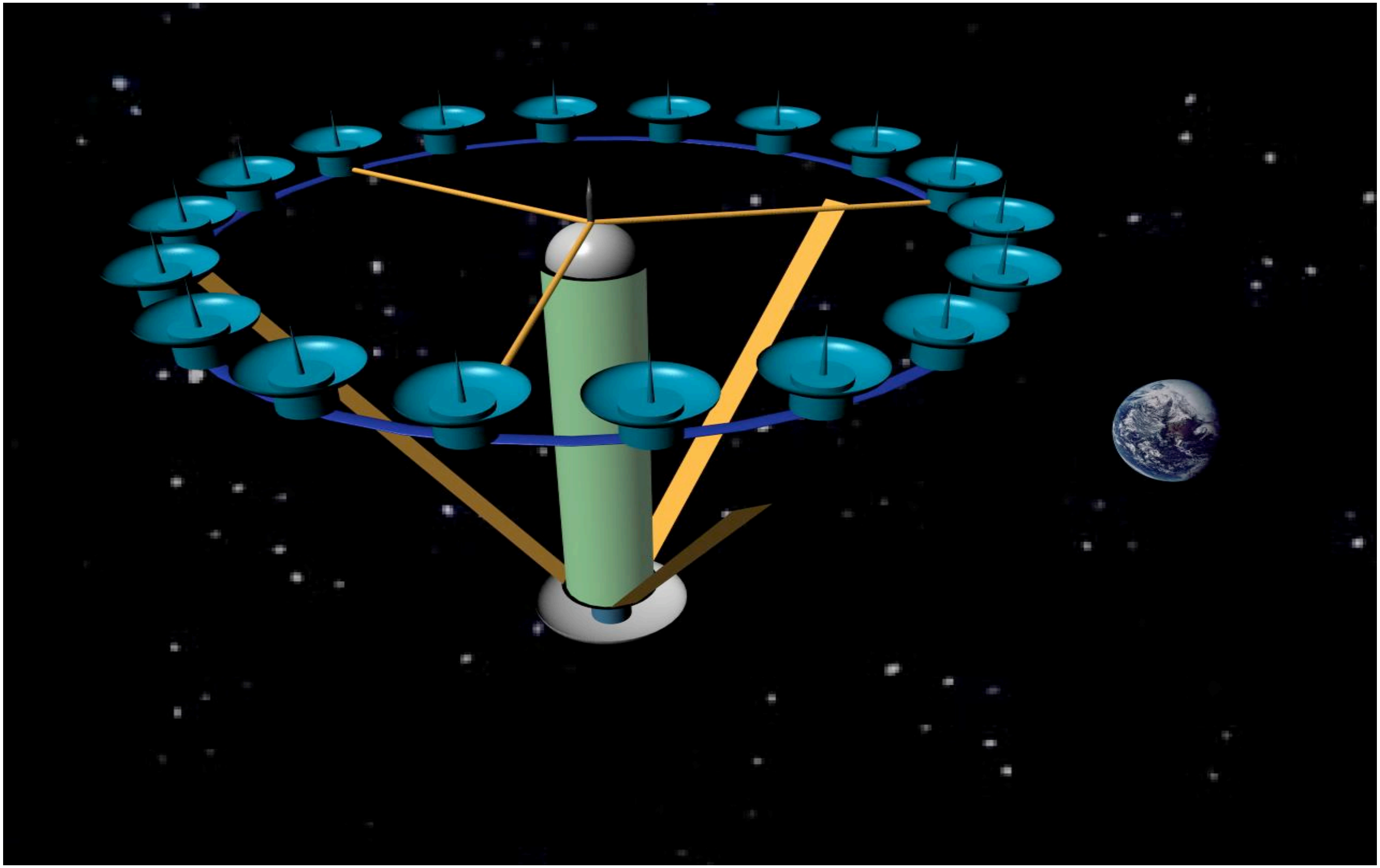
Low-g Retirement

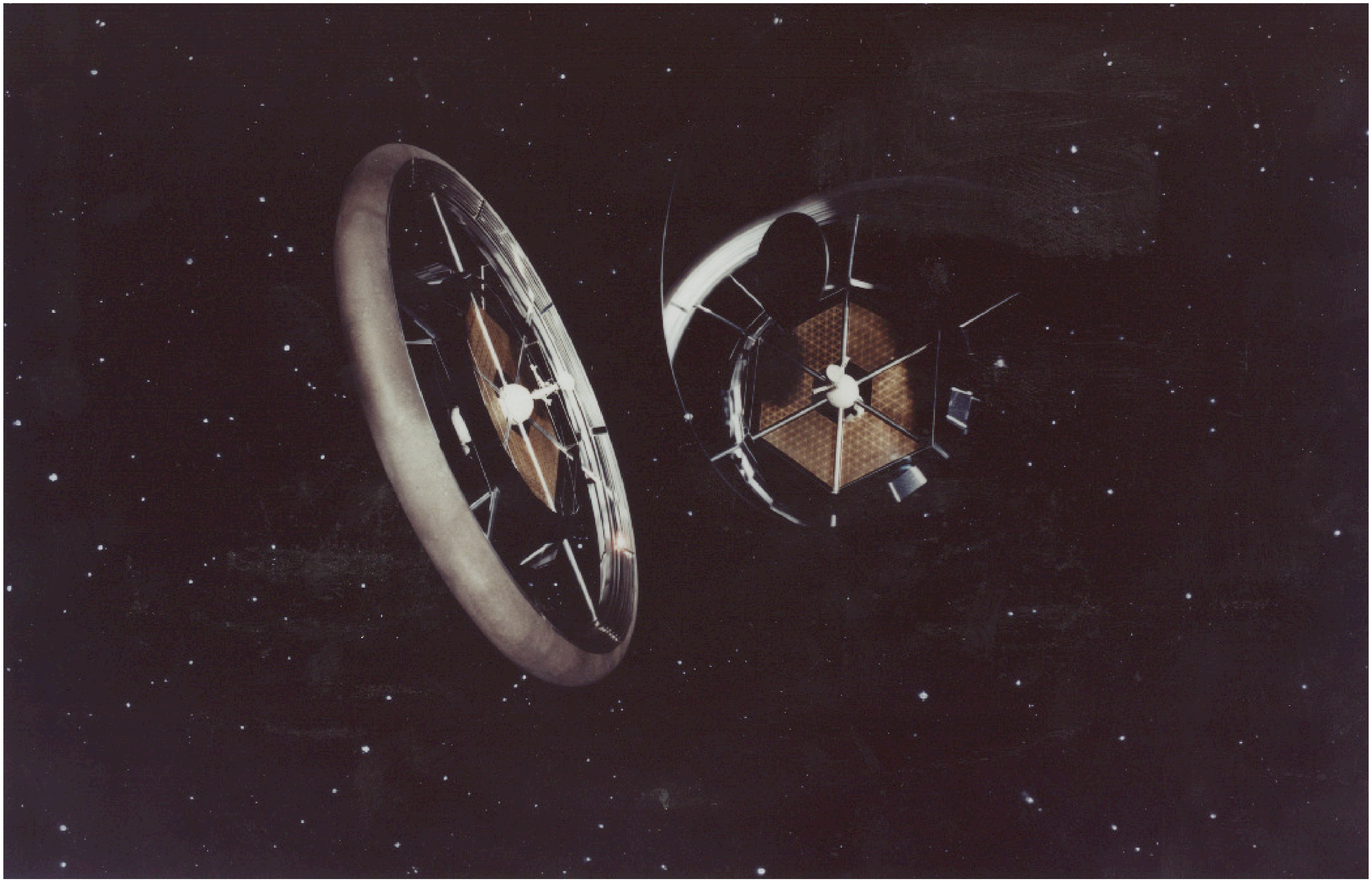
- No wheelchairs needed.
- No bed sores.
- Never fall and break hip.

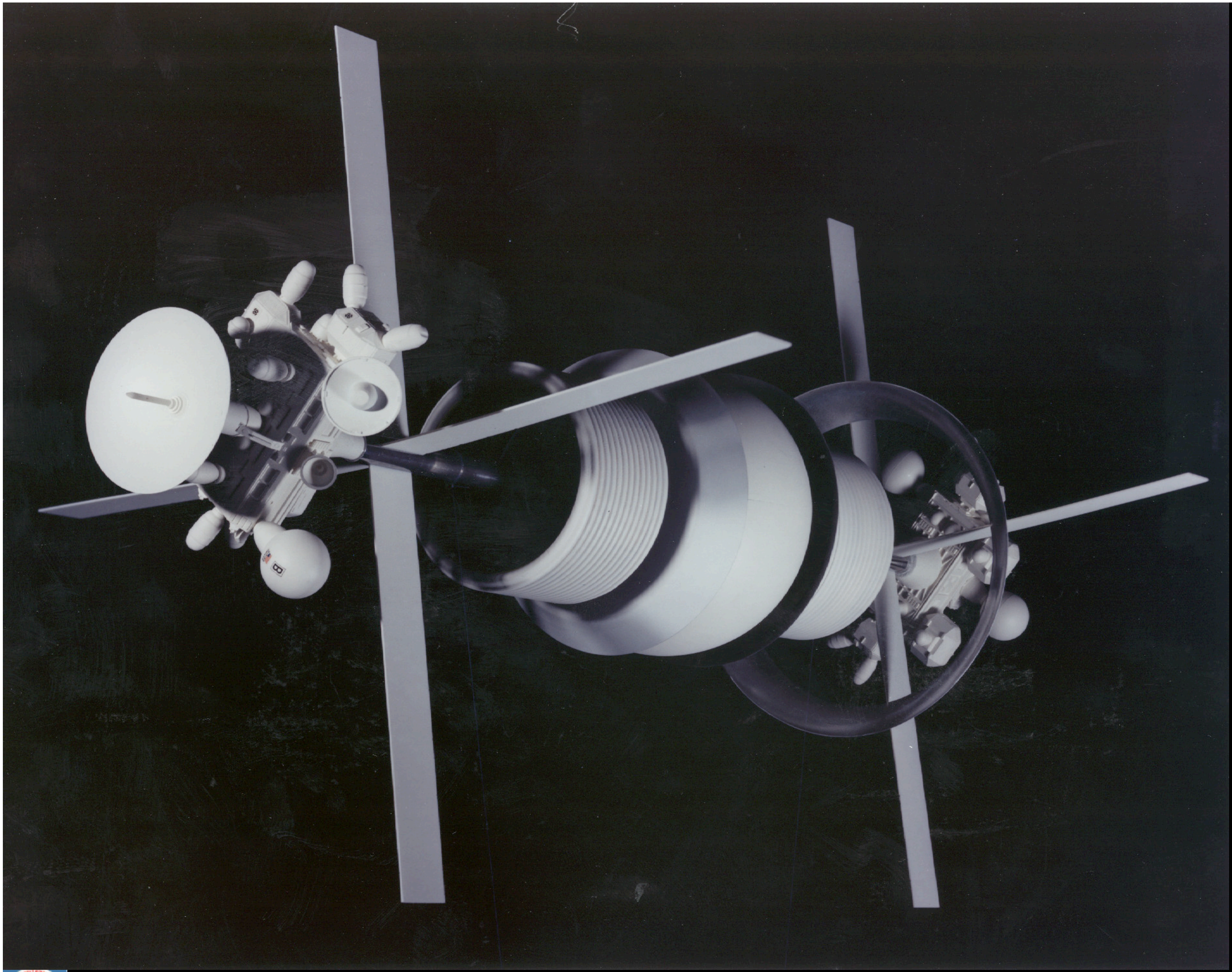
- Grandchildren will love to visit.
- Need good medical facilities.
  - Telemedicine
- Probably can't return to Earth.

O'Neill Cylinder



Stanford Torus





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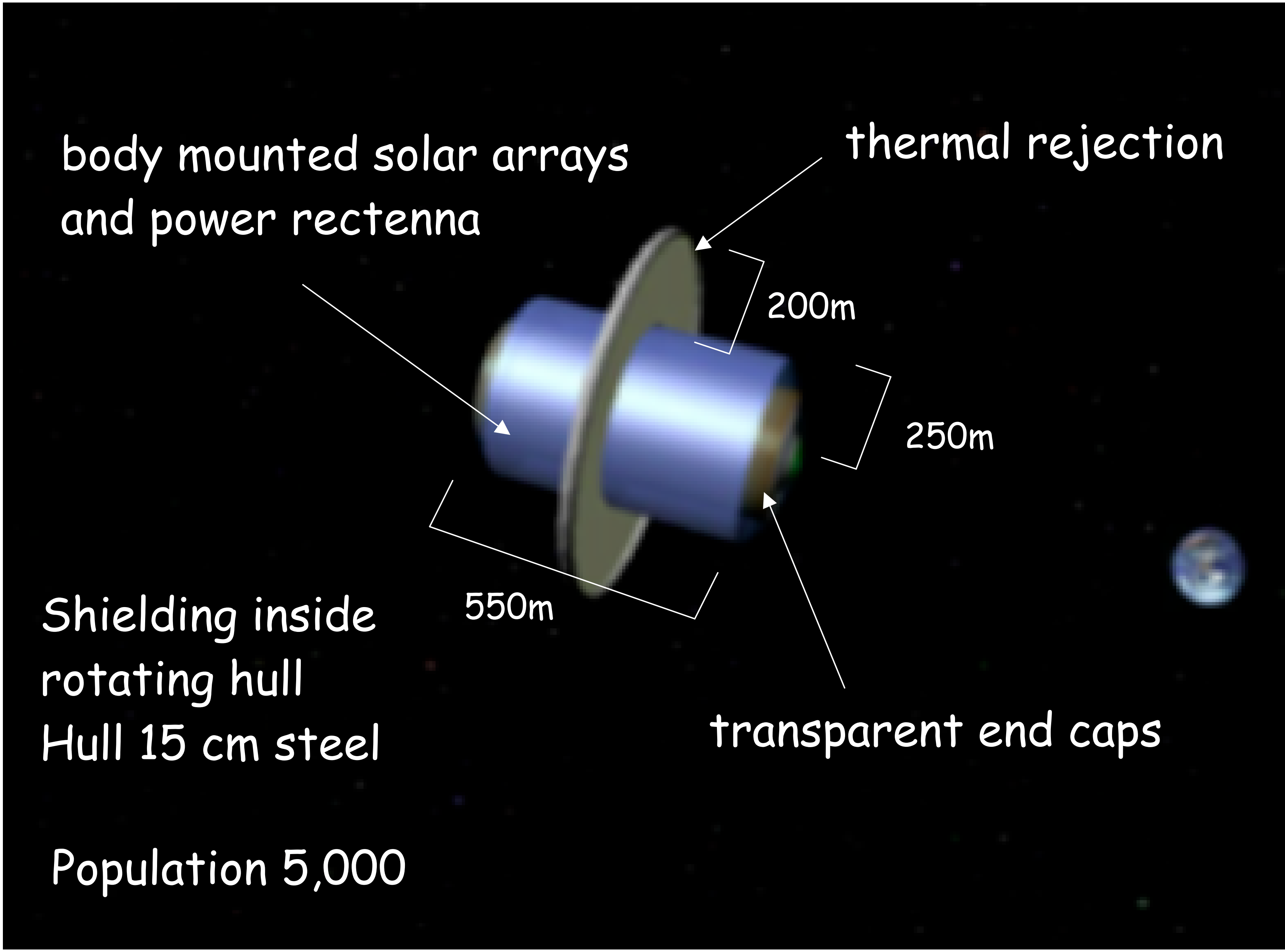
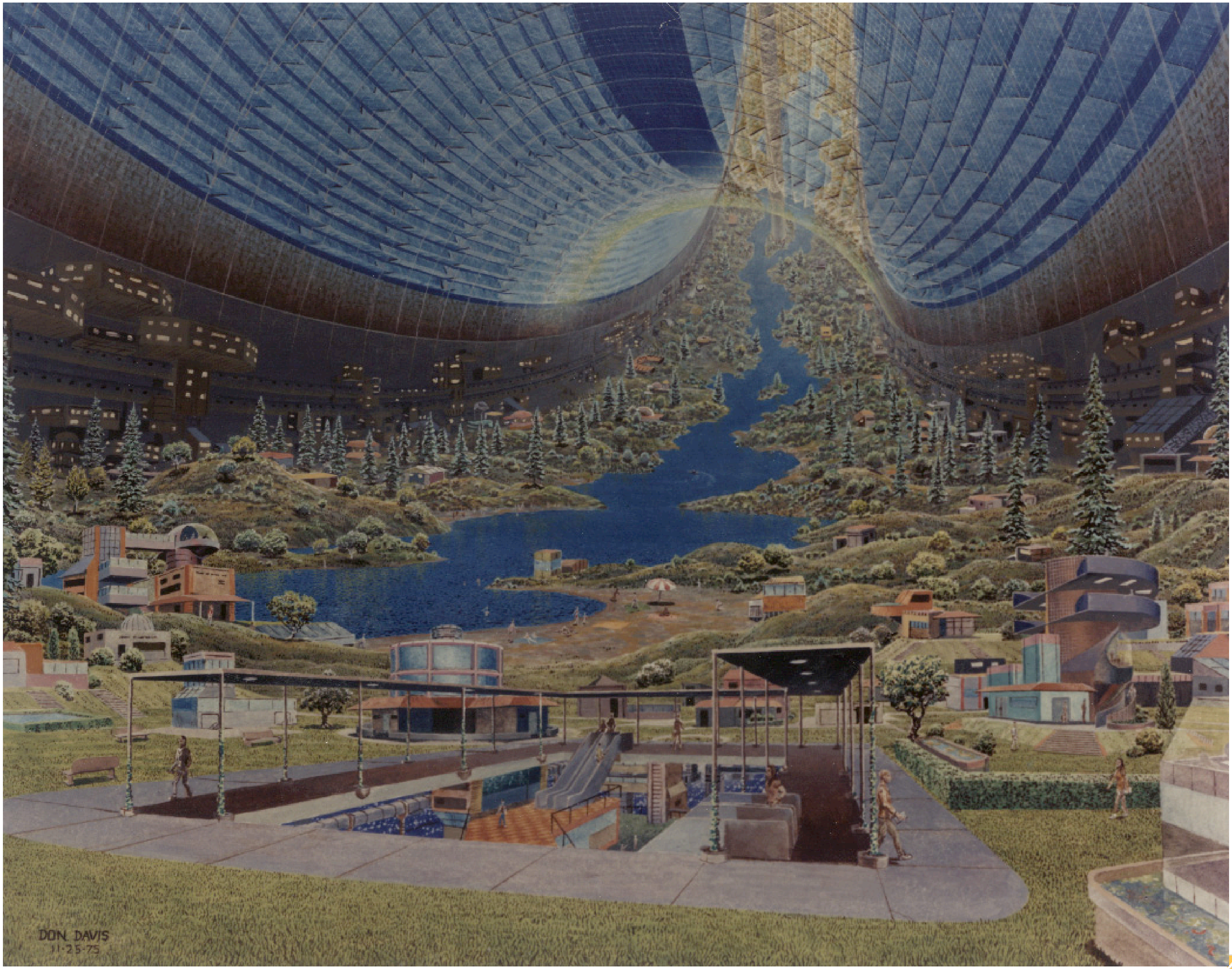
Kalpana One


body mounted solar arrays
and power rectenna
thermal rejection
200m
250m
550m
Shielding inside
rotating hull
Hull 15 cm steel
transparent end caps
Population 5,000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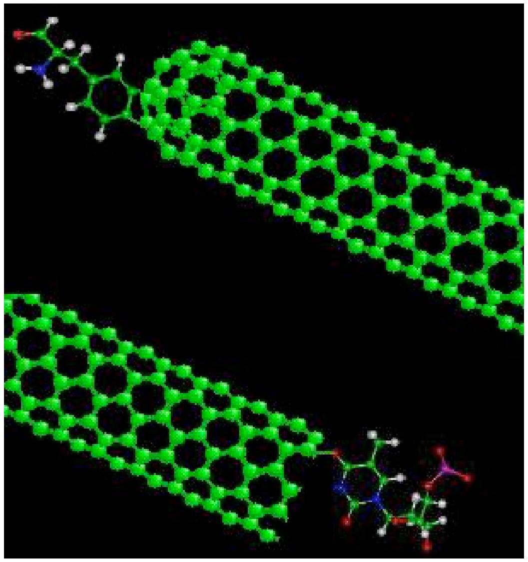
Growth

- Largest asteroid converted to space settlements can produce 1g living area 100-1000 times the surface area of the Earth.
  - Reason: 3D object to 2D shells
  - Easily support trillions of people.
  - New land
    - Build it yourself
    - Don't take from others

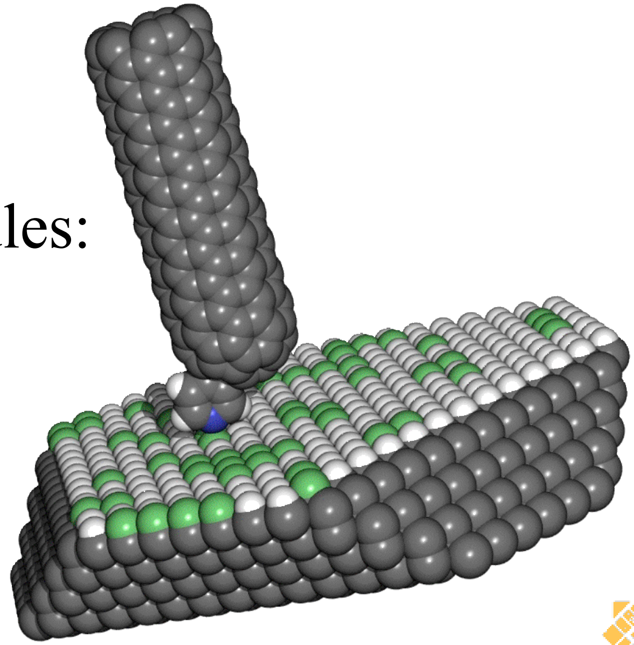
Three Pillars of Molecular Nanotechnology

- Atomically precise control of matter
- Molecular machines
- Programmable matter

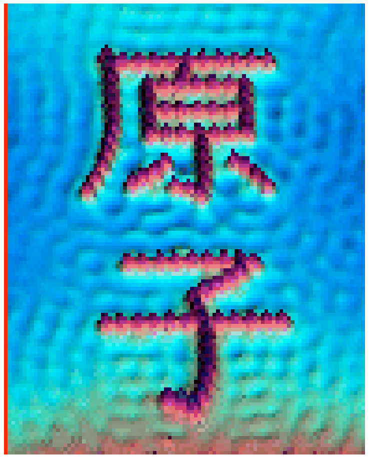


Our favorite molecules:

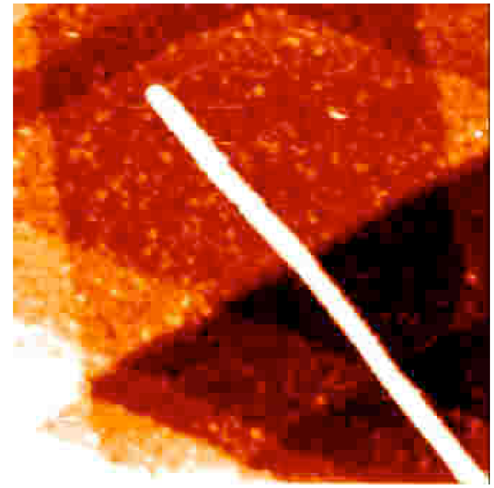
carbon Nanotubes

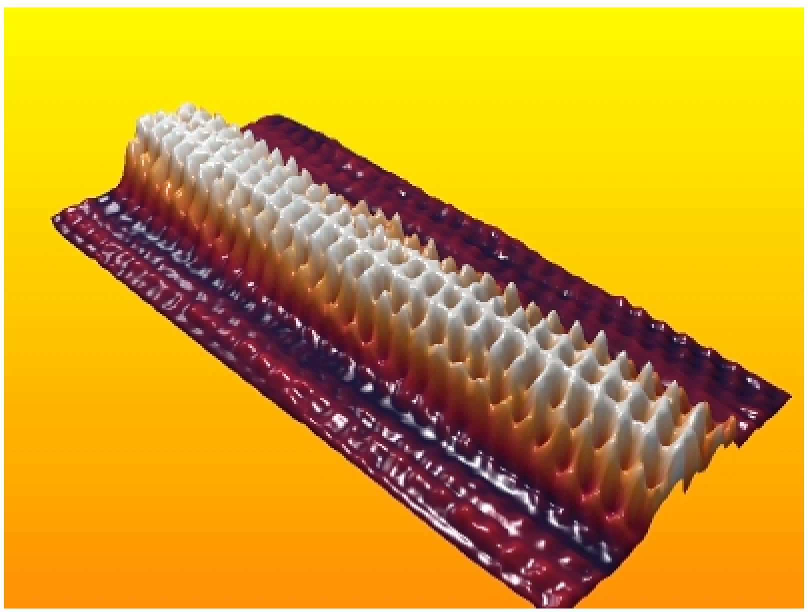


Atomically Precise Control of Matter

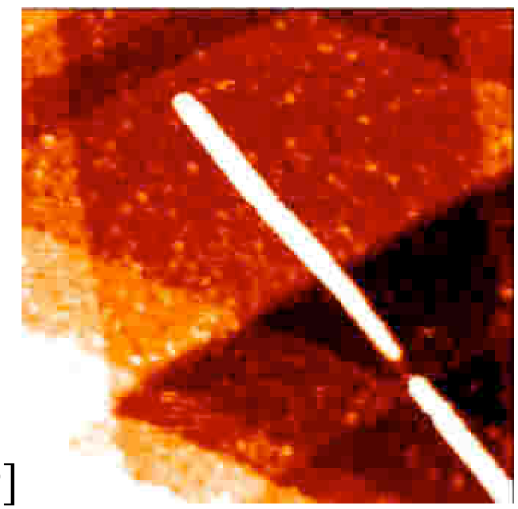


http://www.almaden.ibm.com:80~
/vis/stm/atomo.html

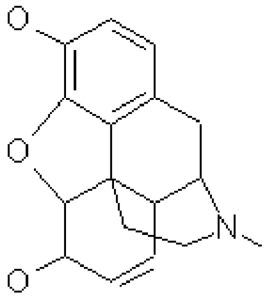


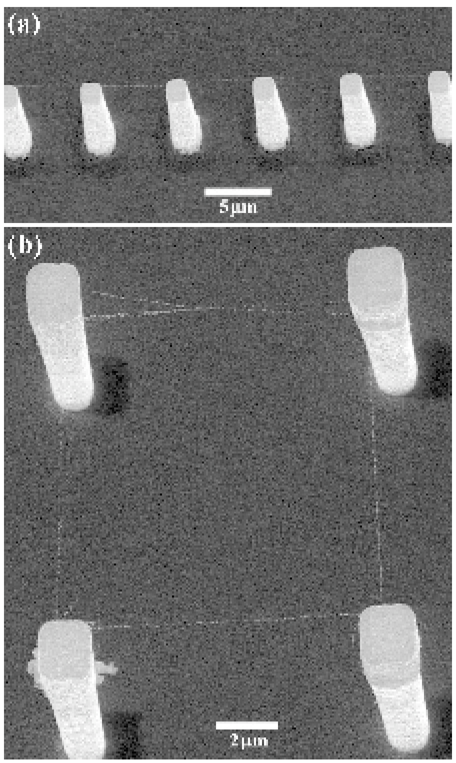


[Dekker 1999]

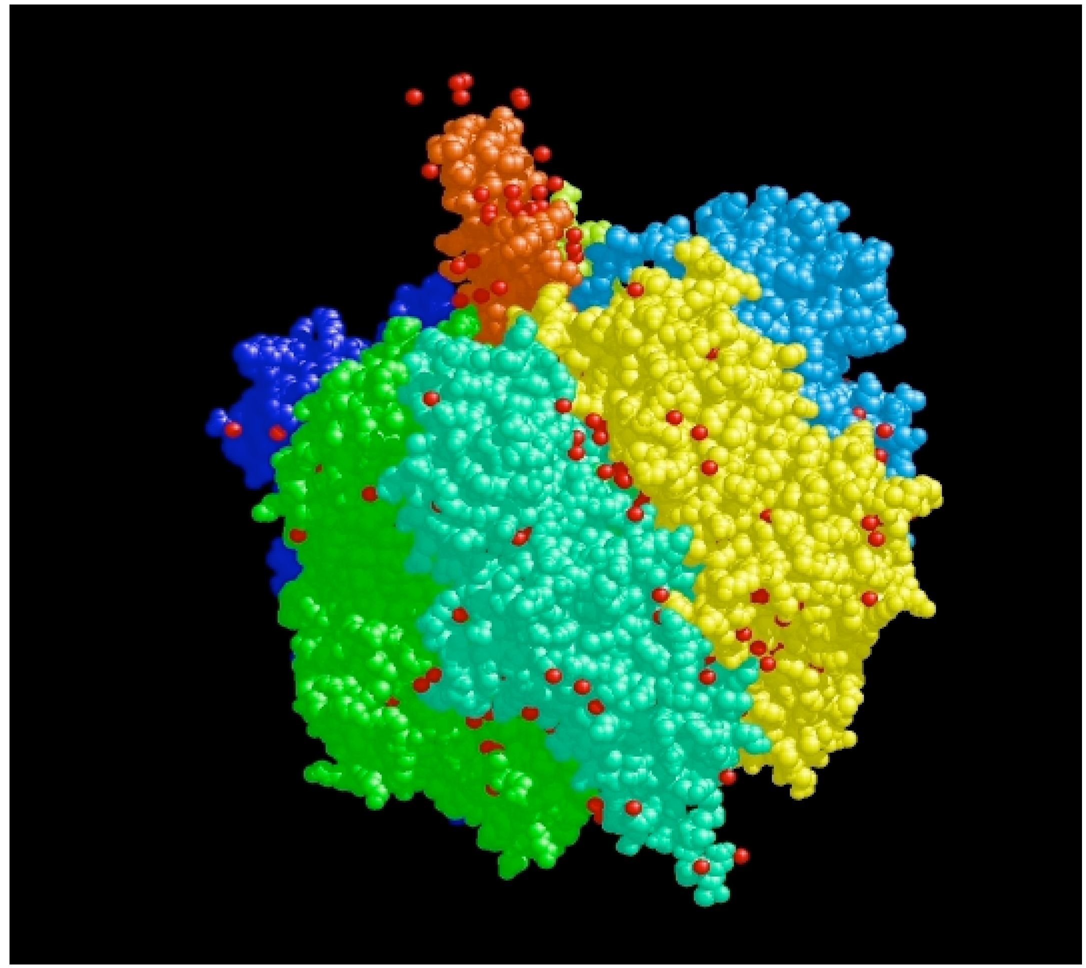


Molecular Machines





[Cassell 1999]



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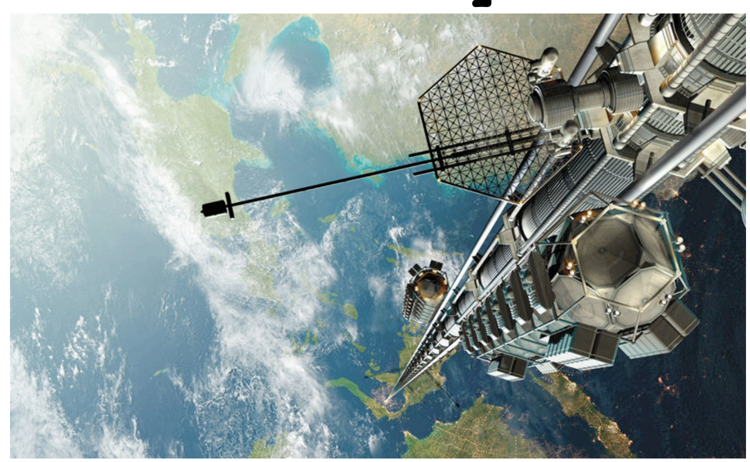
What Can you Get?

- Diamondoid materials with great strength, thermal properties, stiffness.
- Existing design diamondoid SSTO $153-412/kg to orbit vs $16,000-59,000/kg for titanium [McKendree 95]
- Three-ton four-person clean sheet diamondoid SSTO vehicle [Drexler 1992]
- May enable space elevator



Paths

- Space Tourism
  - Launch - Habitats - Life support
- Space Solar Power
  - Launch - Large structures - Lunar ISRU
- Planetary defense
  - NEO ISRU