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Paths to Space Settlement

Space Tourism -- Space Solar Power
Planetary Defense -- Molecular Nanotechnology

"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

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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

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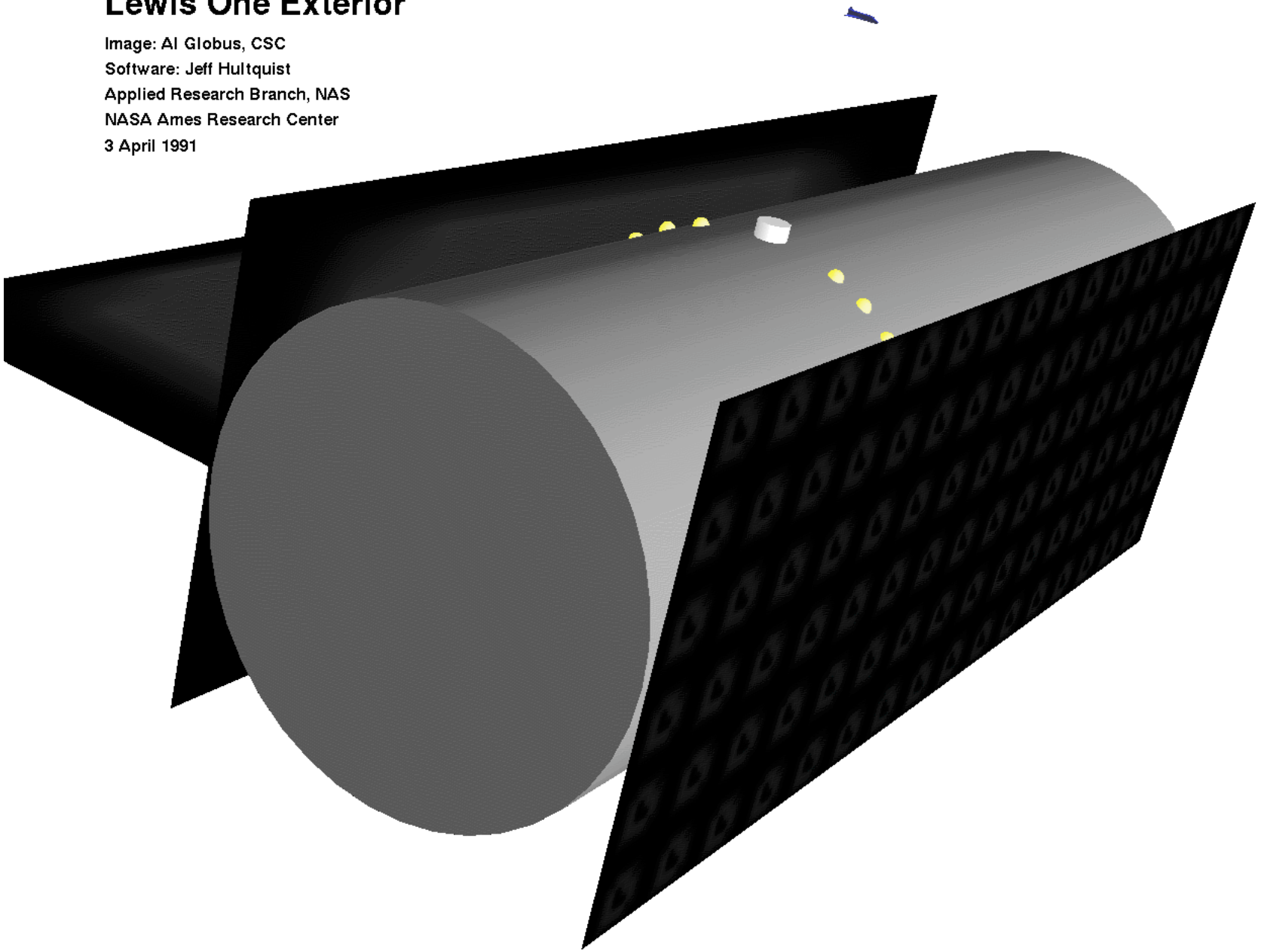
Where? Orbit

- 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)
- 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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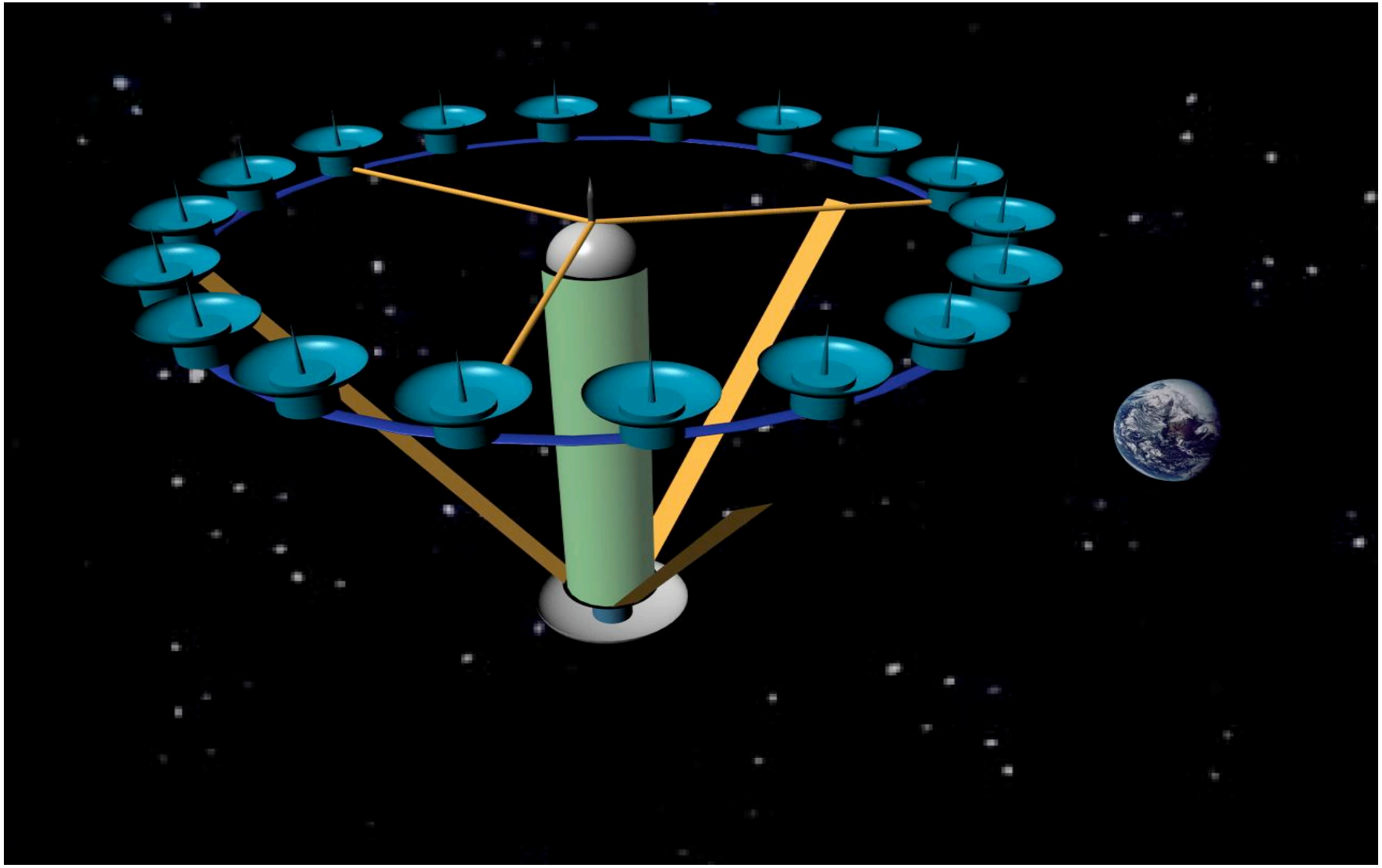
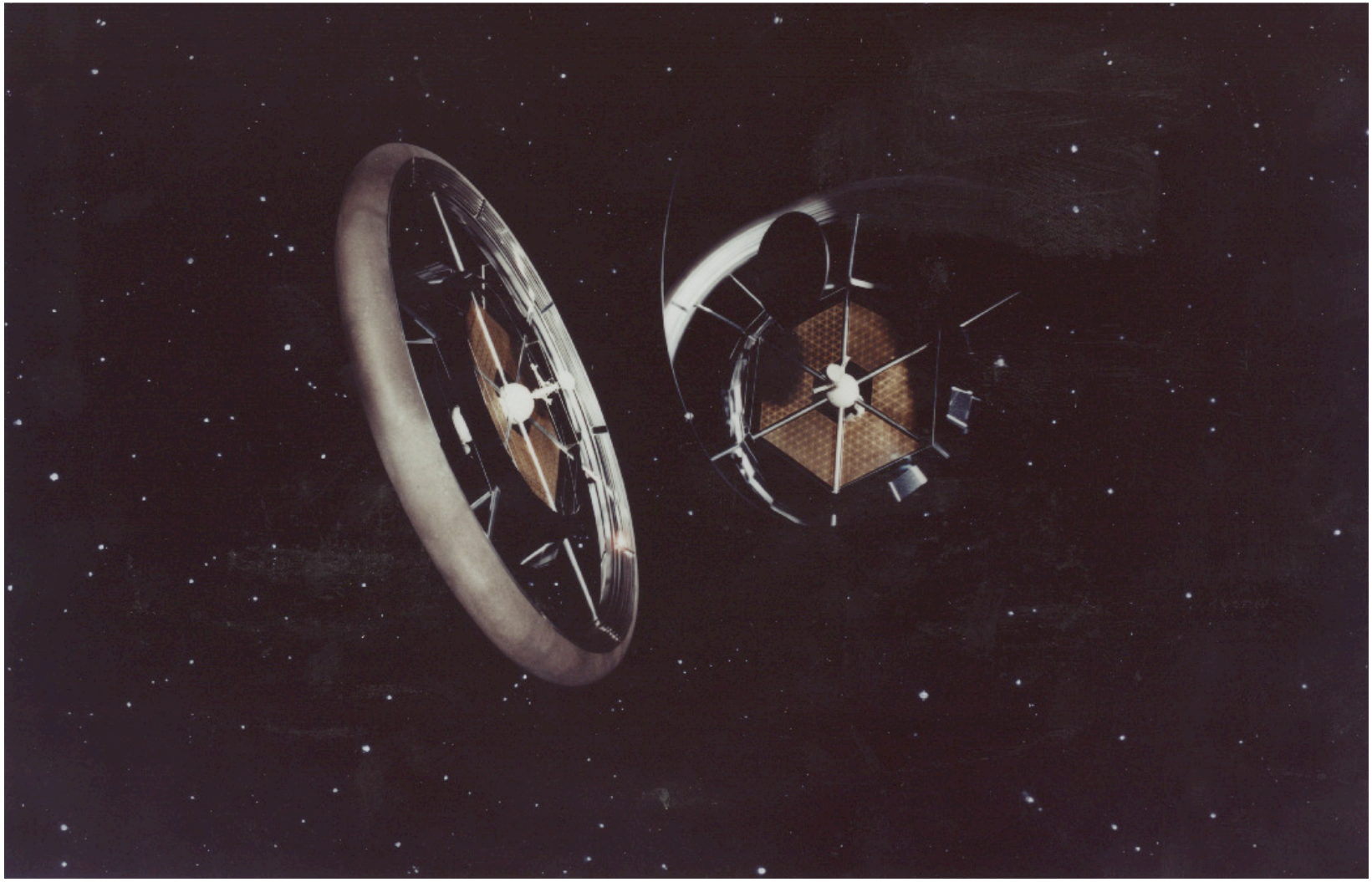
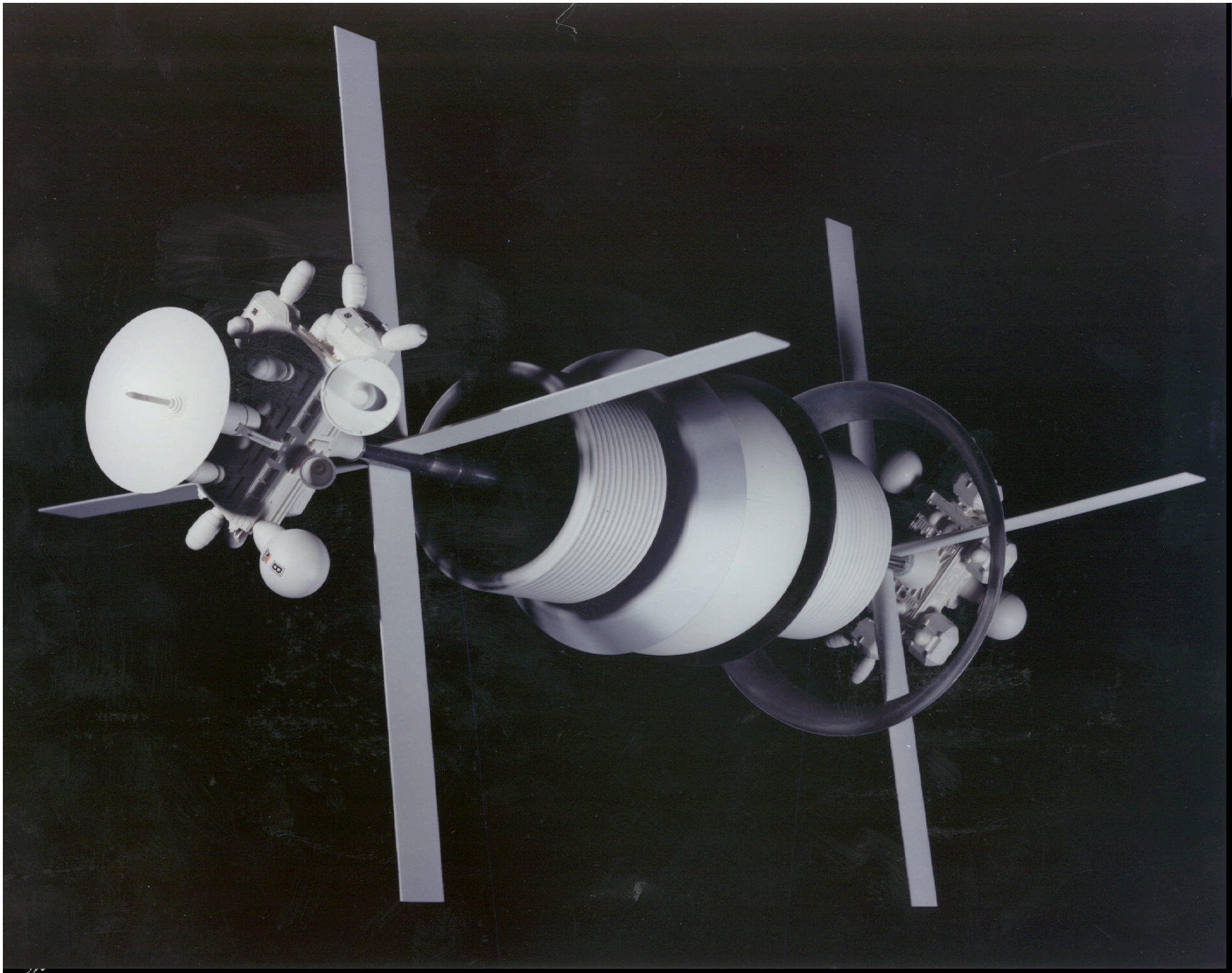
O'Neill Cylinder



Stanford Torus





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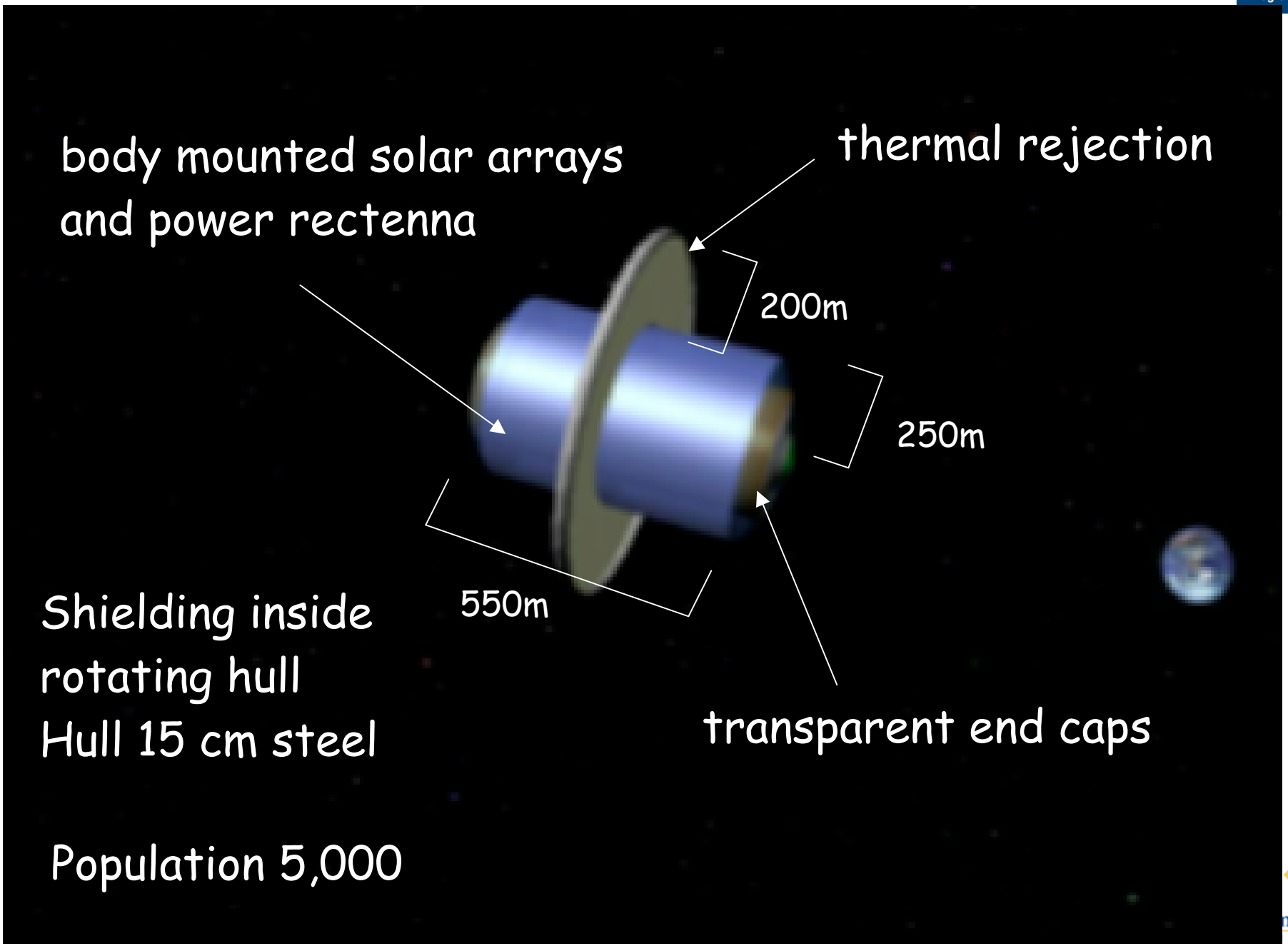
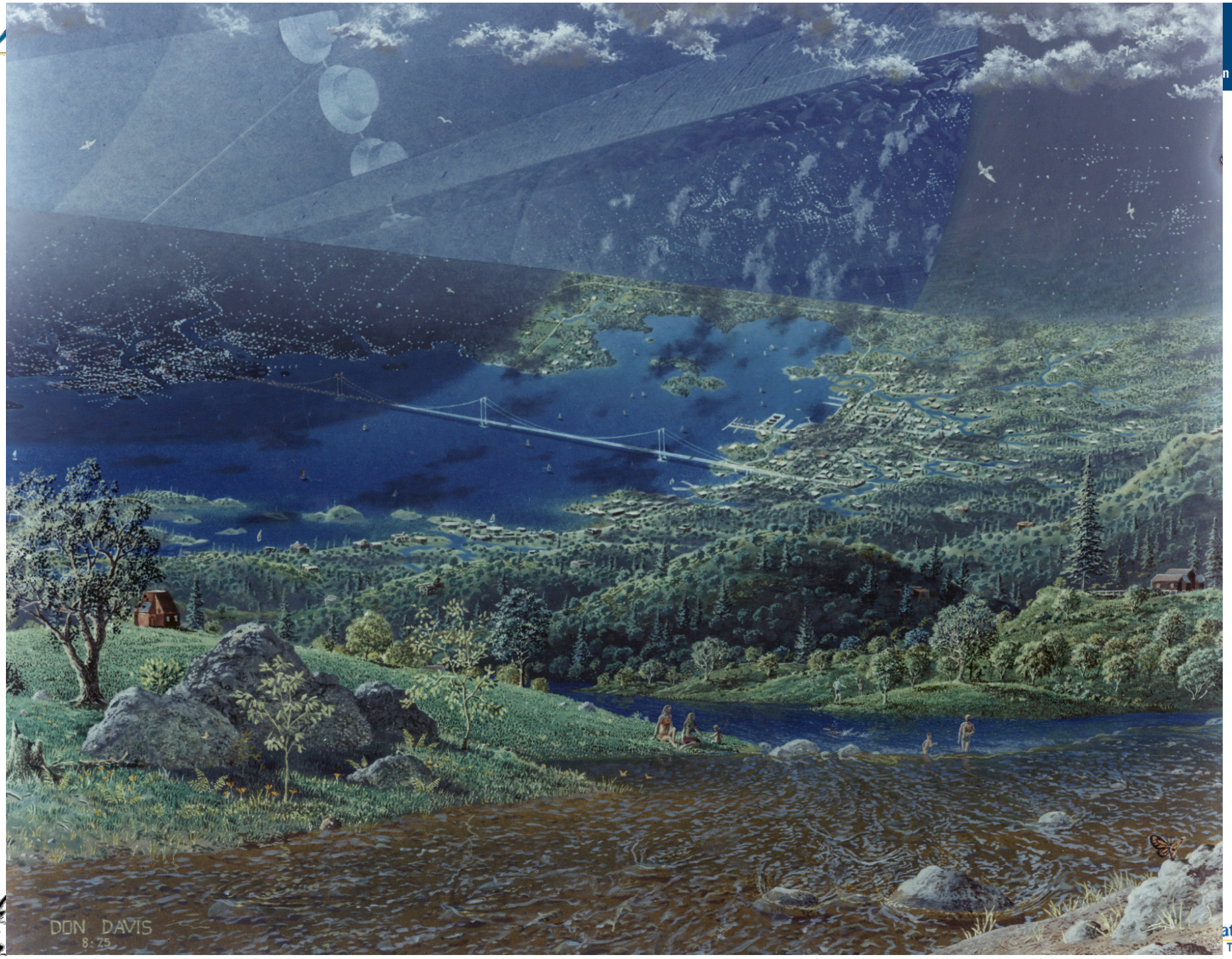
Kalpana One


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


DON DAVIS
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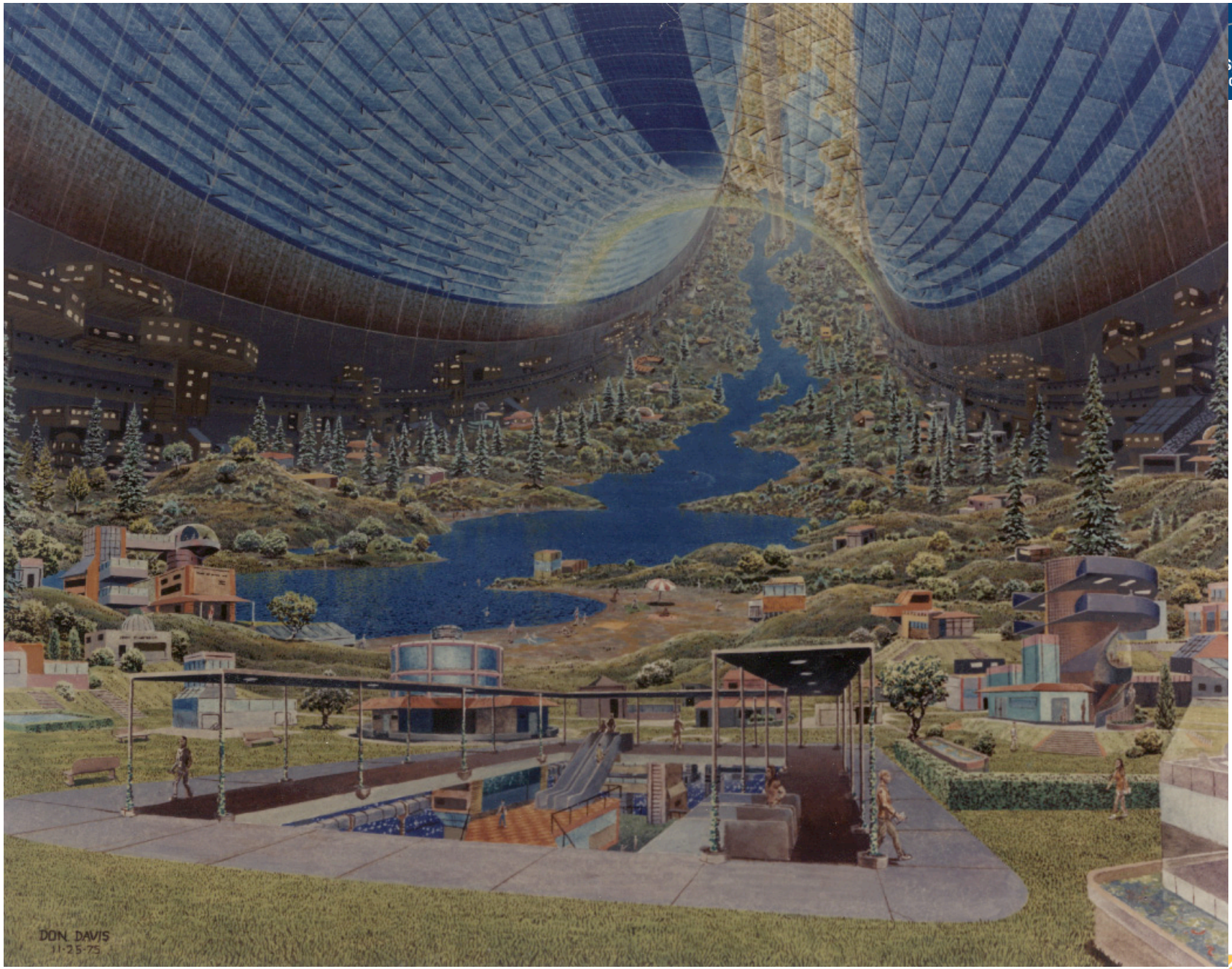

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Why

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Growth

- Largest asteroid converted to orbital 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

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

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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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 on space tourism, SSP, planetary defense, molecular nanotechnology
    - Pay for themselves independent of settlement

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Launch Problem

- Failure rate about one percent
- Thousands of dollars per kg
- 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!
- Cause: low volume (55 launches in 2005)
  - Cheapest commercial vehicles are Russian, who have made, by far, the most launches

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.

Tourism Path

- Sub-orbital -- book flights now
- Orbital
- Orbital hotels -- two tourists/yr now
- Low-g retirement
- Special group habitats
  - Pay a premium to separate from rest of humanity
- General space settlement

Sub-orbital Tourism

- Book flights today
  - Virgin Galactic ($200K)
  - XCOR ($95K)
- Started by $10 million Ansari X-Prize
- Two sub-orbital launches same vehicle within two weeks by end of 2004
- Won by Burt Rutan
  - $40 million of Paul Allen's money
    - Couple million painting Virgin on the tail
    - Lead to a $120 million contract with Virgin
  - Funded by insurance policy
    - All industry experts said it couldn't be done by deadline. Oops.

Orbital Launch Proposal

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

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Launch Prize Schedule

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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
        - » SpaceShipOne too

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Orbital Hotels

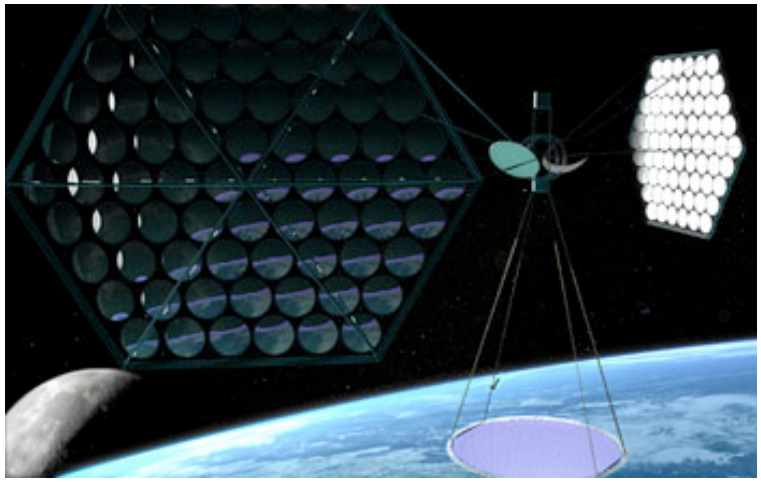
- ISS six guests @ $20-30
  - Russian Soyuz
  - First two-tourist flight advertised
  - May end after 2009 to accommodate 6 person crew
- Bigalow inflatable
  - Two small pressurized spacecraft currently in orbit
  - Habitable version 2010?
  - Market: inexpensive national human spaceflight programs

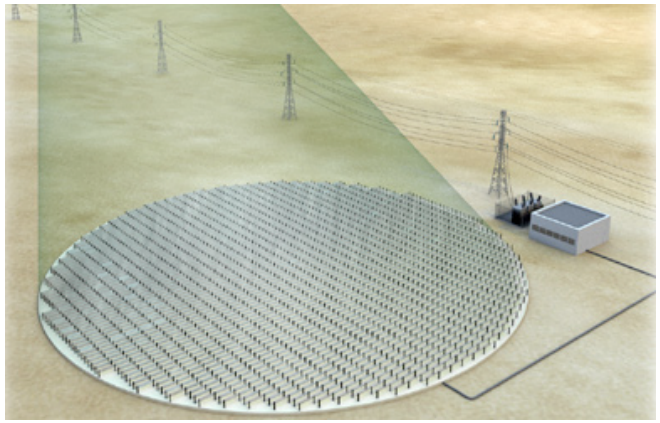
Low-g Retirement

- No wheelchairs needed.
- No bed sores.
- Never fall and break hip.
- Much easier to get around.
- Grandchildren will love to visit
  - 0g play
- Need good medical facilities.
  - Telemedicine
- Probably can't return to Earth.

Space Solar Power

- Gather solar energy in space
- Wireless transmission to Earth
- Convert to electricity
- Vast quantities
  - 24/7 (no night, clouds)
- Extremely green
  - No C02 emissions
- Depose King Oil
  - Requires electric cars





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SSP = Launch Volume, ISRU

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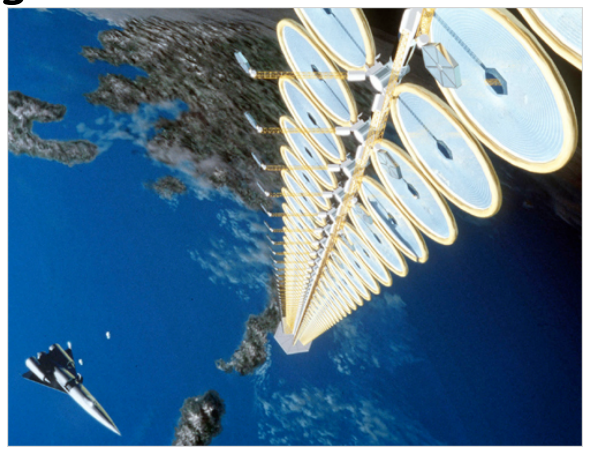
- Today's energy market 18 TW
  - $8Tr/yr @ $0.05/kw-hr
    - US Military will pay $1/kw-hr remote regions
  - Tomorrow's market much larger
  - 18 Mtons sat @ 1kg/kw
    - 100,000 Ares V launches



- ISRU
  - Lunar Si and metals supply most mass
  - Extremely green
    - Most work done thousands of km from biosphere

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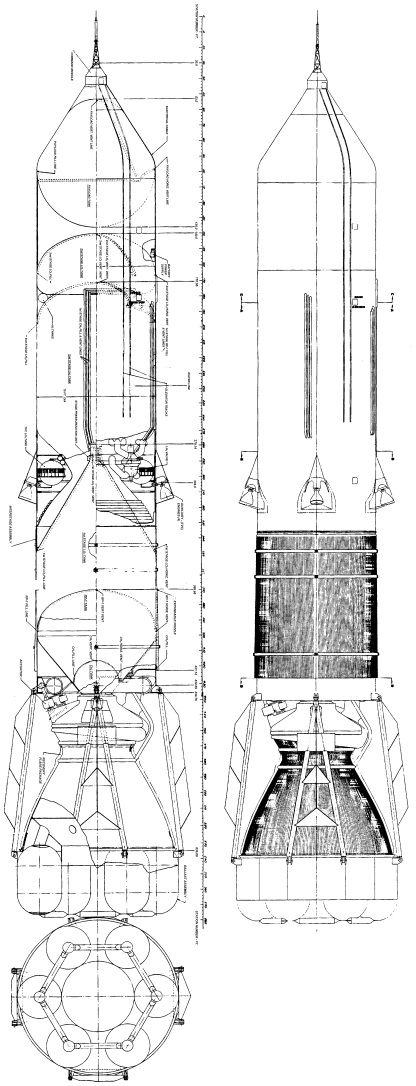
SSP Transportation

- Sea Dragon for launch
  - Big, dumb booster
  - Early 60s design
  - 150m tall, 23m diameter
  - First stage reusable
  - Pressure-fed engines
  - 8mm steel tankage
  - Ocean launch, shipyard construction
  - 500 ton to LEO @ $242/kg
  - 0.5 GW sat per launch
  - $27B development cost
- Solar-electric orbital transfer vehicle



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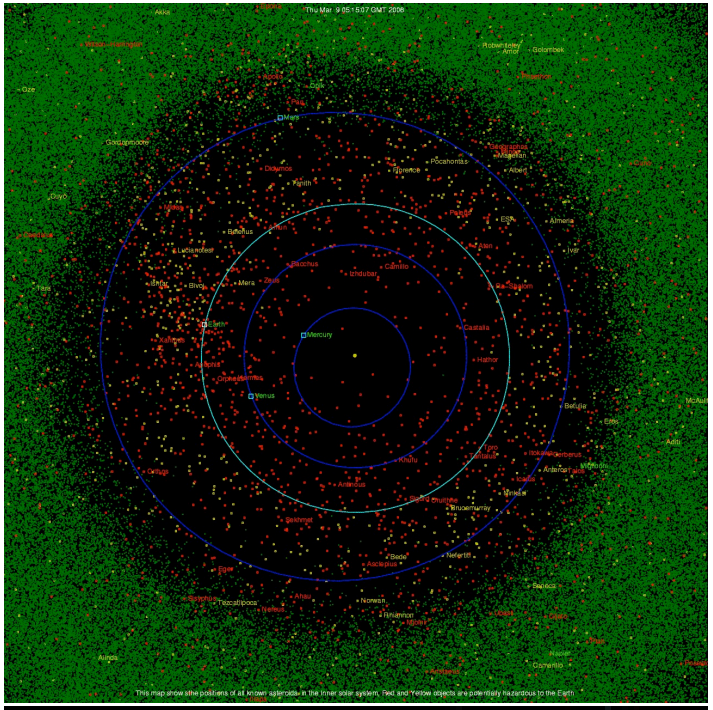
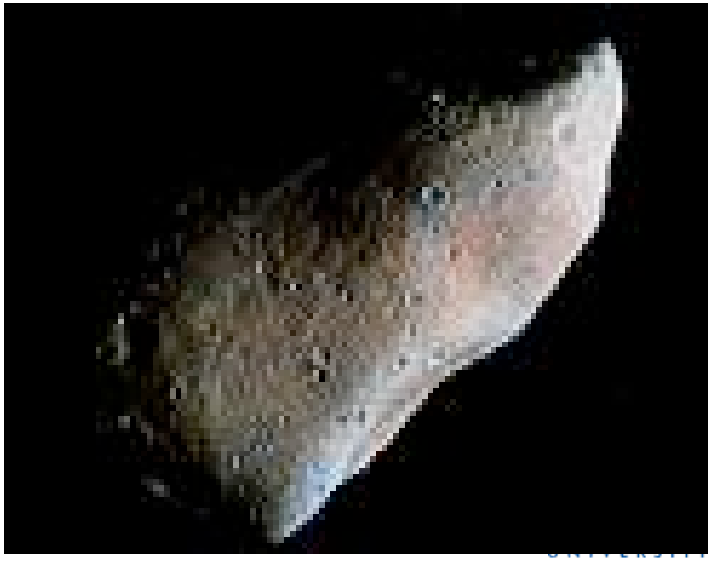
Assembly and Maintenance

- Teleoperated cooperating robots
  - Weightless operations
  - Lighting, power, thermal constraints
  - Handle thin flexible mirrors, wires
- Major man/machine integration issues
  - MACS-like simulator essential
    - Simulate robots, video feeds, data limitations
  - Displays
  - Autonomy issues
  - Input device(s)

Planetary Defense

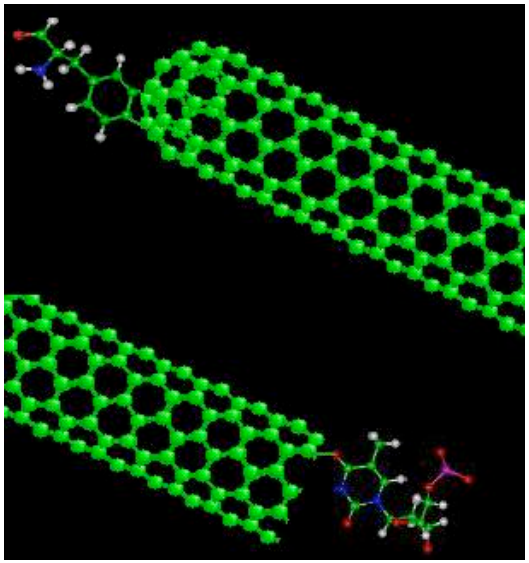
- Thousands of NEOs
- Large fraction impact Earth
  - Eventually, may be awhile
- NEO detection identifies potential materials sources
- Deflection technology may be adapted for retrieval
  - Small NEOs (10-50m) for safety





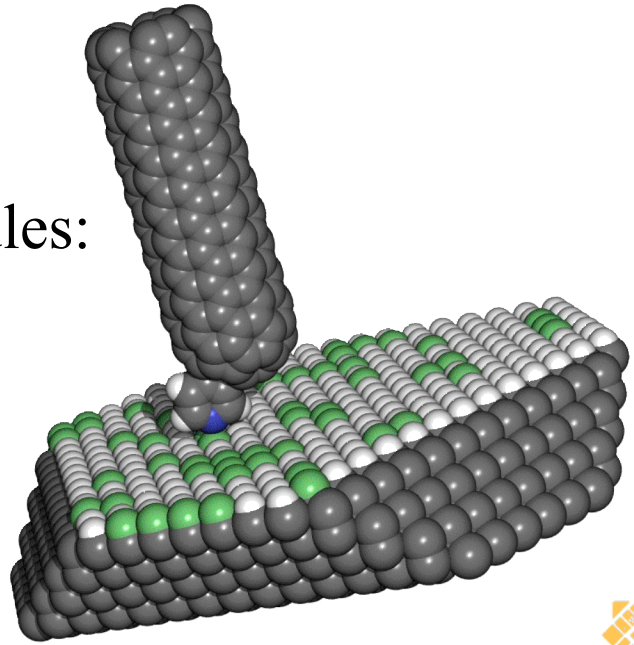
Three Pillars of Molecular Nanotechnology

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



Our favorite molecules:

carbon Nanotubes



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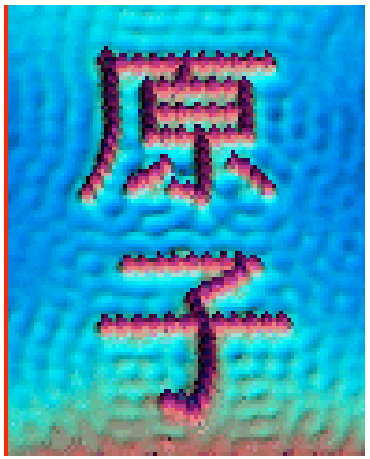
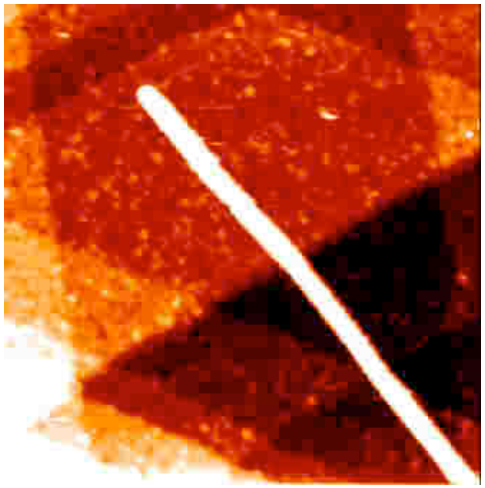
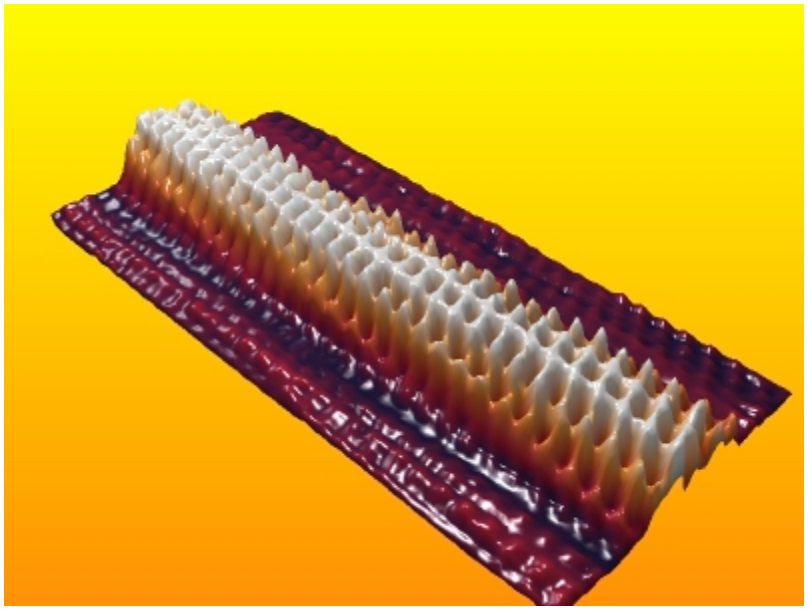
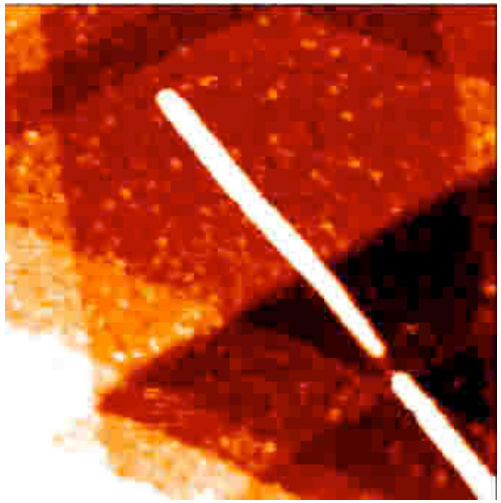
Atomically Precise Control of Matter



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







[Dekker 1999]

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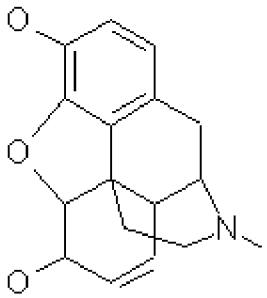
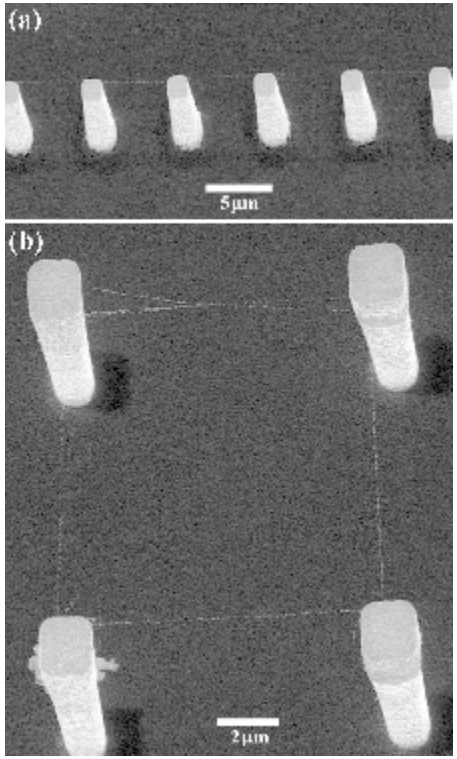
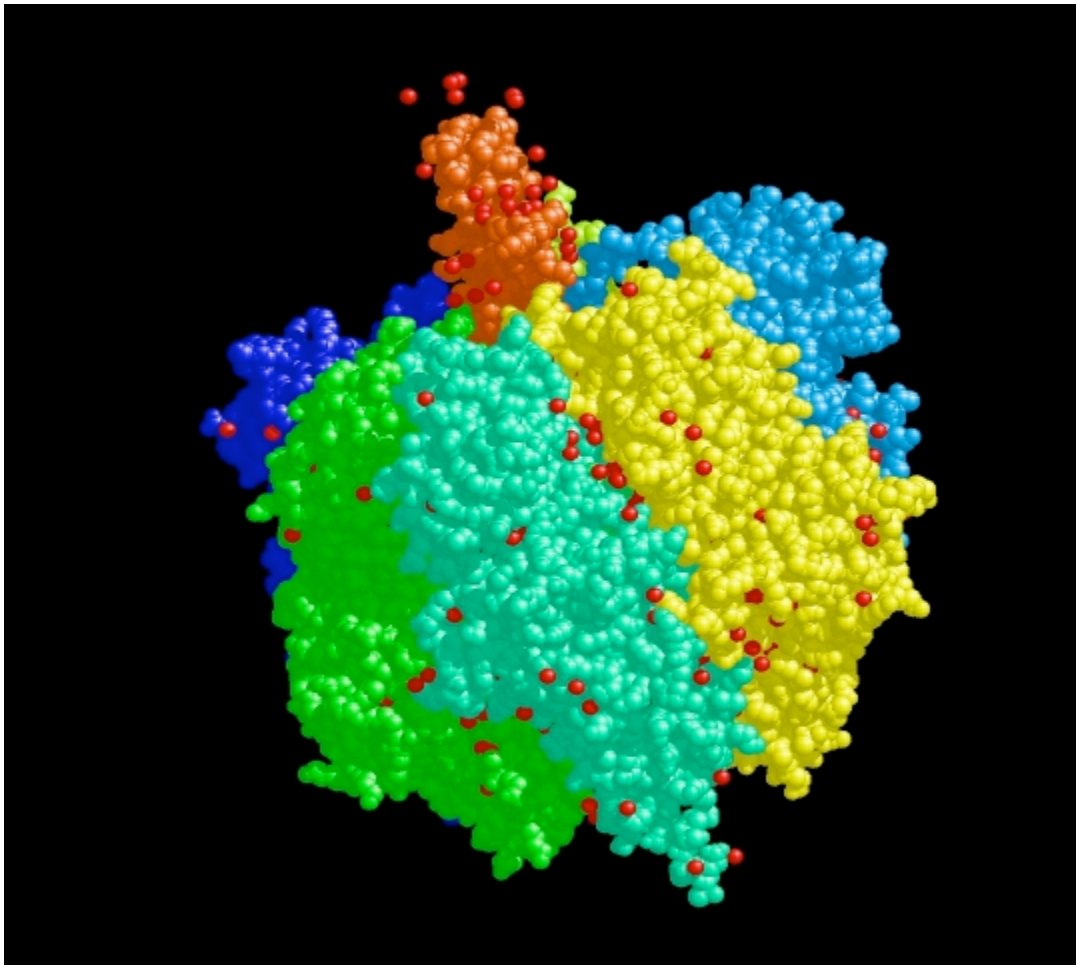
Molecular Machines





[Cassell 1999]



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Programmable Matter

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- Numerical Machine Tools
- Fabbers

http://www.Ennex.com/fabbers/uses.sht

- DNA, RNA, Polypeptide sequencers

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Programmed Molecules for Sale

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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

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

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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.