Space Stations

Osher, Fall 2024

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Outline

- Week 1: Science and Science Fiction Background
- Week 2: Early Space Stations
- Week 3: Mir and ISS Planning and Construction
- **Week 4: ISS Operations**
- Week 5: China, Science and Tech Summary, and the Future

Dextre repairs [CSA 1:21]

https://www.youtube.com/watch?v=AXQ6iSFVwrk

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- **Week 5: China, Science and Tech Summary, and the Future**

China

China spaceflight background

- 1956: Ministry of Aerospace Industry of the People's Republic
- 1970: First satellite, Dōngfāng Hóng 1 on a Long March 1 rocket
- 1993: China National Space Administration (CNSA)
- 1993: China Aerospace Science and Technology Corporation (CASC)
- 2004: Tàikōnaut Yáng Lìwěi into orbit in Shénzhōu 5 (Long March 2)

Location of China's spaceports

- Yǔ háng yuán: astronauts and cosmonauts in general
- Hángtiān yuán: Chinese crew

China’s first two space stations

- Tiāngōng 1 (Heavenly Palace) launched 2011, crewed for 6 days in 2012 and 12 days in 2013, lost control 2016, reentered into the Pacific in 2018
- One woman and two men on each expedition
- 530 cubic feet of living space (vs. Salyut 3200)
- Exercise gear and two sleep stations
- Toilet and cooking facilities on docked Shénzhōu ships
- Science experiments and video lectures
- Tiāngōng 2 was launched 2016, crewed for 26 days in 2016, docked with its cargo ship three times including refueling, and had a controlled reentry into the Pacific in 2019

2021 Tiāngōng space station [CGTN: 7:06]

https://www.youtube.com/watch?v=DAzoVdrppHs&t=2s

Tàikōnauts in Tiāngōng [VideoFromSpace 1:10]

https://www.youtube.com/watch?v=egbN4zDcYcU

Tiāngōng space station compared to ISS

ISS	Tiāngōng
420 tons (100-ton truss system)	100 tons
Truss for enough solar panels	No-truss design with more efficient solar panels
120 kw power	100 kw power
16 pressurized modules	3 large modules
35,000 cubic feet (pressurized)	3900 cubic feet (pressurized)
Cluttered	Uncluttered (wireless technology)
15 countries (5 docking systems)	One country (1 docking system)
60 decibels	50 decibels in sleeping quarters (1% of 60 db)
7 tons/year of fuel for orbital maintenance	Chemical fuel plus electric ion thrusters using xenon
Canadarm2 on mobile base system, Strela cranes	Long and short arms
Started 1998, completed 2011	Started 2021, completed 2022 (can be doubled)
Several smaller telescopes	Developing large separate, dockable telescope

Comments and Questions

Science and Technology Summary

Areas of research

- Human physiology and psychology
- Approaches to closed systems for sustaining life
- Observation of Earth
- Observation of the Sun and outer space
- Construction in space
- Robotics
- Effects of space exposure on materials
- Science in free fall, e.g., combustion
- Manufacturing in free fall

Research goals

- Prepare for long duration missions, especially Mars
  - Humans
  - Equipment
  - Robots
  - Operations and communications
- Technology transfer
- Basic science
  - Biology, chemistry, physics, astronomy
- Space manufacturing
- Assessment of Earth as a whole, e.g., climate change
- Inspiring STEM education and international cooperation

Examples from astronomy

- The atmosphere absorbs x-rays and gamma rays
  - Mir found stellar, galactic, supernova, black holes, and neutron stars sources
- Mir contributed to knowledge of solar flares and coronal mass ejections, as well as the effects of solar phenomena on the Earth's magnetosphere
- ISS telescopes
  - Measure composition and energy of cosmic rays
  - Provide data on the sun's effect on Earth's climate and weather
  - Monitor black hole x-ray activity
  - Detected an excess of positrons in cosmic rays, which might be a signal of dark matter annihilation
  - More accurately measured sizes and masses of neutron stars
- The ISS is a great platform for testing space telescope technology

ISS examples of Earth observation

- **Cloud-Aerosol Transport System** monitors Earth's atmosphere using lidar technology leading to improved climate models
- **Hyperspectral Imager for the Coastal Ocean** observes marine biology, and coastal management, and monitors pollution
- **Environmental Research and Visualization System** observes Earth’s surface to monitor natural disasters, urban development, and environmental changes
- **InfraRed Imaging Spectrograph** studies auroras and weather patterns
- **Atmosphere-Space Interactions Monitor** observes lightning and other high-energy phenomena in Earth's atmosphere

Human health and space medicine examples

- Terraplasma Medical uses cold plasma to inactivate bacteria, viruses, fungi and multi-resistant pathogens while activating wound healing based on Russian ISS research
- Purer crystals of biological materials such as molecular targets and monoclonal antibodies allows development of new modifications as well as possible IM as opposed to IV administration
- A new drug (BP-NELL-PEG), which is a modification of the NELL protein was tested on mice in space and reduced bone loss
- The DeBakey ventricular assist device has been used in hundreds of patients and is derived from a rocket engine turbopump
- Bioreactor Cell Culture Growth is a device that allows testing of cancer and virus treatments without using test animals

Materials Science examples

- Since 2001, NASA's Materials International Space Station Experiment (MISSE) series has tested some 4,000 material samples and specimens — from lubricants and paints to fabrics, container seals and solar cell technologies — to demonstrate their durability in the punishing space environment
- Concrete mixed and cured in space
- AstroRad vest is designed to protect astronauts from space radiation on long-duration missions and has built-in radiation sensors
- Amorphous metals (metallic glass) have been produced and studied in space and commercialized as Vitreloy

Technology development

- AI for package handling accounting for size and weight in stacking
- Testing life support systems, and spacecraft components for future missions to the Moon, Mars, and beyond
- Optical fiber sensors that change color on contact with targeted substances were designed to warn of corrosive conditions in aerospace vehicles, and can be used to detect chemical warfare agents and toxic industrial compounds
- Envirobot strips paint from ship hulls. It is remotely navigated, attaches itself magnetically, and uses high-power water jets to strip paint down to the steel surface. Wastewater and paint chips are then captured by a powerful vacuum system and filtered, ensuring no toxic residues pollute the environment.

Preparing for deep space exploration

- Test closed-loop systems for recycling air and water, essential for missions beyond Earth
- Gather data to ensure human safety and productivity during long-duration spaceflight
- Study teamwork and psychological resilience in isolated environments to inform future space missions
- First 3-D printer in space in 2014 worked normally for making plastic parts

Inspiring education and collaboration

- Amateur Radio on the ISS (ARISS) has reached one million students
- Dream Up: Free learn-at-home activities; can interact with astronauts and engineers
- GeneLab for High Schools is a four-week intensive training program for rising high school juniors and seniors sponsored by NASA's Ames Research Center
- Standards-based, grade-appropriate lesson plans to help teachers incorporate EarthKAM into their classroom activities
- The ISS fosters partnerships among countries, demonstrating the power of global collaboration in science and exploration

Robert Heinlein on spinoffs

- 1979 congressional testimony: Principal of Serendipity
- “Here is an easy way to spot space-research spinoffs: If it involves microminiaturization of any sort, minicomputers, miniaturized long-life power sources, highly reliable microswitches, remotely controlled manipulators, image enhancers, small and sophisticated robotics or cybernetics, then, no matter where you find the item, at a critical point in its development it was part of our space program.”
- “To me the most ironical thing about the space program is that there are thousands of people alive today that would be dead if not for some item derived from space research … [but] complain about ‘wasting all that money on stupid useless space stunts when we have so many really important problems to solve right here on Earth’.”

NASA economic analysis

- Budget $25 billion
- Generates $75 billion in economic output across all 50 states and D.C.
- Supports 305,000 jobs nationwide
- Generates an estimated $9.5 billion in federal, state, and local taxes throughout the United States

Patents from space research

- NASA: >2600 applications, >2000 patents granted
  - Royalty free for up to three years
  - Total royalties amount to a few million dollars per year
- ESA: >500 applications, freely licensed within the 22 member states
  - Communications, materials, biotech, robotics, energy, data processing
- JAXA licenses its patents
- CSA business expenditures on R&D: $376 million in 2019
  - In 2019, 41 organizations derived $253M in revenues through the commercialization of externally funded R&D projects
- Roscosmos obtains dozens of patents per year

NASA patents most cited in other patents

- Controlling a tendon-driven robot manipulator using closed-loop control [1051]
- Charging and powering of an electrical/electronic device using microwave energy [858]
- Converting bodies of data, such as a database or a subset of a database, into a number of contextual associations or relations [358]
- Multilayer article that can resist a harsh high temperature, water vapor environment [282]
- Reconfigurable Auditory-Visual Display [259]

NASA patents and spin-off technology

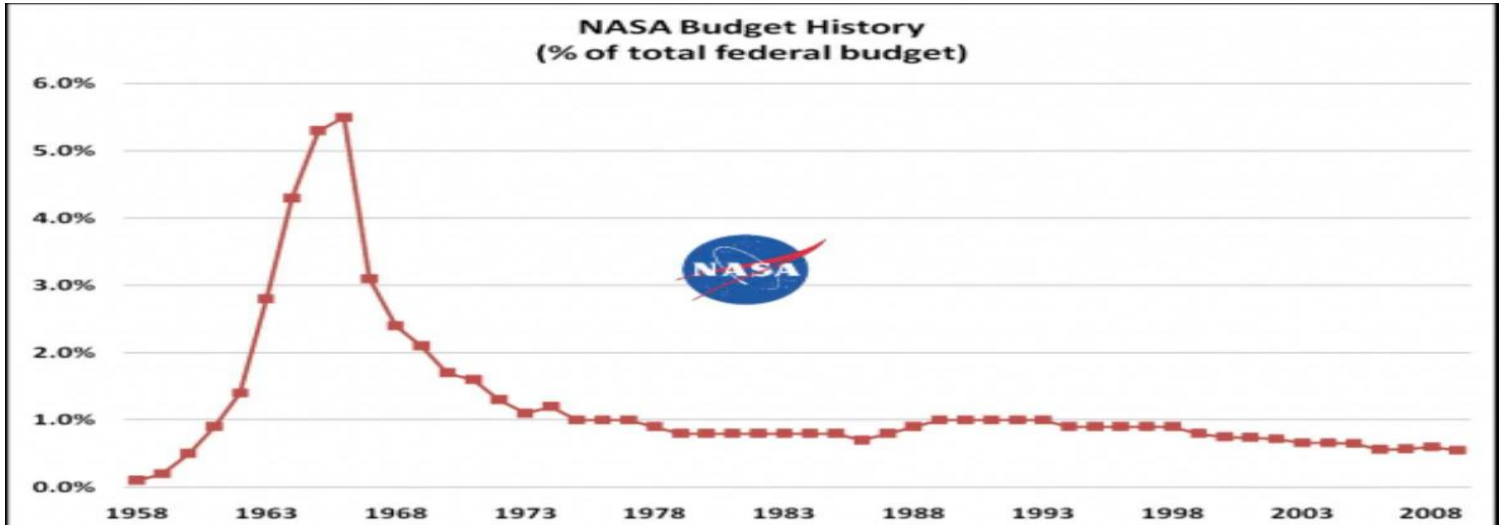
- Technology Transfer Program
- Works through Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) awards, licensing of patents, technical assistance and use of data
- Over 2000 spinoffs published including: memory foam, freeze-dried food, emergency ”space blankets”, cochlear implants, image sensors used in all digital cameras, and portable fluoroscopy
- Since 1976 *Spinoff* publishes about 50 examples yearly
- *NASA Tech Briefs* meets the statutory requirement to report to industry any new, commercially significant technologies developed in the course of their R&D

Highlights from *Spinoff* 2023

- Spacesuit gloves → phase-change materials → clothing from Fifty One Ltd. that helps with both hot flashes *and* cold flashes
- Burnout Mug from ThermaVant Technologies is an improved thermos based on phase-change materials
- Controlled Ecological Life Support System (CELSS) program → Eden Grow Systems combined hydroponic, aeroponic, and aquaponics system in a highly automated form
- Microsoft Learn coding modules to teach Python to kids uses NASA datasets
- *Displays for windowless low-boom supersonic jets
- *Carbon-fiber Blended Hybrid Laminate (BHL) cryotank developed by Gloyer-Taylor Laboratories can safely store liquid hydrogen
- *Skysun has installed Solar Pollinators around Cleveland that use reflectors to direct sunlight to solar panels

Cost of space stations

NASA cost: $33 per year for the median family



Some criticisms

- Takes money away from other programs
  - Martin Luther King Jr.: "Without denying the value of scientific endeavor, there is a striking absurdity in committing billions to reach the moon where no people live, while only a fraction of that amount is appropriated to service the densely populated slums."
- Environmentalists have pointed to the pollution caused by space exploration
- Environmentalists worry about distracting Americans from a mounting pollution problem
- 2018 poll: 23% want to cut the budget, average estimate is 6%

Your thoughts: Is it worth it?

The Future of Space Stations

Why the ISS needs to be deorbited

- Leak in the vestibule of life support module Zvezda (launched in 2000) next to the docking port
  - Patched with Kapton tape and sealant
  - Sealed off from the rest of the station most of the time
  - Leading theory is a problem with internal and external welds
  - Loss as high as three and a half pounds of air per day
  - Russians rule out catastrophic disintegration; US does not
- Wear and tear from heat/cool cycles, free oxygen, micrometeoroids
- Aging equipment with increased repair time and cost
- Focus on commercial space stations
- Focus on lunar and eventual Mars missions

NASA's ISS *Transition Plan*

- "In the future, the United States plans to transition its operations in low Earth orbit to commercially-owned and -operated destinations to ensure continued access to essential research and technology development.

  […] a new or modified spacecraft is needed to provide more robust capabilities for deorbit. NASA has engaged with U.S. industry and is proceeding with plans to procure a spacecraft (U.S. Deorbit Vehicle) that will perform the final, safe, deorbit maneuver of the space station."
- Space-X chosen; target is "spacecraft cemetery" in the early 2030's
- Rejected alternatives:
  - Disassembly and return to Earth: disassembly not pre-planned, shuttle retired
  - Boost orbit: much smaller mean time between impacts but nothing strong enough
  - Random reentry: exceeds required 1 in 10,000 chance of public risk

Russia and China

- Russian Orbital Service Station (ROSS)
  - First module launching in 2027, the core modules in 2030, and the final modules in 2033
  - Plan for near polar, sun-synchronous orbit to get more uniform lighting
  - $6 billion (vs. $150 billion for ISS)
- China has plans to double the size of its station

Axiom Space tourists to the ISS

- Private company based in Houston founded in 2016 by a retired ISS program manager (Michael Suffredini) and an engineer / entrepreneur (Kam Ghaffarian)
- Axiom Mission 1 flew Axiom employee and retired astronaut Michael López-Alegría and three space tourists in a Crew Dragon to the ISS for 17 days in 2022
- Axiom Mission 2 flew Axiom employee and retired astronaut Peggy Whitson and three space tourists in a Crew Dragon to the ISS for 9 days in 2023 (first Saudi woman)
- Axiom Mission 3 flew López-Alegría and three space tourists in a Crew Dragon to the ISS for 21 days in 2024
- Estimated $55 million per seat, science experiments performed
- Part of the money goes to NASA and its space partners

Axiom Space ISS module

- 2020: NASA selected Axiom Space to provide at least one habitable commercial module to be attached to the ISS for $140 million
- Plans are to detach the modules when the ISS is decommissioned and to construct a new private station

https://www.youtube.com/watch?v=cGupZnQxRJ4

Axiom Space [2:43]

Plans for commercial stations

- In 2021, NASA signed agreements with three U.S. companies to develop designs for commercial space stations
  - Blue Origin of Kent, Washington (Bezos), for $130 million
  - Nanoracks LLC, of Houston for $160 million
  - Northrop Grumman Systems Corporation of Dulles, Virginia, for $125.6 million
- 2021: Voyager Space acquired Nanoracks

Plans for commercial stations

- November 2022 NASA announced Second Collaborations for Commercial Space Capabilities
- NASA expertise offered, but no funding
- Seven awardees
  - Blue Origins: space transportation (*New Glenn*)
  - SpaceX: transportation (*Starship*) and a single-module station
  - Sierra Space: commercial space station
  - Think Orbital: research platforms eventually with crew
    - Mission 1: Small payload on a SpaceX Falcon 9 rocket performed autonomous space welding and returned samples for NASA and ESA analysis
    - Planning mission 2 in April 2026: weld, cut, x-ray
  - Vast: commercial space station (initially a single module)
  - Northrup Grumman: autonomous space manufacturing
  - Special Aerospace Services: autonomous maneuvering unit

Plans for commercial stations

- 2023: Northrup Grumman dropped its own space station plans and will work with Voyager Space and Airbus on the *Starlab* station
  - Planned for 2028
  - Single *Starship* launch
  - Science, not tourism
  - Crew quarters designed by Hilton

Plans for commercial stations

- Blue Origins teamed up with Sierra Space to work on *Orbital Reef*
- Designed to support 10 persons in 29,000 cu. ft., including inflatable modules; projected to be operational by 2027
- Called a “mixed use business park”

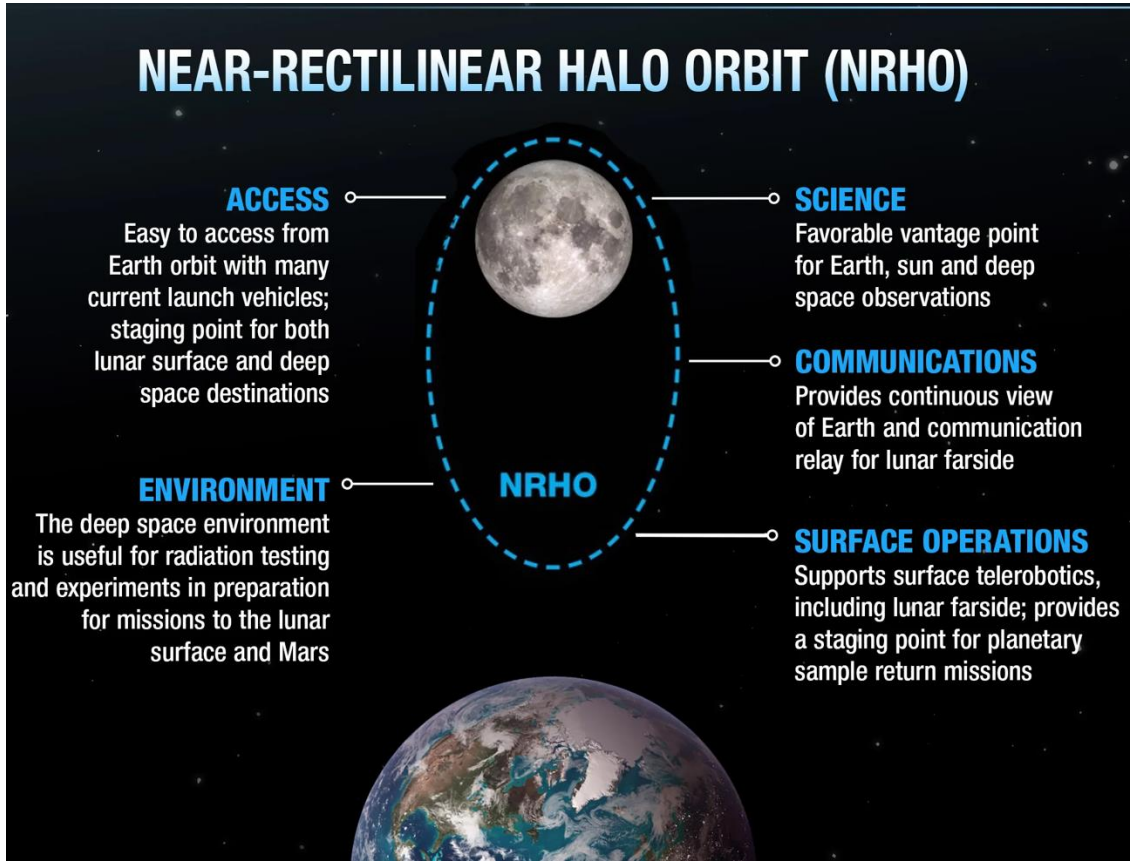
Other commercial stations

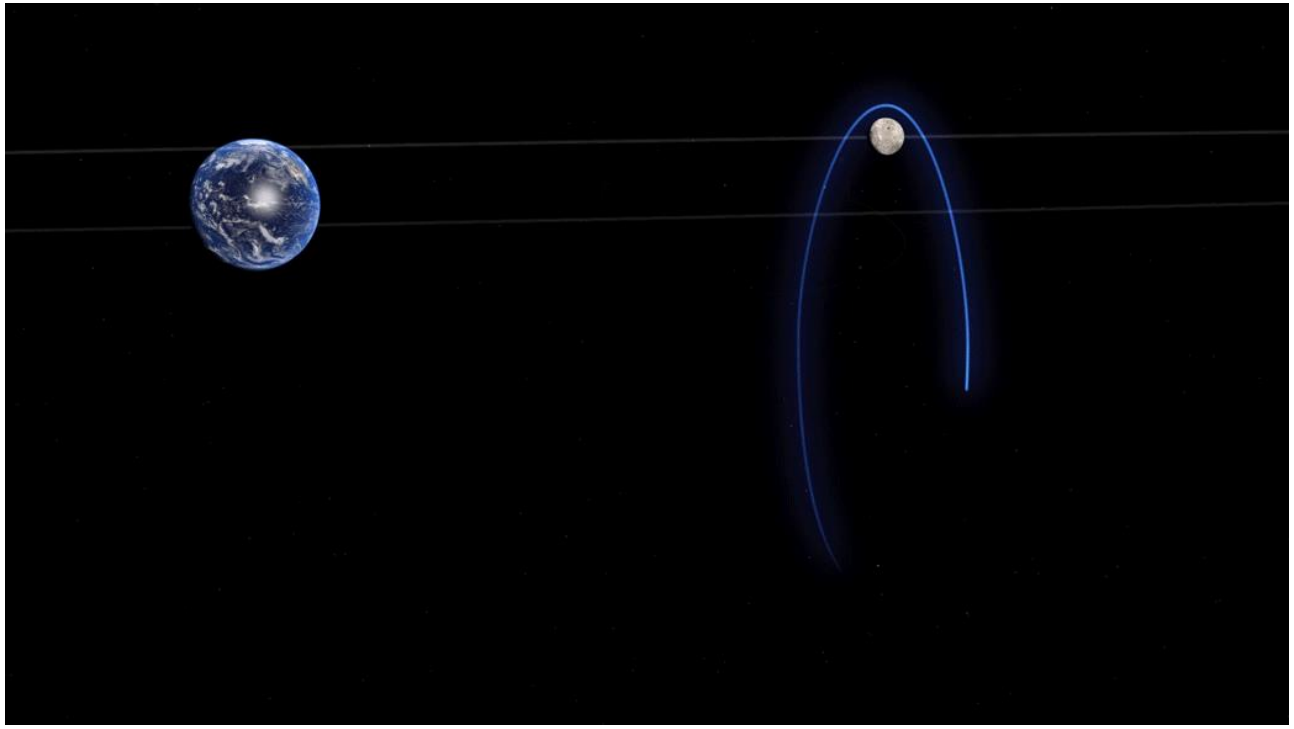
- Vast initially formed to make an artificial gravity station
- Now planning Haven 1, a zero-g station for launch in late 2025

Artemis Lunar Gateway

- NASA Artemis will return humans to the moon
- It includes the Lunar Gateway space station in **lunar** orbit
- Communication hub, science laboratory, and habitation module for Artemis
- Multinational collaborative project: NASA, ESA, the Japan Aerospace Exploration Agency (JAXA), Canadian Space Agency (CSA), and Mohammed Bin Rashid Space Centre (MBRSC)
- Under construction, but Artemis is delayed
- Debate over need for orbital refueling
- SpaceX to provide transportation between station and the moon

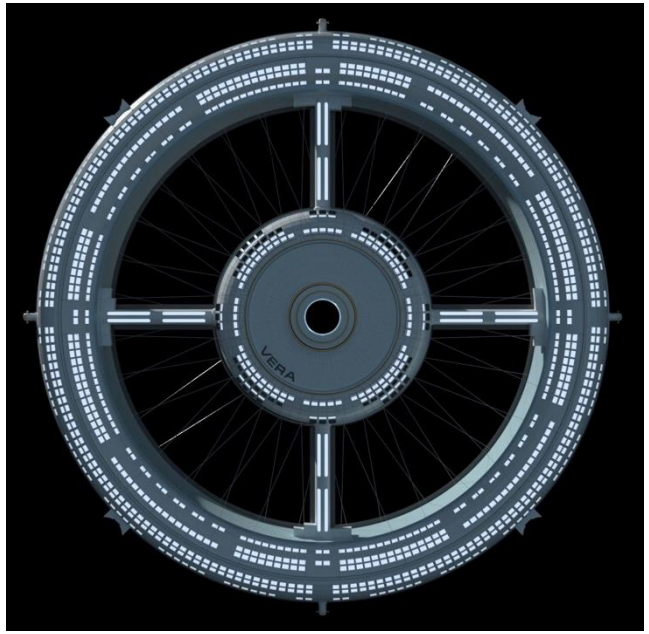
Artemis Lunar Gateway orbit

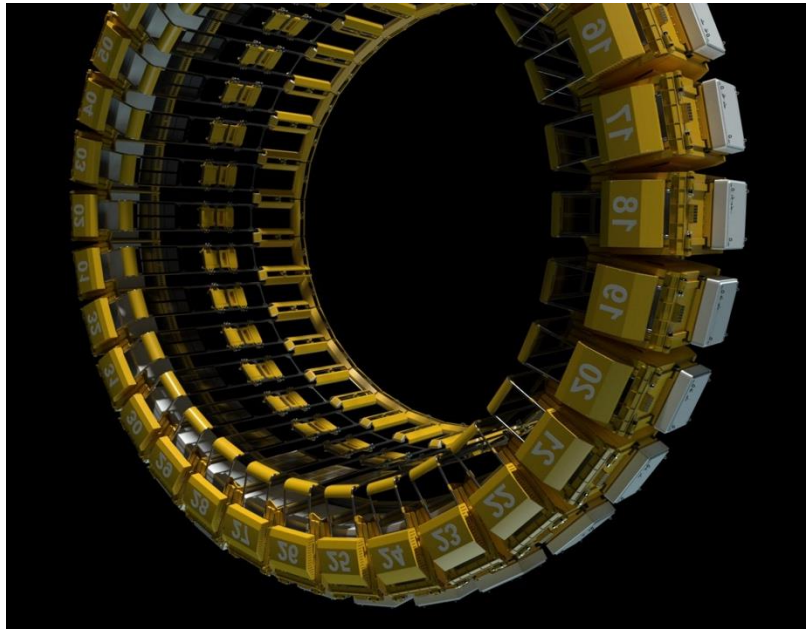


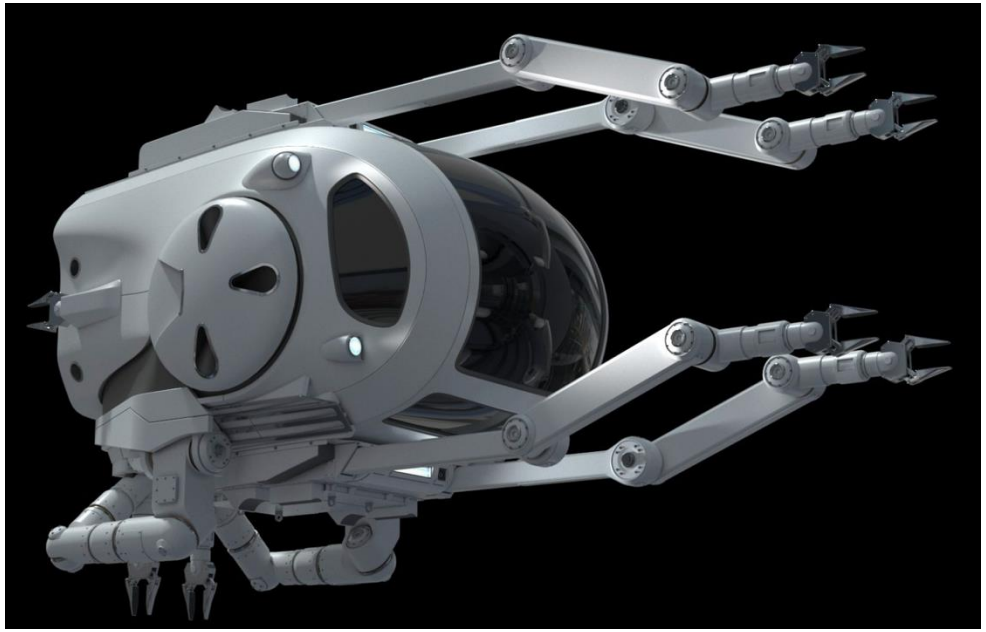


Colonization of Space: Gateway Spaceport

- Gateway Spaceport LLC (unrelated to NASA Lunar Gateway)
- Super slick website with “designs” for drone fabricators and lots of other equipment to build a rotating space station
- Kickstarter to make a video
- A page on how a lottery with a prize of a trip to space could fund the project in states where citizen initiatives are allowed





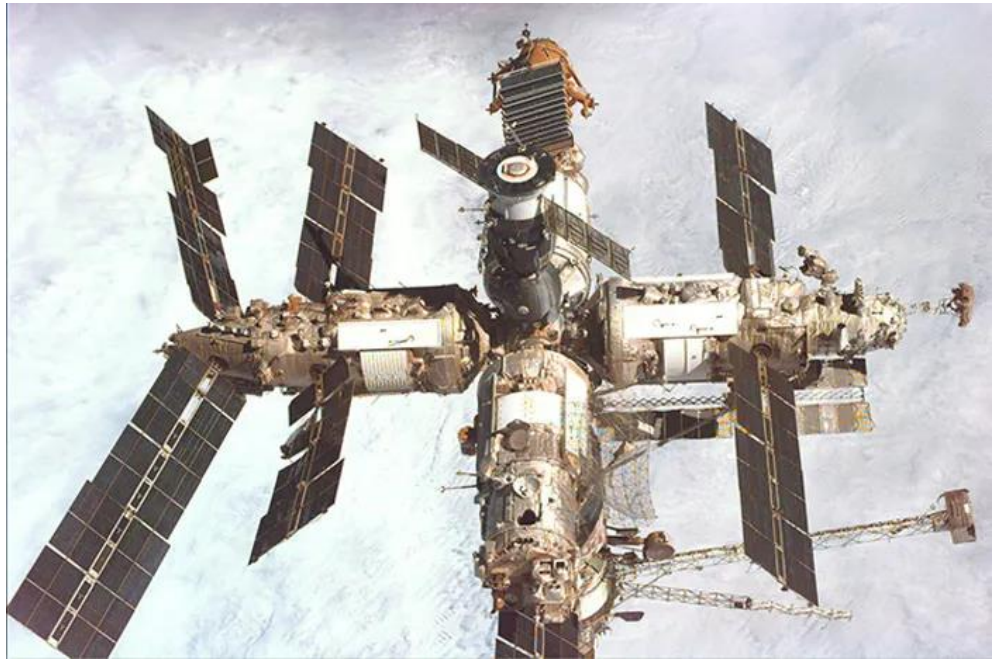


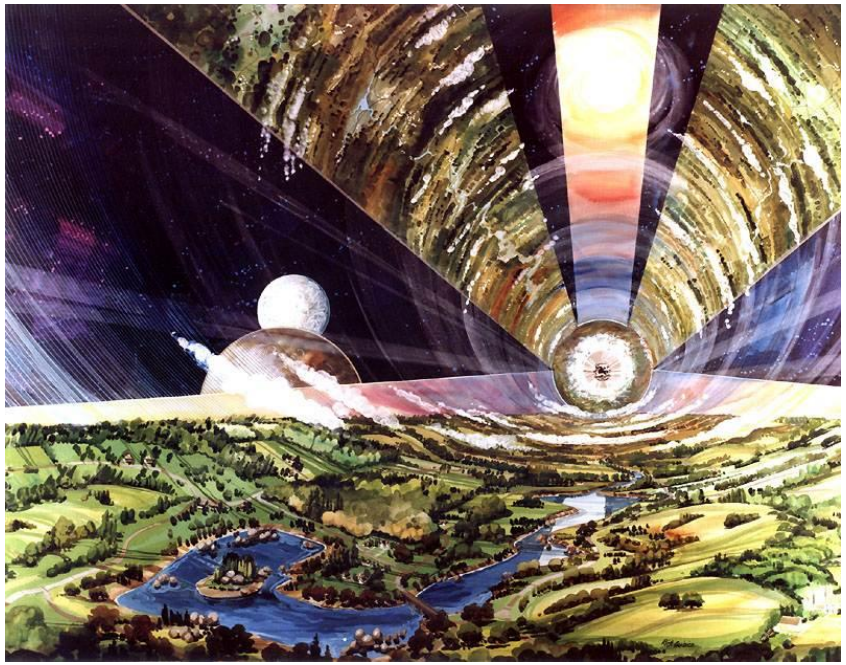
O’Neill cylinders

- Gerard K. O'Neill (1927 – 1992) was an American physicist and space activist who developed a plan to build human settlements in outer space, including a space habitat design known as the O'Neill cylinder
- Four miles in diameter and 20 miles long
- Rotating to generate artificial gravity

Colonization of Space: Jeff Bezos [LEX 4:33]

https://www.youtube.com/watch?v=DcWqzZ3I2cY&t=789s





Comments and Questions