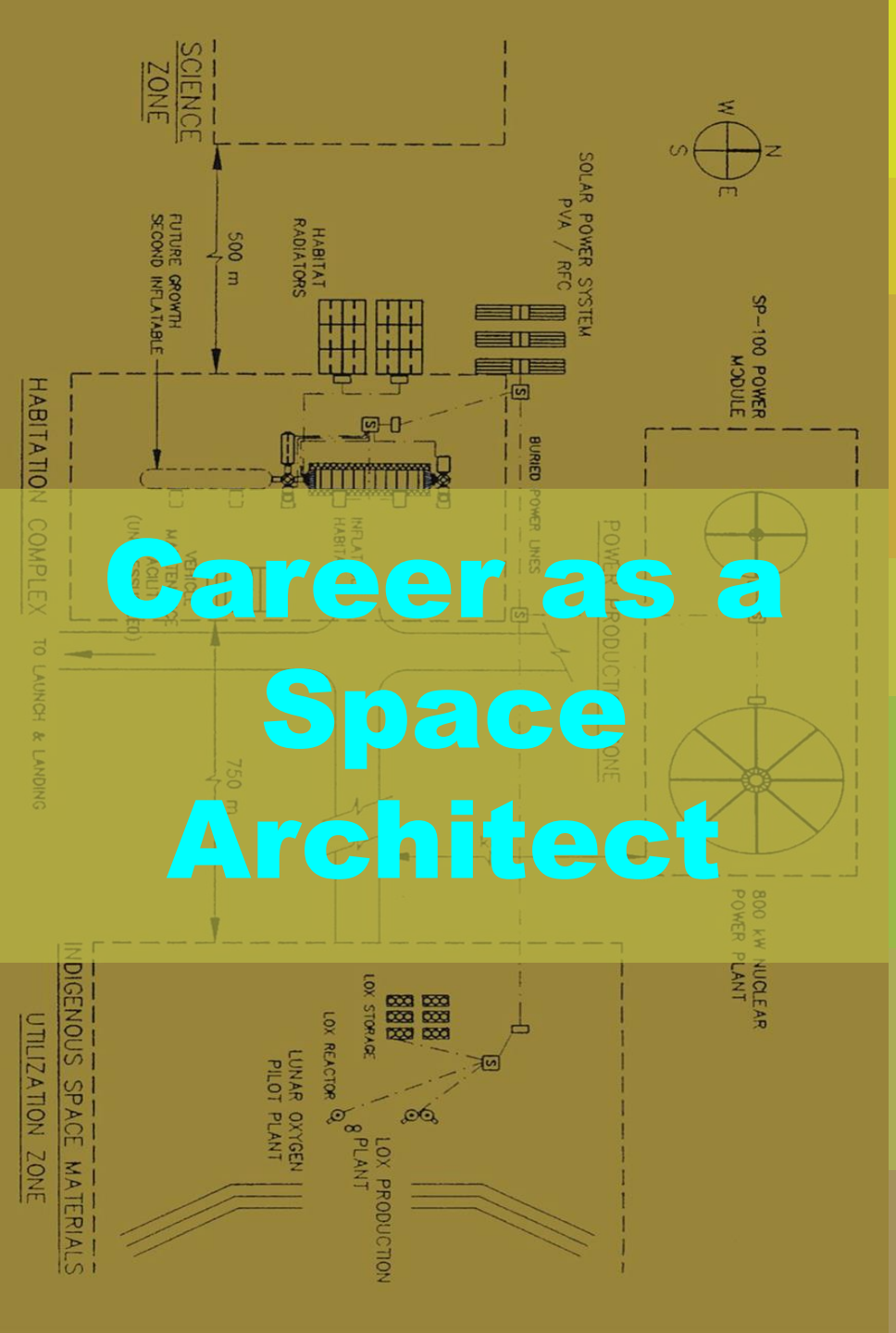
Carnegie Mellon University
SPACE ARCHITECTURE

Kriss J. Kennedy
Architect

Carnegie Mellon University
Space Architecture

- 2.3.16 Space Studio CMU: Mars and Architecture Beyond the Atmosphere
  - A traditional architecture studio focusing on a "post-pioneering“ settlement (a first step research station with an emphasis on material, resources, closed-loop systems, as well as programmatic network and spatial considerations) for the surface of Mars or for Earth-Mars transit.
- Kriss Kennedy
  - History of Human Spaceflight/Space Stations and TransHab



Career as a Space Architect

Three (3) degrees in Architecture

Worked on over 42 designs and projects

Written over 40 publications, papers, or chapters in books

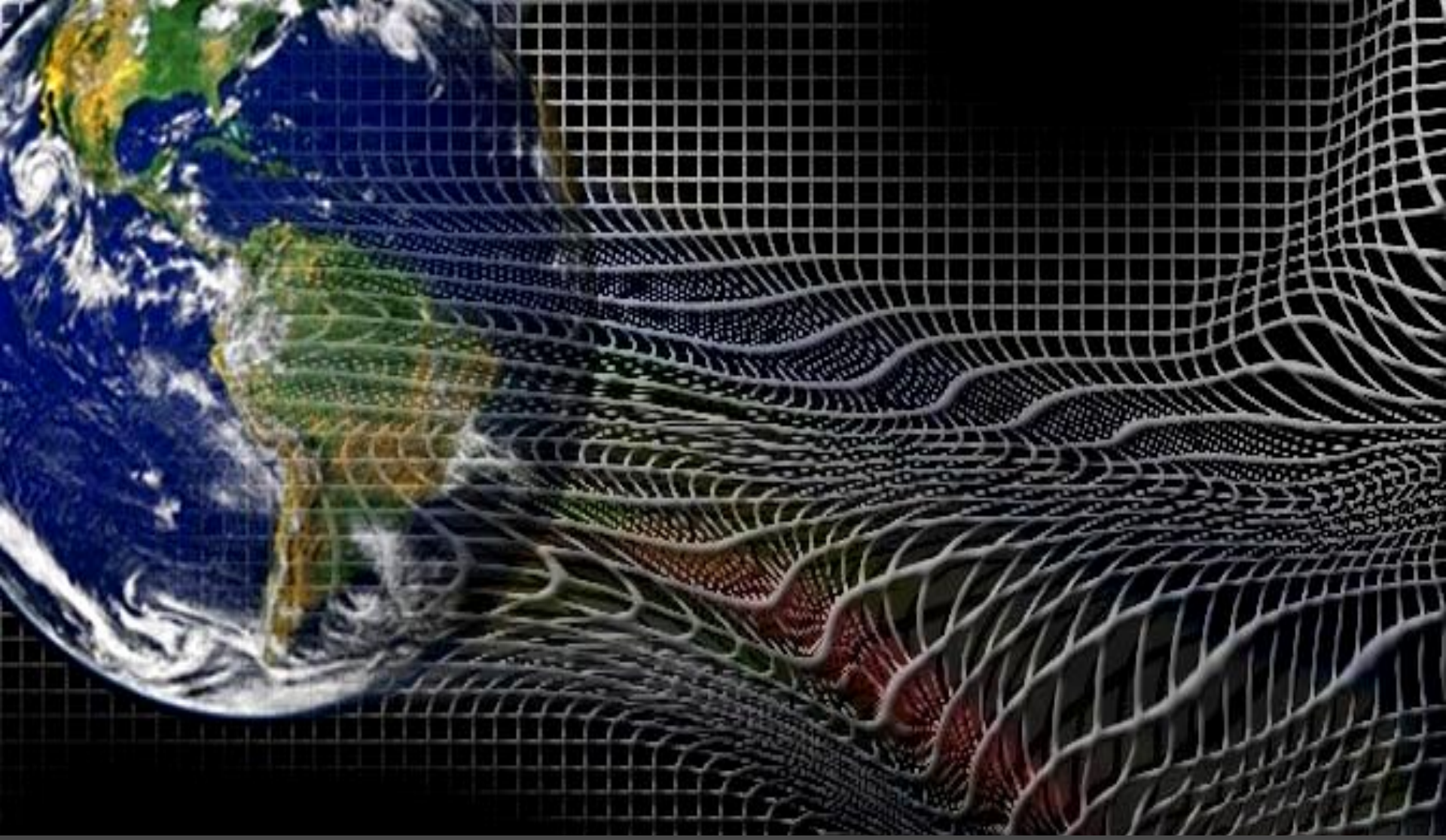
published in numerous magazines, periodicals & books

Has two patents and numerous NASA Technology Brief Awards

Recognized by his architect peers as one of the new upcoming architects in Texas as published in the millennium issue January 2000 Texas Architect magazine.

First space architect awarded the prestigious Rotary National Award for Space Achievement in March 2000

Registered licensed architect in the State of Texas



Space Studio CMU: Mars and Architecture Beyond the Atmosphere

History of Human Spaceflight/Space Stations and TransHab


Space Architecture…
…theory and practice of designing and building inhabited environments in outer space…
…design of living and working environments in space related facilities, habitats, surface outposts and bases, and vehicles…

Human Spaceflight Evolution

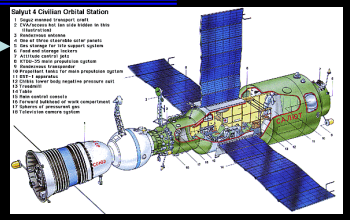
- Russia: Yuri Gagarin, the first person in space, and the first person to orbit the Earth, 1961
- Alan Shepard, the first American in space, 1961
- John Glenn, the first American to orbit the Earth, 1962
- Valentina Tereshkova, the first woman in space, 1963
- Neil Armstrong, the first person to set foot on the surface of the Moon, 1969

Human Spaceflight

Suborbital human spaceflight		
Name	Years	Flights
Mercury	1961	2
X-15	1963	2
Soyuz 18a	1975	1
SpaceShipOne	2004	3
Orbital human spaceflight		
Name	Years	Flights
Vostok	1961—63	6
Mercury	1962—63	4
Voskhod	1964	2
Gemini	1965—66	10
Soyuz	1967—present	126 as of December 2015
Apollo	1968—69	2
Skylab	1973	3
Apollo-Soyuz	1975	1
Space Shuttle	1981—2011	135
Shenzhou	2003—present	5
Lunar human spaceflight		
Name	Years	Flights
Apollo	1968—72	9

History of Space Stations

- Soviet/Russia: Salyut 1-7: 15 years from 1971 to ~1990

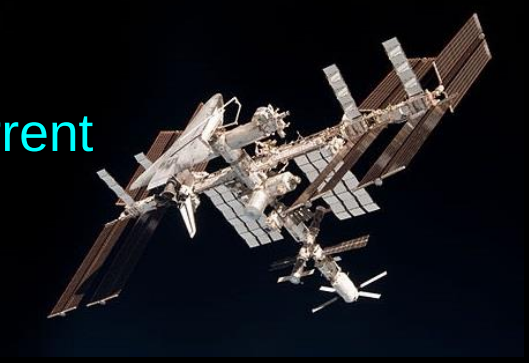


  - Salyut 1, the first station in the program, became the world's first crewed space station

- USA: Skylab 1973 - 1979

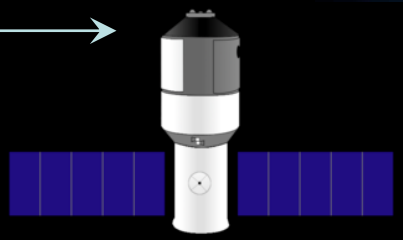
- Soviet/Russia: Mir 1986 - 2001

- USA: Shuttle/SpaceLab 1981 - 2011
- USA/RSA/ESA/JAXA: ISS 1998 (assembly began) - current



  - Continually human occupied and operated for 15+ yrs (2000)

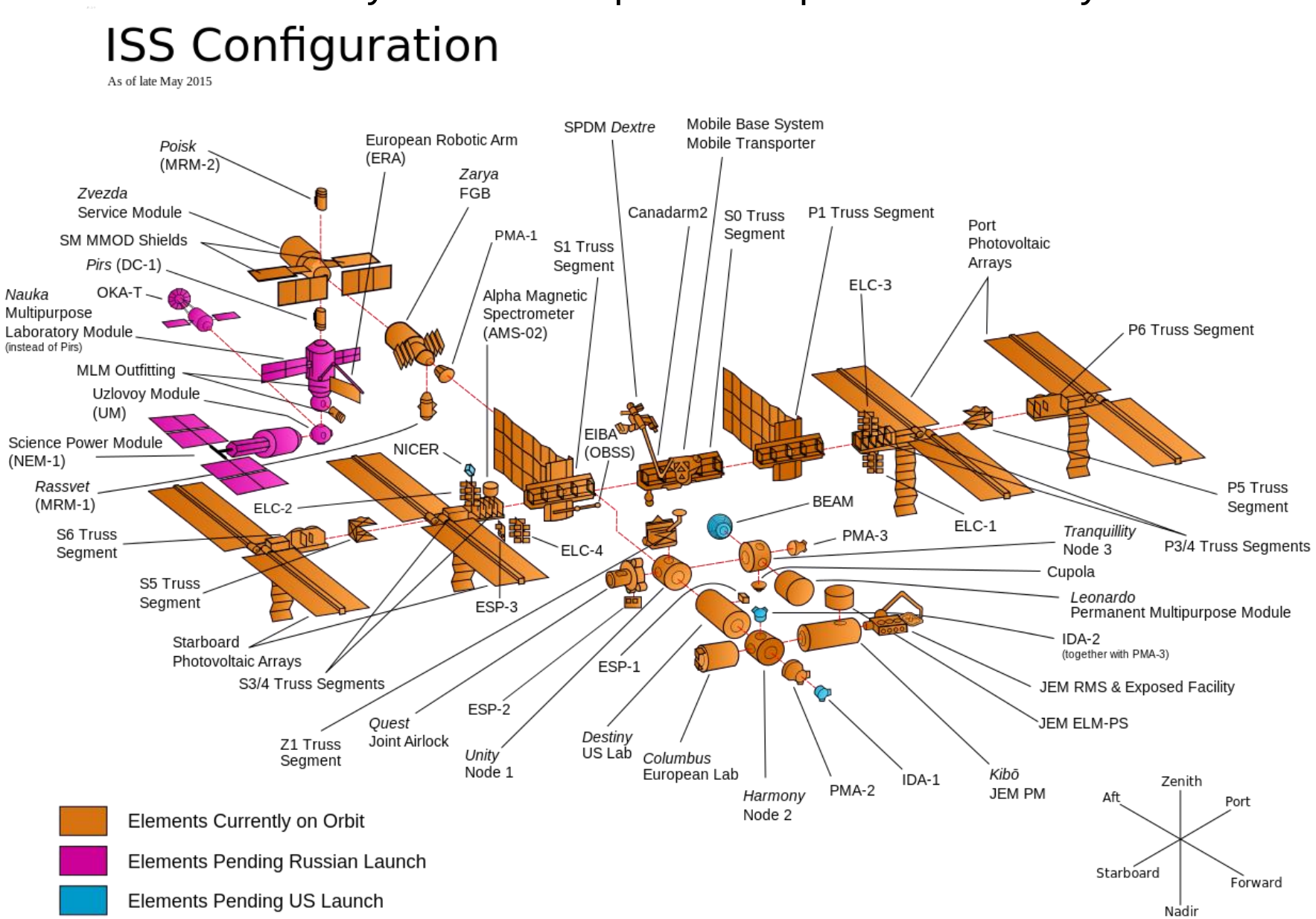
- China: Tiangong-1 2011 - current.

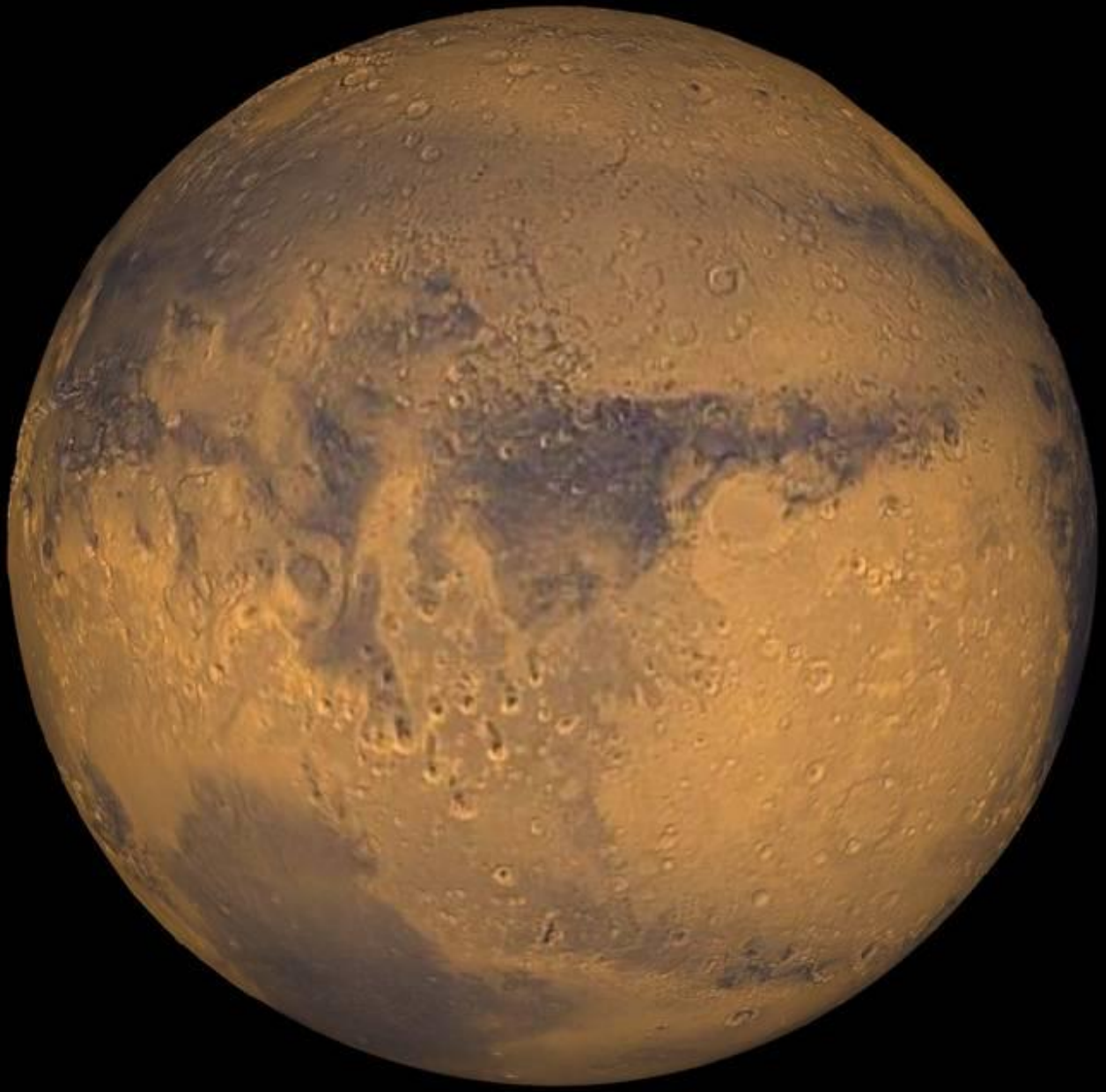


  - Testbed for a larger station in ~2023

International Space Station

Continually human occupied and operated for 15+ yrs





Space Environmental Factors

Consideration	Earth Orbital	Lunar/Mars Transfer	Lunar/Mars Surface
1. Vacuum	Pressurized enclosure	Pressurized enclosure	Pressurized enclosure
2. Debris	Requires Shielding	None	Launch and Landing
3. Gravity	Microgravity	Microgravity Induced gravity	Partial (less that 1 earth g) changes interior architecture
4. Radiation	Protected by Van Allen Belts South Atlantic Anomaly potential problem	Lunar transfer protection probably not required Mars transfer protection required	Lunar protection required Mars: TBD protection required
5. Dust	None	None	Lunar dust is a design challenge Mars dust a potential issue

Human Exploration Destination Systems

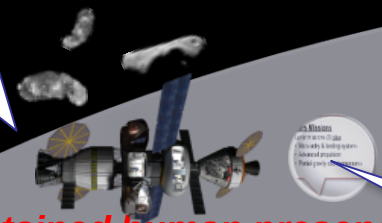
a sustained human presence

Lunar Missions
lunar orbit, lunar surface
- Landing systems
- Nuclear power
- In-situ resource utilization
- Surface Habitation
- Autonomous Operations
- Surface Rover
- Surface EVA mobility

Deep Space
LaGrange Points, NEOs and beyond
- Crew support for 30-60 + days (habitat)
- Radiation protection (habitat)
- Life support (habitat)
- Deep space propulsion
- Cryogenic fluid management
- Supportability & maintenance
- Autonomous Hab Operations

Mars Missions
Lunar missions plus:
- Mars entry & landing systems
- Advanced propulsion
- Partial-gravity countermeasures

Remote Earth Destinations
Antarctica, Deep-Water
- Analogs
- Operations Concept Validation
- Science & Mission Ops
- Autonomous Hab Operations
- Hardware/Software Demos
- Closed-loop life support
- Inflatable Hab Demos
- Environmental monitoring
- Supportability & Maintenance



sustained human presence

Near-Earth Space
HEO, lunar orbit, Libration Points
- Heavy lift launch
- Autonomous Hab Operations
- Inflatable Hab Module
- Closed-loop life support
- Crew support for - 20 days
- Deep-space propulsion
- Radiation protection

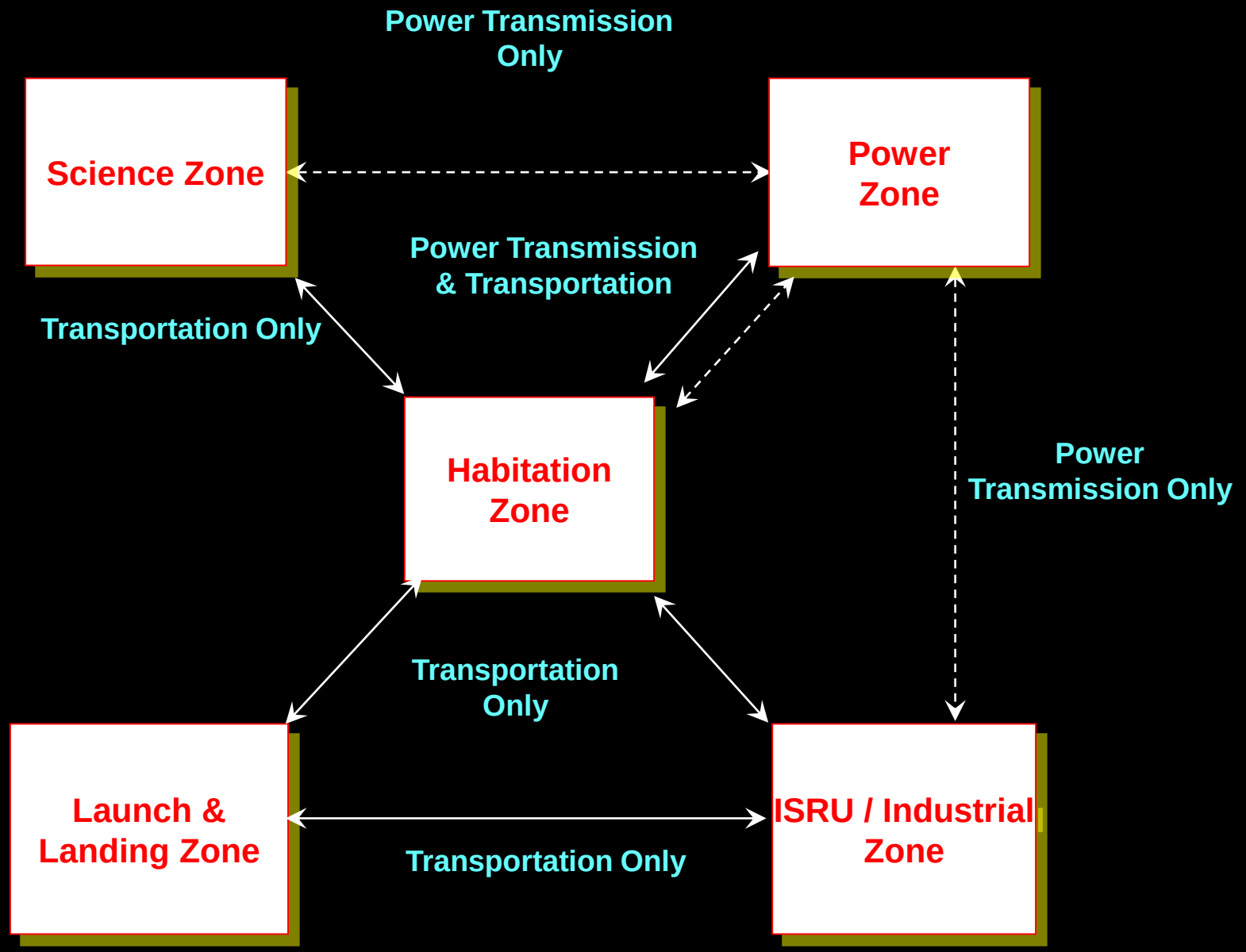
Low-Earth Orbit
Commercialization
- Zero-g research platform
- Autonomous Hab Operations
- Inflatable Hab Module
- Closed-loop life support
- Environmental monitoring
- Supportability & Maintenance concepts

Interplanetary Transportation
LEO to Destinations
- Heavy lift launch
- Autonomous Hab Operations
- Inflatable Module
- Closed-loop life support
- Crew support for long-duration flights
- Deep-space propulsion
- Radiation protection

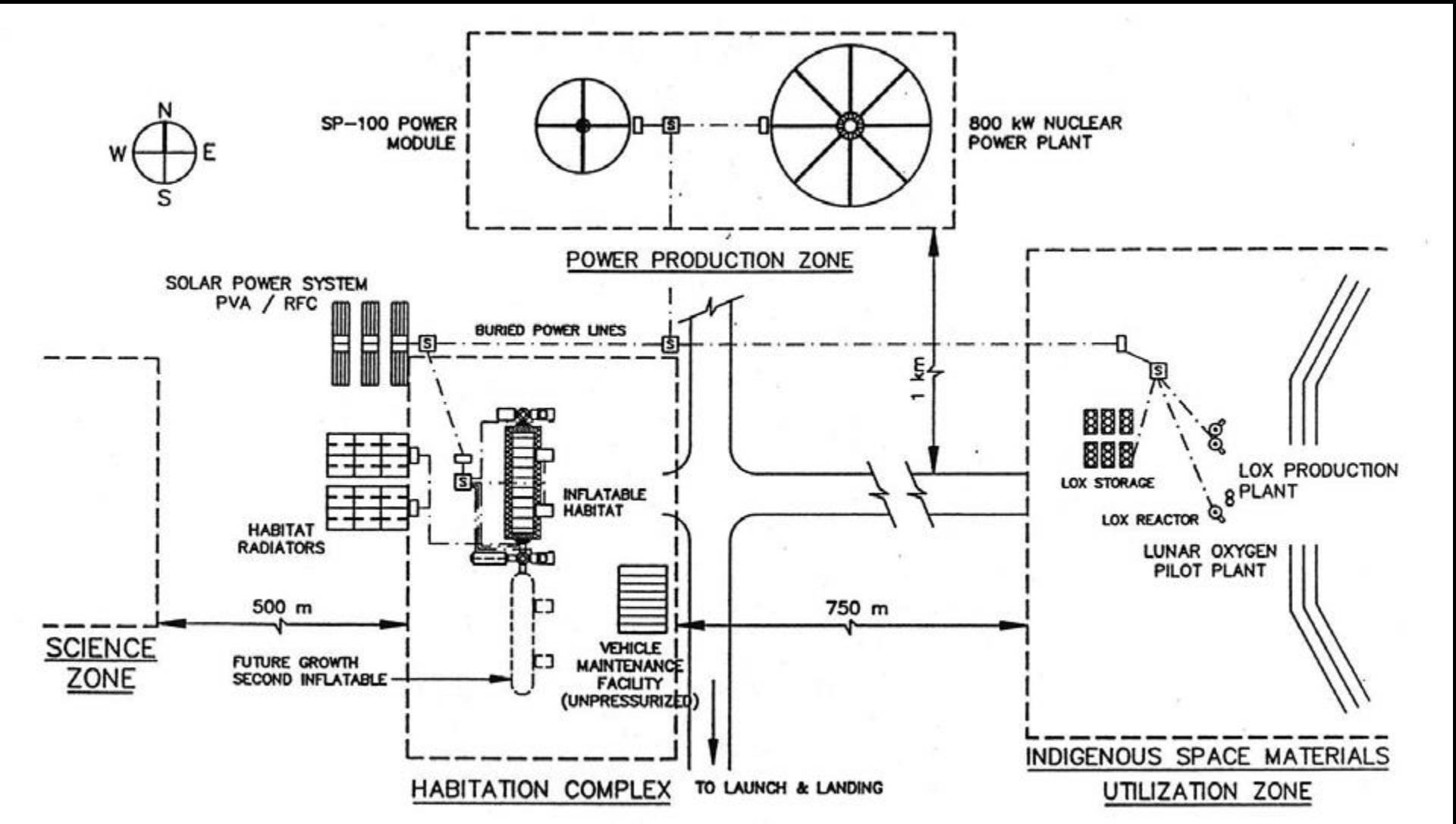
Surface Exploration Development Phases

- **Surface Exploration Sorties**
- **Base Planning**
- **Surface Research Outpost**
- **Initial Outpost**
- **Resource Production & Utilization**
- **Surface Base**
- **Industrialization / Exploitation**
- **Sustained Human Presence**

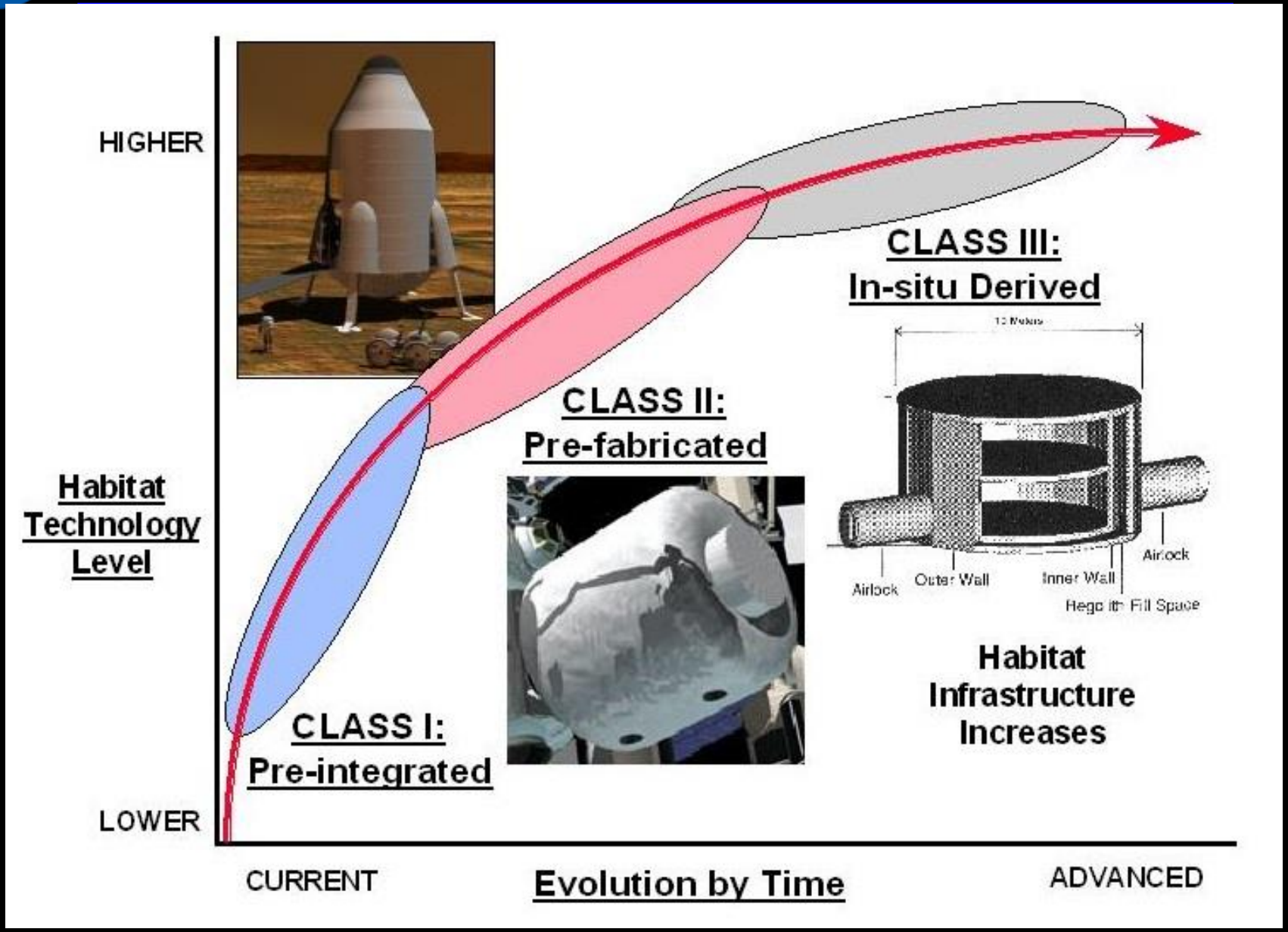
Surface Outpost Organization and Layout



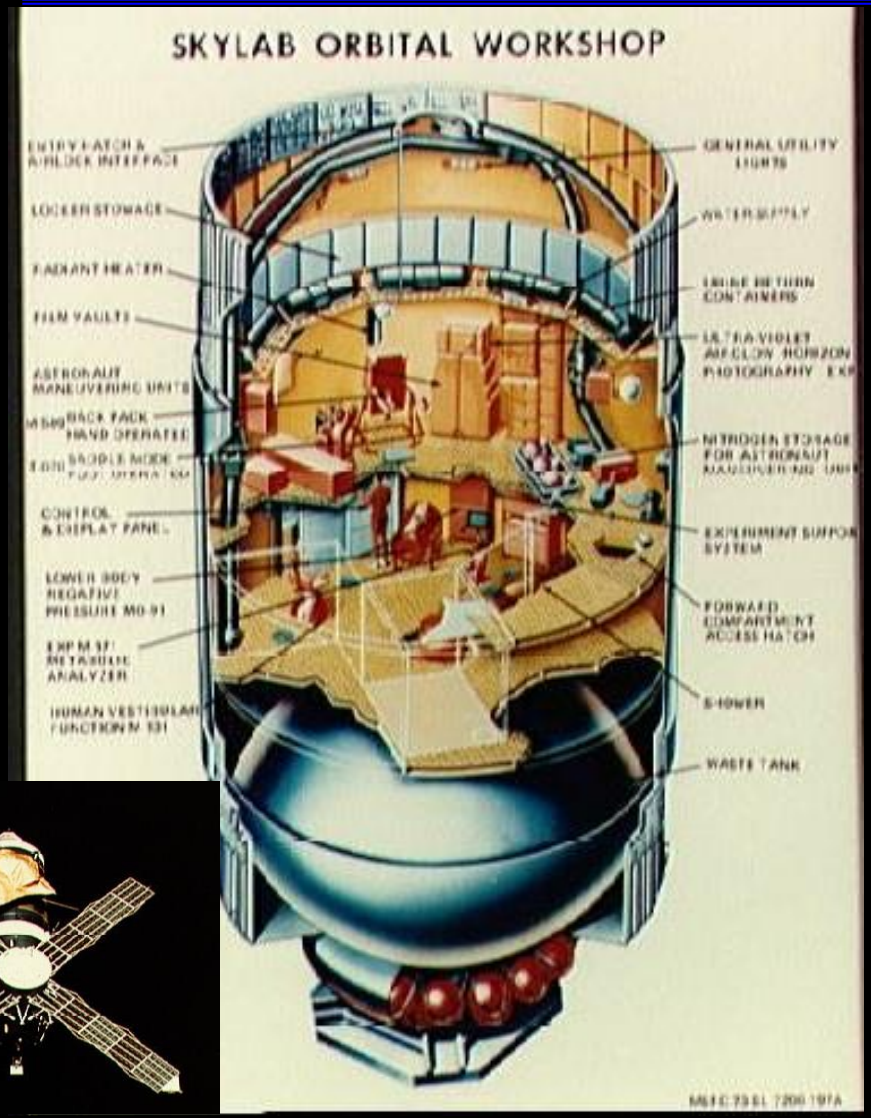
Surface Base Concept



Space Habitat Classifications



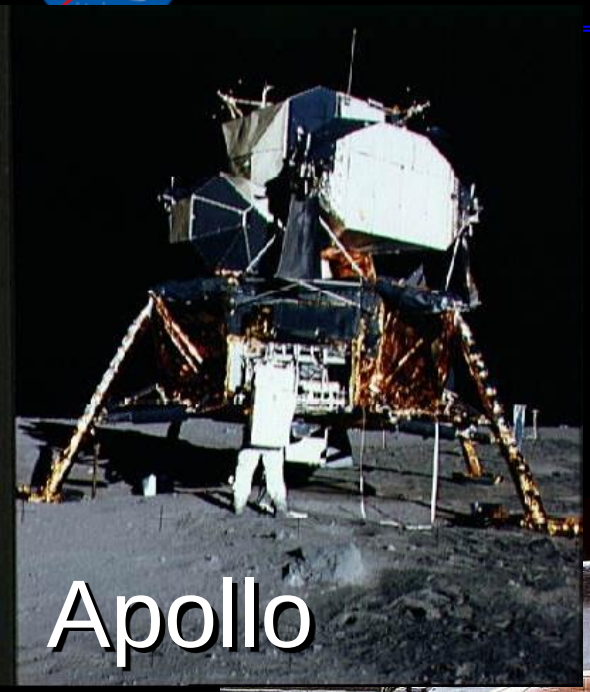
Orbital Habitats



SKYLAB

US HAB

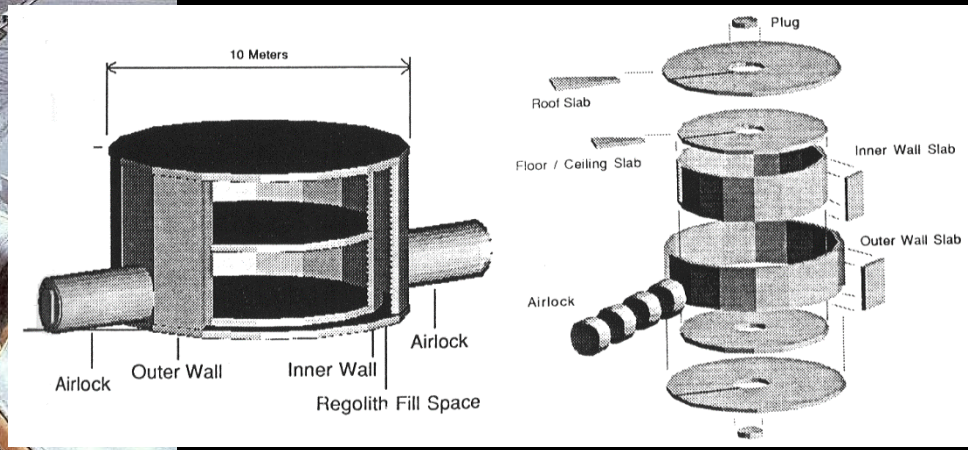
Planetary Habitats



Apollo

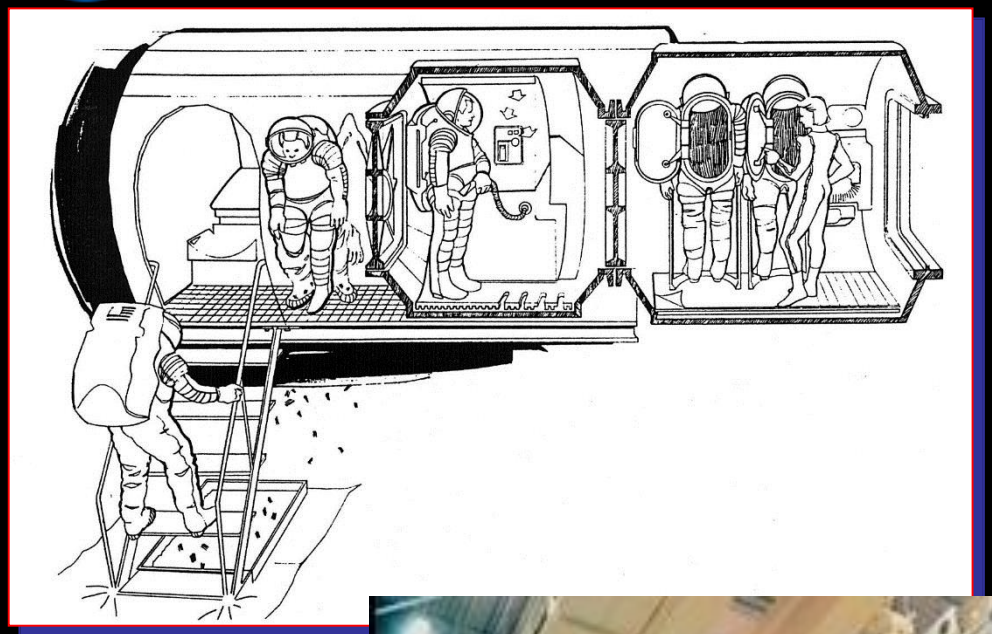
1st Lunar Outpost

Inflatable

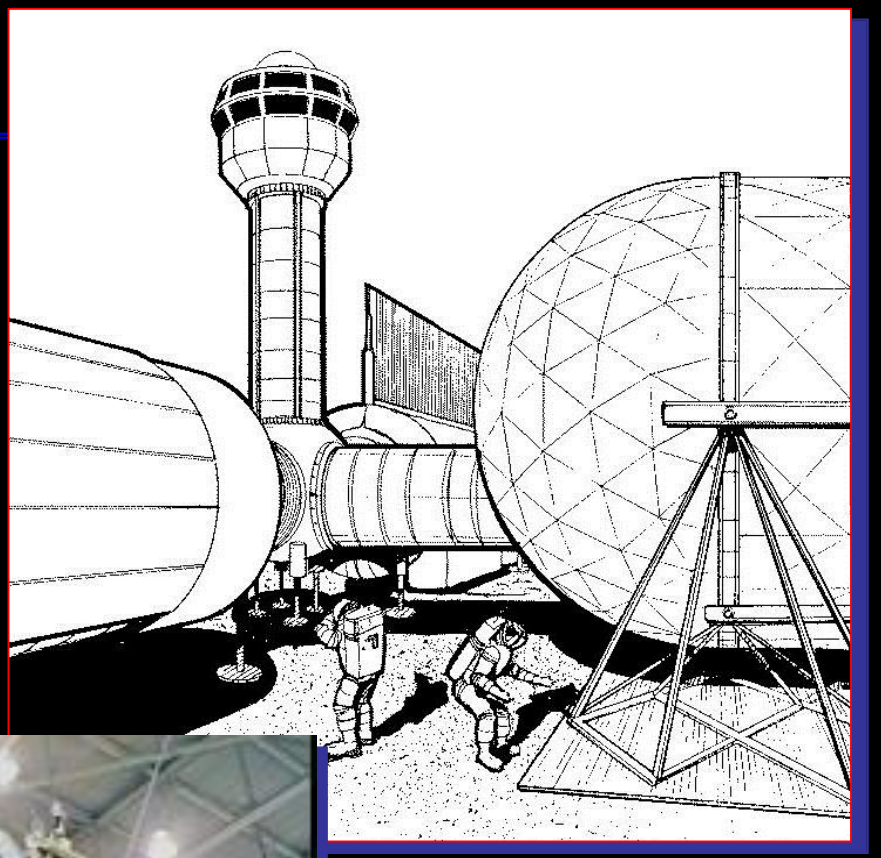


ISRU Hab

Airlocks & Nodes



Planetary Airlock



Planetary Node

Human Exploration Systems

Elements

- Crew Return Vehicle
- Deep Space Habitat (DSH)
- Space Exploration Vehicle
- Propulsion Stage
- EVA Capabilities
- Power Generation & Storage
- Deep Space Communications

Exploration Habitat Systems

- Environmental Protection
- Life Support
- Power Management & Distribution
- Thermal Control
- Crew & Medical Systems
- Laboratory Systems (Geo & Life Science)
- Logistics, Repair & Manufacturing

Habitation Operations

Crew Operations - IVA

Sustain crew on lunar surface for mission. These functions are necessary to insure the safety of the crew. It also includes providing the functions necessary to sustain the crew from a health and well being perspective.

Crew Operations – Supporting EVA

Enable Redundant EVA Function & Enhanced EVA Capability. These functions are necessary to provide the crew with additional means to conduct routine EVAs. The extent provided is driven by the mission duration and the number of EVAs required to conduct that mission.

Mission Operations

Enable Enhanced Mission Operations Capability. These functions are those that enable the lunar surface crew to conduct surface operations in concert with the Earth based mission control. For longer surface stays it should also establish autonomy from the Earth based "mission control" enabling command and control with other surface assets such as rovers, landers, etc.

Science Operations

Enable IVA Bio/Life Science & GeoScience Capability. These functions are necessary to conduct the science involved with the mission. It can include sample collection, sample analyses, sample prioritization and storage, and any sample return required. It also is meant to include any specific "environmental" requirements specific to Life Science or GeoScience

Logistics & Maintenance Operations - IVA & EVA

Enable Maintenance, Resupply, & Spares Cache. These functions are those that allows for maintaining the surface assets during recognized maintenance intervals. It also includes those functions necessary to resupply the habitat(s) with consumables (both pressurized and unpressurized) to support the crew for the mission. Lastly, it also includes the functions necessary to deliver and store the necessary spares related to the maintenance as well as unexpected failures.

Habitation Functional Elements and Operations

Crew Operations (enable sustainability of 4 crew on lunar surface for 7-180 days)

EVA Operations (enable redundant EVA function & enhanced EVA capability)

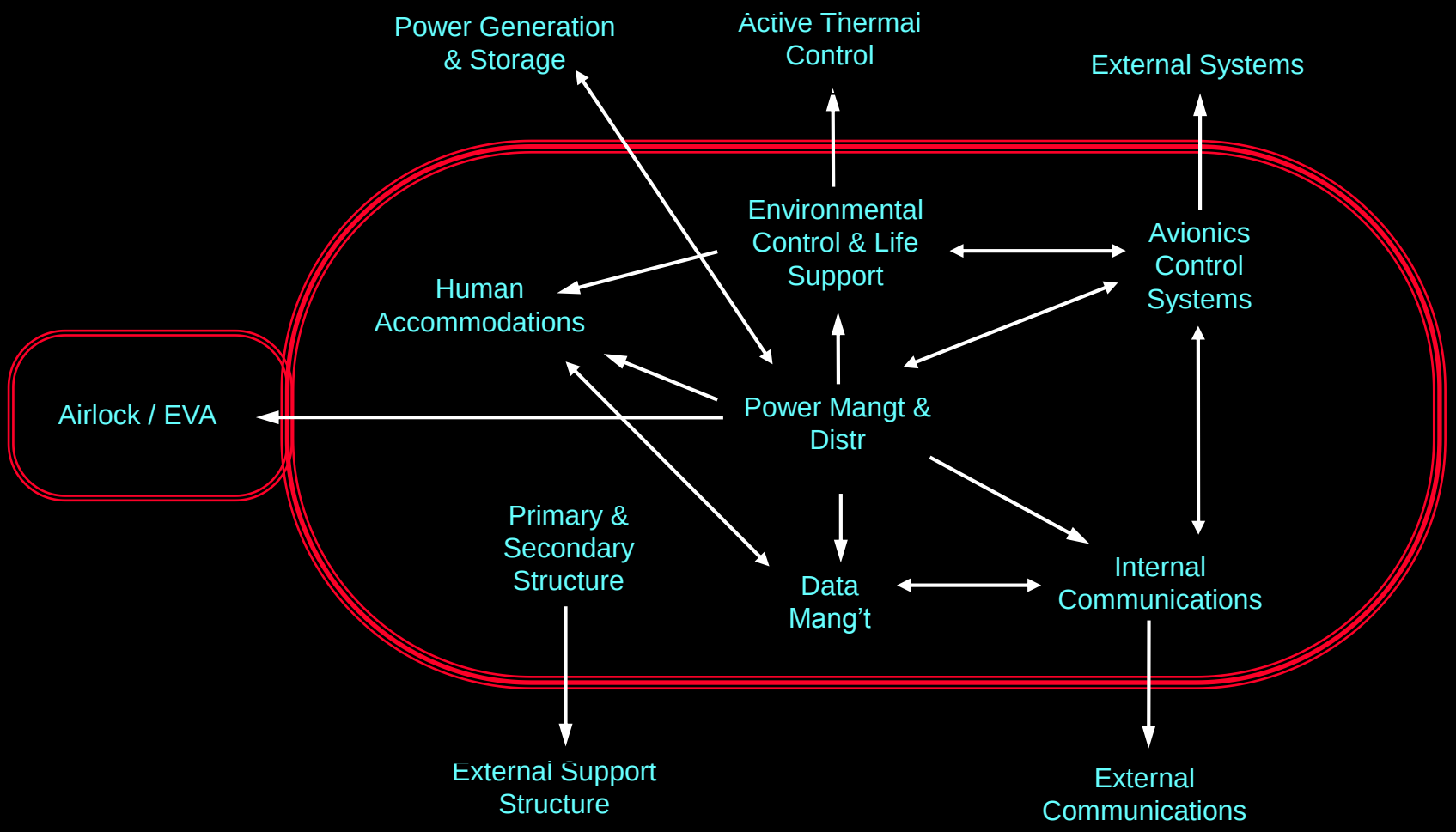
Mission Operations (enable enhanced mission operations capability)

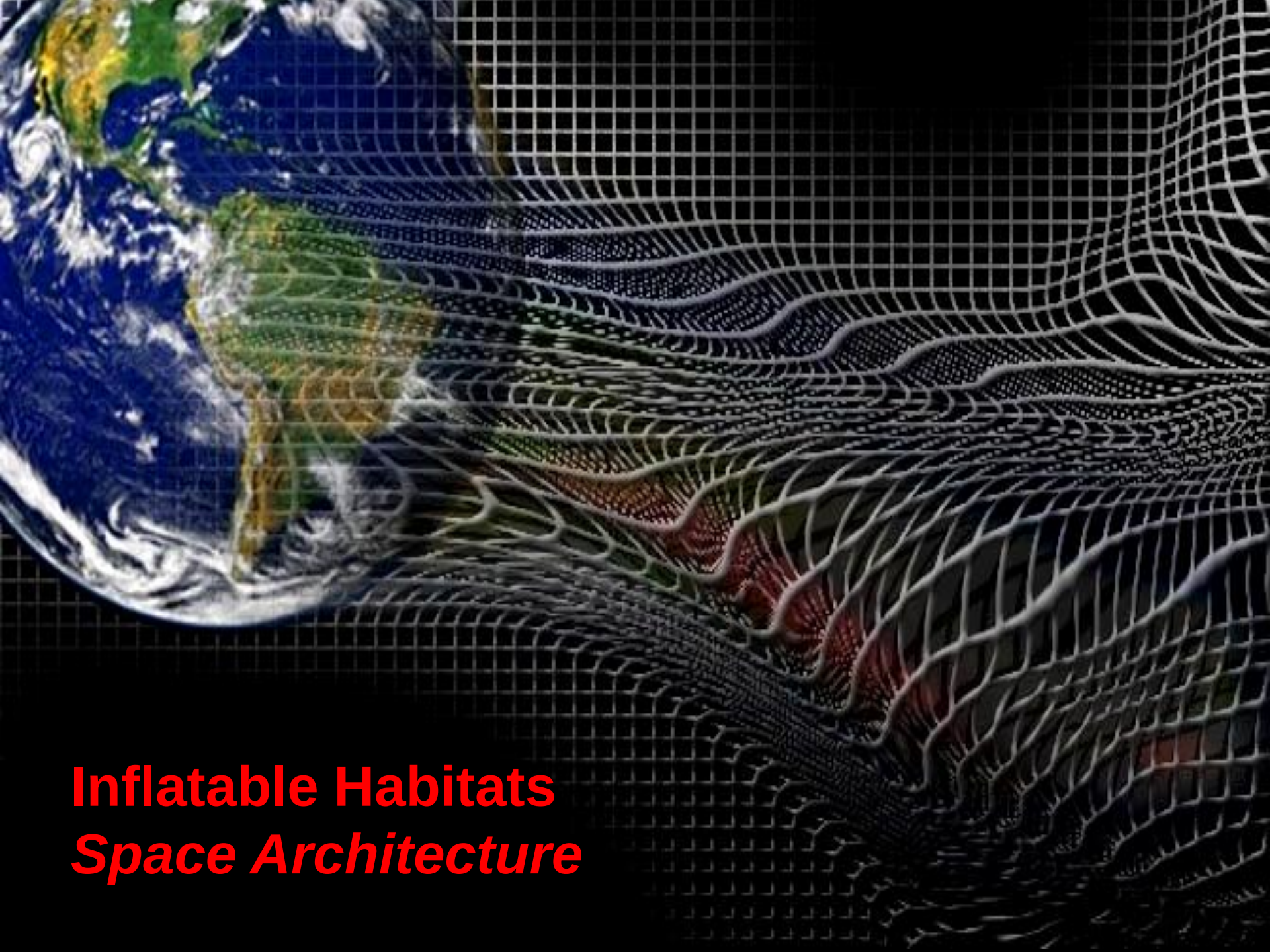
Science Operations (enable enhanced IVA bio & geo science capability)

Logistics Operations (enable resupply & spares cache)

- Structure and Environmental Protection
- Power Management and Distribution
- Life Support
- Thermal Control
- Lunar Surface Science and Technology Demonstrations
- Communications
- EVA Support
- Crew Accommodations

Habitation Elements & Interfaces

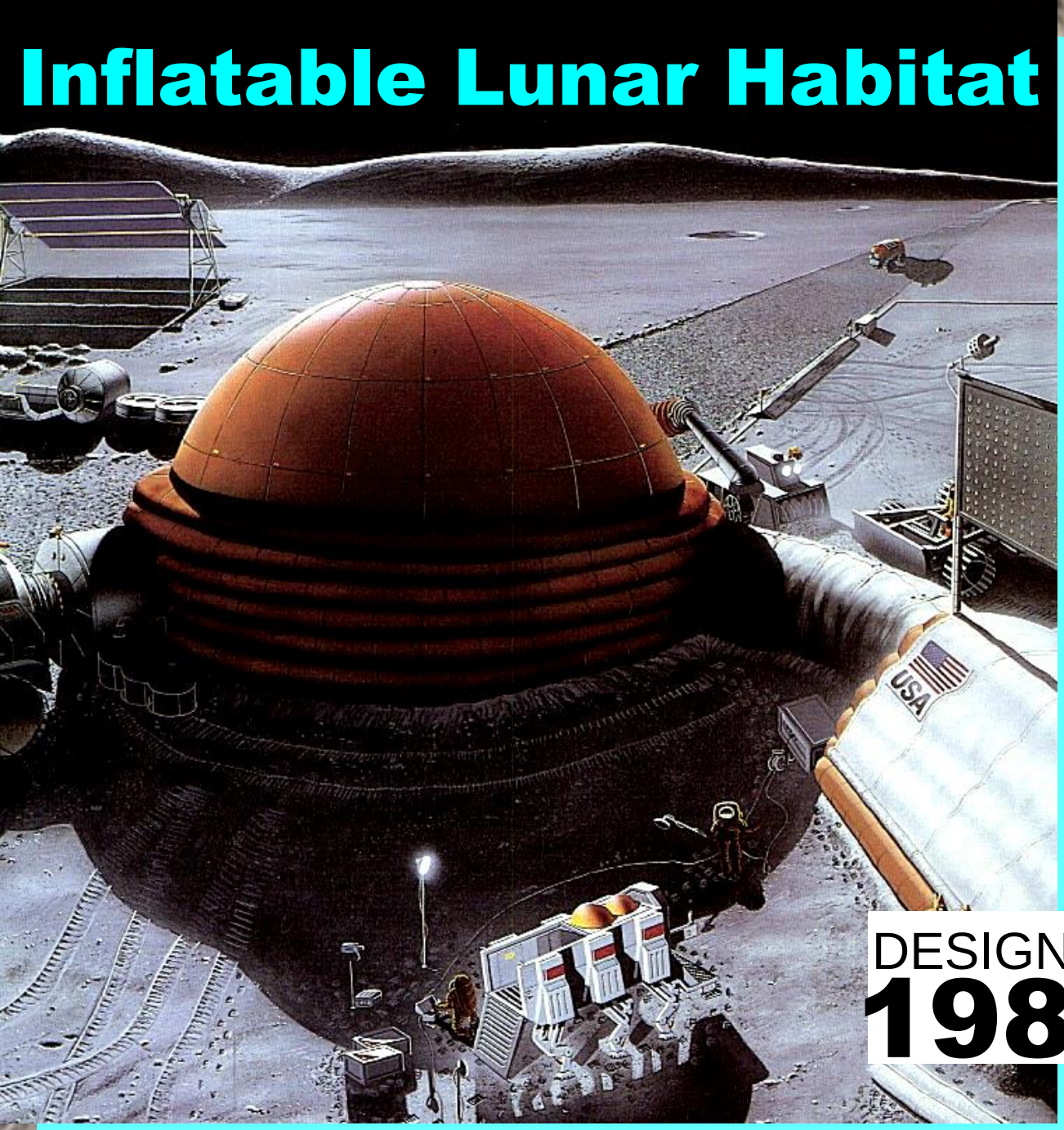



Inflatable Habitats
Space Architecture

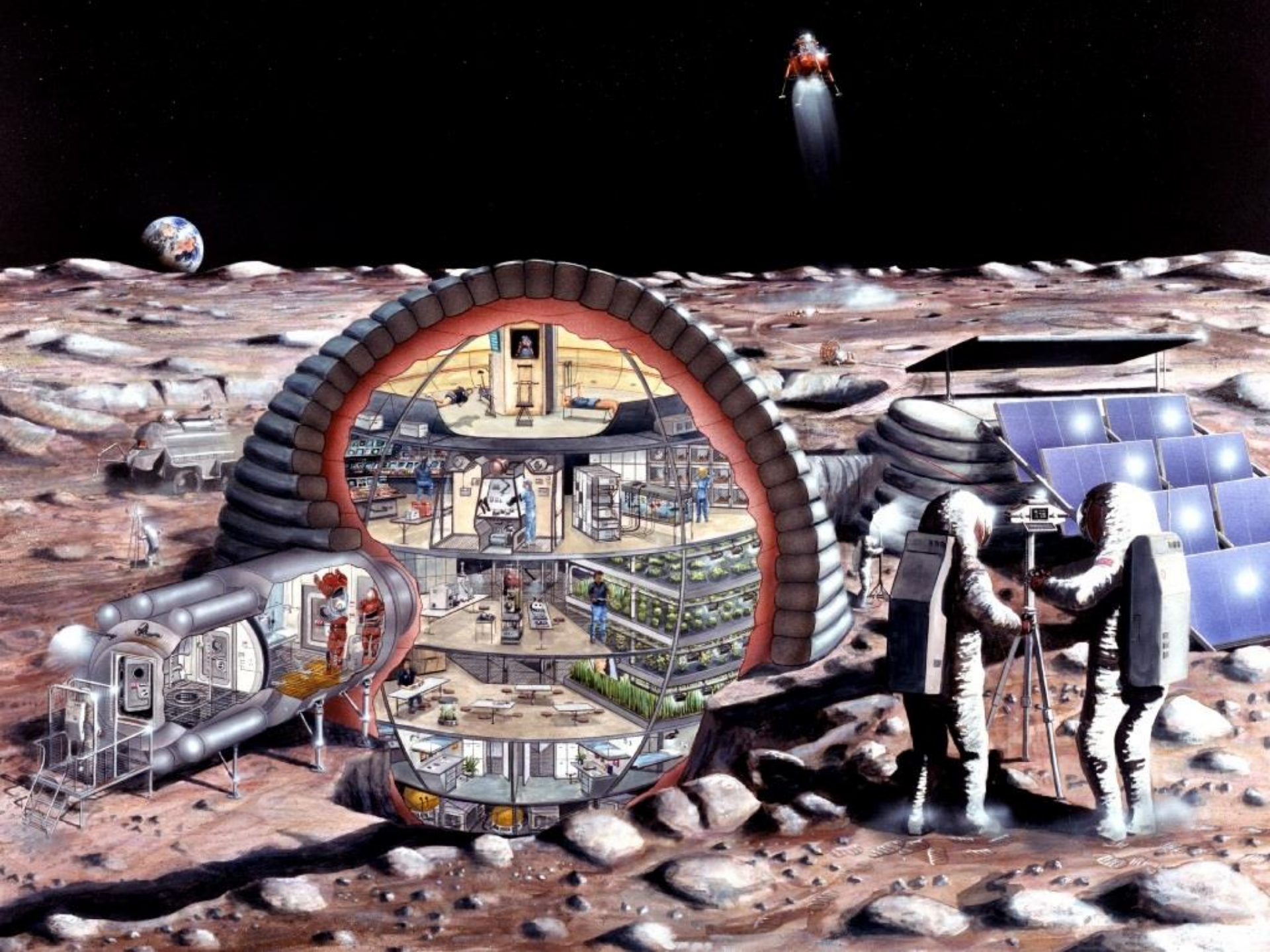
Inflatable Stuctures Overview

- Materials:
  - Kevlar
  - Vectran
  - new tensile fabric materials
- Construction:
  - “basket weave” w/ Clevis Pins
  - wound spun fibers on a mandrel like a tube sock
  - Bladder Seal: Marman Clamp
- Assembly:
  - Pure Inflatable
  - Hybrid (hard and soft materials)
  - Packaging
  - Deployment
  - Internal Assembly
  - Outfitting
  - Checkout and initial ops. Verify human occupancy ready
- Interfaces:
  - Fabrics to hard end caps or bulkhead. termination
  - Airlock, other modules, Common Berthing Mechanism (ISS derived)
  - Structural Nodes
  - Surface: Foundation or support
- Design:
  - Pressure Vessel shapes
    - Sphere, cylinder, torus, hybrids
- Architecture:
  - External Protection
  - Internal Layout
  - Utilities Distribution
  -

Inflatable Lunar Habitat



DESIGNED
1989

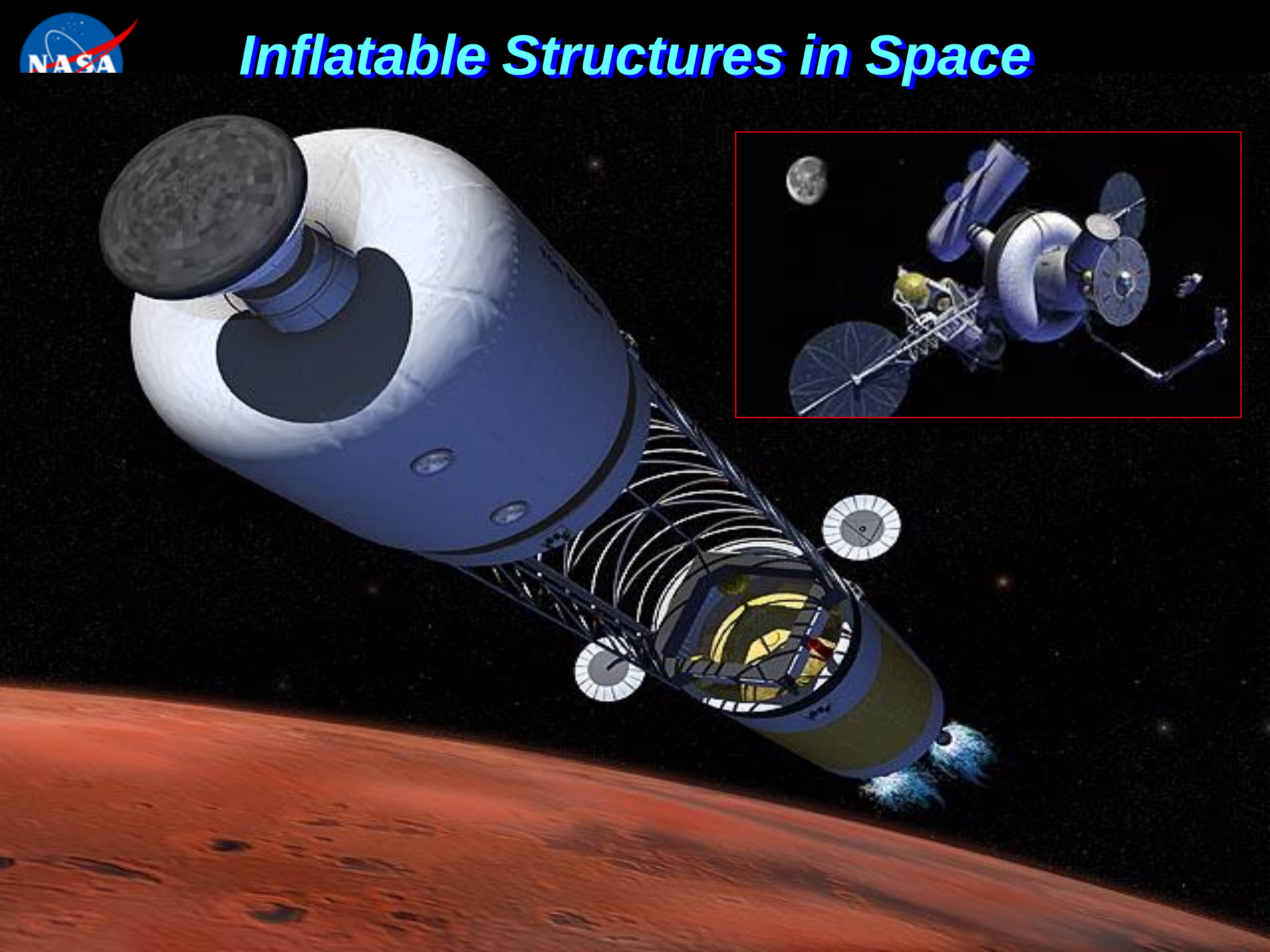


Inflatable Lunar Habitat

DESIGNED
1992


Mars Base &
Mission
Planning
1996

Inflatable Structures in Space



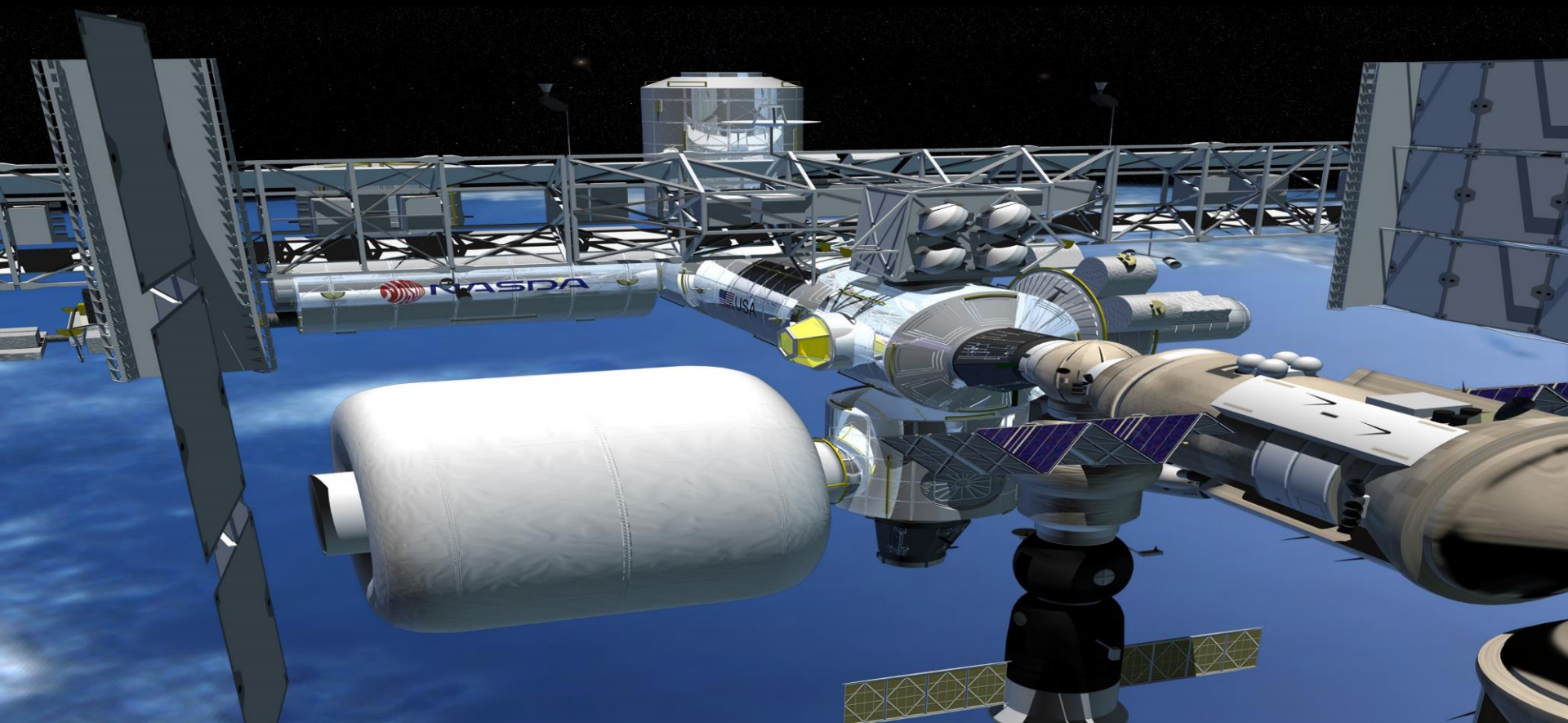
TransHab (Inflatable Space Habitat)

- U.S. Patent granted

DESIGNED
1997

NASA TransHab Concept

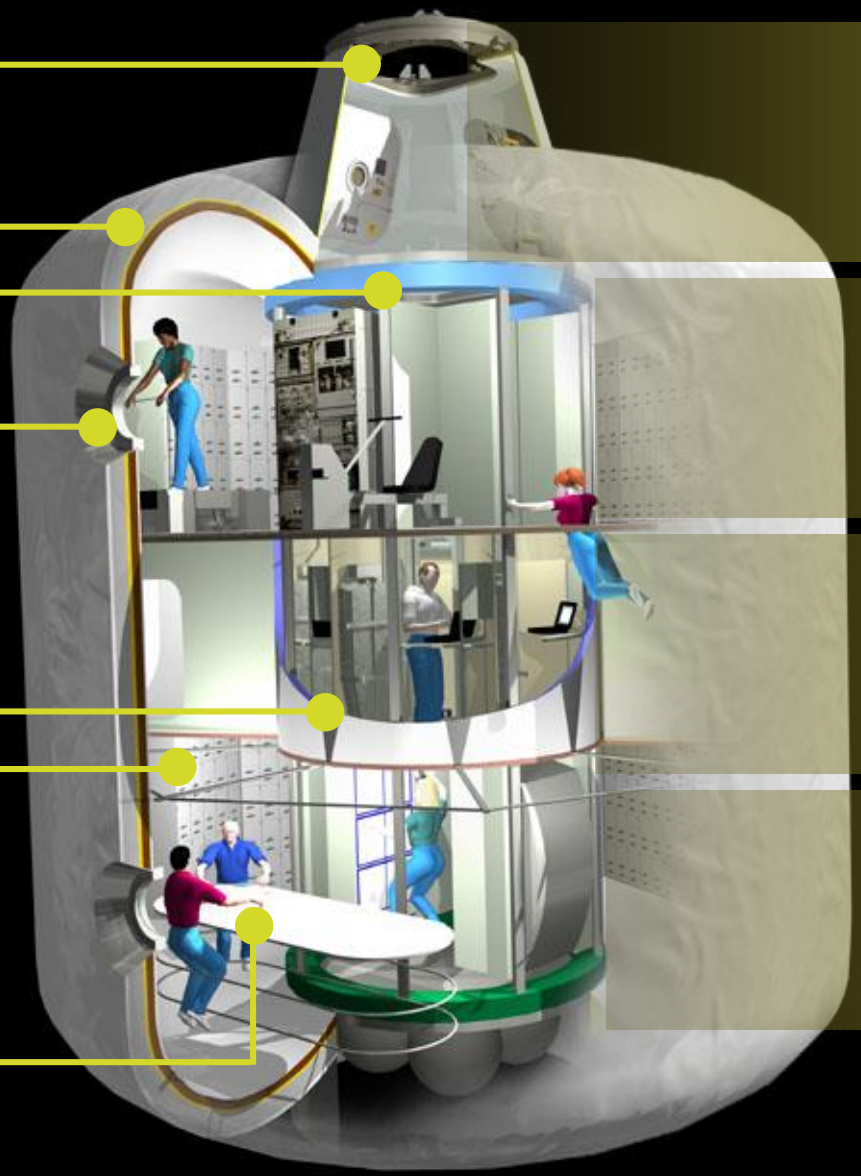
- **TransHab was a light weight inflatable habitation module for space applications**
- **Original 1997 concept for light weight habitat module for human mission transit to Mars**
- **Proposed to the International Space Station (ISS) Program as a replacement for a Hab Module**

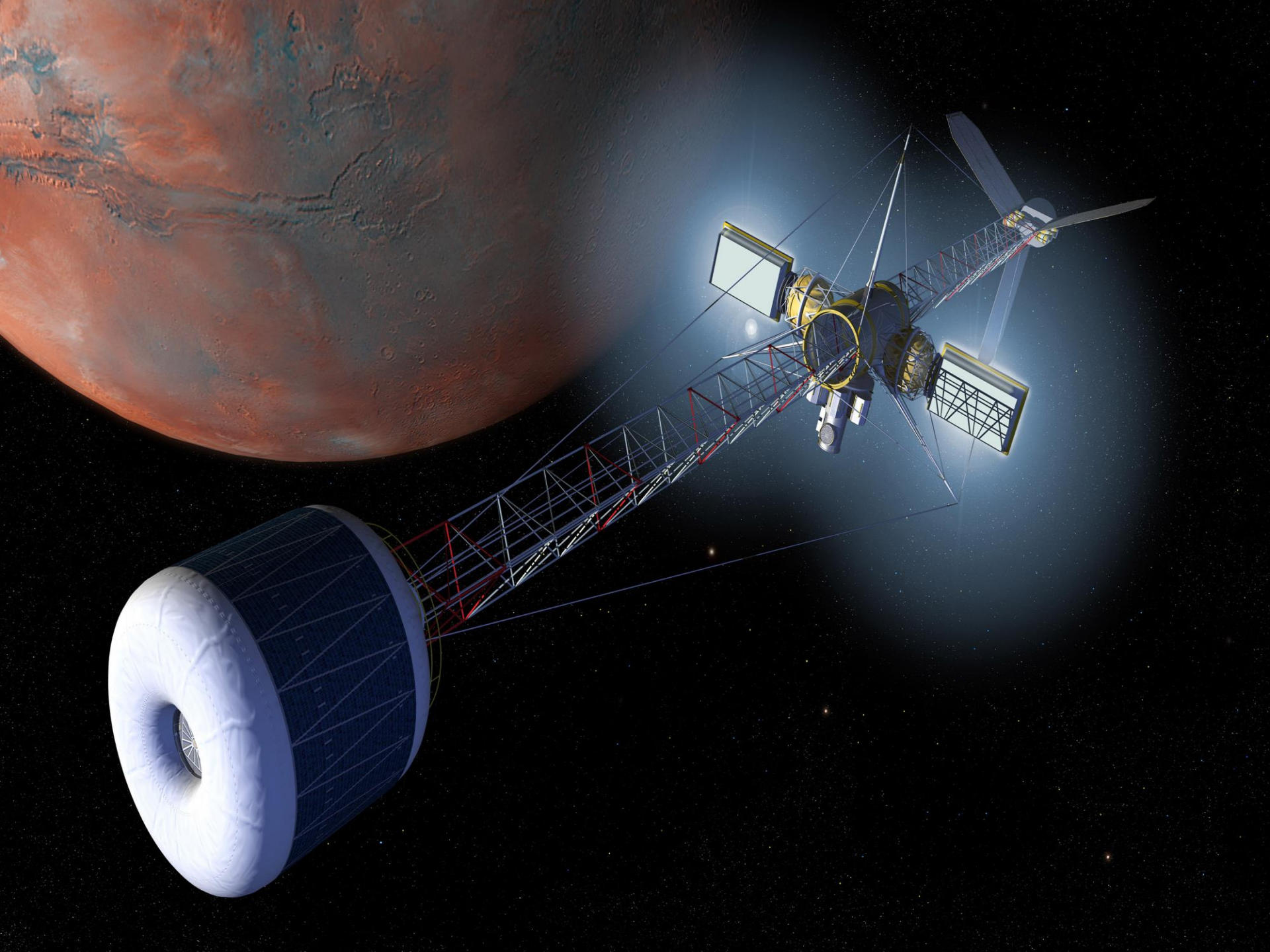


ISS TransHab *Full Scale Shell Development Unit (SDU-3)*

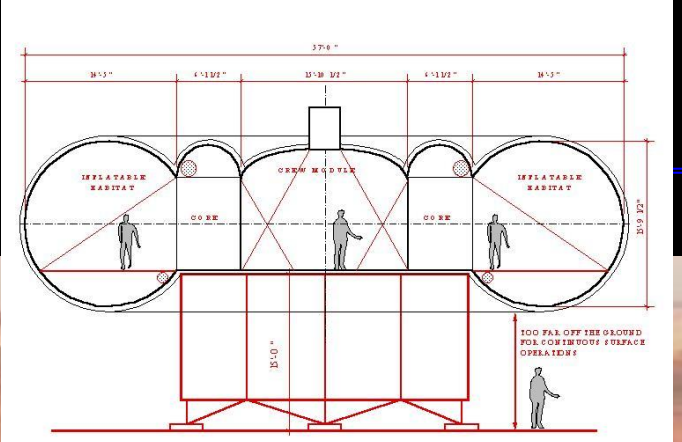
First Inflation: November 17, 1998

ISS TransHab





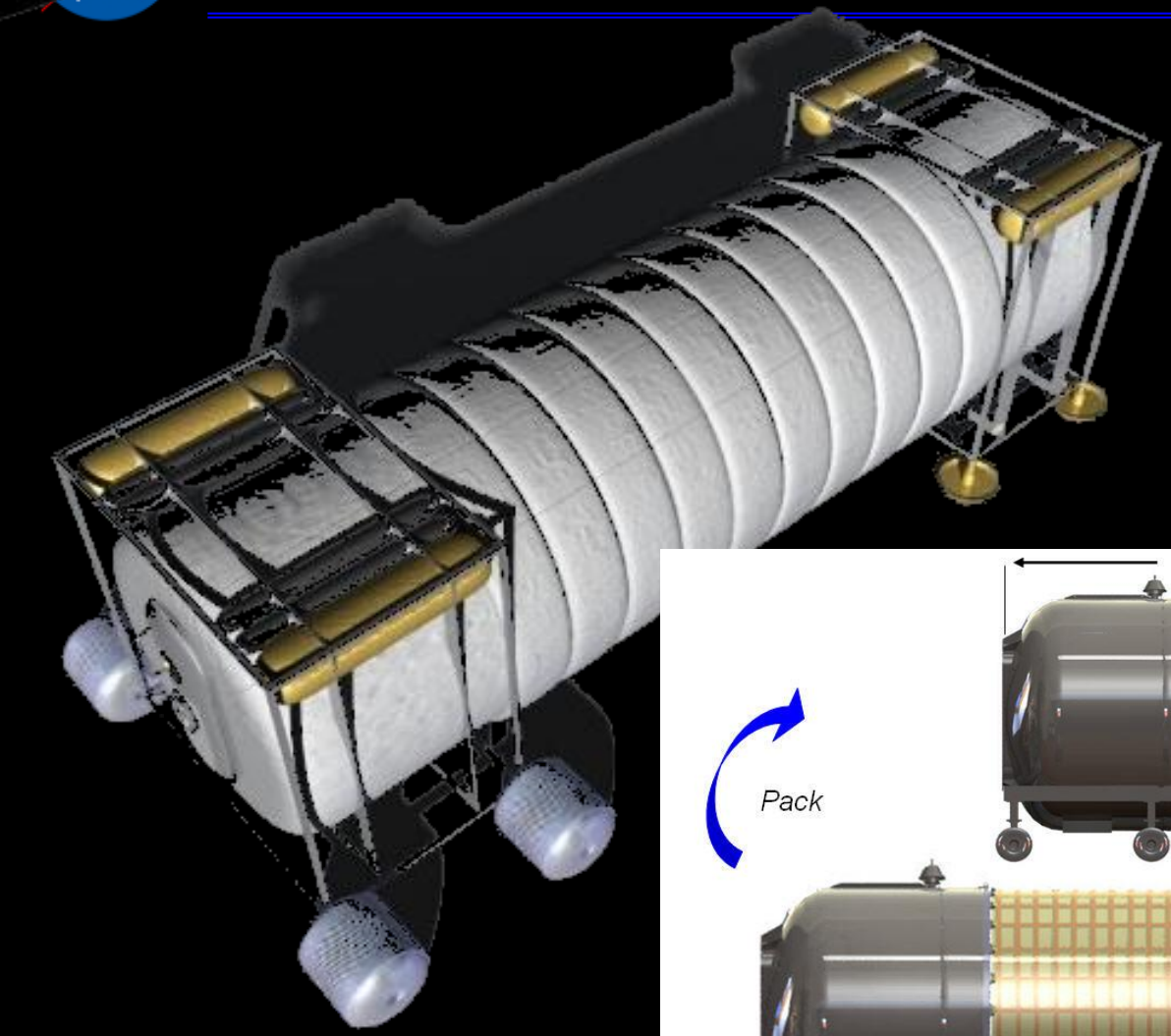
Mars Surface Hab/Combo Lander



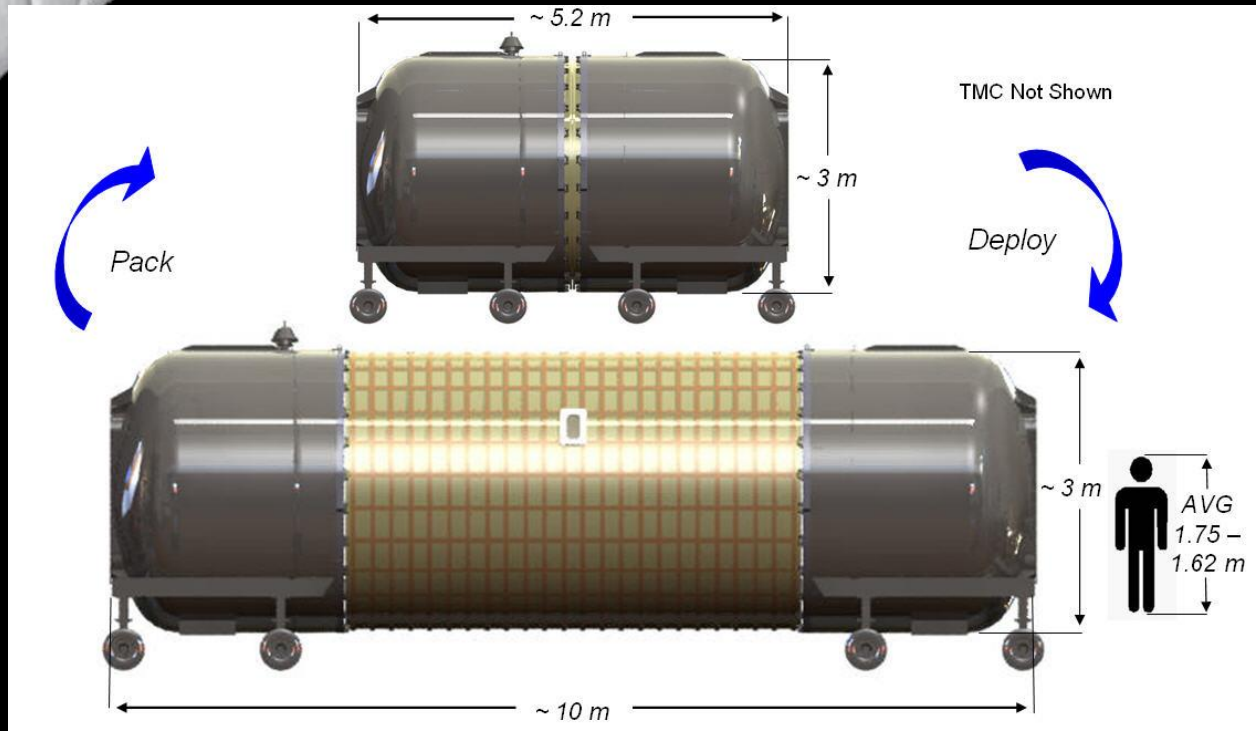
MARS SURFACE HABITAT CROSS SECTION

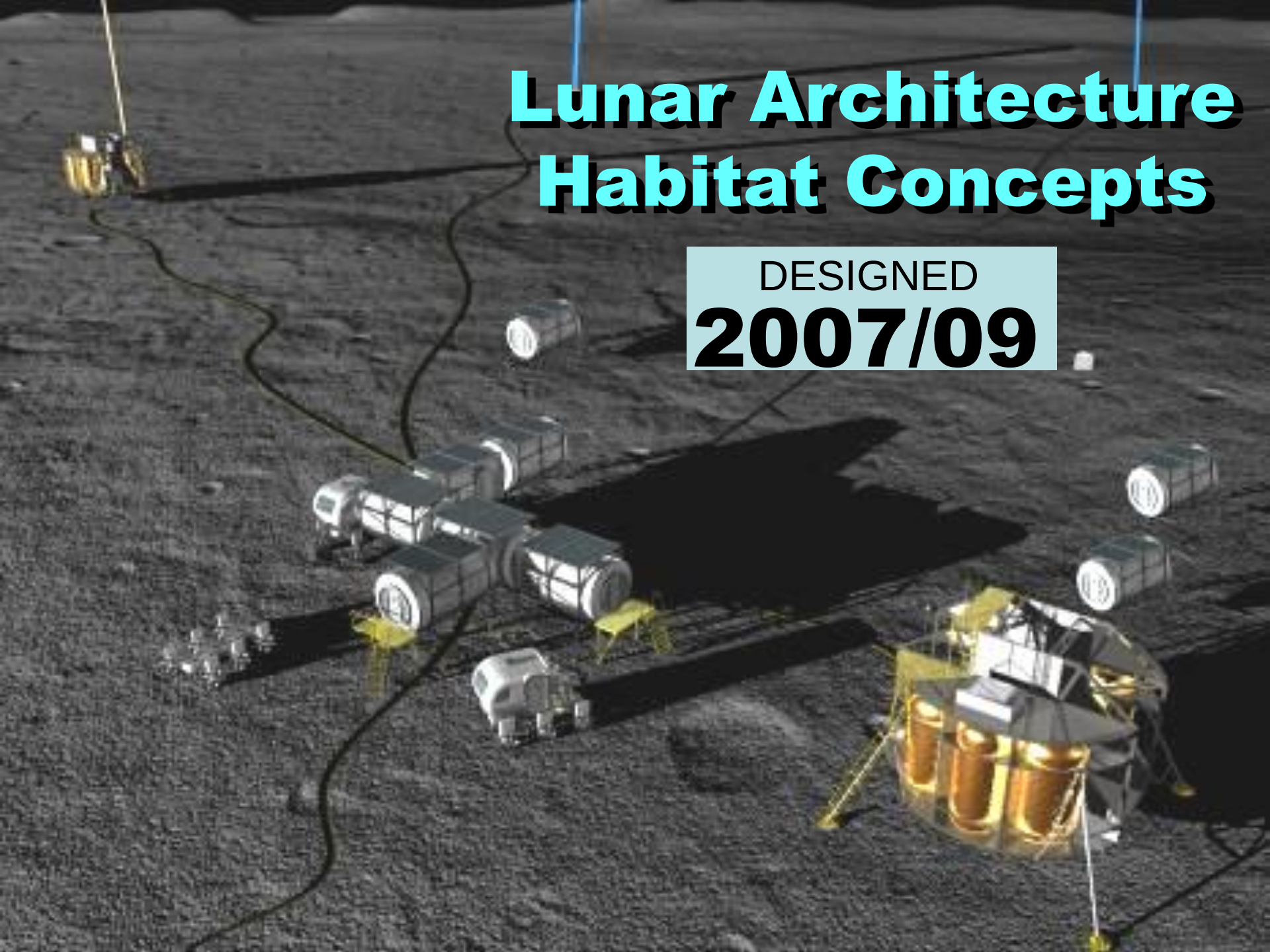
DESIGNED
2000

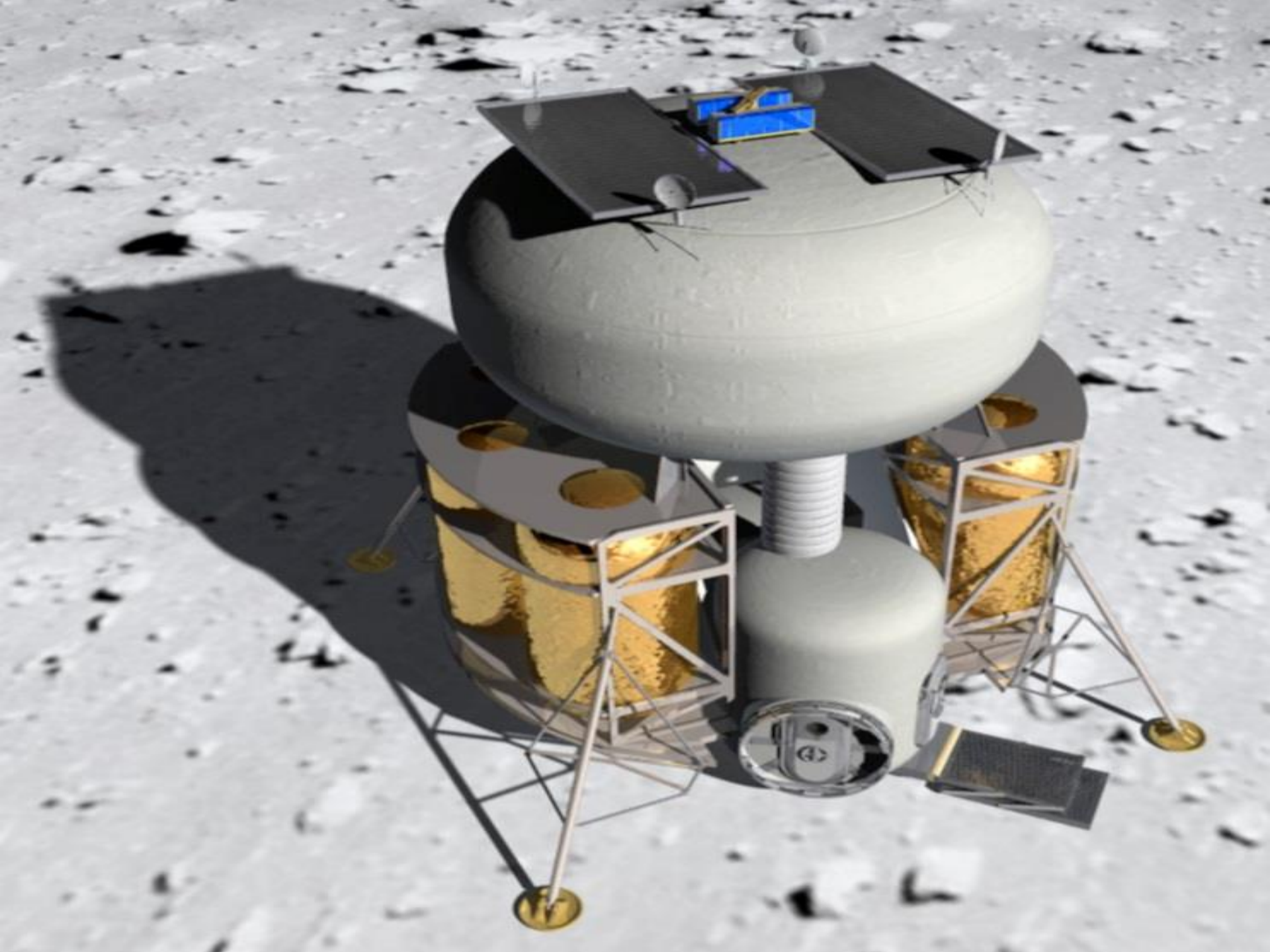
Mid-Expandable Habitat Concept

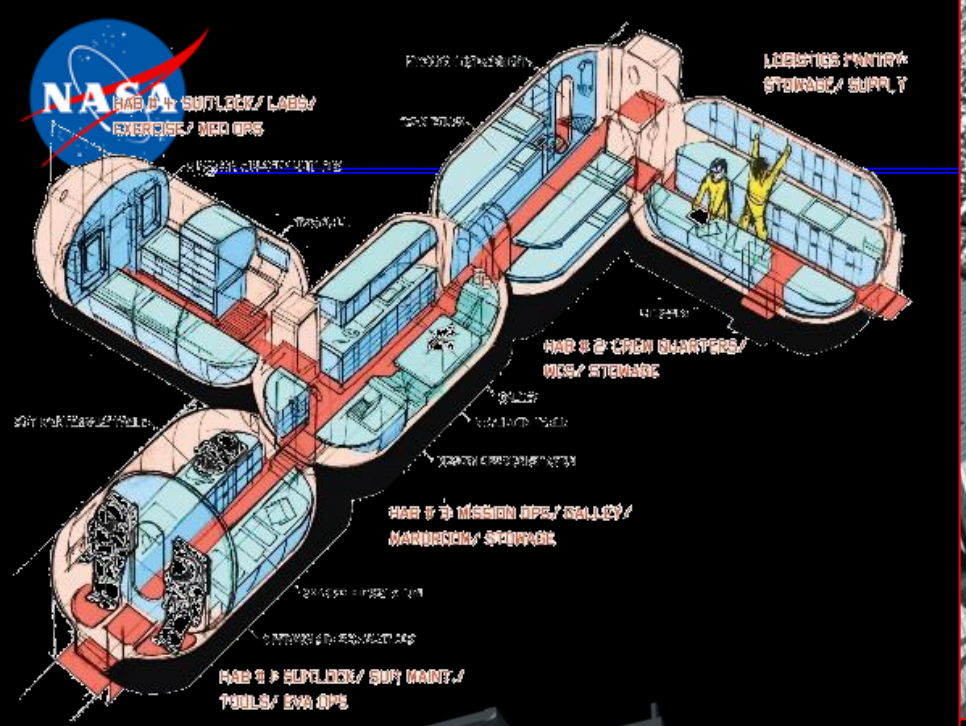


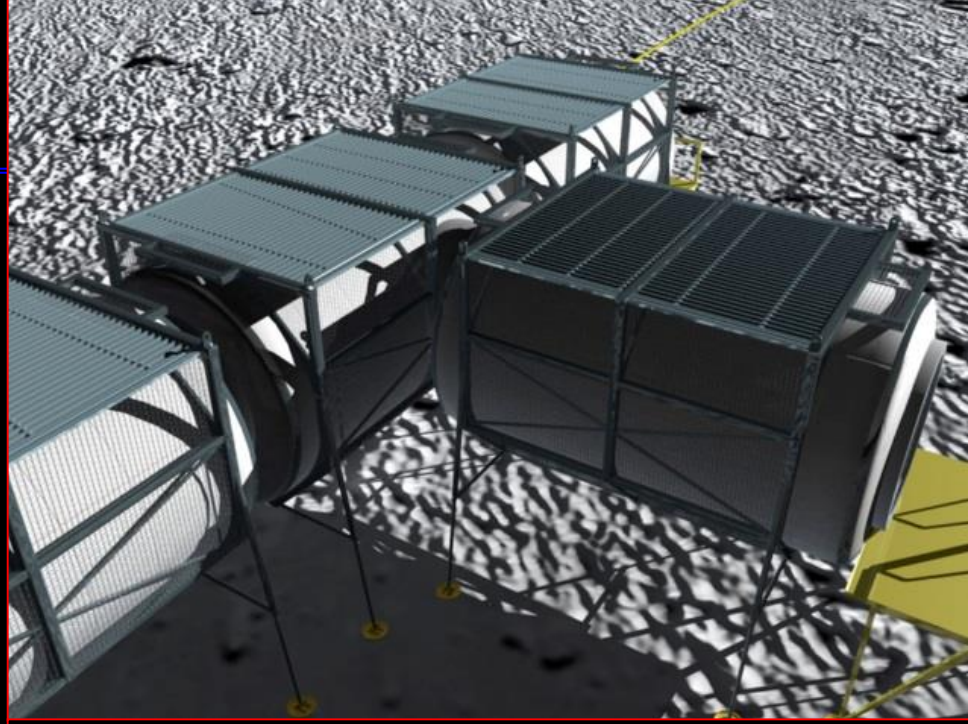
DESIGNED
2008

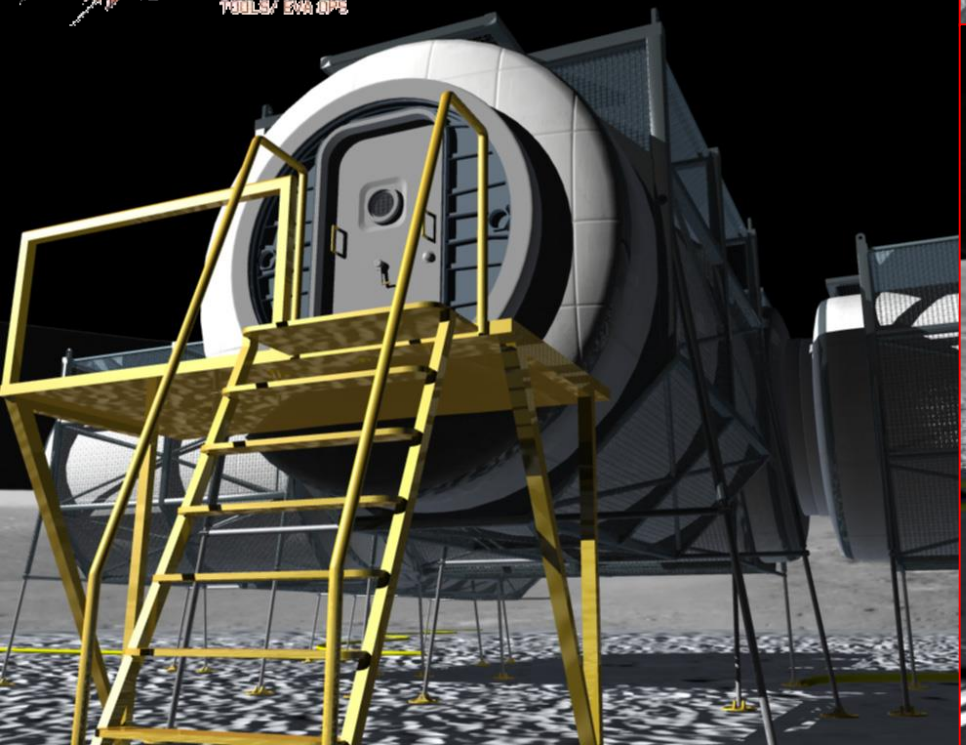


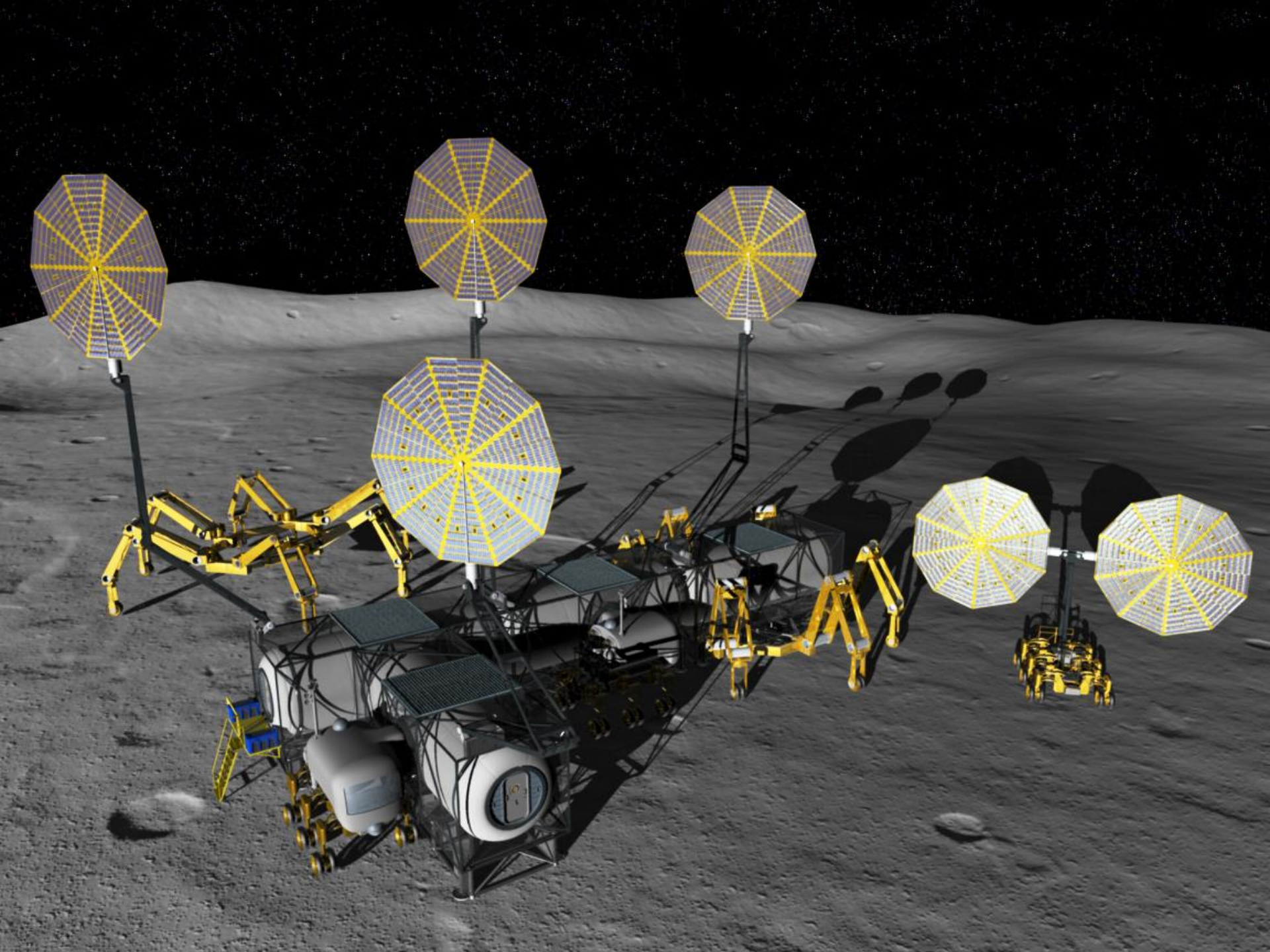

Lunar Architecture
Habitat Concepts
DESIGNED
2007/09

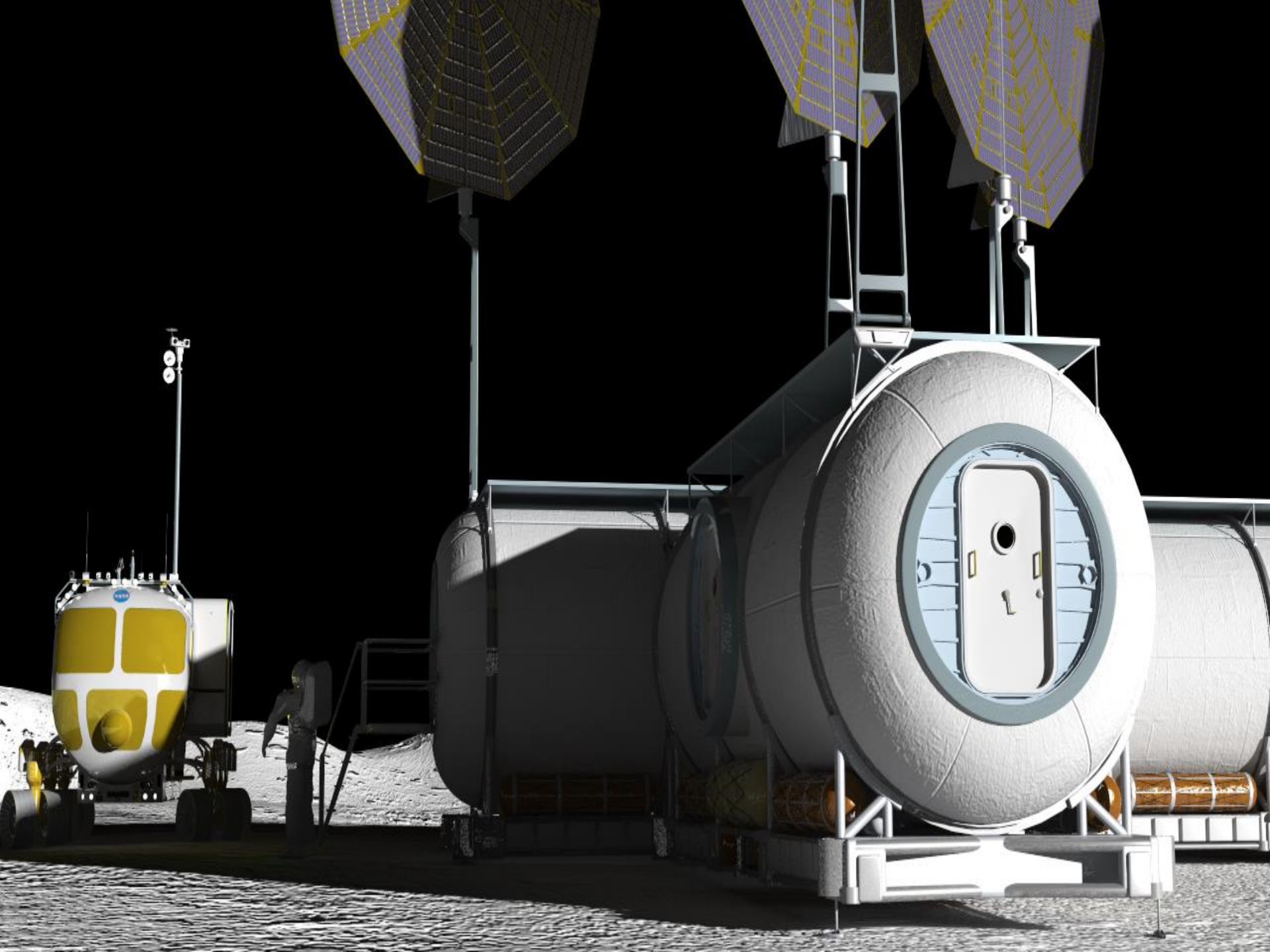


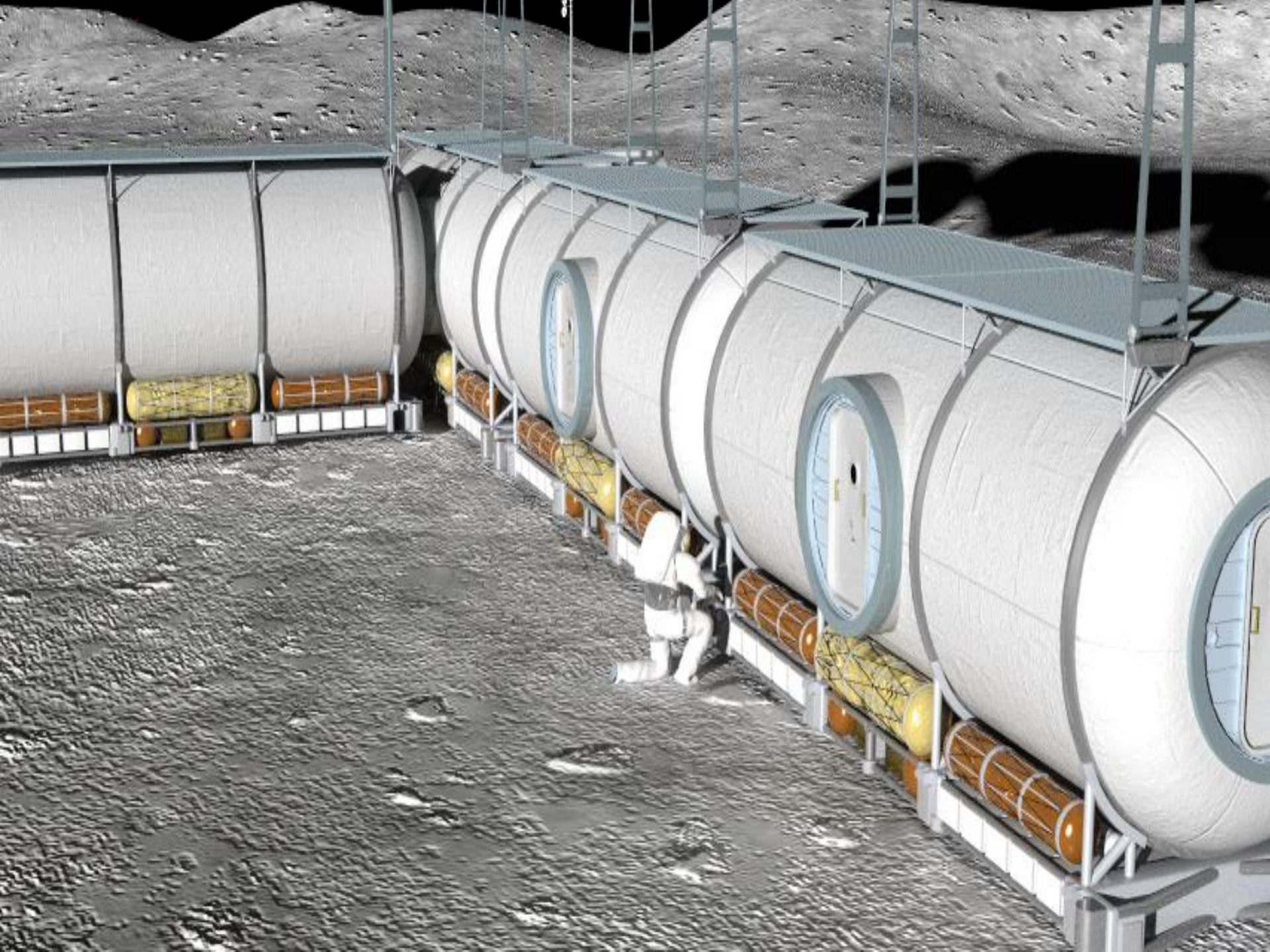

NASA

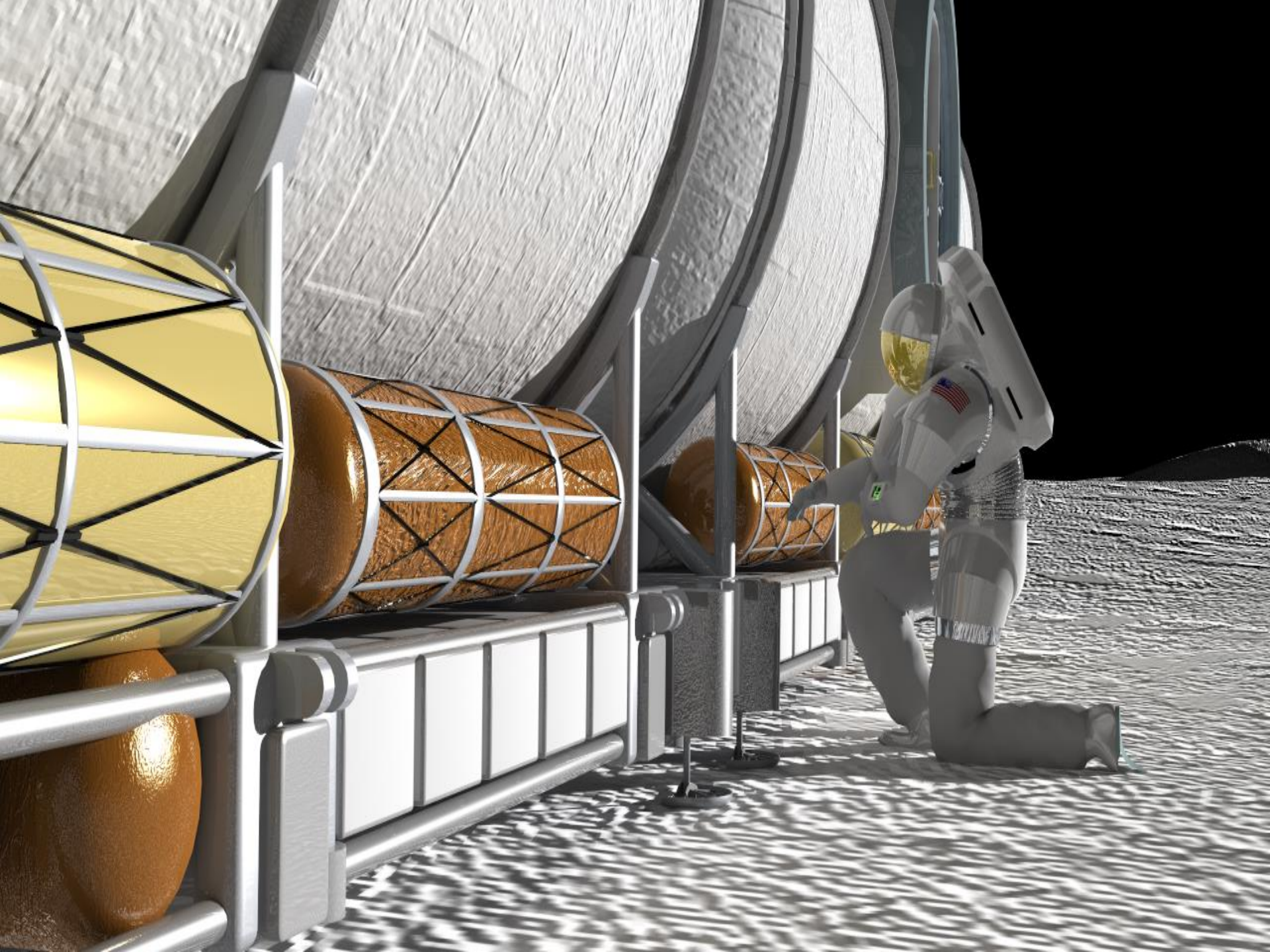


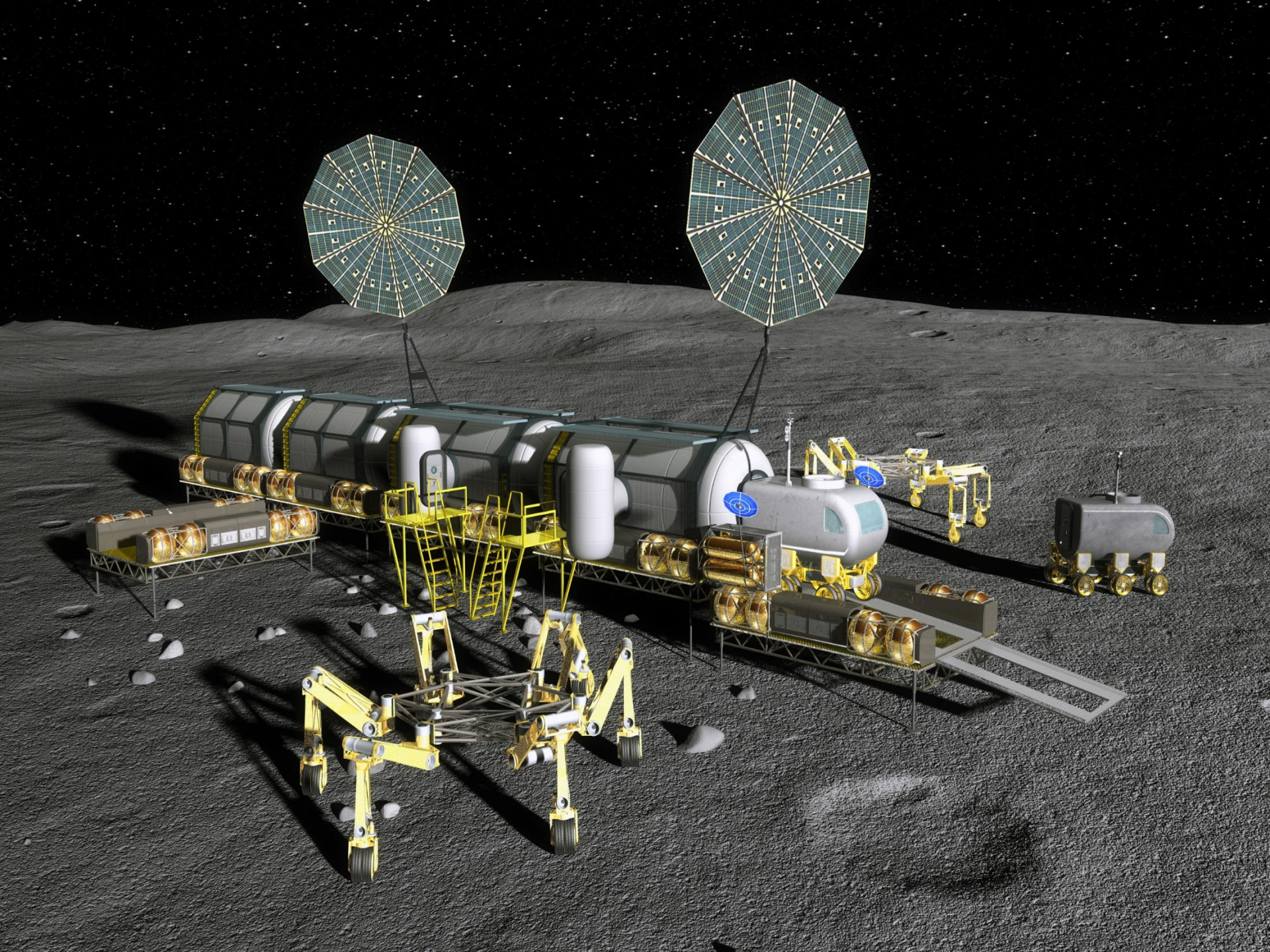




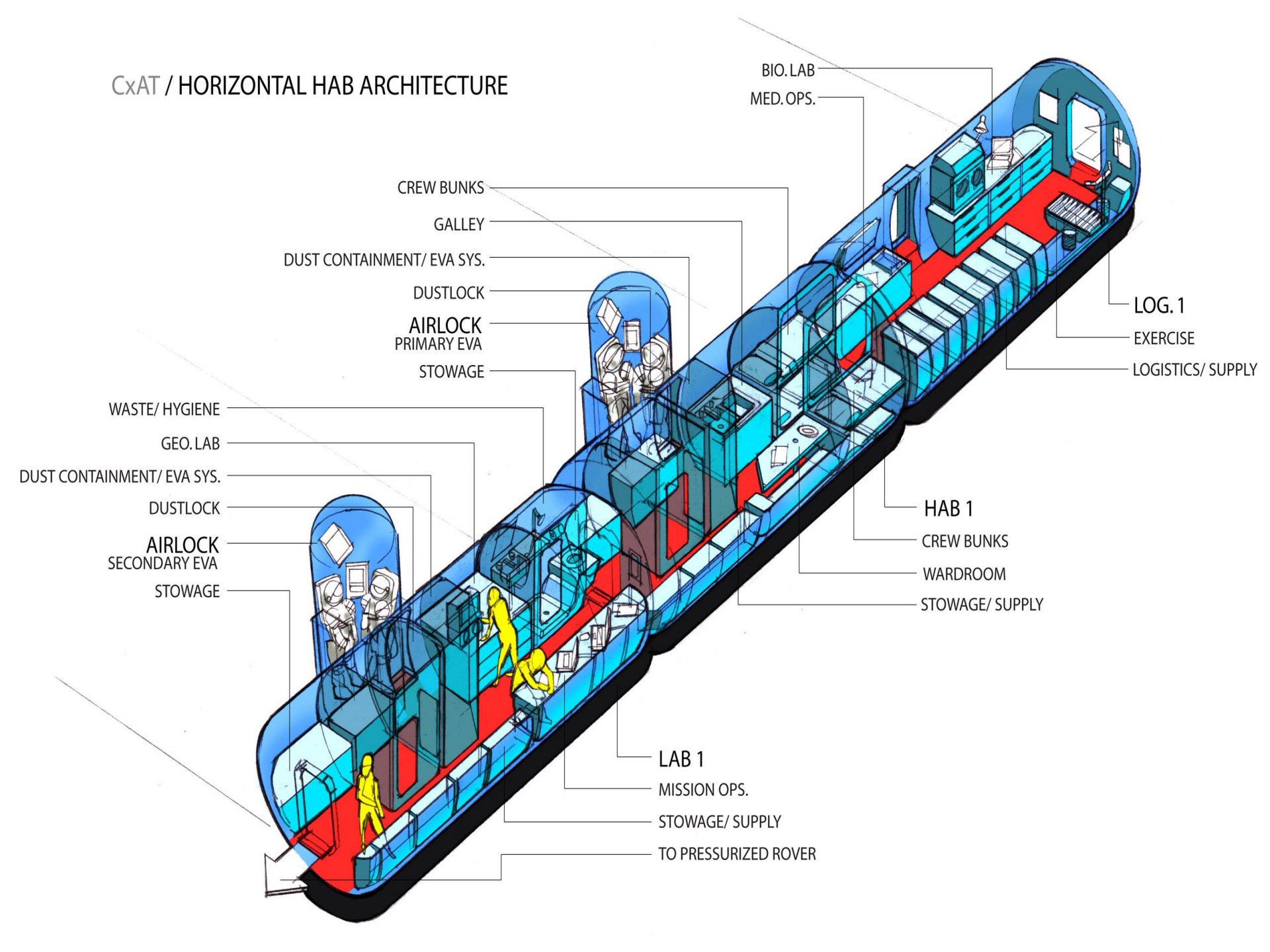


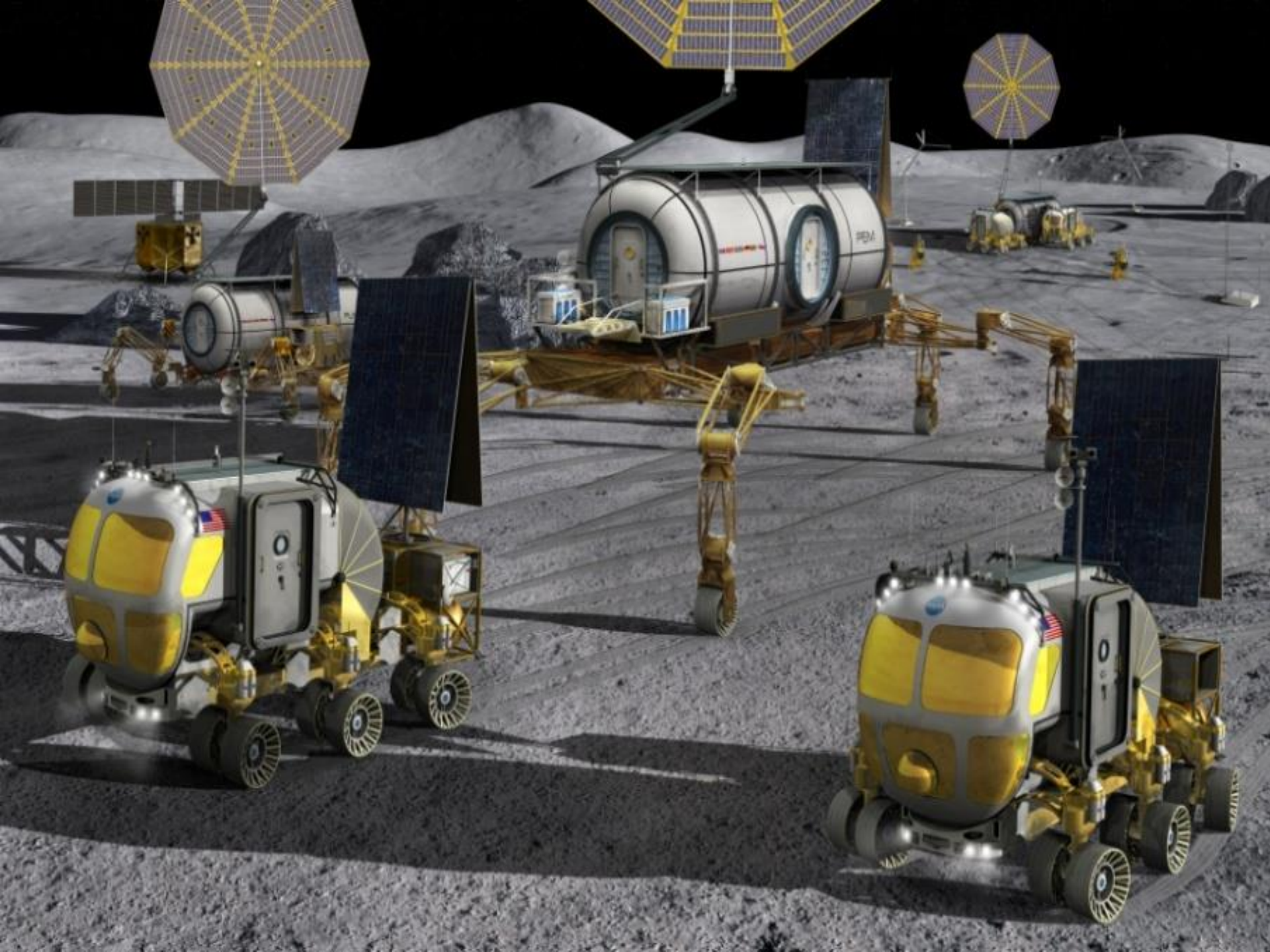


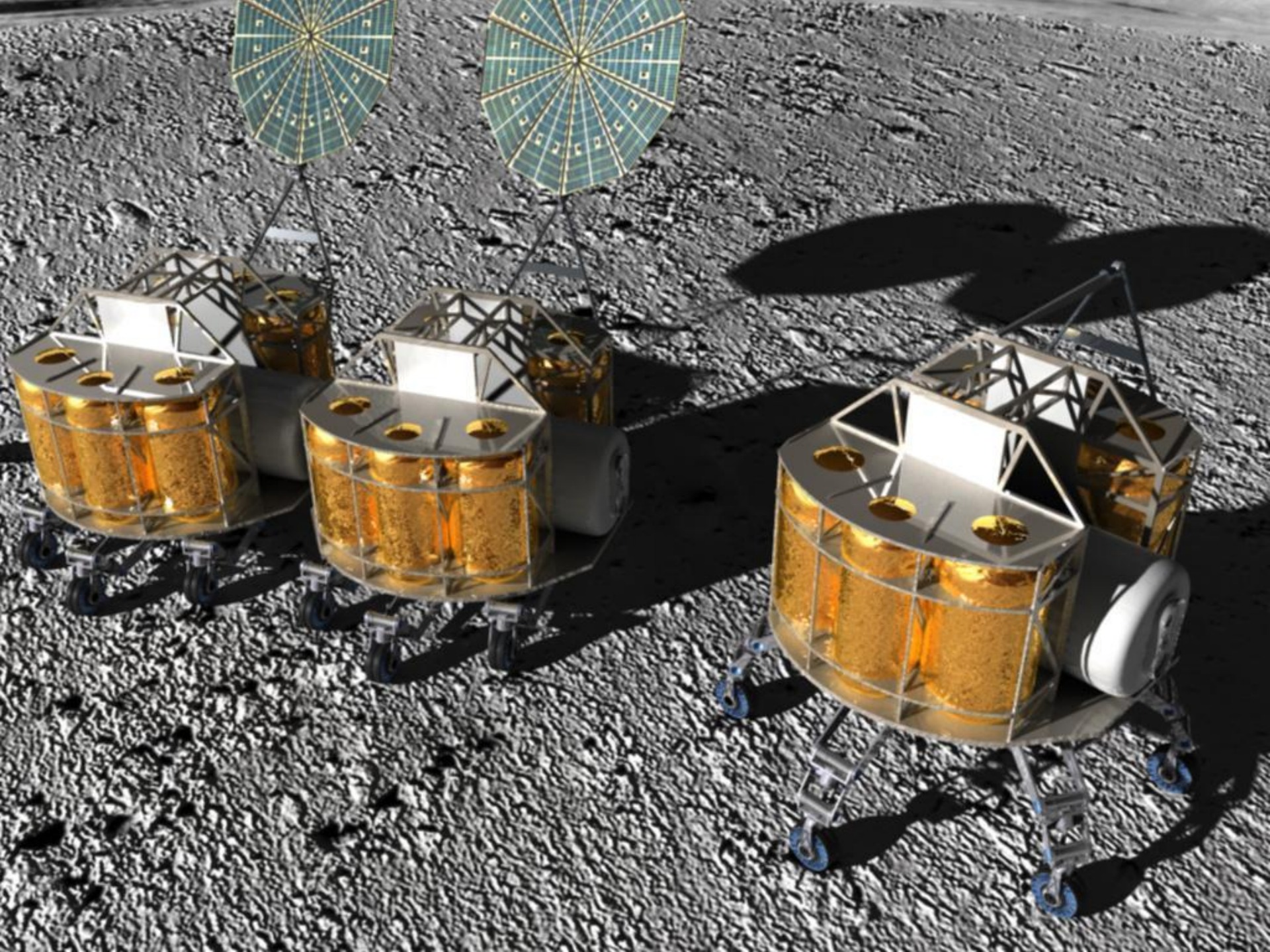


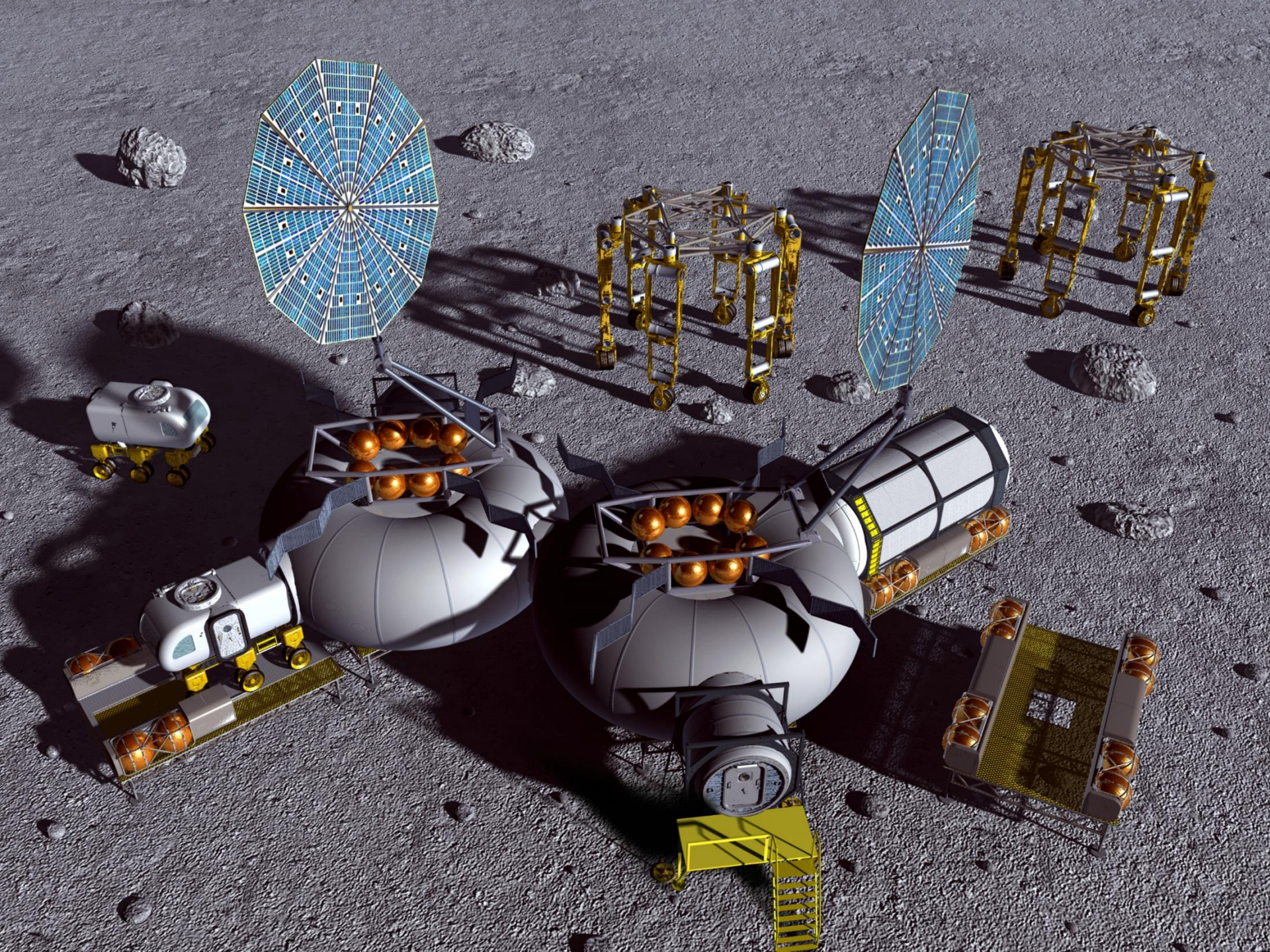


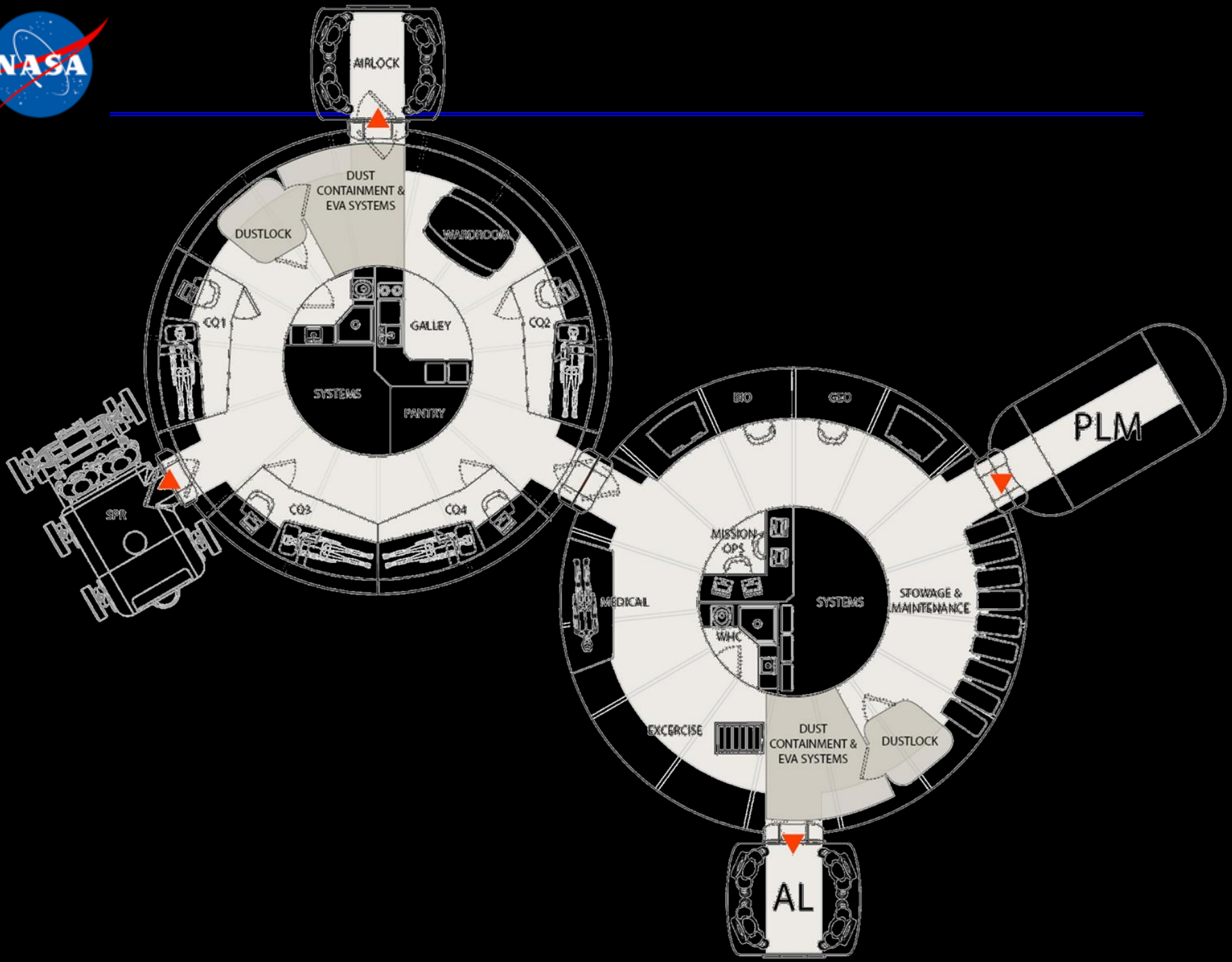
CxAT / HORIZONTAL HAB ARCHITECTURE

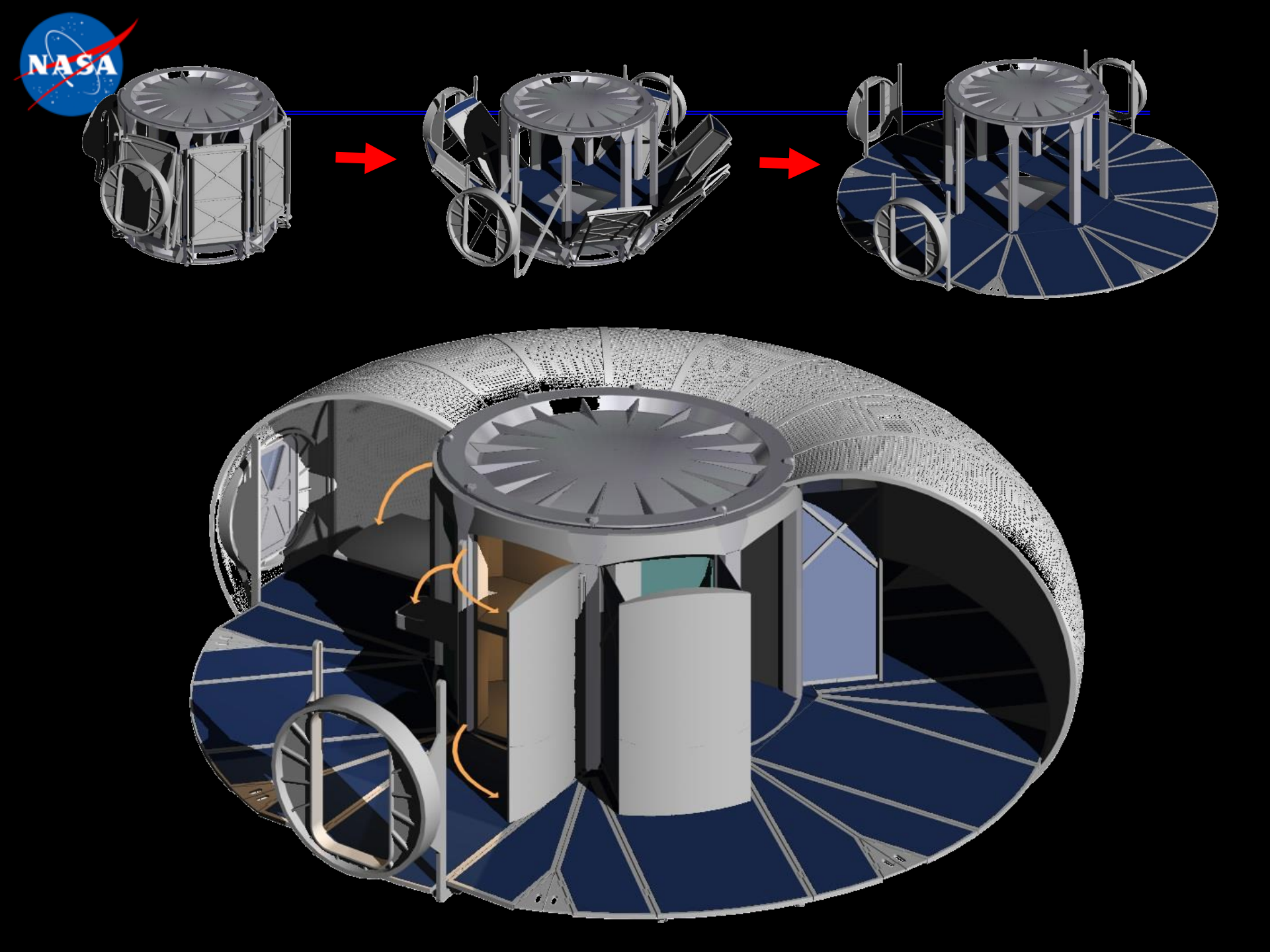


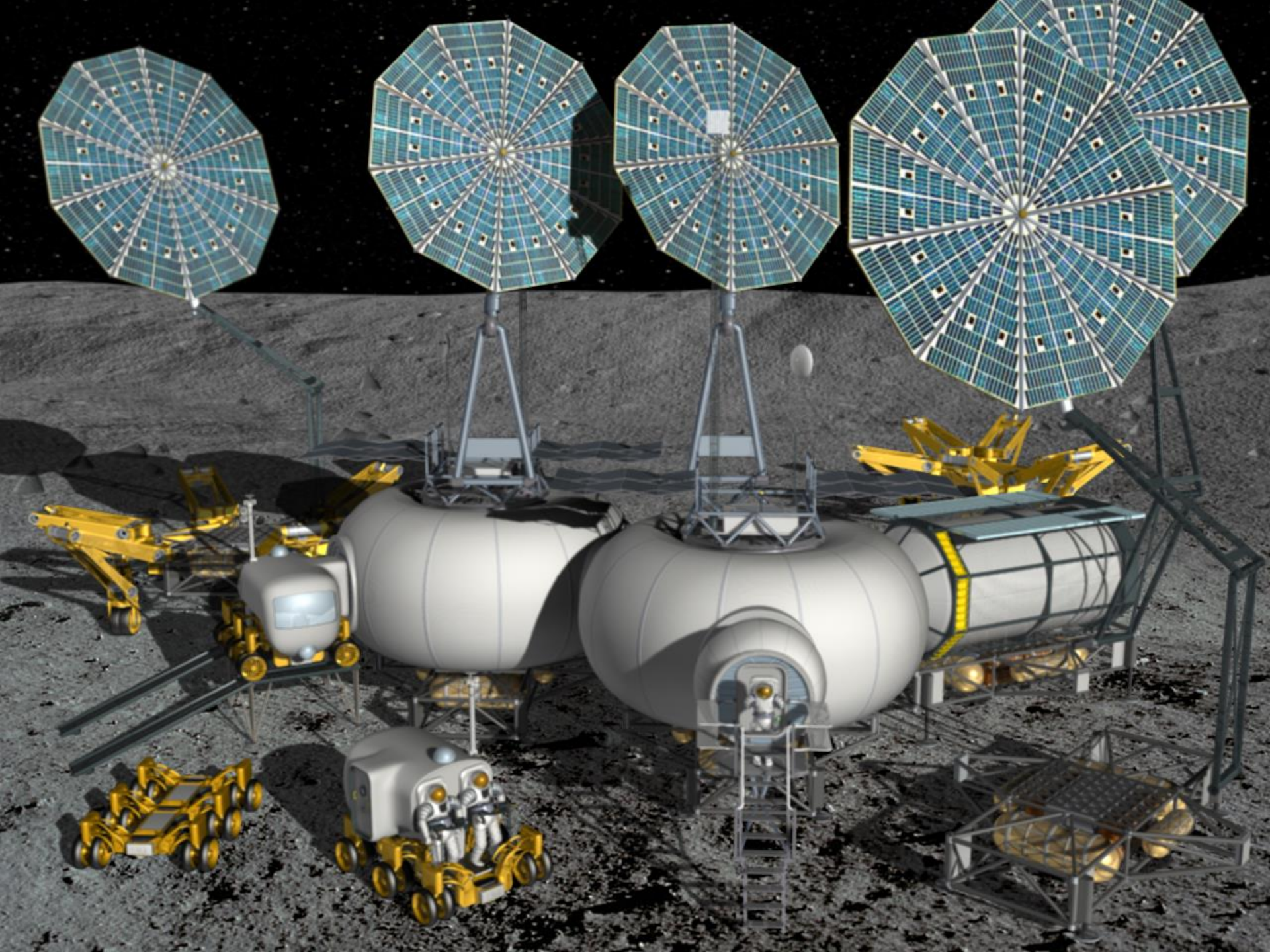







AIRLOCK
DUST
CONTAINMENT &
EVA SYSTEMS
DUSTLOCK
WARDROOM
CQ1
GALLEY
CQ2
SYSTEMS
PANTRY
SPR
CQ3
CQ4
BIO
GEO
PLM
MISSION
OPS
MEDICAL
SYSTEMS
STOWAGE &
MAINTENANCE
WHC
EXCERCISE
DUST
CONTAINMENT &
EVA SYSTEMS
DUSTLOCK
AL





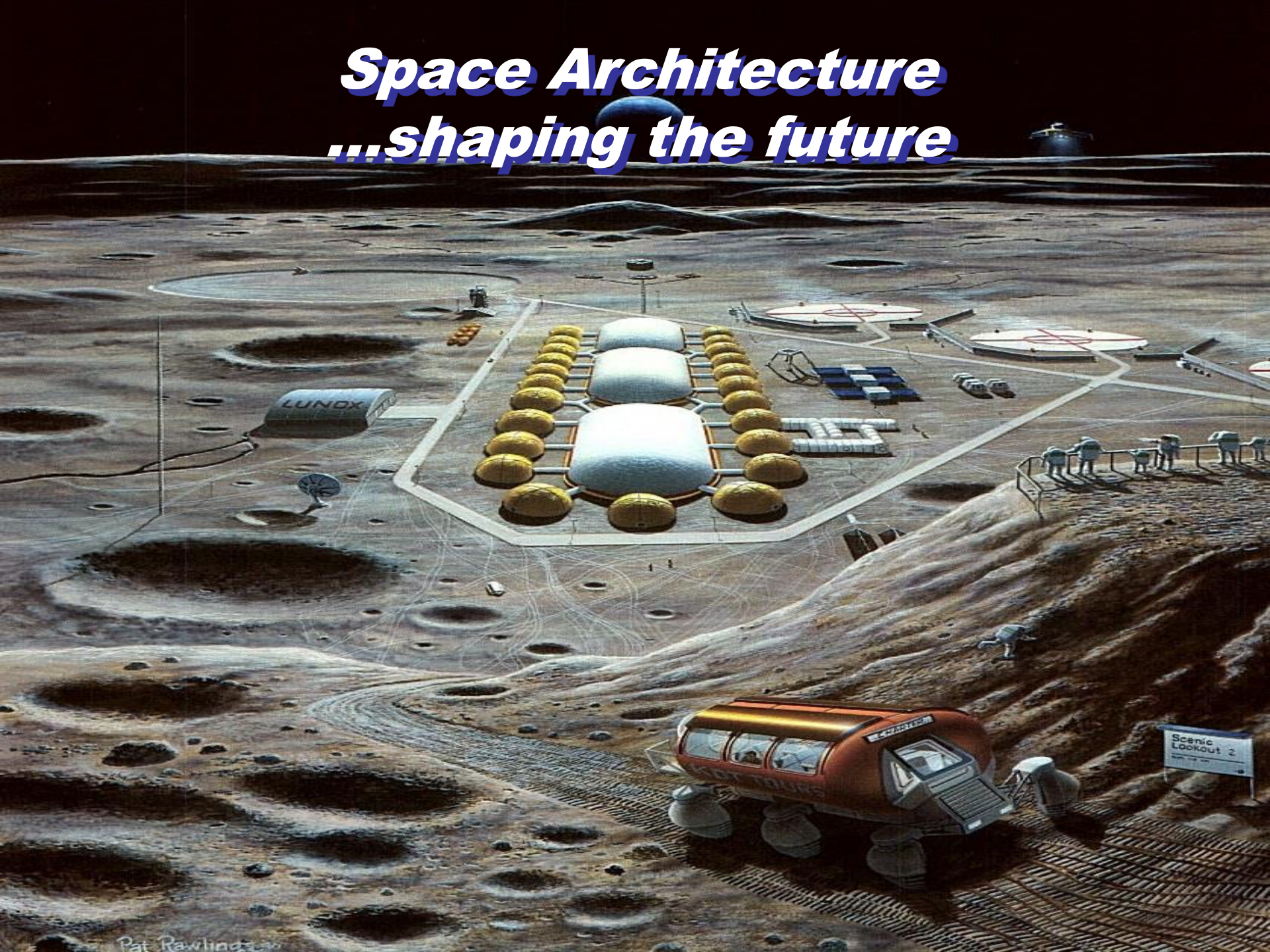

Providing the knowledge, the hardware, and the materials to support human life beyond our world

DRIVE – DESIRE – DETERMINATION

HDU

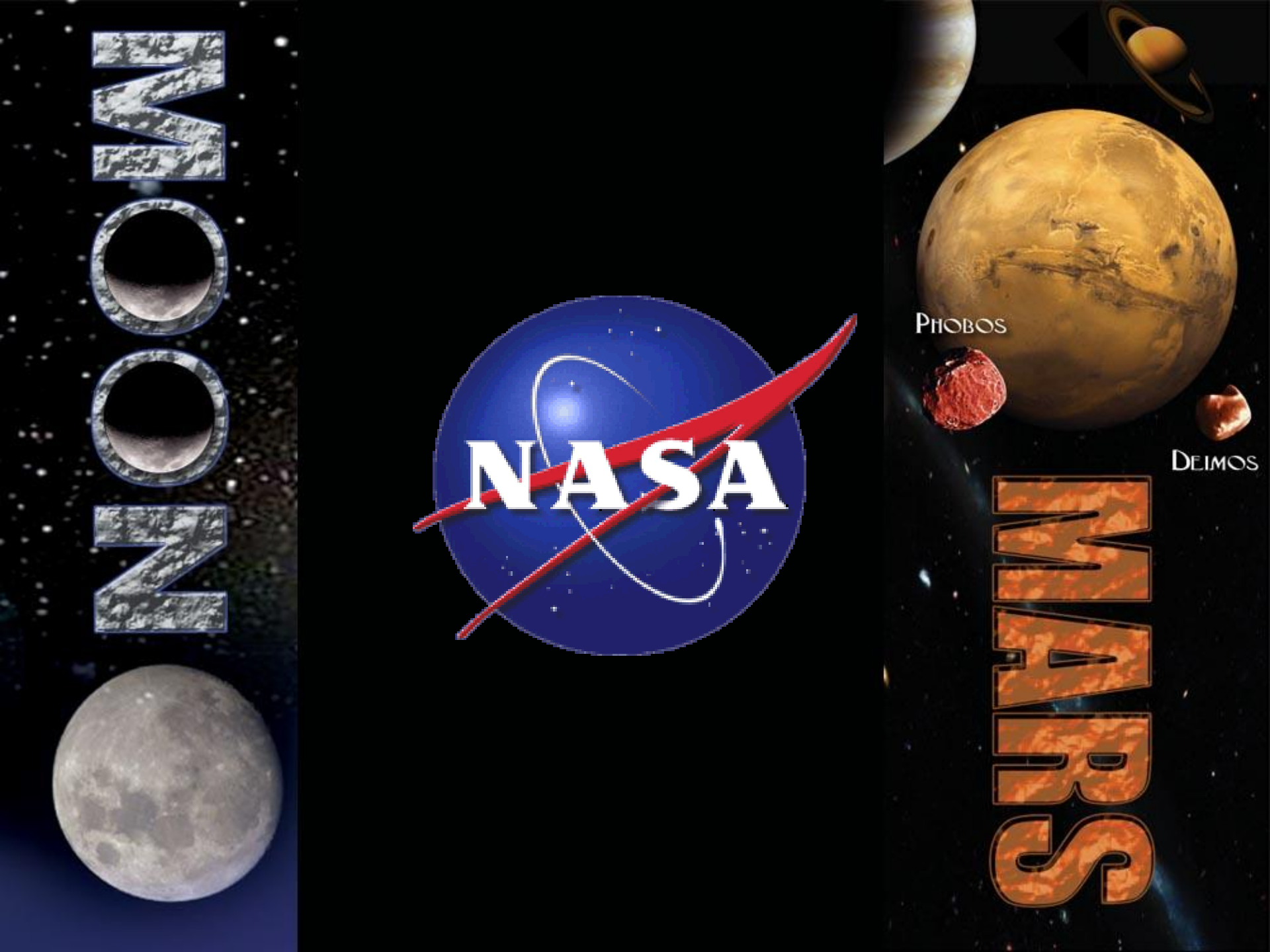
Moon, Mars, Beyond…

Space Architecture ...shaping the future



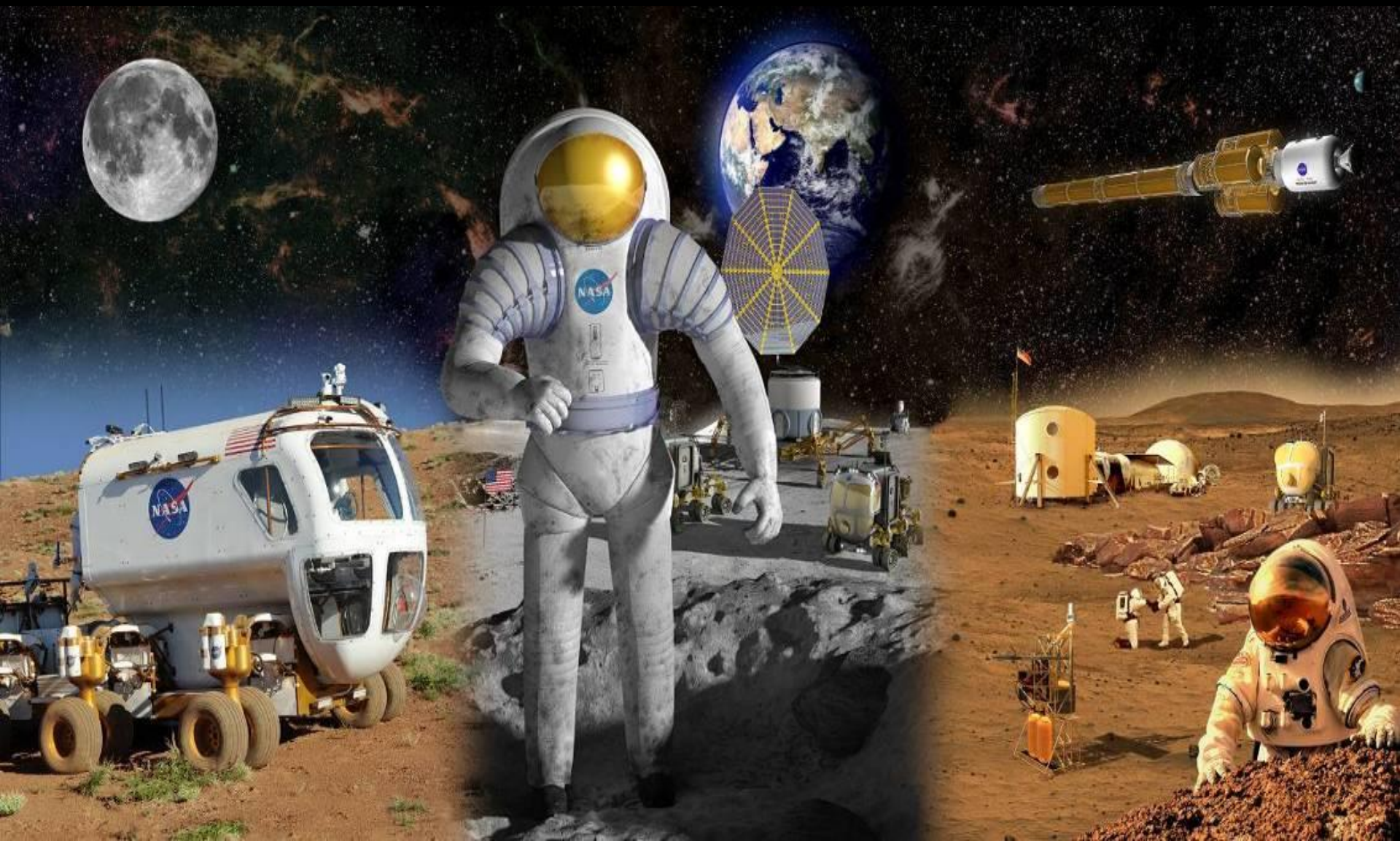

Be inspired…
Artwork by Joe Bergeron

...inspire others


MOON
NASA
PHOBOS
DEIMOS
MARS

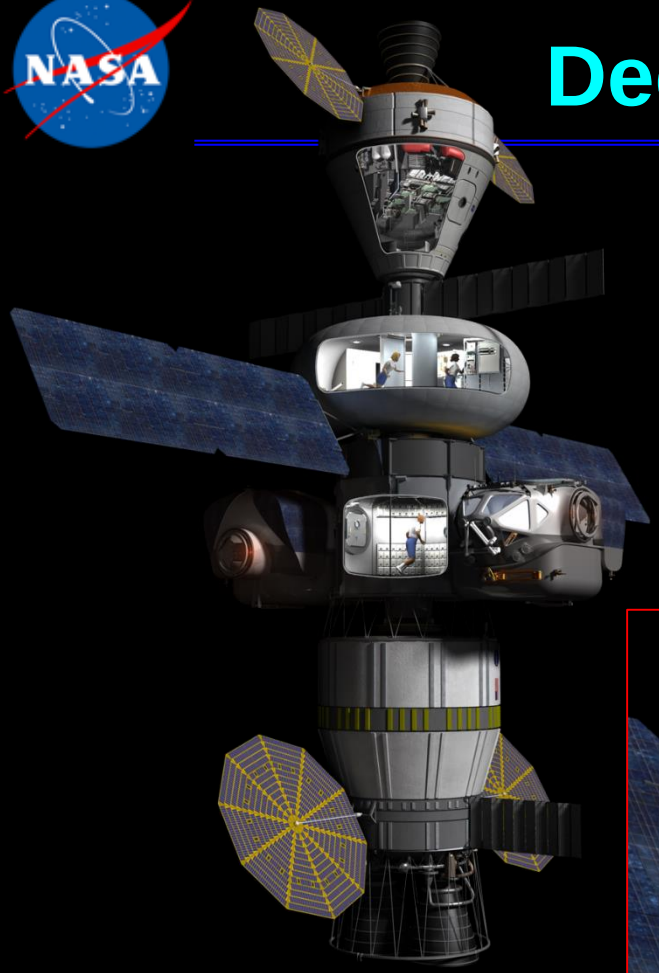
BACKUP

Earth Analog Testing



Deep Space Habitat

DESIGNED
2010



RAPID PROTOTYPING

Habitat Demonstration Unit

HDU

STARTED
2009

Habitat Demonstration Unit

Rapid Prototyping


HDU

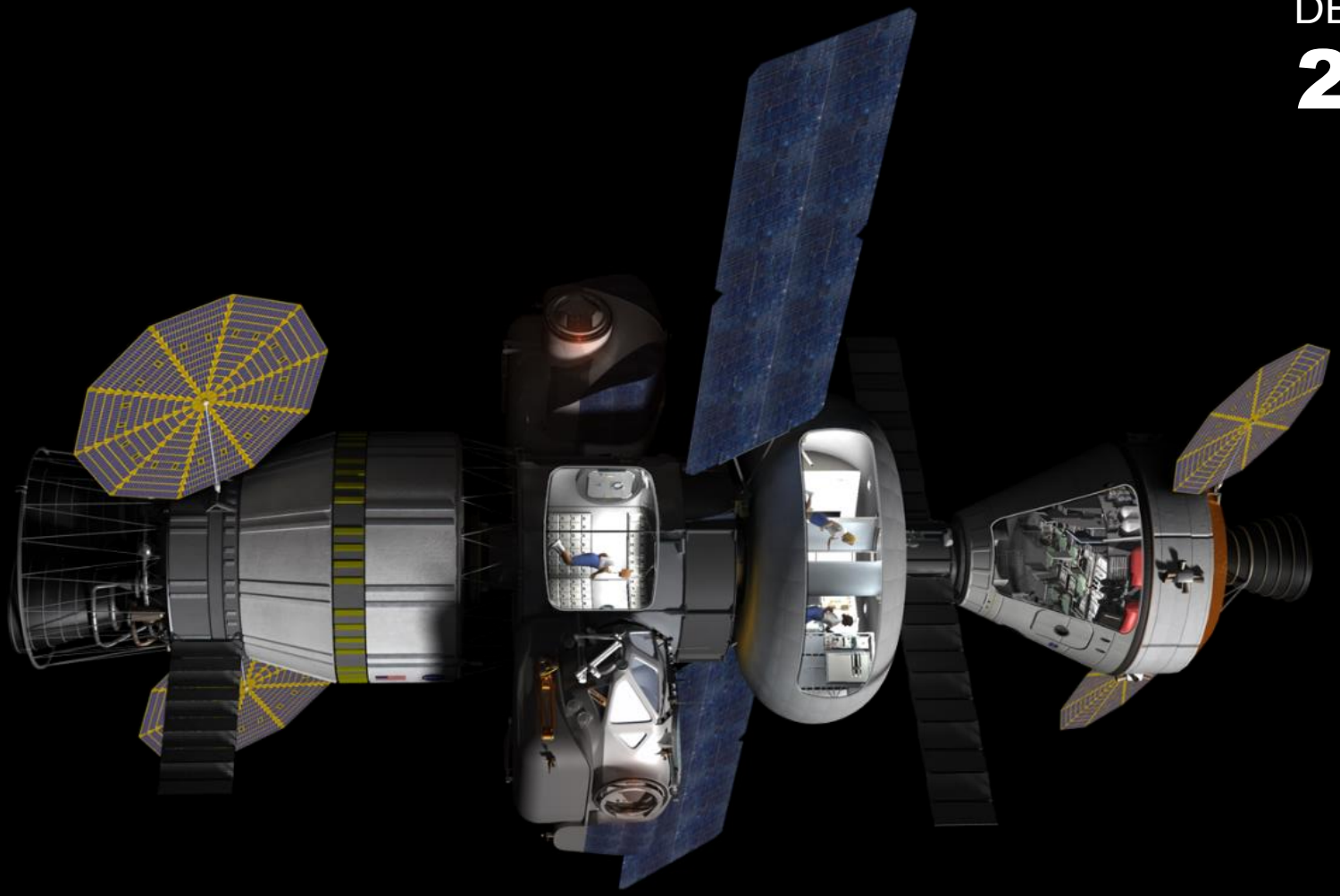
Habitat Demonstration Unit

2010 Fit Check w/ Rover


AIRLOCK
RETURN AIR

Deep Space Habitat

DESIGNED
2010



Deep Space Habitat Inflatable Loft added

Exploration Habitat Academic Innovation Challenge

Started
2010


DEEP
SPACE
HABITAT
Segment B
Segment A
HYGIENE MODULE
NASA


DEEP
SPACE
HABITAT
Segment B
Segment C
Segment A
NASA
NASA


NASA
HABITAT
DEMONSTRATION
UNIT
Segment H
1
2
Segment


DEEP
SPACE
HABITAT
Segment B
Segment A
HYGIENE MODULE