In-Space Fabrication and Repair Research

Prospective Missions & Applications

8 July 2003

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NASA - Jet Propulsion Laboratory
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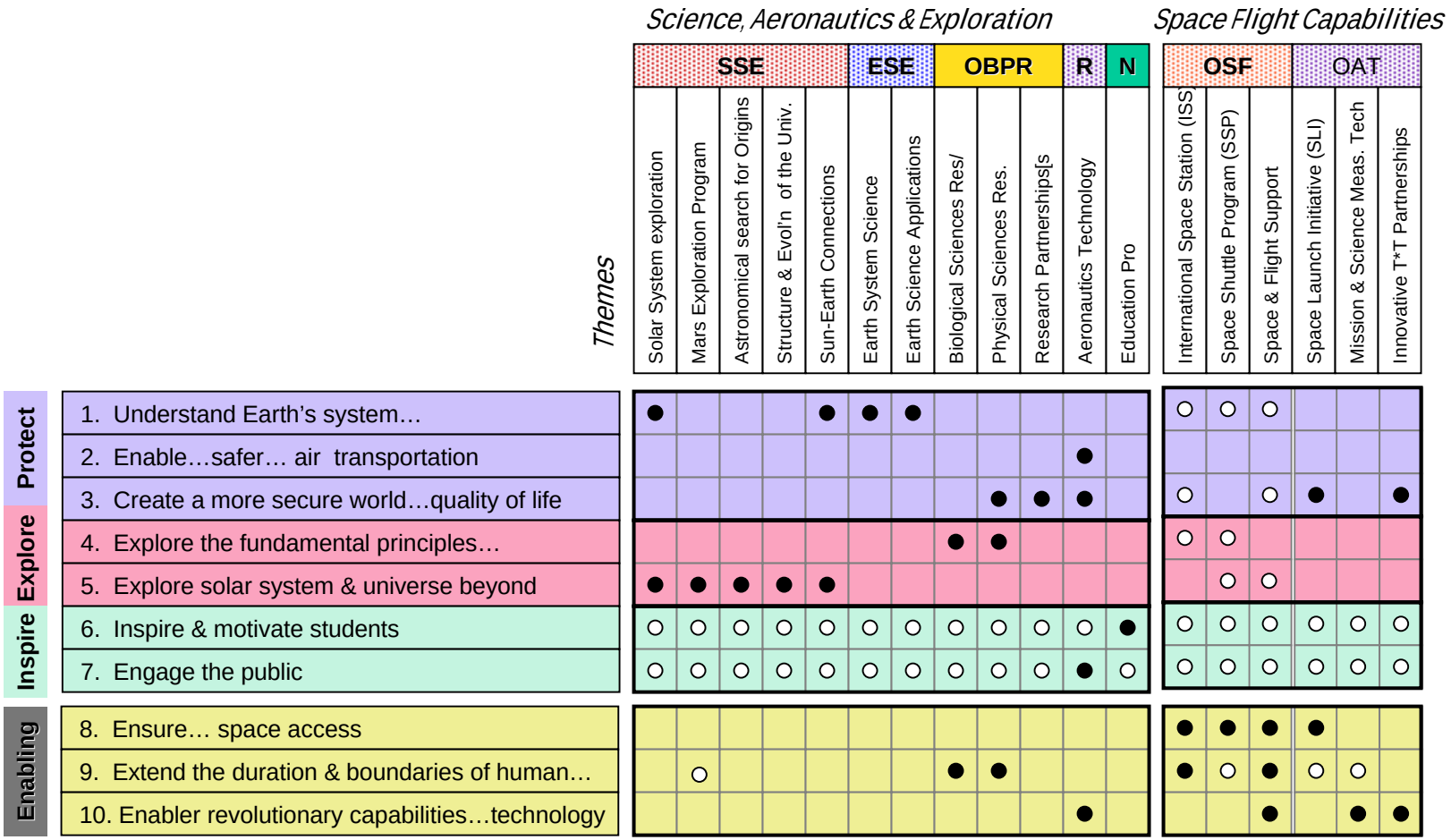
NASA's Vision, Mission & Goals

"We are developing a robust, integrated exploration strategy to guide our investments. Through our new building block capabilities and scientific discoveries, we create stepping stones to the future…"

- **Mission 1: to Understand and Protect Our Home Planet**
  - Goal 1: Understand Earth's system and apply Earth-system science to improve the prediction of climate, weather and natural hazards
  - Goal 2; Enable a safer, more secure, efficient, and environmentally friendly air transportation system
  - Goal 3: Create a more secure world and improve the quality of life by investing in technologies and collaborating with other agencies, industry and academia
- **Mission 2: To Explore the Universe and Search for Life**
  - Goal 4: Explore the fundamental principles of physics, chemistry, and biology through research in the unique natural laboratory of space
  - Goal 5: Explore the solar system and the universe beyond, understand the origin and the evolution of life, and search for evidence of life elsewhere
- **Mission 3: To Inspire the Next Generation of Explorers**
  - Goal 6: Inspire and motivate students to pursue careers in science, technology, engineering, and mathematics
  - Goal 7: Engage the public in shaping and sharing the experience of exploration and discovery
- **Space Flight Capabilities**
  - Goal 8: Ensure the provision of space access and improve it by increasing safety, reliability, and affordability
  - Goal 9: Extend the duration and boundaries of human space flight to create new opportunities for exploration and discovery
  - Goal 10: Enable revolutionary capabilities through new technology

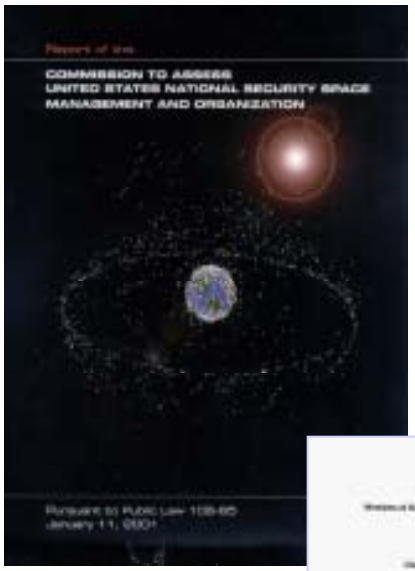
NASA 2003 Strategic Plan
Strategic Relationships Matrix



● Primary contributor toward achieving Goal, accountable for at least one Objective.

○ Supporting contributor toward achieving Objective, accountable for at least one Performance Measure.

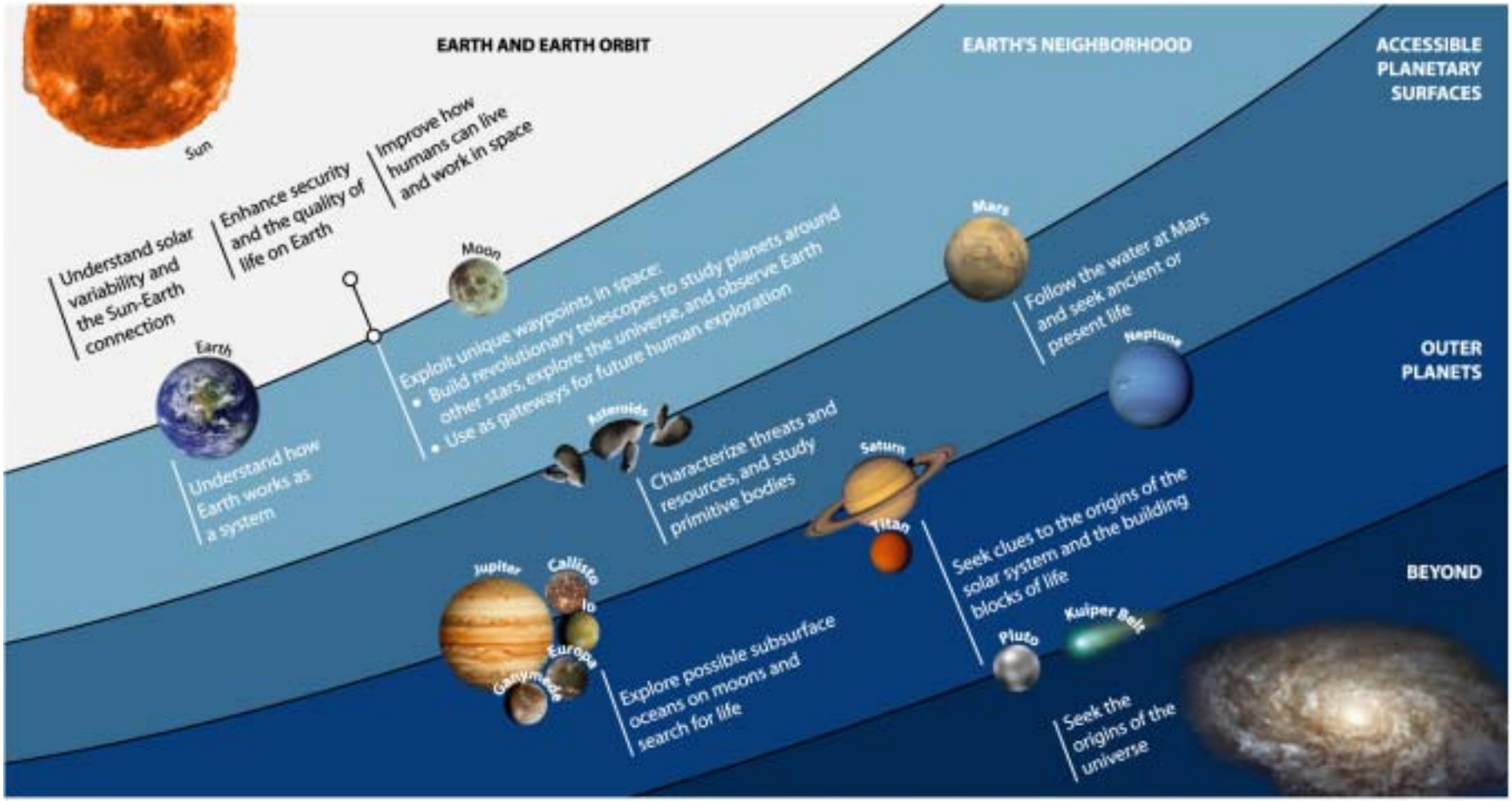
Space Commission
Space Technology Goals



Chair: Hon. Donald H. Rumsfeld
(through Dec. 28, 2000)

- **The DOD should focus its space technology investment strategy on…**
  - **Reducing the cost of** launch and **space systems by emphasizing miniaturization and new ways of doing business**
  - Developing new sensors that can detect and track smaller, moving and concealed targets under all environmental conditions
  - **Promoting** on-orbit data processing and **artificial intelligence to reduce human operator costs** and the burden of high data volume on the communications infrastructure
  - **Developing advanced** launcher and **propulsion technology to reduce the cost of** getting to and **maneuvering on orbit**
  - **Developing on-orbit servicing equipment that can extend space system life expectancy and makes it possible to upgrade system capabilities on orbit**
  - **Developing advanced** surveillance and **defensive and offensive technologies needed for space control and information operations**
  - **Developing advanced command and control, guidance and pointing, power generation, materials and optics technologies needed for power projection from space**

2003 NASA Strategic Plan
Stepping Stones to the Future



"We are developing a robust, integrated exploration strategy to guide our investments. Through our new building block capabilities and scientific discoveries, we create stepping stones to the future…"

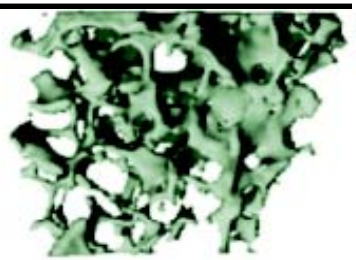
Highlighting the Human Material Experience in Space

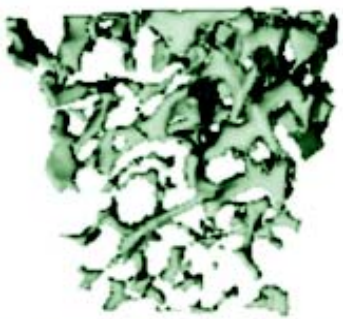
Osteoprotegerin (OPG) is
a physiological
Regulator of bone density


Normal OPG

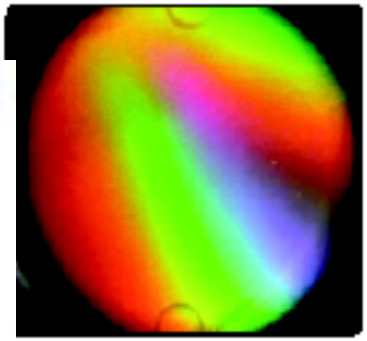

Extra OPG (transgenic)

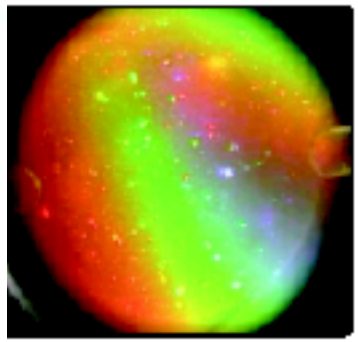

Lack of OPG (knockout)





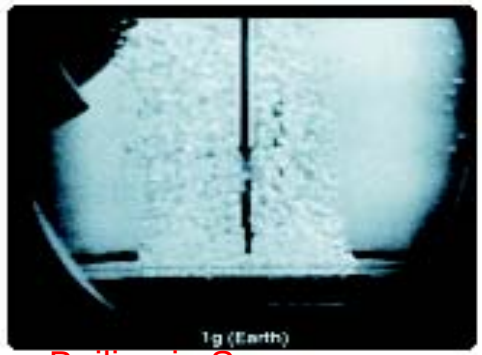
Loss of bone
Under microgravity



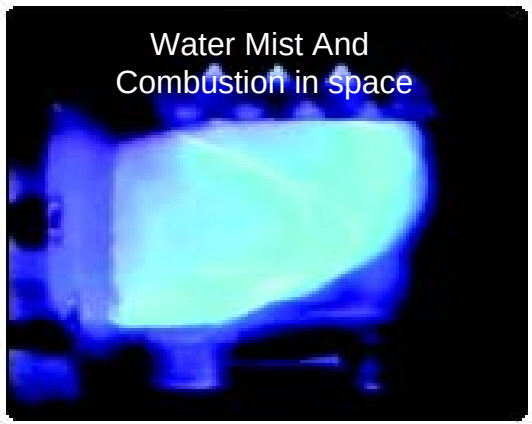


Colloids in Space

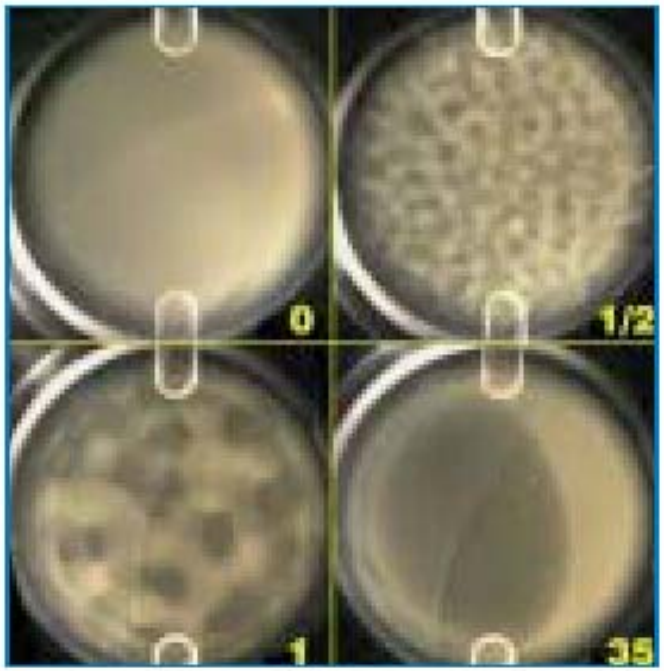
Role of Gravity
on Fertilization



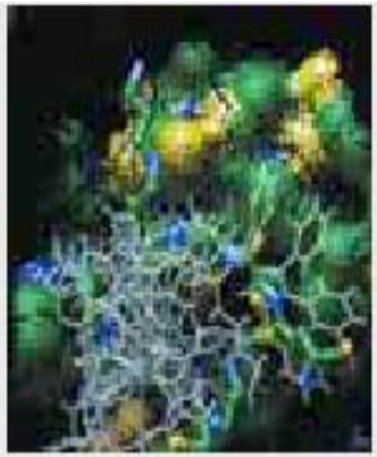
Boiling in Space



Space Environment as a Laboratory



Microscopic particles suspended in a liquid as they separate without the settling effects



Science: Use the space environment as a laboratory to test the fundamental principles of physics, chemistry, and biology

Protein Crystal grown on Shuttle

QuickTime™ and a TIFF (Uncompressed) decompressor are ne

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

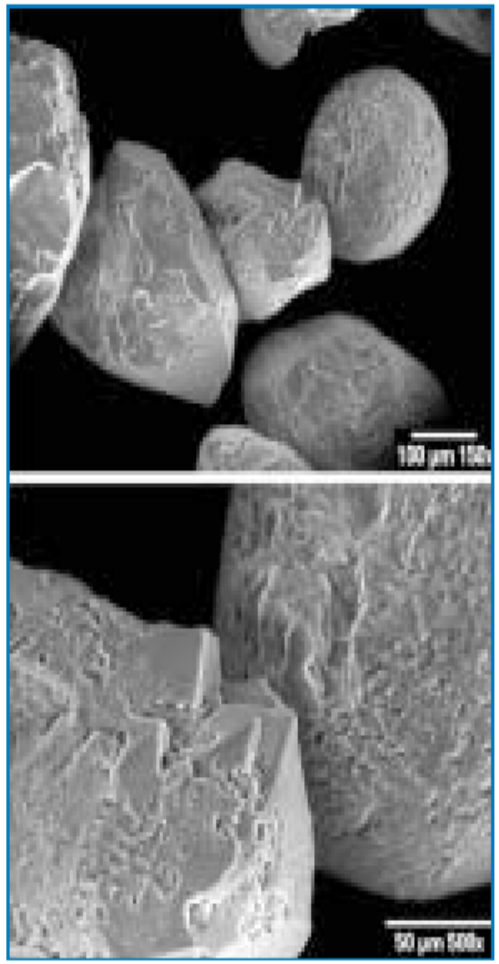
Rack for CVD Crystal Growth

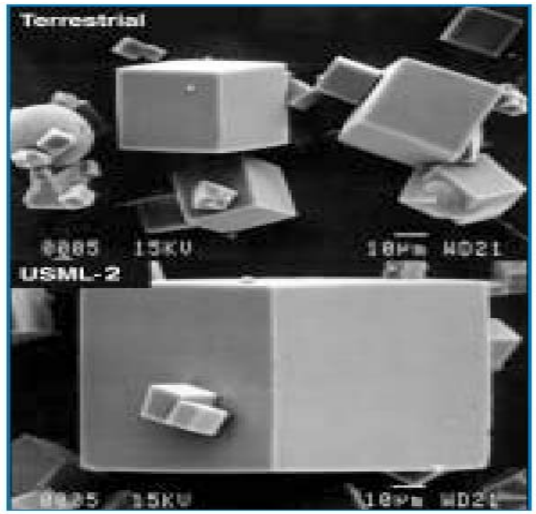
Metal and Material Behavior in Microgravity

Research conducted to study the impact of no gravity of high quality sand molding process for creating precision parts

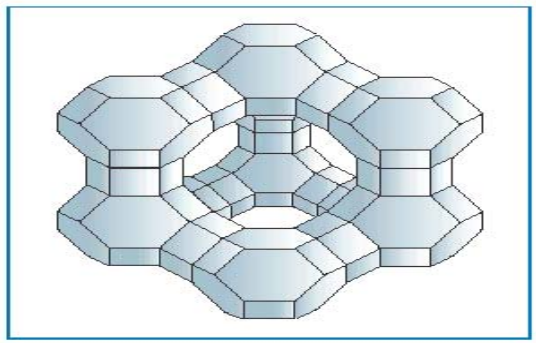
Pores and voids in Metal Casting

Materials behavior under frictions



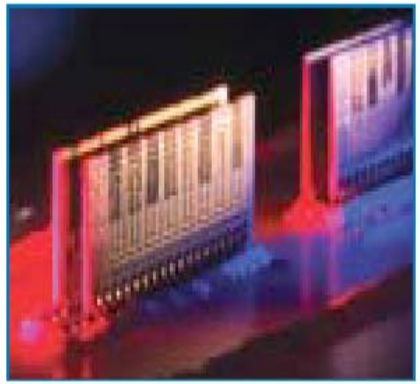


Zeolite crystals grown on Earth (top) are smaller than those grown by Dr. Sacco on the Space Shuttle in 1994. What appears to be solid blocks are quite porous, as illustrated by the drawing (below). Understanding the exact atomic structure and how to control it are keys to tailoring zeolites to a wider range of uses.

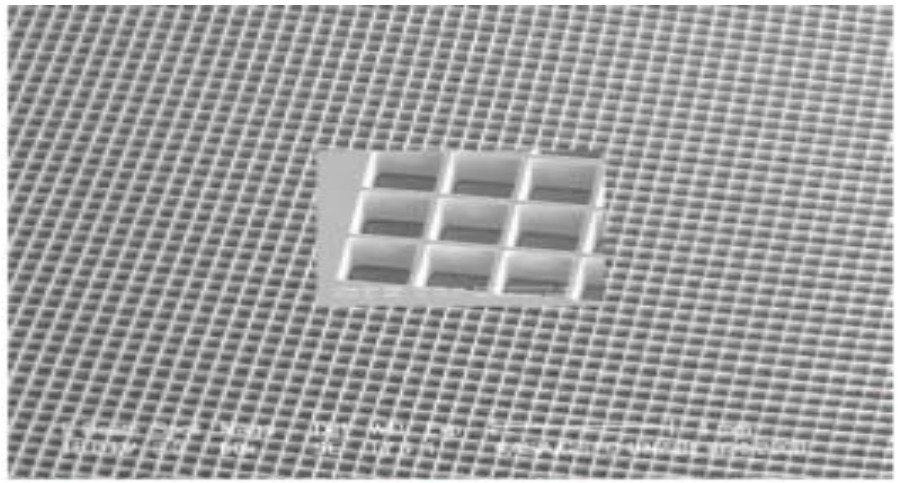


Research Instruments, Tools, Equipment and Facilities

Trace Gas Analyzer
3in tall , weighs 4oz



ENose: 32 sensors,
3Ibs Flight Instrument



Micro-shutter for in-space applications

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Carousel to
Provide 1-g controls

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Small Furnace

Hungarian Space Furnace

Selected Capabilities Needed for Our Future in Space

"Science-Direct"

- Multipspectral sensing
- Large aperture systems - RF to sub millimeter
- Large aperture systems - visible and near visible
- Large aperture systems - X-ray
- Very precise pointing
- In situ resources and laboratory science - in space
- In situ laboratory science - accessible planetary surfaces
- Sample return to Earth-based laboratories (planetary and other)

Space Systems

- Low cost spacecraft/platforms
- High power onboard computing
- Reusable / long-life /self-healing, repairable space assets
- High power spacecraft/platforms
- High efficiency in space propulsion
- In space services - repair and fabrication, assembly, refueling, inspection, maintenance
- IVHM
- Collaborative Systems, Constellations / formations of spacecraft
- In situ presence of human crews

Space Operations

- High bandwidth communications
- Low cost operations
- Accommodations for in space fabrications under microgravity
- Significantly improved human/robotic team effectiveness
- Operations / material behavior under extreme space environments

Space Launch

- Assured Earth to orbit transportation
- ,

Capabilities On Earth

- Very high power computing

Mission unique

- Interstellar flight to 200 AU

Special topics/issues identified:

- Systems Analysis / Design Tools, and Modeling
- Industrial Base
- Facilities Base
- Planet defense issues (i.e., from impactors)
- Planetary protection (i.e., forward and backward contamination issues)

Future Capability Goals
Key Drivers for in-Space Fabrication and Repair Research

- **Ultra-Long-Life Safe, Affordable, Reliable and Self-Healing /Repairable Space Systems. New Space Materials**
- **Robust, Affordable Fabrications in Low Earth Orbit (LEO)**
  - Lower repair cost space systems with increased reliability/safety
  - Space platforms larger than those that can be launched on a carrier
    - Including deployment, maintenance, fabrications, servicing and/or repair
  - Components fabricated from in-space resources or earth provided resources
    - New space born materials, hybrid materials, layered structures, amorphous structures
- **Affordable In-Space Self-Sustainable Systems**
  - The cost of access to space remains a major barrier towards the development of space. Until a breakthrough occurs in reducing the cost, the only options are to extend the life of everything we send to space by extending its life indefinitely by repairing it every time it fails, or recycling it by fabricating what we need at the expense of what we do not need.The utilization of space resources at any stage of space system development is desirable
- **Ambitious Operations beyond LEO**
  - Assemble at LEO and propel beyond LEO, thus lowering the cost of space systems without sacrificing reliability/safety
  - Space platforms larger than those that can be launched on a carrier
    - Including deployment, maintenance, fabrication, servicing and/or repair
  - For example, very large aperture imagers, SARs, radiometers, or other systems

F&RR – Future Missions and Applications
Examples

~2015-2025

- **Scenario 1** — **Fabrication of photovoltaic arrays from space resources**
- **Scenario 2** — **GEO Deployment of Space Infrastructure**
- **Scenario 3** — **CommSats: LEO Check-out and repair to GEO Deployment**
- **Scenario 4** — **Repair of sensors and damaged shuttle tiles**
- **Scenario 5** — **Fabrication of components from existing materials, welding (electron beam, lasers, etc) , free-forming, etc.**
- **Scenario 6** — **Fabrication of propellants from space resources**

~2020-2030

- **Scenario 7** — **Growing new materials in space(chemicals, gases, solids, liquids, polymers and biological cells) with new physical characteristics**
- **Scenario 8** — **Growing layered materials developed across micro-g environment. Growing of hybrid-materials**
- **Scenario 9** — **Preliminary testing of Factory of the Future**
- **Scenario 10** — **Human/Robotic Lunar fabrication and Repair Campaign**
- **Scenario 11** — **Reconfigurable/Evolvable Spacecraft**

~2025-2035

- **Scenario 12** — **Large Space Telescope Constellation Deployment (Terrestrial Planet Finder-to-Imager (TPF-to-TPI) Class)**
- **Scenario 13** — **Large Space Utilities in LEO**
- **Scenario 14** — **Human/Robotic Global Mars Exploration Campaign assembled, checked and launched from the moon, Libration or Gateways**

What Might Be Accomplished in the Next Decade?

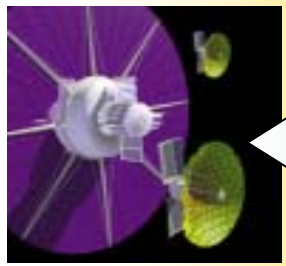
2- to 5- Fold "Factors-of Improvement" in Key Earth Orbit & Neighborhood Space Systems Capabilities

- Increased Available Power at Reduced Cost for Earth Neighborhood Space Systems
- Extension of Effective Operational Lifetime for Systems Beyond Low Earth Orbit
- Improvement in Fuel Efficiency for Transportation in the Earth's Neighborhood
- Reduction in Operations and Logistics Costs
- Increase in the Scale of Systems Beyond LEO (without New Launchers)
- ***What ELSE Might be Accomplished??***

In-Space Fabrication and Repair Research

Space Science Missions

Communications Satellites



National Defense Systems

New Industries

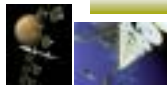
Integrated Strategy for In-Space Fabrication and Repair Research

(Notional Draft - 23 June 2003)

< 2005		2005-2009					2010-2014					2015-2019					2020-2024				
FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24

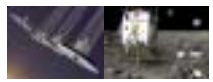
In-Space Fabrication And Repair Research

3rd Gen F&RR Decision
Earth Neighborhood Infrastructure
Inner Solar System Infrastructure Option
Meteorites "Reach"
New Space Utilities Infrastructure
Factory of the Future



Earth Neighborhood F&RR

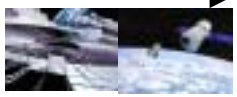
2nd Gen F&RR Decision *Beyond LEO*
Infrastructure Option
Meteorites "Reach"
Lunar "Reach"
New Free Form Fabricated Components



2nd Gen F&RR Flight Option

Beyond LEO Initial F&RR

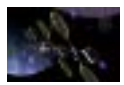
1st Gen F&RR Decision
LEO Infrastructure
Beyond LEO "Reach"
Early Lunar Option
Materials Research



1st Gen F&RR Flight Option

Initial F&RR Architecture Selections

Flight Expts — **TFDs** — Flight Expts — **TFDs** — Flight Expts — **TFDs** — Flight Expts — **TFDs** — **Capability R&D**



Long Term Research and Technology

ISS Complete

International Space Station

ISS Long-Term Ops Decisions

Space Shuttle

Shuttle Extension?

Shuttle Extension?

Expendable Launch Vehicles

New DOD Heavy ELV?

OSP Decision

OSP *Crew Return*

OSP *Crew Transfer*

NGLT

1st NGLT FSD Decision *Early Booster Option*

1st Flight Option

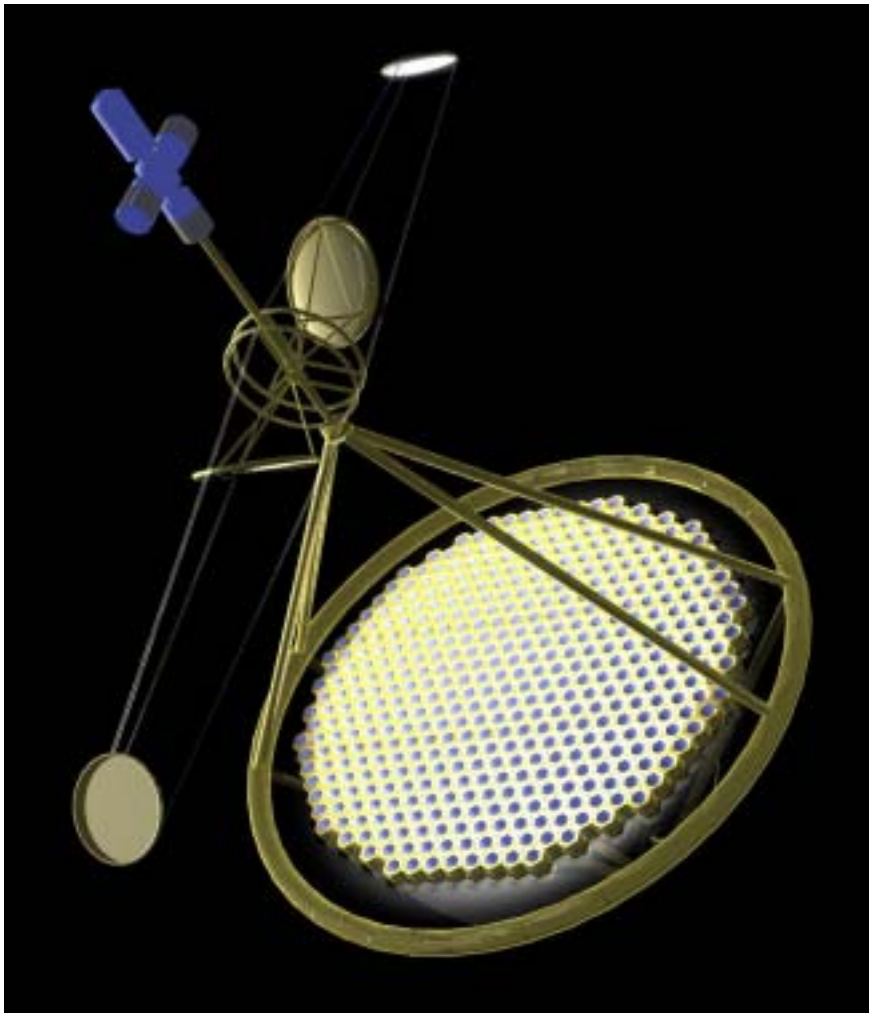
2nd NGLT FSD Dec. *Early RLV or HLLV*

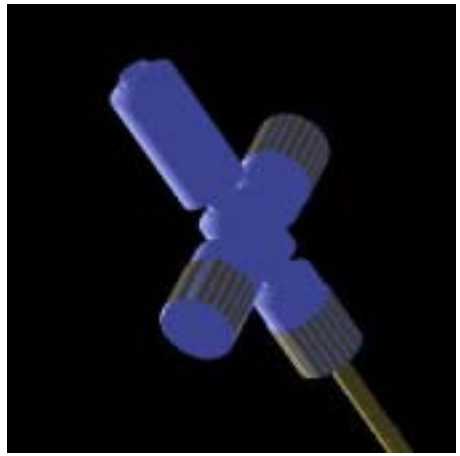
2nd Flight Option

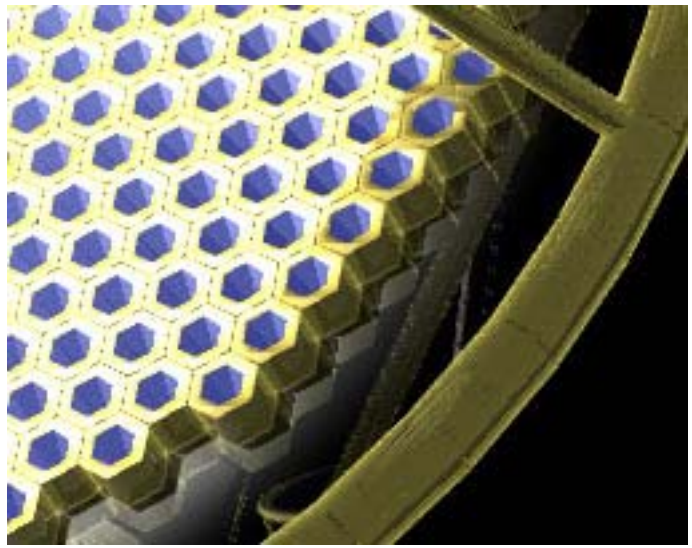
3rd NGLT FSD Dec. *Early Booster Option*

Circa~2015-2025 — Scenario 1

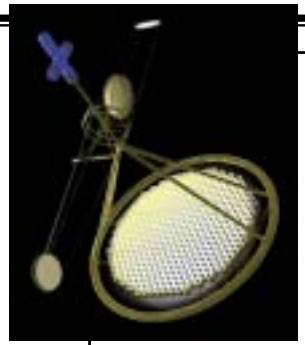
Deploy, Repair, and Assemble 100m-200m Phased Array System Concepts

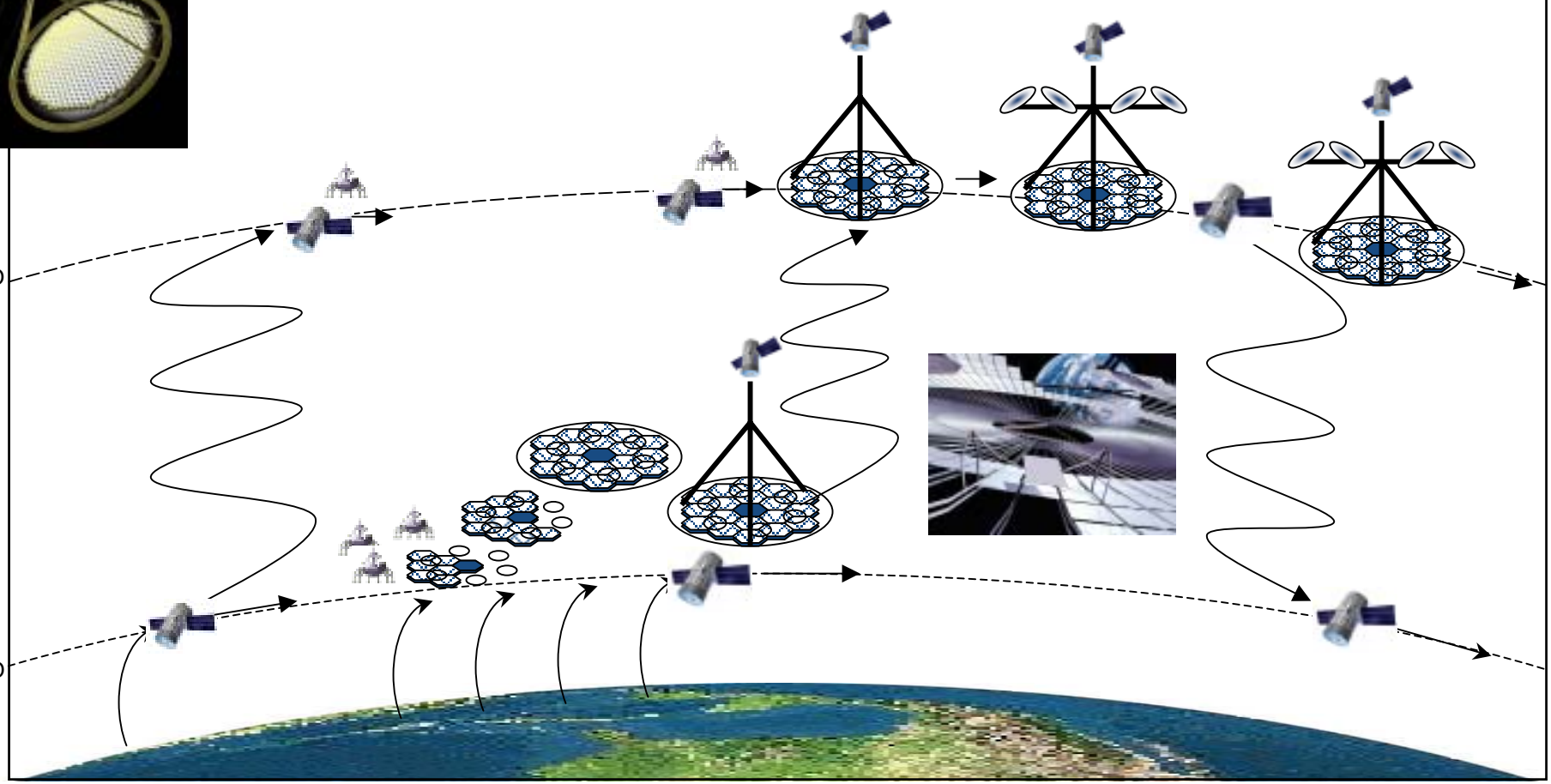




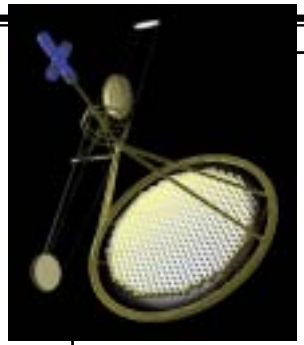


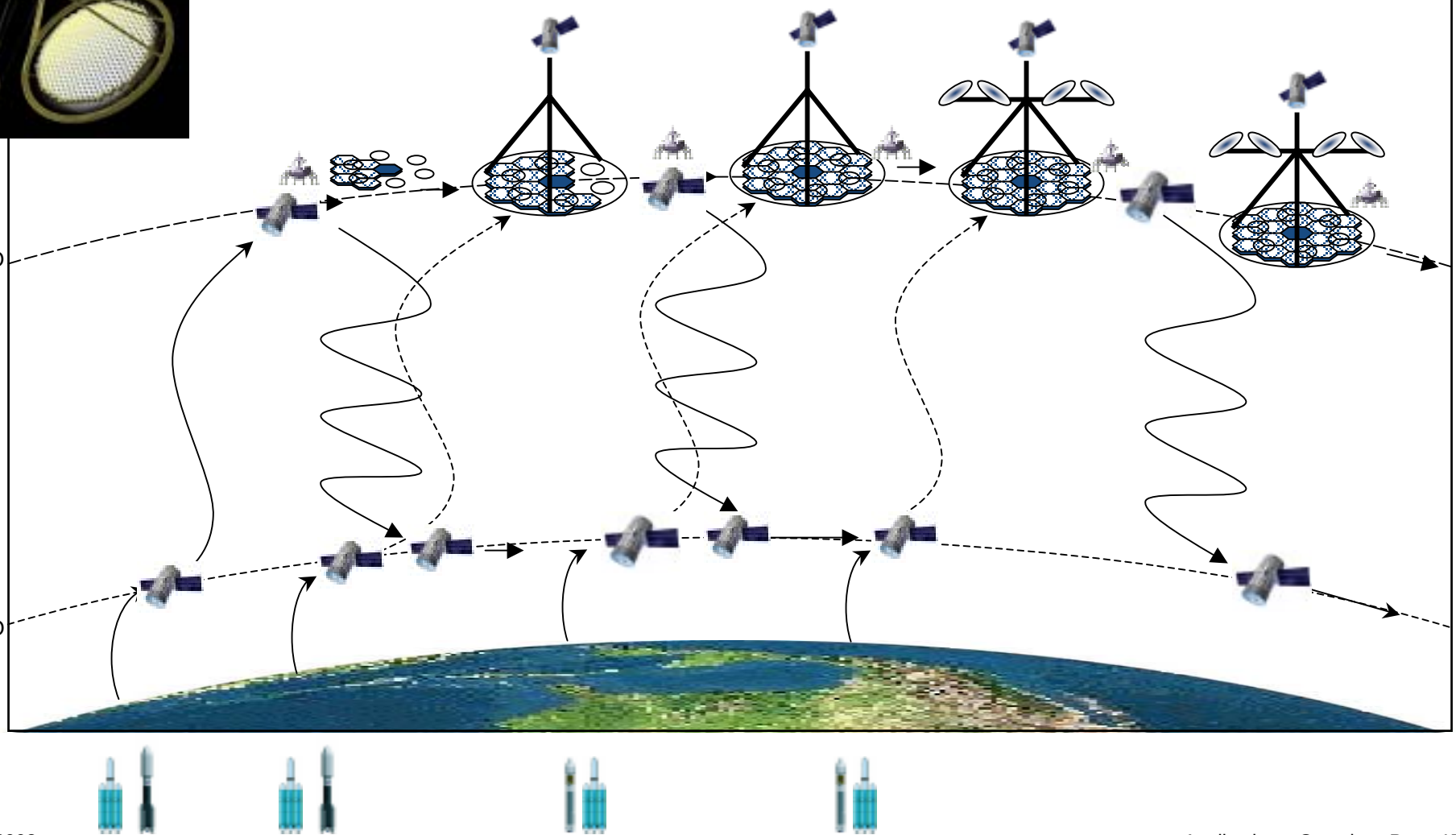
Circa~2015-2025 — Scenario 2
LEO Phased Array Assembly-to-GEO Deploy



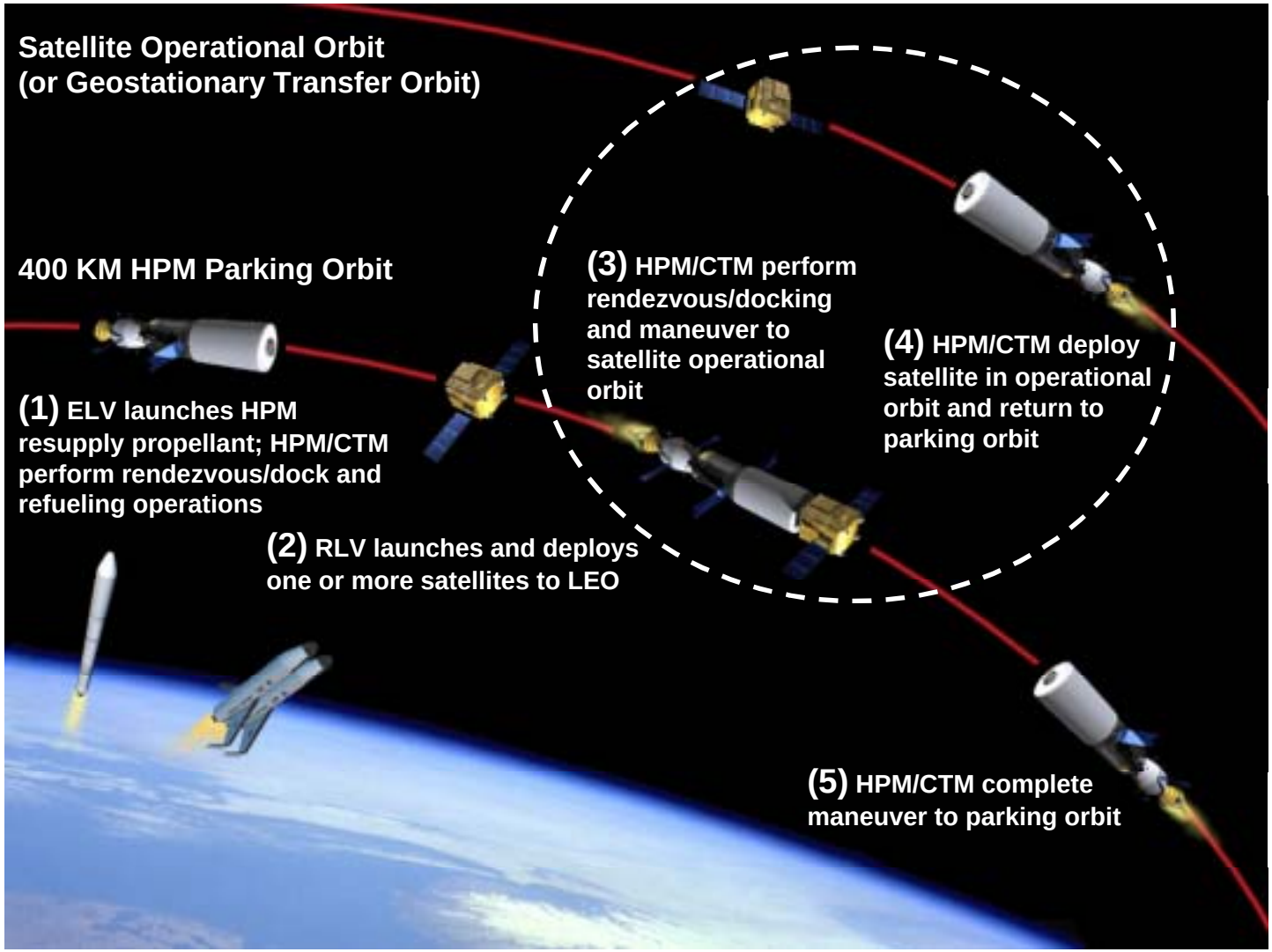


Circa~2015-2025 — Scenario 3
GEO Phased Array Deploy & Assembly

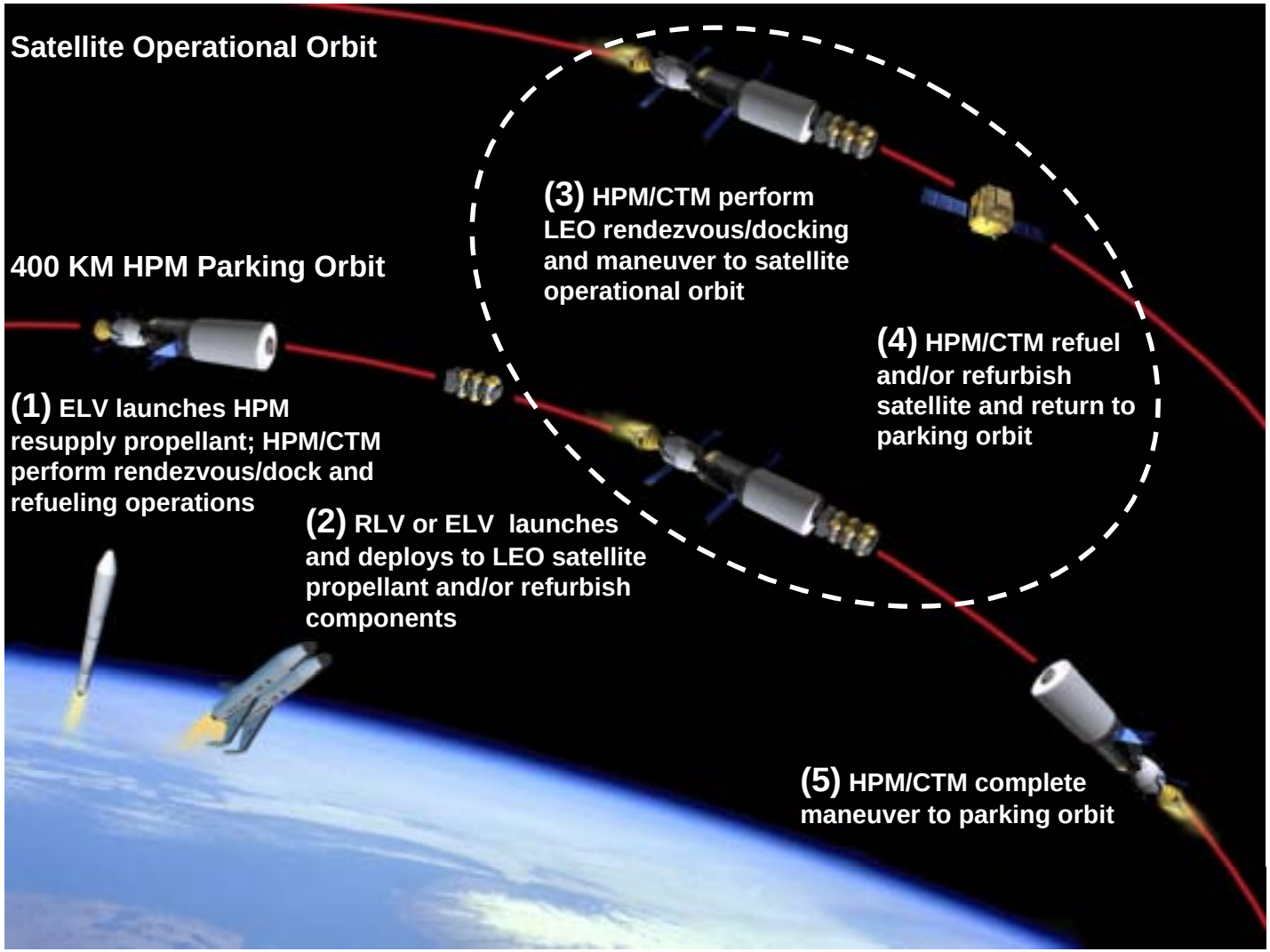




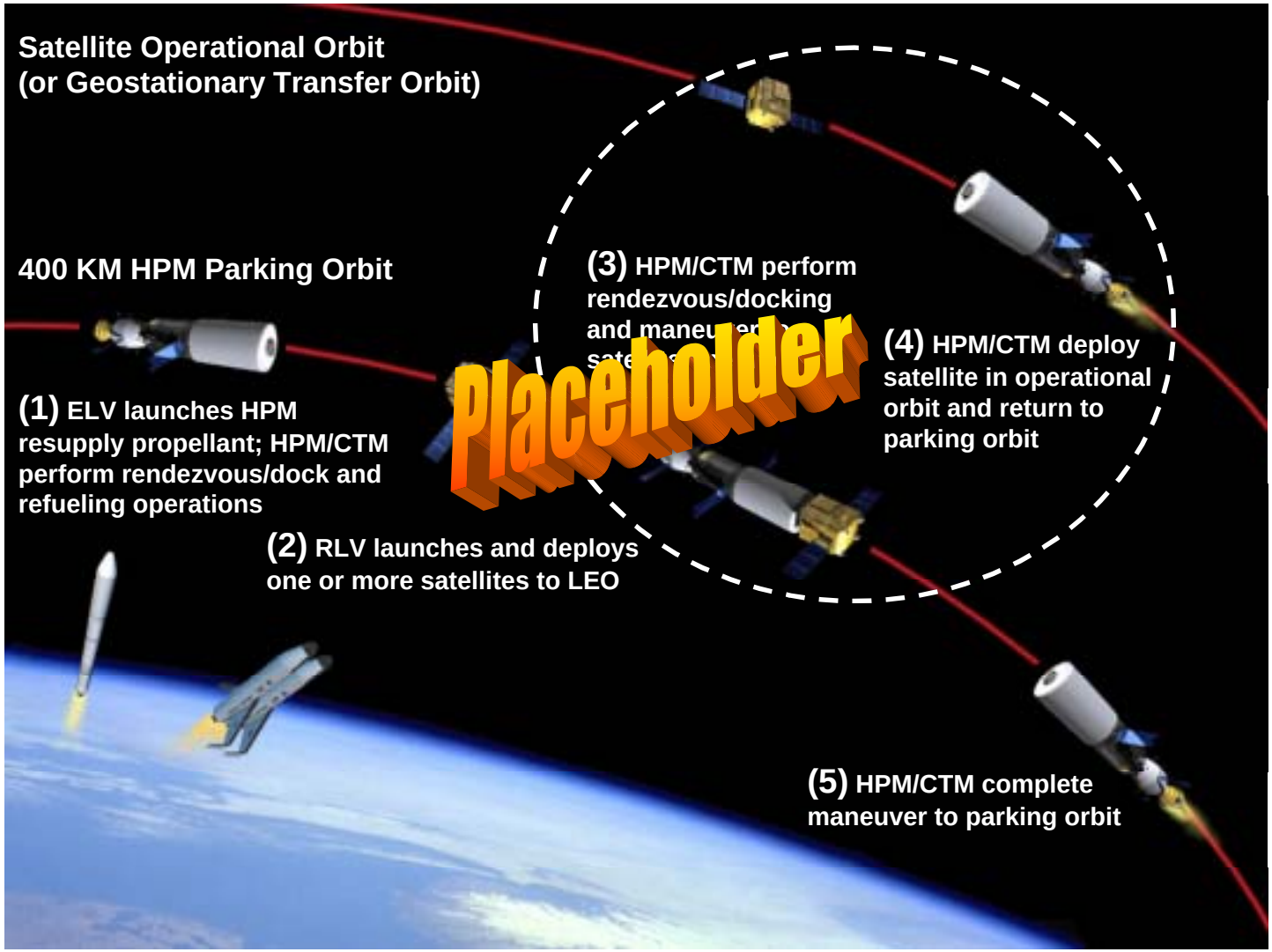
Circa~2015-2025 — Scenario 4
Satellite Deployment - Notional Scenario



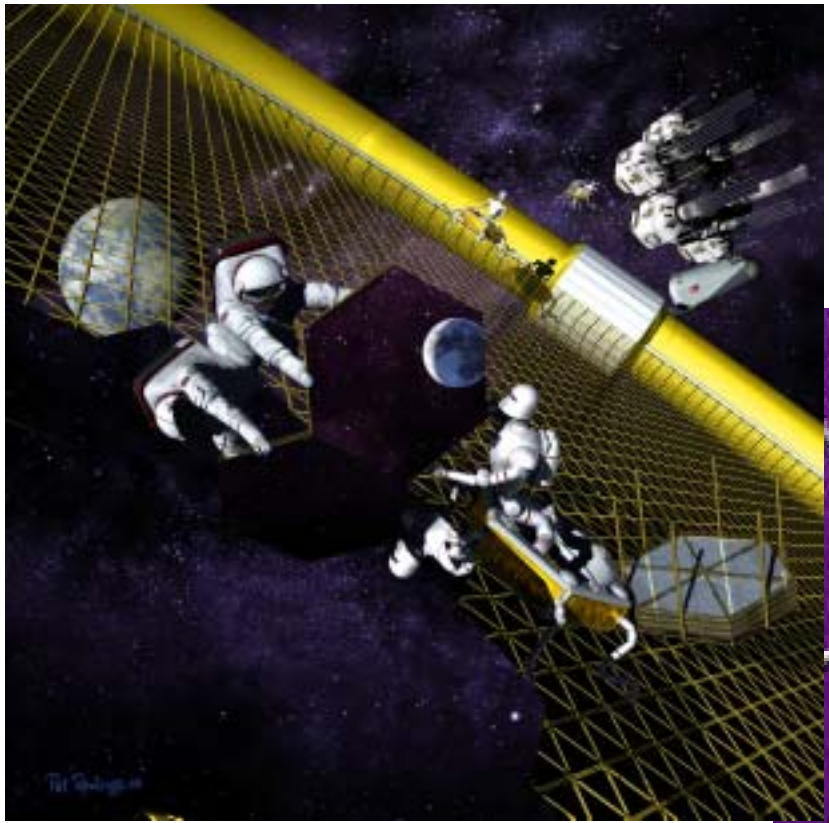
Circa~2015-2025 — Scenario 5
Satellite Servicing and/or Refueling

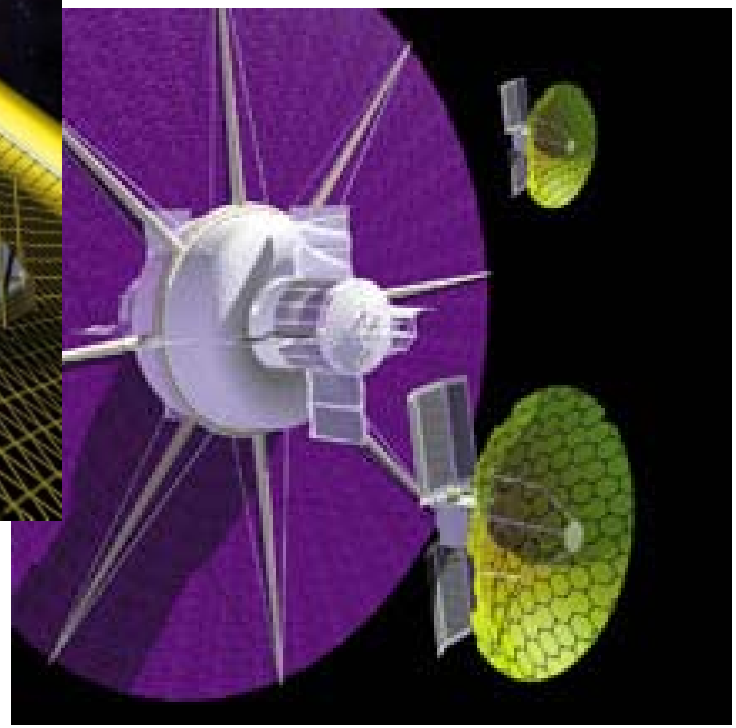


Circa~2015-2025 — Scenario 6
Satellite Rendezvous & Retrieval

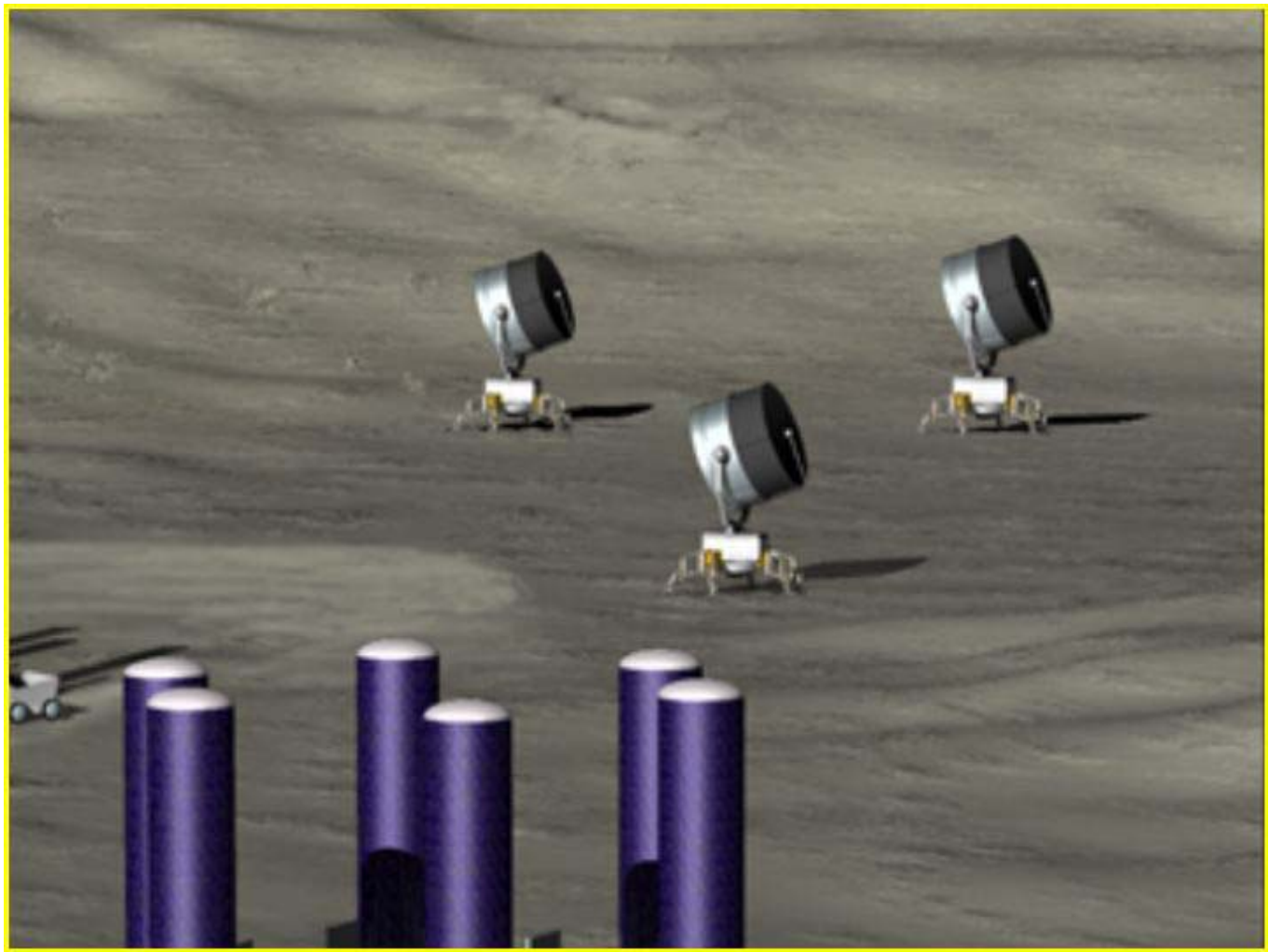


Circa~2020-2030 — Scenario 8
Modular Libration Point “Gateway” Station Deployment

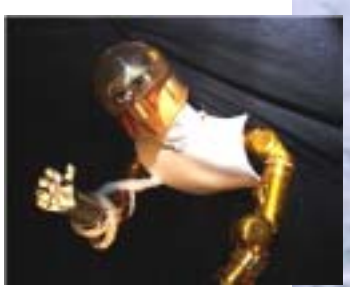




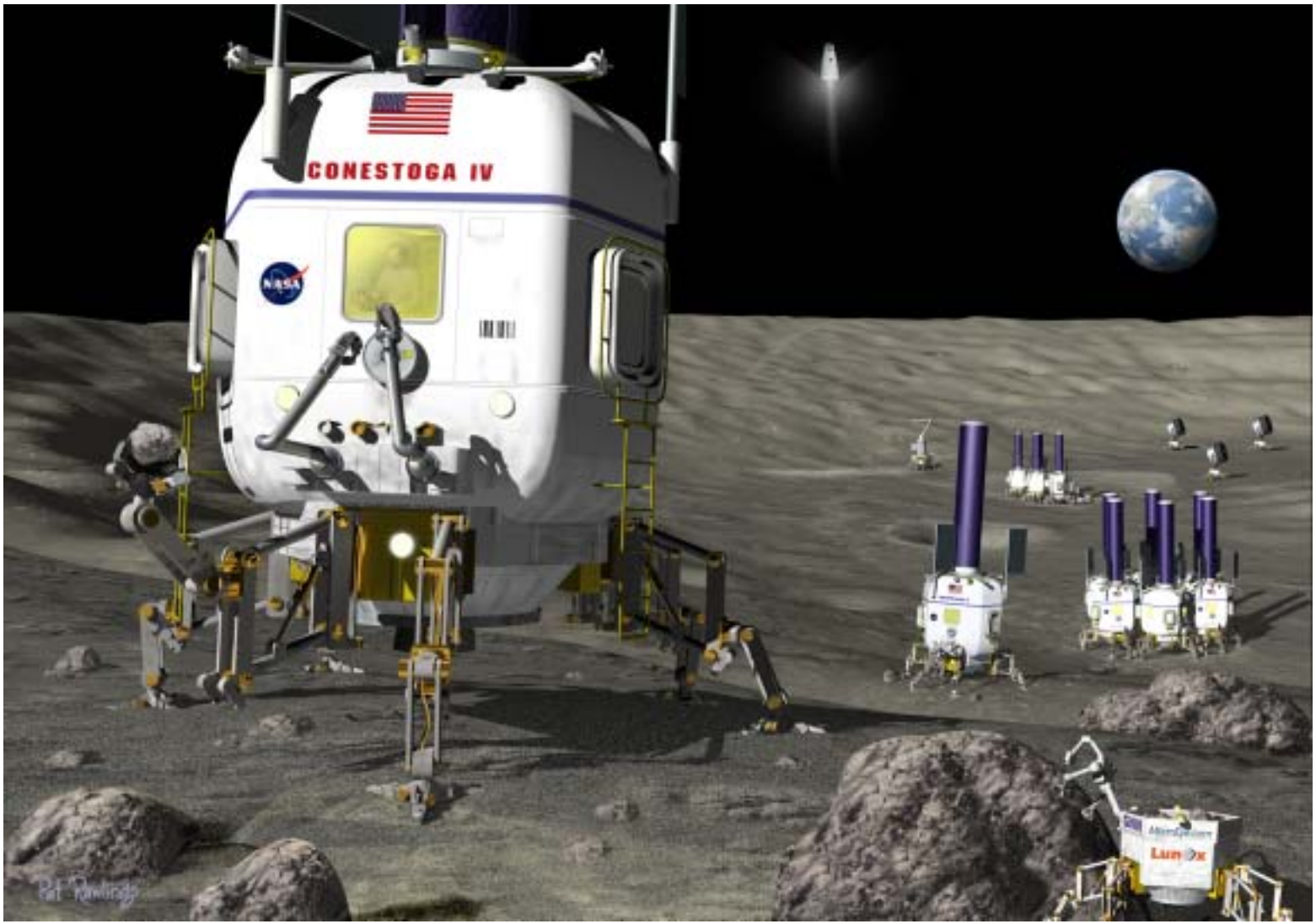
Circa~2020-2030 — Scenario 9
Self-Mobile Fabrication and Repair Facilities in Space



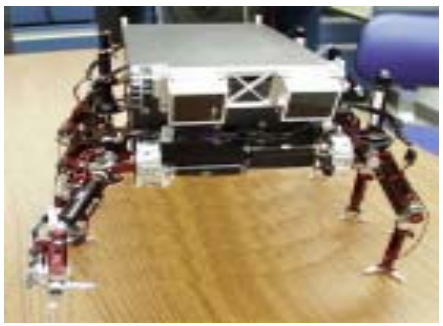
Circa~2015-2025 — Scenario 10
Human/Robotic Fabrication and Repair

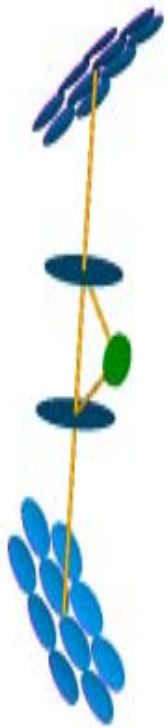


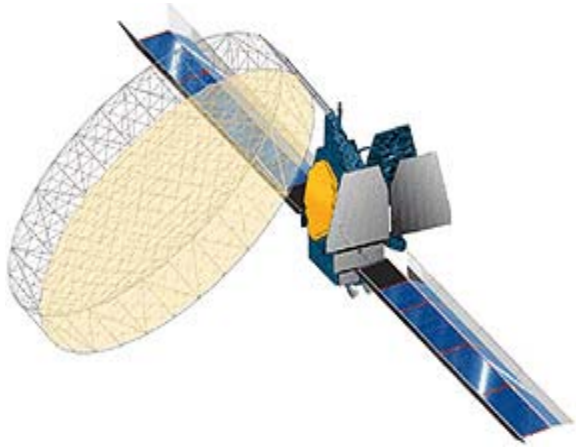
Circa~2020-2030 — Scenario 10
Campaign of Lunar Exploration

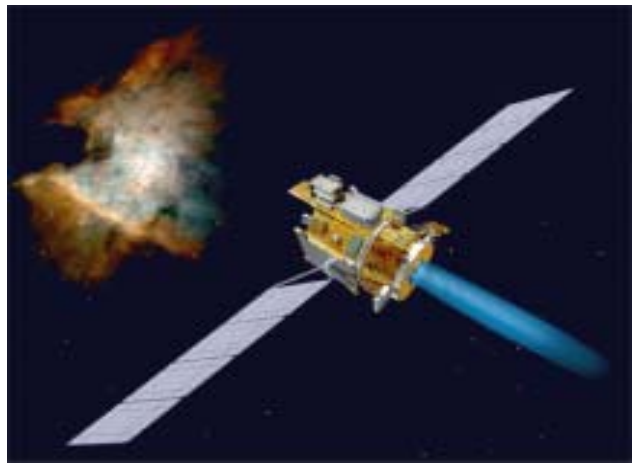


Circa~2020-2030 — Scenario 11
Reconfigurable / Evolvable Spacecraft



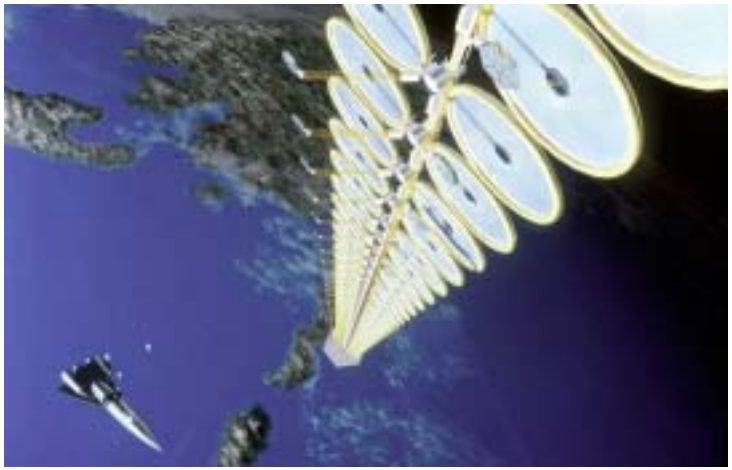


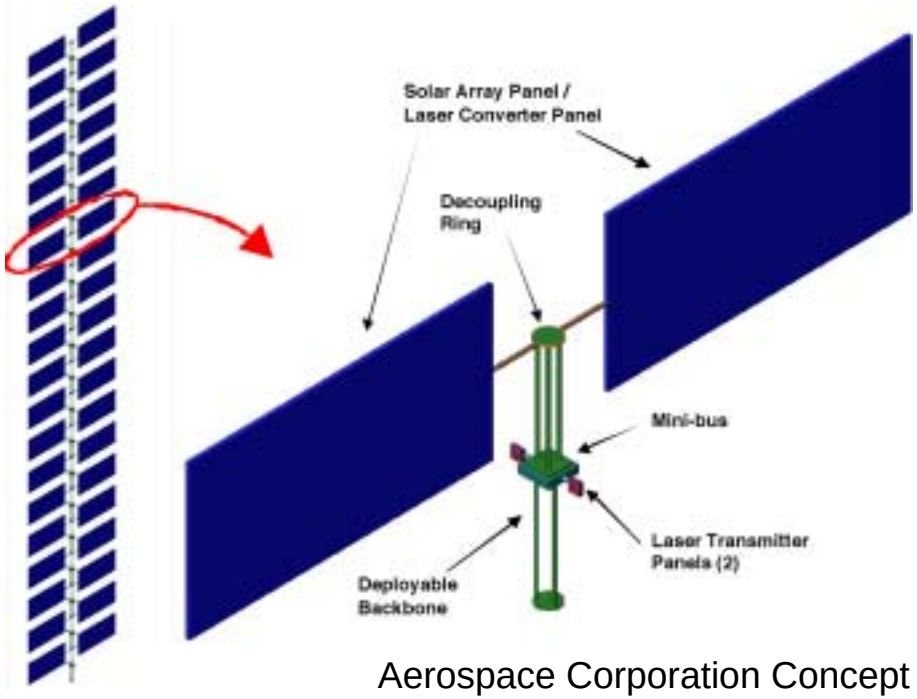




Circa~2020-2030 — Scenario 12
Modular Laser Systems Concepts

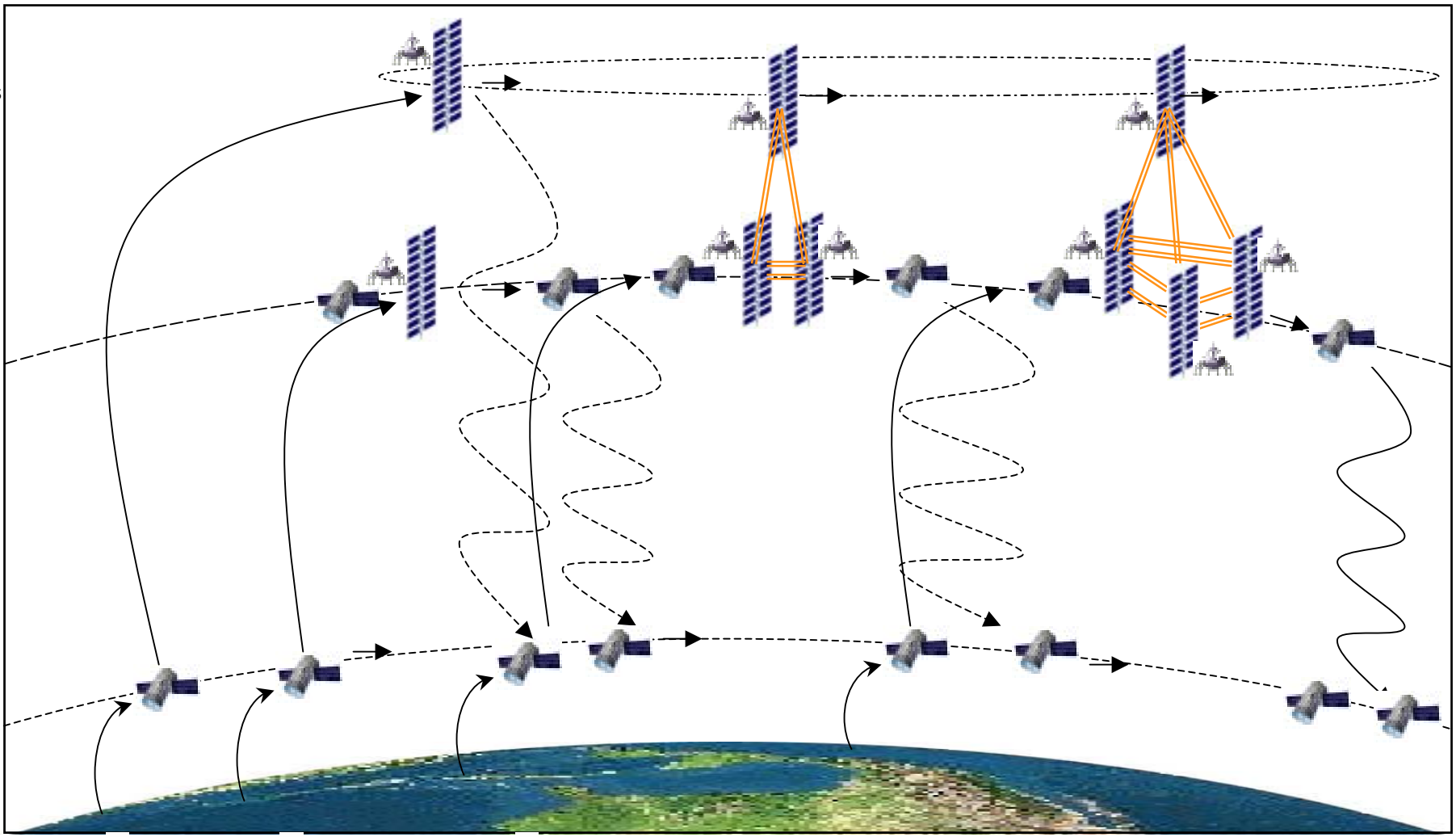
“Fresh Look” Study (1997)



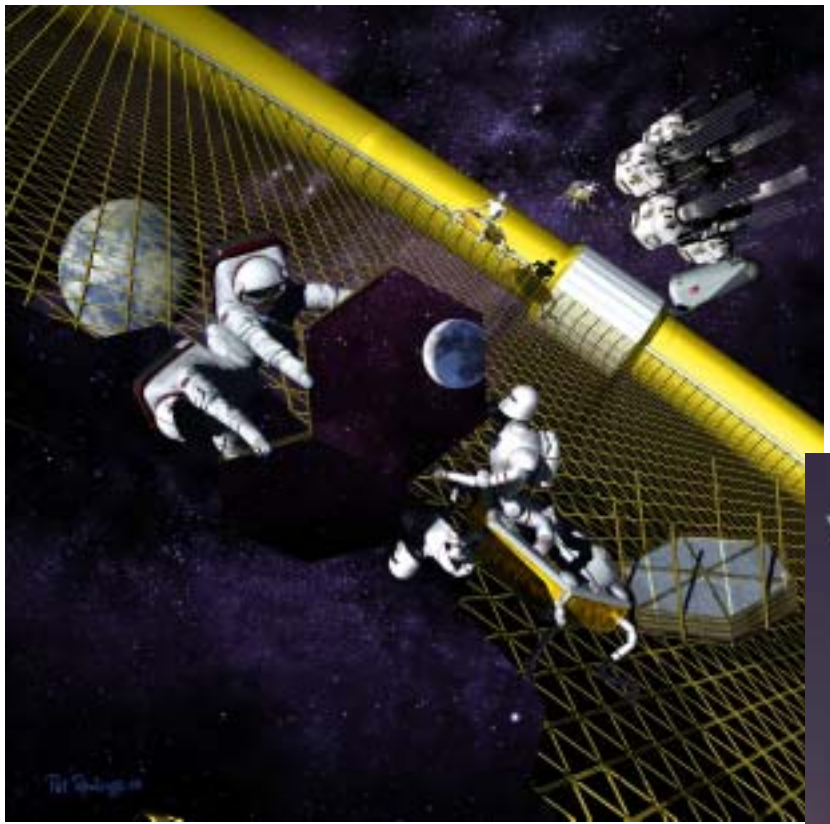


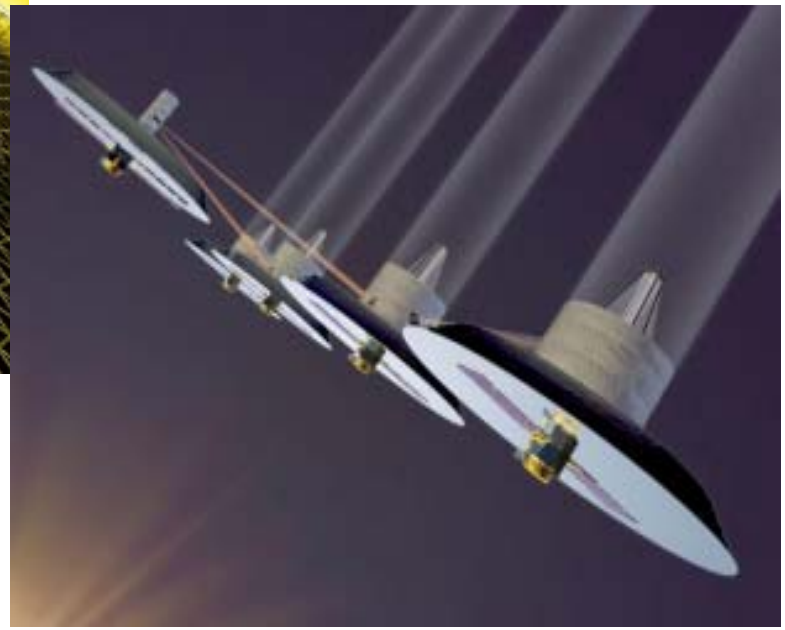
Aerospace Corporation Concept
SERT Program (2000)

Circa~2020-2030 — Scenario 12
Scenario 3 - Laser Comm “Hyper-Grid”

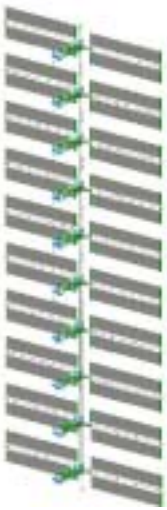


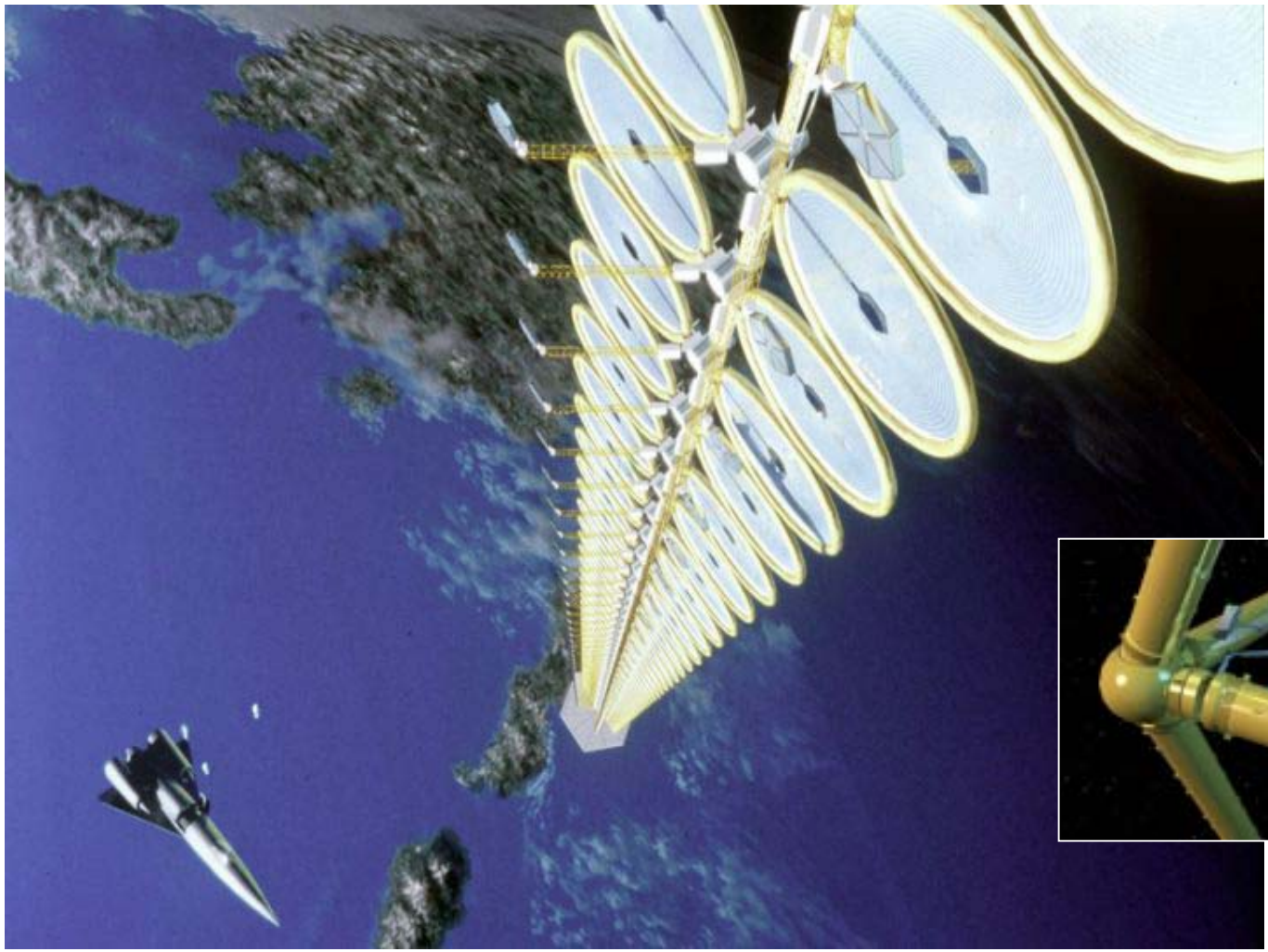
Circa~2025-2035 — Scenario 12
Large Space Telescope Constellations (e.g., TPI)





Circa~2025-2035 — Scenario 13
Large Modular Earth Neighborhood Space Utilities





Circa~2025-2035 — Scenario 14
Campaign of Mars Exploration