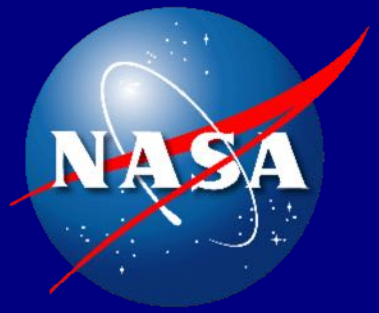

Future Architecture for Servicing and Assembly of Large Telescopes in Space

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HST Development Project, Code 442
NASA Goddard Space Flight Center
Greenbelt, MD 20771

Society of Logistics Engineers
17 August 2005

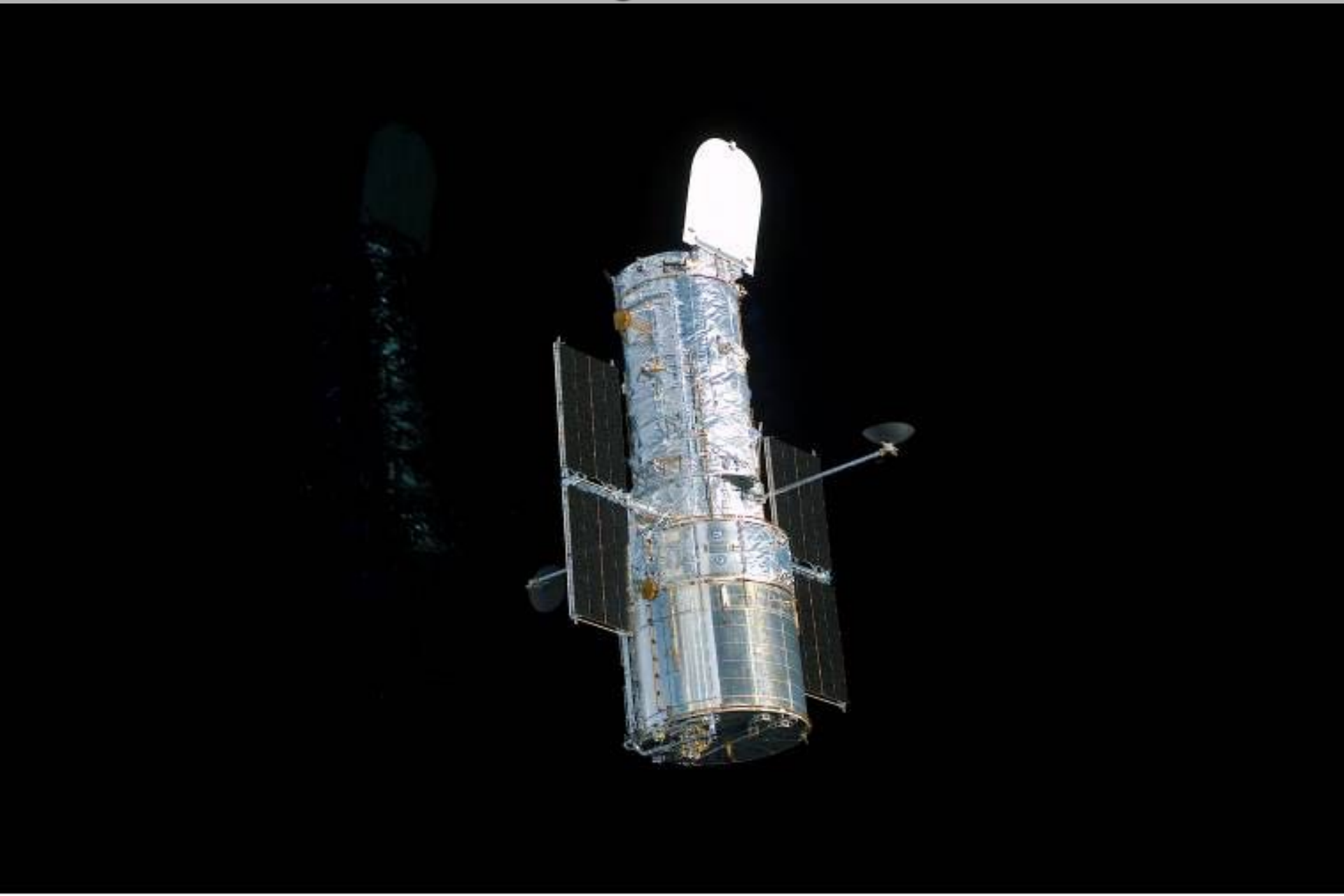
Background: Hubble Space Telescope Servicing

- A brief history
  - Launch in 1990 on Space Shuttle
  - 4 Shuttle-based HST servicing missions using astronaut extravehicular activity (EVA)
    - Optical correction, SA vibration correction, coprocessor retrofit, repairs
    - Instrument upgrade, technology upgrade, repairs, impromptu repair
    - Recovery repairs, technology upgrade
    - Instrument upgrade, technology upgrade, repairs, retrofit of new technology for instrument recovery

HST Servicing Mission Operations

S109E5457

HST Servicing Mission Success



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Background: HST Servicing Experience

- Our current dilemma
  - Access to space, a recurring problem
  - Use of robots versus use of humans

Concept for HST Robotic Servicing

Atlas-V Launch

Shuttle Launch

Background: NASA Current Architecture

- Current Shuttle and ISS experience
  - Large scale docking of habitable modules and preintegrated structures
  - Astronaut-supported utilities integration, outfitting
- Current capabilities are limited for telescope assembly

International Space Station

S114E7246

ISS Operations

Background: NASA Near-term Architecture

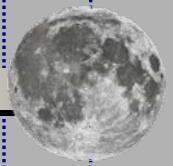
- Move operations beyond Shuttle and ISS
- Return humans to Moon
- Starts first implementations of the Vision for Space Exploration
- Does not (yet) implement assembly of large telescopes in space

NASA Exploration Roadmap

05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

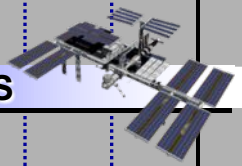
1st Human CEV Flight

Robotic Precursors



7th Human Lunar Landing

Lunar Outpost Buildup



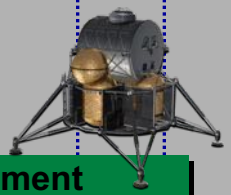
Commercial Crew/Cargo for ISS

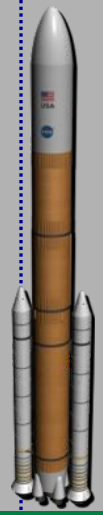
Mars Development

Space Shuttle

CEV Development

Crew Launch Development





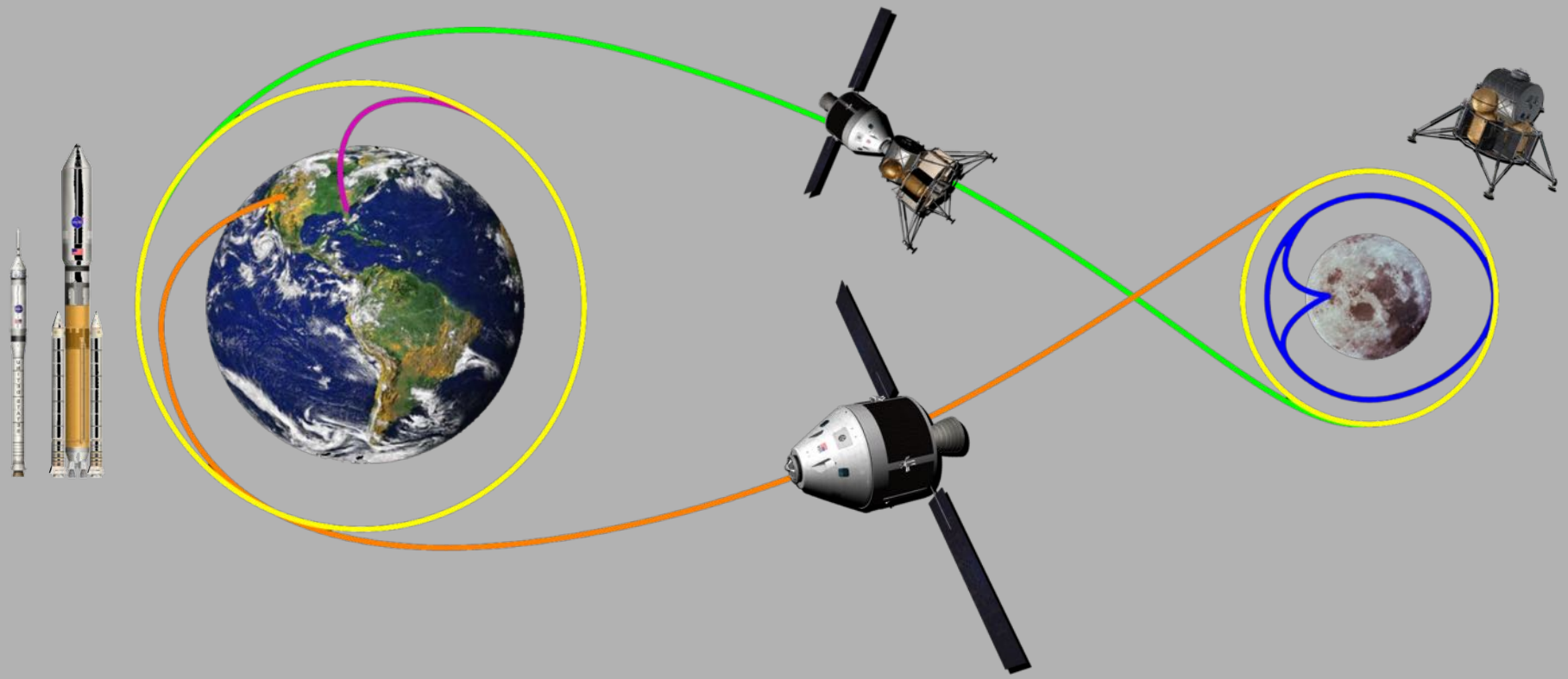
Lunar Lander Development

Lunar Heavy Launch Development

Earth Departure Stage Development

Surface Systems Development

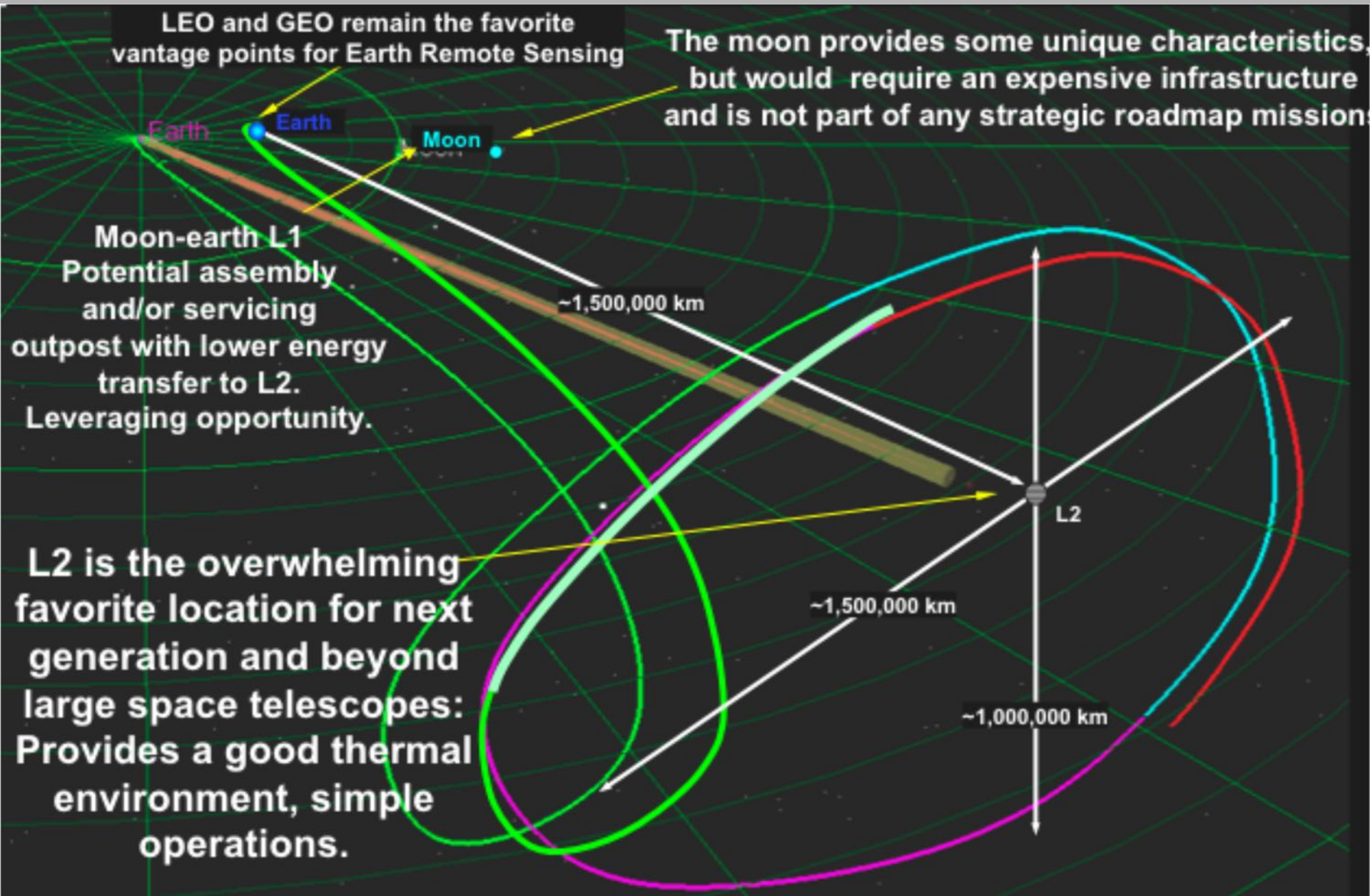
Concept for Lunar Missions Architecture



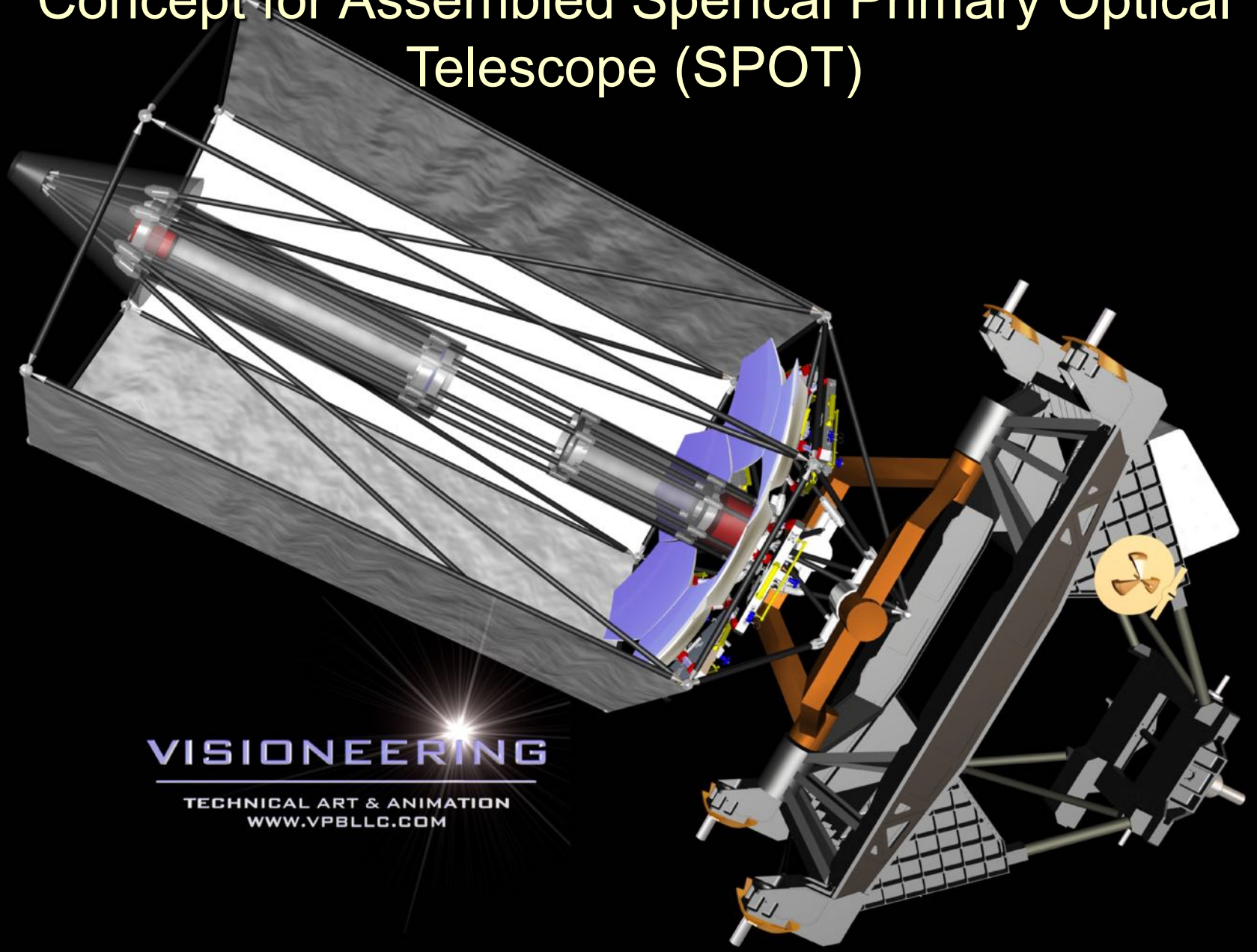
Some Future Space Telescope Concepts

- Sun-Earth libration point orbits
  - Favorable for quiet astronomy
  - Inaccessible to human access for decades
- Cryogenic telescopes
  - Early universe observations
  - Inaccessible to access due to extreme environment
- Very large telescopes
  - Breakthrough science observations of cosmos
  - Assembly in space needed
  - Servicing needed to realize full benefit of investment

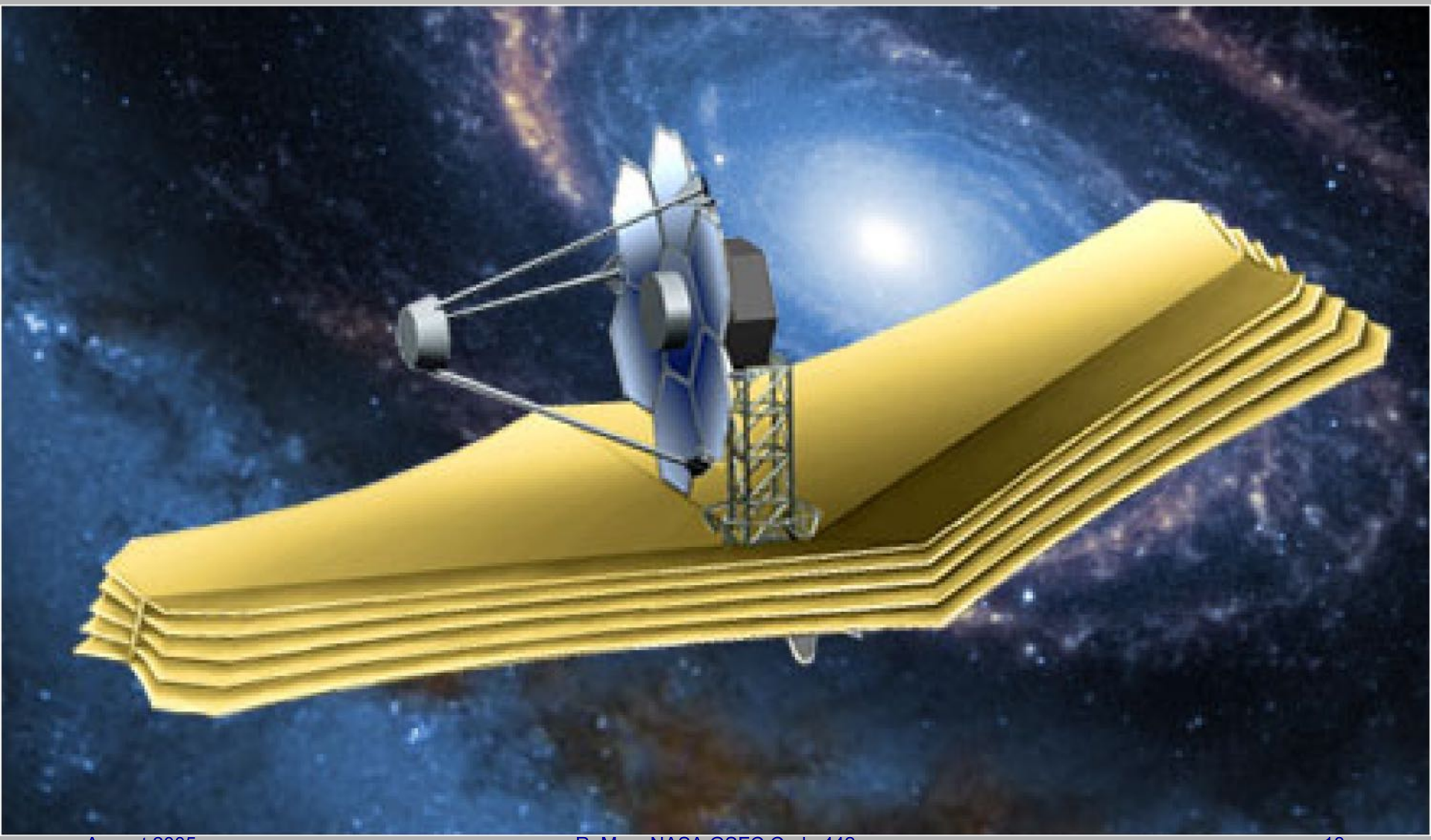
Key Vantage Points for Large Observatories



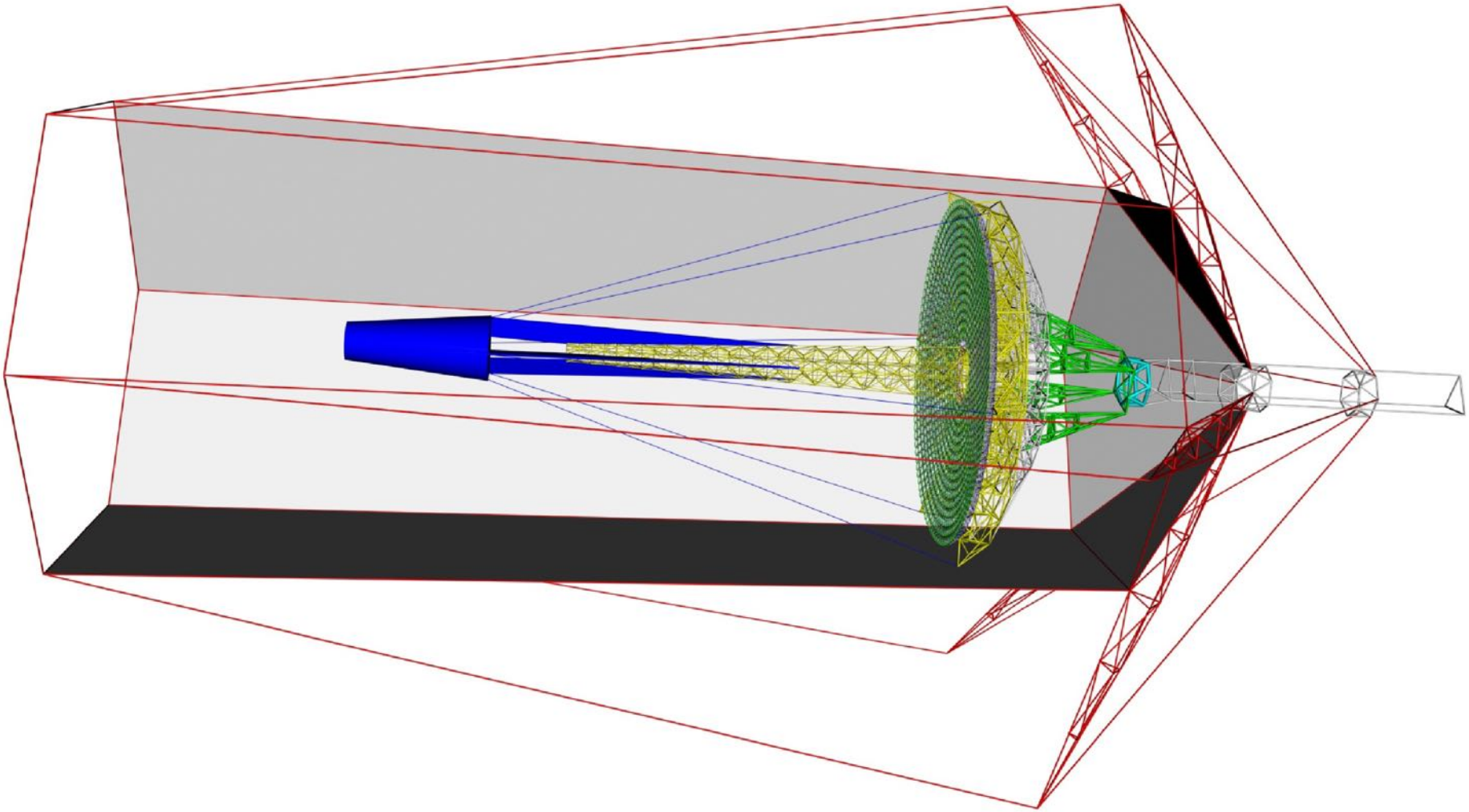
Concept for Assembled Sperical Primary Optical Telescope (SPOT)



Concept for Single Aperture Far-InfraRed (SAFIR) Telescope



Concept for Thirty-Meter Space Telescope

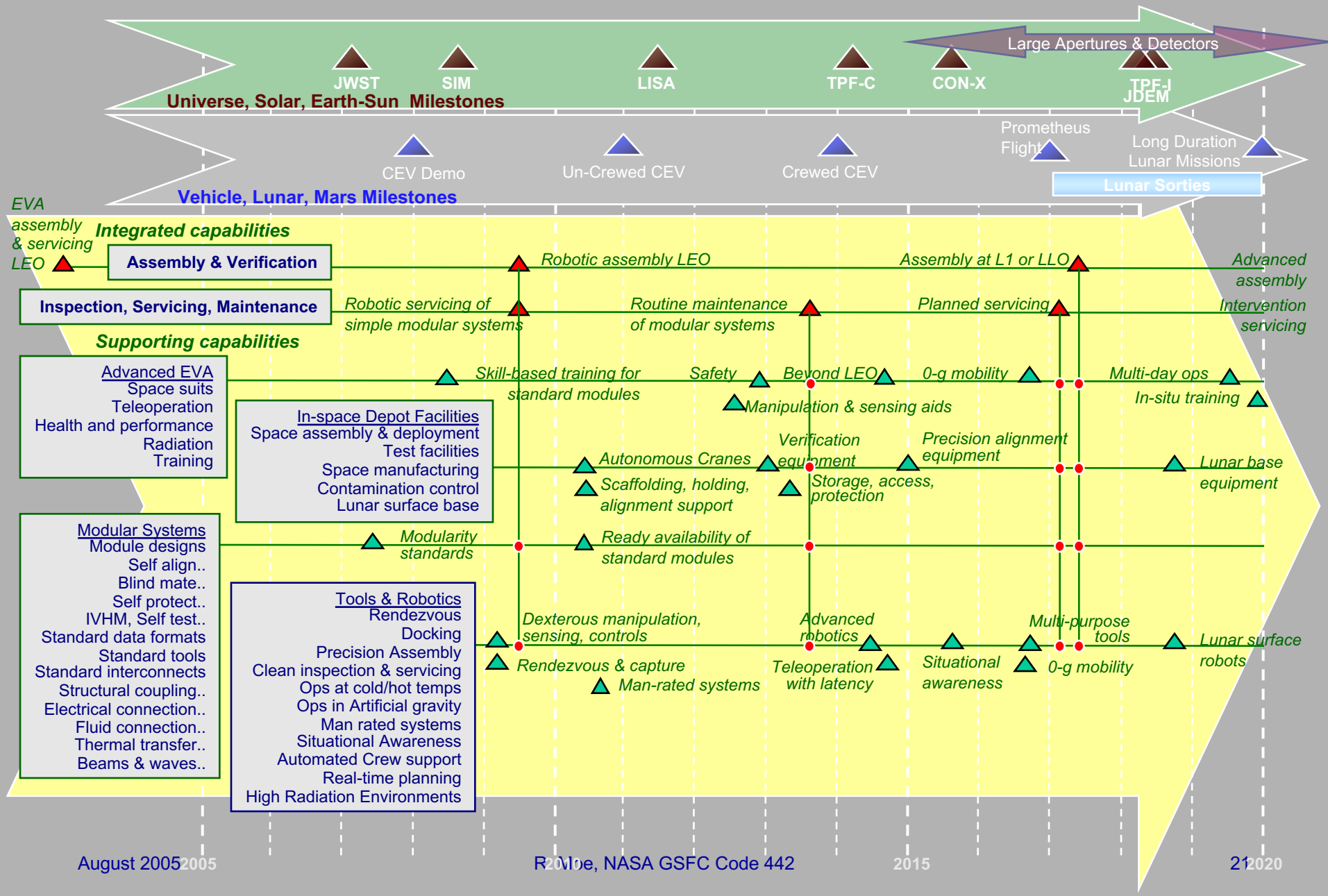


In-space Assembly & Servicing Needs

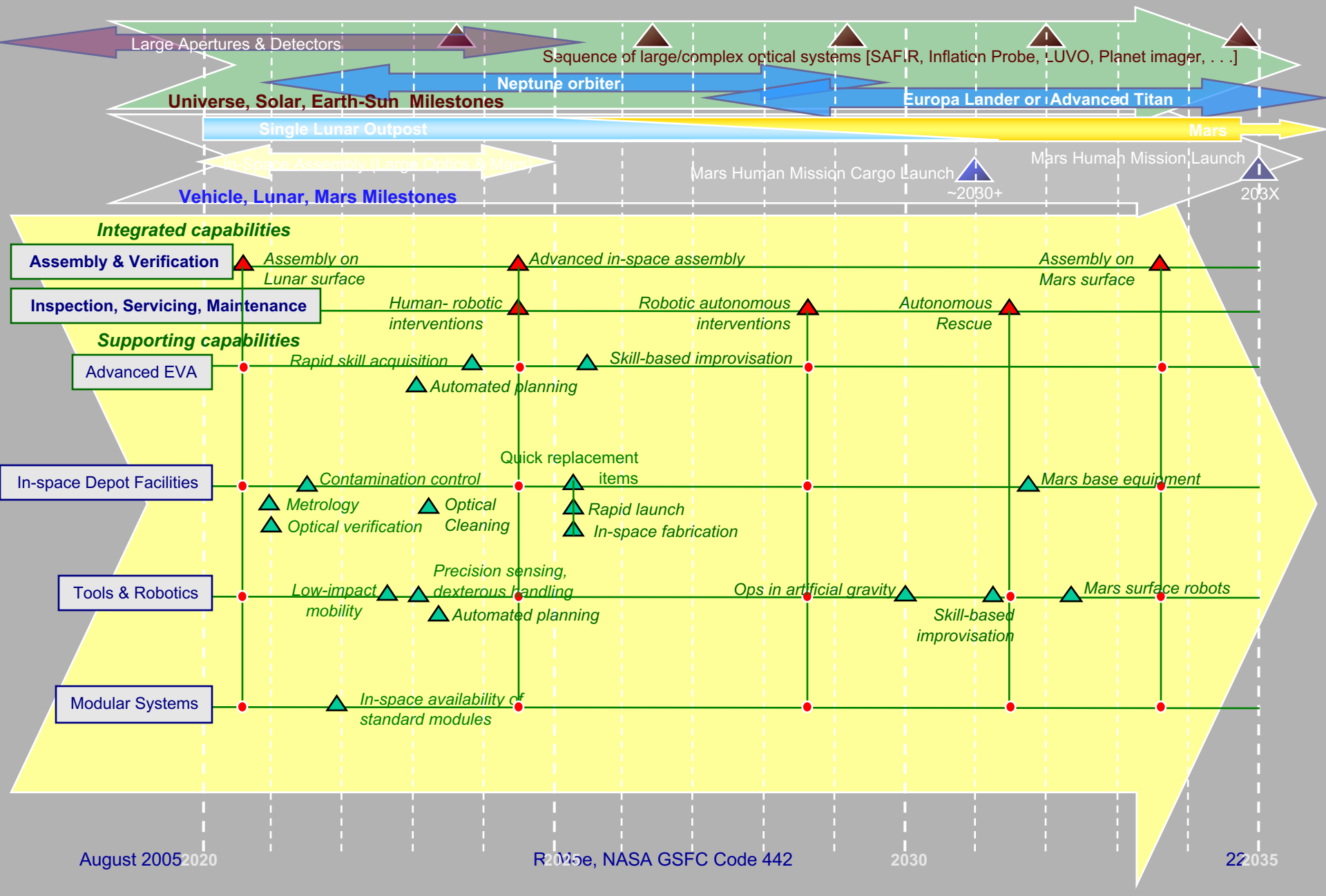
"Too big to launch, too valuable to throw away"

- Assembly: Reconfiguration from launch-optimized packaging to integrated and verified operational state
- Servicing: Reconfigure elements to replenish consumables, to compensate for degradation or obsolescence, or to reoptimize utilization of capital
- Modularity: Design accommodation for reconfiguration – system partitioning, operable interfaces, access
  - Reduces risk for user by reducing operations complexity
  - Reduces cost for user and service provider by reducing capability requirements for assembly & servicing agents (robots and astronaut-robot teams) and other infrastructure
- In-space Supporting Systems: Reusable multi-purpose infrastructure capable of supporting operations
  - Optimizes allocation over long-term broad market of users
  - Increasing capability of assembly & servicing agents (robots and astronaut-robot teams) and other infrastructure captures broader markets, increases return on investment

In-space Assembly & Servicing Roadmap



In-space Assembly & Servicing Roadmap



In-space Operations

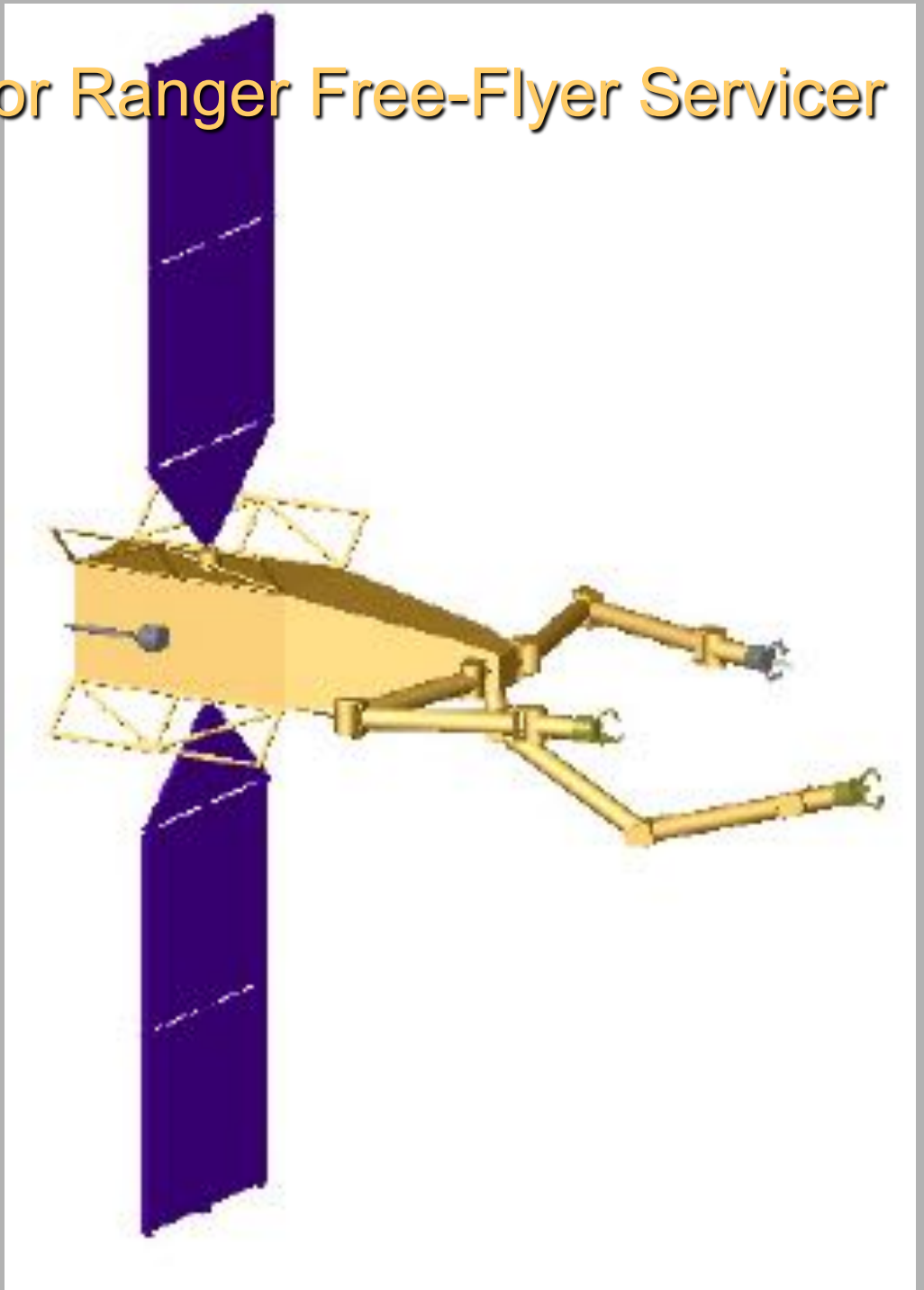
- Access
  - Launch, rendezvous, capture, berth, support and keep-alive services
- Handling
  - Agent use of tools, module features, intermediate configurations, operations sequences, enclosure access and unpack, access trajectory clearance, inspection, disassembly, reassembly, stow or jettison
- Environmental protection
  - Reconfigurable elements transition from launch states through temporary handling to operational state
  - Attitude control, cleanliness control, thermal control, keep-alive utilities
- In-space verification
  - Allocation of test functions to built-in or mission-specific equipment versus portable and reusable facility equipment

Active Agents: Human-robotic Operations

- Development Evolution of Roles
  - Allocation of functions between built-in versus reusable equipment
  - Technical maturity of robotic sensing and manipulation, advanced EVA, and human-robotic cooperative operations evolves with devlopment investments
  - Humans retain responsibilities beyond the capabilities of autonomous systems
  - Increasing capabilities of robotics and autonomous systems relieve humans of unnecessary risk and burden, increase mission productivity

Concept for Robonaut

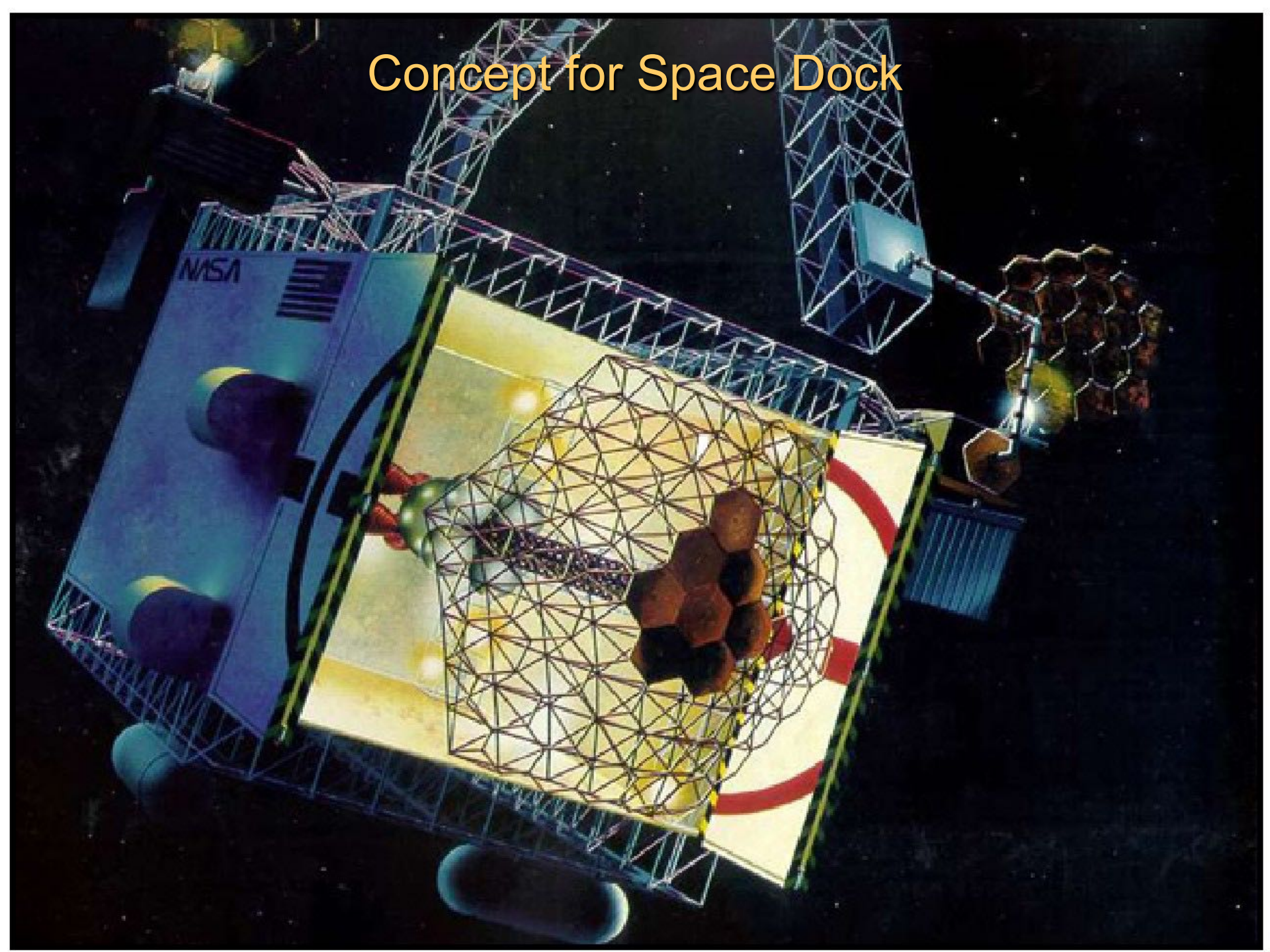
Concept for Ranger Free-Flyer Servicer



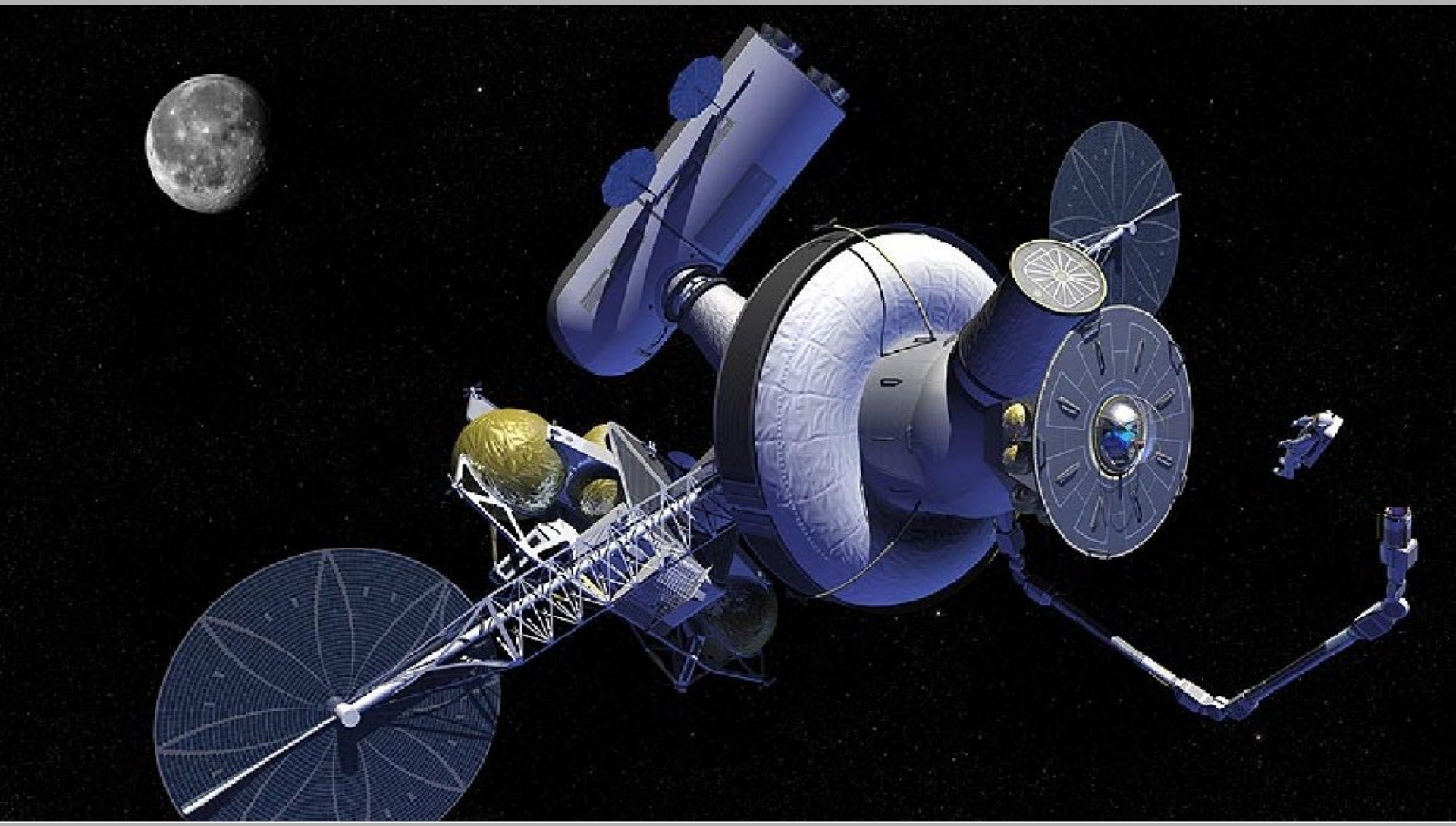
Sharing In-Space Facilities

- Reuse of Supporting Systems
  - In-space facilities for refueling, staging, assembly, servicing
    - Rendezvous & dock
    - In-space utilities, power, communication
    - Environmental control for elements and components
    - Access for robotic and human EVA active agents
    - Warehousing of consumables, spares
  - Incremental build-up by users accumulates capabilities
    - Core: rendezvous and utilities support
    - User-provided: handling, storage, refueling, crew exchange, habitation and life support, assembly, servicing, verification equipment, clean ops, cryo ops, nuclear ops, etc.

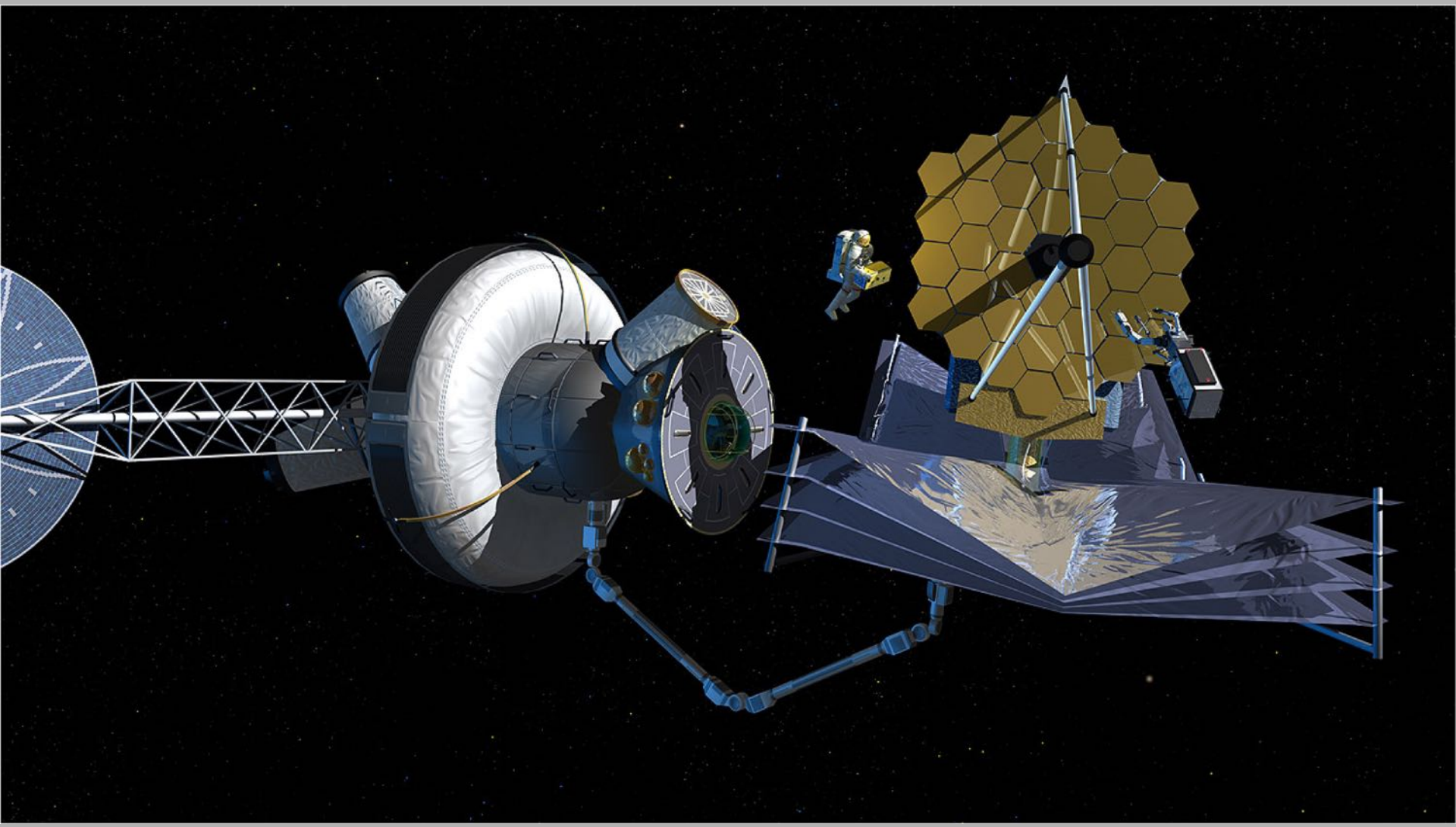
Concept for Space Dock



Concept for In-Space Facility



Concept for SAFIR Servicing at In-Space Facility



Sharing In-Space Facilities

- Reuse of Interoperable Components
  - Architecture based on modular reconfigurable components reduces launch weights over decades for a broad market of users
    - Strut & node space frames
    - Enclosures
    - FPGA electronics for multiple functions
    - Restartable refuelable engines
    - Common elements built to interoperability standards, e.g., antennas, reaction wheels, star trackers, etc
  - Share production facilities, space launch and transport, in-space inventory
  - Decommission facilities after mission completion and salvage for reusable elements and components

Staging and Depots

- Staging facilities in space provide for crew exchange, refueling, logistics support
  - Reduce demand for large launch vehicles; aggregate materials and components in space
    - Assembly
  - Mission sustaining, repair, upgrade, repurpose
    - Servicing
  - Preposition assets to reduce crew transport vehicle requirements
    - Staging, crew transfer

Concept for In-Space Depot

Concept for In-Space Depot Operations