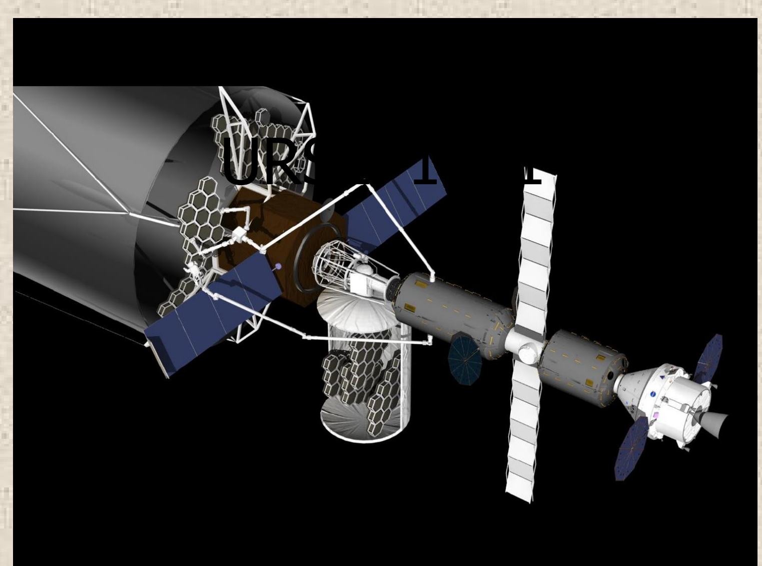
Findings and Observations from the November 2017 NASA in-Space Servicing and Assembly Technical Interchange Meeting



Nick Siegler (NASA JPL/Caltech)
Brad Peterson (OSU/STScI)
Harley Thronson (NASA GSFC)

70+ participants from government, industry, and academia

- 30 NASA Centers
- 29 Industry
- 7 NASA HQ
- 4 academia
- 4 STScI
- 1 DARPA

Planning team chair: Harley Thronson (NASA GSFC)

Co-Chairs: Brad Peterson (OSU/STScI), Nick Siegler (NASA JPL)

Motivation for Coming Together

"…we are now 'hitting a wall' in terms of the ability to build the missions we are considering, and thus novel methods may be needed, such as on-orbit assembly."

– Scott Gaudi
Chair, Astrophysics Advisory Committee
Ohio State University

Additional Contributing Factors

1. Significant reduction in cost of medium-lift launch vehicles
2. Continued advances in robotic/telerobotic servicing and assembly capabilities
3. Deployment in cis-lunar space of an intermittently-occupied Deep Space Gateway facility
4. Advances in scientific instrument technologies
5. Congressional language for future space assets to be serviceable

Key Acronyms

iSS = in-space servicing
iSA = in-space assembly
iSSA = in-space servicing and assembly

Servicing = repair, replacement, upgrade, refuel, re-position

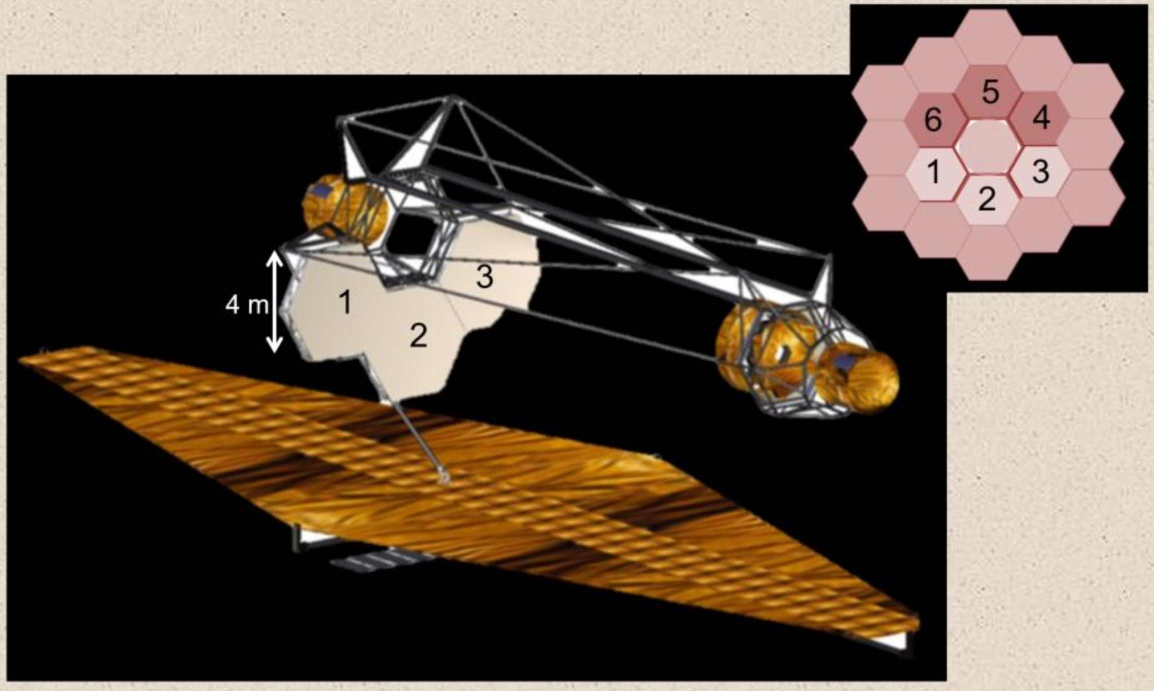
How does iSSA enable innovative instrument and telescope designs? (1 of 2)

- **iSA <u>enables</u> space telescope designs that are not limited by launch vehicle fairing size and mass constraints.**
  - Examples: > 15 m aperture telescopes and long-baseline interferometers
  - 15 m is the reported maximum-size telescope aperture that fits in the fairing of a future SLS Block II
- **iSA <u>enables</u> space observatories and large structures to be designed with architectures too complex to be reliably deployed autonomously.**
  - Examples: large JWST-like segmented telescopes, interferometers, starshades
- **iSS <u>extends</u> the lifetime of observatories.**
  - Potentially enabling a Great Observatories paradigm (persistent assets)
  - Spacecraft could be refueled, subsystems could be replaced or upgraded
  - Mirrors could be recoated and decontaminated
  - Starshade membrane and edges could be repaired after micrometeoroid damage
- **iSS <u>enhances</u> our capability to more rapidly respond to new science questions through the replacement and upgrade of payload instruments**
  - "HST is a better observatory today than when it first launched"
  - Instrument technology is ~ 10-15 yr old by launch (technology lag)

How does iSSA enable innovative instrument and telescope designs? (2 of 2)

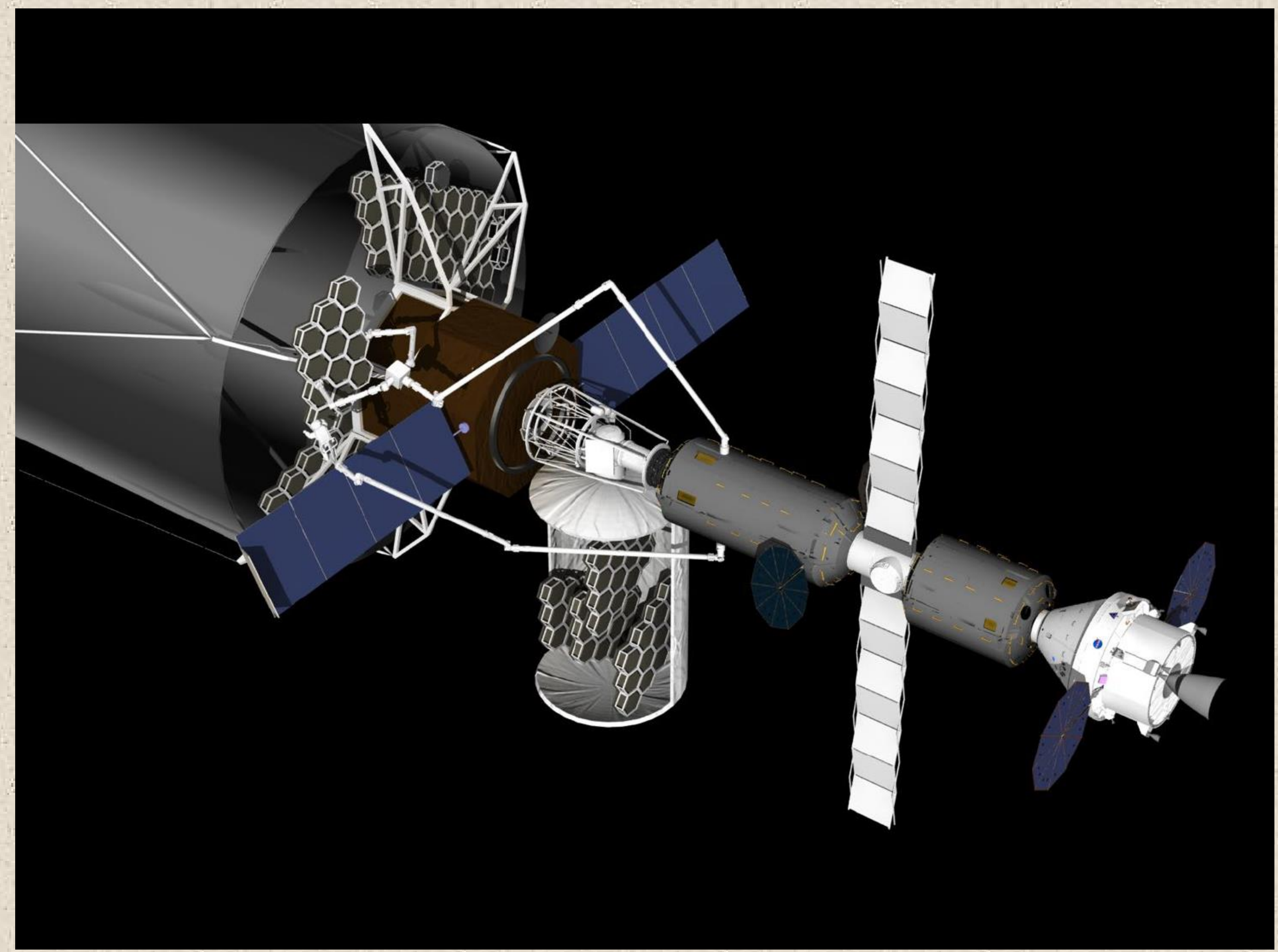
- **iSSA <u>enables</u> telescope architectures that can grow in aperture size over time and hence, <u>enhancing</u> science through greater resolution and signal-to-noise**
  - "evolvable observatories", "Pay as you go"

- **iSA <u>enables</u> the use of new materials in space, for example ultra-low weight optics, that cannot be adequately tested at 1 g or safely survive launch environment in an integrated state.**

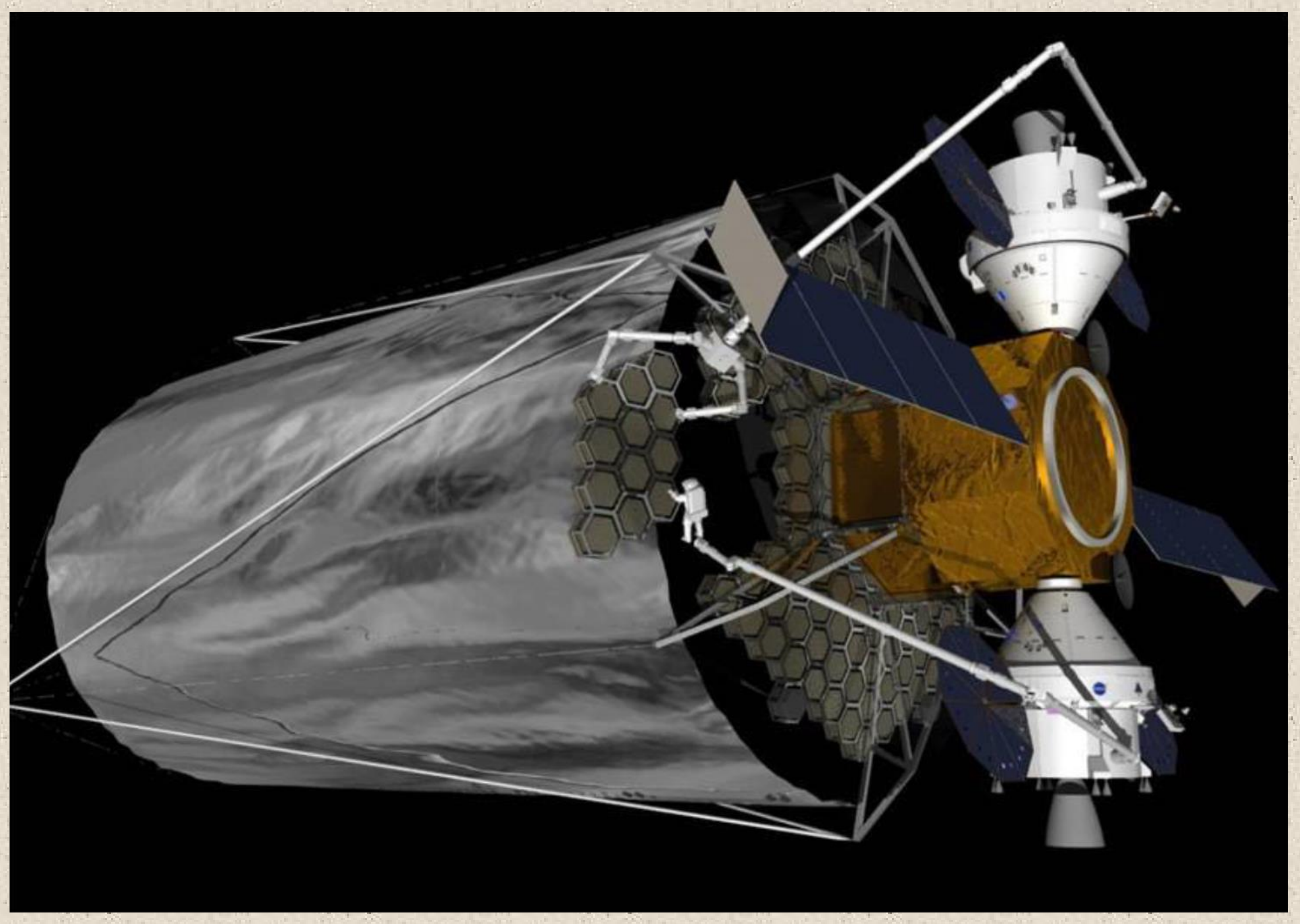


Polidan et al. 2016

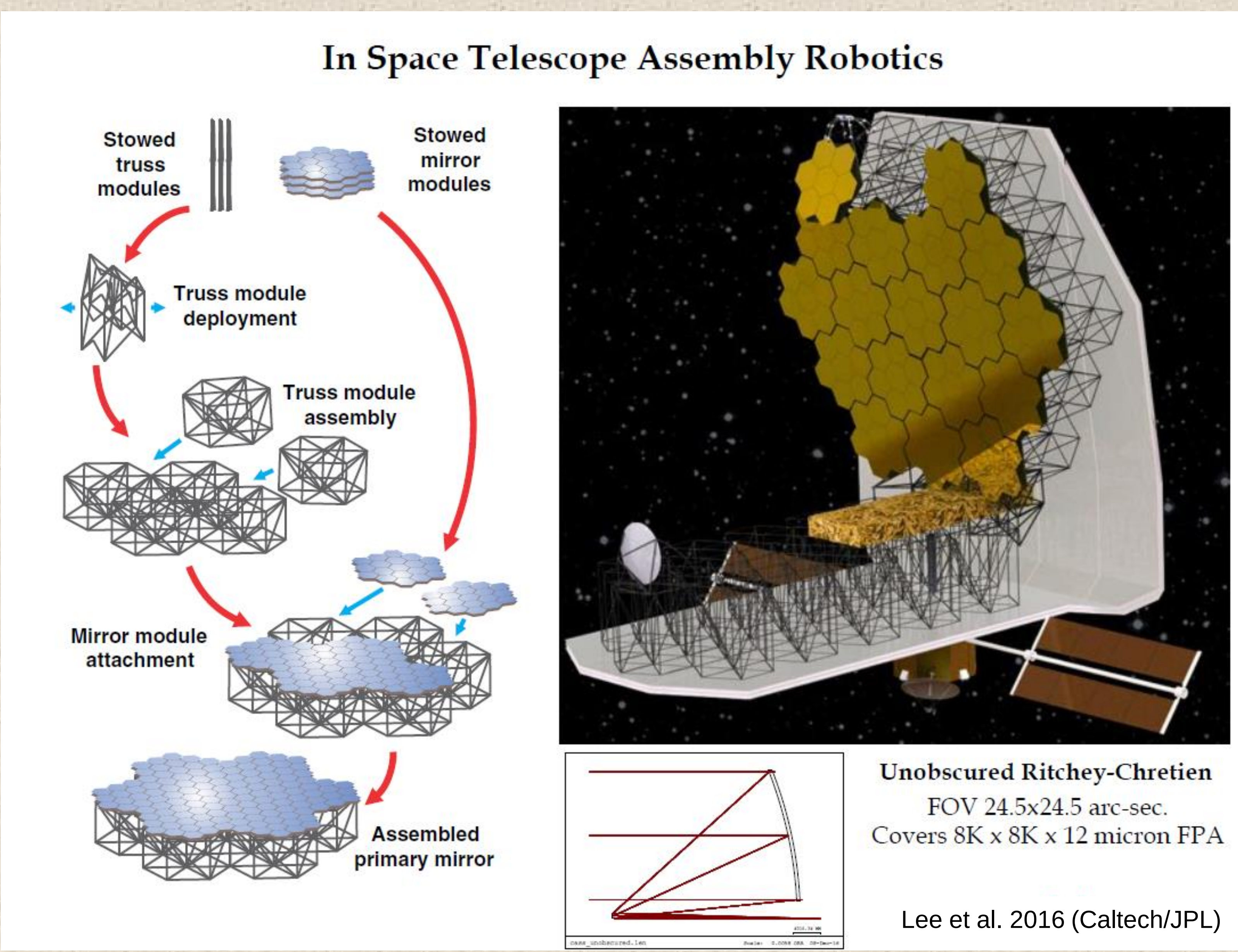
Telescopes assembled with a Gateway



Telescopes assembled without a Gateway



Telescopes assembled from modular deployable trusses



Key TIM Questions

How does iSSA reduce cost and risk, both technical and programmatic? (1 of 4)

- **Beyond cost and risk, iSA is an <u>enabling</u> capability for the realization of large telescopes and interferometers in the not-too-distant future.**
  - At some aperture size (~ 17-20 m), even the next generation of LV fairing sizes will not be large enough to enable an autonomous telescope deployment

- **The case for "iSA of large observatories (4-15 m apertures and greater) being less expensive than autonomous deployment" has to date <u>not</u> been made.**
  - Potential cost savings may very likely be offset with new sets of unknown challenges (see next slide).
  - A more detailed study of how a large observatory would be built in space could examine this issue to the next level of needed fidelity.

- **By extending the lifetime of future NASA observatories, the cost of fewer new observatories results in a lower total cost amortized over more years.**

How does iSSA reduce cost and risk, both technical and programmatic? (2 of 4)

Potential cost savings offered through iSSA:

- **Eliminates engineering design work and testing required to (1) creatively fit large structures into existing fairings and (2) autonomously deploy**
  - JWST invested a significant effort into designing and testing the telescope's folded wing design; even more for the observatory deployment with > 100 single point failures
- **Moves architecture away from "every new telescope is a new point design"**
  - Greater commonality with previous system reducing development costs
- **Reduces "ruggedization" to survive launch environment**
- **Reduces need for new and unique ground test facilities**
  - JWST required new ground facilities to be built
- **Reduces need for hardware redundancy**
- **Leverages existing and less-costly medium-lift launch vehicles**
- **New instruments can be swapped out without additional observatories**
- **Leverages investments in human space flight facilities**

How does iSSA reduce cost and risk, both technical and programmatic? (3 of 4)

Potential new challenges may also INCREASE costs:

- **Would a full-scale, robotically-assembled telescope have to be demonstrated on the ground to mitigate concerns and risks? And then disassembled?**
- **Potential additional cost for any astronauts in the loop**
- **New robotic capabilities will be required as part of iSSA that would not be required in the autonomous deployment approach.**
- **Sending multiple modules into space will require new containers and interfaces each having to undergo environmental testing.**
- **New Earth-based problems yet unknown in standardization and assembly, as well as new unknown problems created in space, will likely need to be solved.**

How does iSSA reduce cost and risk, both technical and programmatic? (4 of 4)

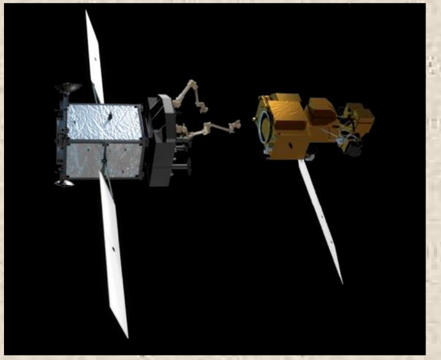
Risk reduction opportunities arising from iSSA

- **Reducing risk becomes increasingly more important as mission costs increase.**
- **Future larger observatories are likely to require more complex deployment schemes. iSSA can mitigate risk of failure by:**
  - Modularizing the design enabling repair and replacement of faulty sections
  - Designing servicing capabilities (robotic and/or human) into the architecture
  - Minimizing single-point failures
  - Enabling end-to-end testing (often not possible on ground)
- **iSA does not require next-generation launch vehicles**
  - Several future mission concepts under study rely on the SLS Block II (a potential programmatic uncertainty)
- **Launch failure need not be equivalent to mission failure**

How will future large observatories be serviced? (1 of 2)

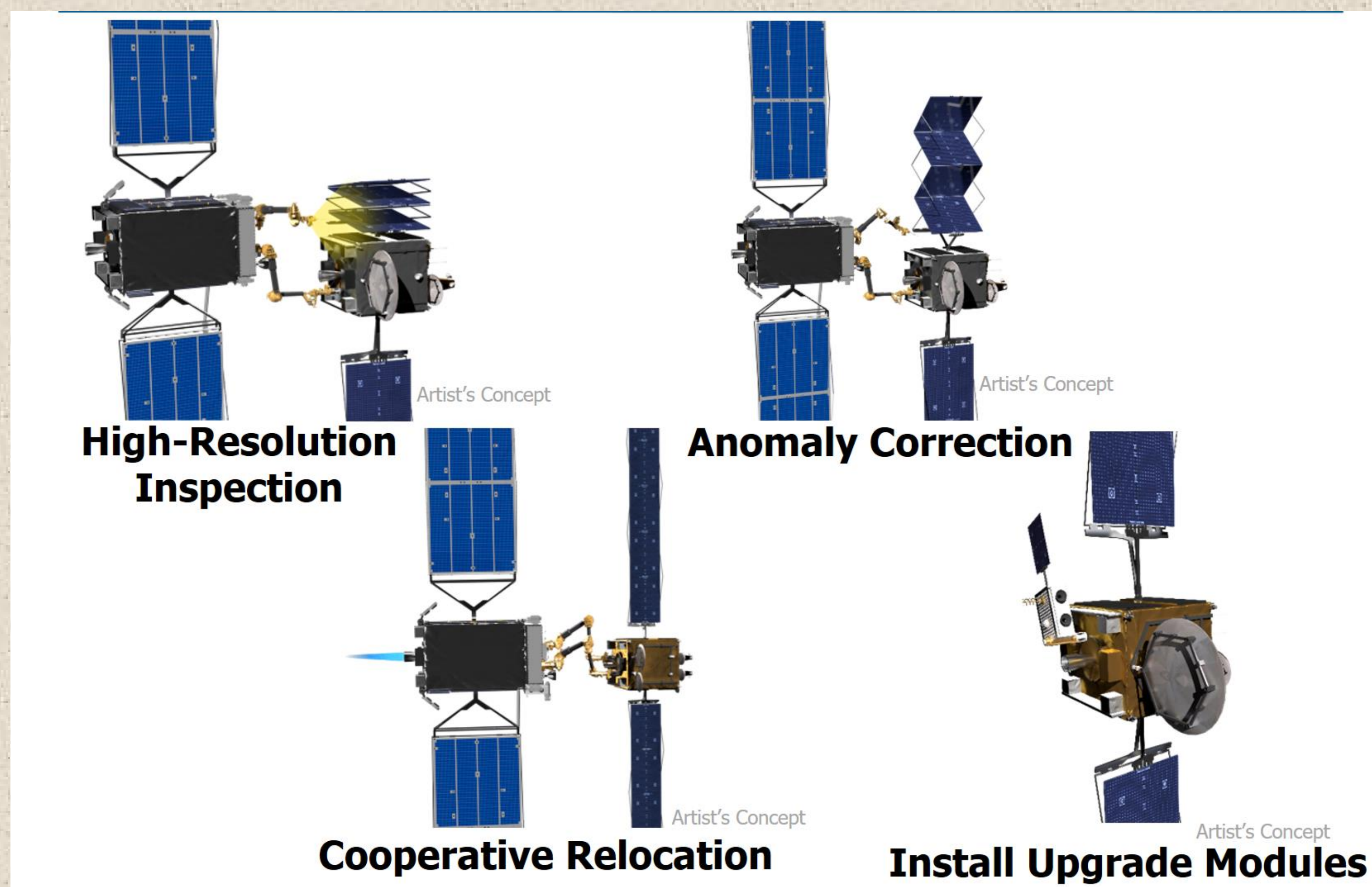
- **As Sun-Earth L2 is the likely operational destination for many science missions, servicing could be performed in situ or in an orbit in the lunar vicinity.**
  - Earth-Sun L2 ←→ cis-lunar has a delta-v of 10's of m/s
  - LEO, GEO are other options but have large delta-v and are outside of their operational environment

- **Servicing observatories at Sun-Earth L2 may be preferred if operations are relatively <u>simple.</u>**
  - Simplicity – cooperative architecture aided by high levels of modularity
    - Re-fueling, swapping out instrument payloads, replacing solar arrays and batteries
  - Due to relatively long latencies operations would be semi-autonomous
  - Servicing can be conduced by a free flyer (e.g. DARPA RSGS, Restore-L)



DARPA RSGS

(Geosynchronous orbit)



RSGS = Robotic Servicing of Geosynchronous Satellites

How will future large observatories be serviced? (2 of 2)

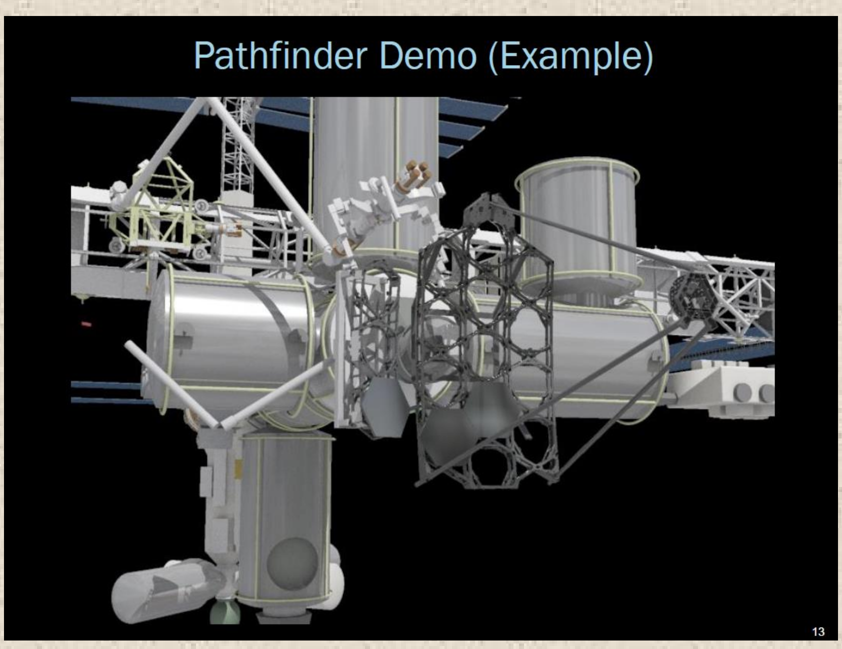
- **If servicing operations are relatively <u>complex</u>, then the mission can transfer from Sun-Earth L2 and be serviced at an accessible orbit in the lunar vicinity (e.g. Earth-Moon L1).**
  - Human and robotic support may be both important
  - Can leverage existence of an in-space assembly infrastructure (e.g. DSG)

What additions to a Gateway would be most valuable for servicing and assembling future space observatories?

- **We don’t yet know.**
- **An assembly design study would be required to answer this question. Such a study would assess, for example:**
  - Defined ports, power, propulsion, attitude control
  - Autonomous and dexterous external robotic arms capable of assembling and servicing future observatories
  - Ability to free-fly near Gateway (keep-away region, multiple sites?)
  - Capability for multiple astronaut EVAs for about 2 people over 2 weeks
  - Contamination mitigation
  - Photogrammetry capabilities

What are possible precursor demonstration activities? (1 of 2)

- **Valuable <u>servicing</u> demonstrations already planned:**
  - DARPA RSGS program and NASA Restore-L
- **Possible precursor <u>assembly</u> demonstrations on the ISS:**
  - Vibration isolation
    - ❖ floating systems are hard to demo in 1-g
  - Robotic assembly of a small segmented telescope (e.g. OpTIIX, JWST Pathfinder)
    - ❖ backplane
    - ❖ segment integration (power, alignment)
    - ❖ 0-g effects on mirror sag, alignments, and assembly feed back into models



What are possible precursor demonstration activities? (2 of 2)

- **Contamination analysis on a cis-lunar station**
- **Robotic arms dexterity tests on the ground relevant to telescope assembly**
- **Planned GEO activities to demonstrate assembly concepts may be worth considering as a demonstration venue.**
  - DARPA RSGS expected to have a commercial free-flyer and dexterous robotic capability infrastructure

Why Now?

- **There are large future space observatories being studied and designed today to be <u>serviceable</u> but the servicing capabilities do not currently exist.**

- **There are large future space observatories being studied and designed today that are limited by current <u>and</u> future launch vehicle fairing sizes.**
  - *"We are now hitting a wall [towards what is possible]"*

- **Potential space telescope missions planned to be serviced and/or assembled in the 2030s need to start their technology activities in the 2020s.**

- **A valuable venue for assembly demonstrations, the ISS, may be decommissioned in the mid-2020s.**

- **There is a near-term opportunity to inform the 2020 Decadal Survey about the potential benefits of iSSA as a potential implementation approach for future large apertures and the current SOA.**

- **There is at present a window of opportunity through 2019 to recommend augmentations to the DSG team before their designs are frozen.**
  - *March-July 2018 is the optimal window*

TIM Findings

The TIM Findings (1 of 2)

1. **iSSA is an important and enabling capability that has clear applications to near-term APD objectives**

2. **The current paradigm of telescope design (deployed or monolithic) does not contribute to the design of subsequent large-aperture space telescopes. Hence, the cost model for large telescopes is unlikely to change unless there is a paradigm shift.**

3. **There is a revolution in the TRL of robotics on the ground**
   – DARPA RSGS and NASA Restore-L are embodiments of this for space demonstrations and have legacy from the 15+ years of Mars and ISS robotics

4. **NASA STMD is already funding various iSSA Tipping Point efforts that can be built on for future iSSA**

5. **DARPA RSGS is a game changer**

6. **The ISS is potentially an ideal testing platform for many iSA technology development activities but is planned to be decommissioned mid-next decade**

The TIM Findings (2 of 2)

7. **The 2010 Decadal made no mention of iSSA**
   – Is this just an implementation issue?

8. **The "serviceability" of future telescopes is ambiguous as there is recognition that there are no ready servicers**
   – Consideration ought to be given on how to leverage existing servicer work (RSGS, Restore-L) including the opportunities enabled by a DSG

9. **Industry has very strong interest in iSSA and can play an important role**

10. **Large future space observatory concepts depend on availability of SLS Block II**
    – Some STDTs are relying on it

11. **A completed NASA Gateway infrastructure potentially offers a unique facility in which SMD may be able to leverage the iSSA of future large telescopes.**

Key TIM Suggestion

Commission a design study to understand how large-aperture telescopes could be assembled and serviced in space

- *Suggest joint SMD/STMD/HEOMD study with industry and academia participation*
- *Multi-disciplinary, multi-institutional*
- *Initiate the study in time for initial results to be available to Gateway and robotics designers within 2018, but certainly before end 2019.*

A. Produce several iSA concepts and prioritize them

B. Select one implementation concept for a deeper engineering study

- *identify capability needs, SOA, and technology gaps and produce a list of technologies that could be demonstrated to close these gaps*
- *assess opportunities for engineering demonstrations that may be deployed on the ISS within the next few years.*
- *determine balance of human and robotic support*
- *understand servicing options*
- *produce an early list of preliminary interface consideration to the DSG*

C. Estimate the cost and understand scaling laws to compare costs/risks to an autonomously deployed telescope

Breaking the Cost Curve

Breaking the cost curve on building large observatories may include:

1) **<u>assembling</u> large-aperture telescopes in space**

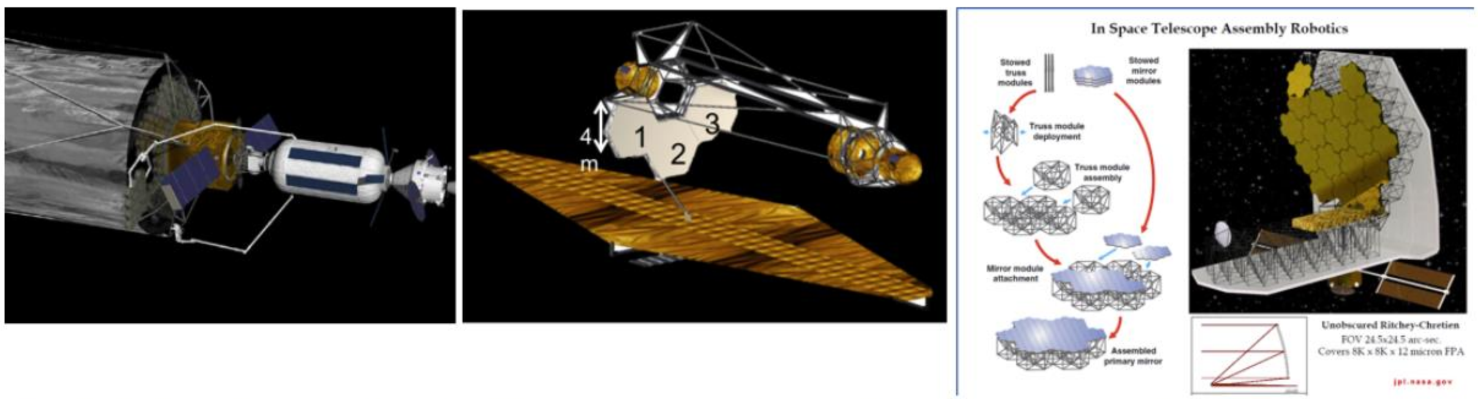
2) **<u>servicing</u> these observatories to extend their utility by:**
   - replacing the instrument payloads with newer more advanced ones
   - upgrading spacecraft subsystems as they wear and age
   - refueling to extend their lifetimes,
   - repairing when needed, and
   - incrementally enlarging the apertures over time

The potential benefits of iSSA of large future telescopes requires studying in more detail.

iSSA Website

EXOPLANET PROGRAM — About | Studies | News | Meetings/Events | Resources | Technology | NExScI | ExoPAG | Outreach Site

In-Space Servicing and Assembly



Above: Concepts for servicing and in-space assembly of future large space telescopes. Left: Deep Space cis-Lunar Gateway (NASA). Center: Polidan et al (2016) Evolvable Space Telescope. Right: Lee et al. (2016)

https://exoplanets.nasa.gov/exep/technology/in-space-assembly

Acknowledgments

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