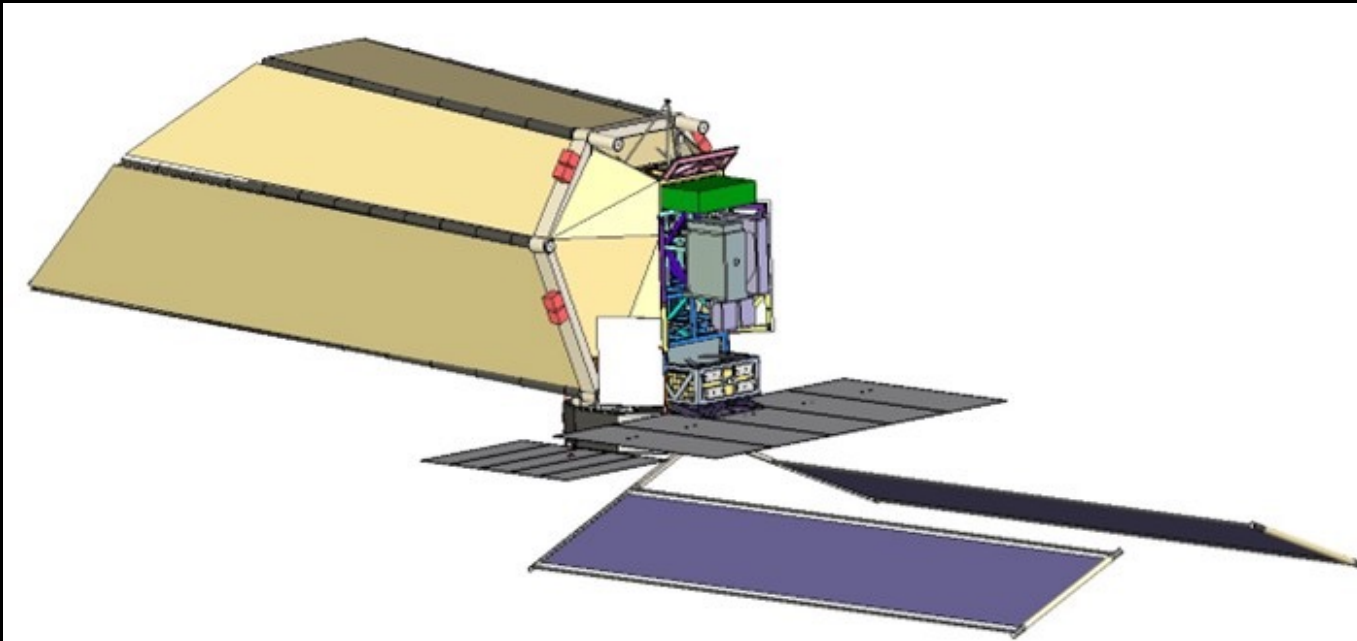
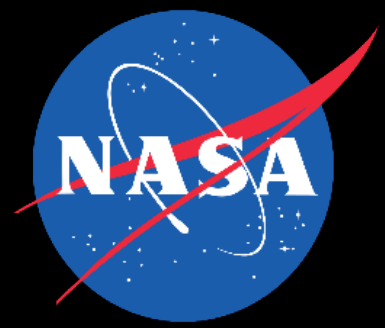


Concepts for servicing Habitable Worlds Observatory



Pioneering Sustainable Observatories
Summer 2024 Workshop Exploring
Servicing Capabilities for the Habitable
Worlds Observatory

College Park, MD
August 7-8, 2024

Notional thoughts for discussion purposes only!

Bo Naasz

NASA ISAM and RPOC System Capability Lead

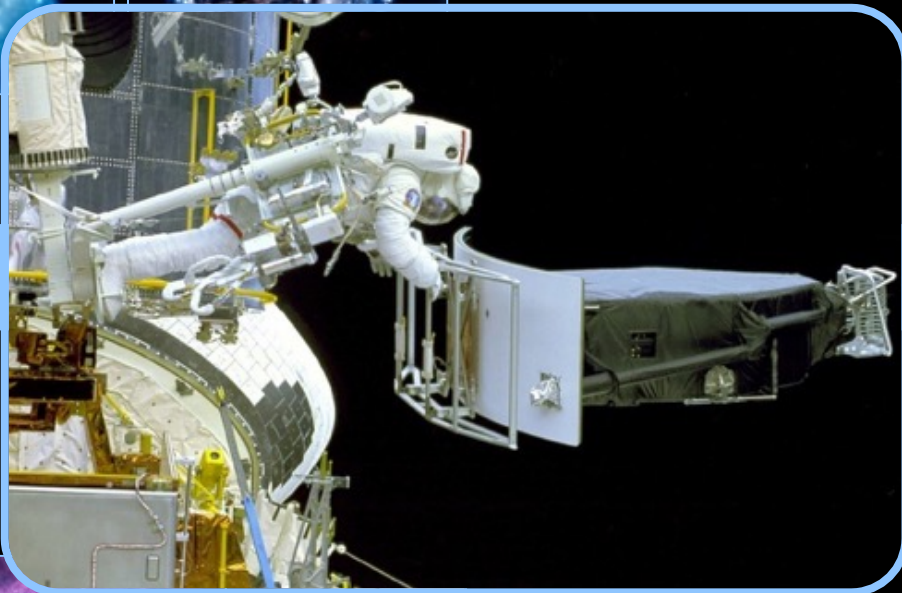
In-space Servicing Assembly and Manufacturing (ISAM)
Rendezvous Proximity Operations and Capture (RPOC)

Why Service Great Observatories?

Rescue



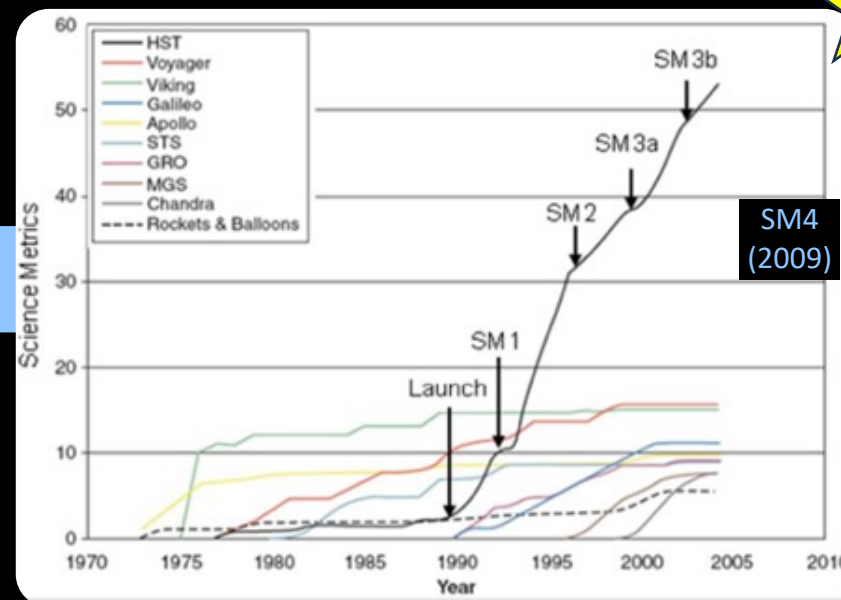
Upgrade



Extend



Cumulative Science contributions of the ten most productive NASA programs over time



The Nobel Prize in Physics 2011

Adam G. Riess
Prize motivation: “for the discovery of the accelerating expansion of the Universe through observations of distant supernovae”

“I thank the men and women who have helped make the Hubble Space Telescope the premier scientific instrument of our time and the astronauts who risked their lives to maintain it”

“My Path To The Accelerating Universe – Nobel Lecture”
Adam G. Riess, Stockholm, December 8, 2011

<https://www.nobelprize.org/prizes/physics/2011/riess/lecture/>

“The Science News Metrics” Carol A. Christian, Greg Davidson, October 2006, DOI: [10.1007/1-4020-4056-3_11](https://doi.org/10.1007/1-4020-4056-3_11) and

“Determining the Value of On-Orbit Telescope Servicing”, Zach Bailey, FISO Colloquium June 3, 2009, <http://fiso.spiritastro.net/archivelist.htm>

Great Observatory Servicing Value Proposition



Servicing must provide one or more of these values over new Observatory flight

- **Increase performance and science cadence**
 - New cutting-edge instruments
 - Instrument development and delivery time sets critical path for innovation (not funding profiles to build a new observatory)
 - **New world class science every ~5 years as opposed to every two decades**
- **Reduce risk**
 - Risk of servicing mostly retired by ISS RPOD and robotics operations
 - Almost 600 RPOD events historically, very few failures
 - Thousands of hours (?) of ground controlled robotic operations
 - Planned robotic servicing provides greater flexibility and mitigation options for issues / anomalies discovered late in development or post launch
- **Reduce cost**
 - Cost of new instrument delivery and installation a fraction of the cost of building a new Observatory
 - Additional launches provides opportunity to reduce the correlation between mass and cost (eg, less need for lightweighting 2nd generation instruments)
- **Goal: Enable more frequent upgrades to science capability with an upgrade mission total cost << less initial observatory launch**

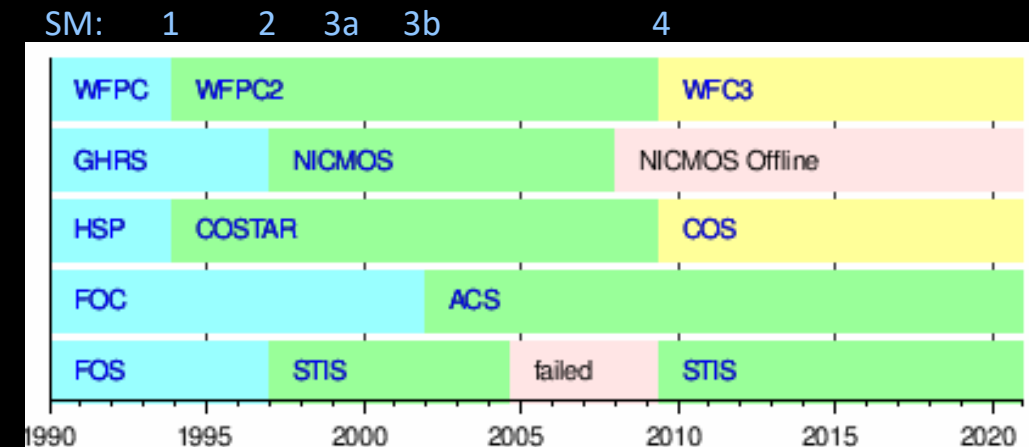
Challenges

- Cost of infrastructure cannot be borne by a single user
- Robotics systems are still very expensive – need commercial applications
- Lack of other users in deep space – Gateway, HLS, other Observatories coming
- HWO servicing will compete with other science objectives, how to address “gaps in panchromatic coverage”? Consider interoperability for upgrade of multiple SE-L2 observatories to enable more frequent advances across the spectrum

Observatory	Endorsement	Launch	Development (years)	Cost at time of Launch	2019 Cost
<i>Hubble (LST)</i>	1972	1990	18	\$4.7B	\$9.2B
<i>Compton (GRO)</i>	1977	1991	14	\$0.6B	\$1.2B
<i>Chandra (AXAF)</i>	1982	1999	17	\$1.9B	\$3.0B
<i>Spitzer (SIRTF)</i>	1991/92	2003	11	\$0.7B	\$1.0B

Table 3.2. NASA's Great Observatories: Timescales & Costs. The inflation-adjusted 2019 cost of each mission has only been roughly estimated using the average Consumer Price Index for each calendar year since the mission's launch. Costs for Chandra (AXAF) and Spitzer (SIRTF), respectively, are courtesy R. Holcombe and M. Werner (pvt. comm.). Note that although SIRTF was formally top-ranked in the 1991 Decadal Survey, it was canceled later that same year, and restarted in 1992 (Rieke 2006). The Hubble Space Telescope 2019 cost does not account for five subsequent servicing missions that have extended its mission beyond 30 years.

From “Great Observatories: The Past and Future of Panchromatic Astrophysics”, a report by the NASA Great Observatories Science Analysis Group, November 2020 (<https://arxiv.org/abs/2104.00023>)

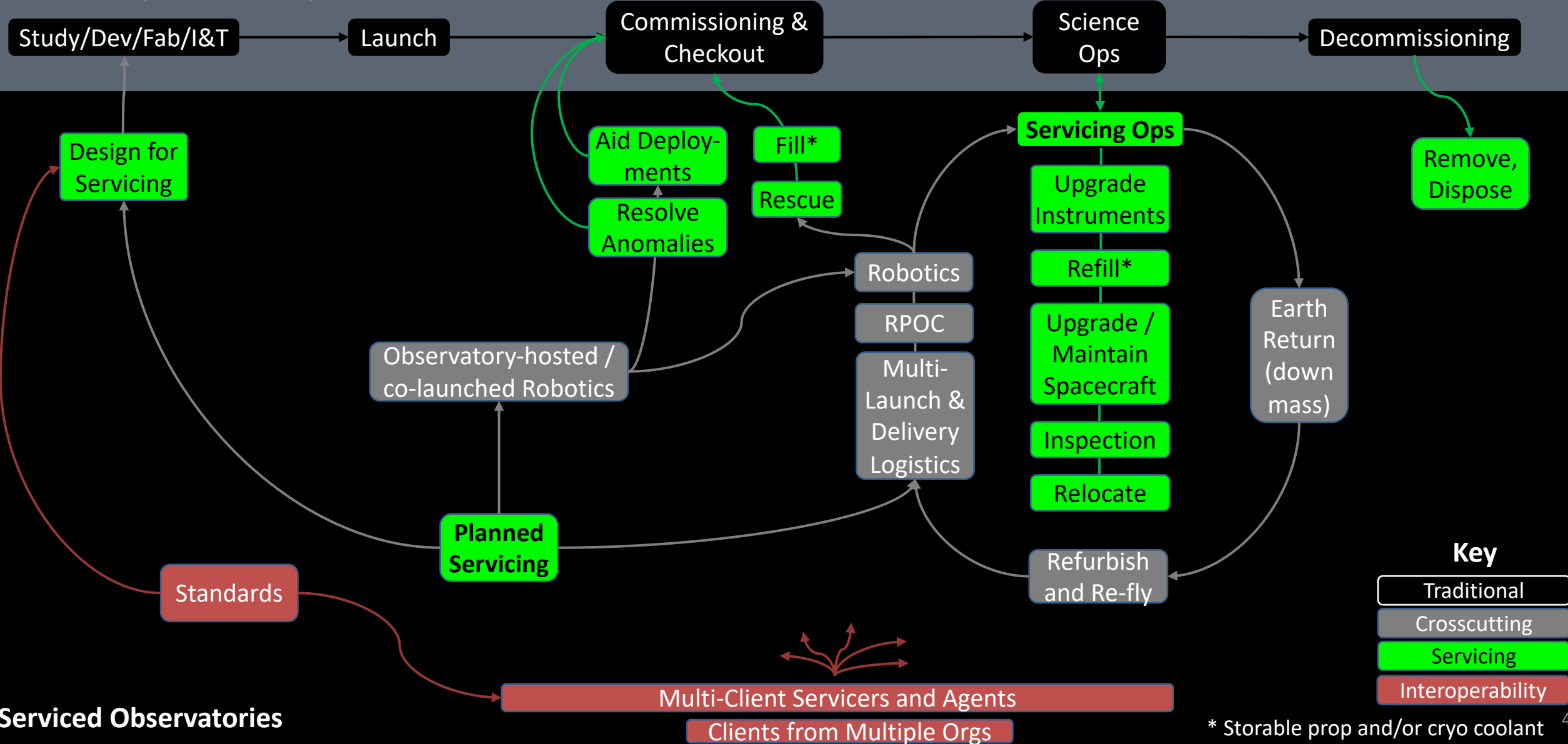


Timeline of the Hubble Space Telescope's instruments and their replacements during servicing missions. (Credit NASA)

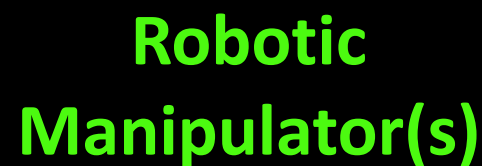


Great Observatory Servicing Scope Options

Traditional (non-serviced) Observatories



Visiting Vehicle(s)



- Relative Navigation Sensors (not shown)
- Docking and/or Berthing System (active half)
- Docking and/or Berthing Fixture (passive half)
- Robot Base (eg Low Profile Grapple Fixture)
- Robot Arm
 - Module grapple and manipulation fixture
- Free-flyer grapple fixture (not shown)
- Fluid Transfer interface (not shown)
- Module temp stowage location (not shown)

Servicing Architecture Options

(in approximate order of appearance)



- 1 – Servicing location
- 2 – Visiting Vehicle configuration and reuse
- 3 – Capture method
- 4 – Robotic manipulator hosted by Observatory, Visiting Vehicle, or both
- 5 – Robotic manipulator type
- 6 – Robotic manipulator size and quantity
- 7 – Observatory Spacecraft Bus level of modularity
- 8 – Servicing Scope and order of operations
- 9 – Frequency, and cadence of servicing operations
- 10 – Instrument bay closeout
- 11 – Instrument module thermal interfaces
- 12 – Instrument power and data interfaces
- 13 – Instruments modularity
- 14 – Visiting Vehicle trajectory
- 15 – Vehicle designated as active GNC for RPOC, and active mechanism for capture
- 16 – RPO approach trajectory
- 17 – Approach & Capture axis (docking/berthing mechanism location on Observatory)
- 18 – Instrument (or other) module temporary stowage
- 19 – Refueling interface type, mating process, and transferred commodities

...

- These marks throughout this presentation refer to this (very much in-work) list of implementation options

Notional Servicing Architecture Elements



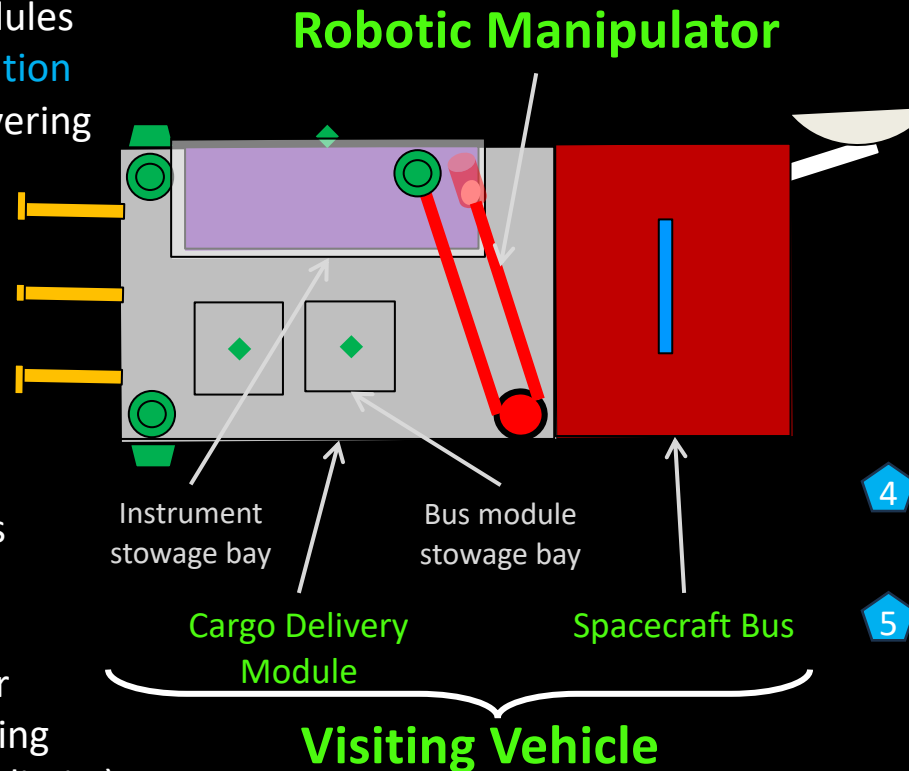
Visiting Vehicle

Functions

- 1 • Transfer, delivery of replacement modules and commodities to the **servicing location**
- Relative navigation and 6DOF maneuvering as required for **Sun-Earth L_2** RPOC
- Stowage and accommodations for replacement modules during transit from launch to pre-installation
- 18 • Module **temporary stowage** during servicing
- Stowage for disposal operations
- Delivery and/or operational interfaces for the robotic manipulation system
- Fluid delivery, and transfer system
- 3 • **Capture method:** grapple and berth or a direct docking system (existing docking systems may exceed observatory load limits)

Configurations

- 2 • **Single use or reusable**
- Tug or tender for in-space transfer and RPOD
- Could include Earth return for refurb and relaunch of observatory modules or flight support



Key:	
	Relative Navigation Sensors (not shown)
	Docking and/or Berthing System (active half)
	Docking and/or Berthing Fixture (passive half)
	Robot Base (eg Low Profile Grapple Fixture)
	Robot Arm
	Module grapple and manipulation fixture
	Free-flyer grapple fixture (not shown)
	Fluid Transfer interface (not shown)
	Module temp stowage location (not shown)

Robotic Manipulation System

Functions

- Reposition delivered replacement modules from storage on logistics vehicle to mating envelope on the observatory (and temp stow locations if required)
- Capture and Berth of Observatory to Visiting Vehicle (if method is robotic grapple)
- Assisted deployments (planned or unplanned)

Configurations

- 4 • **Robotic manipulator host** could be observatory, visiting vehicle, or both
- 5 • **Robotic manipulator type** could include **mobility**, or “inch-worming” capability
 - increase operational and programmatic flexibility (add arm re-use and replacement options)
 - reduce arm length at the cost of multiple base stations (eg LPGF for Gateway’s Canadarm 3)
- 6 • **Multiple or longer dedicated arms** to provide necessary reach and access to stowage bays on logistics vehicle and observatory

Notional Observatory Elements

Observatory

4
6
5

- Could launch with and /or **host** the robotic manipulation system(s), and/or, if a **mobile robot** is used, include base stations from which the robot could operate (cartoon below shows an option with bases on both elements)

Telescope Assembly

Servicing accommodations

10

- Instrument bays with, at a minimum, mechanical, electrical and data interfaces
- Instrument mechanical interfaces include robotic manipulation fixtures, course alignment guides, precision latches
- **Instrument bay closeout approach** to minimize contamination and stray light while permitting instrument change out (likely a mechanical door)

11

- **Instrument module thermal interfaces** large dedicated radiators or a centralized approach requiring thermal interface mating during change out operations

12

- **Instrument power and data interfaces** historically (HST, ISS) via blind mate connector and wireless (data only, ISS) – note Roman Space Telescope challenges associated with high data rates (high pin count), and JWST challenges with instrument mechanical (jitter) and thermal isolation

13

- **Instruments modularity** traditionally full-instrument level, could be lower (sub-module, eg card-level) replacement, or augmentation via an external expansion port (or a combination of these.)

Observatory Bus

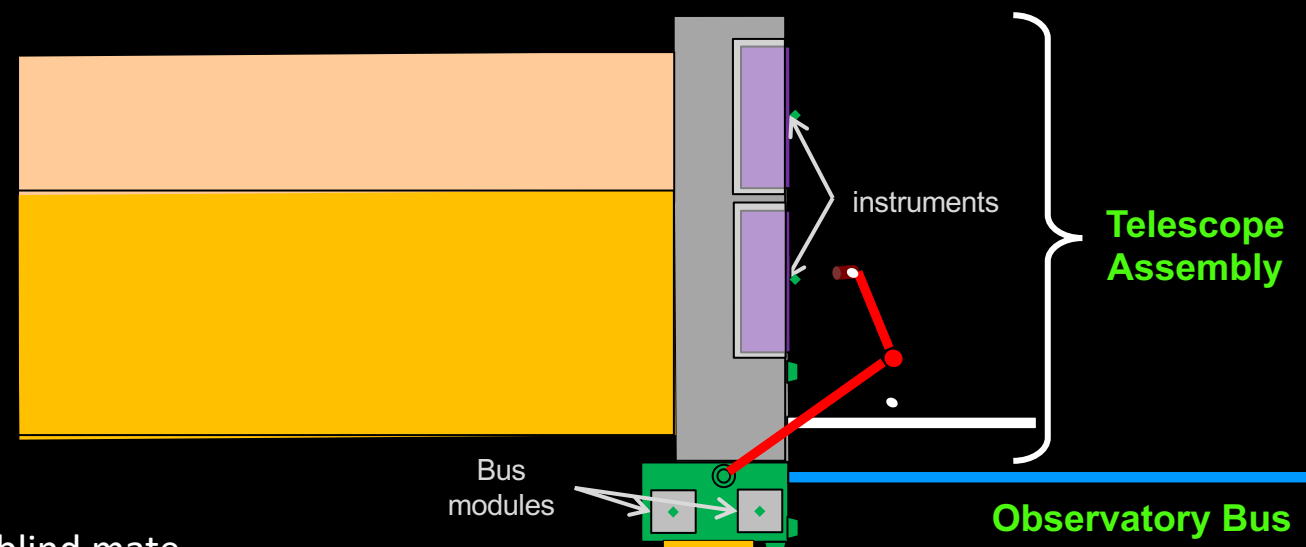
Servicing accommodations

7

- Swappable bus modules, at component, subsystem, or higher **level of modularity**

3

- Rendezvous and proximity operations fiducials
- **Capture** features (free-flyer grapple and berthing fixtures)
- Fluid transfer interfaces and refillable propulsion system
- Some of these could be mounted on the Telescope assembly



Key:

- Relative Navigation Sensors (not shown)
- Docking and/or Berthing System (active half)
- Docking and/or Berthing Fixture (passive half)
- Robot Base (eg Low Profile Grapple Fixture)
- Robot Arm
- Module grapple and manipulation fixture
- Free-flyer grapple fixture (not shown)
- Fluid Transfer interface (not shown)
- Module temp stowage location (not shown)

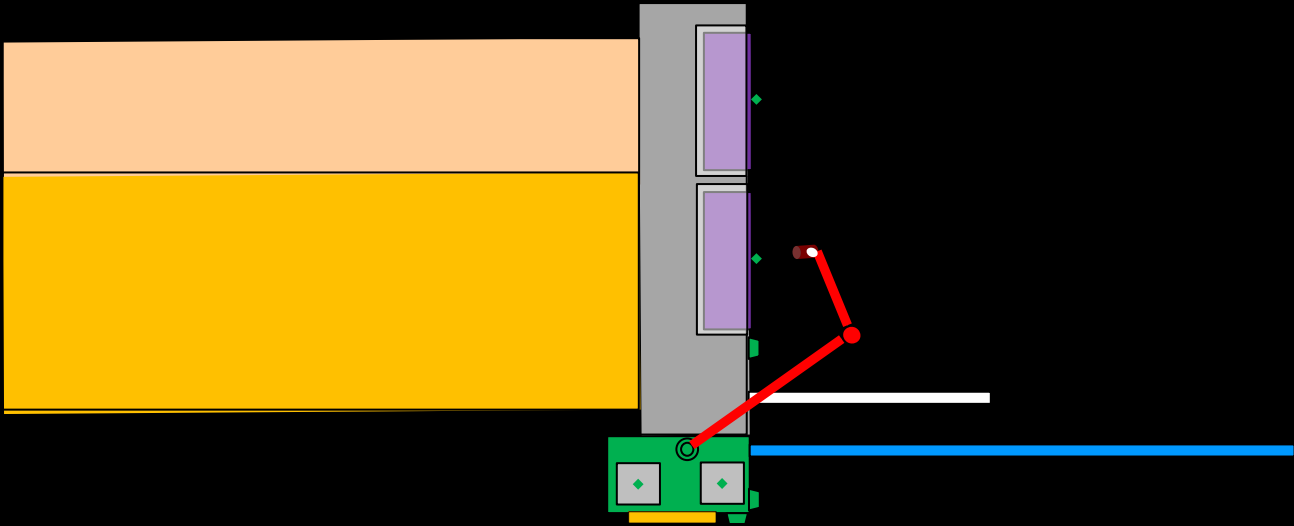
Notional Mission Phases



Observatory

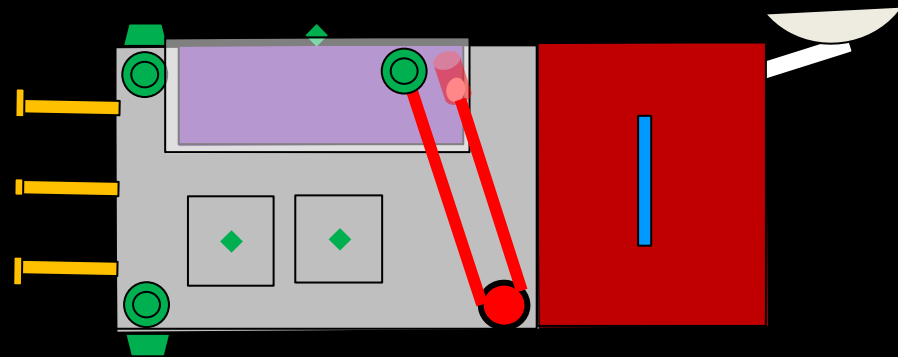
9
Repeat
n times

Mission Phase	Duration
Launch and Commiss.	weeks
Science Ops (n)	years
Servicing Ops (n)	days
Post-Servicing Commiss.	days
Final Science Ops	years
Decommissioning	weeks



Visiting Vehicle

# Mission Phase	Duration
1 Launch and Commissioning	weeks
2 Transit to servicing orbit	months
3 Pre-rendezvous Preparation	days
4 Rendezvous, Proximity Operations and Capture	days
5 Observatory Servicing	days
5a* - Propulsion System	
5b* - Instrument ORU Changeout	
5c* - Bus ORU Changeout	
5d* - Other Services (relocate, inspect)	
6 Release and Departure	days
7 Decommissioning / parking or other 2	days



2 This example assumes servicer is single use -
Alternative option: reusable tug and/or tender

8 *order and scope of mated servicing operations is TBD

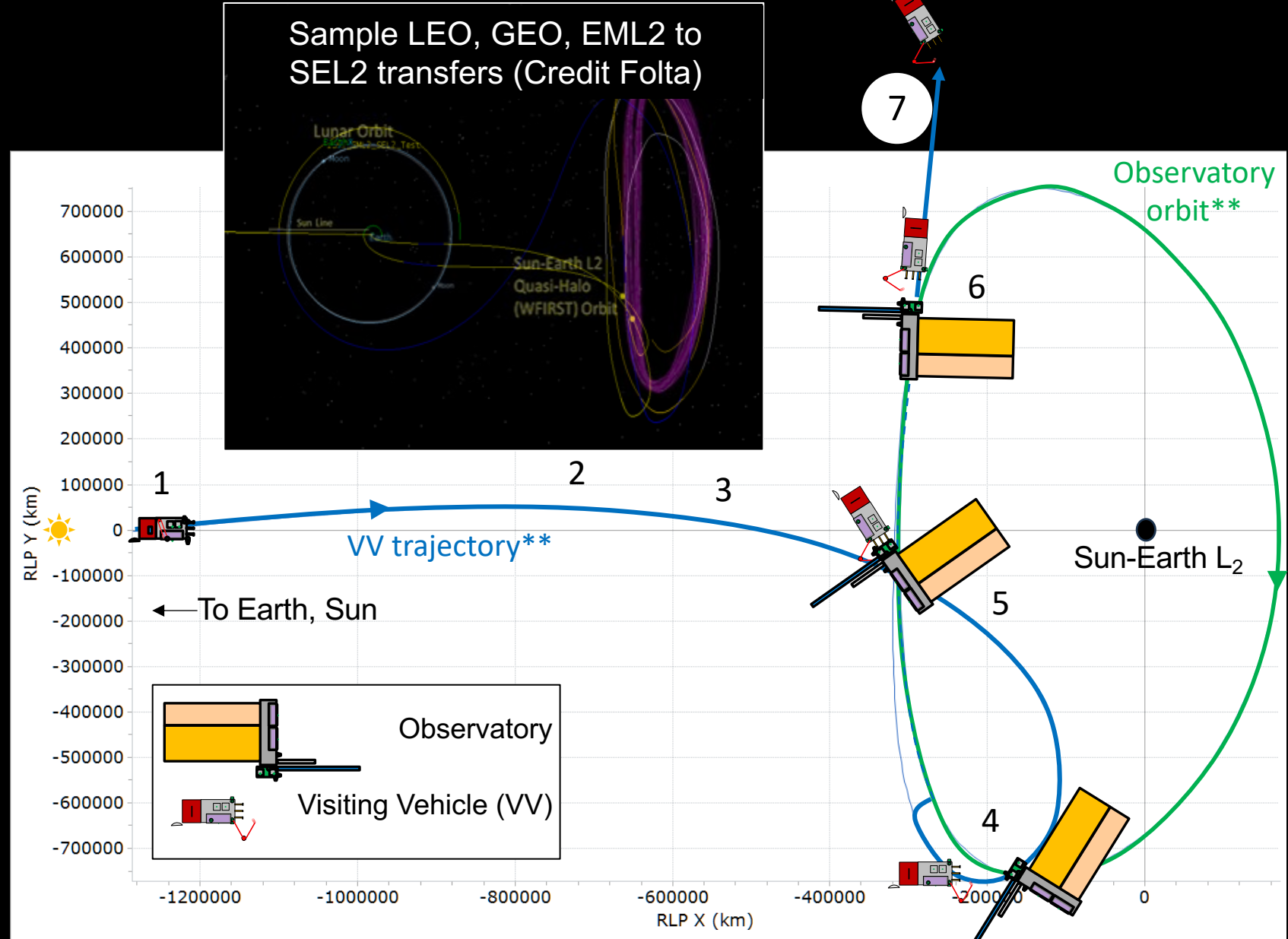
Visiting Vehicle (VV) Launch and transfer to Servicing Orbit



Options:

- 1 • Servicing in HWO operational orbit at SE-L2 shown (alternative options: HWO maneuvers to separate servicing orbit in cislunar or SE-L2 space)
- 14 • Visiting Vehicle direct transfer to SE-L2 servicing orbit (alternative option: transfer via cislunar space or other). Slow transfer shown (~6 months); What faster transfer options are possible?
- 15 • Visiting Vehicle is active GNC during RPO

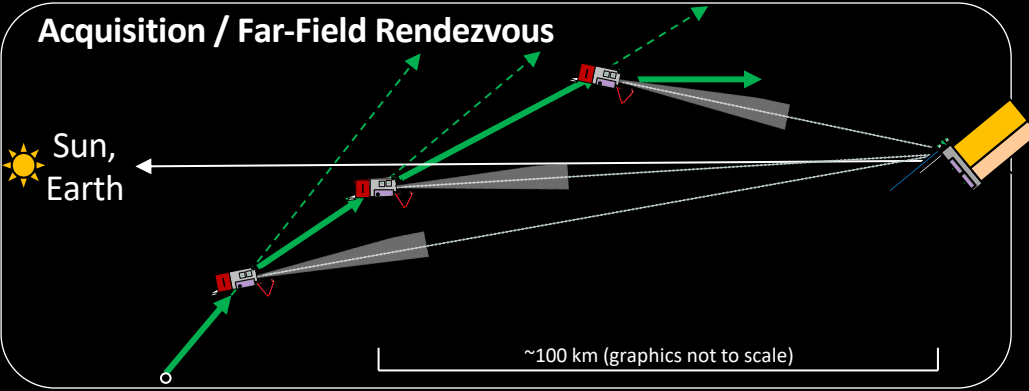
#	Phase Name
1	VV Launch and Commiss.
2	Transit to servicing orbit
3	Pre-rendezvous Preparation
4	Rendez, Capture, and Berth
5	Servicing
6	Release and Departure
7	Decommissioning



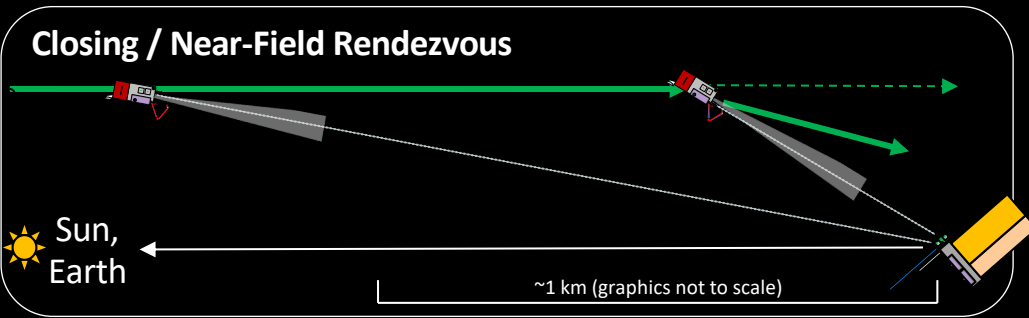
** trajectory for illustrative purposes only

Rendezvous and Proximity Operations

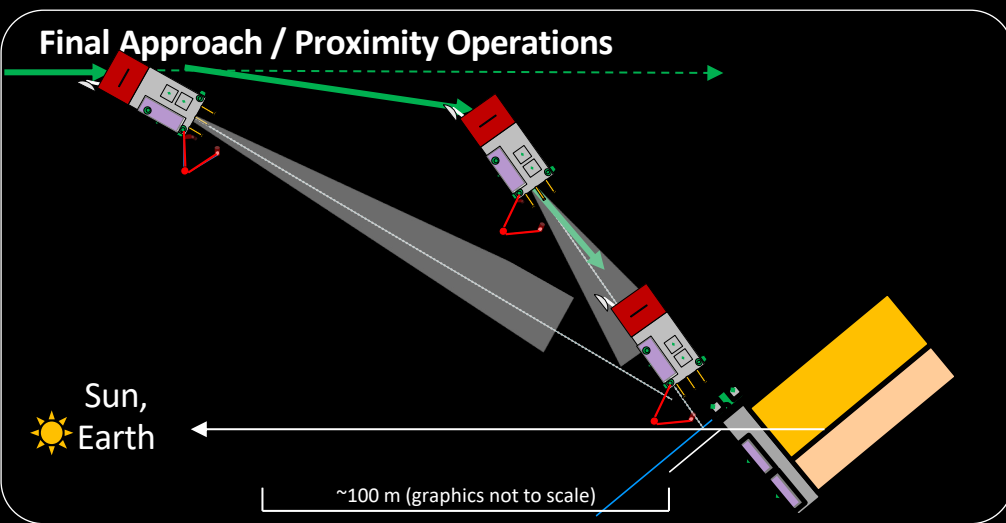
Acquisition / Far-Field Rendezvous



Closing / Near-Field Rendezvous



Final Approach / Proximity Operations



Observatory fixed frames

Approach & Capture Axis

17

Sun, Earth

16

Notional Deep Space RPO Approach like Orion (ref Woffinden et al, AAS 18-142)

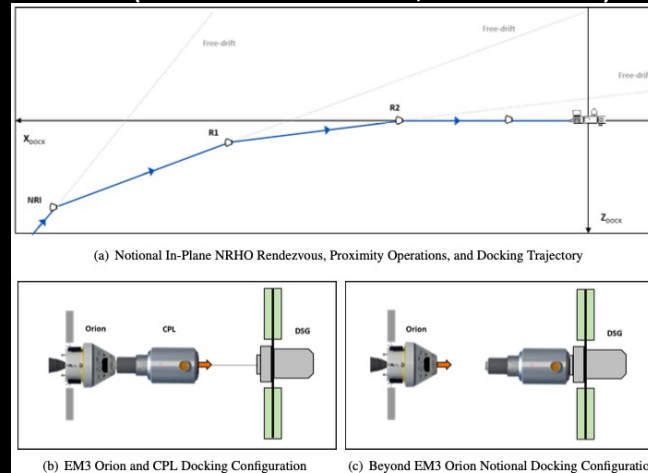
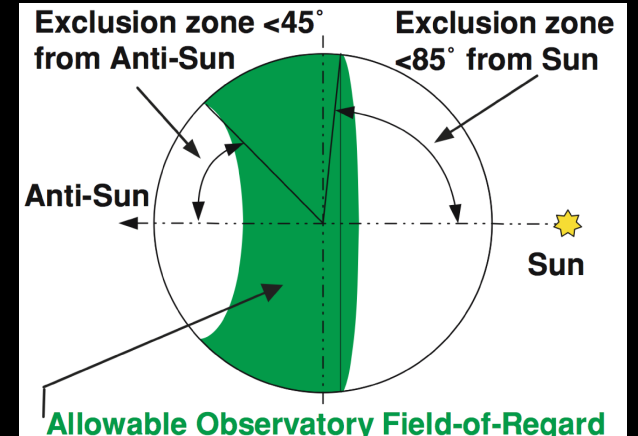


Figure 3. Notional EM-3 NRHO Proximity Operations and Docking Concepts

JWST allowable attitudes for reference (note sun direction is mirrored below)



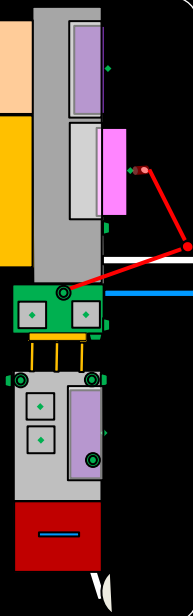
Notional Observatory Servicing (Instrument Module Changeout)



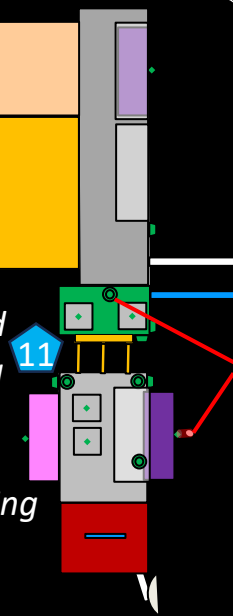
Notional sequences for discussions purposes. Several required steps not shown

Single long arm

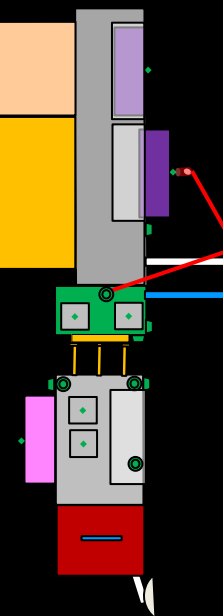
i. Observatory or robot opens **instrument closeout door** (not shown). Arm removes old instrument from Observatory.



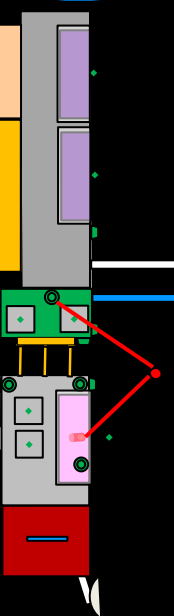
ii. Arm **temp stows** old instrument on Visiting Vehicle (not shown), removes new instrument from Visiting Vehicle (VV) stowage bay



iii. Install new instrument in Observatory

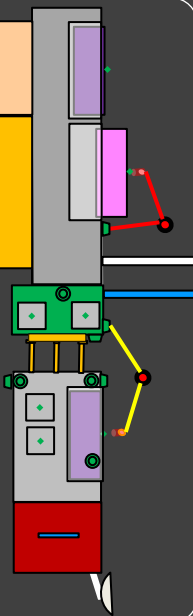


iv. Stow old instrument in Visiting Vehicle instrument stowage bay for disposal

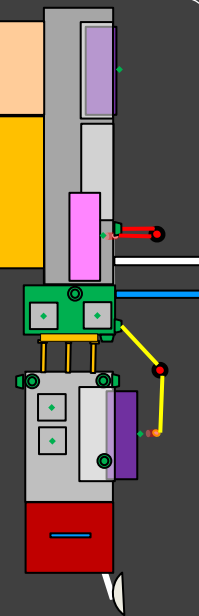


Two mobile arms

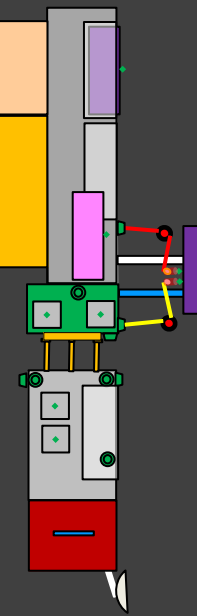
i. Arms **inchworm** to instrument changeout base stations. **Arm 1** removes old instrument from Observatory. **Arm 2** prepares to extract new instrument from VV



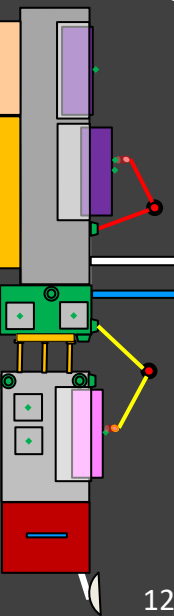
ii. **Arm 1 temp stows** old instrument on observatory, **Arm 2** removes new instrument from Visiting Vehicle



iii. **Arm 2** hands off new instrument to **Arm 1**



iv. **Arm 1** installs new instrument in Observatory. **Arm 2** stows old instrument in Visiting Vehicle stowage bay

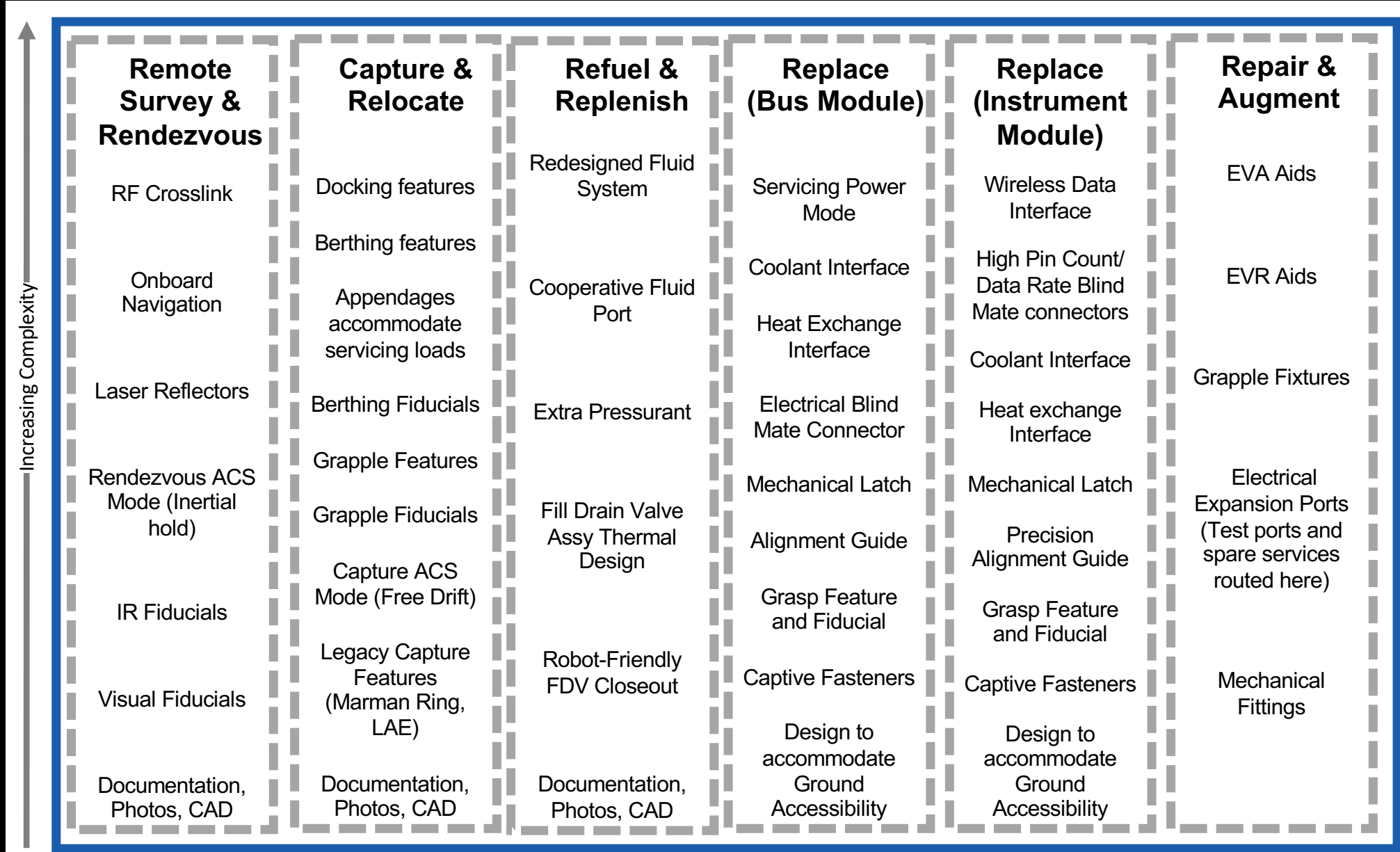




Observatory Servicing (continued)

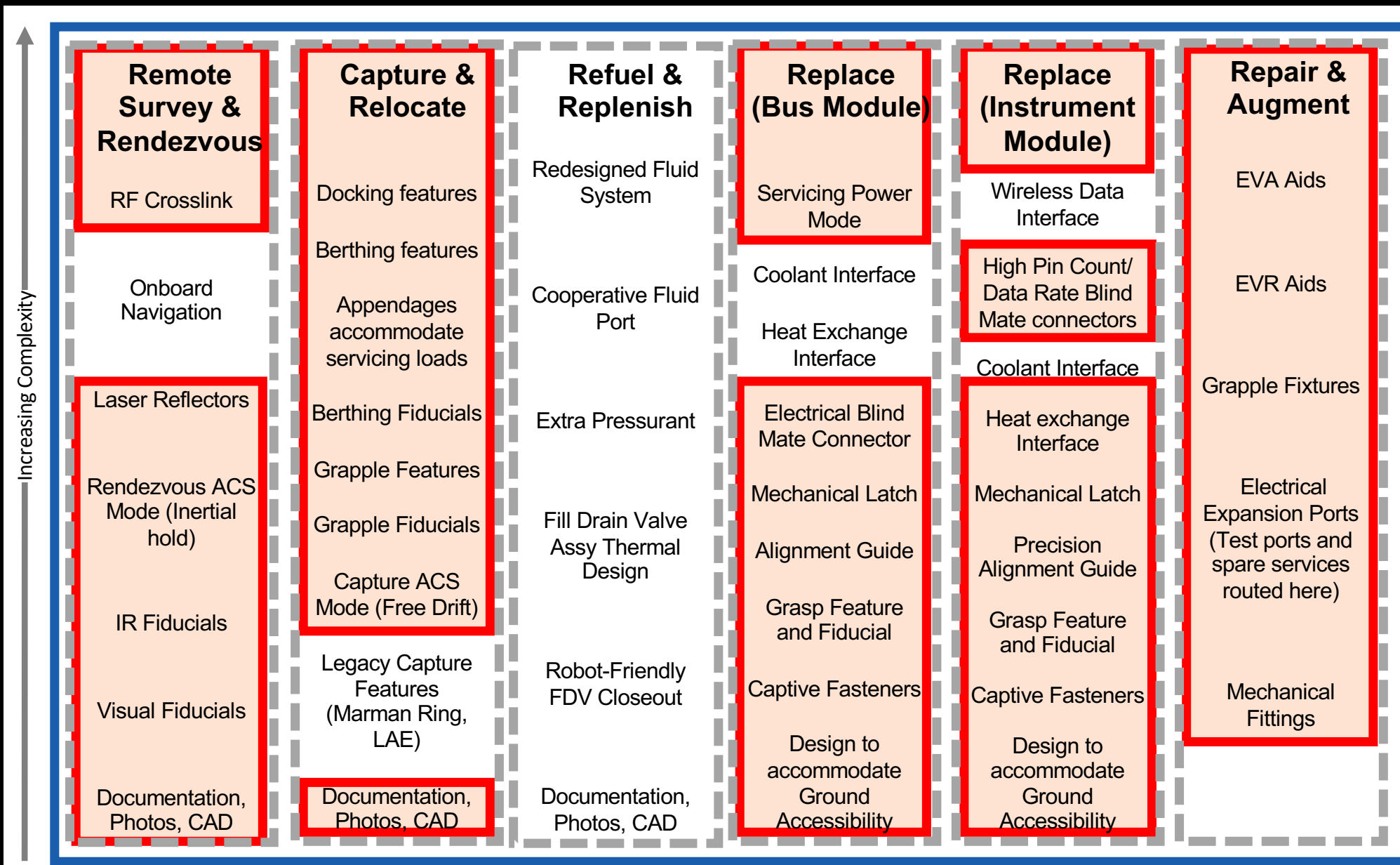
- Observatory **Propulsion System servicing options** 19
 - Key driver: Observatory design life, orbit maintenance and attitude control propellant requirements, **frequency and cadence of servicing operations** 9
 - Interface options
 - Fluid transfer via Docking/Berthing-aligned fluid coupler and mech (Mir, ISS, Gateway, others)
 - Fluid transfer via Robotic manipulator and fluid hose mated to cooperative servicing valve (OSAM-1, Roman)
 - New tank install or modular propulsion subsystem (including thrusters) replacement or augmentation (Mission Robotic Vehicle (MRV) Mission Extension Pods (MEPs))
 - Observatory propulsion subsystem design considerations
 - Launch load for full mission life vs partial load assuming later refueling
 - Propellant type – monoprop vs biprop vs electric prop vs mix
- Observatory **Spacecraft Bus servicing**
 - **Modularity options:** 7
 - Component-level ORU (HST and ISS)
 - Subsystem-level modules (Roman and others for expedited ground I&T)
 - Full spacecraft swap
- Other potential **servicing scope** 8
 - Inspection – pre and/or post servicing free-flying (remote) inspection, or mated robotic (close) inspection?
 - Relocation – Visiting Vehicle maneuvering of Observatory while mated (HST, Mir, ISS, Mission Extension Vehicle)

Cooperative Servicing Spectrum

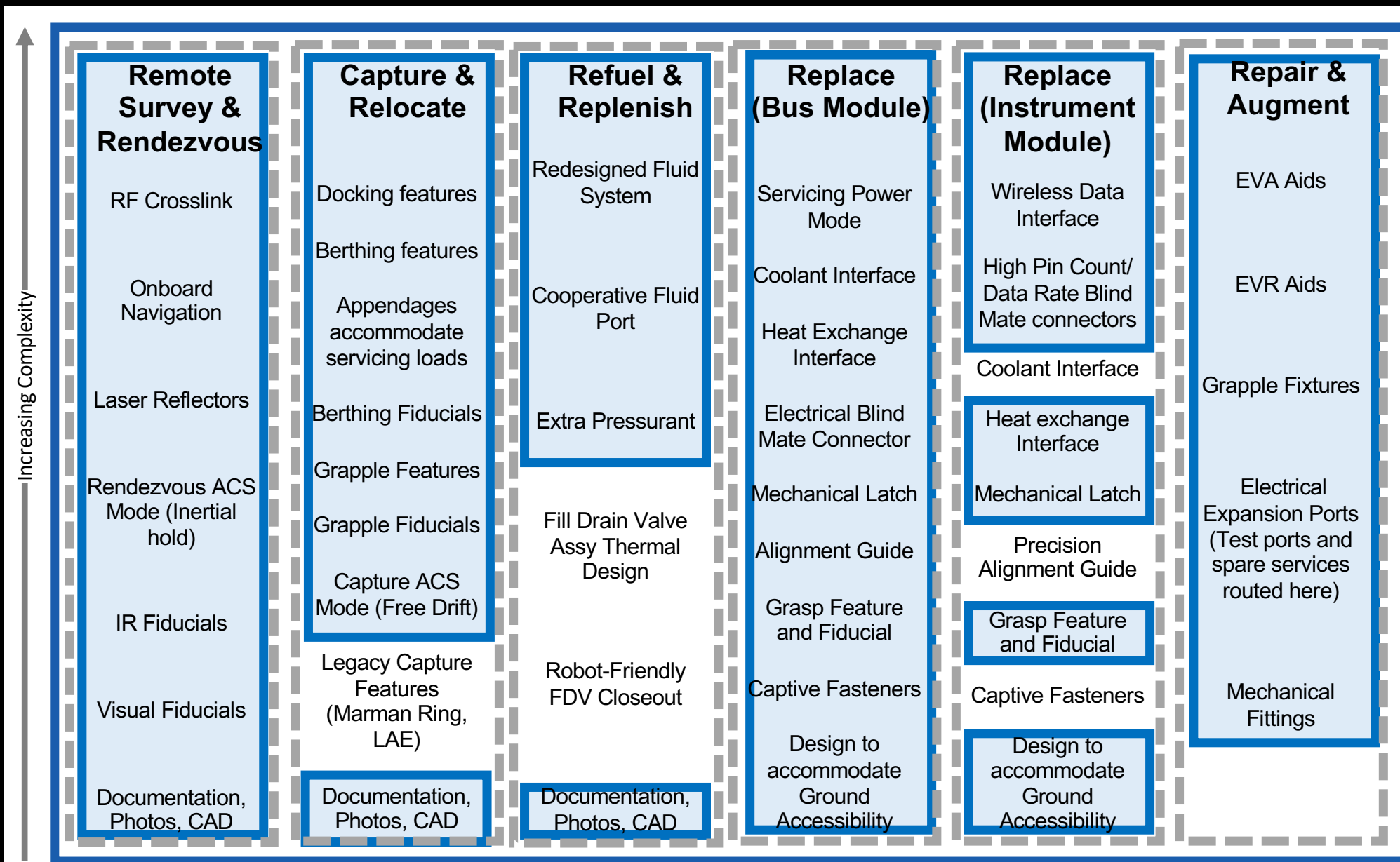


Cooperative Servicing Spectrum

Hubble

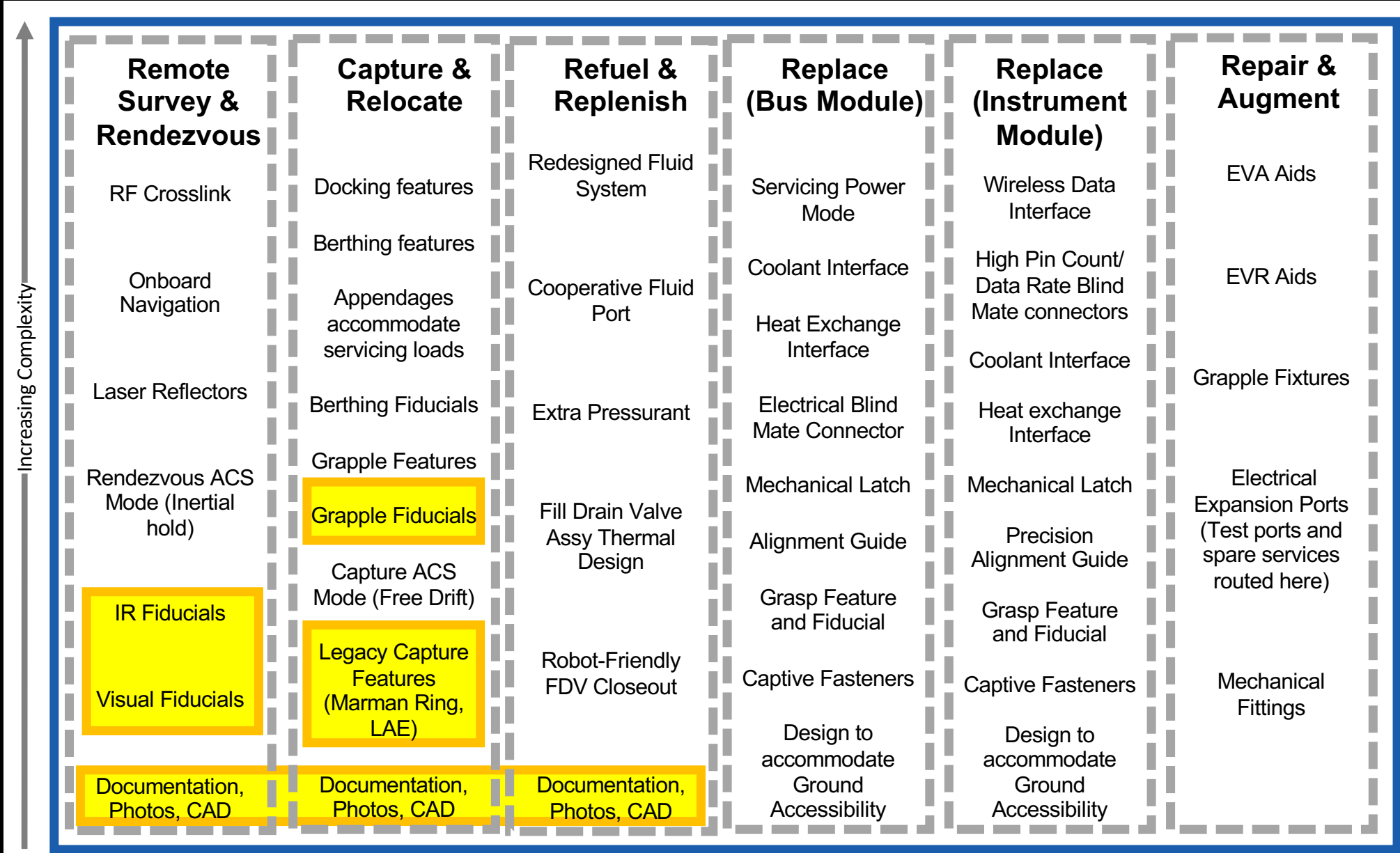


Cooperative Servicing Spectrum ISS



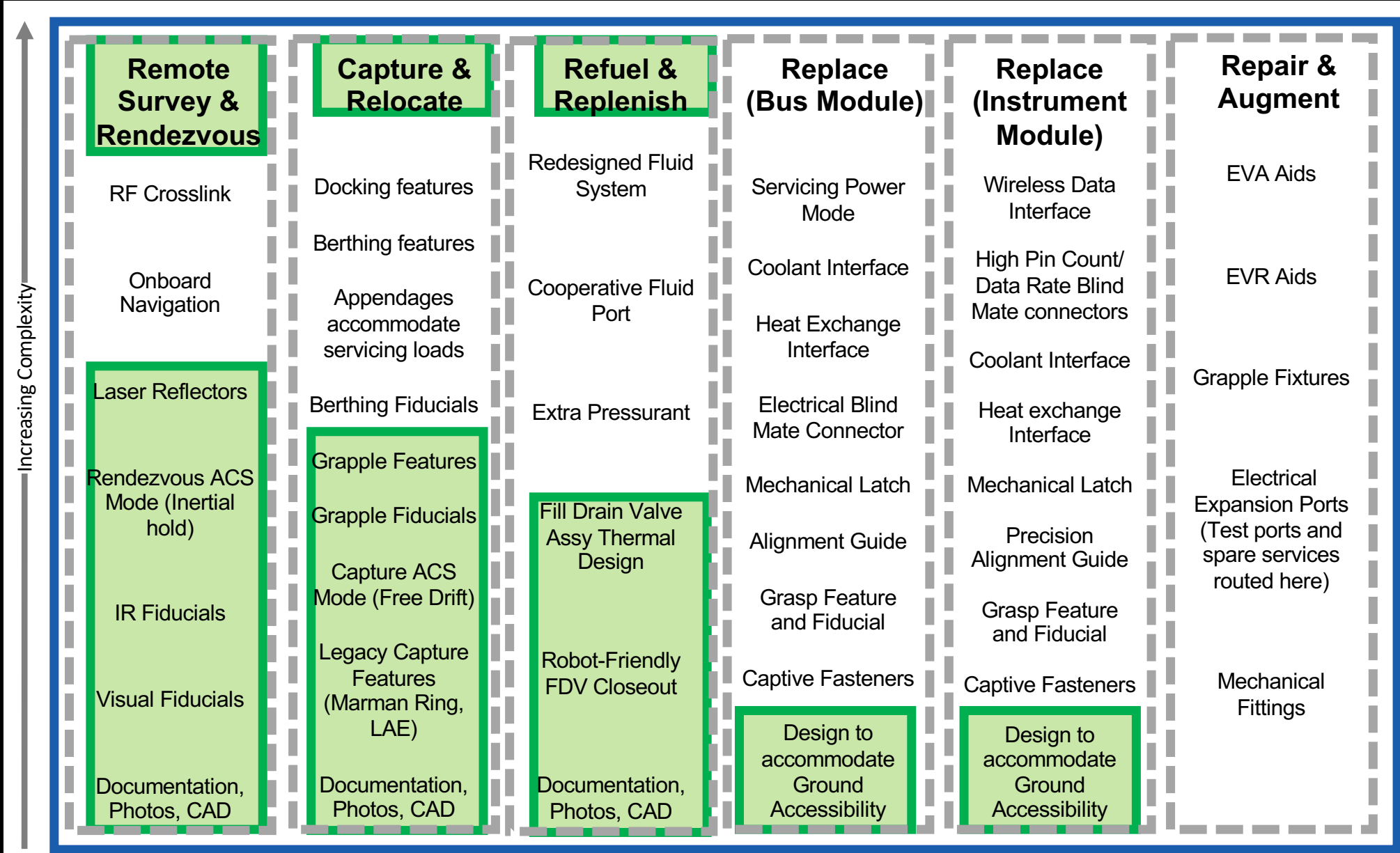
Cooperative Servicing Spectrum

JWST



Cooperative Servicing Spectrum

Roman Space Telescope



Cooperative Servicing Spectrum

Habitable Worlds Observatory

