National Aeronautics and
Space Administration

A Better Path to Habitable Worlds

A NEW APPROACH TO DEVELOP FLAGSHIPS

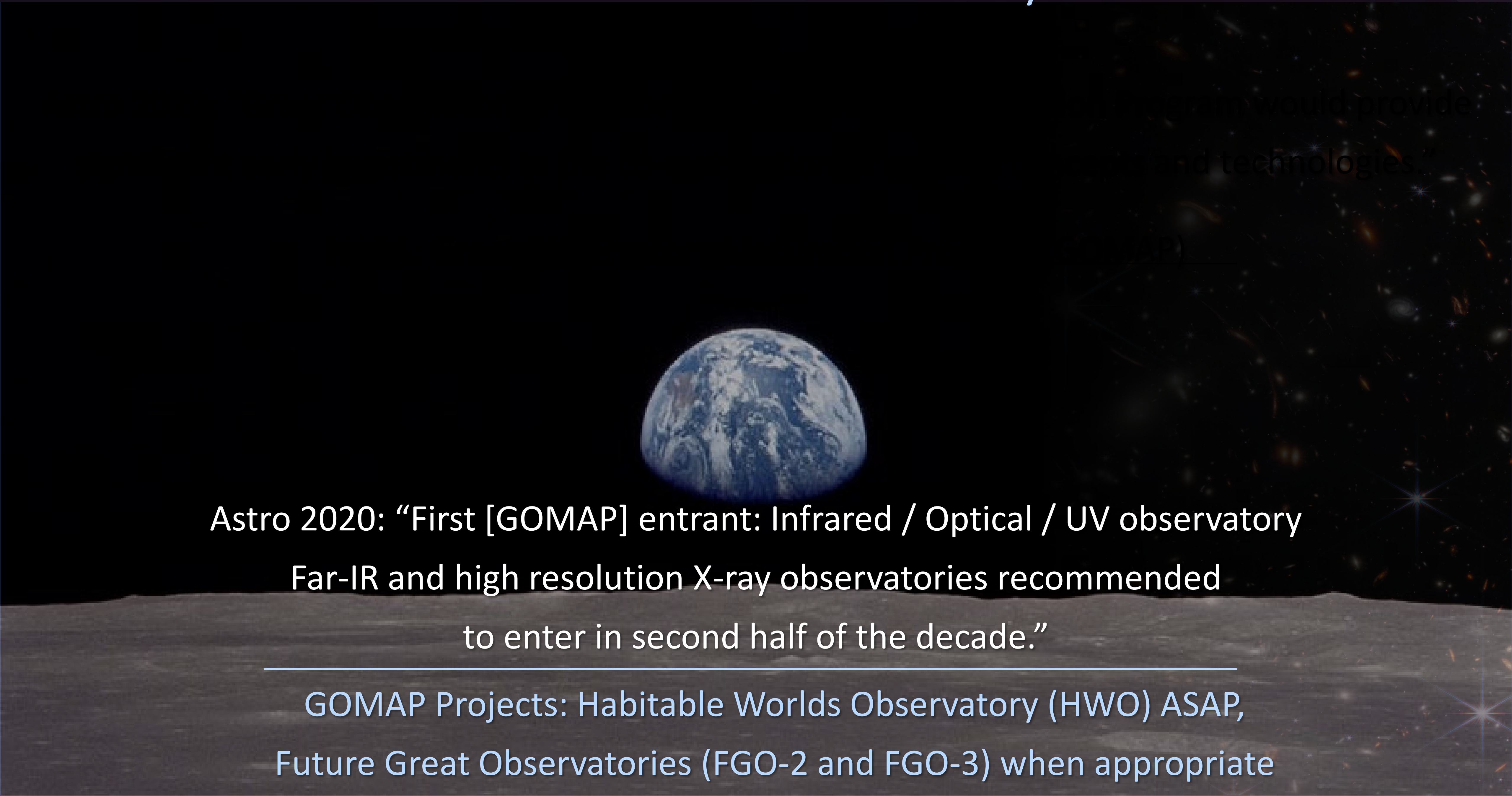
NASA Astrophysics Great Oservatory Maturation Program (GOMAP)
Program Executive: Julie Crooke (julie.a.crooke@nasa.gov)
Program Scientist: Shawn Domagal-Goldman(shawn.goldman@nasa.gov)
March 29, 2023

National Academies Astro2020 Decadal Survey

Astro 2020: “Great Observatories Mission and Technology Maturation Program would provide significant early investments in the co-maturation of mission concepts and technologies.”

NASA: Great Observatory Maturation Program (GOMAP)

National Academies Astro2020 Decadal Survey



Astro 2020: "First [GOMAP] entrant: Infrared / Optical / UV observatory

Far-IR and high resolution X-ray observatories recommended

to enter in second half of the decade."

GOMAP Projects: Habitable Worlds Observatory (HWO) ASAP,

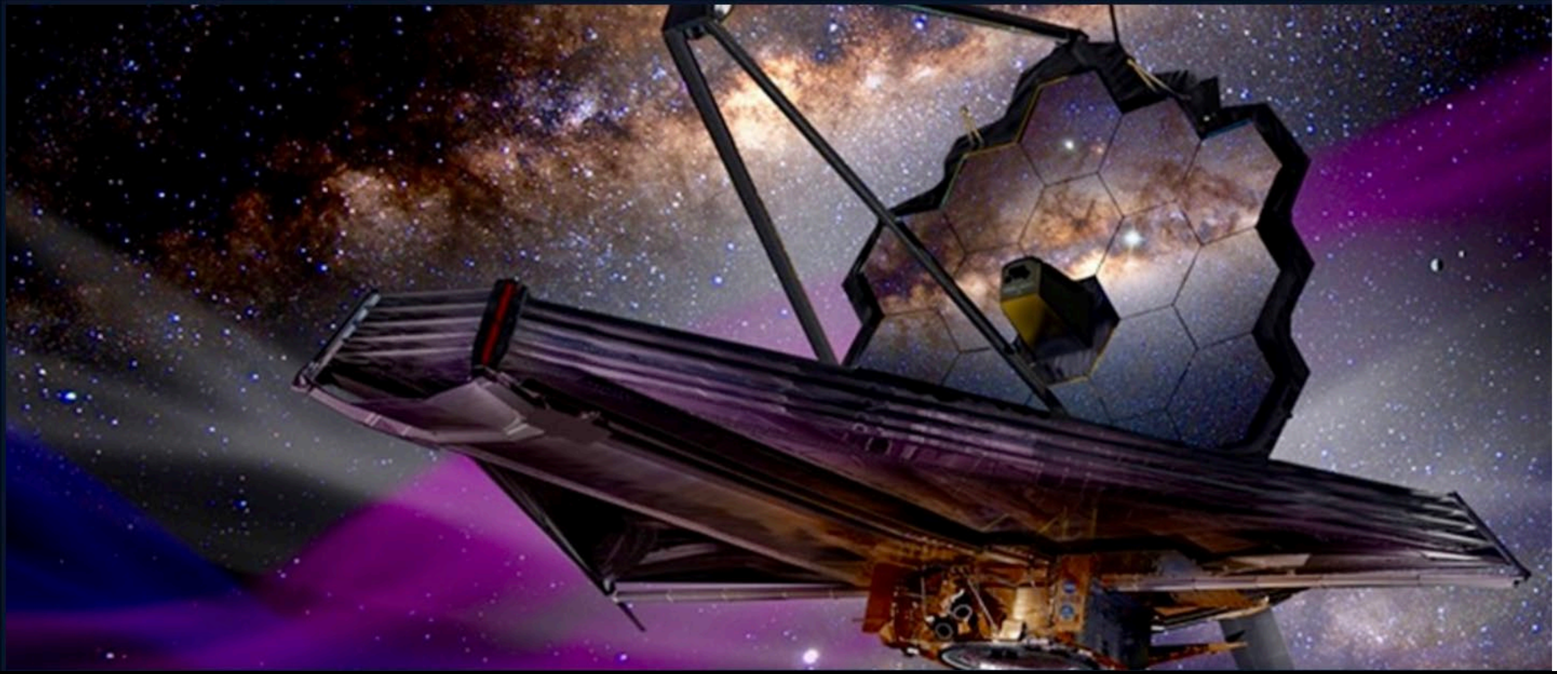
Future Great Observatories (FGO-2 and FGO-3) when appropriate

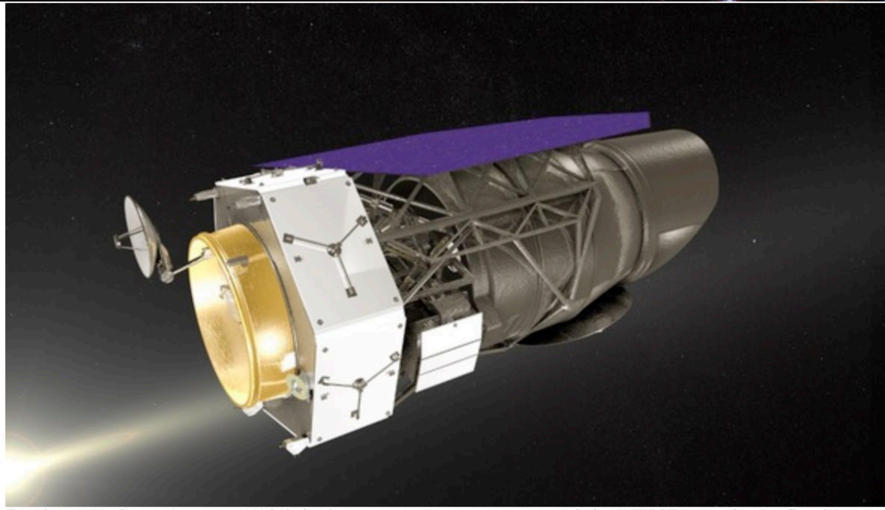
Why GOMAP?

JWST EXCEEDS COST CAP, LAUNCH DELAYED TO 2021

JUNE 28TH, 2018

1 Shares

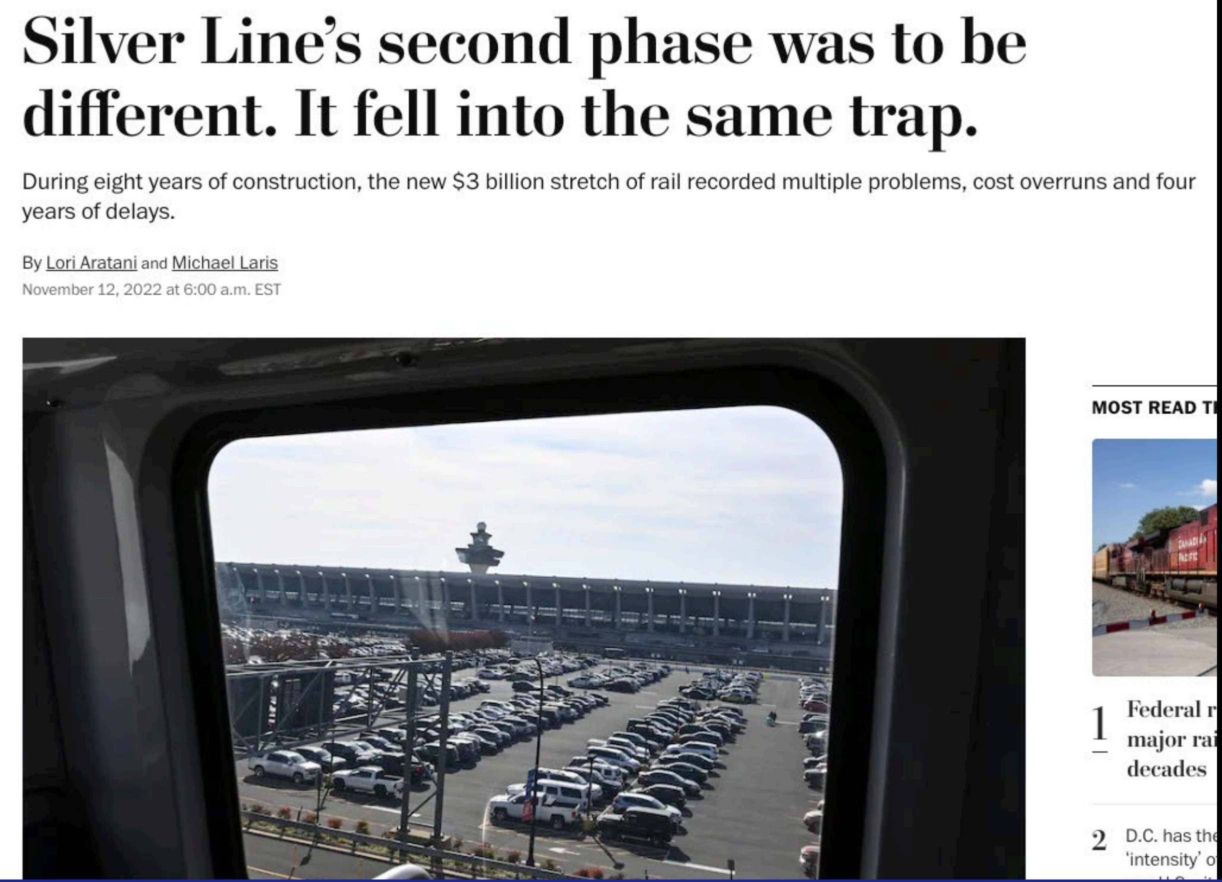




For the second year in a row, NASA's budget request proposes to cancel the WFIRST astrophysics flagship mission. (credit: NASA)

Cost challenges continue for NASA science missions

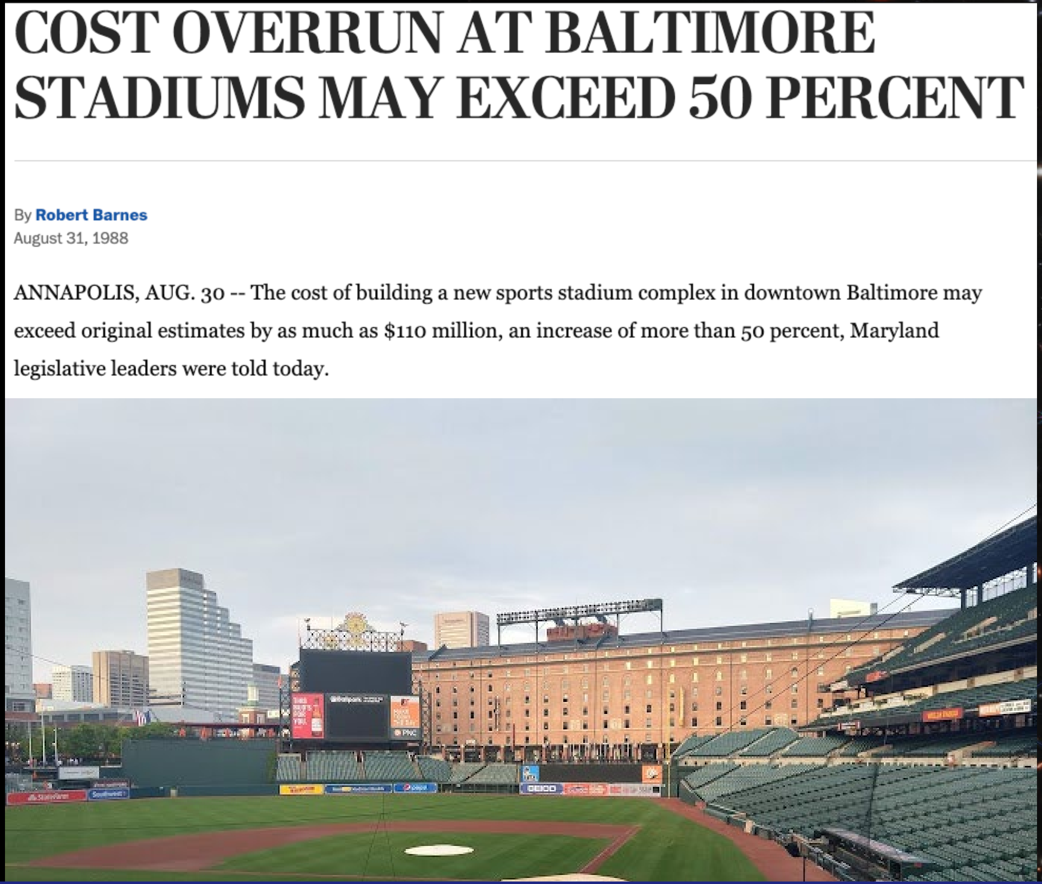
by Jeff Foust
Monday, March 25, 2019



Silver Line's second phase was to be different. It fell into the same trap.

During eight years of construction, the new $3 billion stretch of rail recorded multiple problems, cost overruns and four years of delays.

By Lori Aratani and Michael Laris
November 12, 2022 at 6:00 a.m. EST



COST OVERRUN AT BALTIMORE STADIUMS MAY EXCEED 50 PERCENT

By Robert Barnes
August 31, 1988

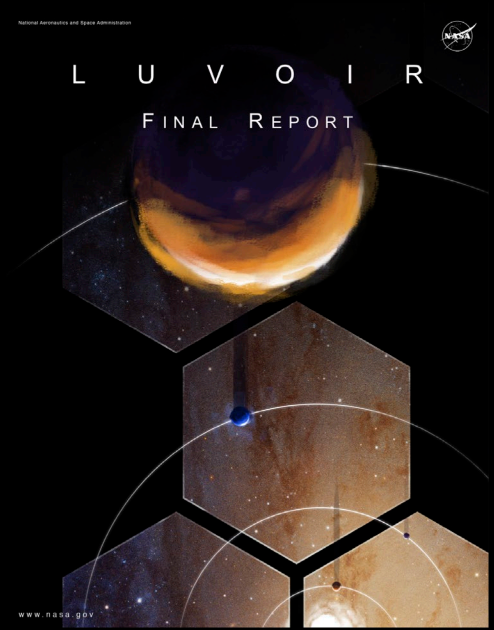
ANNAPOLIS, AUG. 30 -- The cost of building a new sports stadium complex in downtown Baltimore may exceed original estimates by as much as $110 million, an increase of more than 50 percent, Maryland legislative leaders were told today.

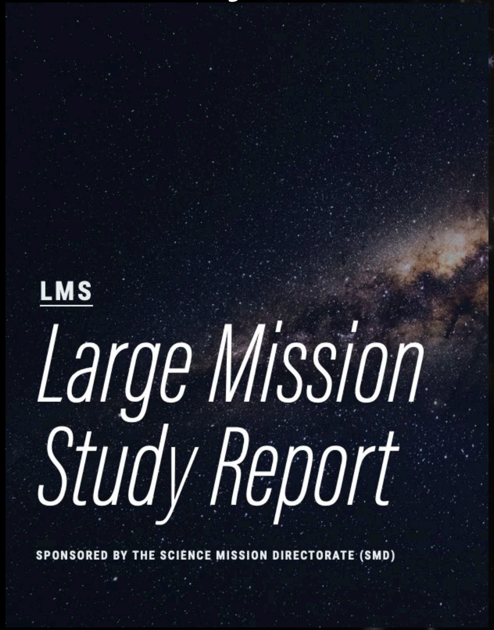
"From a database of more than 16,000 megaprojects from 20-plus different fields in 136 countries, only 0.5 percent are delivered on cost, on schedule, and with original stated benefits." **(Flyvbjerg, B., Gardner, D., "*How Big Things Get Done*" ©2023)**

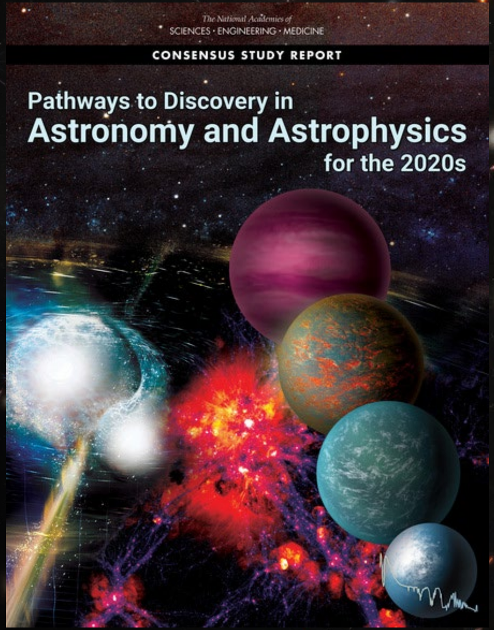
Why GOMAP? Decades of research-based consensus on megaprojects

Independent Research Papers	Mission Concept Reports	GAO Report on Major Projects	SMD Internal Study on Flagship Projects	National Academy Recommendations


Challenges and Potential Solutions to Develop and Fund NASA Flagship Missions



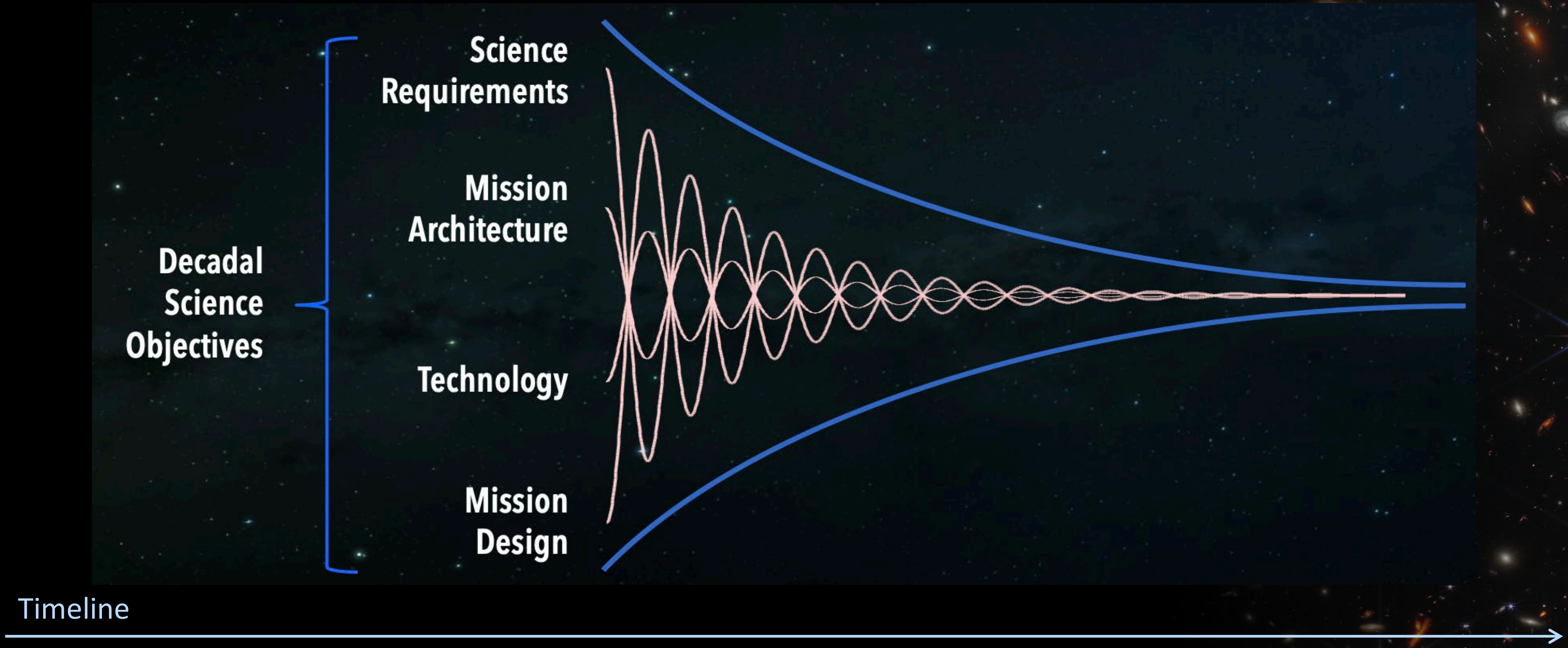




A variety of documents from internal, external, and oversight groups all point to a consistent set of problems & solutions for large/flagship projects, across sectors

How Do Complex Things Get Done On Time?

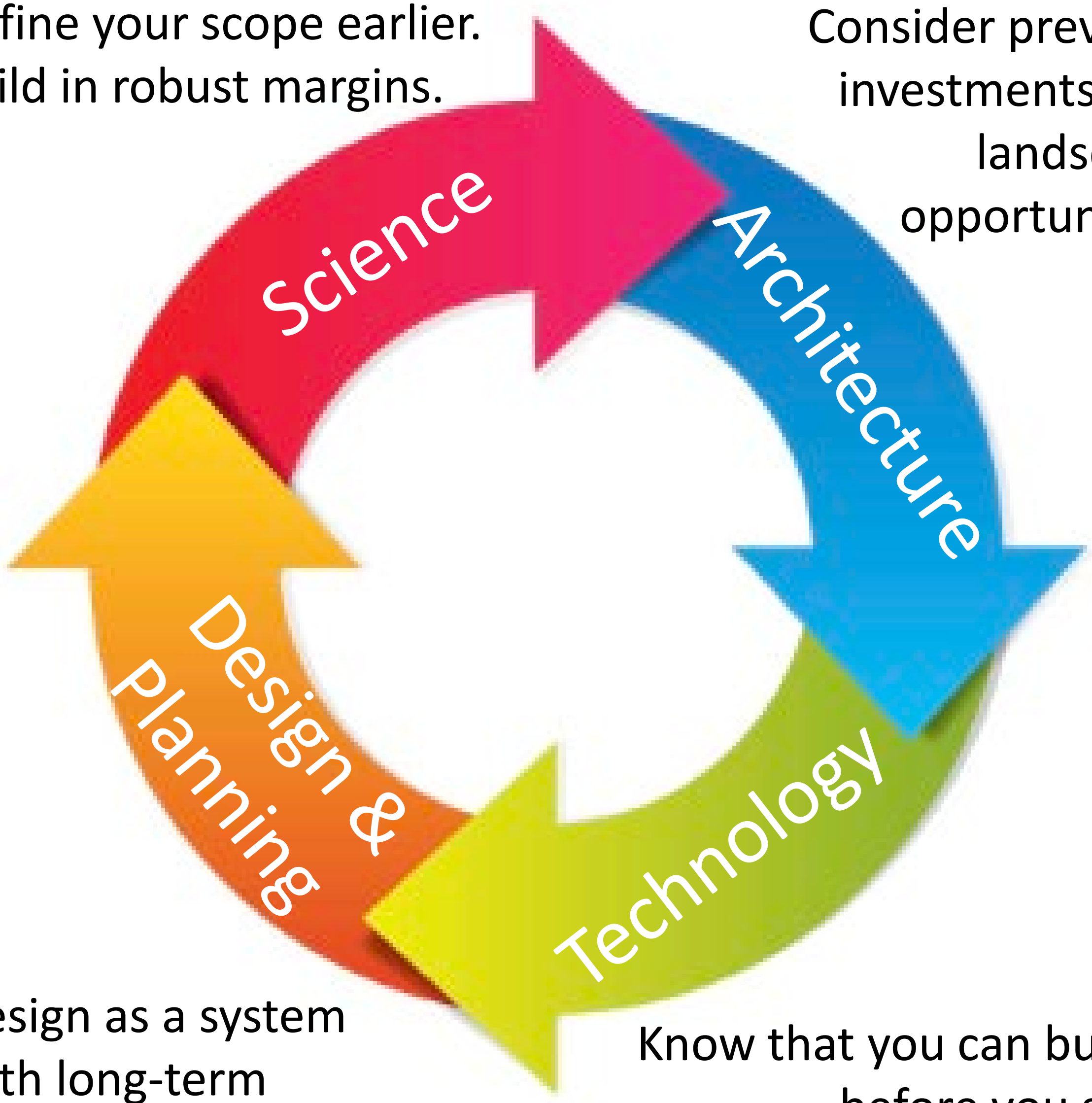
- A successful flagship starts long-term work before staffing ramps up, and details get refined as the trade space continually gets more focused.



How Do Complex Things Get Done On Time?

Define your scope earlier.
Build in robust margins.

Consider previous investments and landscape opportunities



Design as a system with long-term needs in mind

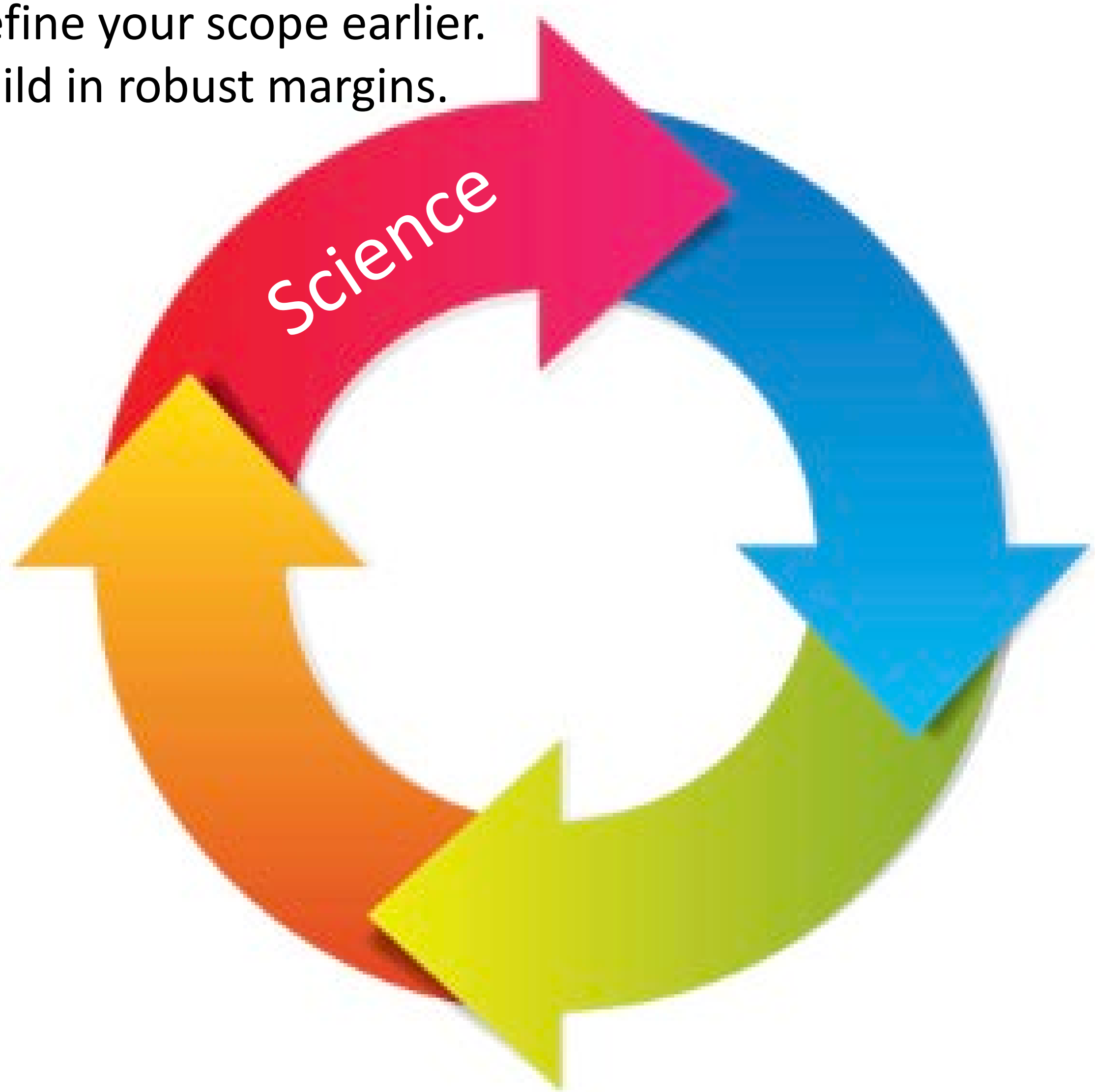
Know that you can build it before you start.

How Do Complex Things Get Done On Time?

Science, Technology, Architecture Review Team (START)

- Start with Decadal science
- Quantify all science objectives including their break points & slope of performance degradation
- Identify observatory/instrument capability needs

Define your scope earlier.
Build in robust margins.



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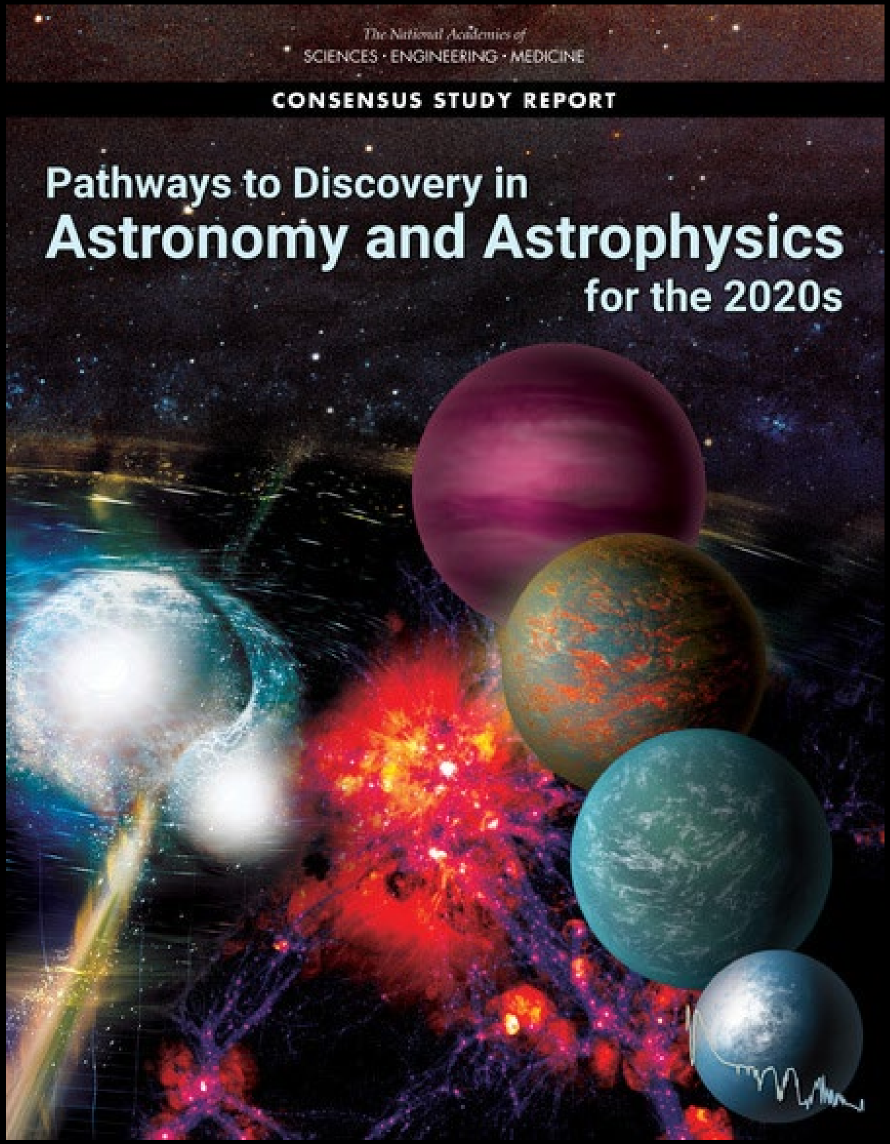


Acting groups:

START (Science, Technology, Architecture Review Team)

Precursor Science teams

Extreme Precision Radial Velocity teams

Responsibility:

HWO Scope

Objectives:

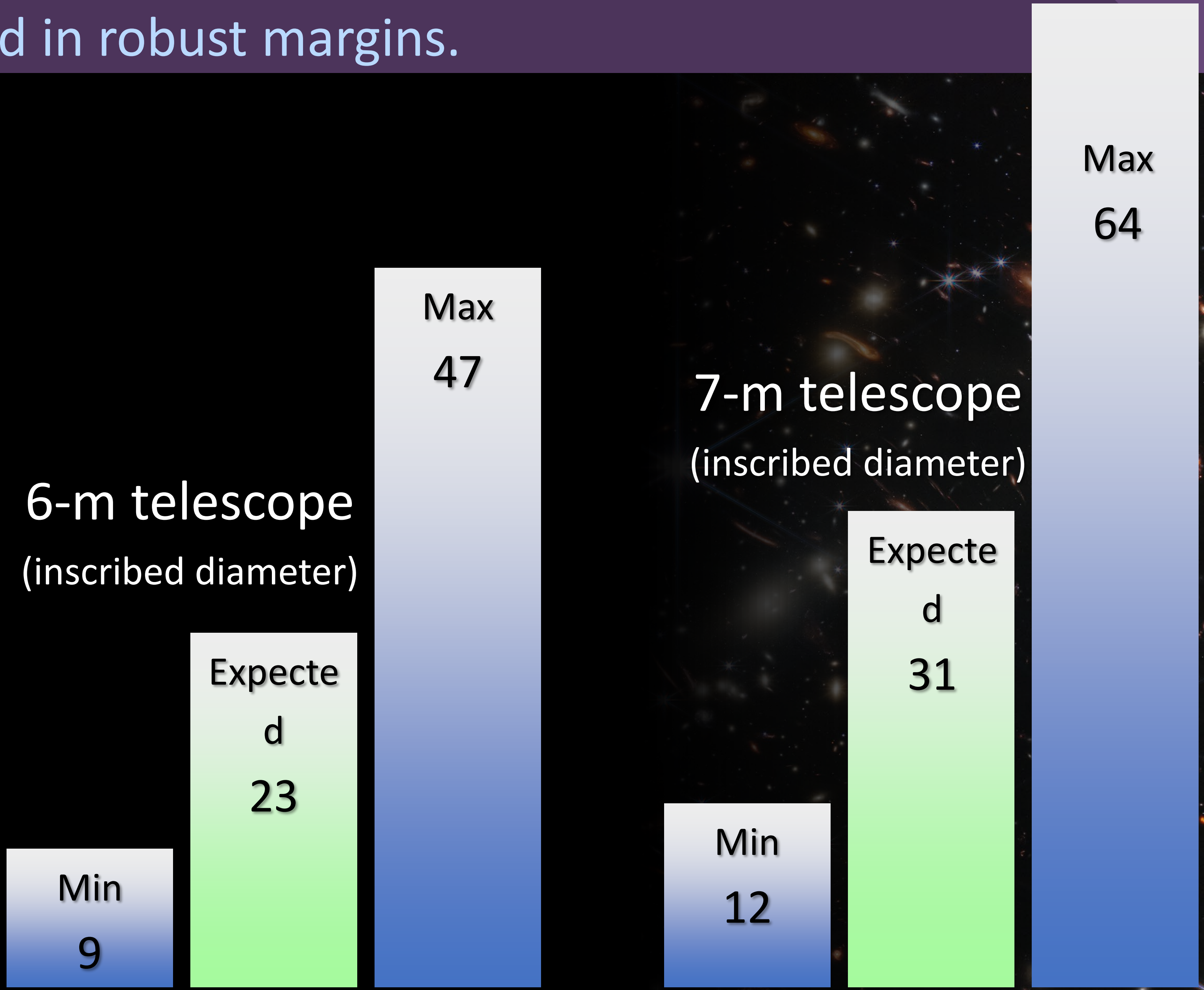
List HWO Goals, Objectives, and Types of Observations

Roadmap to full/final Science Traceability Matrix (STM)

Define your scope earlier. Build in robust margins.

Define scope, including sufficient margins to avoid redesigns.

Example: Need to define margins on goal of 25 Exo-Earths/100 Exo-systems



Input analysis to HabEx and LUVOIR Studies by Chris Stark

Large margins against scientific & technical uncertainties prevent costly late redesigns

How Do Complex Things Get Done On Time?

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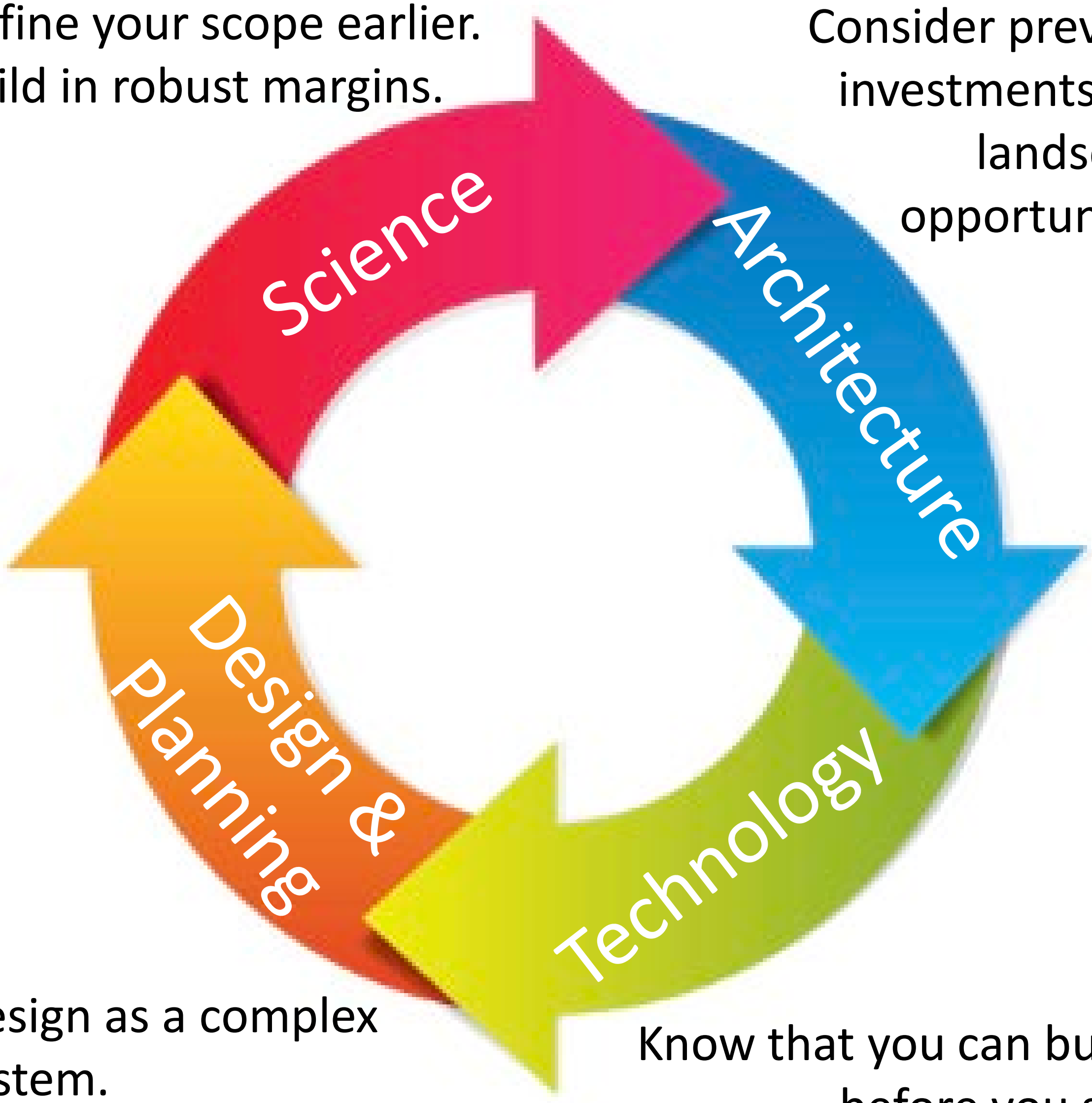
Build in robust margins.

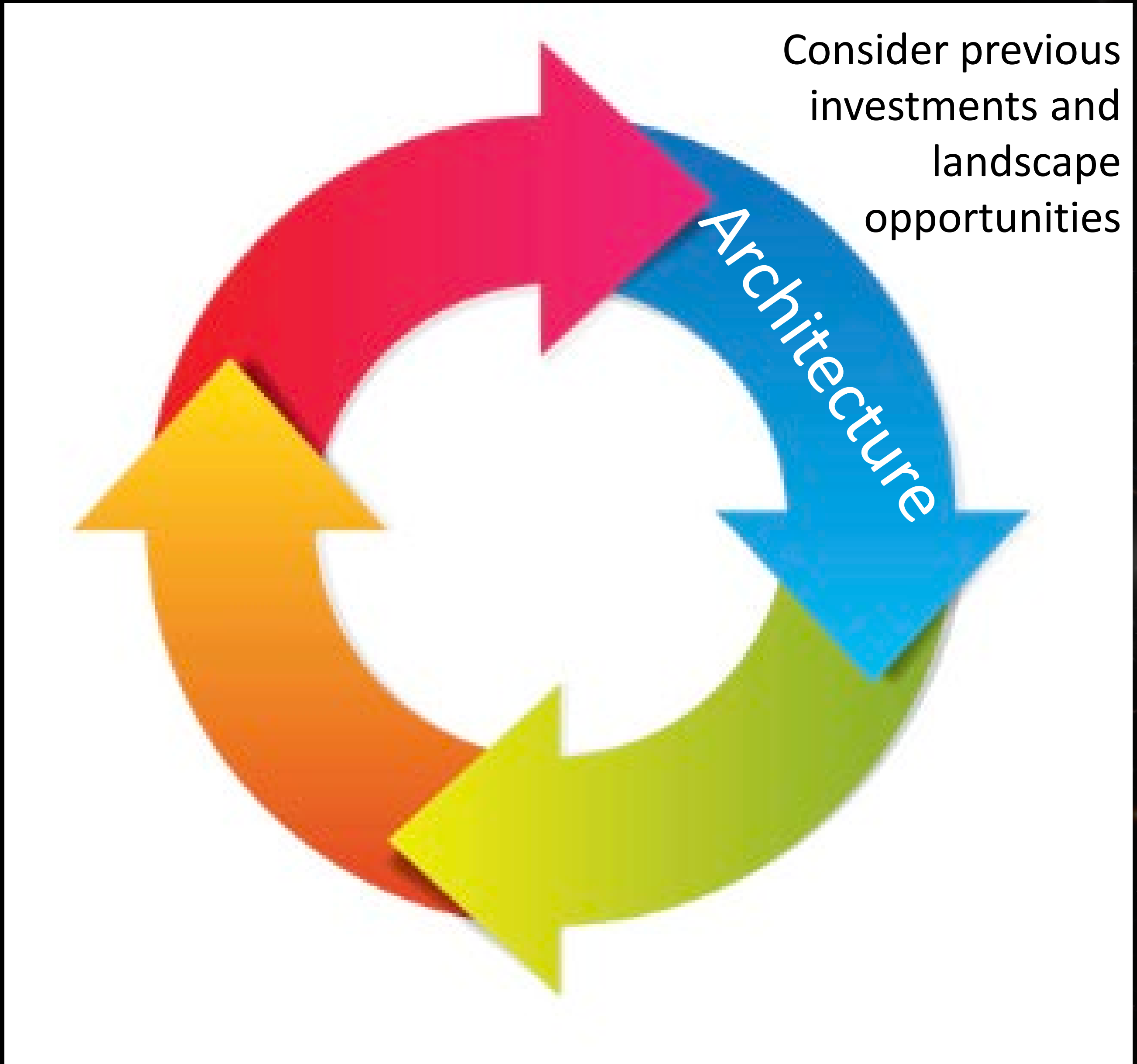
Consider previous investments and landscape opportunities



Design as a complex system.
Plan long-term.

Know that you can build it before you start.

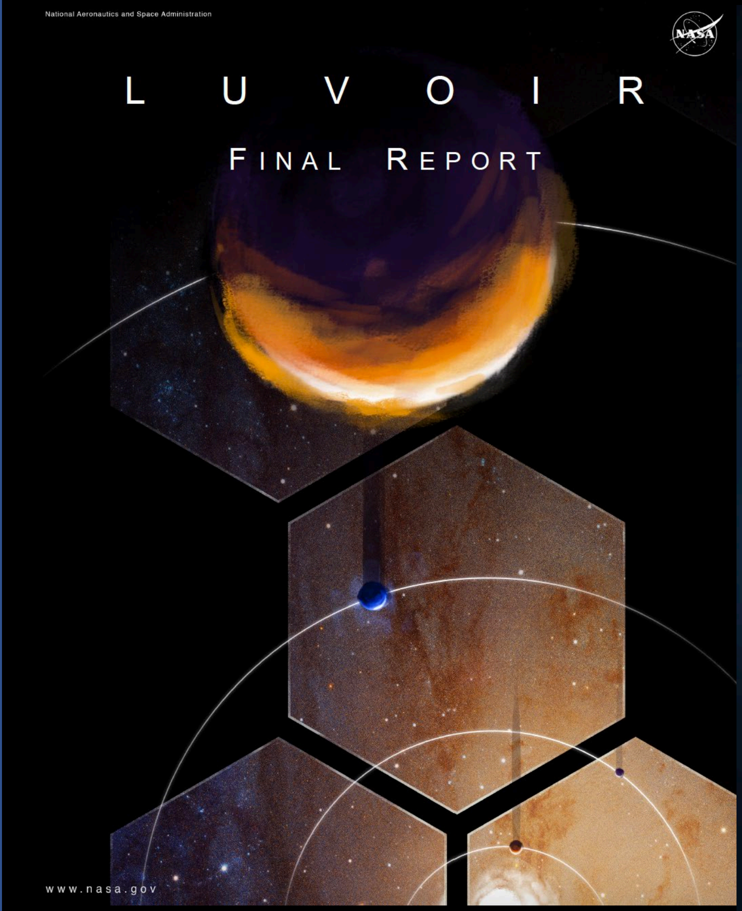
How Do Complex Things Get Done On Time?



Prior work and lessons learned

- Maximize use of high TRL architectures (i.e., Hubble, Roman, JWST)
- Survey and leverage industry landscape opportunities (i.e., launch vehicles, robotic servicing, AI/ML)

Consider Previous Investments and Landscape Opportunities



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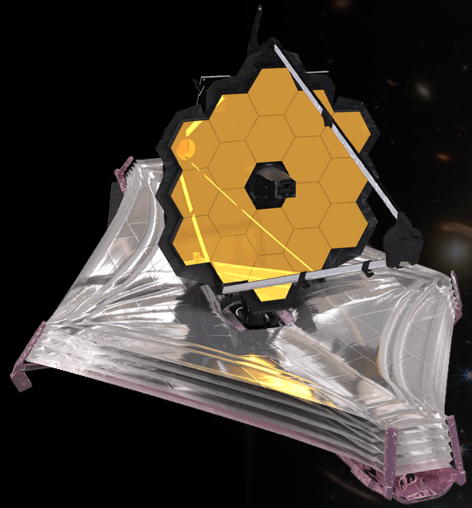

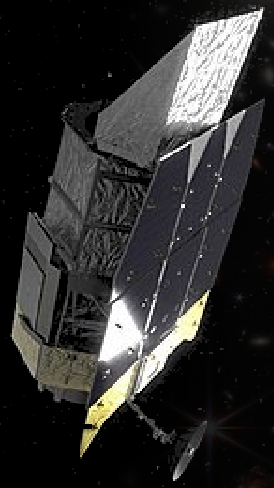

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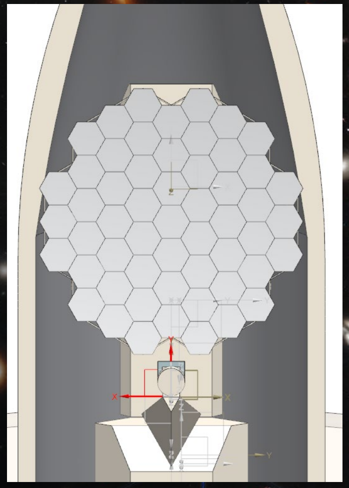

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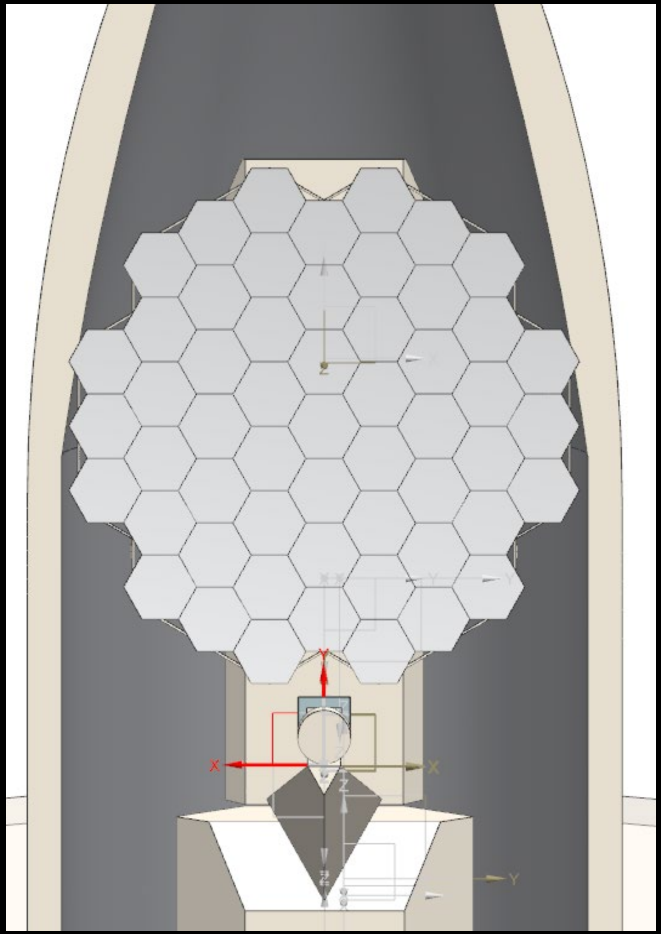
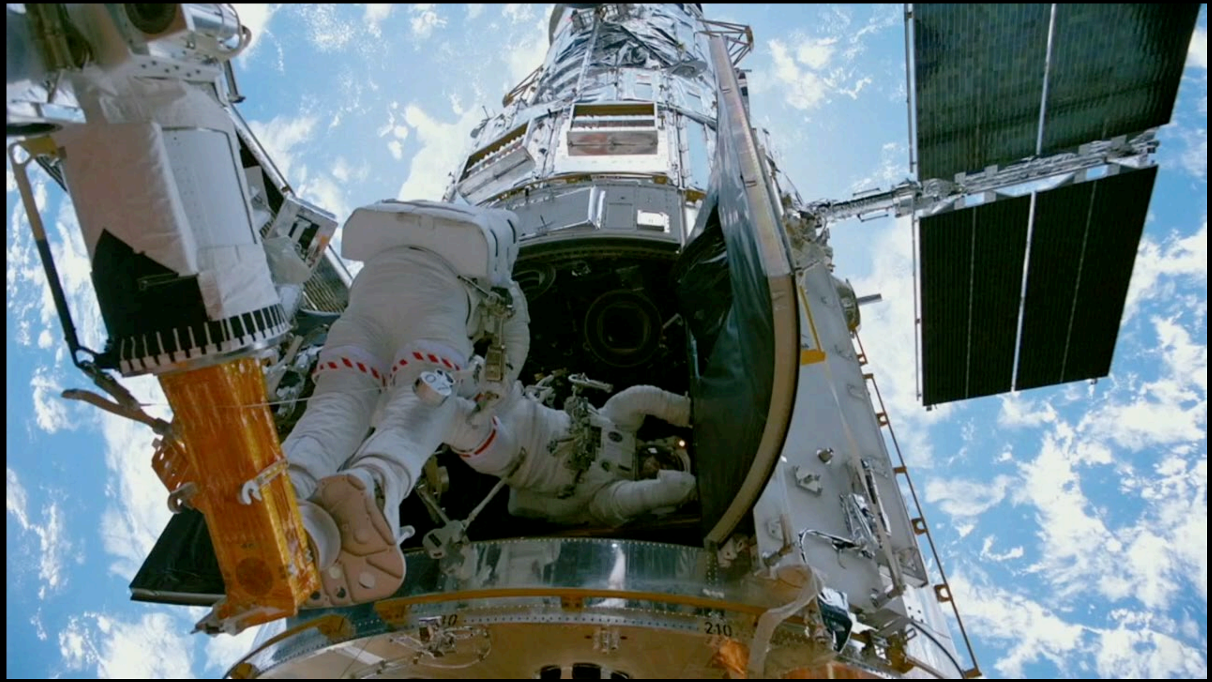


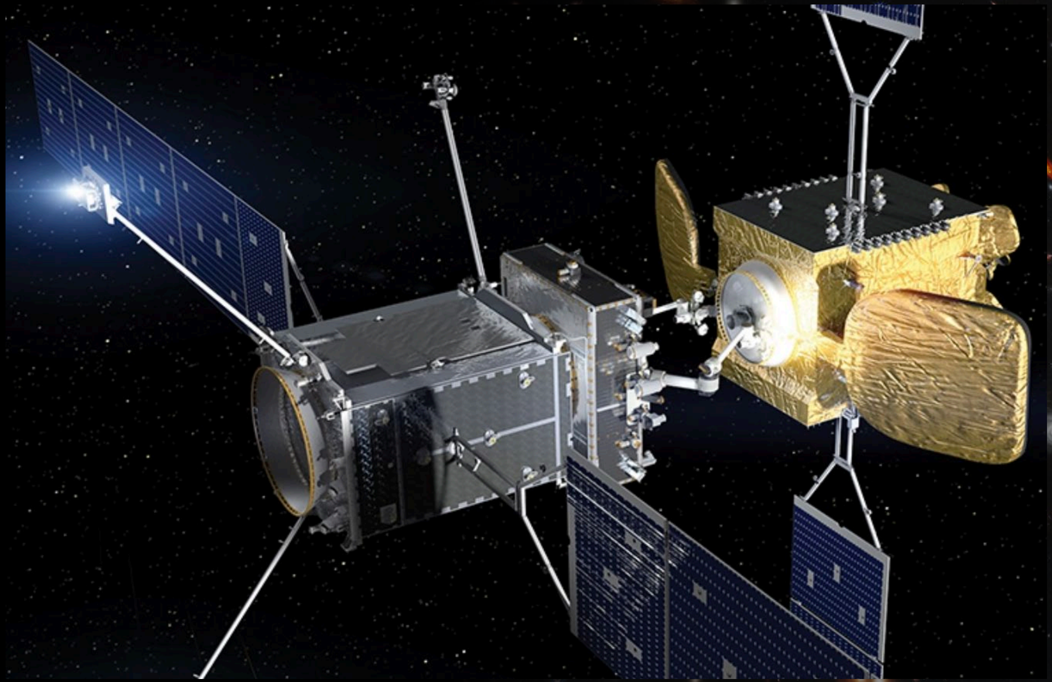
Potentially greater mass & volume capacity enables …

- More conventional materials
- Modular design to ease I&T
- Innovative design trades (e.g., launch deployed mirror)

Analyze alternative materials & designs to reduce system complexity

Consider Previous Investments and Landscape Opportunities





A Mission Robotic Vehicle servicing an on-orbit satellite.
Credit: SpaceLogistics/Northrop Grumman

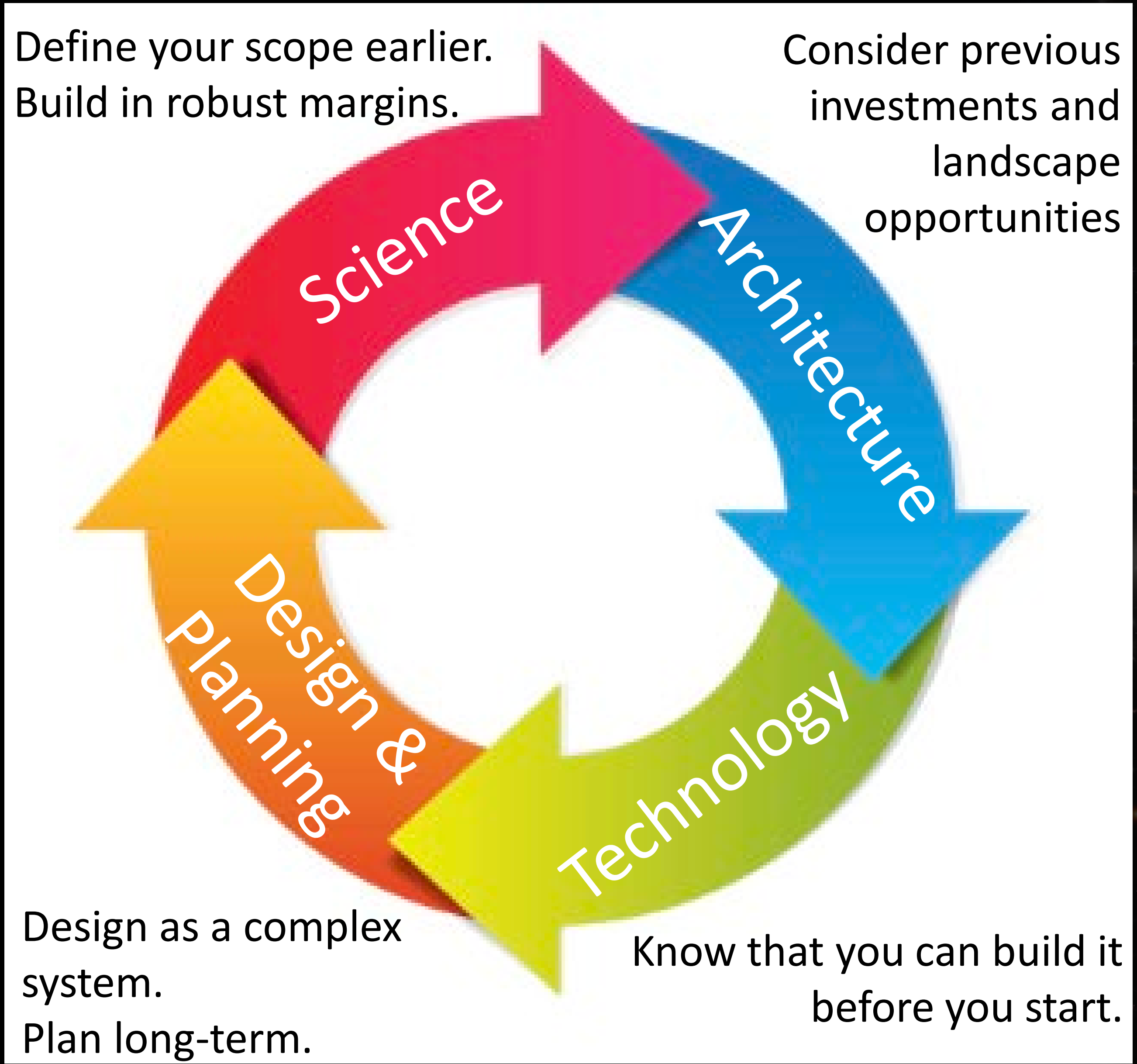
https://www.nasaspaceflight.com/2022/05/intelsatvi-mrv-mep/

Hubble servicing of instruments has kept it at the forefront of science for over three decades

Frequent, inexpensive launches & new in-space services enable planned servicing

Analyze alternative implementation strategies to reduce schedule & risks

How Do Complex Things Get Done On Time?



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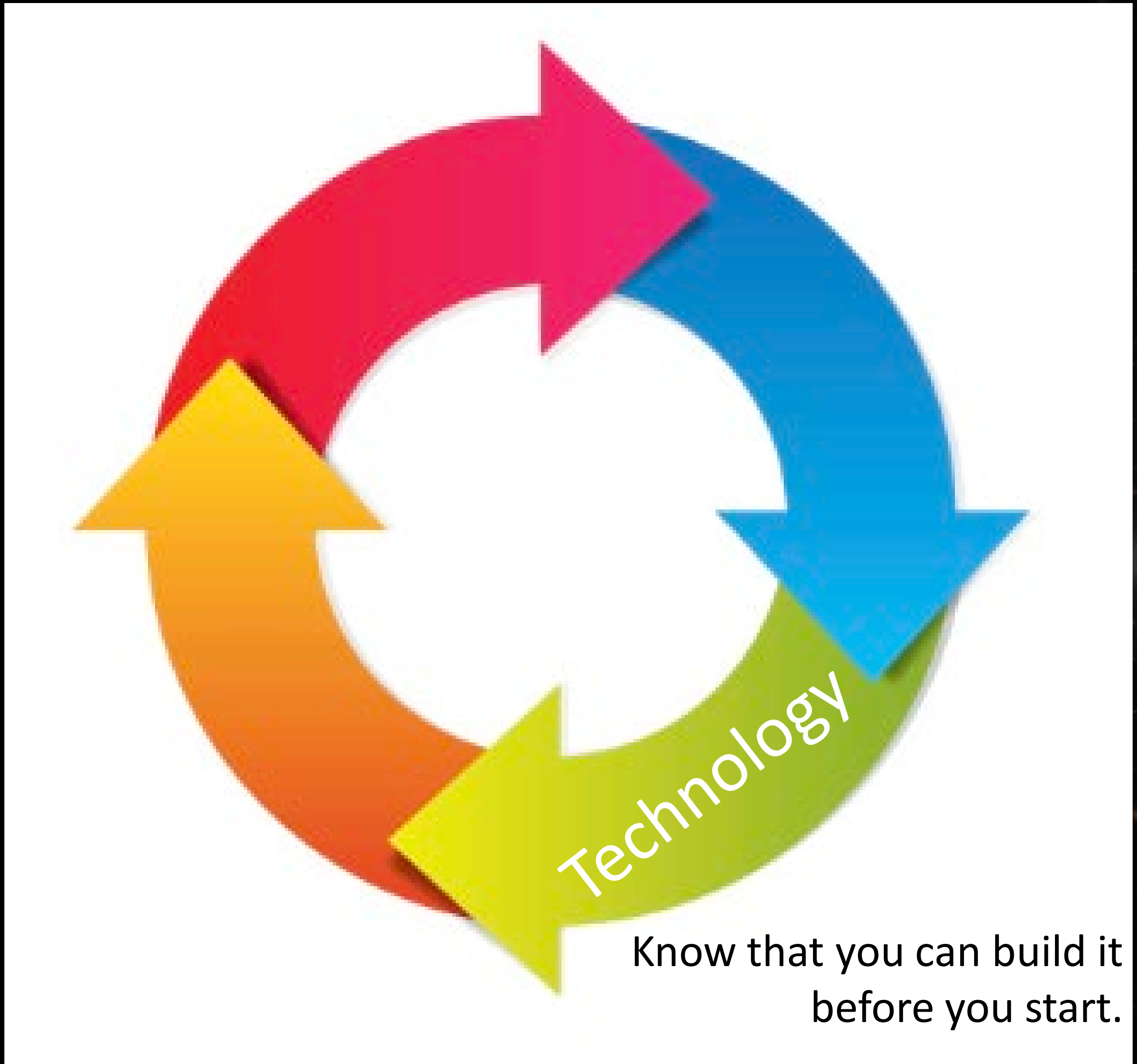


Many Parallel Activities

- Leverage past technology investments
- Develop technologies earlier
- Identify testbed & pathfinder needs
- Demonstrate science performance of critical subsystems
- Develop modeling capability & fidelity needs throughout mission phases

Technology Readiness Level Definition

TRL 9
- Actual system “flight proven” through successful mission operations

TRL 8
- Actual system completed and “flight qualified” through test and demonstration (ground or space)

TRL 7
- System prototype demonstration in a space environment

TRL 6
- System/subsystem model or prototype demonstration in a relevant environment (ground or space)

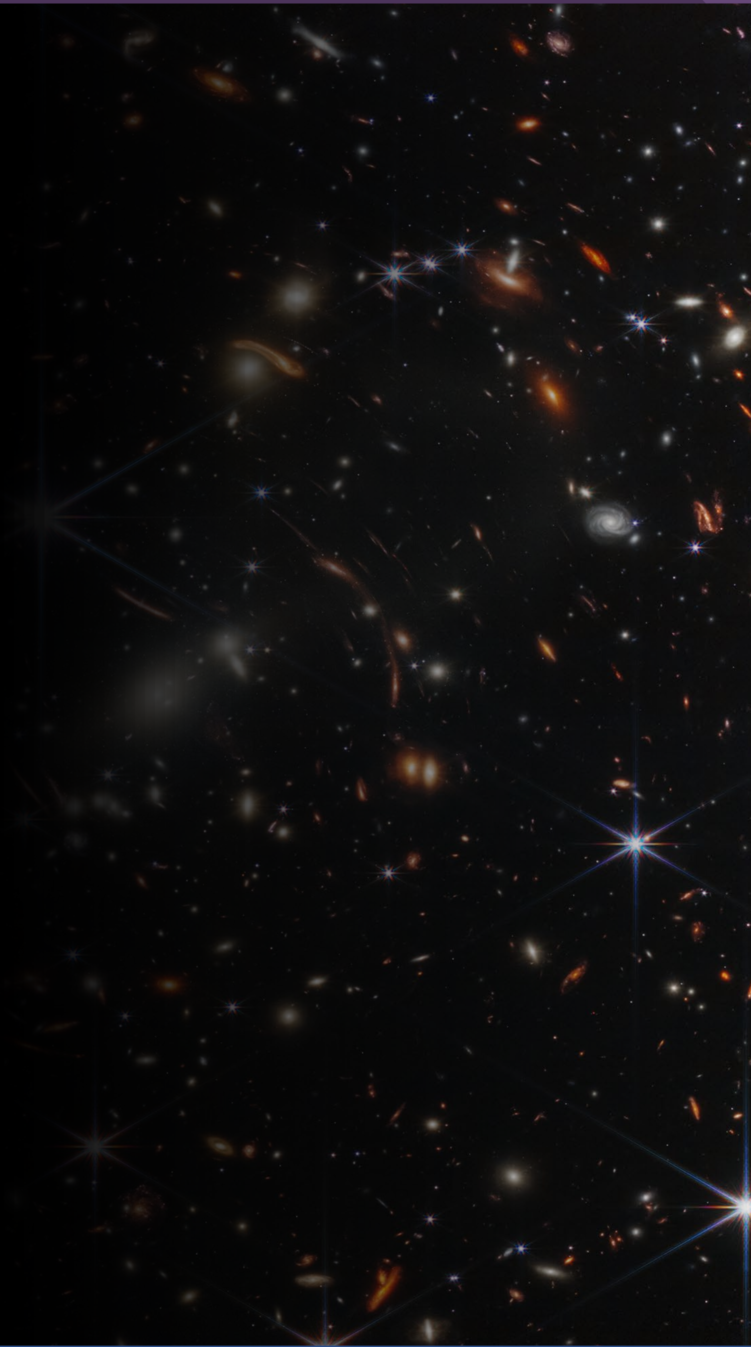
TRL 5
- Component and/or breadboard validation in relevant environment

TRL 4
- Component and/or breadboard validation in laboratory environment

TRL 3
- Analytical and experimental critical function and/or characteristic proof-of-concept

TRL 2
- Technology concept and/or application formulated

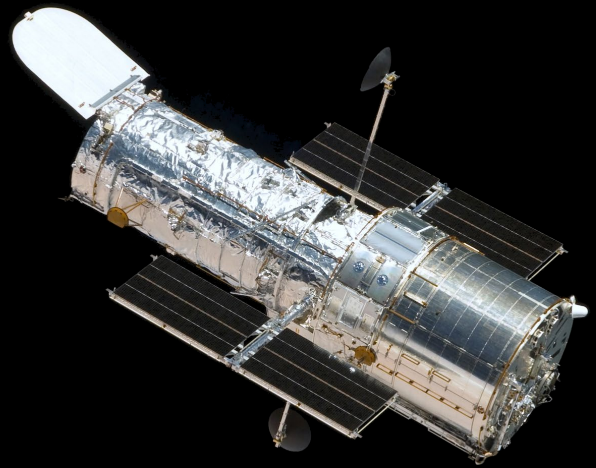
TRL 1
- Basic principles observed and reported



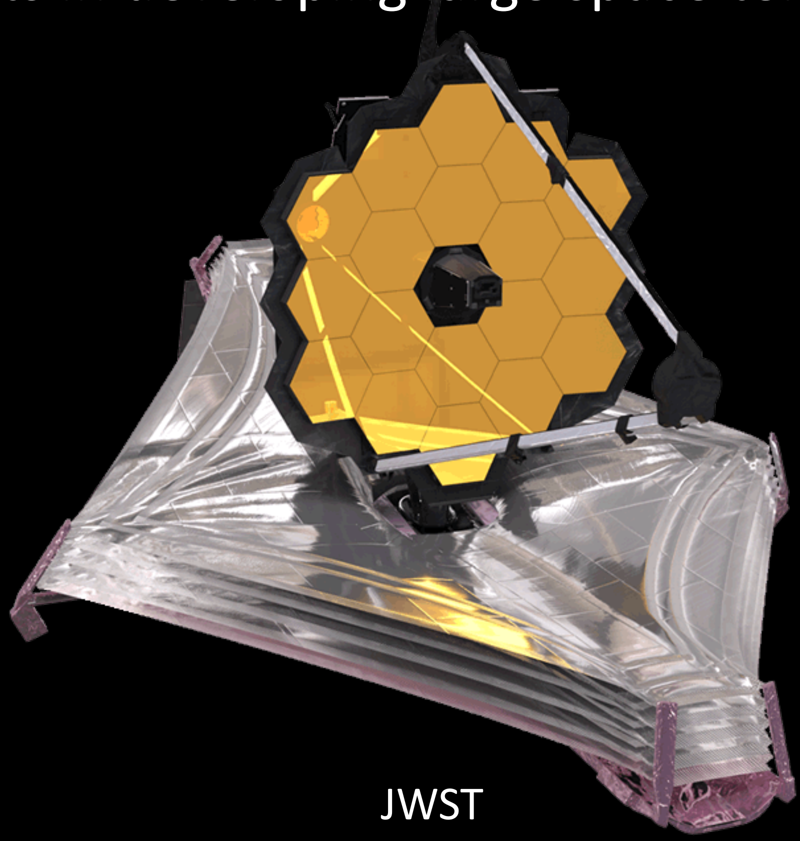
https://www.nasa.gov/directorates/heo/scan/engineering/technology/technology_readiness_level

Know that you can build it before you start.

NASA's decades-long investments in developing large space telescopes pay off with awe-inspiring science results



Hubble Space Telescope
UV-Vis-NIR Flagship
Serviceability



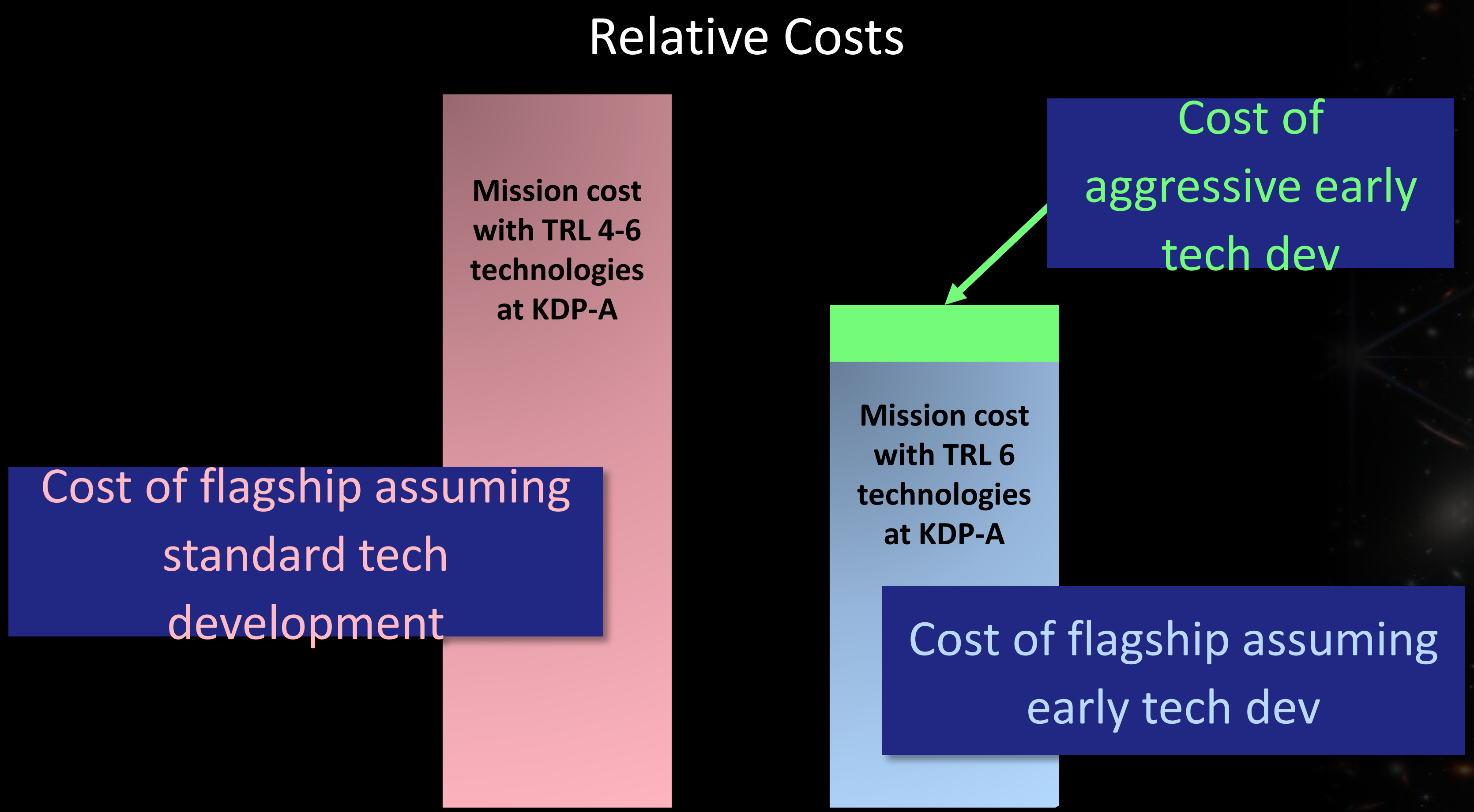
JWST
Scalable Observatory
L2 Operations

Nancy Grace Roman Space Telescope
High-Contrast Imaging
Vis-NIR Detectors

Focus on new challenges, not inventing new ways to do things we know how to

20

Know that you can build it before you start.

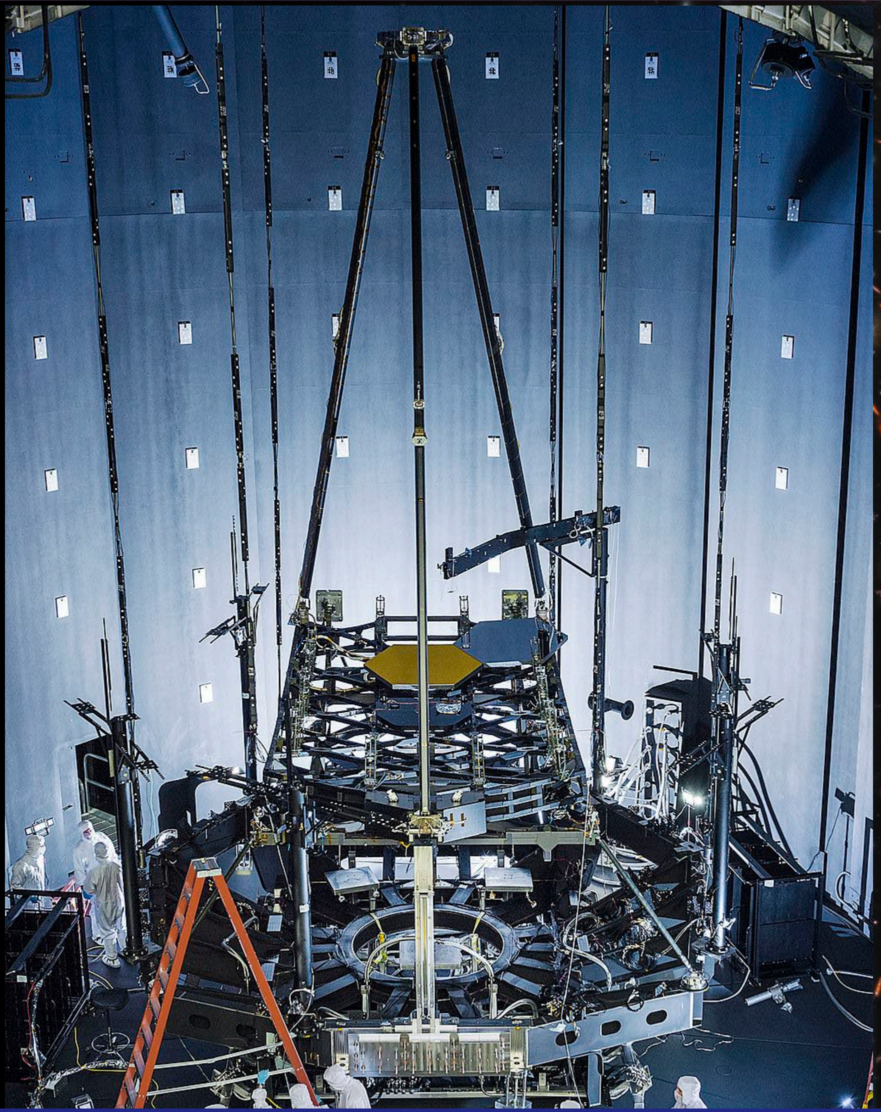


Focus early investment on the mission-enabling technologies and understand the trades between science, cost, and risk

Know that you can build it before you start.

Strategically use pathfinders, testbeds, Engineering Test Units, and validation tools such as integrated modeling to:

1. Inform designs and their realism
2. Inform and validate models
3. Inform / practice testing processes and procedures
4. Define ground test facility and GSE requirements



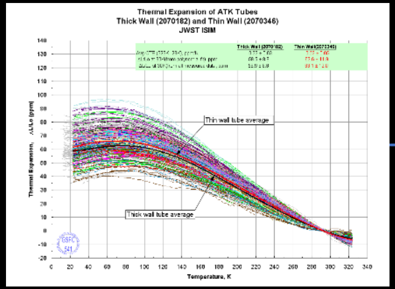
Credit: NASA/GSFC

Pathfinders allow teams to practice with non-flight hardware off the critical path. Use pathfinders & testbeds to inform and validate realism of models

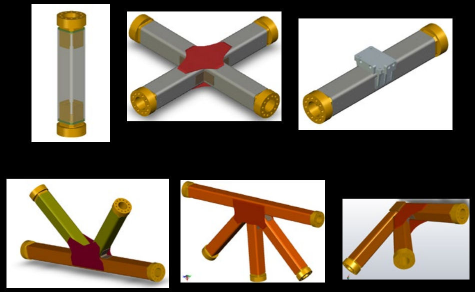
Know that you can build it before you start.

- As with many missions, the flight environment will be impossible to completely replicate on the ground
- Verification by analysis with models that have been validated via tests will be used to show compliance with performance requirements
- Integrated modeling was used on Chandra and JWST with limited number of iterations of trade space optimization

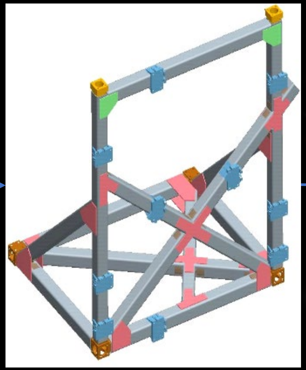
Detailed material characterization



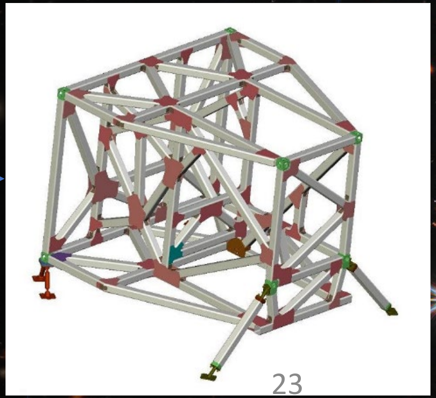
Joint development tests



Sub-assembly development tests



ISIM structure verification



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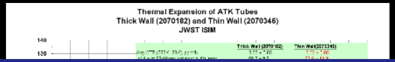

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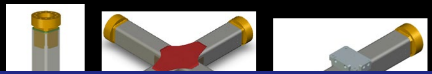

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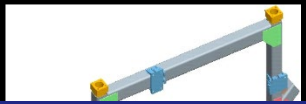


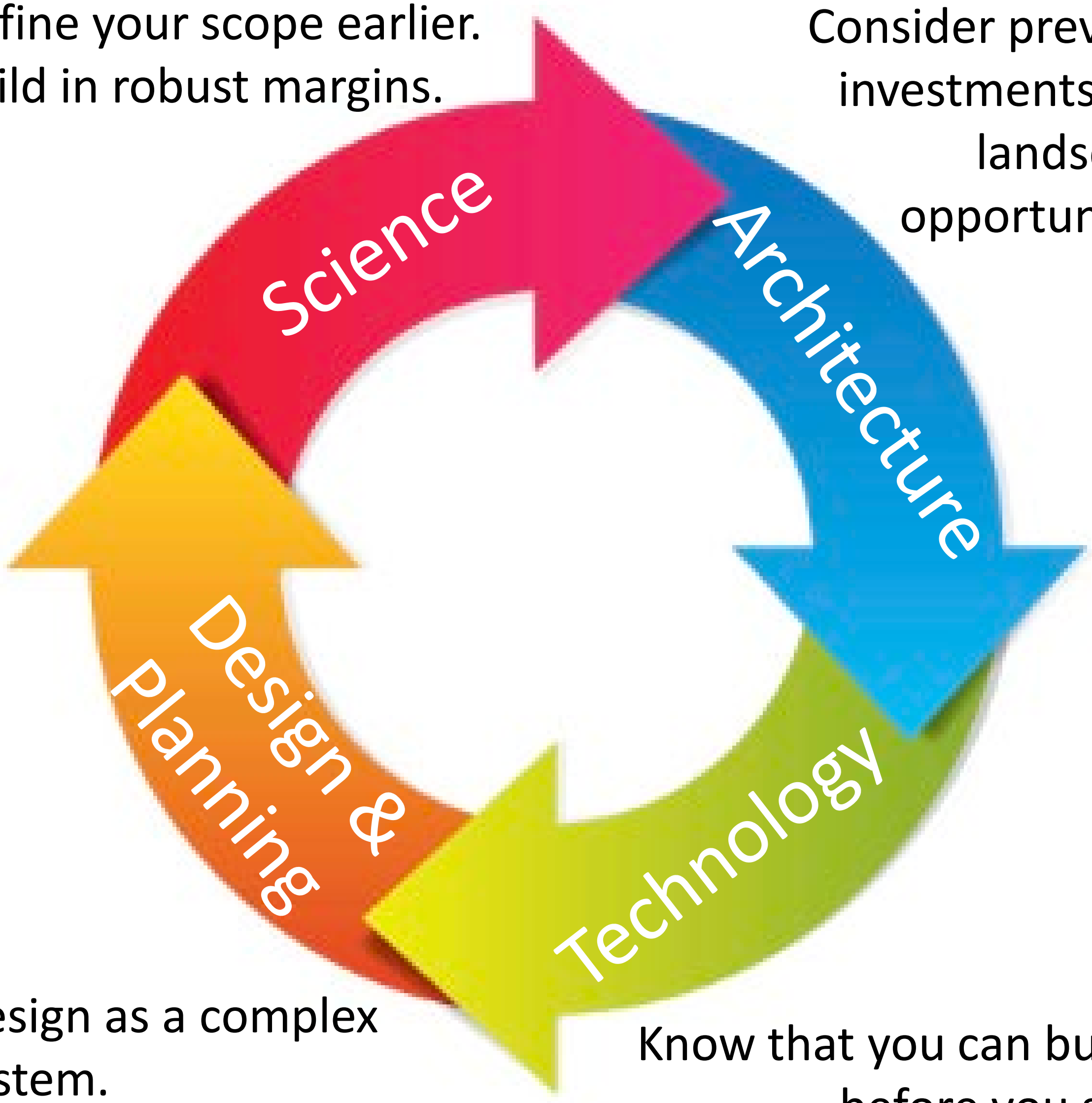
ISIM structure verification

Establish an interoperable, integrated modeling framework to enable global partner communication, work coordination, and multi-discipline assessments of the full design trade space

How Do Complex Things Get Done On Time?

Define your scope earlier.
Build in robust margins.

Consider previous investments and landscape opportunities

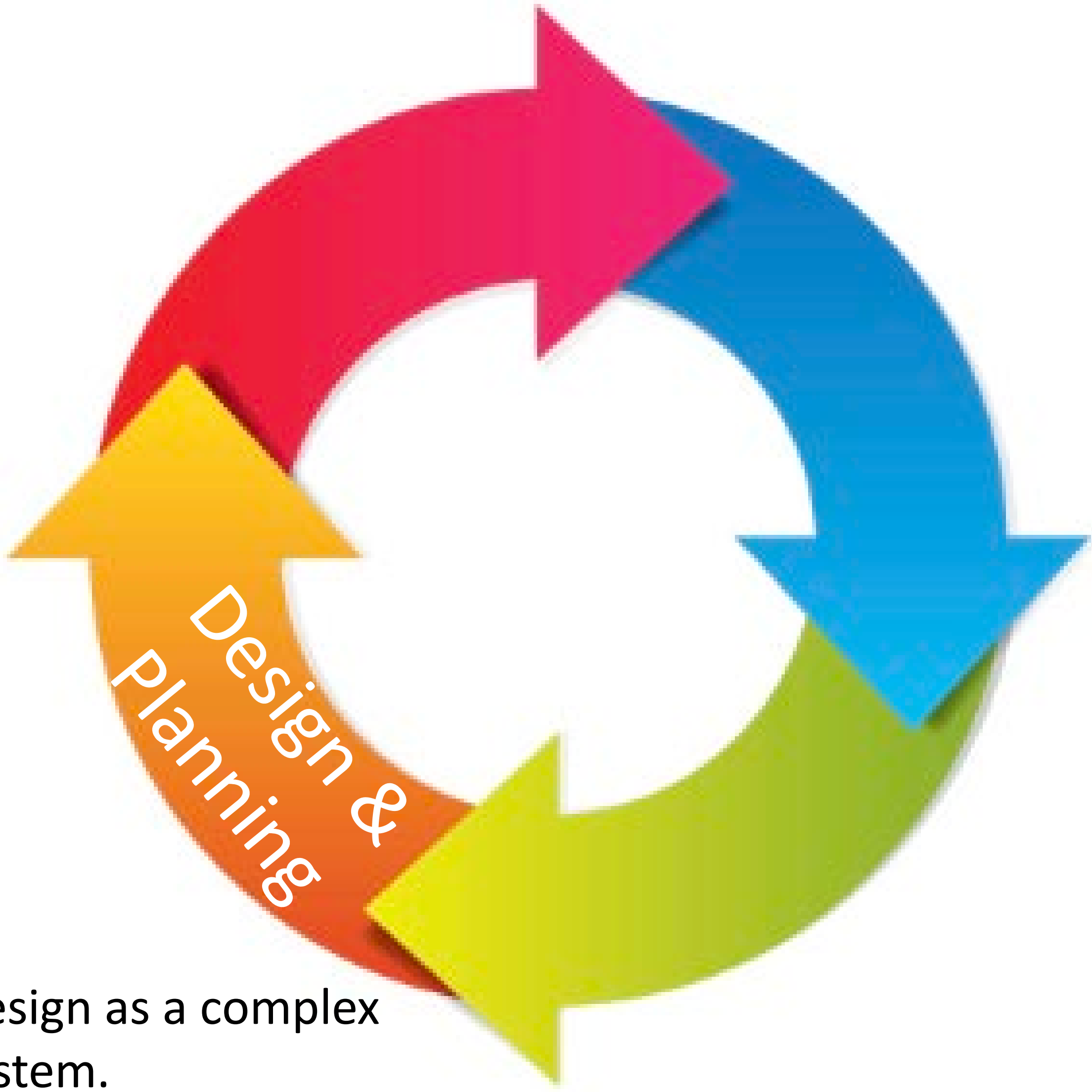


Design as a complex system.
Plan long-term.

Know that you can build it before you start.

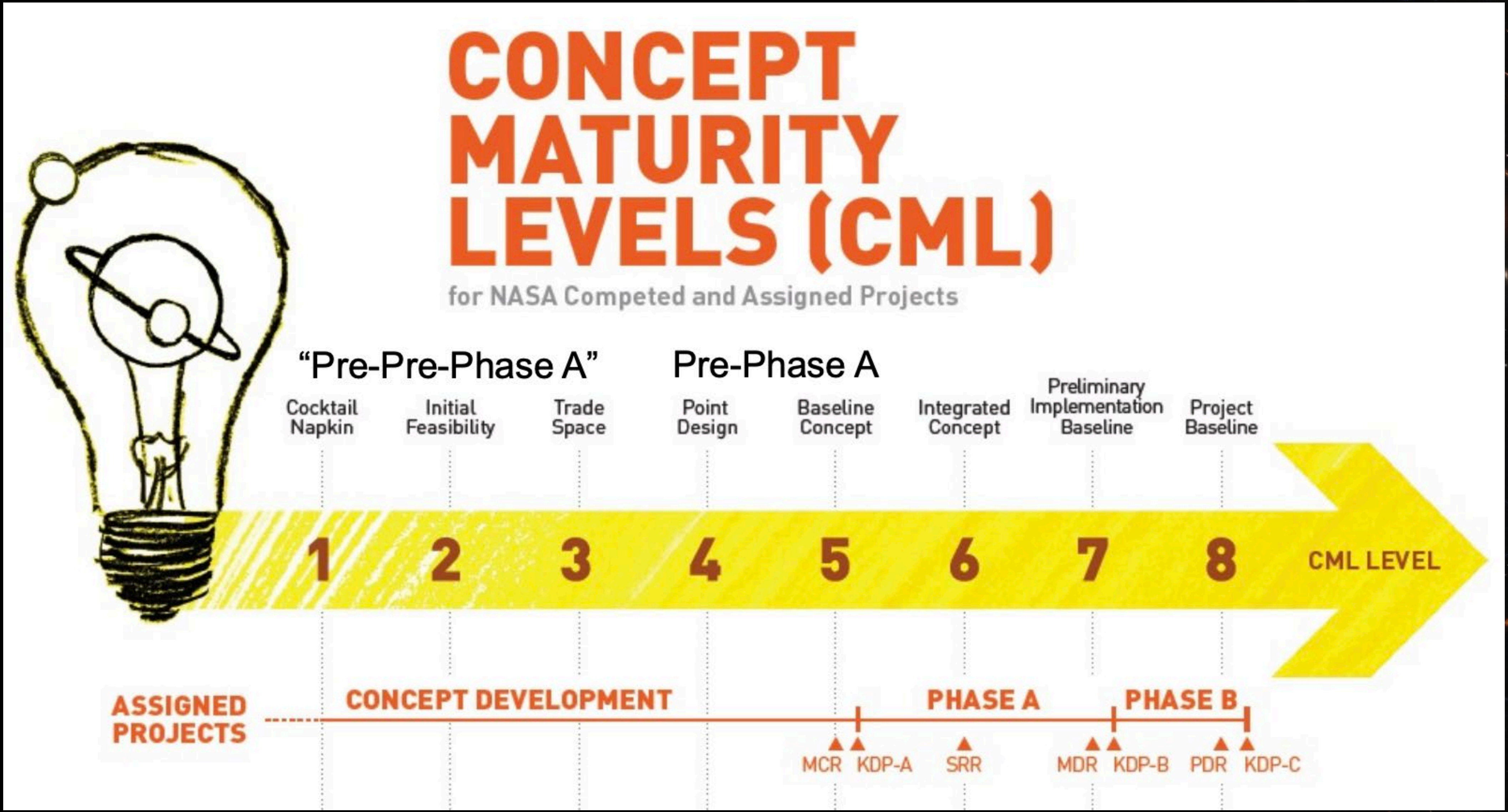
How Do Complex Things Get Done On Time?

- Design as a System
- Use modular design
- Standardize interfaces
- Build in robust margins
- Develop long-lead roadmaps and Integrated Schedule to achieve them



Design as a complex system.
Plan long-term.

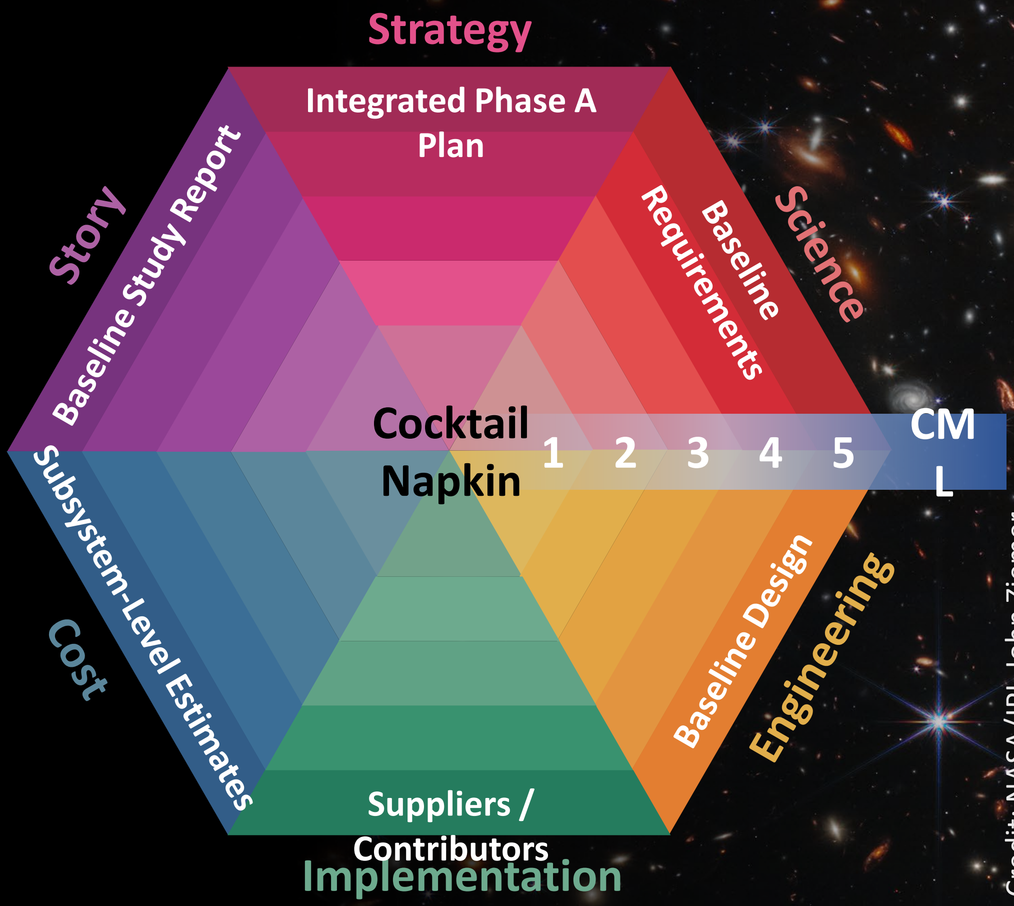
Mission Concept Maturity Level Definition



https://exoplanets.nasa.gov/internal_resources/2232_Session-2_1_Linking_Science_and_Mission_Architecture-John_Ziemer.pdf

Plan out entire mission development lifecycle holistically

- Large missions are inherently complex. "Humans are bad at accurately assessing complexity" – *NASA SMD Large Mission Study (2020)*
- Impact of complexity on technology transition, manufacturing, integration & test, and operations often requires lifecycle systems engineering approach (System of systems)

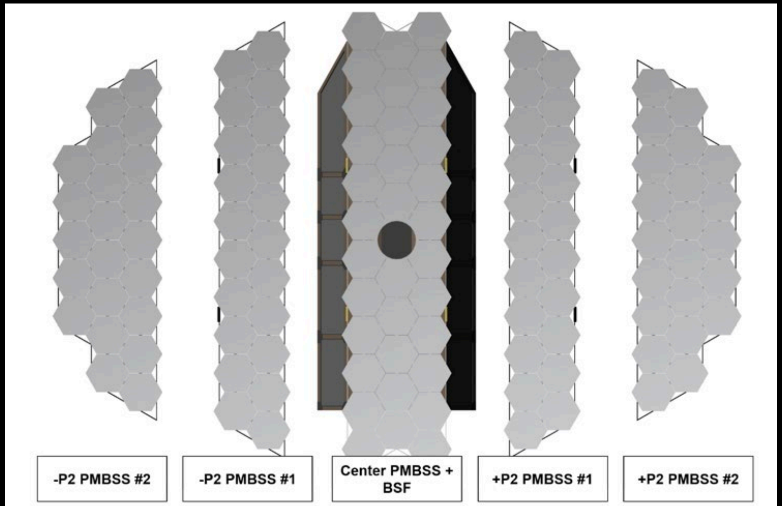


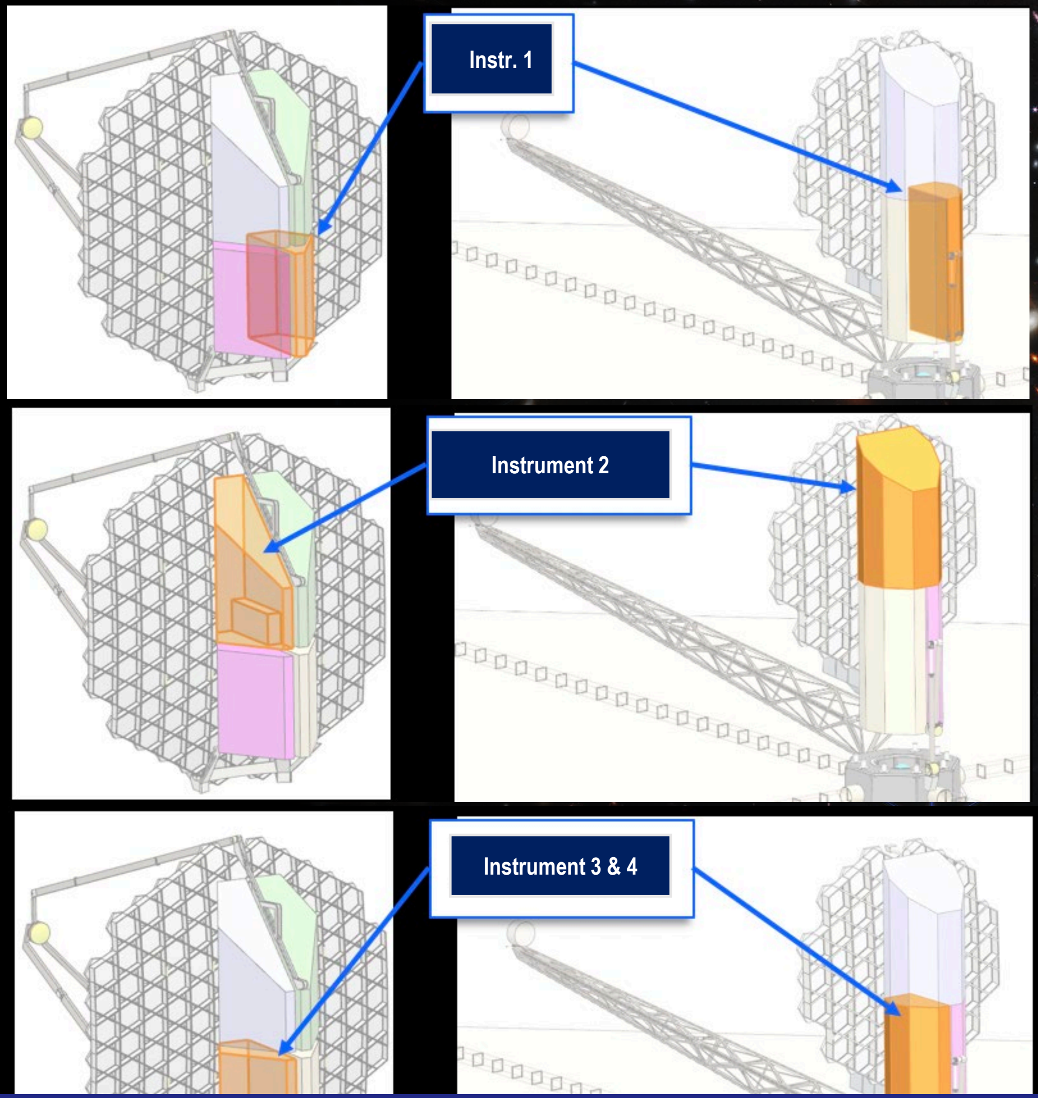
Credit: NASA/JPL John Ziemer

…/internal_resources/2232_Session-2_1_Linking_Science_and_Mission_Architecture-John_Ziemer.pdf

GOMAP will assess progress on all aspects of the mission concept using the Mission Concept Maturity Level system

Manage complexity with a modular design





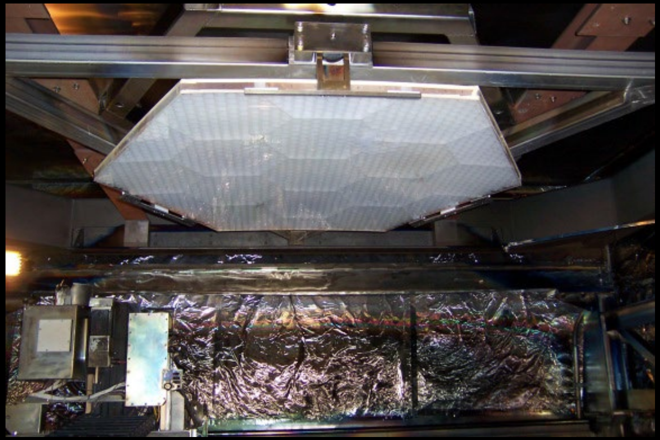
Designing your mission to be modular enables:

- Less complex I&T
- Ease of access to systems and subsystems during I&T
- Ease of transportation considerations
- Less complex servicing

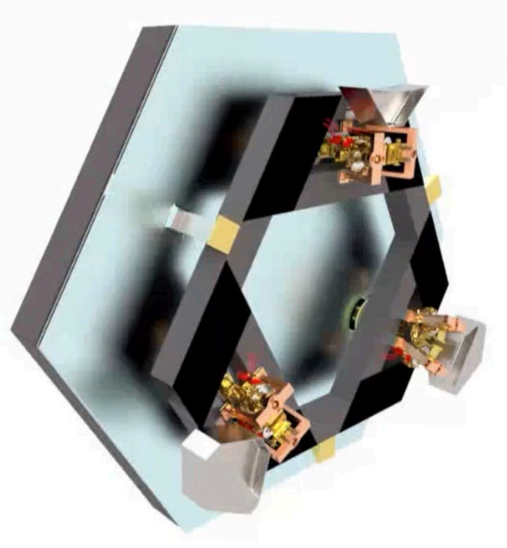
Designing the mission architecture to be modular pays off in spades reducing risk to flight hardware and minimizing risk of schedule erosion

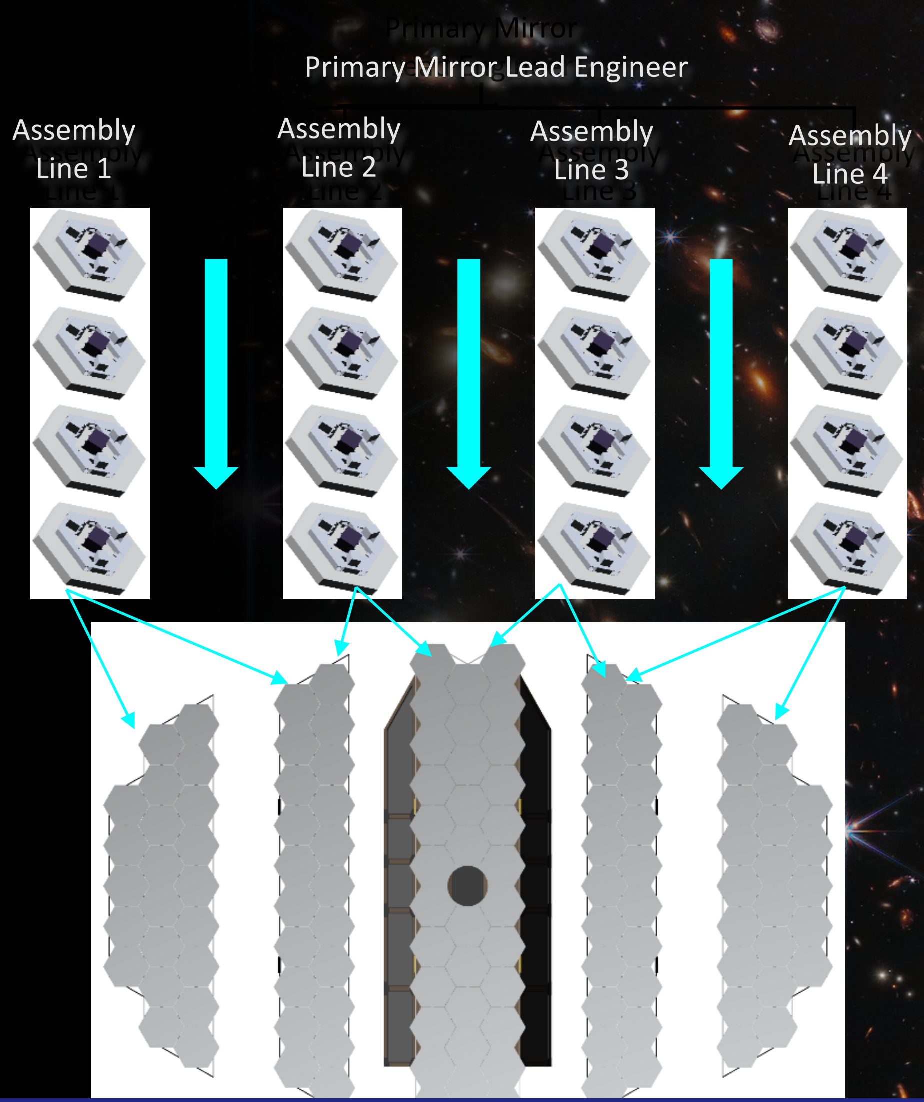
Manage complexity with parallel operations

Lightweight ULE mirror segment



Credit: L3/Harris





More parallel operations lead to a more efficient schedule

- e.g. Parallel integration of N nearly identical primary mirror segment assemblies

Schedule modeling **can help determine the optimal number of parallel vs. serial operations for fabrication, coating, or integration procedures.**

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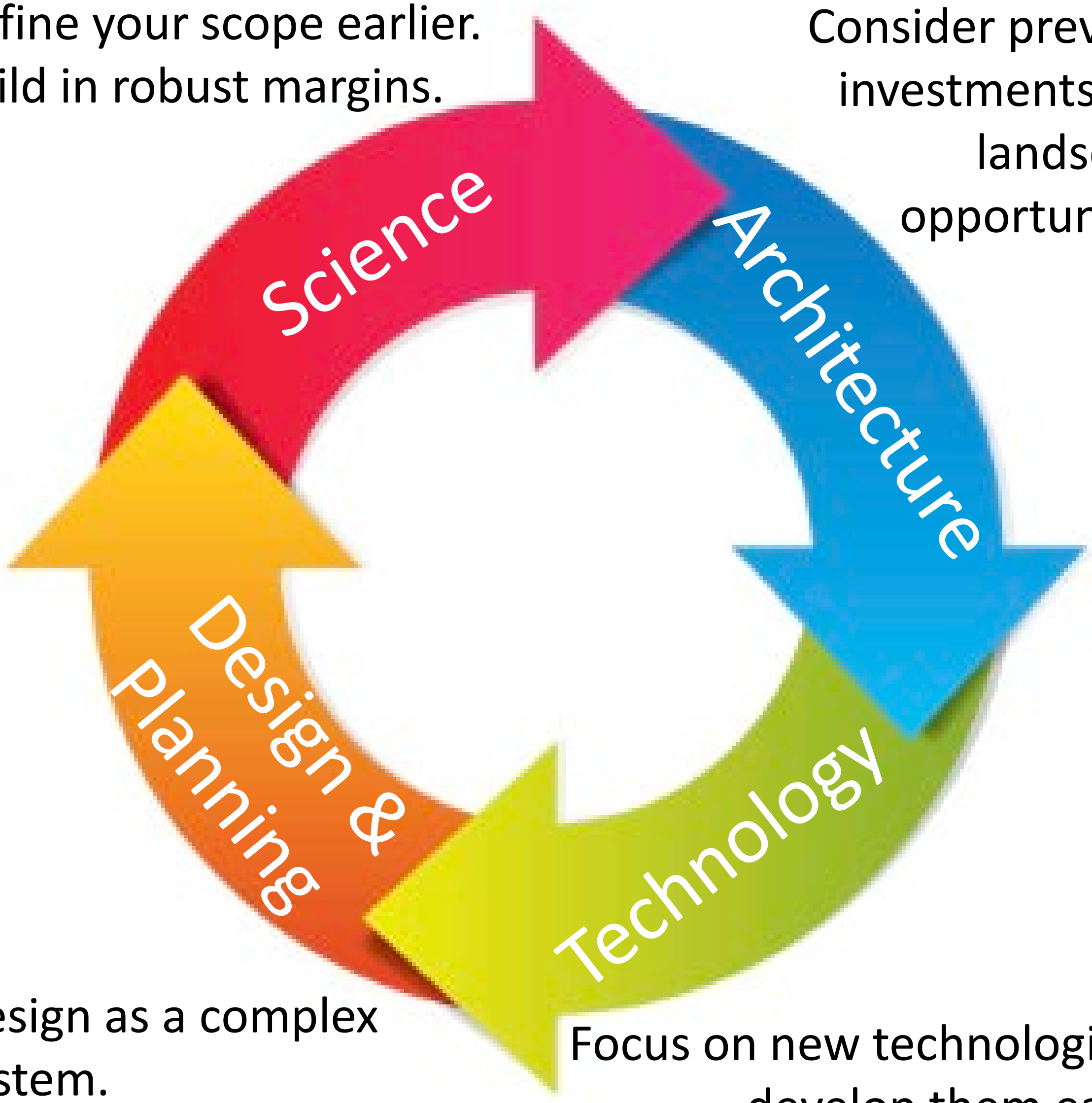
Build in robust margins.

Consider previous investments and landscape opportunities



Design as a complex system.
Plan long-term.

Focus on new technologies & develop them earlier

Near-Term HWO

Goal:
- Efficient project ready for funding

Objectives:
- Ready for formal Pre-Phase A
- Concept Maturity Level 3 Technologies at TRL4
- Science goals & objectives explored

Roadmaps for:
- Concept Maturity Level 5
- Technology Readiness Level ≥ 6
- Science Traceability Matrix Definition

HWO By Astro2030

Goal:
- Successful independent assessment

Objectives:
- Ready for mission formulation
- Concept Maturity Level 5
- Technologies ≥ TRL 5
- Science Traceability Matrix finalized

Roadmaps for:
- Concept Maturity Level 8
- Technology Readiness Level ≥ 6

Near-Term FGOs 2,3

Goal:

- Continue advancing science/technology development via opportunities (probes, Explorers, suborbital missions, technologies)

Objectives:

- Technologies development
- Precursor science

FGOs 2,3 By Astro2030

Goal:

- Prepare and be ready for prioritization at Astro2030

Roadmaps for:

- Concept Maturity Level 5
- Technologies ≥ TRL 6
- Science Traceability Matrix definition

Range of opportunities to mature science and technologies:

- Probes
- Explorers
- Suborbital missions
- Technology development

Before HWO Project

HWO

- Science, Technology, Architecture Review Team (START)
  - Develop left 2 columns of Science Traceability Matrix (STM)
  - Explore trade space in context of current landscape opportunities
- Precursor science proposals
- SAT Competed Technology Calls
- Technology Roadmapping via Astrophysics Program Offices

FGO-2, FGO-3:

- Precursor science proposals
- SAT Competed Technology Calls

With HWO Project

HWO

- Projectized Pre-Phase A and Phase A – managed by NASA HQ Astrophysics Strategic Mission Program (ASMP)

Pre-2030 Decadal: FGO-2, FGO-3

- Technology Roadmapping
- Precursor science proposals
- SAT Competed Technology Calls
- Pre-Astro2030 Study Team

NASA ROSES solicitation: System-Level Segmented Telescope Design

HWO Technology Development through NASA ROSES Solicitation

Ball
L3HARRIS™ FAST. FORWARD.
SPACE TELESCOPE SCIENCE INSTITUTE Operated for NASA by AURA
NORTHROP GRUMMAN
KRATOS | SRE
KBR

Ultra-Stable Large Telescope Research and Analysis – Technology Maturation (ULTRA-TM)

LOCKHEED MARTIN
Endless Frontier Associates LLC
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PSSL
ILLINOIS INSTITUTE OF TECHNOLOGY

Technology Maturation for Astrophysics Space Telescopes (TechMAST)

https://science.nasa.gov/researchers/sara/grant-solicitations/roses-2017/amendment-50-release-d15-system-level-segmented-telescope-design

Near-term HWO technology roadmapping

NASA Astrophysics Program Offices Facilitating HWO Roadmapping

HWO Technology Roadmapping

Ultrastable Observatory
Lead: Lee Feinberg (GSFC)
Tech Coordinator: Laura Coyle (Ball)

Subteams:
- Observatory/System/ACS
- Sensing and Control
- Mirrors/Thermal/Coatings
- Backplane/Structure/Deployment
- Verification/Facilities/Demos

Facilitated by the Physics of the Cosmos (PhysCOS) & Cosmic Origins (COR) Astrophysics Program Office

Coronagraphs
Co-Lead: Pin Chen (ExEP/JPL)
Co-Lead: Laurent Pueyo/(STScI)

Subteams:
- Deformable Mirrors
- Coronagraph Design Options
- Segmented Telescope Sims
- Workshop Planning)

Facilitated by the Exoplanet and Exploration (ExEP) Astrophysics Program Office

GOMAP/HWO Groups – How To Get Involved

Science

- Pre-Cursor Science (ROSES call)
- Science, Technology, Architecture Review Team (START) (Dear Colleague Letter)
- Extreme Precision Radial Velocity (EPRV) (ROSES)

Technology

- Technology Development: (SAT, APRA, ROSES, Directed, etc.)
- Technology Roadmapping (Facilitated by the Astrophysics Program Offices)
- Interoperable Integrated Modeling

APAC GOMAP Findings and Responses

Recommendation (GOMAP)	Response
The APAC advises that APD not only support cross-PAG SAGs and SIGs as community interfaces to the GOMAP process, but to explore the efficacy of establishing formal GOMAP structures operated by the Division for all three Great Observatories simultaneously.	Not Accepted. See Mark Clampin's presentation
The APAC advises APD to consider formal stewardship of early GOMAP Integration/Strategy teams for the X-ray and FIR concept missions envisaged withing the Astronomy and Astrophysics 2020 Decadal Survey that can interface with community-led initiatives such as SAGs and SIGs.	Not Accepted. See Mark Clampin's presentation
The APAC requests at its next meeting a thorough discussion by APD leadership of a Great Observatory Mission and Technology Maturation Program (GOMAP) implementation roadmap commensurate with the prioritization of this activity over the next decade dictated within the 2020 Decadal Survey recommendations.	See Mark Clampin and Julie Crooke's presentation on Day 1
The APAC advises APD to understand whether the demands on the telecom infrastructure and the data downlink bandwidth environment and access is sufficiently robust for Webb alongside simultaneous operations of pending missions such as Euclid and Roman, and those envisioned in the GOMAP vision, in concert with the broader portfolio of mission operations conducted by NASA.	See Mark Clampin's presentation on Day 1 of this meeting

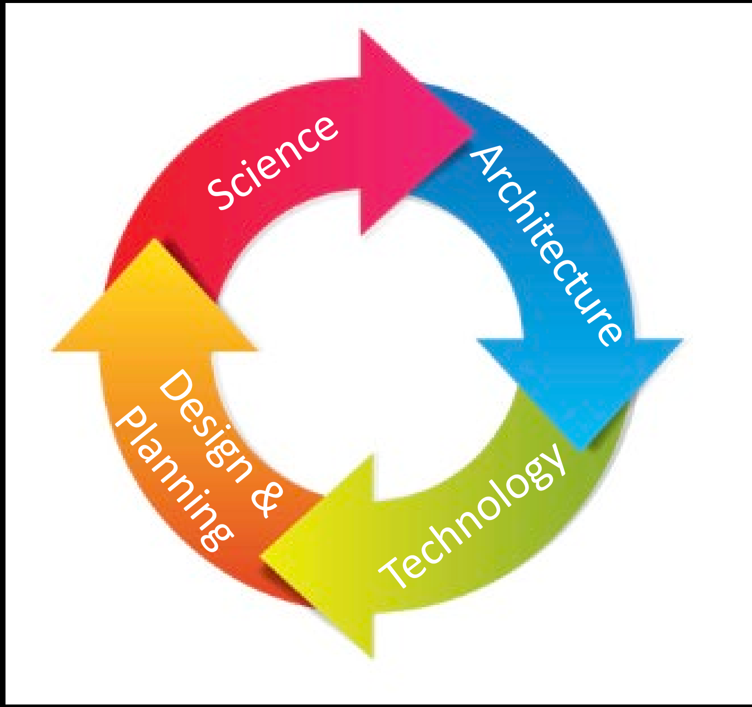
Backup

How Do Complex Things Get Done On Time?

- A successful flagship starts long-term work before staffing ramps up, and details get refined as the trade space continually gets more focused.

- Start with Decadal science
- Quantify all science objectives including their break points & slope of performance degradation
- Identify observatory/instrument capability needs

- Design as a System
- Use modular design
- Standardize interfaces
- Build in robust margins
- Develop long-lead roadmaps and Integrated Schedule to achieve them



- Maximize use of high TRL architectures
- Survey and leverage industry landscape opportunities (i.e., launch vehicles, robotic servicing, AI/ML)

- Develop technologies early
- Identify pathfinder needs
- Develop modeling capability & fidelity needs throughout mission phases
- Demonstrate science performance of critical subsystems

What does inscribed diameter mean?

Inscribed diameter
6 m

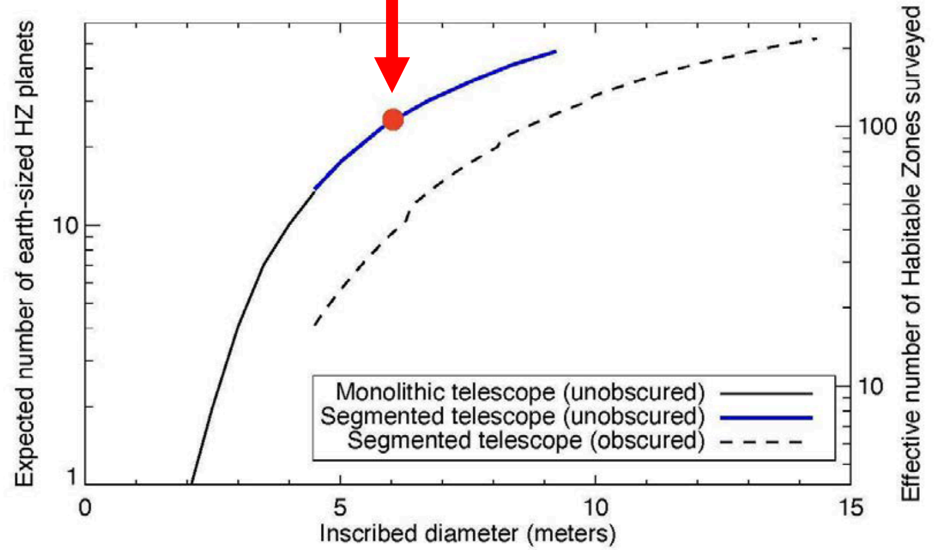
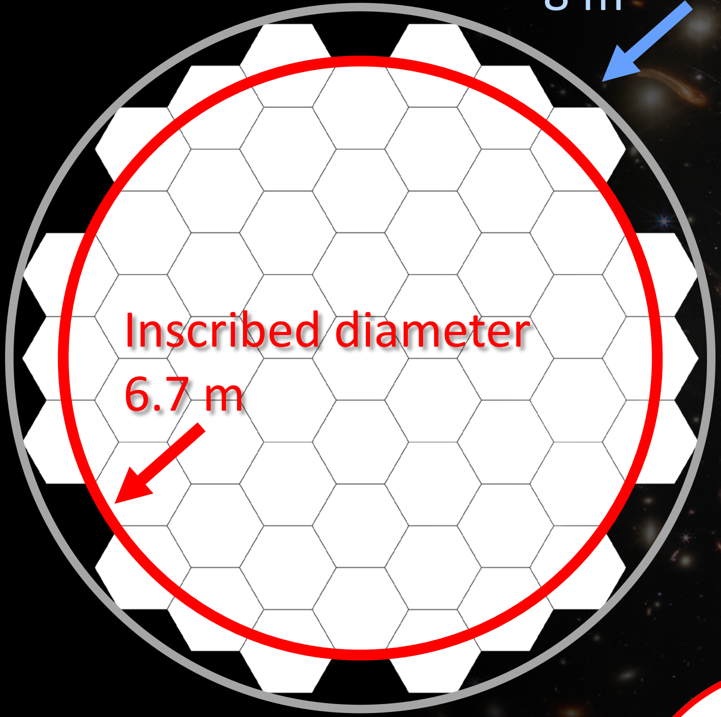


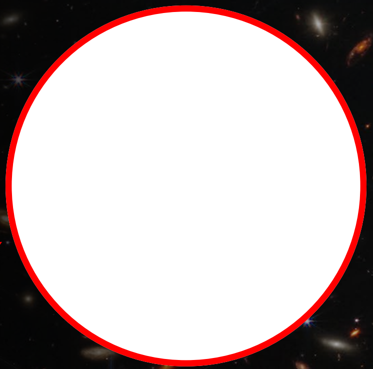
FIGURE 7.6 Potentially habitable exoplanet yield vs telescope diameter for different telescope architectures. Right axis shows the number of habitable zones surveyed (weighted by completeness); left axis shows the expected number of planets discovered assuming the occurrence rate of rocky planets in the optimistic habitable zones of different stars, eta_earth=0.24 (Bryson et al. 2021). The red dot shows the expected yield for the target 6-m inscribed diameter. NOTE: Habitable zone is defined as 0.95-1.67 AU for planets of 0.8-1.4 Earth radii. SOURCE: Adapted from C. Stark (Space Telescope Science Institute), D. Mawet (California Institute of Technology), and B. Macintosh (Stanford University).

LUVOIR-B

Circumscribed diameter
8 m

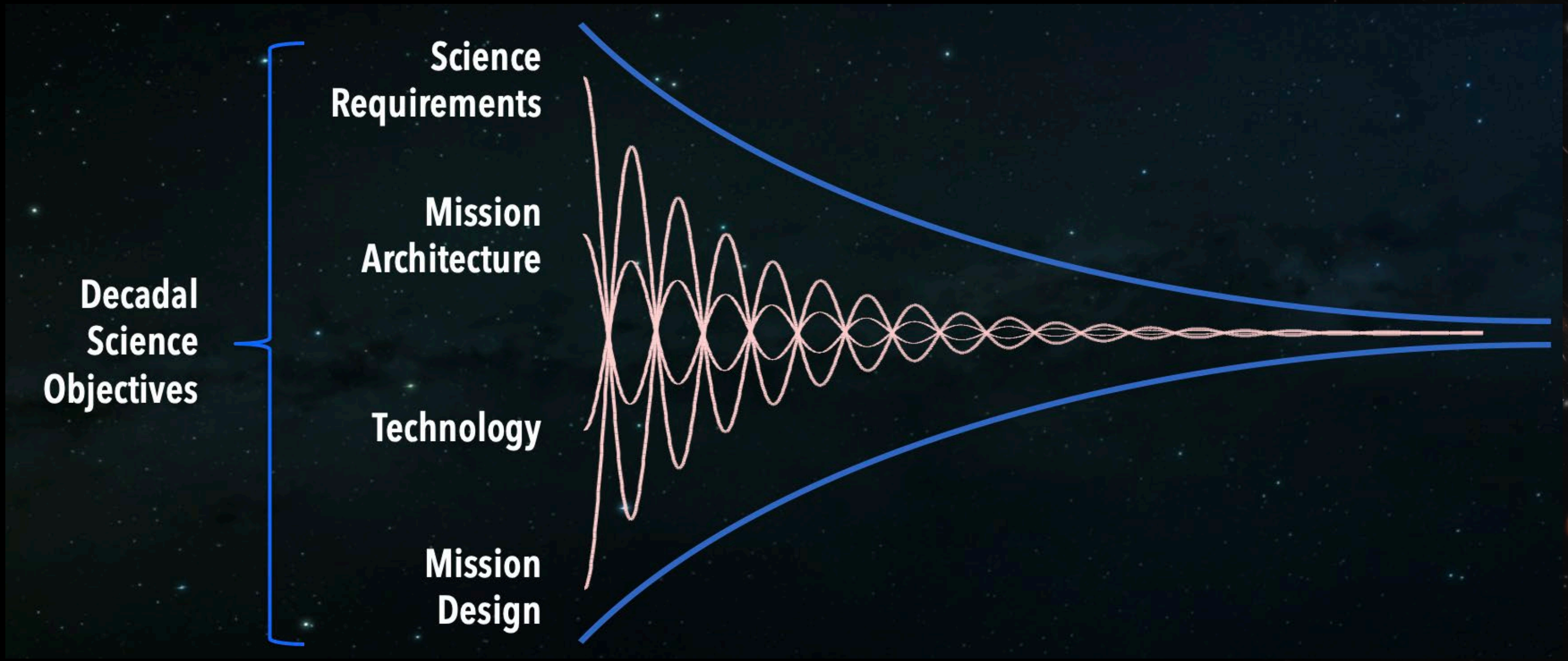


HabEx



Inscribed / circumscribed diameter
4 m

A successful flagship starts long-term work ***before*** staffing ramps up…



- Science definition
- Architecture & concept development
- Technology development
- Facility development planning
- Verification & validation planning
- Pathfinder/engineering demonstration planning
- Servicing approach & partnership
- Partner interface development

Pre-Phase A

A successful flagship starts long-term work ***before*** staffing ramps up…

Establishing this work in Pre-Phase A isn’t the same as shifting Phase A early

This critical step between the Mission Concept Study and Phase A involves government, science community, industry, and other partners to coordinate efforts, refine the flagship’s definition, and prescribe how to proceed in Phase A

NASA and DoD Flagship Published Lessons Learned/Observed

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