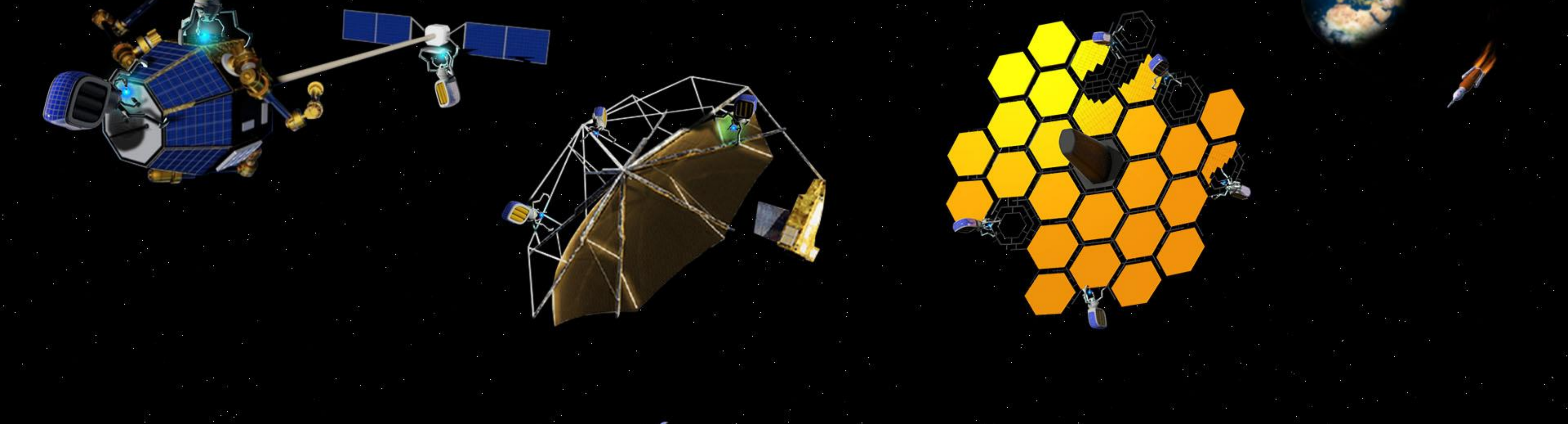
DARPA NOM4D Program Overview

Novel Orbital and Moon Manufacturing, Materials, and Mass-efficient Design



Dr. Andrew Detor

Program Manager, Defense Sciences Office

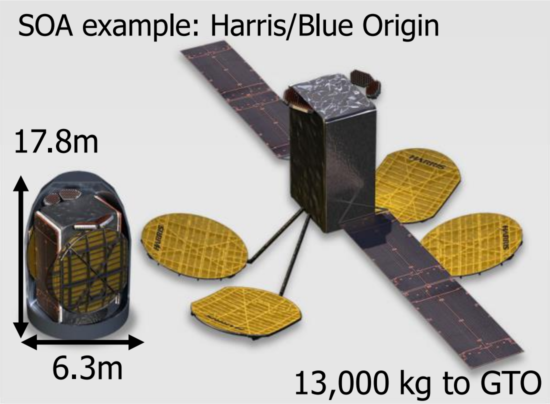
DARPA

"Tyranny of Launch" Limits Capability of Space-based DoD Missions

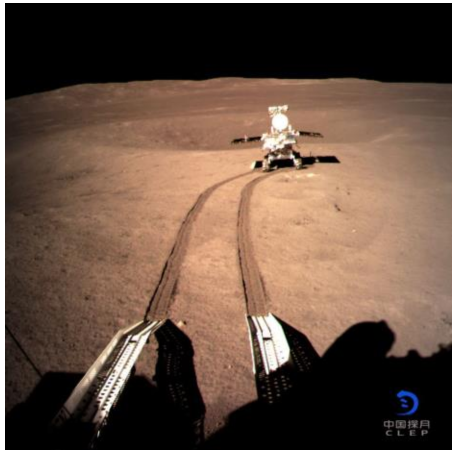
Payload allowance confines systems & missions

Mass and volume limits require system density to be less than ~100 kg/m^3

Limitations:
- Design and materials must survive launch (~100 minutes of >10 year life)
- Specific deployed area per mass launched constrained to ~1-2 m^2/kg



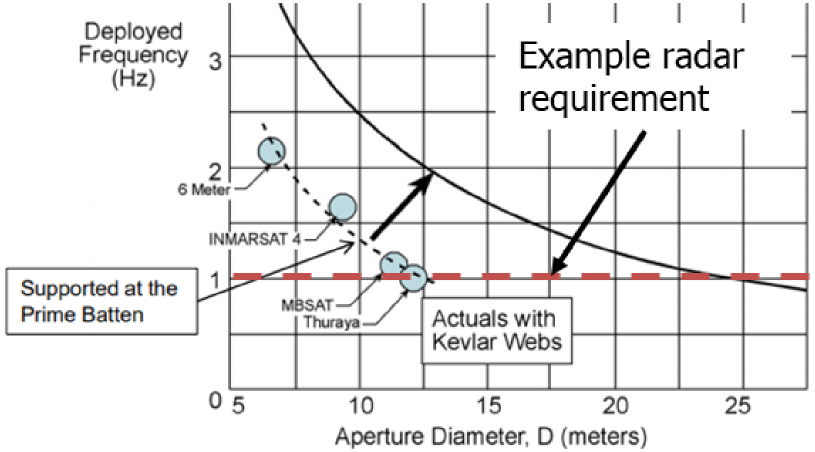
Space & lunar applications must be self-sufficient (power/fuel, mobility, dynamic response)



Limitation: DoD missions require enhanced properties to enable effective operations on-orbit (lighter structures with greater mobility)

Deployment has inherent size & operational limits

System stability defined by lowest resonant mode (e.g., 1 Hz)



Deployment and ground test requirements define structural efficiency

Northrup Grumman – Astro Aerospace

Limitation: Structural elements limited to ~100:1 aspect ratio, simple topologies, hinges, single-use mechanisms

Materials selection, manufacturing, and system design needed to mitigate restrictions imposed by launch

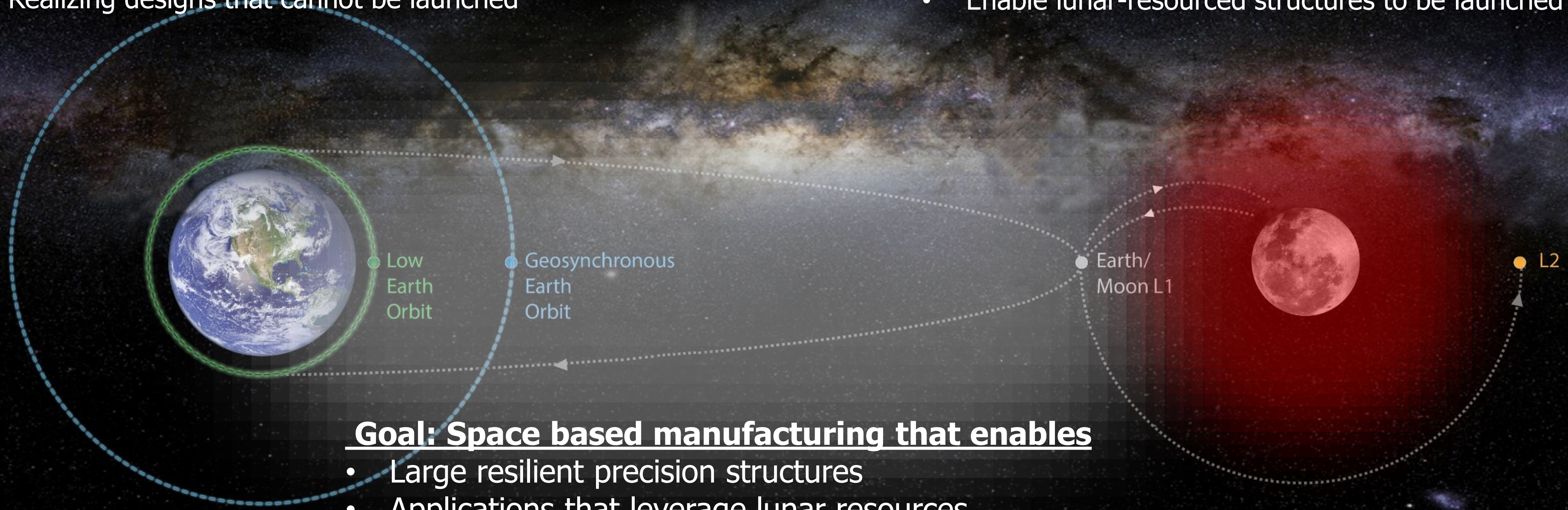
NOM4D Goal and Objectives

Space: Placing larger systems in higher orbits

- Large, scalable structures beyond deployment limits
- Realizing designs that cannot be launched

Moon: Develop foundations for new applications

- Determine range of capabilities based on ISRU
- Enable lunar-resourced structures to be launched



Goal: Space based manufacturing that enables

- Large resilient precision structures
- Applications that leverage lunar resources
- Designs for extreme mass efficiency across all domains

Today: Launch survival imposes large mass penalty on orbit, limits systems' ability to respond dynamically

⇨

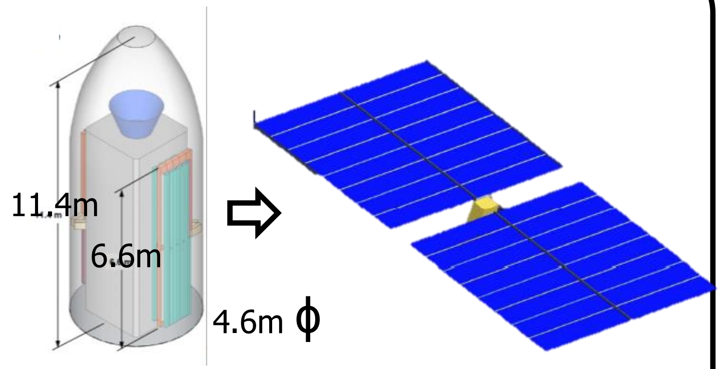
NOM4D: Manufacturing off-Earth maximizes mass efficiency and simultaneously enhances stability, agility and adaptability

Adaptive off-earth manufacturing needed to produce large space-based structures

ISRU: in-situ resource utilization

Exemplar missions illustrate enduring DoD needs

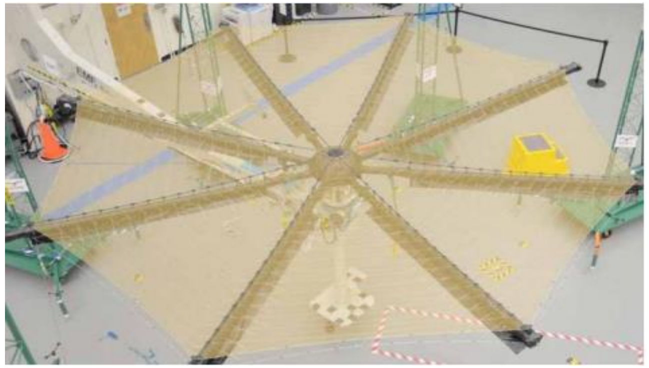
MW Solar Array[1]



Example design: *Gov Ref. Array (300 kW)*

- Folded high-modulus composite box beam members with tension stiffeners
- 22% structural mass fraction, 27% mass parameter
- Single launch, no EVA, 16 winglets
- Power per volume of 24 kW/m^3

Large RF Antennas[2]



Example design: *Harris 12m reflector*

- 12m projected diameter
- 4mm root mean square (RMS) on-orbit surface accuracy
- Stowed dimensions of 4.3m height and 0.7m diameter, weight 94.1 kg
- Stowed stiffness of 30 Hz, deployed 0.18 Hz

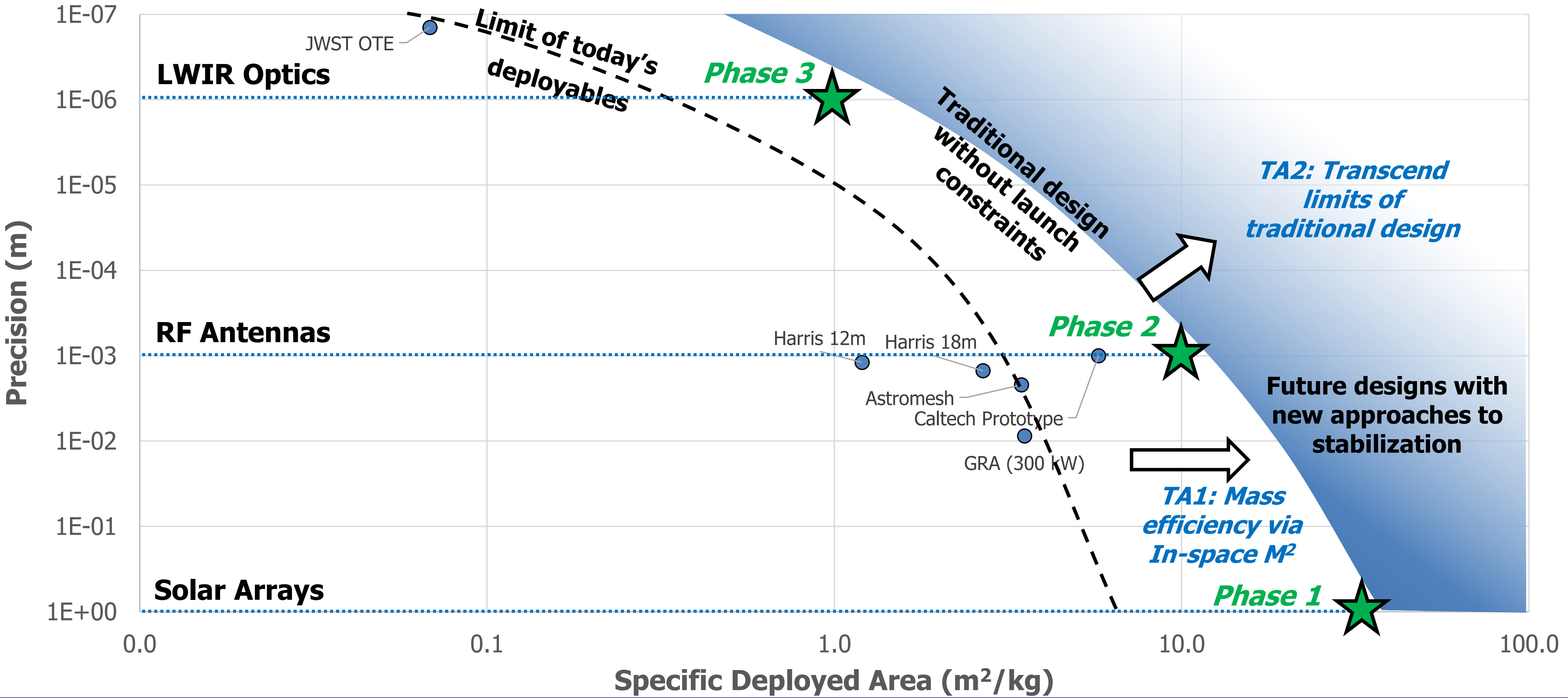
In-space Optics[3]

Example design: *James Webb Telescope*

- 18 hexagonal gold-coated beryllium reflectors, 6.5m total diameter
- Each reflector is 1.32m in diameter and weighs >20kg (>40kg with motors)
- 126 small motors to adjust optics
- Reflectors aligned to ~10's of nm accuracy using wavefront sensing

1) Reference solar array design: Pappa, R. S. et al., "Solar Array Structures for 300 kW-Class Spacecraft," Presented at the Space Power Workshop, April 24, 2013. PDF: https://core.ac.uk/download/pdf/42735272.pdf
2) Reference RF antenna design: Thomson, M.. (1999). The AstroMesh Deployable Reflector. Antennas and Propagation Society International Symposium. 3. 1516 - 1519 vol.3. 10.1109/APS.1999.838231. and https://www.l3harris.com/sites/default/files/2020-06/sas_ss_prebuilt_12m_unfurlable_mesh_reflector.pdf
3) Reference LWIR optic design: https://jwst.nasa.gov/content/observatory/ote/mirrors/index.html

NOM4D Impact: On-orbit Manufacturing to Defeat the Tyranny of Launch



New materials, manufacturing, and designs can enable 5-10x larger structures through better mass utilization

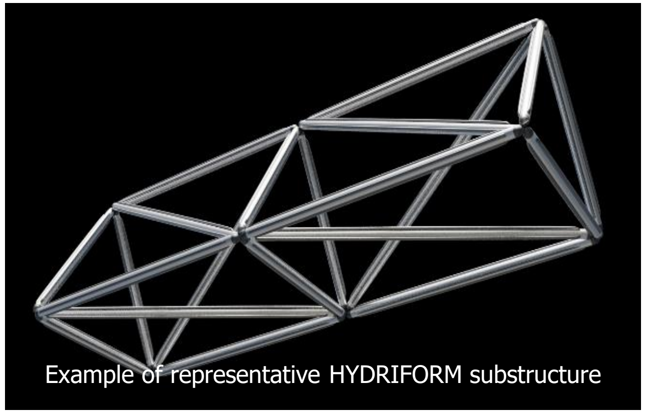
JWST OTE: James Webb Space Telescope Optical Telescope Element
GRA: Government Reference Array
LWIR: longwave infrared RF: radio frequency

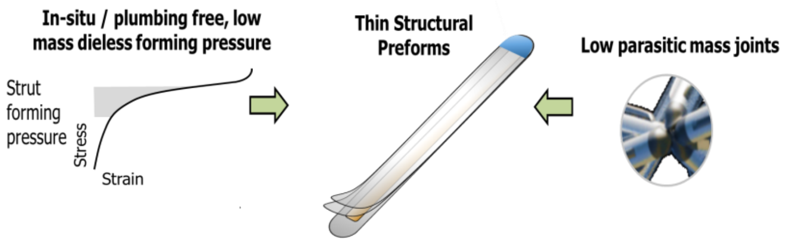
Brief overview of performer concepts

TA1/FA1: Large Earth-derived precision structures

HRL

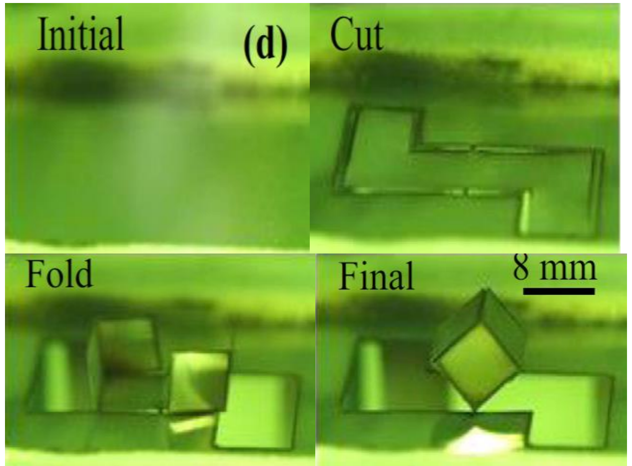
- Hydride-Based Die-less Metal Forming
- Cold Braze Joining
- Zero Thermal Expansion Laminates


Example of representative HYDRIFORM substructure



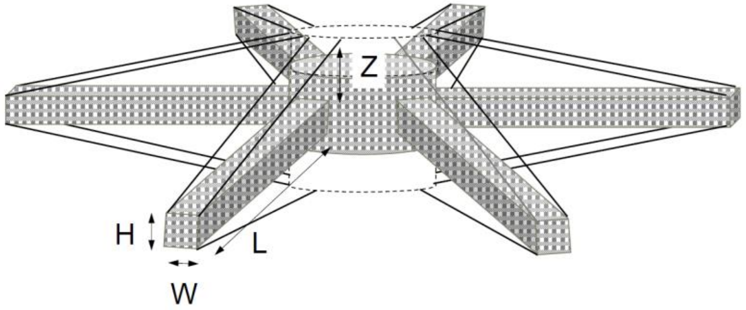
University of Florida

- Automated laser cutting, folding, and welding of arbitrary feedstock
- Coupled finite element thermomechanical model with material-process model
- Enable accurate prediction of bend angle and material properties for the first time

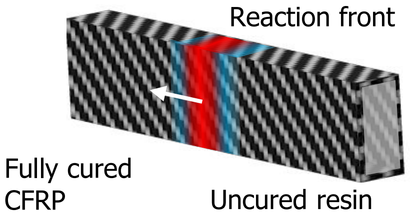


UIUC

- Self-energized frontal polymerization (FP) chemistry
- Rapid extrusion of long hollow CFRP beams
- Numerical modeling of the fabrication process in space and the structural mechanics



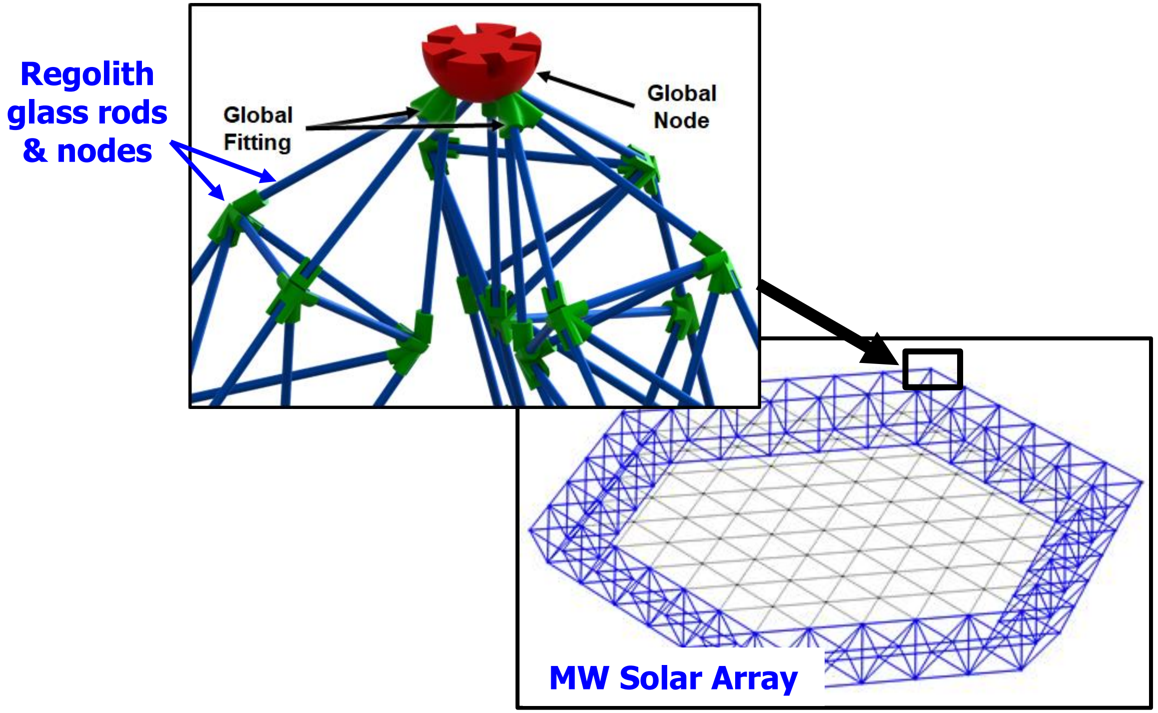
CFRP strut (beam) extrusion



TA1/FA2: Lunar-derived precision structures

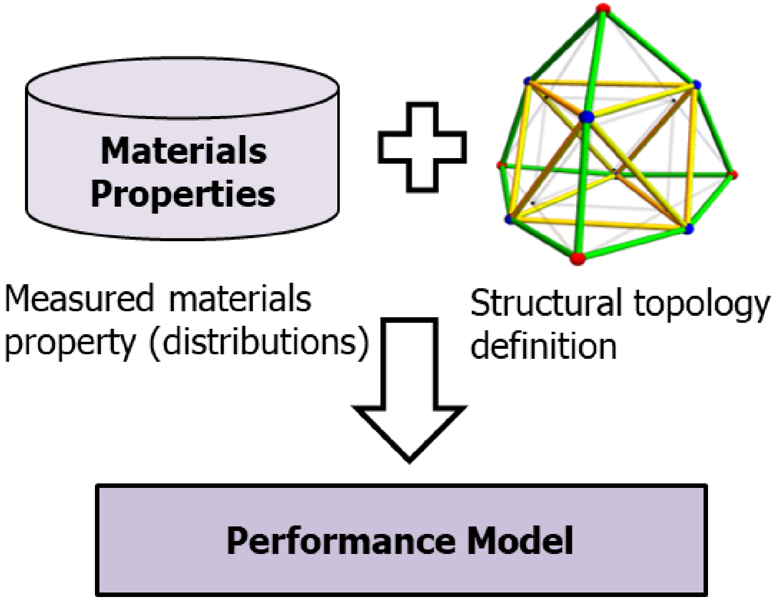
Physical Sciences

- Goal: Demonstrate the viability of in-space manufacture of large, mass-efficient structures from melted and reformed lunar regolith
  - Design, fabricate, and test a novel lunar base part-production platform (Molten Regolith Fabricator (MRF))
  - Demonstrate proof of principle via construction of a precise 2m rod-truss from regolith glass rod (extruded) and nodes (cast)
  - Demonstrate strength and structural figure characteristics



Teledyne

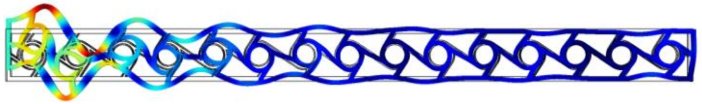
- Build materials properties database of additive-modified regolith simulants and use knowledge to develop alloy composition guidelines for authentic lunar regolith
- Process natural or refined regolith into structural materials via susceptor assisted microwave casting
- Zero Thermal Expansion (ZTE) structural unit cells



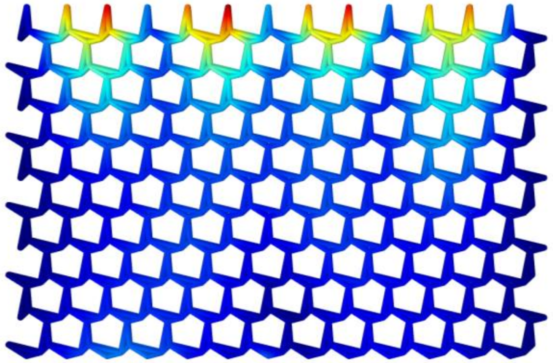
TA 2: Mass efficient designs for in space manufacturing

University of Michigan

- Programmable stiffness and stress distribution of high mass-efficiency structures and topological protection for local damages
- Metadamping emergence for broadband high passive damping and high stiffness for precision operation
- Novel solutions for shape and thermal stability and structural efficiency



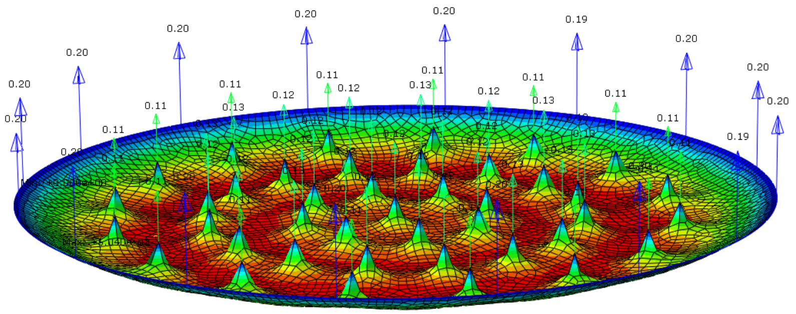
Metadamped tetra-chiral beam

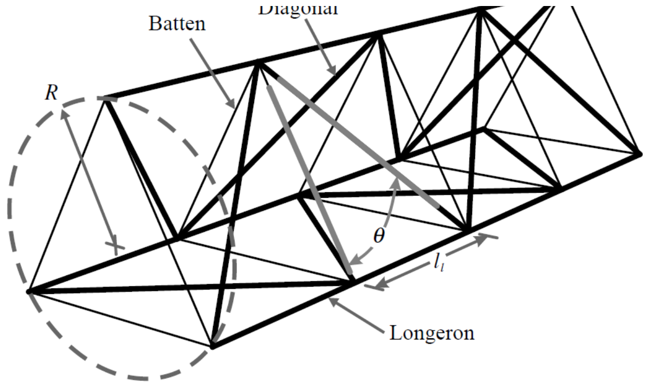


Topological bilayer Kagome network

Opterus

- Tension alignment enables precision without zero CTE materials
- Extremely low structural mass fraction through low frequency structures
- Resilience through redundant structural members
- Distributed thrusters and actuators move system without deformations





Caltech

- Ultralight Deployable Bending-Stiff Structures
- Ultralight Metamaterial Plates
- Targeted Innovations for Areal Density of 80 g/m2 @ D=100 m

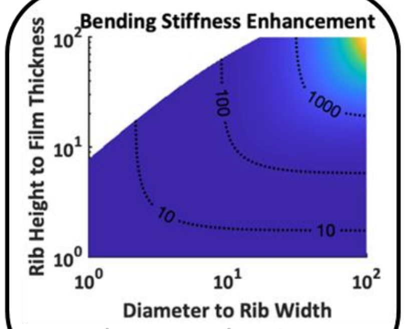
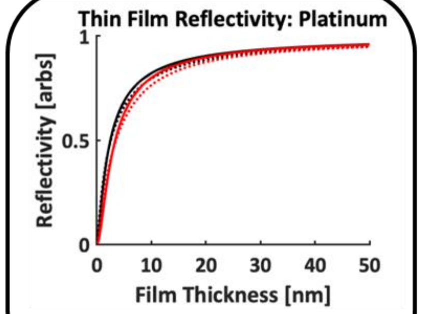
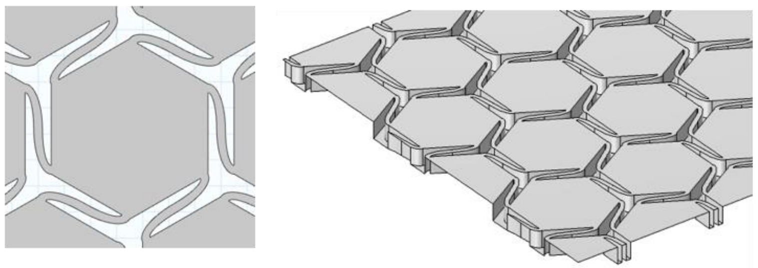


Plate mechanics



Thin film reflectivity



COMSOL

New corrugation pattern

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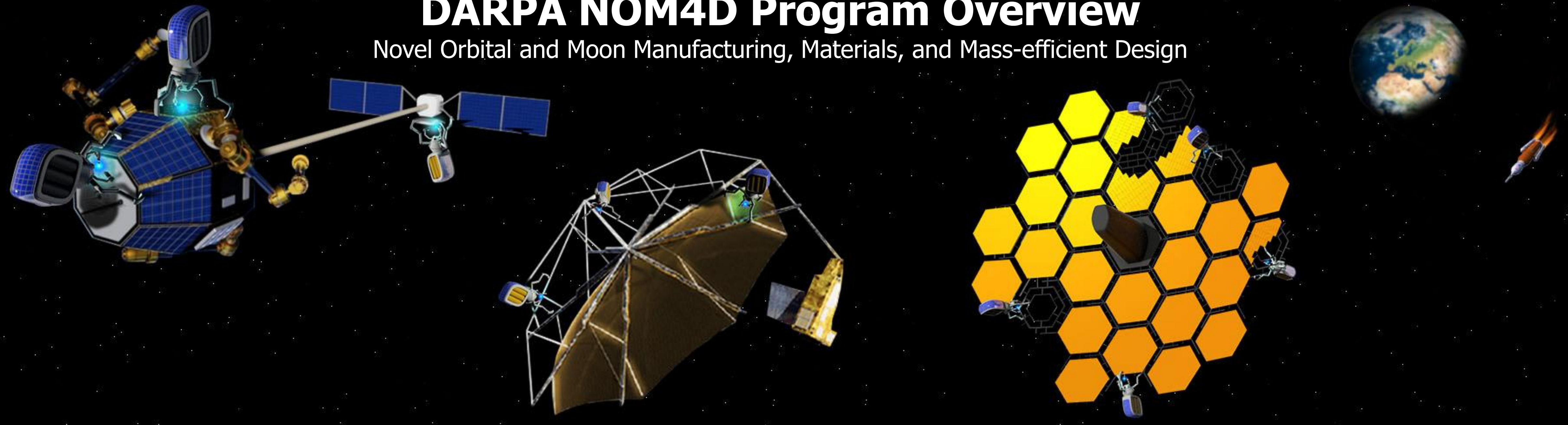

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