Autonomous Systems & Robotics for Lunar Surface Infrastructure

EXPLORESPACE TECH
TECHNOLOGY DRIVES EXPLORATION

CLB.PNL-49: Infrastructure to Stay – Moon
AIAA ASCEND
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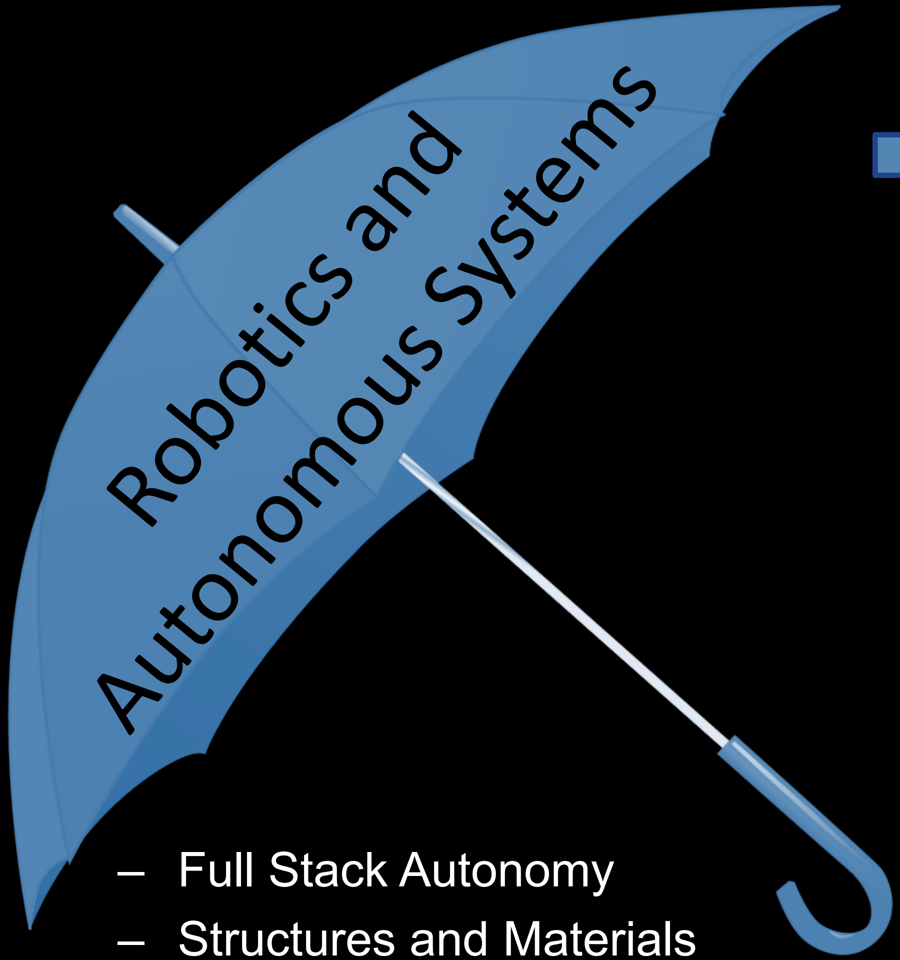
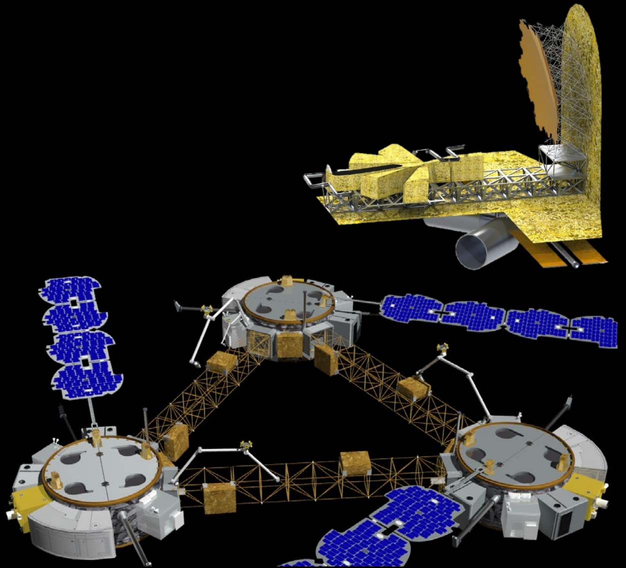
Near-Term Envisioned Future:
Bridge from STMD Demonstrations to Sustained Lunar Surface Operations



- Full Stack Autonomy
- Structures and Materials
- Modeling and Simulation
- System Architecture and Analysis

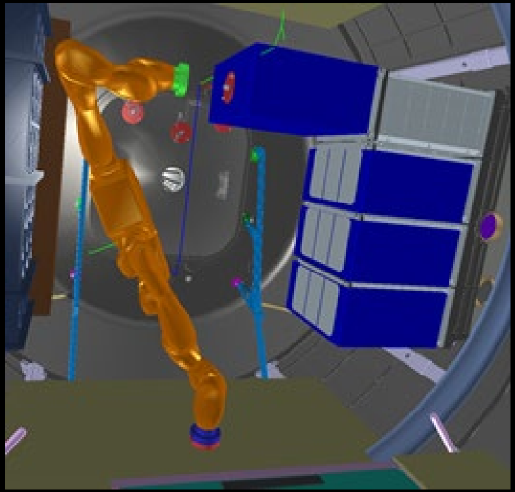
- Persistent Space Assets
  - Transport
  - Observatory
  - Platforms



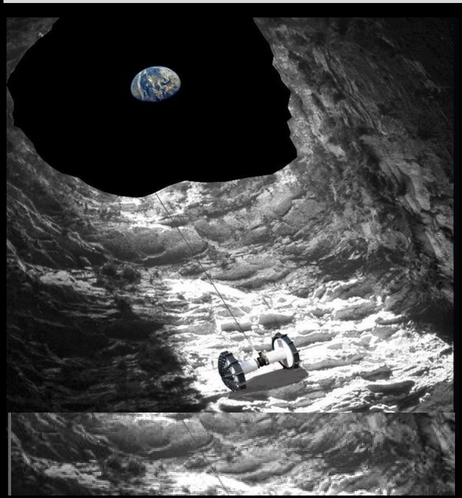
- Persistent Surface Infrastructure
  - Habitats and Safe Havens
  - Autonomous Mobility
  - Launch and Landing
  - Power and Data Distribution

EXPLORE: Develop **advanced robotics** and spacecraft autonomy technologies to enable and augment science/exploration missions

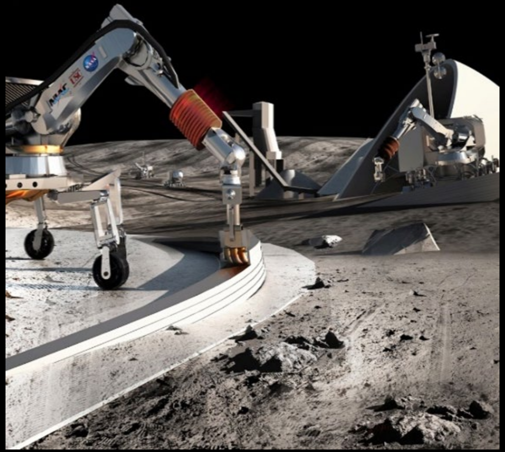
ROBOTIC CARETAKING INSIDE HABITATS AND SPACECRAFT



ROBOTIC EXPLORATION OF EXTREME ENVIRONMENTS



ROBOTIC CONSTRUCTION OF SURFACE INFRASTRUCTURE



ROBOTIC RESOURCE EXTRACTION + TRANSPORT

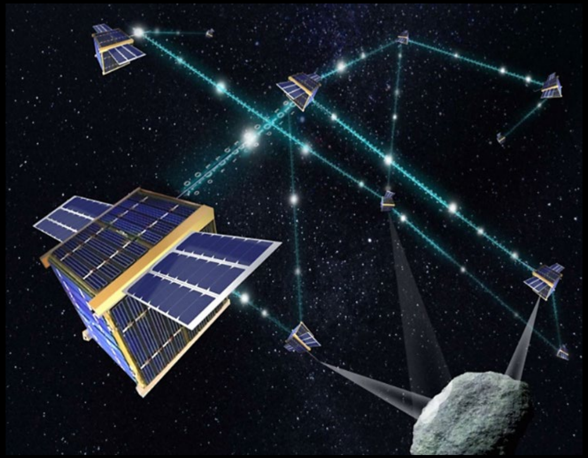
Technology Objectives

- **Remotely operated intra-vehicular robotics for maintenance and utilization** (4,000+ hr/yr) of uncrewed (up to 90% time) exploration spacecraft and surface habitats
- **Robust robot mobility for extreme access**: surfaces (5,000 km life-cycle drive), deep interiors (up to 25 km) through rock and cryogenic ice, and handling of dangerous topography (up to 90° slopes)
- **Durable, self-maintainable robotics for heavy-duty surface work**: bulk excavation (100-400 metric tons), material transport (500-600 km/yr), and surface construction (15,000 kg carrying capacity)

All activities depicted not currently funded or approved. Depicts "envisioned future" to guide technology vision.

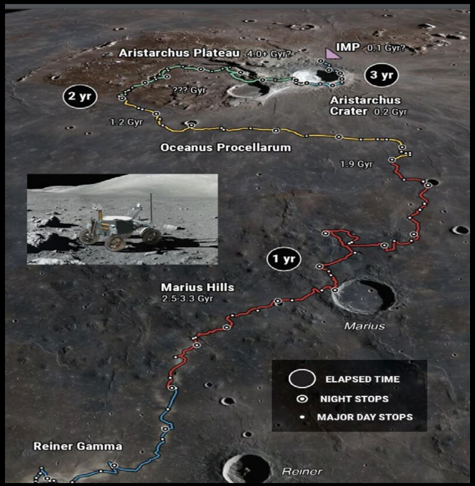
EXPLORE: Develop advanced robotics and spacecraft autonomy technologies to enable and augment science/exploration missions

Autonomous Multi-Spacecraft System for Distributed Science Measurements

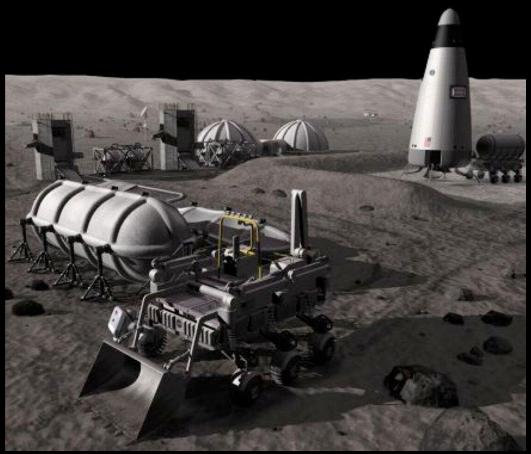


Autonomous Fail-Active, High-Tempo Science Missions

Autonomous High Progress Rate Science Rover



Autonomous Continuous Lunar Surface Operations



Technology Objectives

- **Cooperative multi-spacecraft system with efficient human teaming** for interdependent and distributed action (system operable as a single "entity")
- **Self-adaptive and fail-active autonomy for high-tempo missions** in high-risk environments (example: guaranteed acquisition of 5 high-value samples during 20-day Europa mission)
- **High progress rate self-driving planetary rover** with cost-effective mission control (1/10 cost of current practice) and increased performance (10x productivity / time) for long range (450 km/yr) or continuous worksite operations (750 km/yr)

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STMD Strategic Framework

Lead	Thrusts	Outcomes
Ensuring American global leadership in Space Tech • Advance US Space technology innovation and competitiveness in a global context • Encourage technology driven economic growth with an emphasis on the expanding space economy • Inspire and develop a diverse and powerful US aerospace technology community	**Go** Rapid, Safe, and Efficient Space Transportation	• Develop nuclear technologies enabling fast in-space transits. • Develop cryogenic storage, transport, and fluid management technologies for surface and in-space applications. • Develop advanced propulsion technologies that enable future science/exploration missions.
	Land Expanded Access to Diverse Surface Destinations	• Enable Lunar/Mars global access with ~20t payloads to support human missions. • Enable science missions entering/transiting planetary atmospheres and landing on planetary bodies. • Develop technologies to land payloads within 50 meters accuracy and avoid landing hazards.

	Live
	Sustainable Living and Working Farther from Earth
		• Develop exploration technologies and enable a vibrant space economy with supporting utilities and commodities
		  • Sustainable power sources and other surface utilities to enable continuous lunar and Mars surface operations.
		  • Scalable ISRU production/utilization capabilities including sustainable commodities on the lunar & Mars surface.
		  • Technologies that enable surviving the extreme lunar and Mars environments.
		  • Autonomous excavation, construction & outfitting capabilities targeting landing pads/structures/habitable buildings utilizing in situ resources.
		• Enable long duration human exploration missions with Advanced Habitation System technologies.

	Explore Transformative Missions and Discoveries	• Develop next generation high performance computing, communications, and navigation. • **Develop advanced robotics and spacecraft autonomy technologies to enable and augment science/exploration missions.** • Develop technologies supporting emerging space industries including: Satellite Servicing & Assembly, In Space/Surface Manufacturing, and Small Spacecraft technologies. • Develop vehicle platform technologies supporting new discoveries. • Develop transformative technologies that enable future NASA or commercial missions and discoveries.

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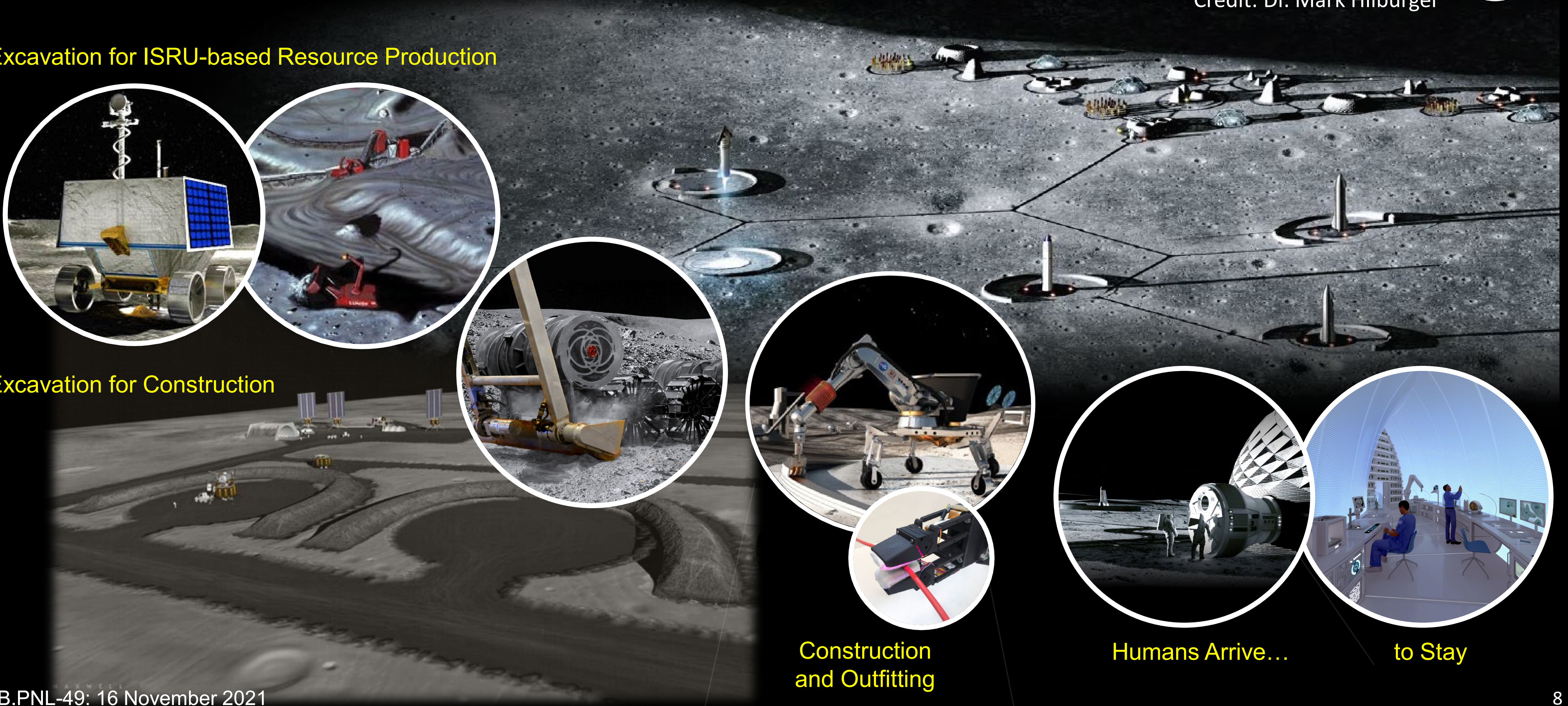
Autonomous Lunar Excavation, Construction, & Outfitting (ECO)

targeting landing pads, structures, habitable buildings… utilizing in-situ resources

Credit: Dr. Mark Hilburger



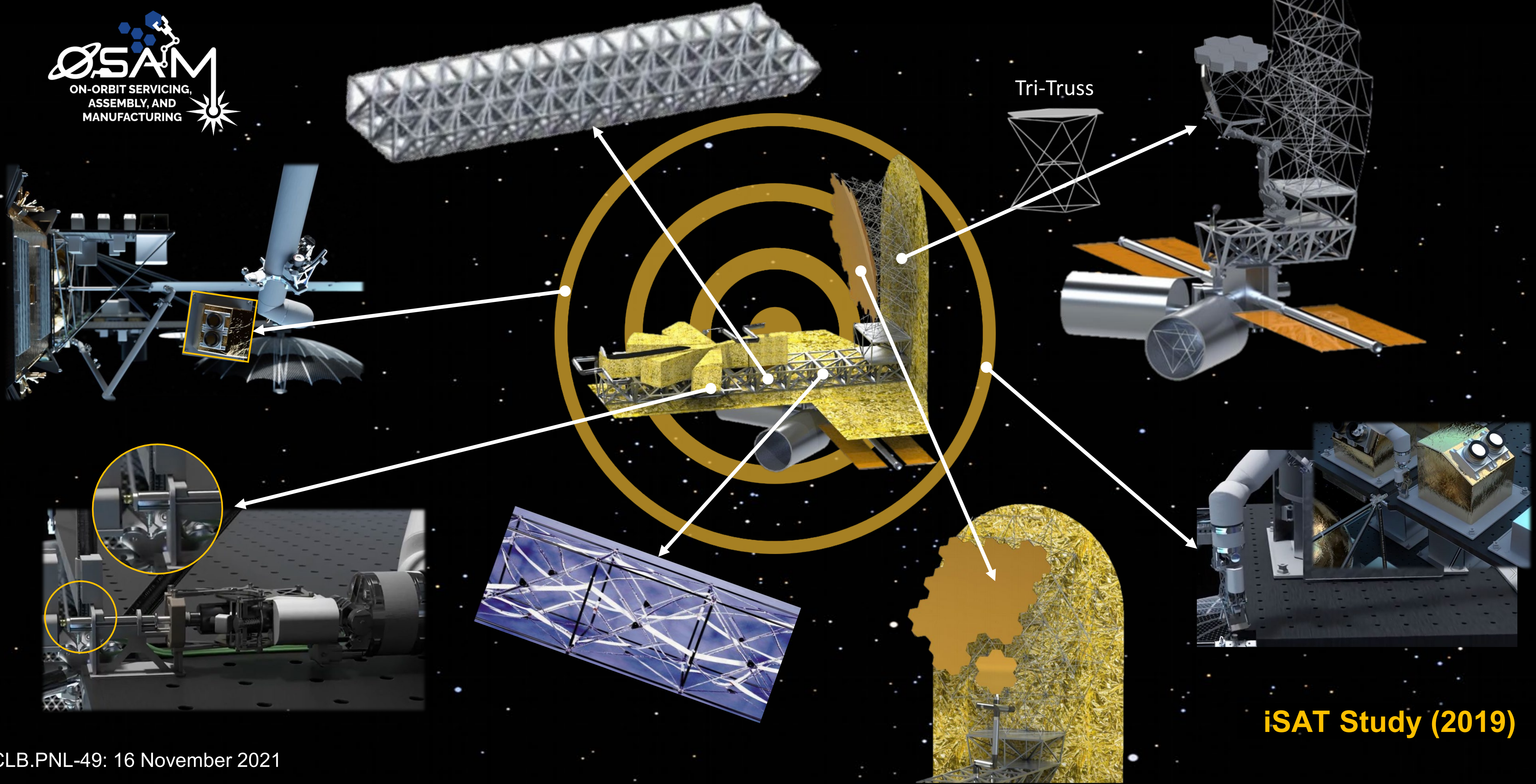
AS&R Technology Taxonomy

- **Self- and Situation Awareness**
  - Sensing and Perception
  - State Estimation and Monitoring
  - Object, Event, Trend, & Activity Recognition
  - Force and Tactile Sensing
  - Remote Sensing
  - Onboard Science Data Analysis
  - Knowledge and Model Building
  - Hazard Assessment
  - Anomaly Detection
- **Mobility**
  - Extreme terrain Mobility
  - Below Surface Mobility
  - Above-Surface Mobility
  - Small-Body and Microgravity Mobility
  - Surface Mobility
  - Robot Navigation
  - Mobility Components
  - GN&C Algorithms
- **Manipulation**
  - Manipulator Components
  - Dexterous Manipulation
  - Control of Contact Dynamics
  - Mobile Manipulation
  - Sample Acquisition and Handling
  - Grappling
- **Multi-Agent Cognition and Operations**
  - Collaborative Mobility
  - Collaborative Manipulation
  - Distributed Cooperation and Collaboration
  - Agent Coordination
  - Joint Knowledge and Understanding
  - Behavior and Intent Prediction
  - Goal and Task Negotiation
  - Operational Trust Building
- **Human System Interaction**
  - Multi-modal Interaction
  - Supervisory Control
  - Proximate Interaction
  - Intent Recognition and Reaction
  - Common and Standard HSI
  - Remote Interaction
- **Reasoning and Acting**
  - Mission Planning
  - Activity and Resource Planning and Scheduling
  - Motion Planning
  - Execution and Control
  - Fault Diagnosis and Prognosis
  - Fault Response
  - Learning and Adapting
- **Systems Engineering and Integrity**
  - Modularity, commonality, and interfaces
  - Verification and Validation
  - Modeling and Simulation
  - Architecture and Frameworks
  - Safety and Trust
  - Test and Evaluation
  - Operational Assurance
  - Design Tools

- Includes elements from multiple areas (TX4, TX10, TX11) of the 2020 NASA Technology Taxonomy
- Achieving a specific functional capability generally requires multiple technology areas
- The technologies used from each area depends on mission requirements, concept of operations, program constraints (budget, schedule, etc.), risk tolerance, management approach, etc.

Example: AS&R Technology for In-Space Assembly

Autonomous, cooperative, durable, and high-progress rate robotics



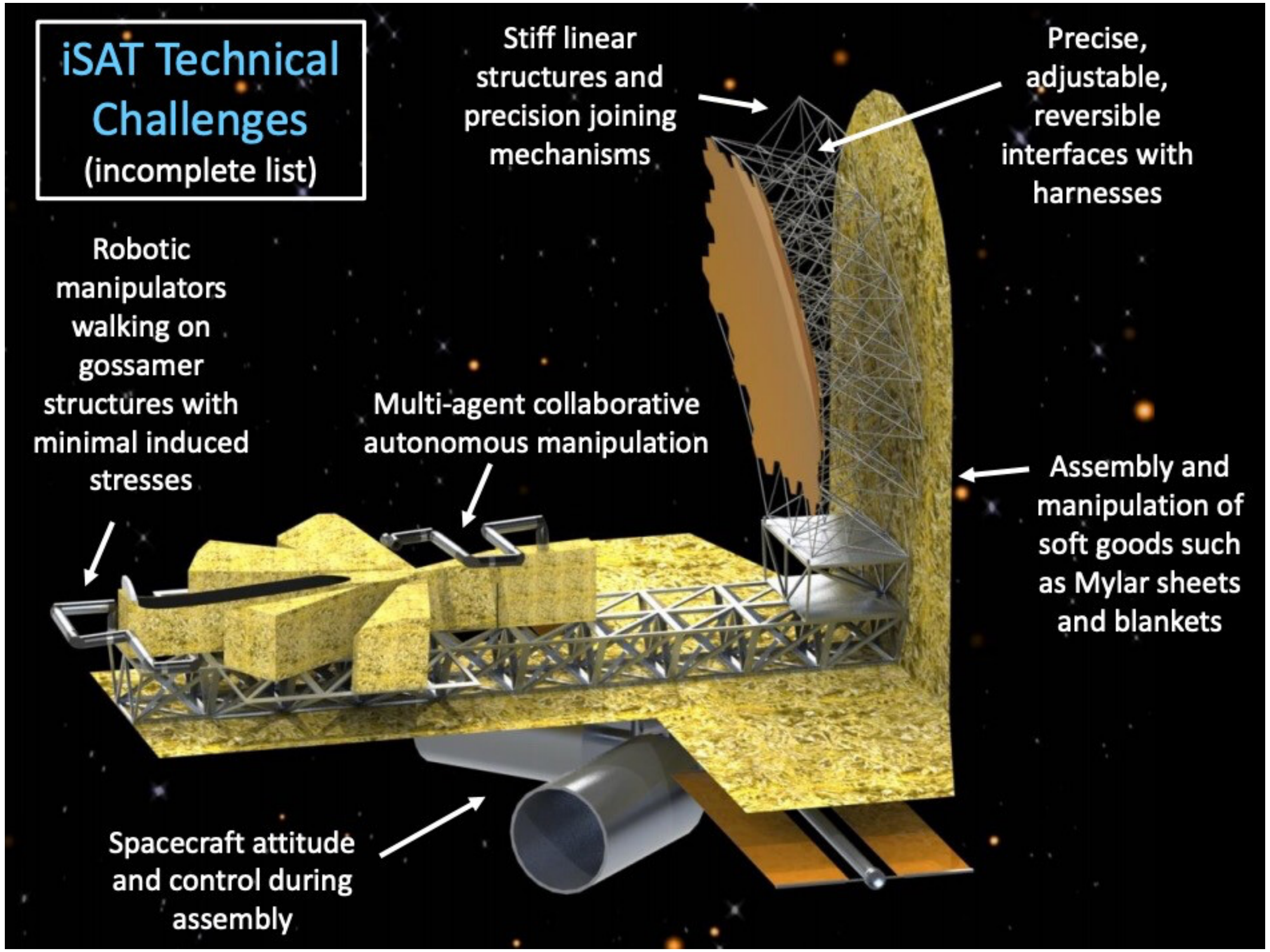
iSAT Study (2019)

Example: AS&R Technology for 20m iSAT Telescope (2019)

- 5 of the top 6 top technical challenges involve autonomous systems and robotics
- iSAT study identifies 14 In-Space Assembly (ISA) Capability Needs. 12 of these needs involve ASR technology:

1. Deployable Modules
2. Structural Assembly
3. Connecting Utilities
4. Ability to Disjoin
5. Sensing, ModSim, & Verification
6. Interoperability
7. Automation/Autonomy
8. Precision
9. Adaptive Correction
10. Design
11. Tunability
12. Stability
13. Standard Interfaces
14. Docking/Berthing

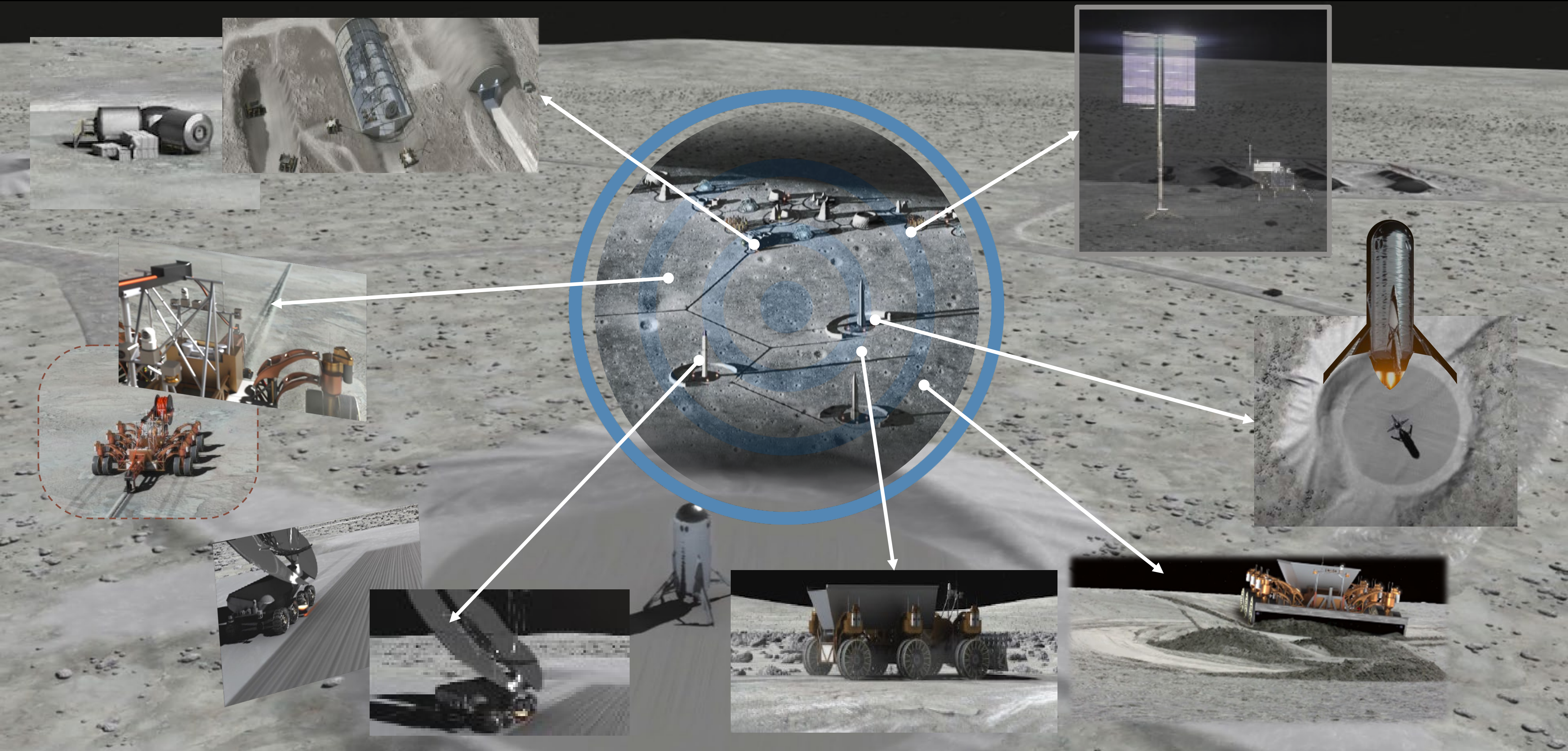
- 7. “Automation/Autonomy” Need:
  - 7.1 Intelligence to make decisions correctly without human input.
  - 7.2 Intelligence for full autonomy
  - 7.3 Fail-safe modes of behavior on failure detection
  - 7.4 Multi-agent autonomy
- Autonomy need 7.3 is the most important overall iSAT need (ranked #1 by tri-agency team)



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

Example: AS&R Technology for Lunar Site Preparation

Autonomous, cooperative, durable, and high-progress rate robotics



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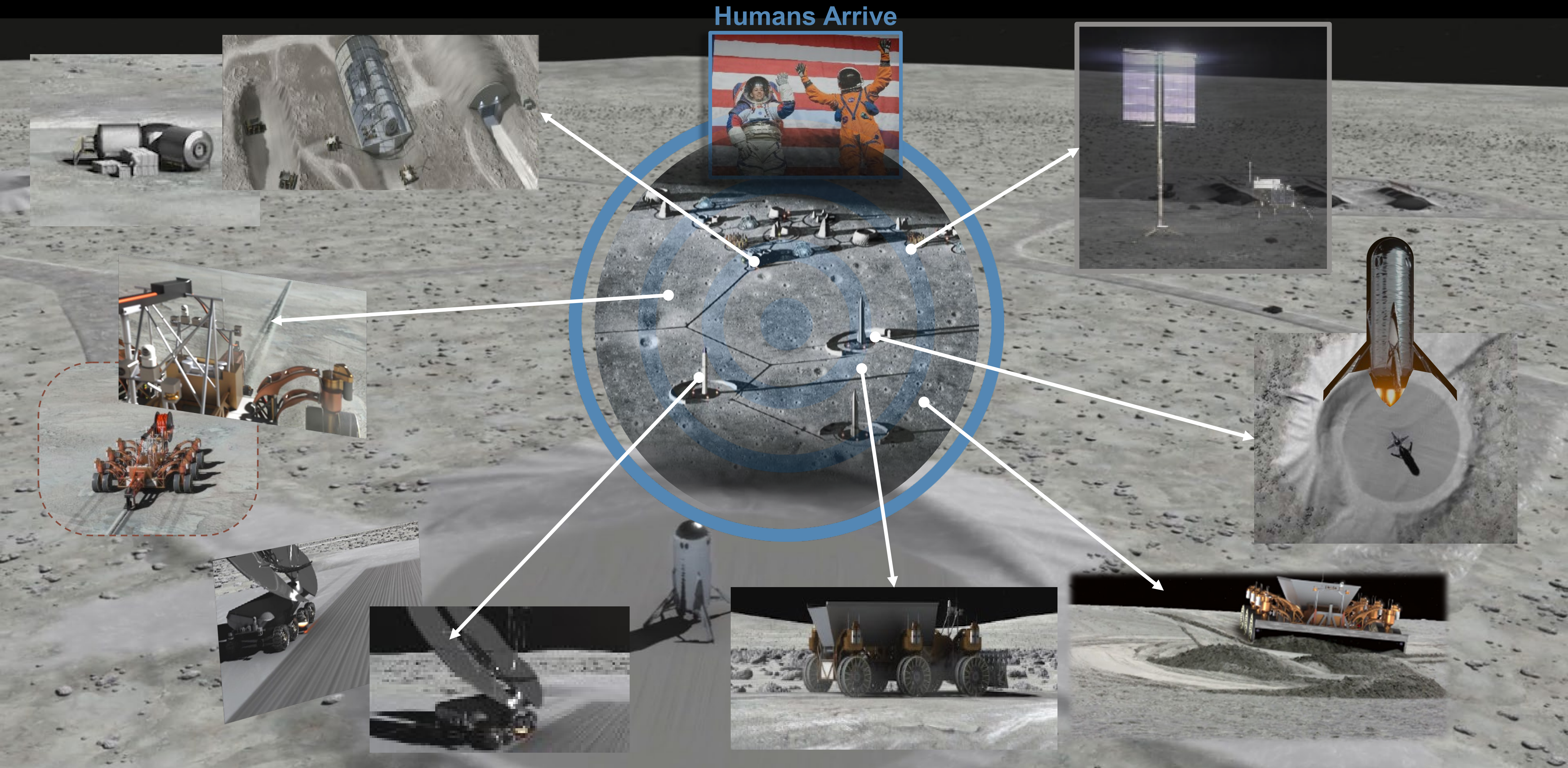
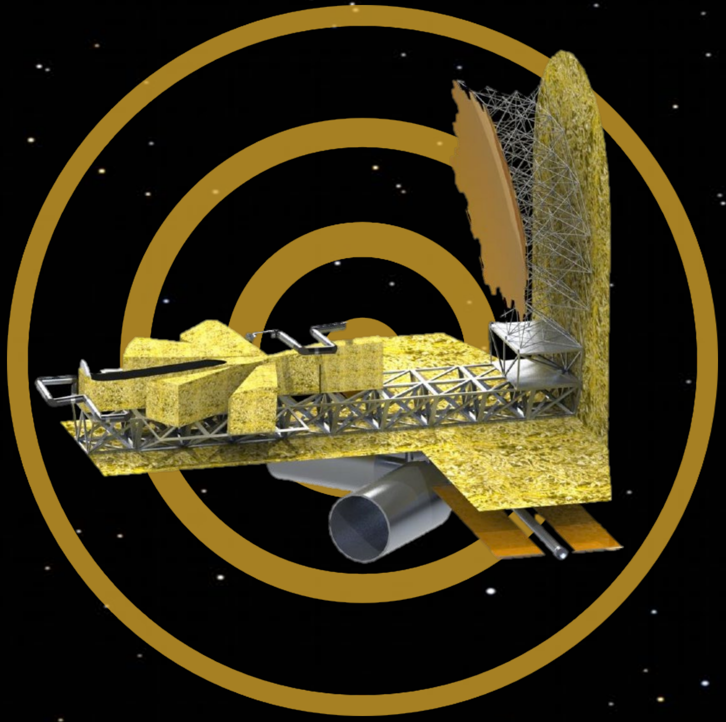
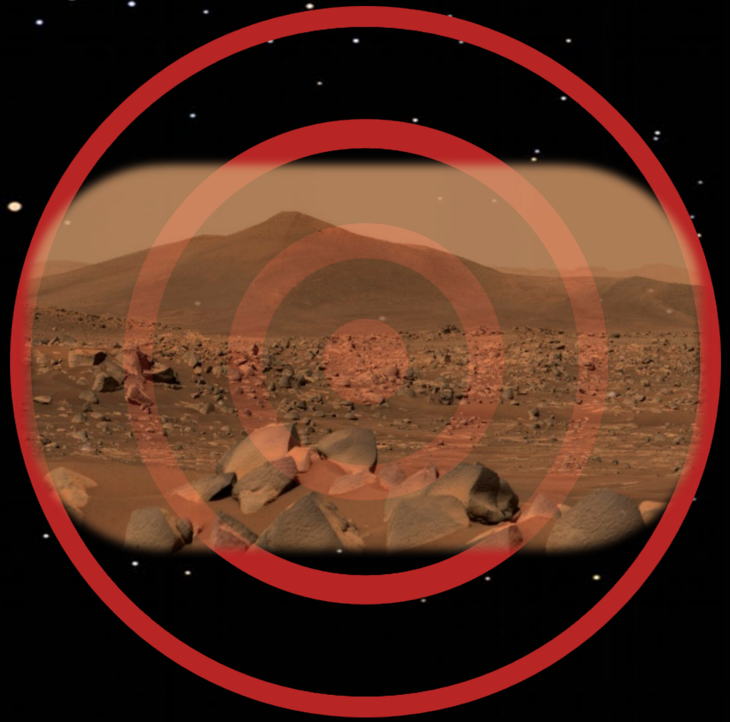
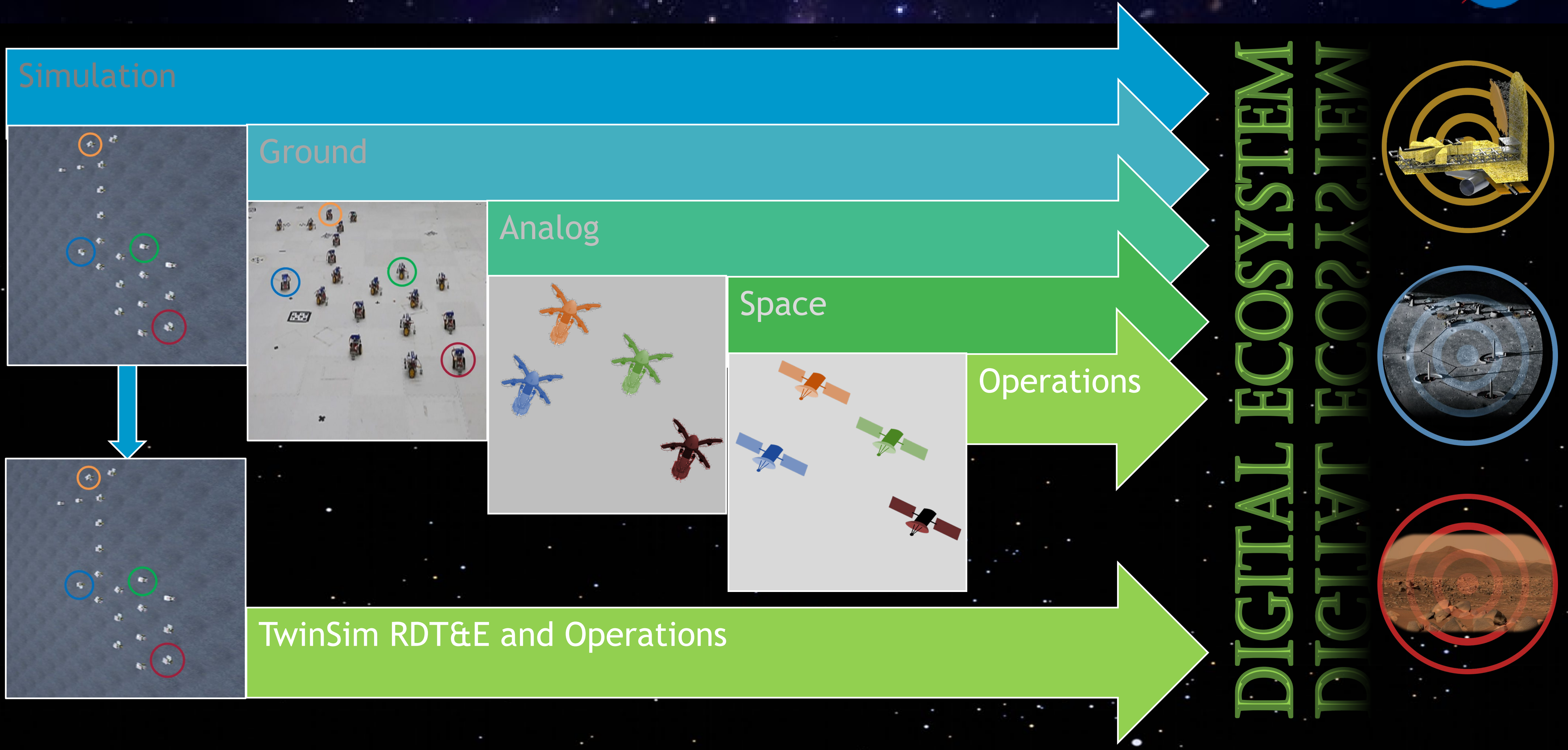


AS&R RDT&E Pipeline?





AS&R RDT&E Pipeline

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