Research at Ho Research Group (Space Systems Optimization Group)

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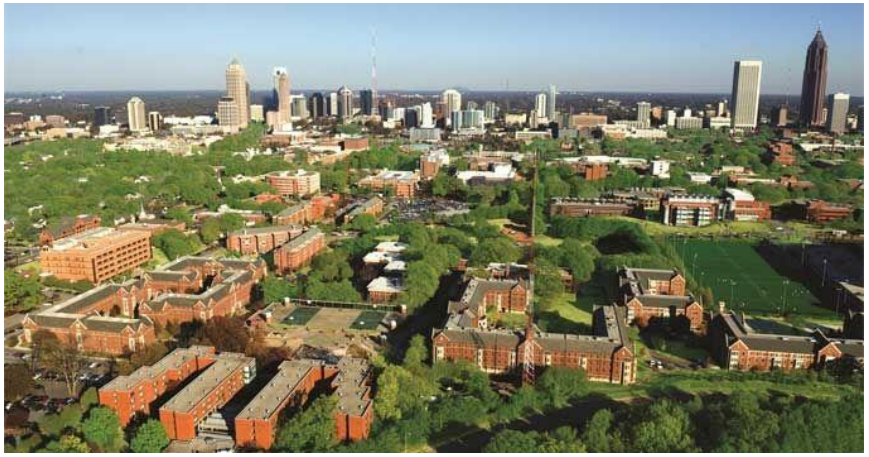
Introduction

Koki Ho

- Assistant Professor
  - at the Georgia Institute of Technology (from Aug. 2019)
  - at the University of Illinois at Urbana-Champaign (until Aug. 2019)
- Chair, AIAA Space Logistics Technical Committee
- Ph.D. in Space Systems, MIT
- Bachelor's and Master's degrees, University of Tokyo, Japan
- NASA Jet Propulsion Laboratory, Caltech (Sep. – Dec. 2015)
- Airbus Defense and Space, Germany (Sep. 2010 – Mar. 2011)

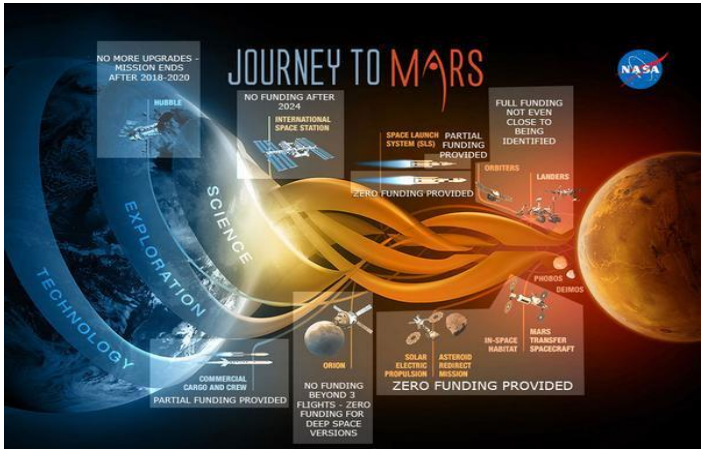


Credit: UIUC, Georgia Tech

Research at Ho Research Group

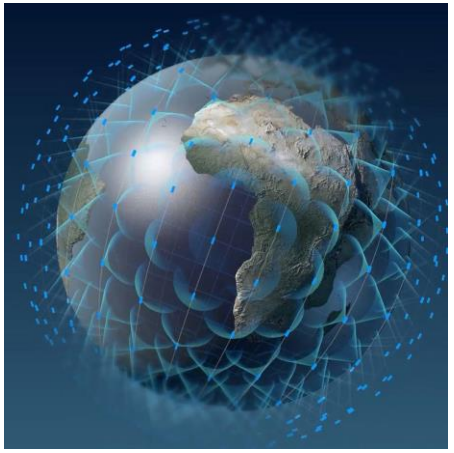
Space Systems Optimization Group

Mission: To develop optimization methods to tackle complex space mission design and systems engineering challenges.



Human Space Exploration Campaign and Its Logistics

On-Orbit Servicing Infrastructure

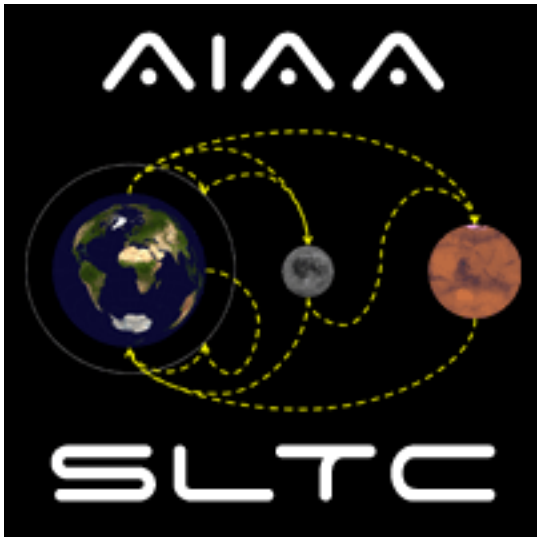


SmallSat Constellation

Credit: NASA, DARPA, OneWeb

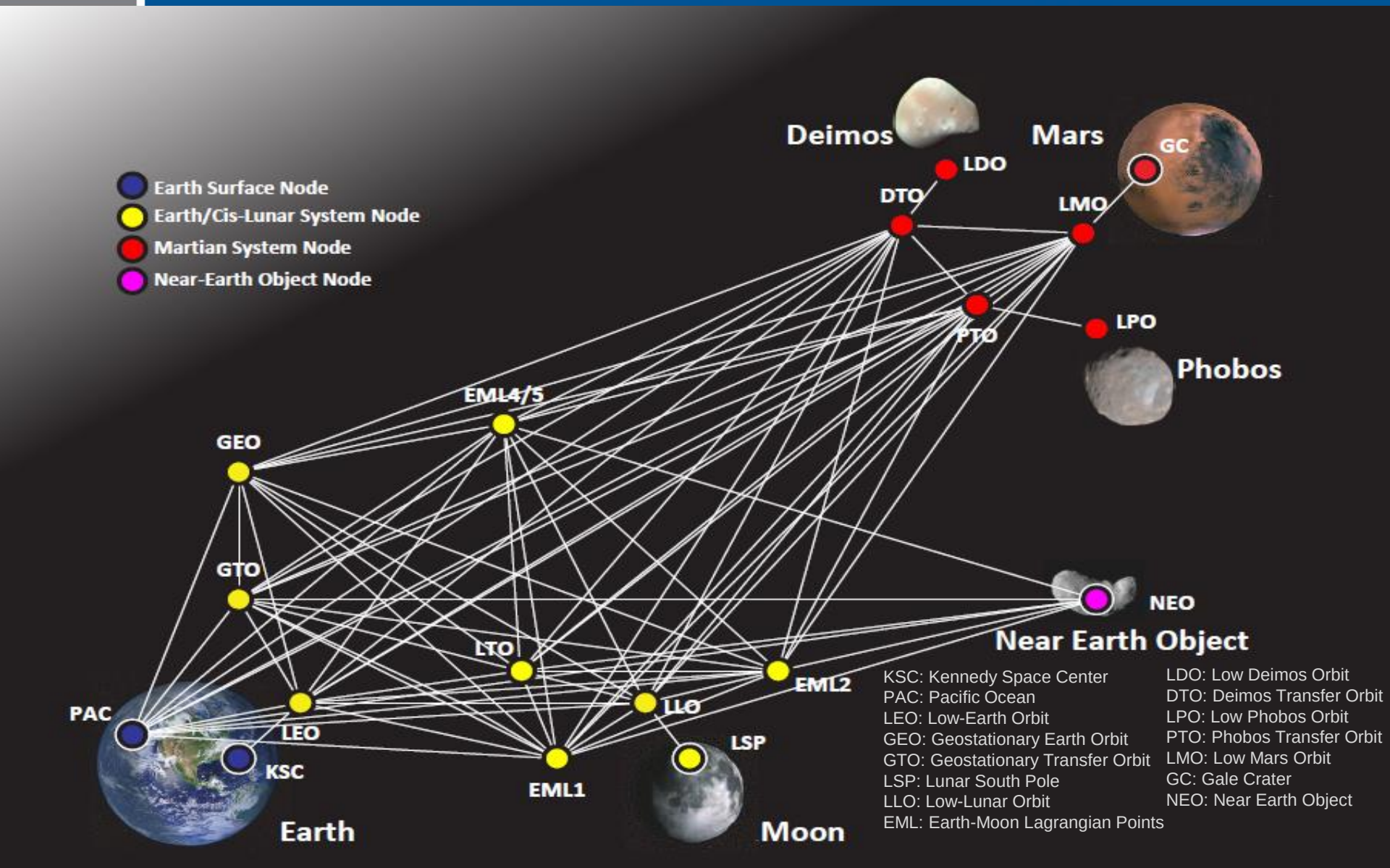
Space Logistics

Space Logistics: The theory and practice of driving space system design for operability, and of managing the flow of material, services, and information needed throughout a space system lifecycle (AIAA Space Logistics Technical Committee)

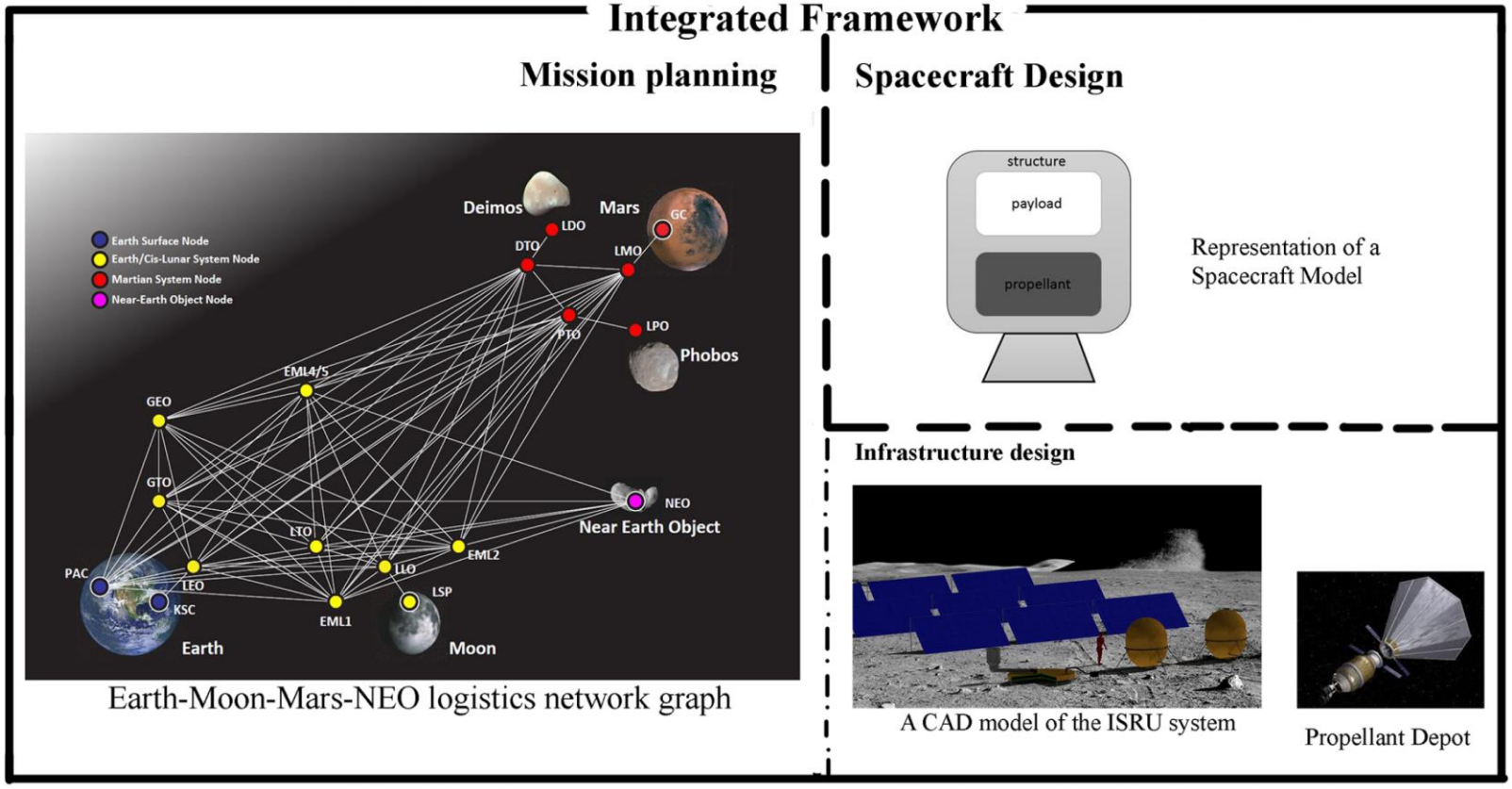


Credit: AIAA

Space Logistics Research 1: Campaign-Level Space Mission Design



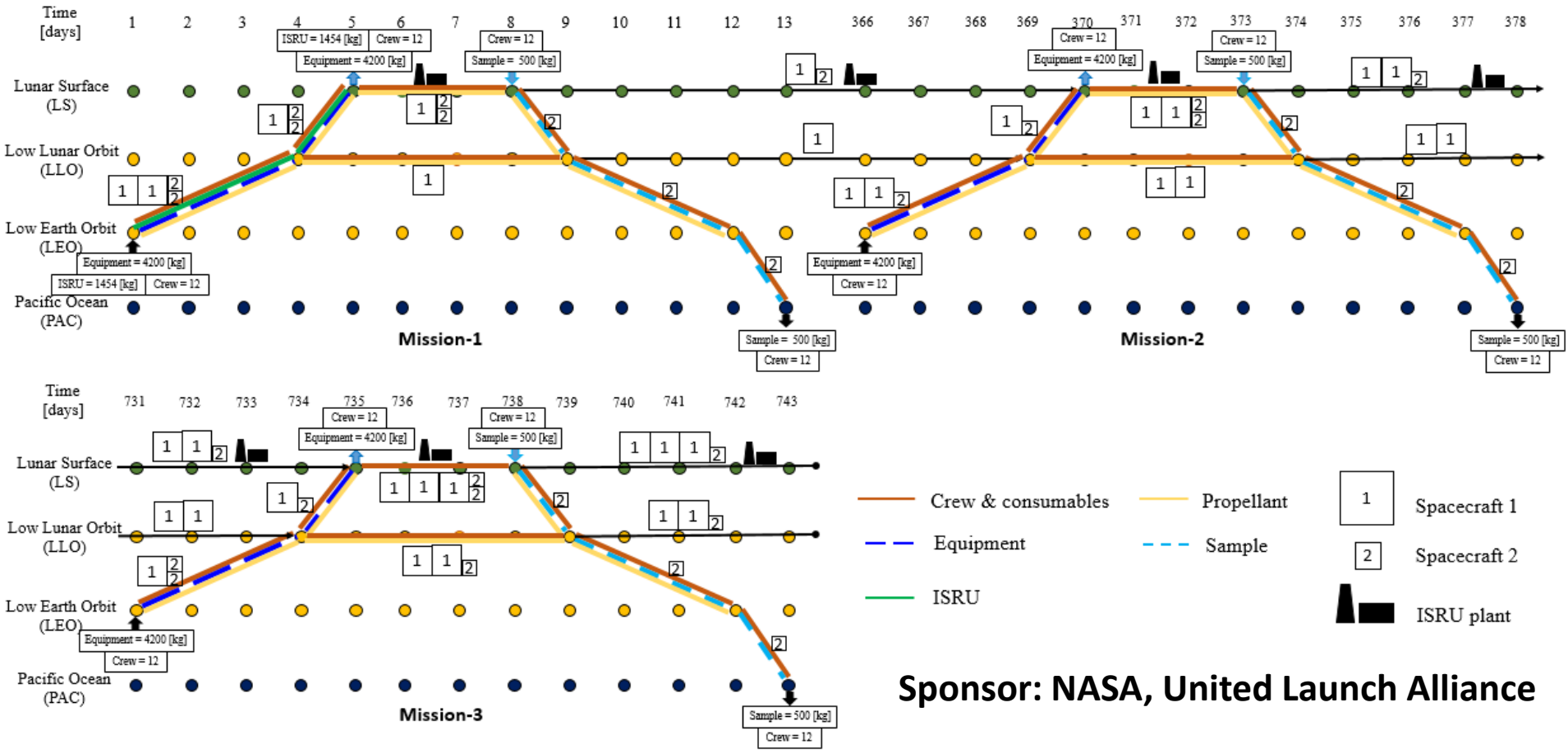
Integrated Campaign-Level Space Mission Design



We aim to optimize architecture and design of the entire campaign:

- Commodity transportation flow for payload, propellant, consumables, etc.
- Sizing (or choice) of spacecraft/infrastructure for each leg of the mission
- Mission timelines and sequences over the entire campaign

Example Results



Sponsor: NASA, United Launch Alliance

Proposed tool can be <u>an effective decision support tool for *automated* space campaign design and analysis</u> considering the deployment and utilization of the infrastructure elements, e.g., ISRU, depots, etc.

Space Logistics Research 2: On-Orbit Servicing Modeling

Manufacturing

Maintenance

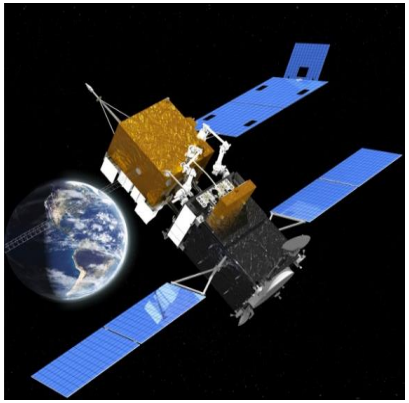
Lifecycle

Design

Sales

End of life

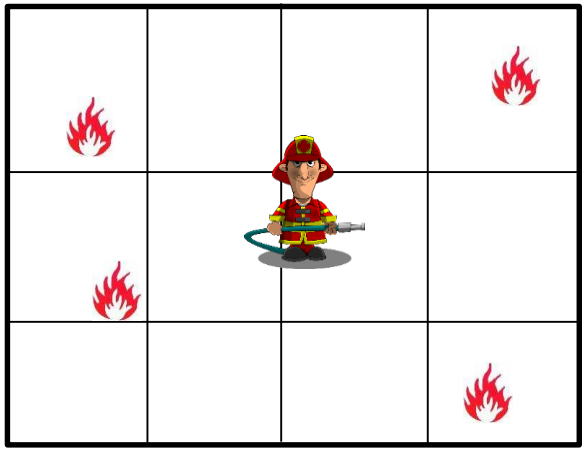
What about satellites ?



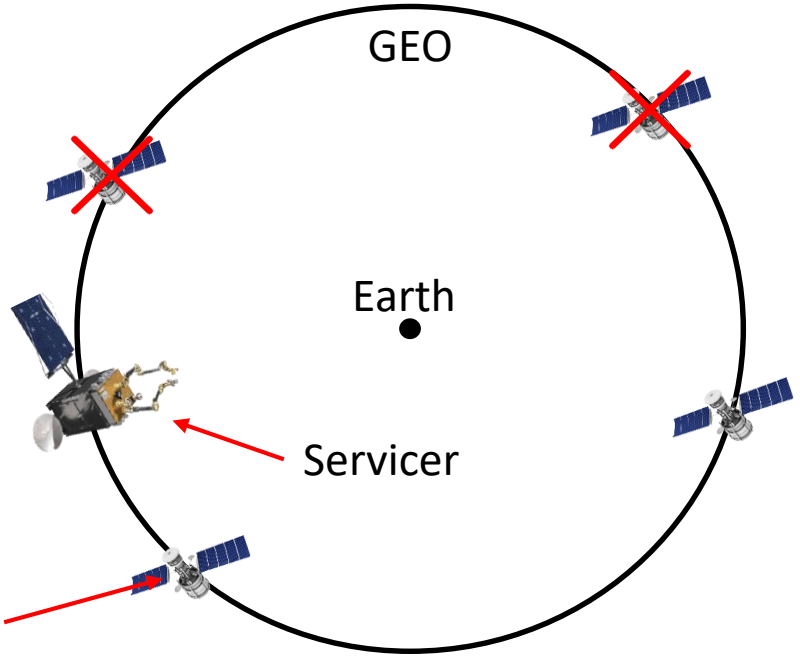
On-orbit Servicing!

Analysis of On-Orbit Servicing Modeling

Urban operations research



Orbital operations research

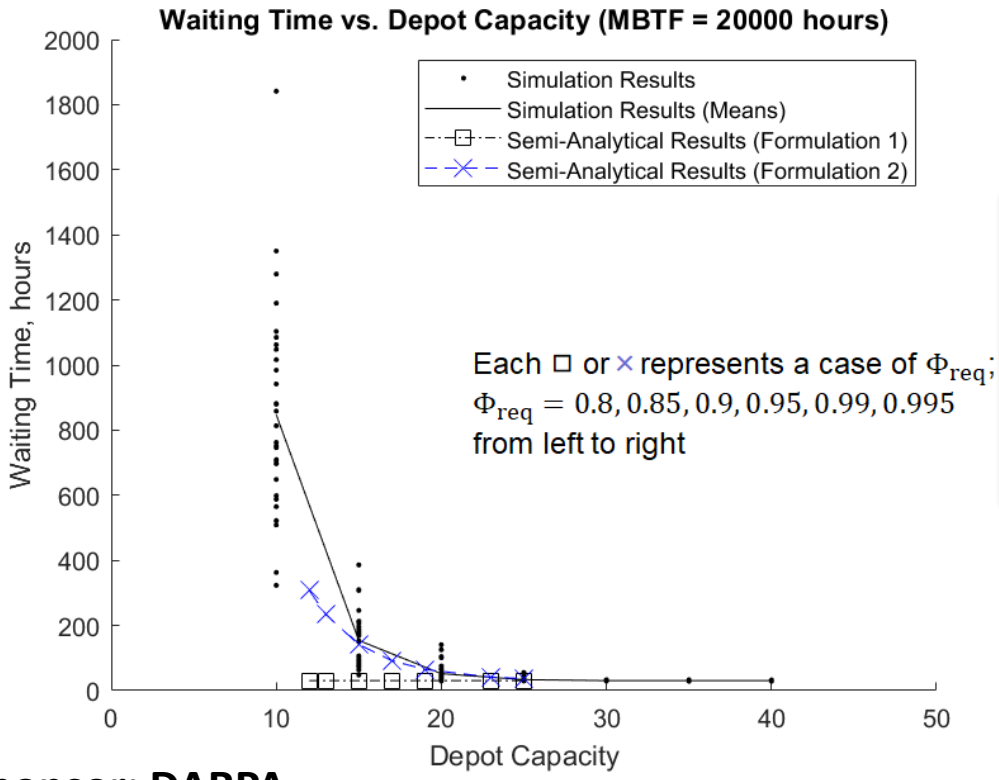


- **Numerical Method:** Agent-based simulations
- **Semi-Analytical Method:** (Modified) spatial queueing theory + inventory management

Example Results

Case Study: trade off b/w waiting time vs. depot capacity

- 10 modular satellites, each with 5 module;
- 1 depot and 1 servicer.
- Interested in the depot capacity X and waiting time Y at its **"knee point"**, i.e., for a depot capacity beyond X, the waiting time is "almost" Y.



Proposed semi-analytical method approximates the simulation results well without computationally costly simulations.

Sponsor: DARPA

Space Logistics Research 3: Satellite Constellation Maintenance

- **Hidden challenges** in recent trend of mega-constellations, e.g., OneWeb, SpaceX, Amazon.
  - Deployment
  - Maintenance logistics

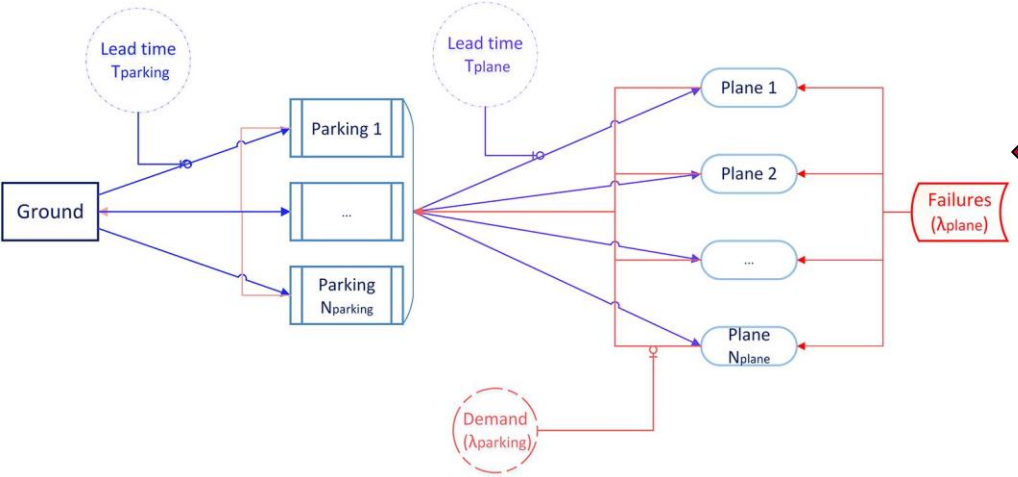
- **Scalability** of existing spare management methods is limited, particularly for mega-constellations.

⇒ **Goal: Design technique for satellite replacement strategy scalable to mega-constellations**

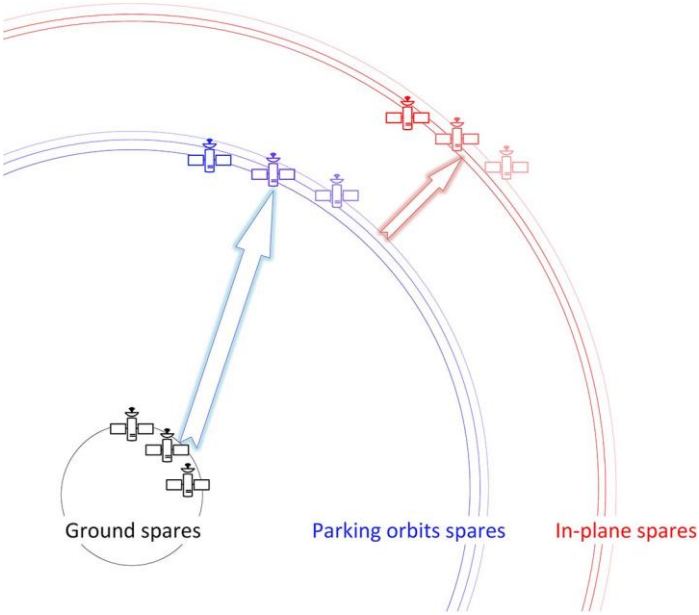
Credit: OneWeb

Optimal Spare Strategy for Mega-Constellations using Inventory Control

Inventory Management for Terrestrial Logistics



Spare Management for Mega-Constellations



Sponsor: Mitsubishi Electric Corporation

- New spare management model developed based on multi-echelon inventory management.
- Enabling efficient and scalable optimization of spare allocation.
- Starting a new project on debris management for mega-constellations.

More Recent Research: Space Situational Awareness

- Catalog upkeep and expansion are critical for SSA.
  - Too many targets; not enough sensors.
  - Especially with sensor performance improvement.
- Needs for quick and efficient sensor planning strategies (i.e., “follow-up”) to search and detect uncatalogued objects.
  - Uncertainties of orbits are much larger with respect to sensor FOV.
  - Missed detection and false-alarm with not-precisely-known probabilities.

$\Rightarrow$ Develop computationally efficient **optimal sensor steering planning optimization algorithms** to search and detect space object(s) in an unknown orbit using imperfect sensor(s)

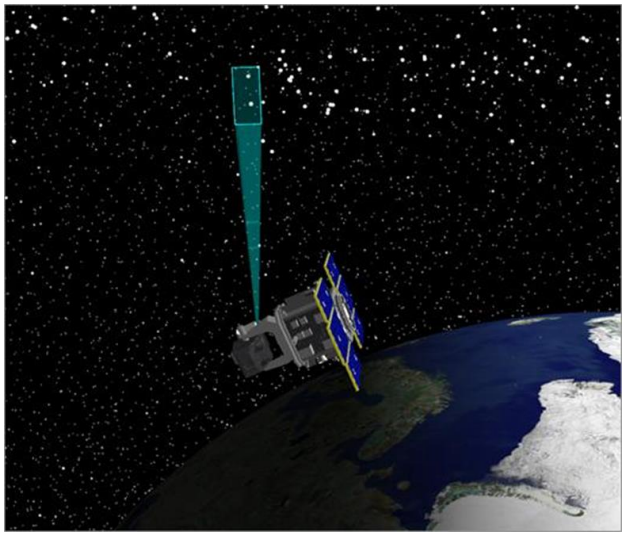


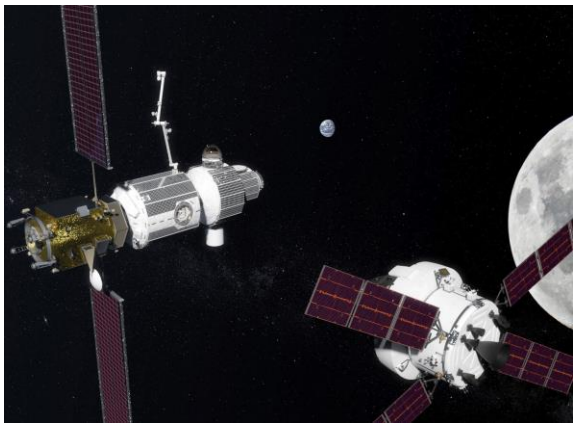
Image Source: USAF

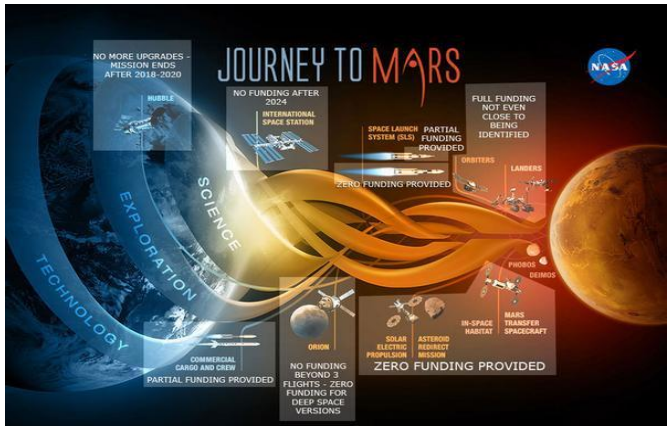
Ongoing Projects

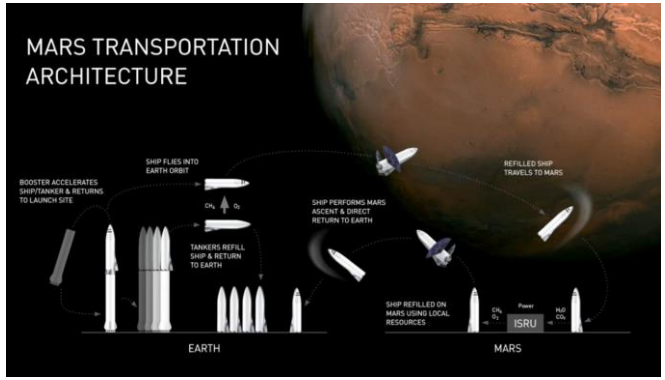
- Time-Expanded Space Logistics Network Modeling and Optimization for On-orbit Servicing, Assembly, and Manufacturing
  - Sponsor: DARPA
- Debris Management and Removal for Large-Scale Constellations
  - Sponsor: Mitsubishi Electric Corporation
- Real-Time Terrain Mapping and Processing for Safe Landing via Deep Neural Networks
  - Sponsor: NASA
- Designing Flexible Complex Systems with Coupled and Co-Evolving Subsystems under Operational Uncertainties
  - Sponsor: NSF
- TeamAstro: Coordination and Sensing for a Team of Spacecraft Swarm
  - Sponsor: NASA/EpiSci

Future Space Exploration Logistics Research

- **Next-generation space exploration requires a rigorous modeling, simulation, and optimization for its logistics mission design and planning.**
- **Operations research with orbital mechanics has a large potential to make space logistics more effective and efficient!**
  - Dynamic optimization/reinforcement learning for campaign planning
    - Integration of parametric vehicle model, high-/low-thrust trajectory design, and infrastructure design (ISRU, depot) under uncertainties
  - Network modeling and mission planning for on-orbit servicing, assembly, and manufacturing (OSAM).
  - More problems to be solved…







Credit: NASA, SpaceX