AFRL Electrospray Workshop

NASA GRC Electrospray Activities Overview

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Electric Propulsion Systems

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NASA & Electrosprays

2015 NASA Technology Roadmap: TA 2.2.1.5

Electrosprays provide thrust using a conductive fluid and electrostatic fields to extract and accelerate charged droplets, clusters of molecules, or individual molecules or ions

- Mission capability
  - Precision 6-DOF actuation with low vibrations
    - Astrophysical observatories
    - Formation flight of coupled / distributed spacecraft
  - Primary propulsion for small spacecraft
- Technology challenges
  - Extended lifetime operations for large total impulse
  - Low contamination impact on spacecraft


HabEx: Habitable Exoplanet Observatory (NASA JPL)

NASA GRC Electrospray Activities

Role: Provide support in maturing electrospray technologies towards engineering integration, flight readiness, and mission success for NASA

- Collaborator for electrospray modeling research
  - Early Stage Innovations (ESI) Modeling for Small Spacecraft Electric Propulsion
- Provider of independent verification and validation (IV&V)
  - Small Spacecraft Technology Program (SSTP) micro-propulsion systems of interest
- Promoter of engineering rigor in technology's path-to-flight
  - DoD-NASA micro-propulsion technology readiness level (TRL) definitions
  - NASA Class-D mission electric propulsion qualification guidelines and best practices

ESI Electrospray Modeling (1/2)

2018 Early Stage Innovations: (T1) Modeling for Small S/C EP

- Advance modeling techniques and simulation capabilities beyond laboratory-level development and empirical trial-and-error
- Address reliability and integration issues that are some of the key obstacles to mission infusion
- Welcome corresponding experimental measurements and system testing that are directly coupled with the modeling activity

Areas of Interest
Ground facility effects vs. the in-space environment
Erosive and other lifetime-limiting mechanisms
System sensitivities and potential failure modes (e.g., tolerance misalignments, propellant contamination, degraded isolation, arcing events, etc.)
Plume neutralization and interactions with s/c
Multi-thruster operations and interactions
System performance stability, repeatability, and transients
Heat generation and dissipation on integrated system operations

ESI Electrospray Modeling (2/2)

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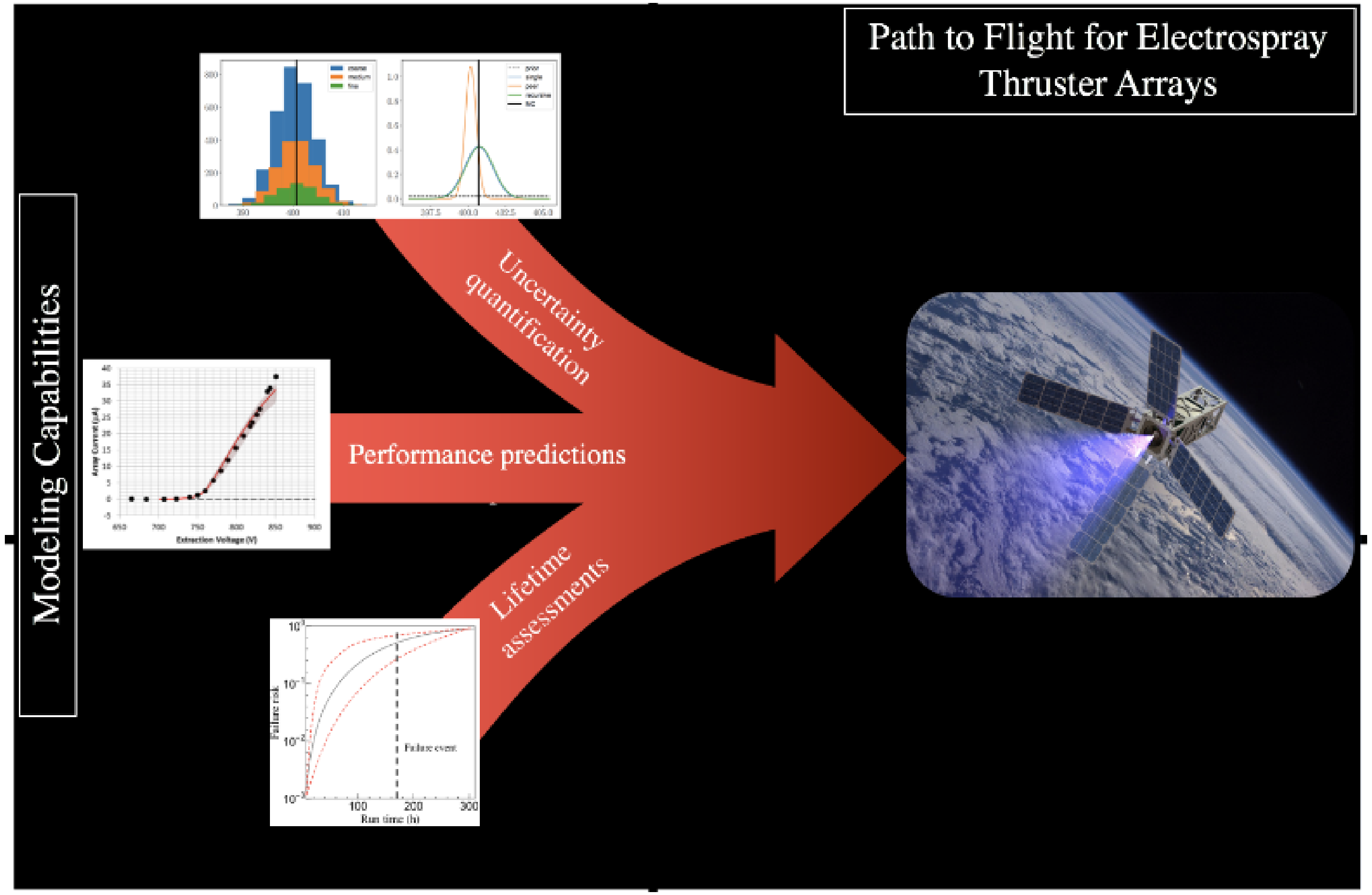
NASA GRC Research Collaboration	
Research Institution	**Project**
University of Michigan	Data-Driven Predictive Modeling of Electrospray Thruster Arrays
Massachusetts Institute of Technology	SOLVEiT: Simulating the Local Operational Volume of Electrospray ion Thrusters
University of Illinois at Urbana-Champaign	Multi-Scale Modeling of Plume-Spacecraft Interactions for Novel Propellants

UM: Data-Driven Predictive Modeling

PI: Dr. Benjamin Jorns (University of Michigan)

- Expand existing numerical framework of the Electrospray Propulsion Engineering Toolkit (ESPET)
- Apply optimal experimental design combining numerical simulations, targeted experiments, and machine learning
- Apply rigorous uncertainty quantification methods

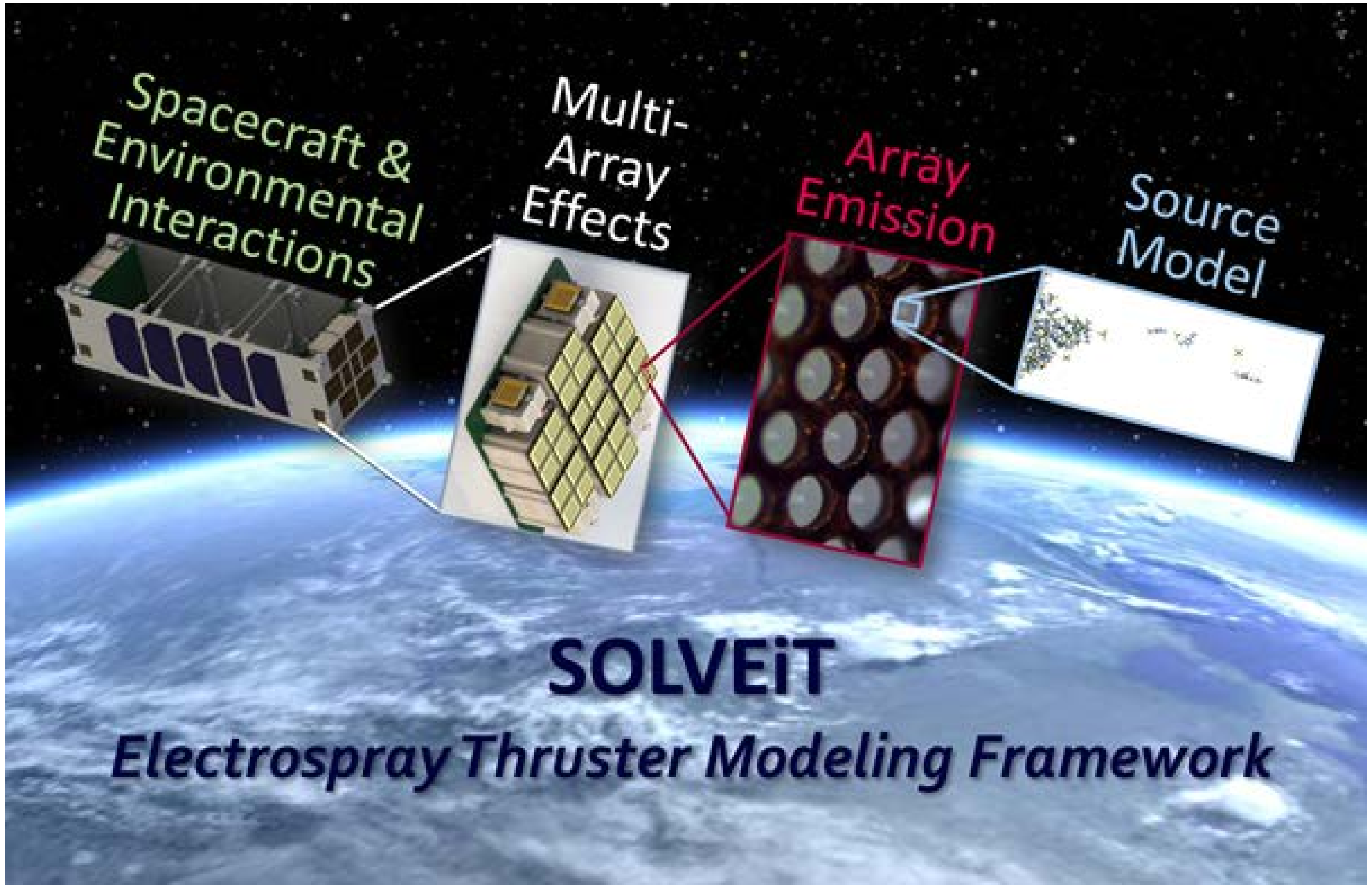


5/20, 1120-1140: ***Data-Driven Modeling and Development of ES Thruster Arrays***

MIT: Simulating Local Operational Volume

PI: Dr. Paulo Lozano (Massachusetts Institute of Technology)

- Develop integrated modeling framework for ES arrays on smallsat platforms
- ➢ Build array source and surface interaction sub-models
- ➢ Integrate sub-models for spacecraft-level simulation of coupled interactions with ES arrays

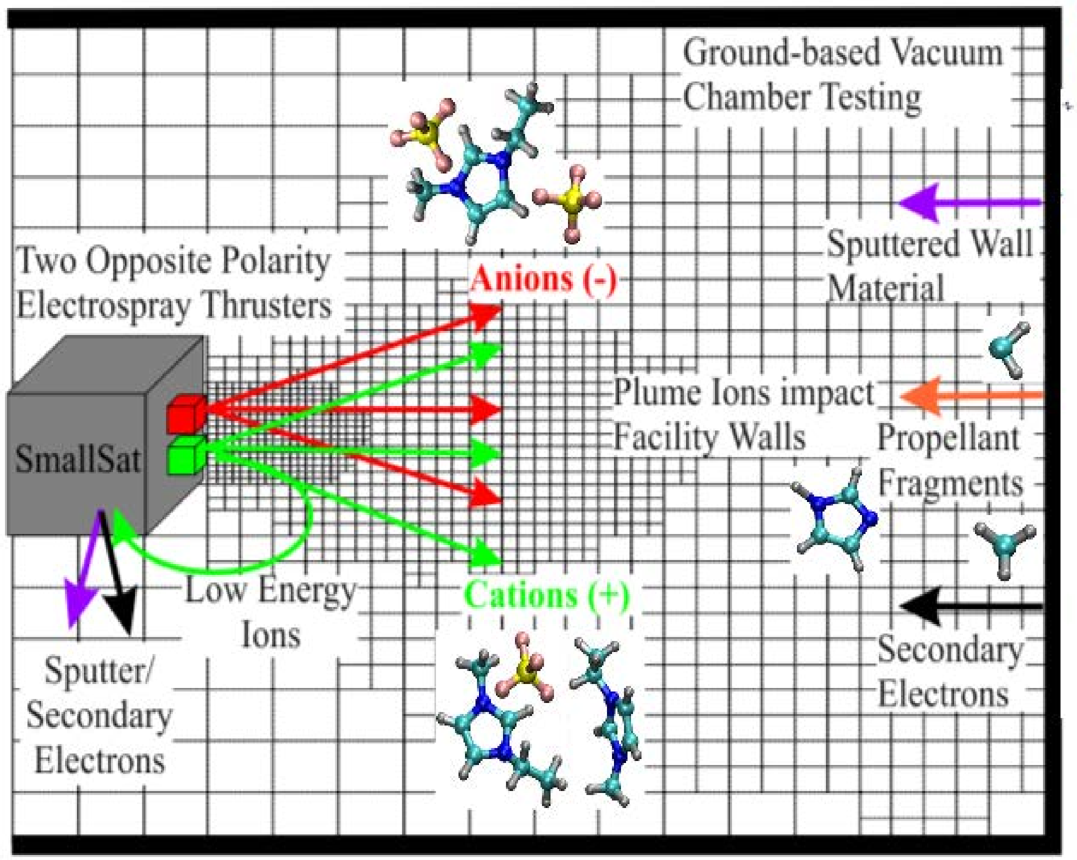


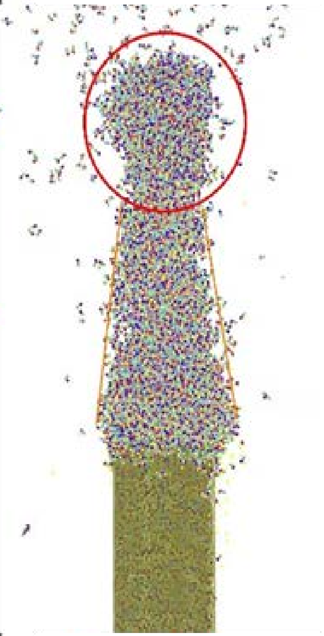
5/20, 1410-1430: ***Electrospray Activities at MIT***

UIUC: Multi-Scale Modeling of Plume-S/C Interaction

PI: Dr. Deborah Levin (University of Illinois at Urbana-Champaign)

- Develop plume model that maintains chemical-atomistic nature of plume up to m-length scales
  - Model jet growth (100-nm to 1-µm scale)
  - Address Coulomb interactions and sputtered species (1-µm through 1-m scale)





5/21, 0920-0940: ***Challenges in Multi-Scale Modeling of Plume-Spacecraft Interactions***

NASA GRC Micro-Propulsion IV&V Testing

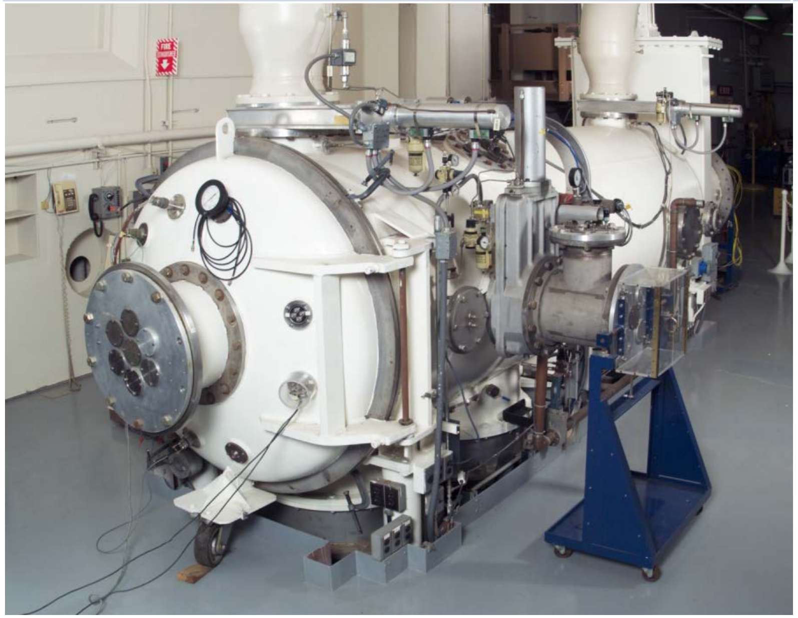
Purpose: Evaluate micro-propulsion systems of interest to NASA SSTP

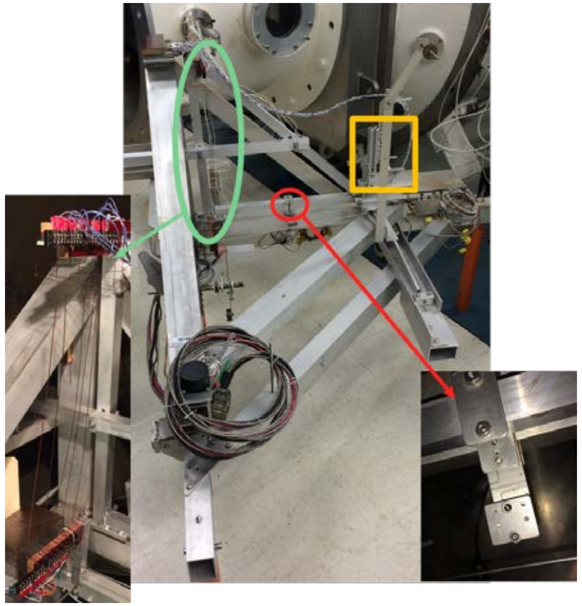
- Characterize beginning-of-life (BOL) performance via direct measurements
  - Validate I-V performance model
  - Map performance envelope
- Track long-duration operational stability to end-of-life (EOL)
- Assess spacecraft integration concerns
  - Plume behavior
  - Thermal soak-back
  - Command / control functionality

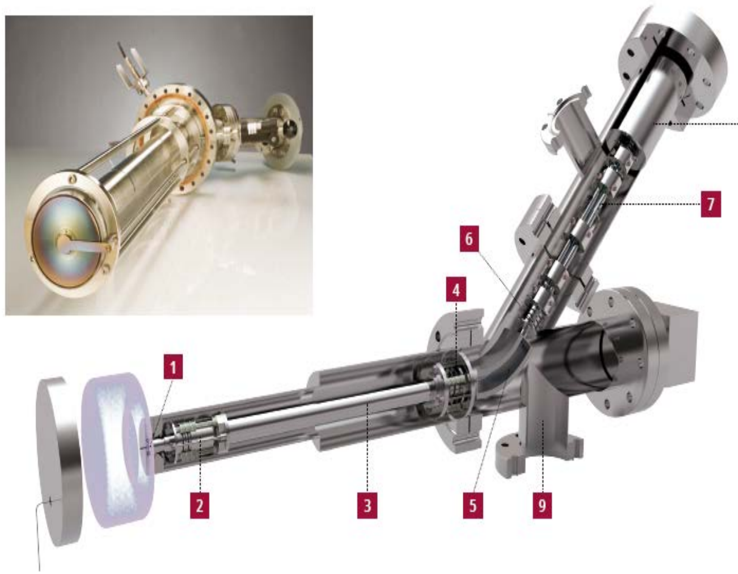
Provide data for Small Spacecraft Systems Virtual Institute (S3VI) databases such as the *Small Satellite Parts Search* and *Small Spacecraft Technology State-of-the-Art*

NASA GRC Micro-Propulsion Test Setup

Vacuum Facility	Thrust Performance	Plume Characterization
VF-3 • Diameter: 1.5 m • Length: 4.5 m • Base *P*: ~4 x 10^{-7} torr (ODP) • Parallel, dry-pumping train activation in summer 2019	**Torsional Thrust Stand** • Resolution: ~10 µN • Pitch / roll control • *In situ* calibration • Thermal compensation activation in summer 2019	**Hiden EQP Mass/Energy Analyzer** • Species: ions (+/-) and neutrals • Mass: ≤ 500 amu, 1-amu res. • Energy: ≤ 1 keV, 1-eV res. • Time-of-flight: ≤ 1 µs res. • Activation in autumn 2019



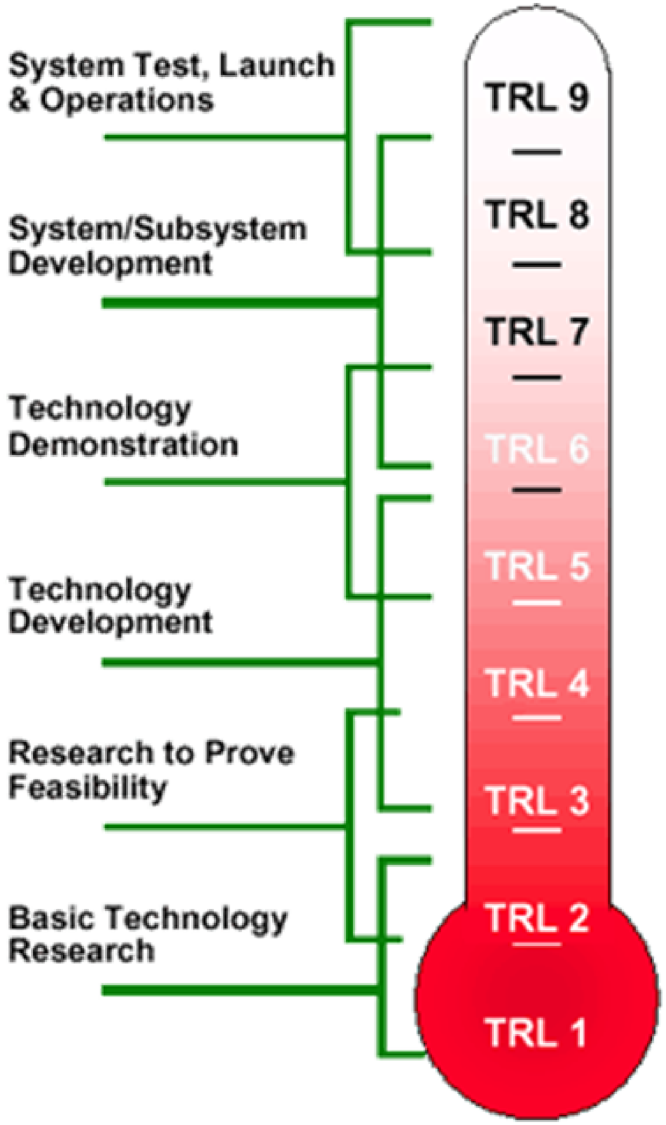




Micro-Propulsion TRL

Problem: Current application of TRL is inconsistent, and self-evaluations are frequently overstated

- Revised update to AIAA-2016-5113 (Hargus & Singleton)
  - Collaboration between AFRL and NASA (GRC / GSFC / JPL)
  - **Presentation / discussion at December 2019 JANNAF?**
- Key features of framework
  - Tailors to micro-propulsion systems for small spacecraft
  - Seeks common ground between DoD / NASA interpretations and terminology
  - Focuses on system rather than component TRL
  - Specifies entrance / exit criteria for TRL



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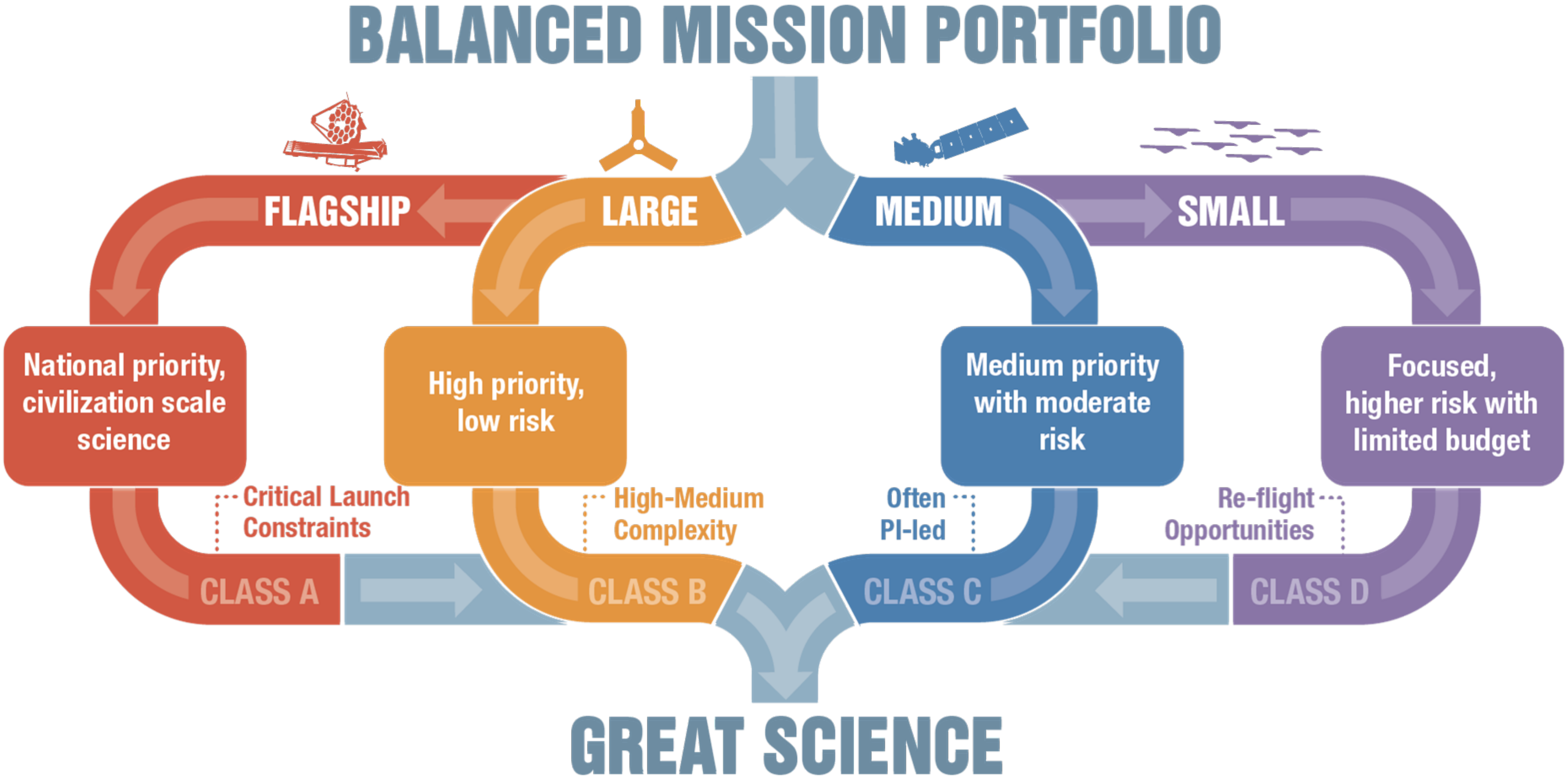
NASA SMD Class-D Missions

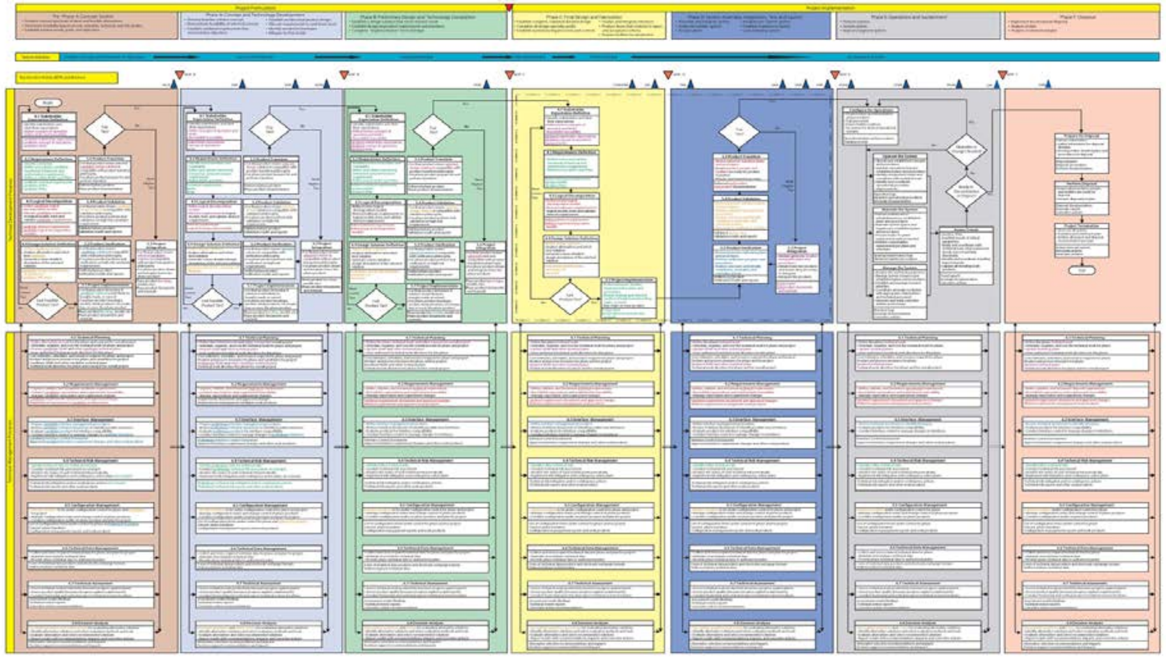


EP Qualification for Class-D Missions

Problem: Need exists to strike better balance between cost effectiveness and engineering rigor

- Recommended guidelines for a minimum threshold of EP flight qualification activities
- Best practices to avoid recurring issues and common pitfalls with EP flight qualification
  - Mission-specific requirements
  - Integrated assembly level
  - Test-like-you-fly (TLYF) qualification sequence

Conventional NASA project life cycle process (*NASA Systems Engineering Handbook, SP-2016-6105*)



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