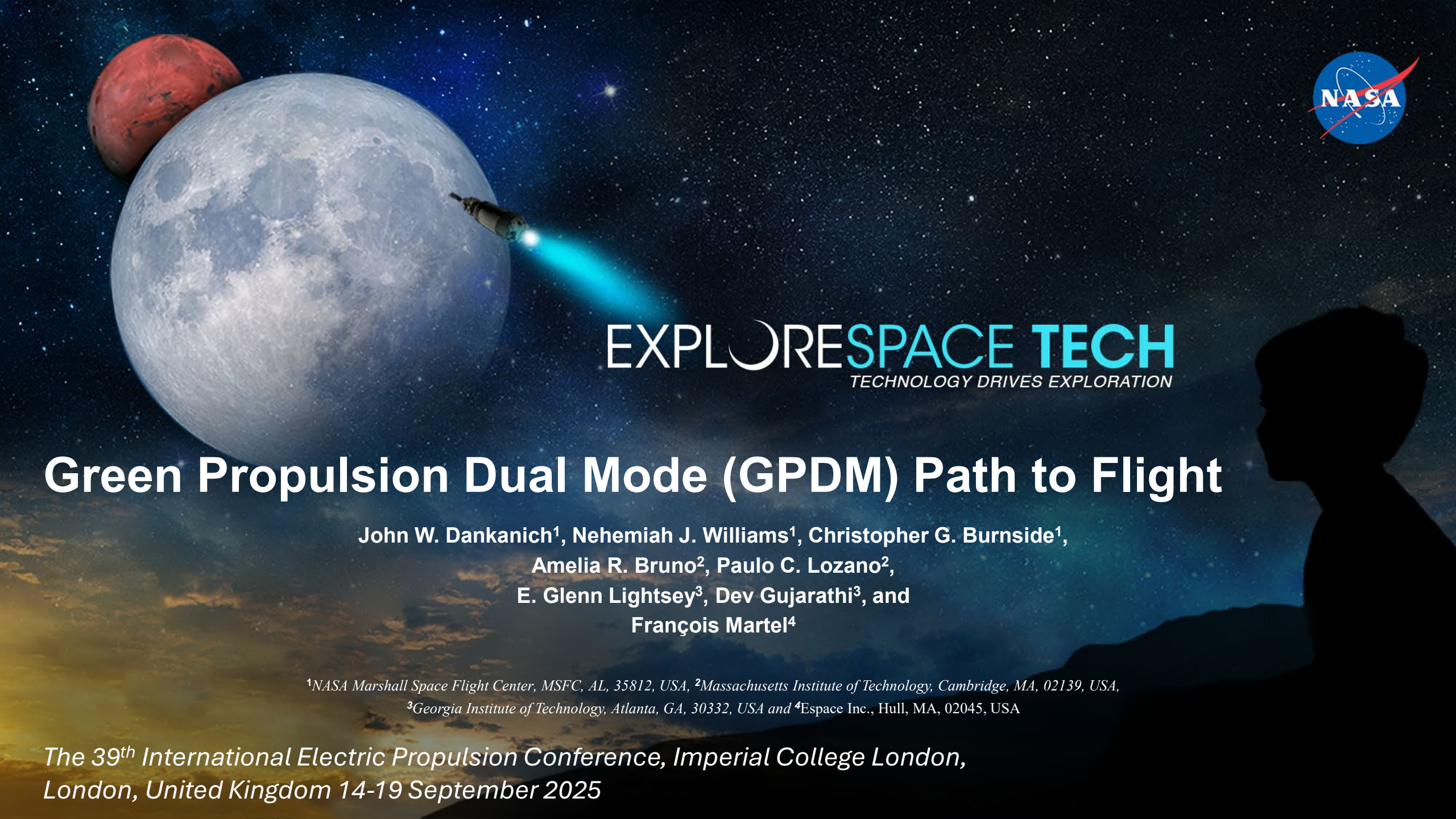

Green Propulsion Dual Mode (GPDM) Path to Flight

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The 39th International Electric Propulsion Conference, Imperial College London, London, United Kingdom 14-19 September 2025

What is GPDM?

Definition:
NPR 7120.8 (R&T) in-space demonstration of green dual-mode (chemical and electrospray) propulsion using common prop tank/feed system on a small spacecraft (6U CubeSat).

Objectives:
Primary – demonstration of dual-mode operations
Secondary – orbit changes/attitude maneuvers with dual-mode system.

Development Scope:
Ground test unit ("Flat Sat") with propulsion system flight unit serving as a payload on a small spacecraft bus using mostly flight proven COTS components.

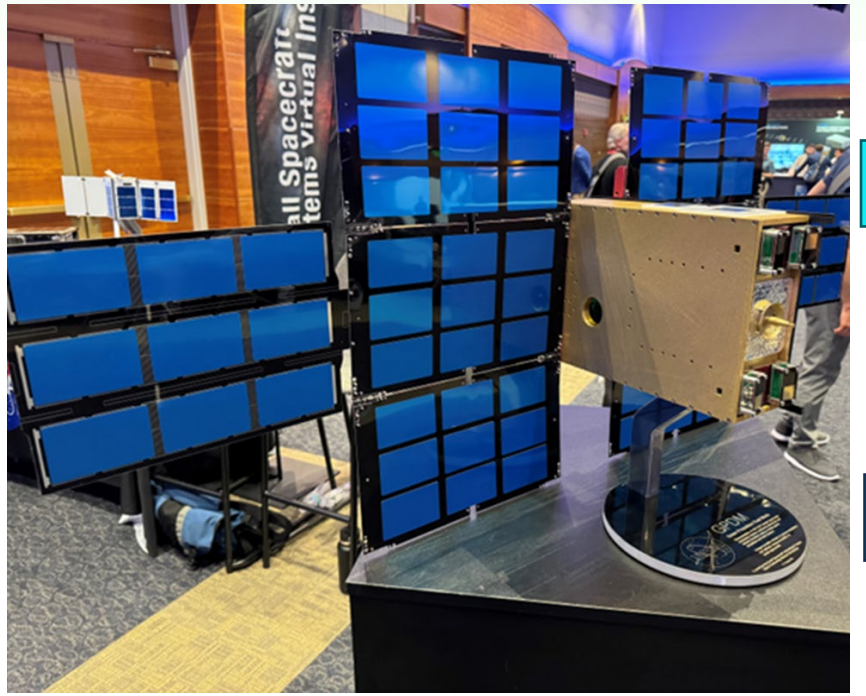
Delivery & Mission Schedule
After ATP in Spring 2023, GPDM is now in the Assembly, Integration, & Testing (AI&T) phase of the project life cycle, and is tracking a **launch date is January 5th, 2026.** The mission is 9-months and will demonstrate chemical/electrospray checkouts and vehicle maneuvers using the dual-mode system.

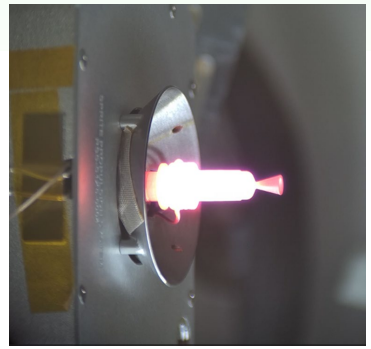
Workforce:
~ 10 FTEs/5WYEs (mostly early career, workforce dev. focus across ER/EM/HP/ST/EV Orgs at MSFC).

Partnerships:
Georgia Tech (providing s/c bus & avionics, environmental testing, mission ops support)/MIT (providing electrosprays)/Plasma (Rubicon) providing self-contained chemical propulsion unit (tank/thruster/manifold)/E-Space (providing power, processing electronic controls).

Advanced Spacecraft Energetic Non-toxic (ASCENT) "low-toxicity" rocket propellant offers propulsion in BOTH modes using a single propellant/feed system:

- High thrust (chemical mode)
- High propellant efficiency (electrospray mode)
- Lighter integrated flight system (sharing common tank, feed system)
- The combination of modes allows for more complex mission profiles across various destinations in space from LEO, to lunar, and interplanetary (e.g., Mars)
- GPDM has worked with MSFC's Advanced Concept Office (ACO) to further explore future flight opportunities





GPDM Mission Requirements (Level 1)

Dual Mode Operation [GPDM-REQ-001]
GPDM shall perform dual-mode operations of Advanced Spacecraft Energetic Non-Toxic (ASCENT) propellant in-space.

> ***Full Success Criteria:*** GPDM should perform a successful orbit change using a combination of chemical and electrospray thrusters and perform attitude control maneuvers performed by the electrospray thrusters.
>
> ***Minimum Success Criteria:*** GPDM shall perform one successful chemical thruster burn and one successful electrospray thruster burn in space.
> This requirement addresses the dual mode and green propellant technology gaps demonstrated in the STMD Small Spacecraft Capability Areas' Gap IDs 1301 and 1304. These gaps are in support of NASA Taxonomies TX01.1.1, TX01.1.2, and TX01.2.2.

GPDM Form Factor [GPDM-REQ-002]
GPDM shall be in a 6U CubeSat form factor compatible with a Maverick Mercury-6T CubeSat dispenser for launch on a SpaceX Falcon 9.

> This requirement addresses the need to demonstrate low-cost, CubeSat capability for STMD. Launch on a SpaceX Falcon 9 (original GR&A) or equivalent rocket is desirable as demonstrated by the Lunar Flashlight successful deployment.

Electrospray Filling Capability [GPDM-REQ-003]
GPDM shall demonstrate electrospray thruster filling in space.

> ***Full Success Criteria:*** Electrospray thrusters should be filled and repeatably refilled during operations of GPDM.
>
> ***Minimum Success Criteria:*** Electrospray thrusters shall be filled once in space.
> This requirement addresses the need to demonstrate in-space refilling capabilities for electrospray thrusters to help demonstrate long life electrospray thrusters. This addresses NASA Taxonomy TX01.2.2. This allows for future development of electrospray dual mode systems that could potentially be refueled in space.

GPDM's Level 1 Mission Requirement Development

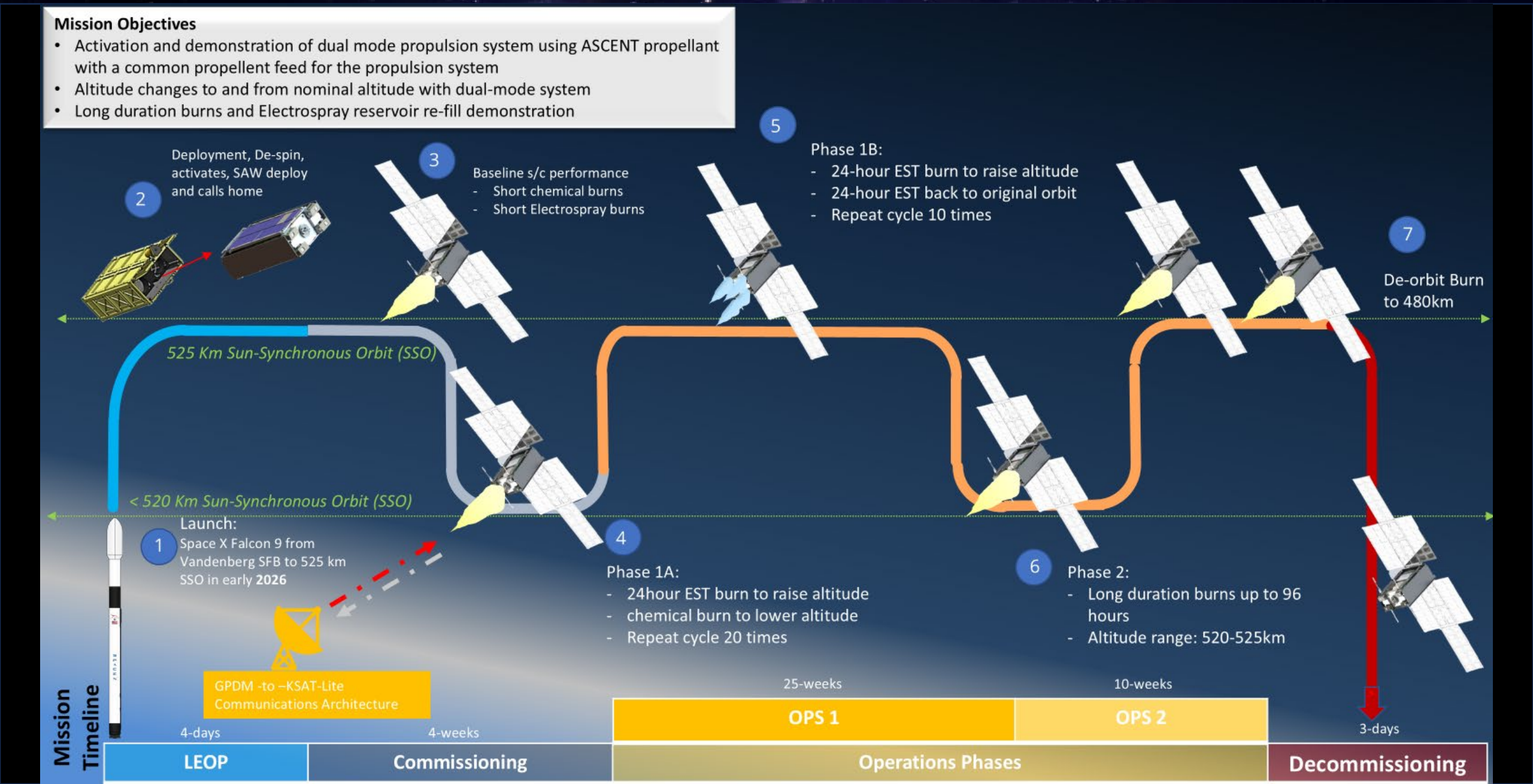
STMD's updated Strategic Framework Thrusts focus on "Go, Land, Live, Expand, and Enable."

- "Go" focus includes R&T into advanced propulsion-focused "technology areas" including green propulsion (TX01)
- Operating within the STMD portfolio, SSTP programmatic requirements focuses on projects which address specific STMD "Small Sat" and "Green Propulsion" Shortfalls:
  - *Gap ID (701) "Green Propellant Propulsion Systems"*
  - *Gap ID (1430) "Propulsion for Small Spacecraft" including developing "high delta V' and "dual-mode" capabilities*
- *To address these Small Sat and Green Propulsion Shortfalls, GPDM has focused its mission level requirements on demonstrating the dual-mode, delta V capability in a small spacecraft platform as well as establishing minimum and full success criteria with buy-in from the Small Spacecraft Technology Program stakeholders*

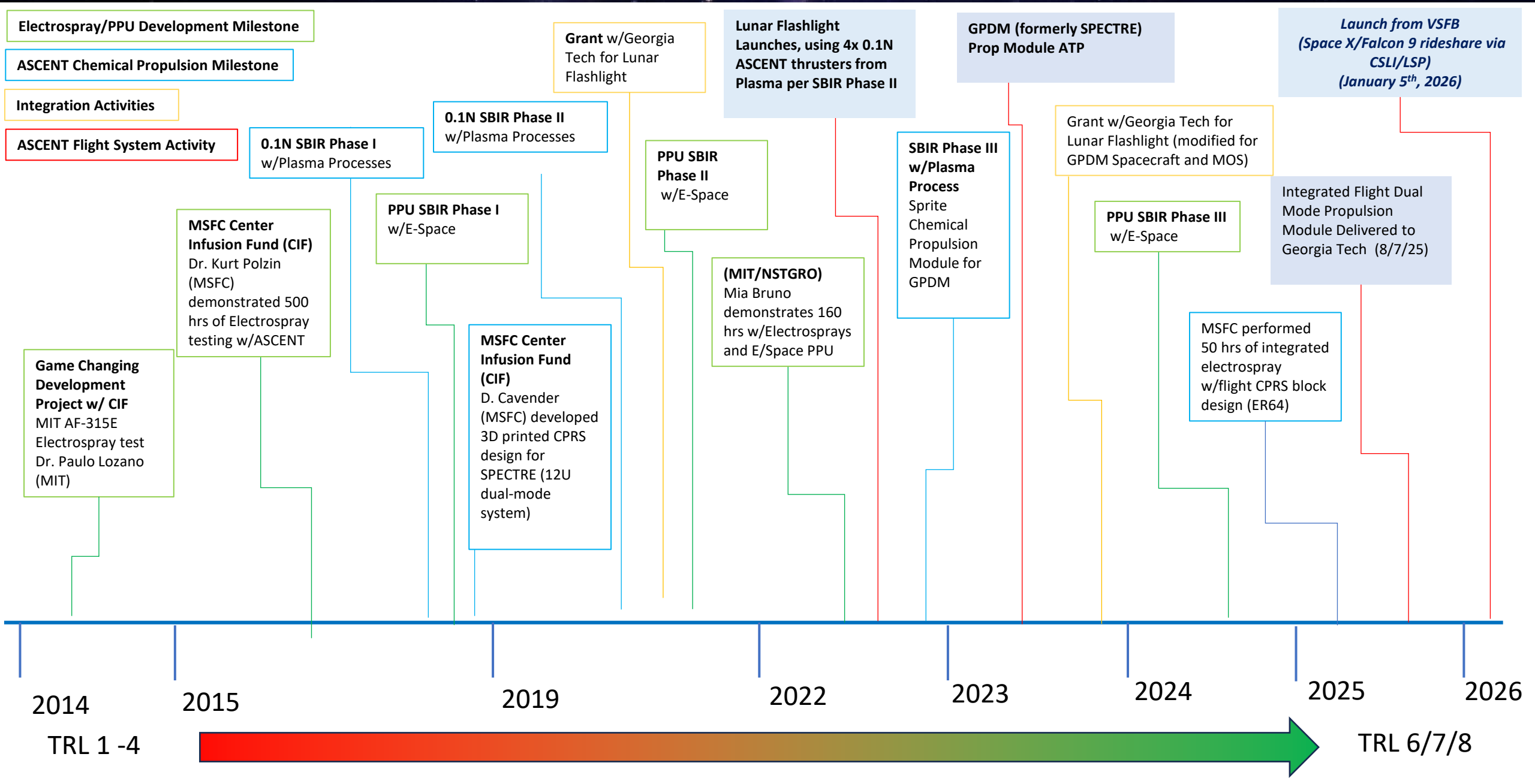
GPDM Mission Concept of Operations (ConOps)

Mission Objectives

- Activation and demonstration of dual mode propulsion system using ASCENT propellant with a common propellent feed for the propulsion system
- Altitude changes to and from nominal altitude with dual-mode system
- Long duration burns and Electrospray reservoir re-fill demonstration

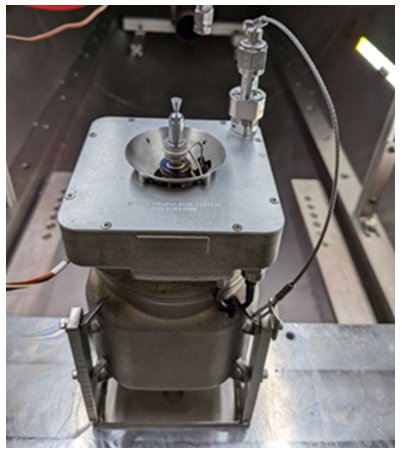


ASCENT Dual-Mode Technology Development Timeline (From TRL< 4 to 8)

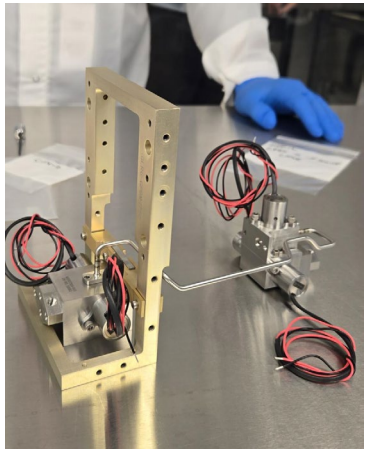


GPDM Team's Roles & Responsibilities

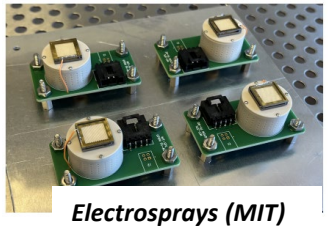
- **Customer(s) –** The GPDM Project is funded by the Small Spacecraft Technology (SST) out of the Space Technology Mission Directorate (STMD); AFRL is also a technical customer though GPDM is not funded through AFRL.
- **Project Management** – GPDM is managed by NASA MSFC in the Science and Technology Office (STO)/Exploration Systems Development Branch (ST-24).
  - The Engineering Department (ED) staffing includes Lead Systems Engineer, Subject Matter Expertise, & analysis
    - ER64/ER41/ER14 designed, developed, and tested the Compact Pressure Reduction System (CPRS)
  - The Mission Operations Department (HP) staffing includes mission operations staff
    - HP developed the TReK software which will be used for GPDM spacecraft to ground communication
- **Partnerships –** The GPDM Project has both university and industry partnerships to support this effort:
  - **Georgia Institute of Technology (Georgia Tech) –** is manufacturing and integrating the GPDM spacecraft bus, performing functional testing, and supporting mission operations.
  - **Massachusetts Institute of Technology (MIT) –** provided the flight electrospray thrusters.
  - **Plasma Processes' Rubicon Space Systems Division –** provided the Sprite chemical propulsion subsystem and is providing hardware integration support.
  - **E-Space, Inc. –** provided the electrospray electrical control board and is providing hardware integration support.



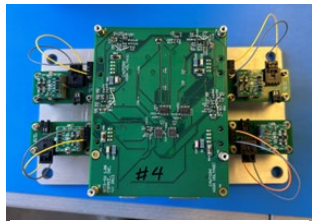
Sprite Chemical Propulsion Module (Plasma Processes)



Compact Pressure Reduction System (CPRS) – NASA MSFC (ER)



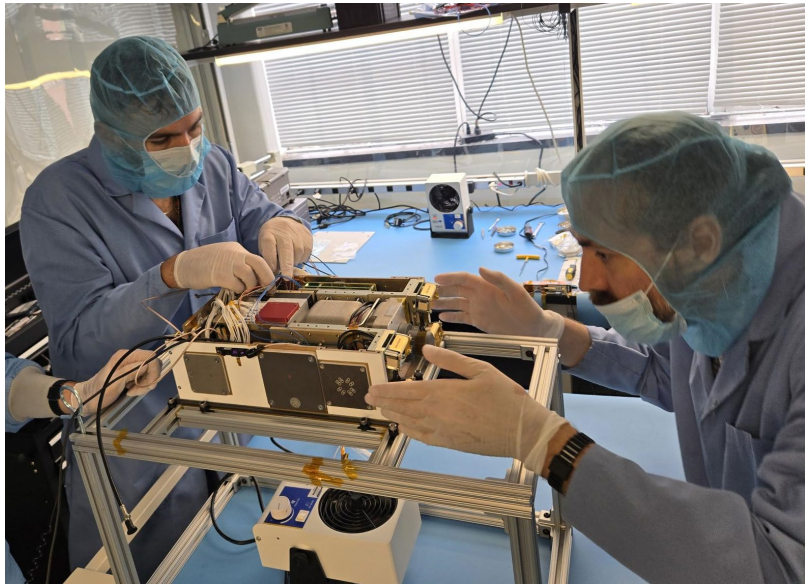
Electrosprays (MIT)



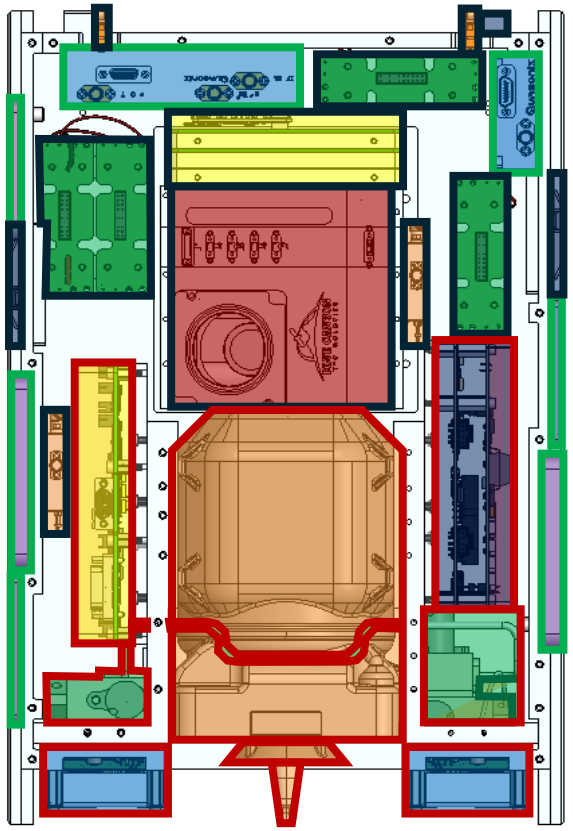
Power Processing Unit (PPU)- E-Space

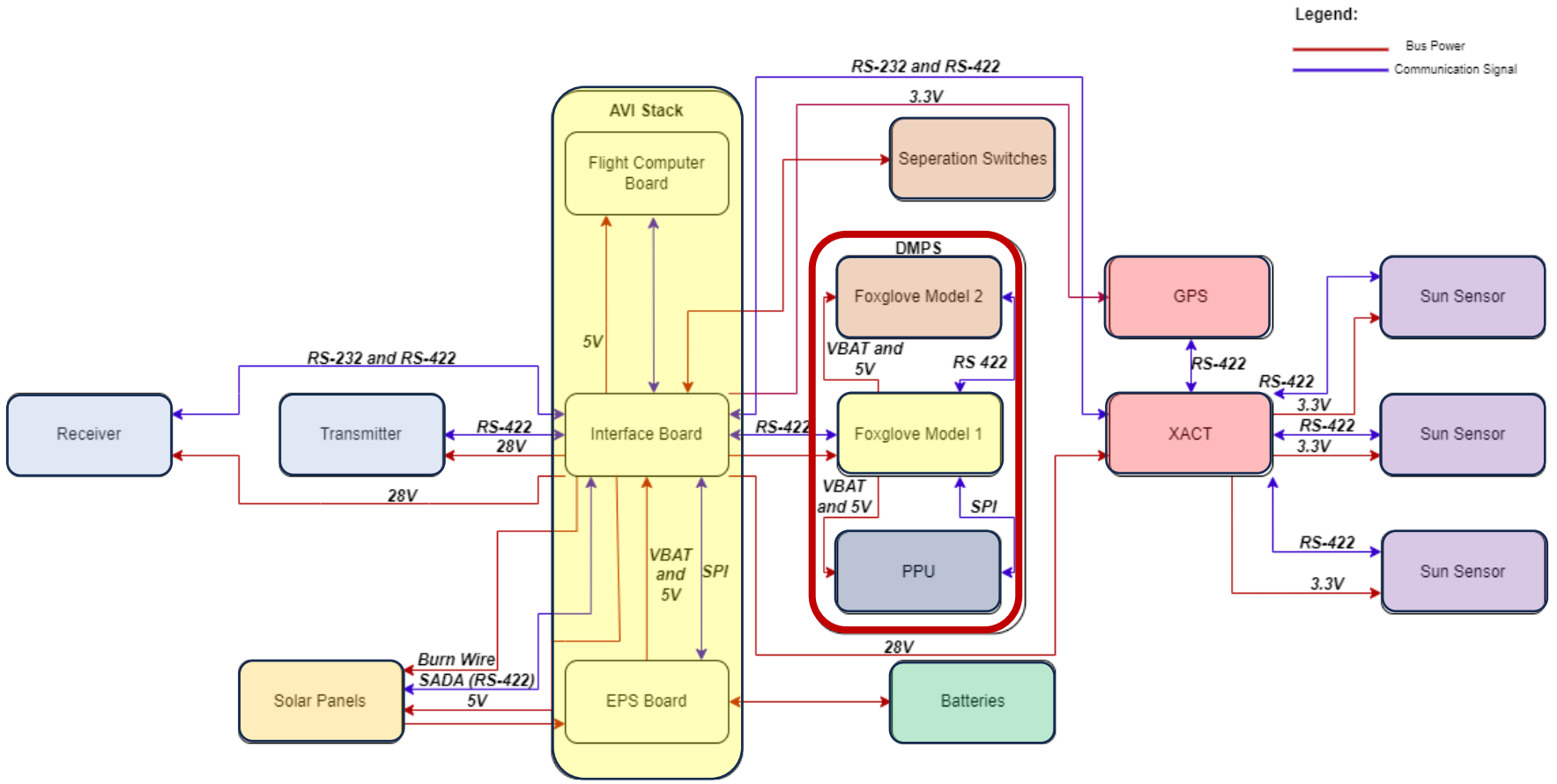
GPDM Spacecraft Bus (Georgia Tech)

- Spacecraft structure was fabricated by Georgia Tech Research Institute (GTRI)
- Georgia Tech per a university grant oversaw the COTS procurement of the spacecraft components including the antennae (High-Farr), radio transponder/reciever (Quasonix), attitude control and determination system (Blue Canyon), and avionics (Sierra Space).



GPDM Spacecraft Power & Telemetry Diagram





Propulsion
Sprite
Electrosprays
CPRS
Foxglove Model 1
PPU

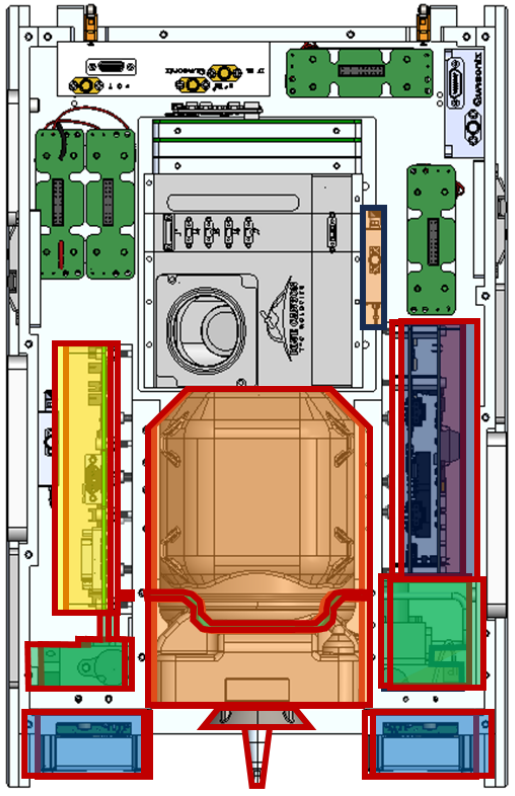
Power & AVI
Sun Sensors (3)
Batteries (4 packs)
Avionics Stack
ADCS

Solar Arrays

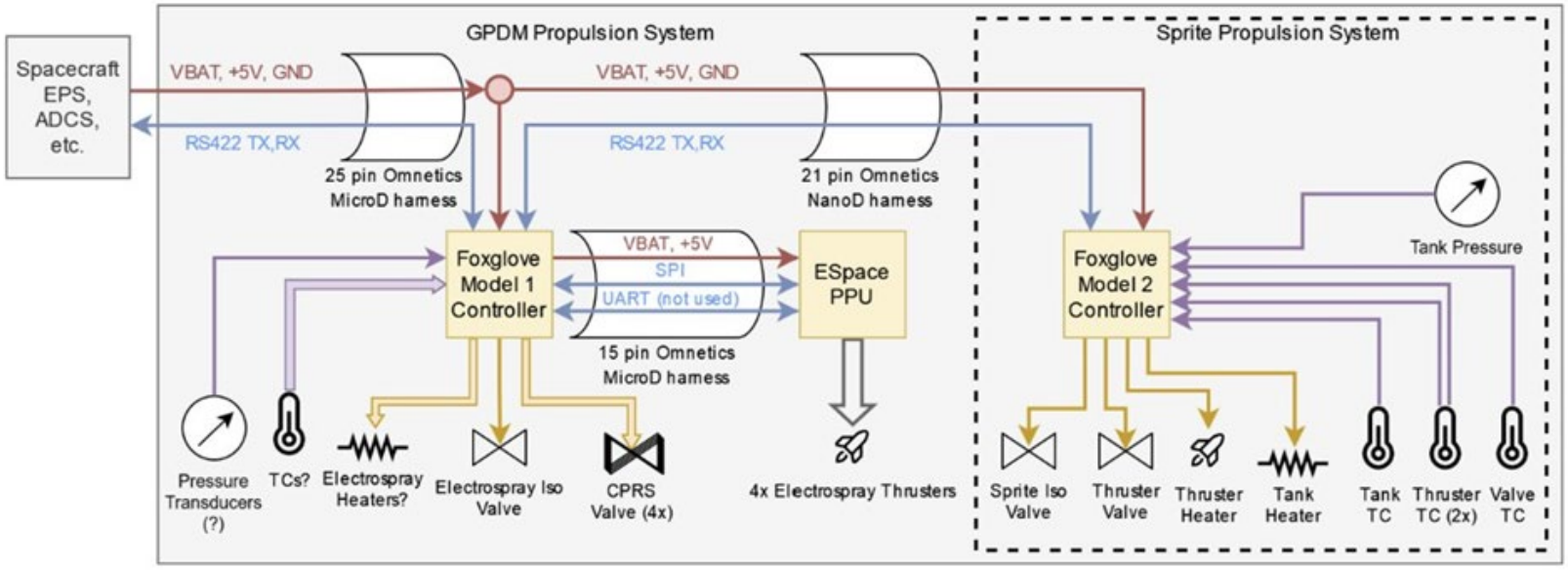
COMS
Antennas (5)
Radios (Tx & Rx)

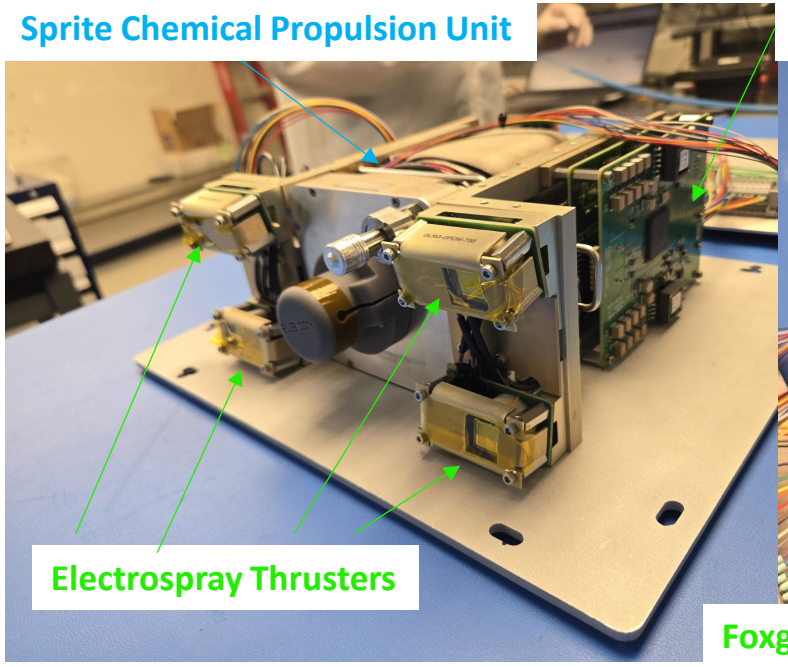
DMPS = Dual-Mode Propulsion System
AVI = Avionics Stack (GT/Sierra Space)
ADCS = Attitude Determination and Control System (XACT-50 from Blue Canyon Technologies)
PPU = Power Processing Unit (E-Space)

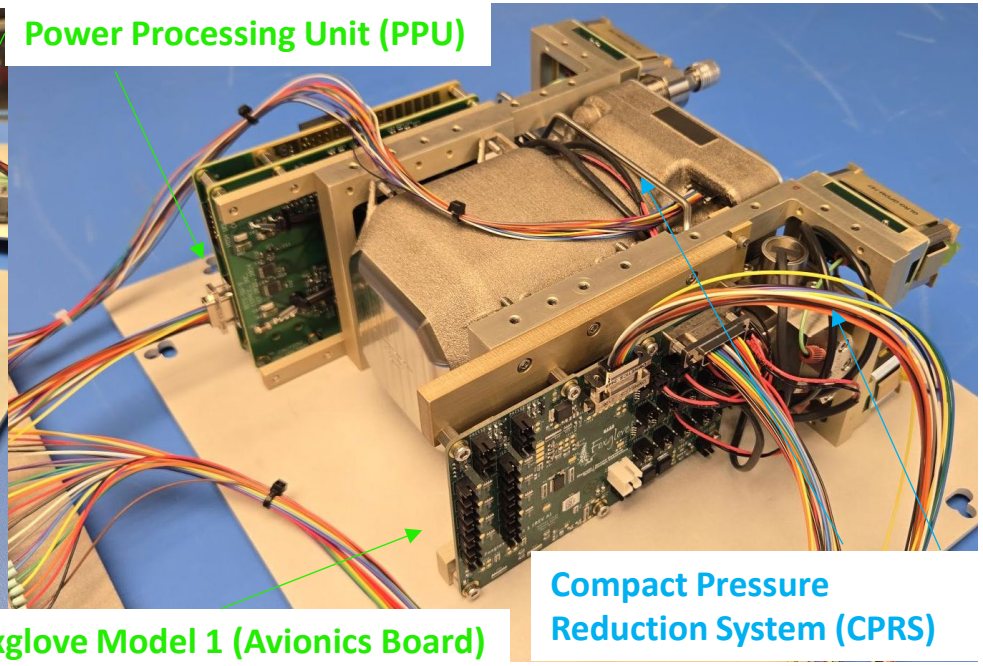
GPDM Propulsion Module Power & Telemetry Diagram



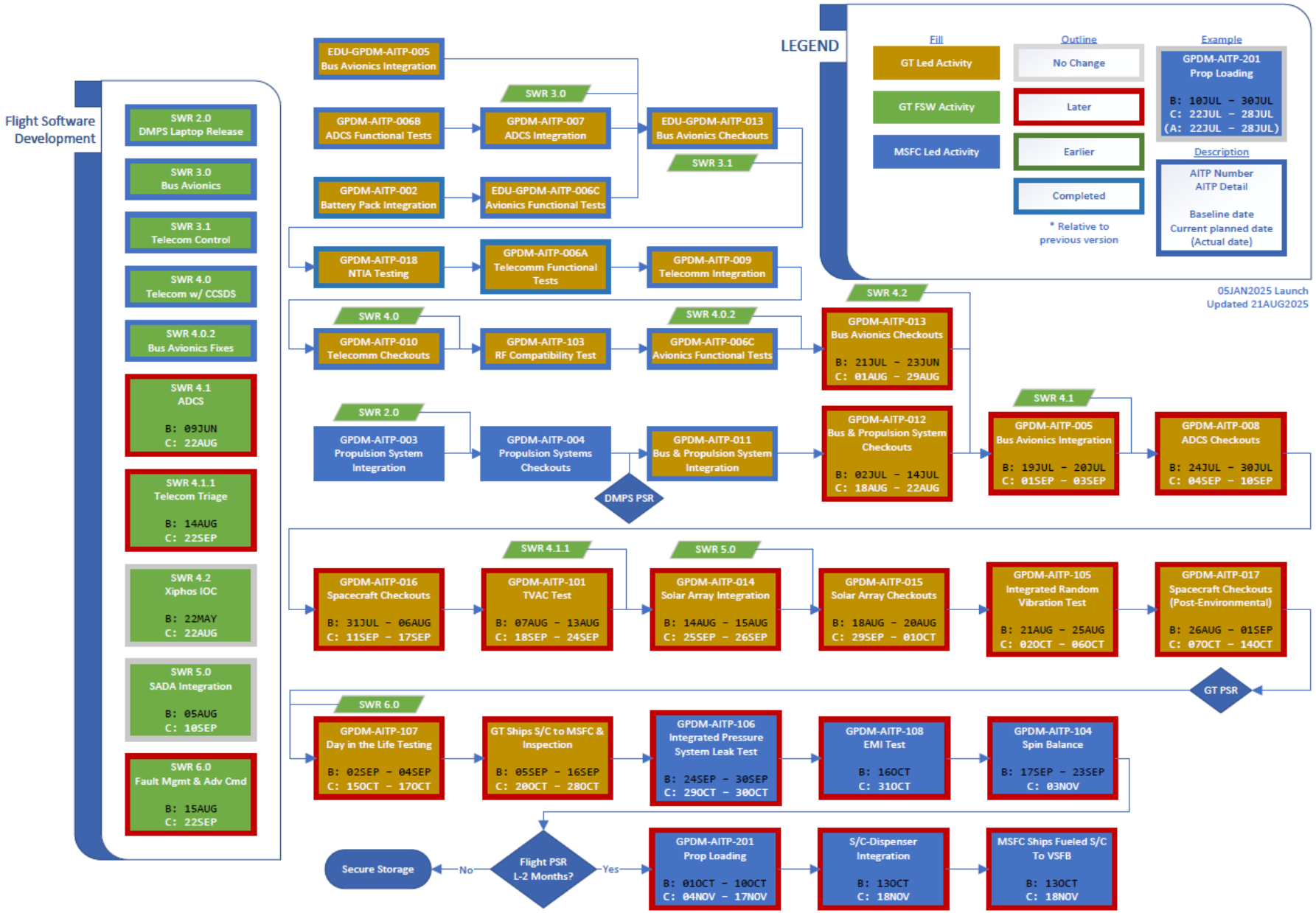
Propulsion
Sprite
Electrosprays
CPRS
Foxglove Model 1
PPU







GPDM Flight System Assembly, Integration, and Test (AI&T) Flow as of August 2025



Takeaway:

- As of 8/25, at total of 20 activities (5 flight software and 15 AI&Ts) have been completed.
- The MSFC team has successfully delivered a healthy propulsion model to GT and subsequently integrated the hardware to the GT bus to close out AITP-011 (Bus & Propulsion System Integration). Plan is to connect harnesses between the propulsion system and GT bus.
- LSP/Maverick is tracking NET January 5th, 2026 (from December 15th) for the Twilight manifest (current GPDM rideshare) having agreed to an NET mid-November delivery date. Conversations continue between GPDM and launch provider.

GPDM Lessons Learned

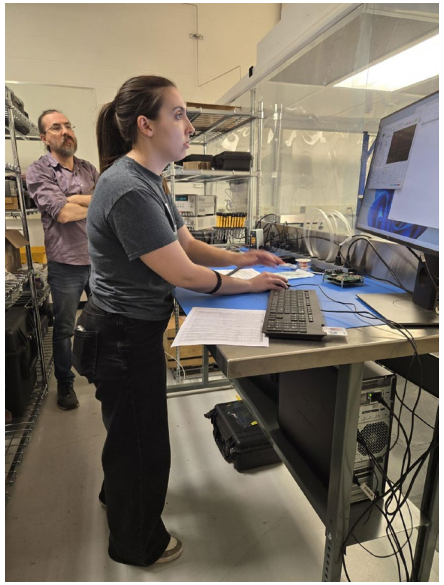
- ***Technical*** – GPDM has applied specific lessons learned from the previous ASCENT mission, Lunar Flashlight. Specifically, the Sprite 3D printed AM Tank/Manifold development included stricter inspection and cleanliness standards (vs. Lunar Flashlight), and subsequent hot-fire testing to ensure manifold passages were unobstructed prior to the delivery of the flight unit for integration.

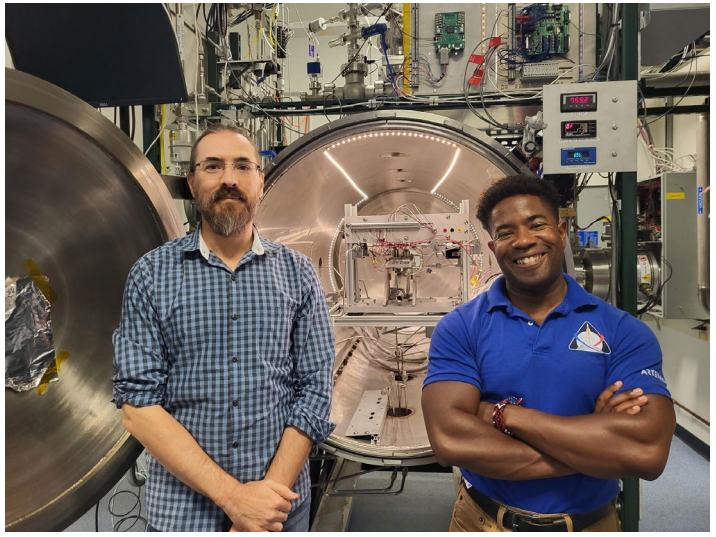
- ***Project/Programmatic*** – a future GPDM-type project should emphasize applying appropriate tailoring (e.g., system requirements) to the appropriate risk posture that is applicable to NPR 7120.8 (R&T) projects vs. NPR 7120.5 HSF projects. Early discussions on requirements for GPDM ran into challenges with which requirements were applicable (e.g. those related to S&MA and quality control).

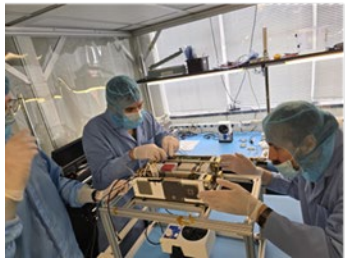
- ***Schedule*** – care must be taken in managing impacts to scope increase; GPDM Project's initial deliverable was a flight propulsion module. 6 Months after ATP, GPDM's scope grew to include management of the entire spacecraft (this was not originally considered in the initial proposal). This change impacted both resources (staffing / cost) and schedule.

- ***Workforce Development/Team Building*** – GPDM was led by mostly early career/first time in role engineering staff members/project leads. The team overcame initial challenges of not having a priori flight hardware/project development experience. In addition, GPDM balanced using NASA's technical rigor with the agility and flexibility of industry and university engineering practices.

GPDM Team





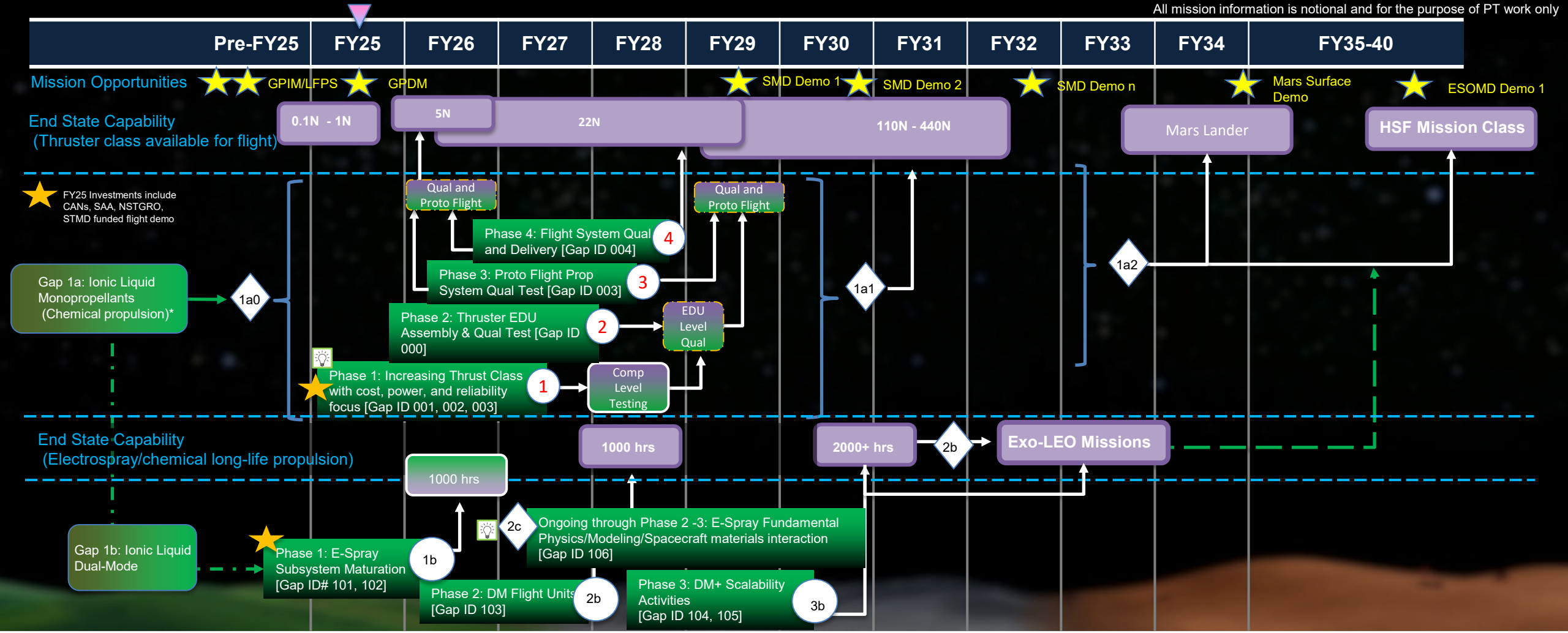


Green Propulsion Technology Development Roadmap

POC(s): Nehemiah Williams, Ph.D./Chris Burnside

Revised: 04/25/25

All mission information is notional and for the purpose of PT work only



Flight Demo Mission
Events/Milestones
Decision Point
Capability
Closure of gap target/ Capability demonstrated
STMD
Partnership
Industry / ESDMD
Study/Pre-formulation
FY25 Investment

KDP1a0: Kickoff of 5N, 22N + ASCENT thruster dev. activity
KDP1a1: Phases 1 -4 reproduced to develop 440 N capability
KDP1a2: Capability ready for SMD, Human Missions (GPRM 2018)
KDP2b: Dual-mode flight systems ready for Exo-LEO missions
KDP2c: Focus on E-Spray fundamental physics/modeling/plume interactions – these drive future Phases, larger system development activities

Major milestone 1: Developed perfomance metrics for specific thruster class/mission application
Major milestone 2: Catalyst dev. and power improved components integrated into ground qual EDU
Major milestone 3: System level development with EDU including pumps, valves completed ground tests
Major milestone 4: TRL at 6+ and ready for integration into a propulsion system for future mission
Major milestone 1b: Electrospray Reliability, refill, "dry" ASCENT requirements and long-life ground test exceeds 1000 hrs in laboratory (TRL-5/6);
Major milestone 2b: 6U CubeSat flight demonstration of 1000+ hrs (TRL-7/9)
Major milestone 3b: Demonstration of a dual-mode flight unit for 12U and larger small sat missions

Thank you!