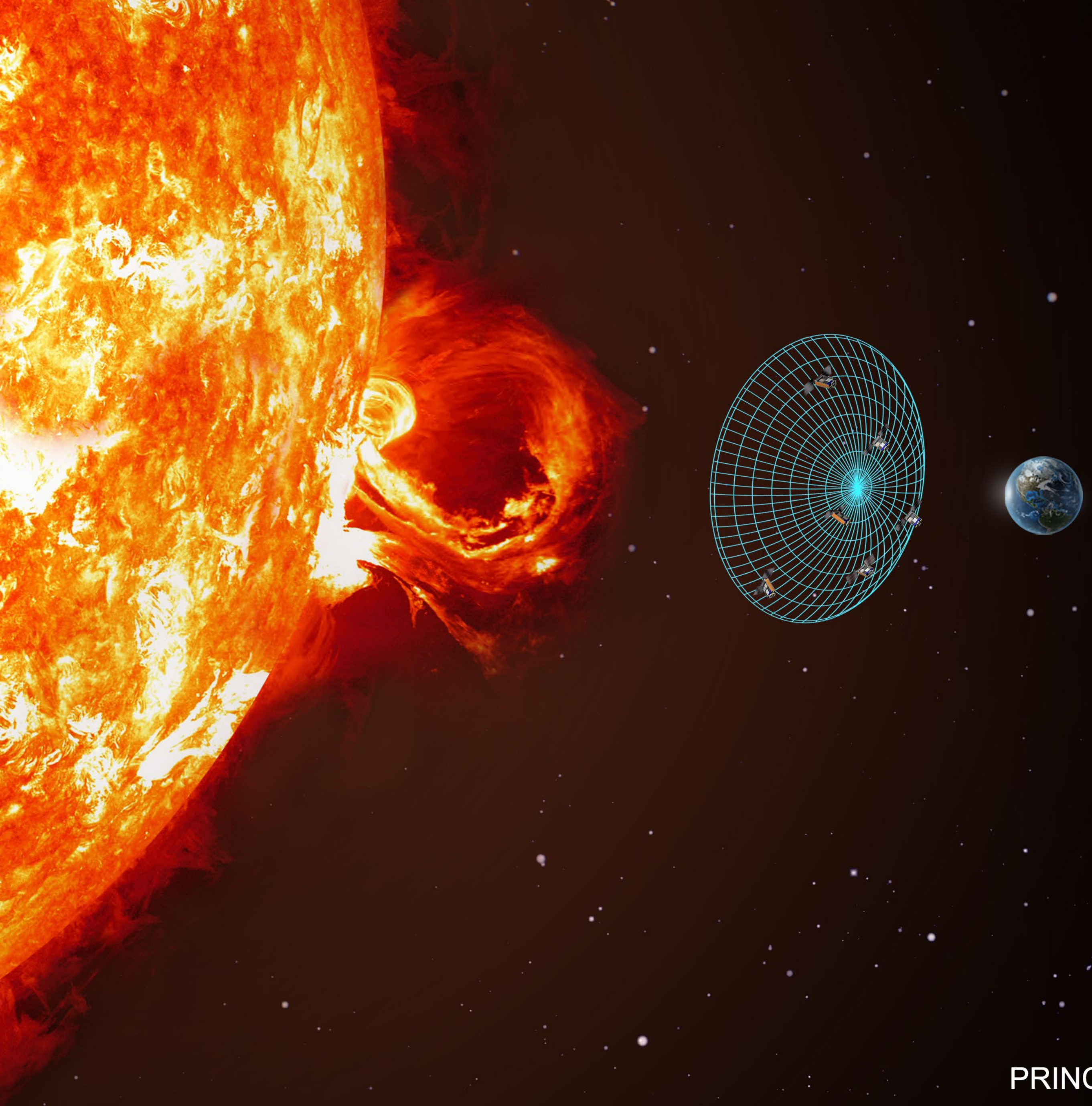

SunRISE Mission Lessons Learned

March 13, 2024

SUNRISE
SUN RADIO INTERFEROMETER SPACE EXPERIMENT

PRINCIPAL INVESTIGATOR: Justin C. Kasper (University of Michigan)

SDL/24-0781 Rev. -

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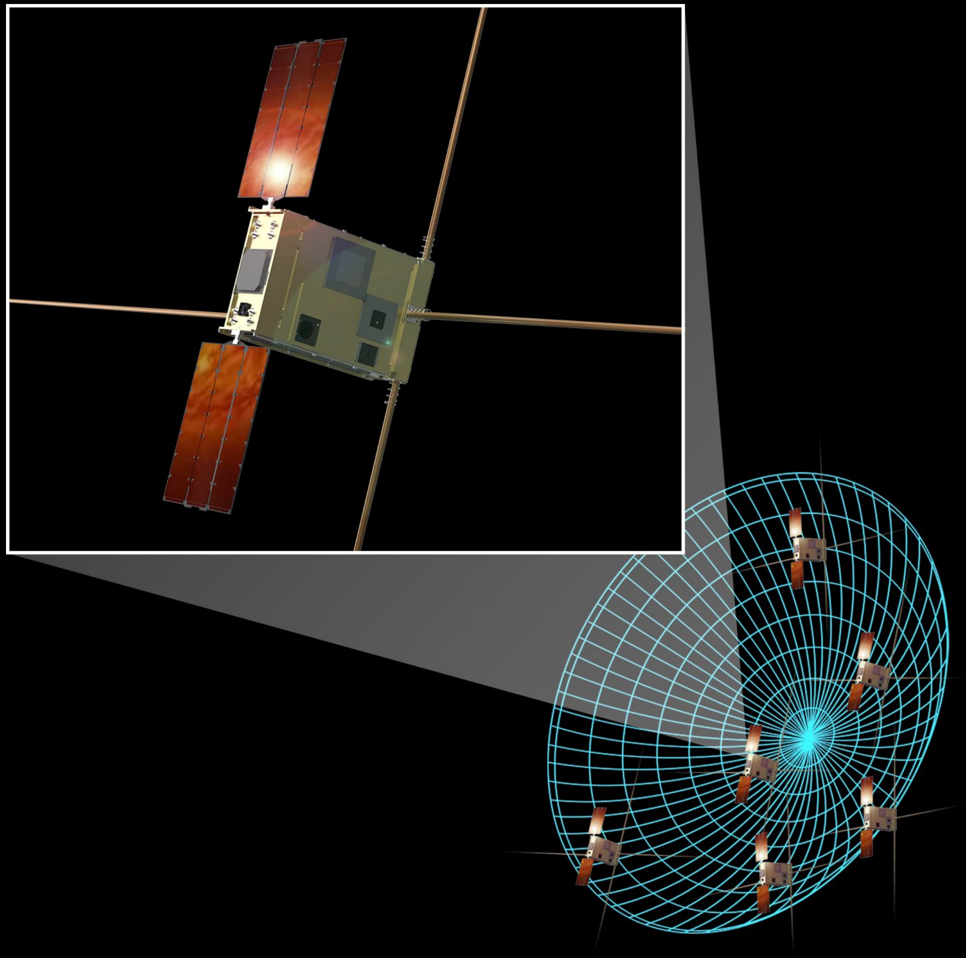
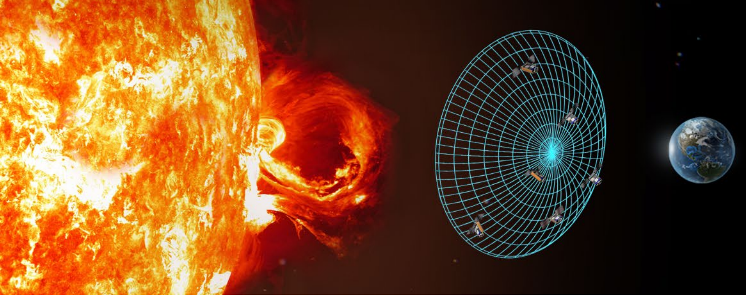
SunRISE Mission Overview





Mission Overview

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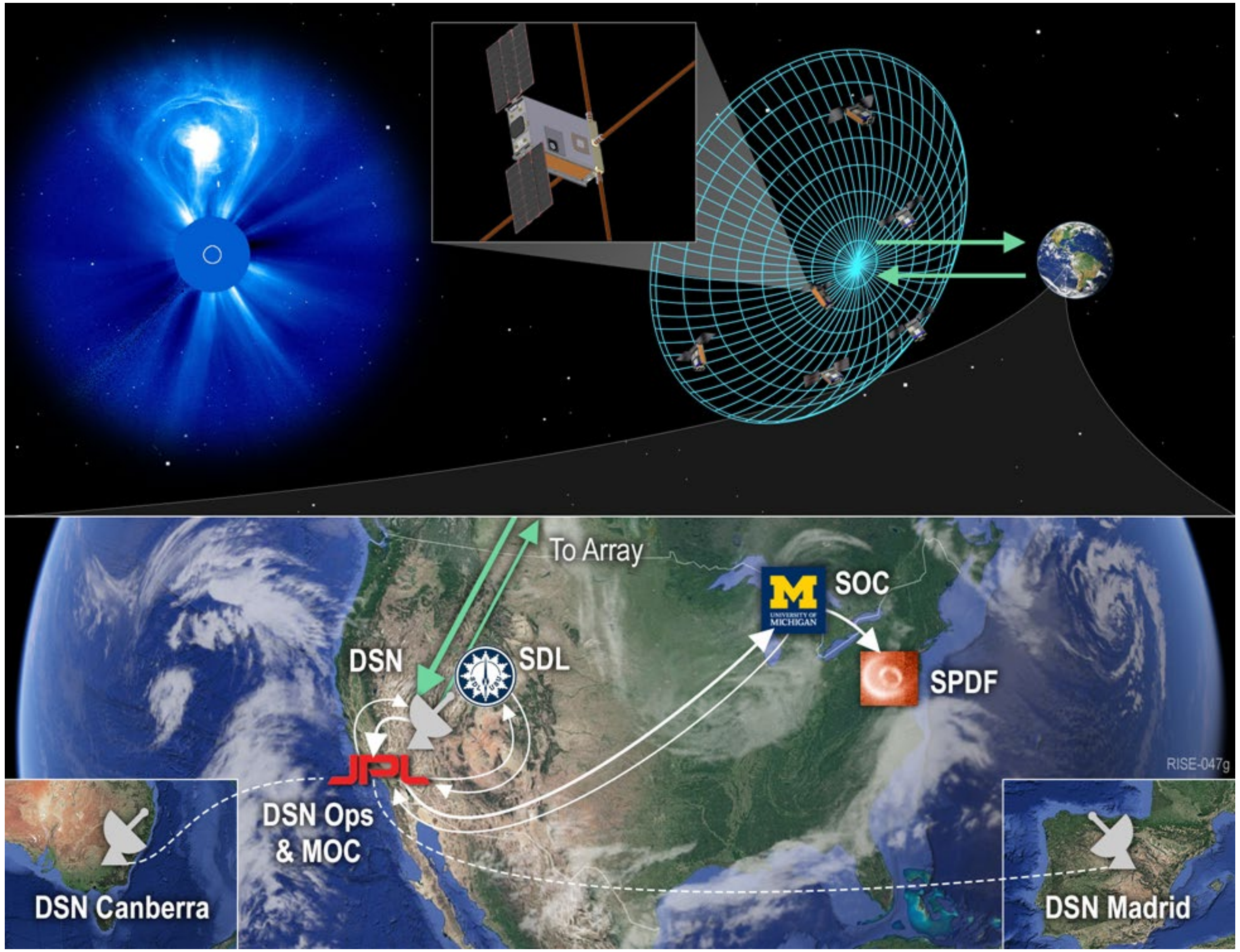
Science & Mission Goals

- Reveal how Solar Energetic Particles (SEP) are accelerated as Coronal Mass Ejections (CME) and how the SEPs are released into interplanetary space
- Provide spatially resolved observations of solar radio bursts (<15 MHz)
- Establish the first low frequency radio interferometer in space

Mission Design

- Create a 10 km sparse aperture interferometer using a constellation of six CubeSats
- High availability observations for 12+ months
- High orbit to avoid ionosphere – inject directly into GEO graveyard orbit (approximately GEO + 400 km)



Program Requirements & Constraints

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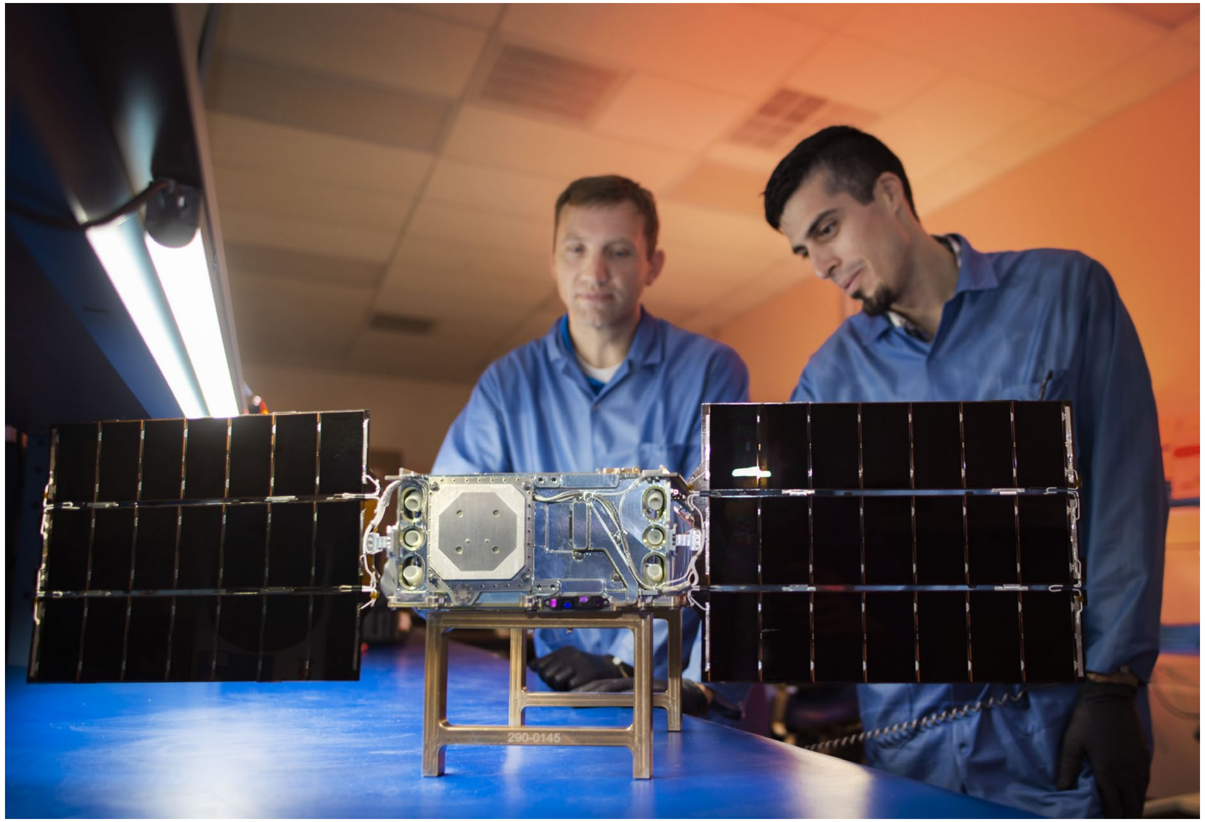
SUN RADIO INTERFEROMETER SPACE EXPERIMENT

Program Constraints

- Class D: “High risk tolerance that is driven more by programmatic constraints” (NASA NPR 8705.4)
- Cost-capped, FY17 $55M
- Six 6U CubeSats: Volume constrained



Spacecraft Requirements:

- 14-month operational lifetime in GEO graveyard
- $\leq$14 outages per week, total of 56 minutes
- Detect and respond to outages automatically
- $\geq$100 mils aluminum shielding
- Surfaces >3 cm^2: $\leq 10^9$ Ω/sq and <0.1 Ω ground

Highlighting Lessons Learned

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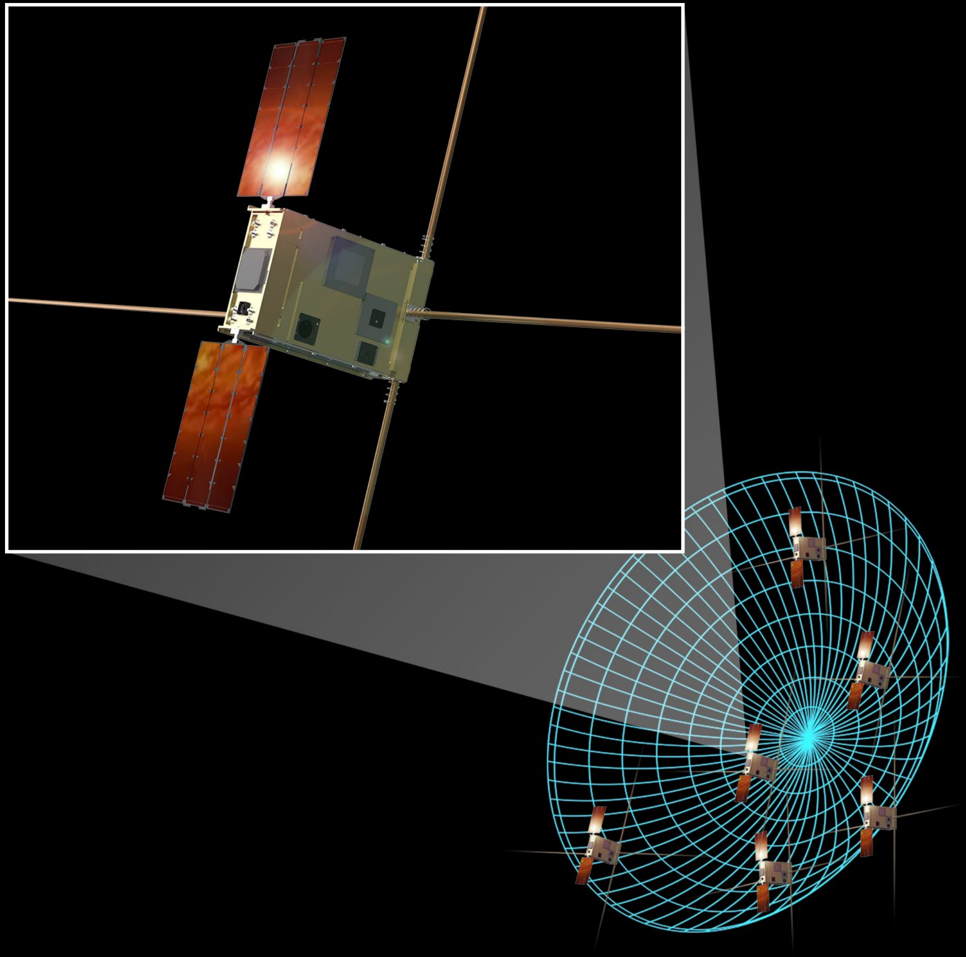
SUN RADIO INTERFEROMETER SPACE EXPERIMENT

- Positive feedback – do these
  - Intentional decisions
  - Efficient or effective approaches
- Negative feedback – avoid these
  - Misses
  - Ineffective or inefficient approaches
- Neutral feedback – be aware of these
  - Challenging constraints

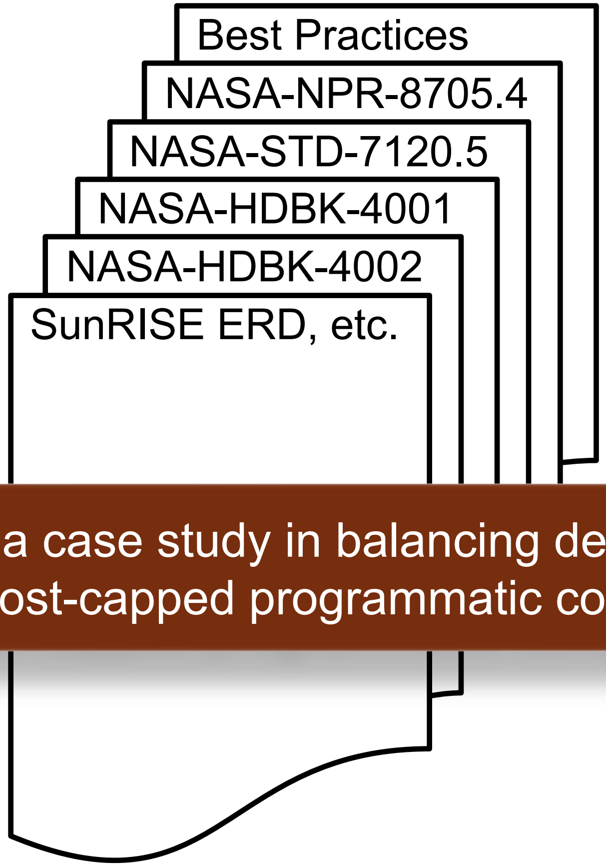


Programmatic Lessons Learned

Mission overview
Implementation approaches & challenges

Development Approach

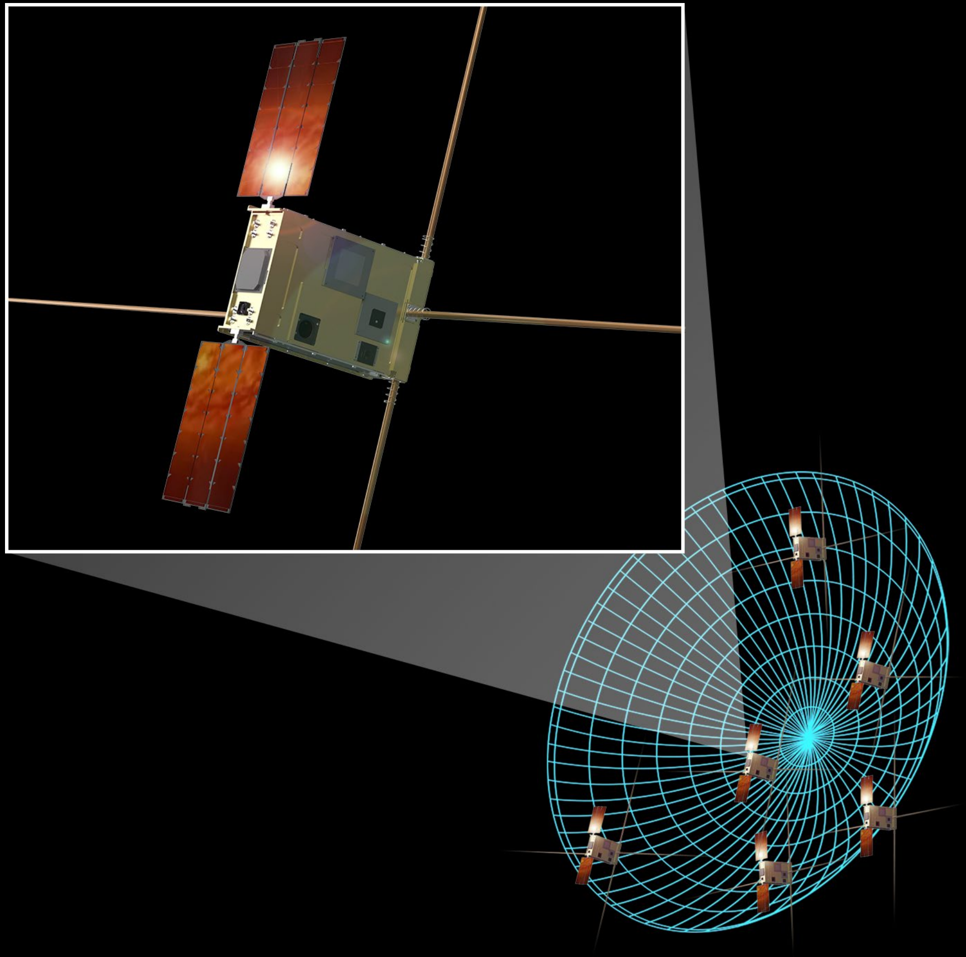
- **“Best effort”** to apply NASA standards and industry best practices – appropriate for Class D
- Approach: **Assess risks and manage costs** (analysis, test, design, etc.) **to implement a balanced design**
  - Focus on system-level implementation
    - Minimal flow-down requirements
  - Prioritize high-value risk reduction activities
- **“Document Lite”** – fewer high-value documents, reject spurious requests



SunRISE is a case study in balancing development rigor and cost-capped programmatic constraints.

Programmatic Challenges

- **Negotiated High Institutional Expectations**
  - Affected both SDL and JPL
  - Class D mission reviewed by implementers of Class A/B/C missions
  - Cautious approach to waivers
  - Conflicting philosophies with New Space vendors
  - Accept low-effort tasks that reduce risk
  - If testing is recommended, evaluate costs
  - Change control boards (CCBs) and safety/mission assurance (SMA) processes to advocate for engineering rigor



Development Lessons Learned

Designing for the GEO region
Telecom & mechanical system interactions
Mechanical design constraints

Designing for the GEO Region

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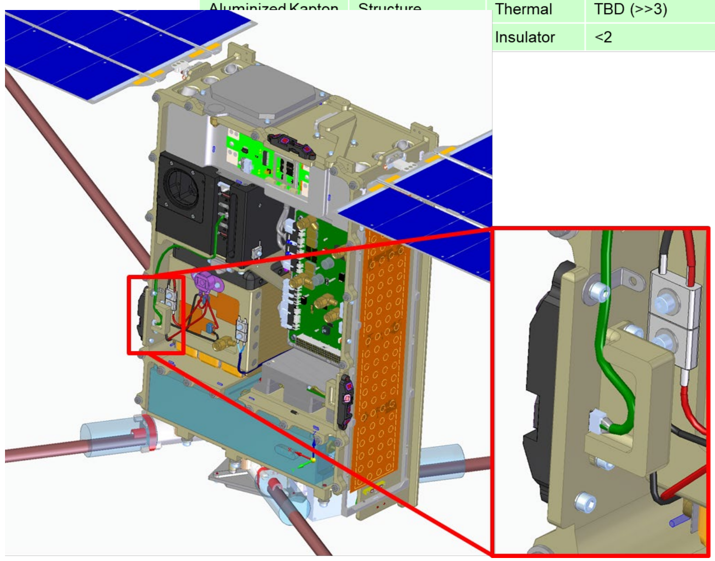
SUN RADIO INTERFEROMETER SPACE EXPERIMENT

High Value Risk Reduction – Mitigate (Amber Kapton, Patch Antennas, Somos PerFORM)

Low Cost Risk Reduction – Mitigate (Carbon Fiber)

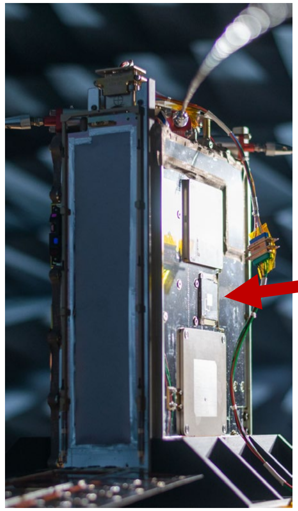
Surface	Placement	Purpose	Surface Area (cm^2)	Surf. Resistivity (Ohm/sq)	Path-to-Ground Resistance (Ohm)	Mitigation
Amber Kapton	Solar Array	Foam Cover	183	10^{16}	∞	Change to StaMet black Kapton
Patch Antennas	Antennas	Antennas	14–72 ea., 426 tot.	10^{13}	Ground planes	DC bleed network
Somos PerFORM	Propulsion	Structure	TBD (>>3)	Unknown (>10^9)	<0.1 at mount	Add aluminized Kapton layer
Anodization	Structure, ADCS, Sun Sensors	CSD Tabs, Other	<80 ea., ~200 tot.	10^{11}	<0.1	
Star Tracker Baffle Coating	Star Tracker Aperture	Light Blocking	TBD (>>3)	TBD	TBD	
Carbon Fiber	Solar Array	Structure	~90 ea., ~500 tot.	TBD (<10^9)	<0.1 for center panel >0.1 for side panels	Ground strap sides to center
Glass	Solar Array	Radiation	27 ea., 1152 tot.	TBD (>10^9)	∞	
Black Kapton	Solar Array	Thermal	5 ea., 533 tot.	$5*10^6$	∞	
Aluminum, Yellow Iridite	Structure	Corrosion Resistance	TBD (>>3)	~1	0	
ITO Silver FEP	Structure	Thermal	TBD (>>3)	10^4	<0.1	
Aluminized Kapton	Structure	Thermal	TBD (>>3)	<1	<0.1	
		Insulator	<2	10^{16}	0	



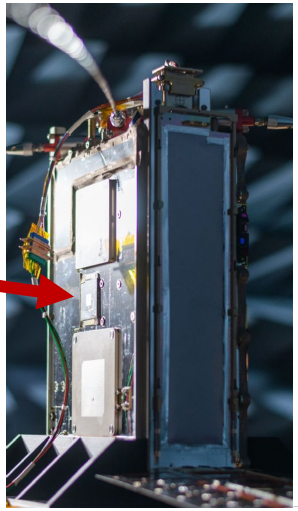
- **Performed qualitative** analysis & design
  - Surface charging materials assessment
  - Cover apertures
  - Labyrinthine paths, gaskets, and harness shields
  - Use common solutions – don't reinvent the wheel
- **Mitigated surfaces** with high-charging risk
  - Modified surface materials for several COTS items to reduce risk
- **Assessed costs** for moderate-risk items
  - Determine acceptable risk level
  - What is too expensive (time OR schedule) to fix?
- **Received limited information** from vendors
  - Incomplete parts lists or property data
  - Proprietary materials

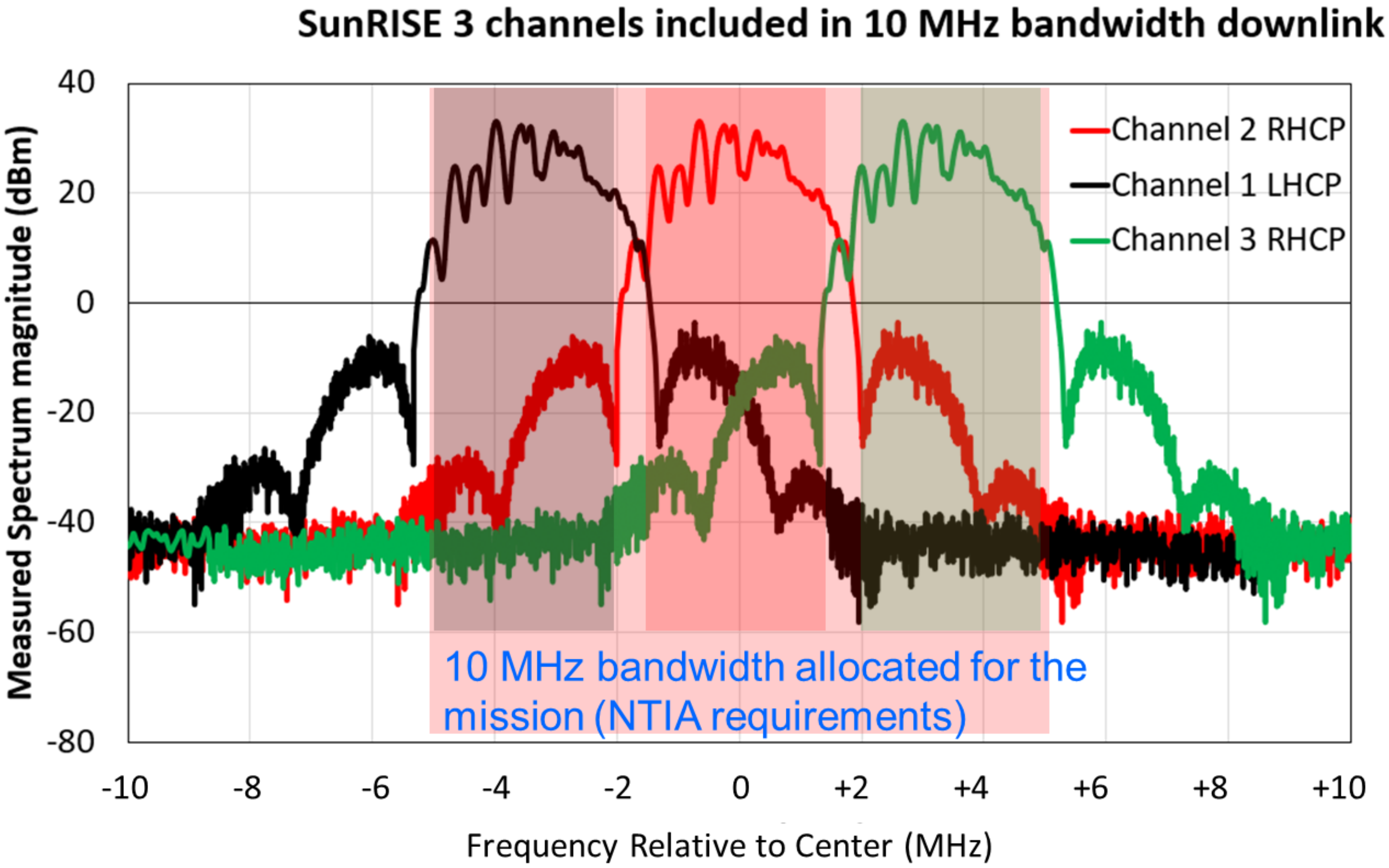
Telecom & Mechanical System Interactions

- **Fit in narrow mission channel bandwidth** using MSPA & alternating polarization
- **Late mechanical design change needed** for multiple antenna configuration
  - Multiples but not all identical



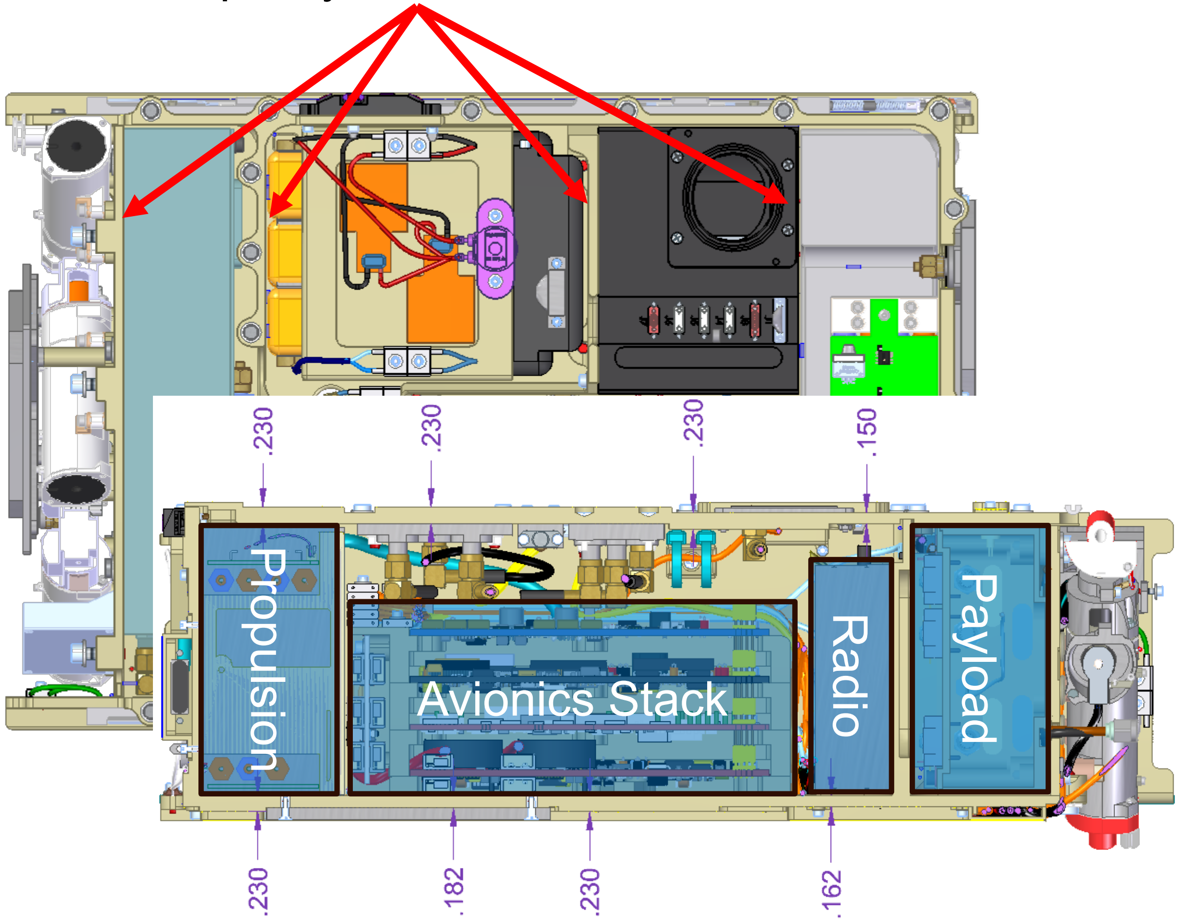
RHCP/LHCP X-Band Antenna



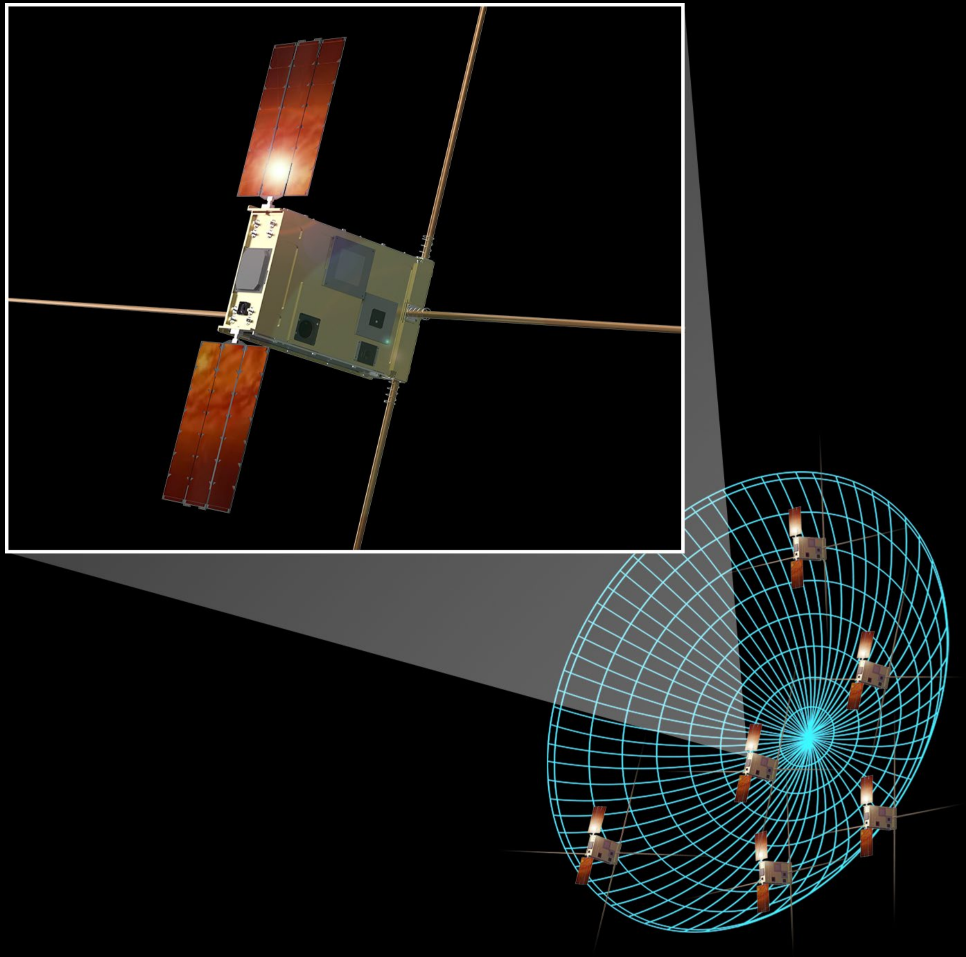


Mechanical Design Constraints

Total dimensions minus tolerance stackup fully utilized



- **Volume constraints drove** mechanical design
  - Allocated to the limits of tolerances
- **Utilized spot shielding** and assessed patch antenna contributions without detailed analysis
- **Planned, tested, and revised** assembly procedure with first flight
  - Early enough for minor design adjustments
- **Accepted some tedious processes** that did not seem so bad on one spacecraft but challenged staff when applied to six builds



AI&T Lessons Learned

Scaling logistics
TVAC lessons
Coordination at scale
Lessons in discipline

Scaling Logistics

- **Same equipment & staff needed** in multiple locations at the same time
  - E.g., EMI & TVAC
  - Test & record keeping often most efficient with at least **three** team members
    - **Two** hands-on operators
    - **One** procedure recorder/signer/checker
  - **Duplicated** some GSE setups but still challenging
- **Used moveable equipment racks** for “pop-up” test stands
- **Configuration managed test scripts**
- **Iterated, streamlined** procedures for many runs
- **Avoided “only once” mentality**
- **Make redline updates** immediately

TVAC Lessons

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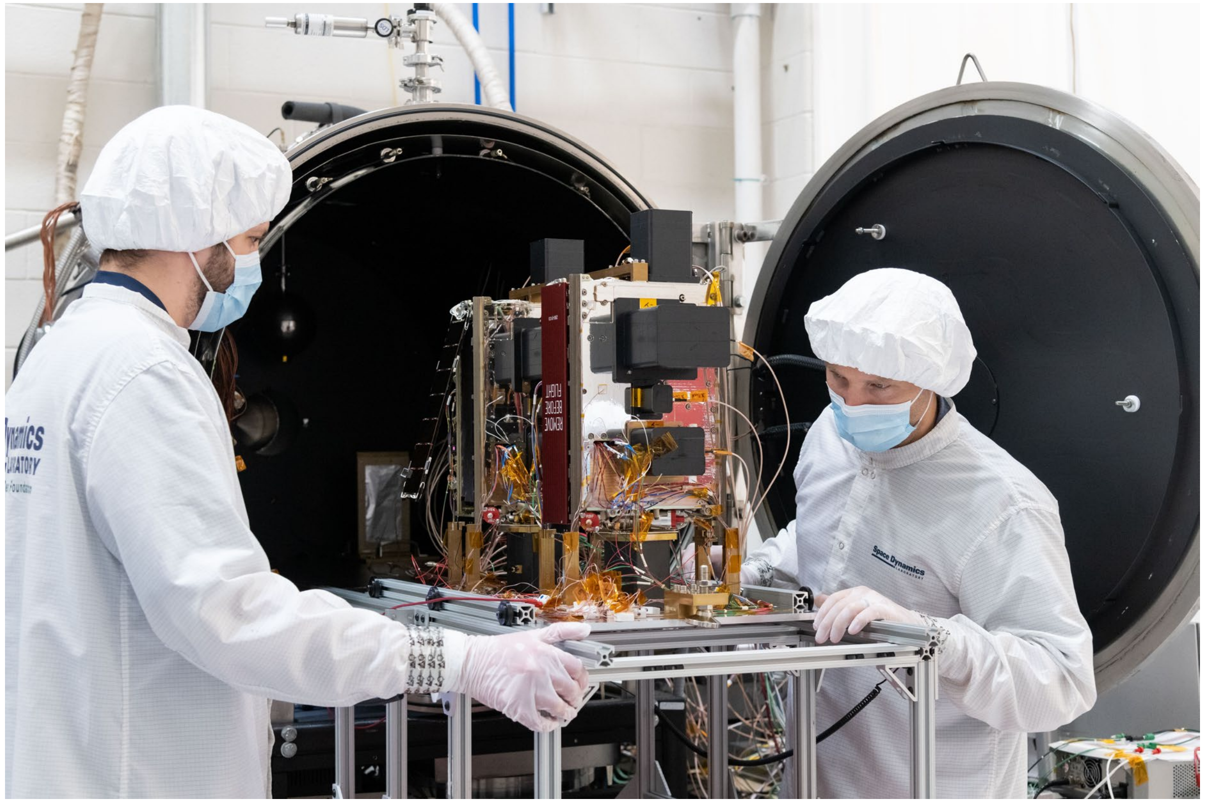
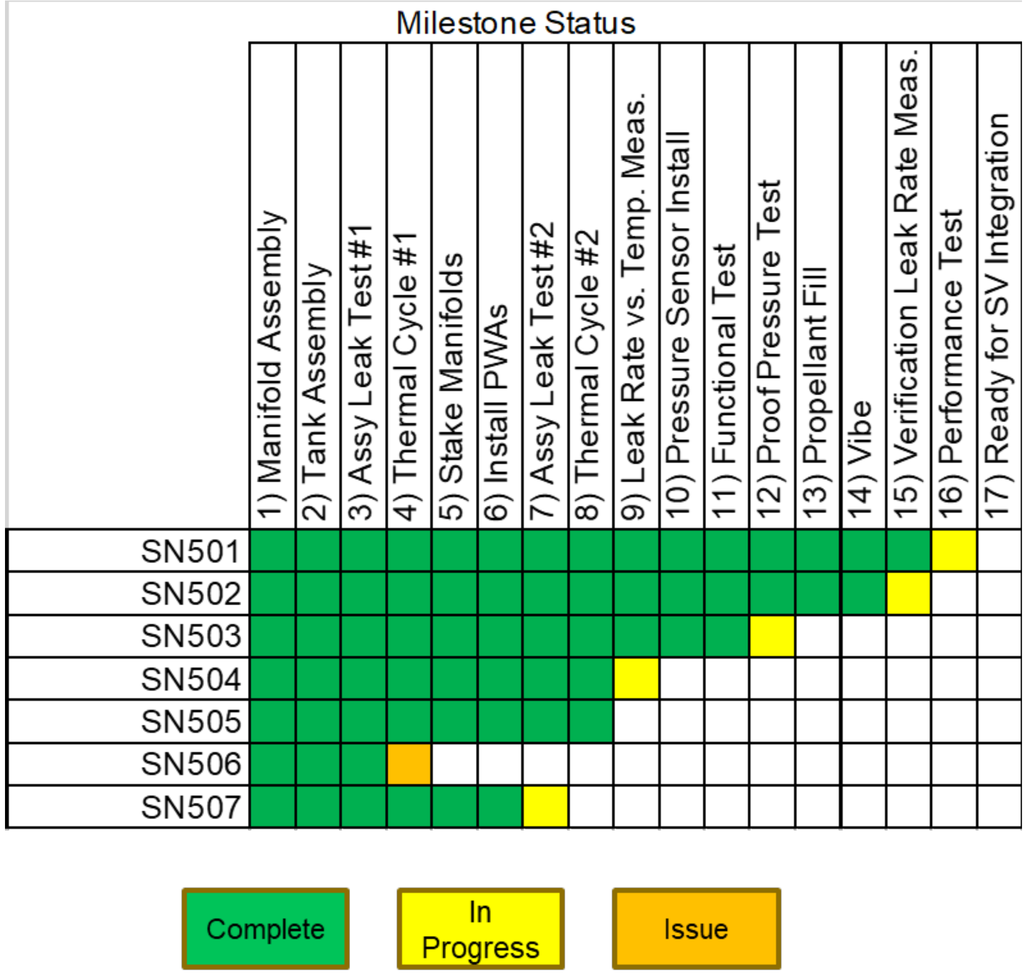


- **Two spacecraft** in TVAC simultaneously
  - Saved chamber time, not setup time
- Used an **extra set of temperature sensors** to prep “on-deck” spacecraft before moving to the TVAC chamber
  - Secured wires with appropriate strain relief
  - Pipelined work
- **Did not always use** an intermediate connector inside the TVAC chamber
  - RF cables were sensitive to noise affected by placement
  - Ideal is to route & secure harnesses in the lab, not in the chamber
- **Assigned test roles** to minimize training & staff scheduling burden
  - Test conductor – responsible, system & test profile aware (24/7)
  - Chamber watcher – chamber operation, logging, and safety (24/7)
  - Test operators – spacecraft hardware specialists (as needed)

Coordinating at Scale

SUNRISE
SUN RADIO INTERFEROMETER SPACE EXPERIMENT

- **Reordered tests** as needed
- Encountered **communication challenges** using common scheduling tools
  - SN1 was not always first in line
  - Real schedule allows flexibility, tools struggled to capture this
  - Issues tracked by SN
  - Most efficient path often difficult to represent in the schedule
- **Used a tailored workflow** for over 600 as-run procedures
  - Operator makes traveler entry, submits as-run to QA
    - Marked for verification or not
  - QA inspects the record and collects corrections
  - QA submits to technical writer to digitize
  - Technical writer updates tracking tool
  - Operator links controlled document to traveler



Lessons in Discipline

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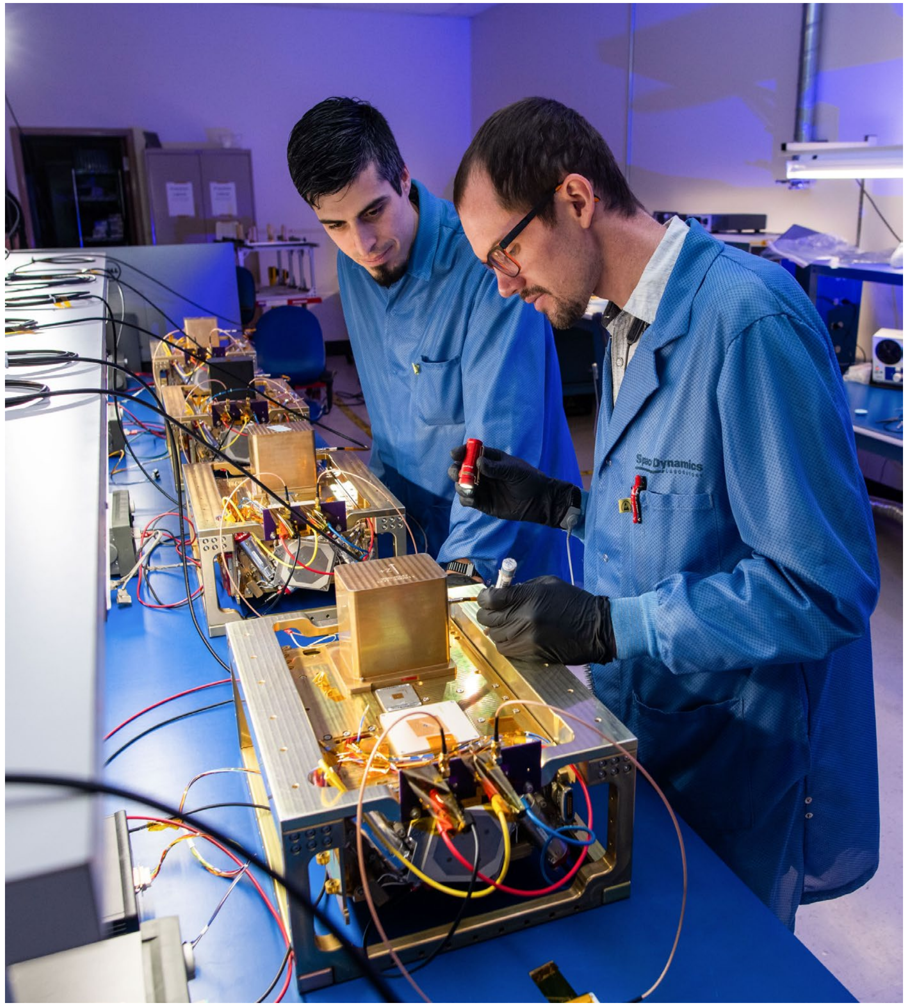
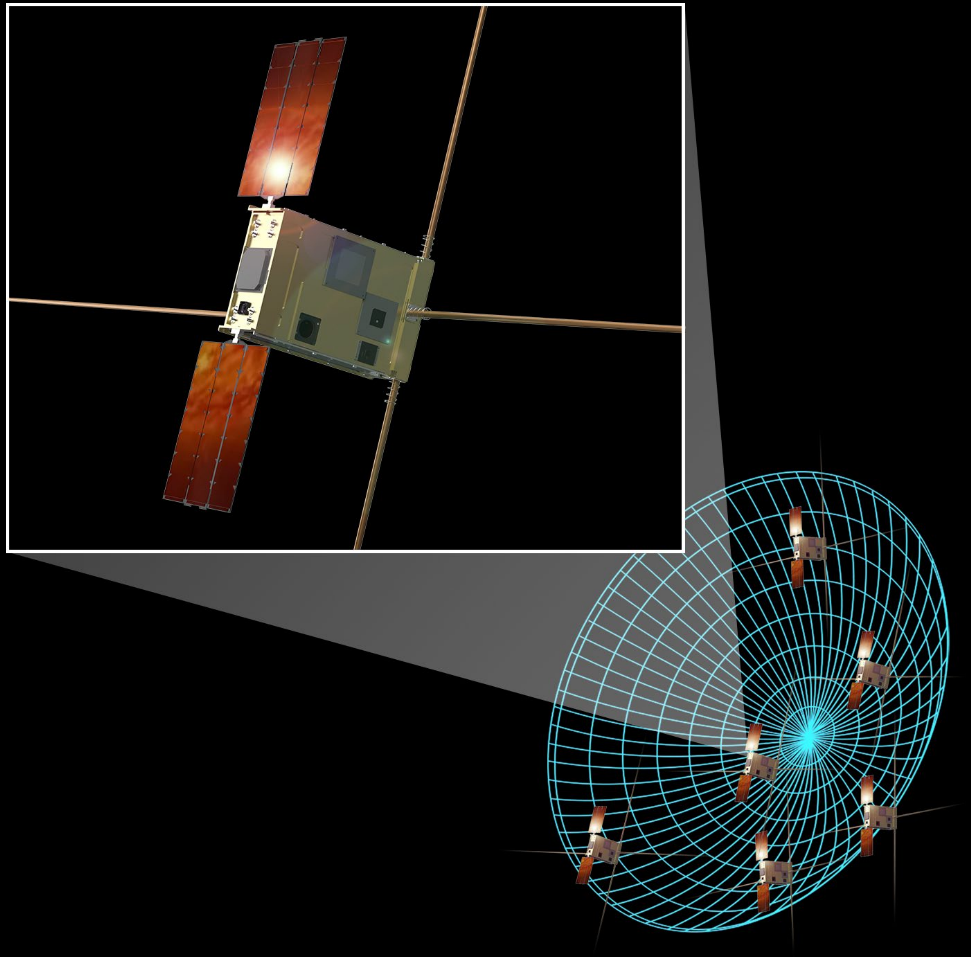
SUN RADIO INTERFEROMETER SPACE EXPERIMENT

- Up-to-date **travelers helped diagnose** issues and find solutions
- **Missed test-on-receipt** for a subsystem
  - Root cause of later hardware failure was ambiguous





Propulsion Lessons Learned

Overview
Technical lessons learned

See also: Martineau, R., Smith, T., Felt, M., Weston, C., Rusch, B., et al. “Lessons Learned During the Implementation of a Cold Gas Propulsion System for the SunRISE Mission.” *Small Satellite Conference*, August 2023.

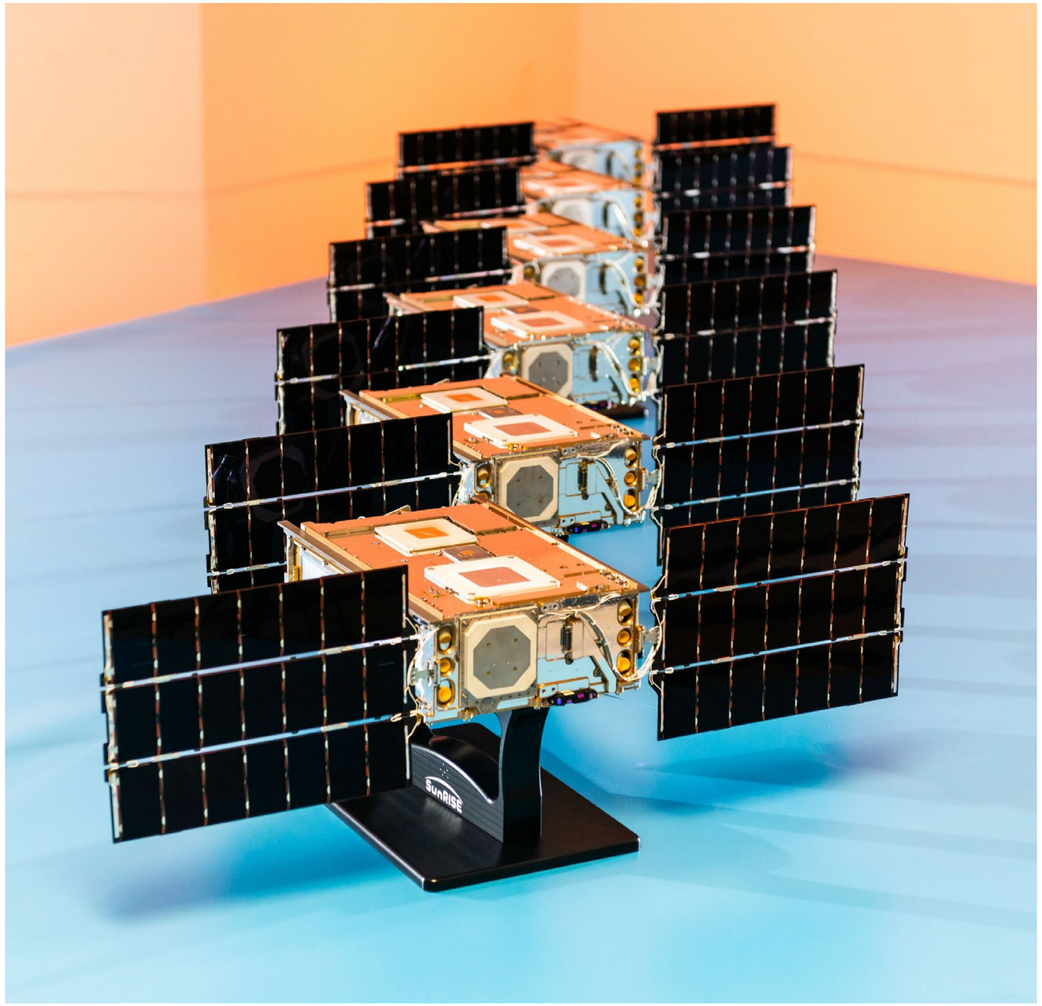
Propulsion Requirements

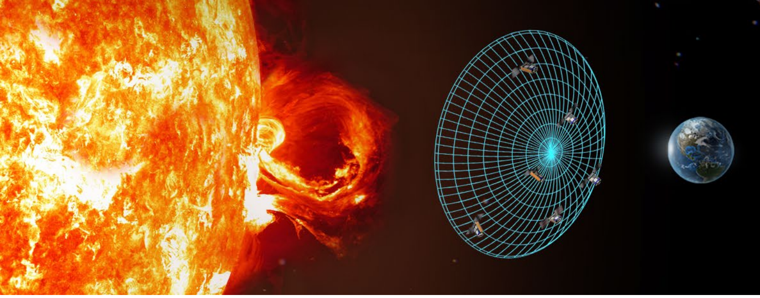
Minimum Capability

- At least 7 m/s delta-V (including RCS equivalent)
- Initial interferometer setup after GEO graveyard orbit injection by rideshare
- 12 months of orbit maintenance
- 12 months of reaction wheel desaturation

Qualitative Features

- ~1U allocation (~2U x 1U x ½U) in 6U CubeSat
- ~12 kg dry mass
- Rideshare-friendly propellant

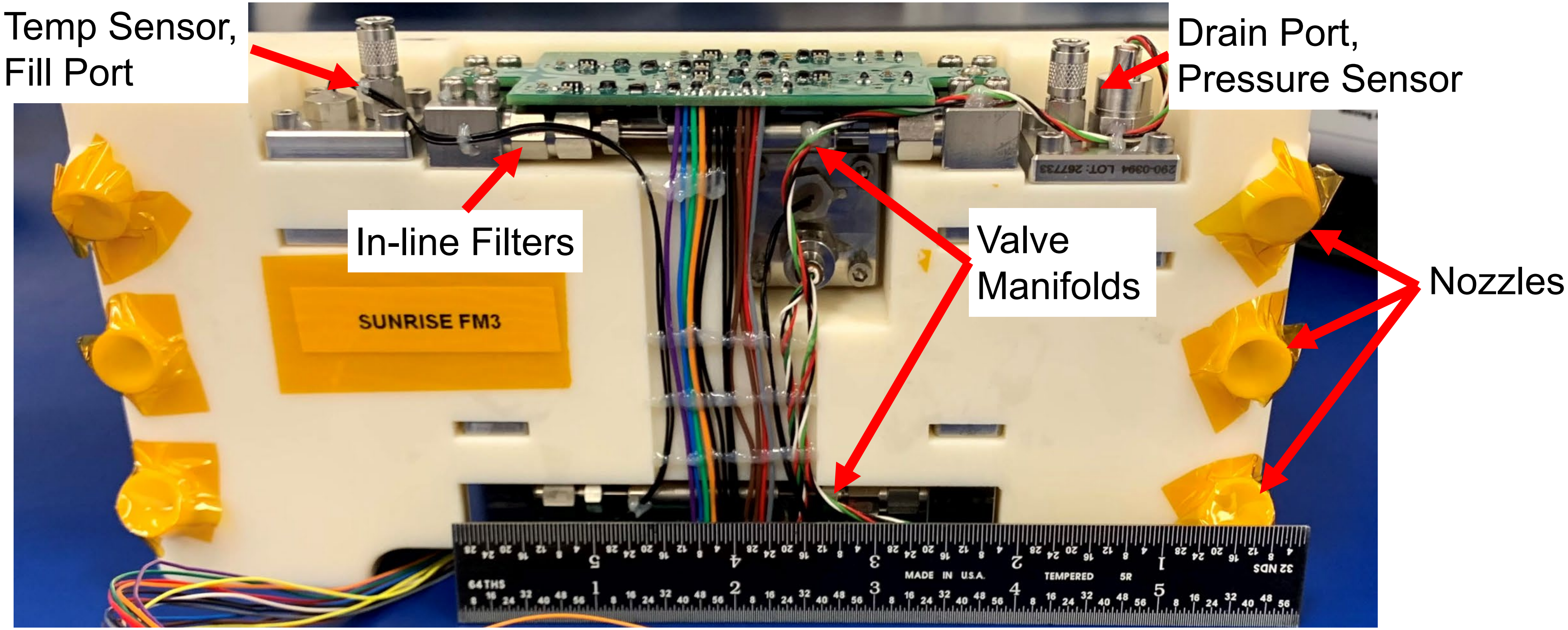


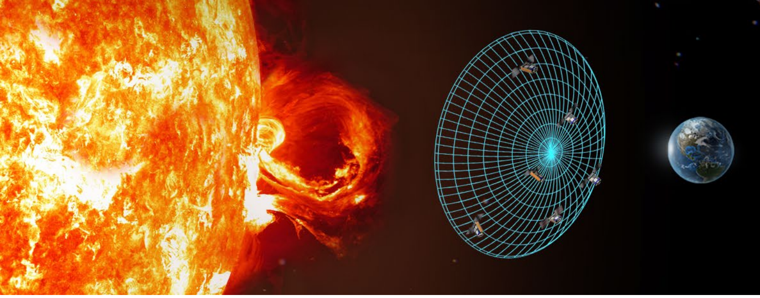


Propulsion System Overview

- Two-phase cold gas propulsion, R-236fa propellant
- Monolithic 3D-printed (SLA) tank and structure, including nozzles and plumbing
- Heritage from BioSentinel and Ascent

Metric	Value
Thrust (0.15s Pulse)	32 mN
Specific Impulse	42.2 s
Dry Mass	1.2 kg
Propellant Capacity	330 g





Valve Stiction

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Symptoms

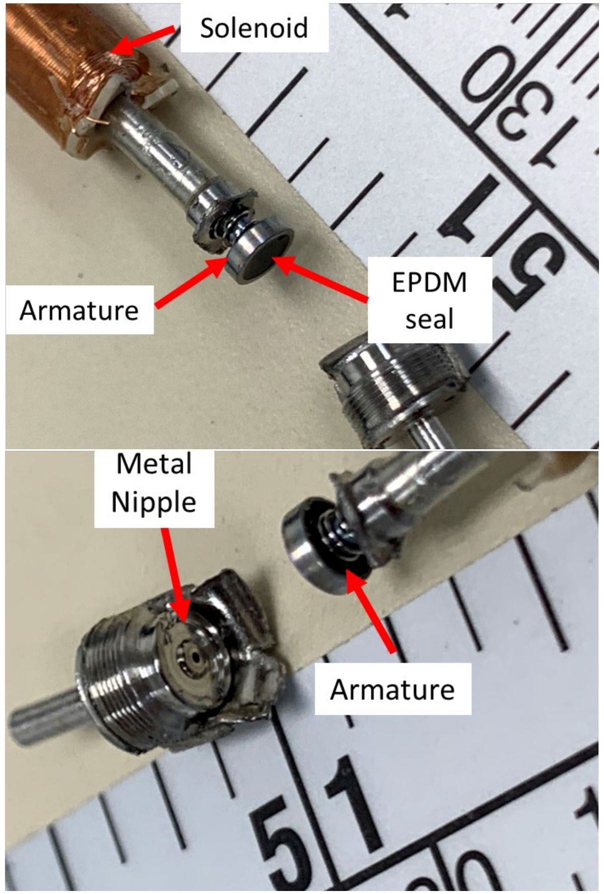
- Valves temporarily stuck after assembly
- Affected valves opened after 5–15 commands
- First open was sometimes sluggish

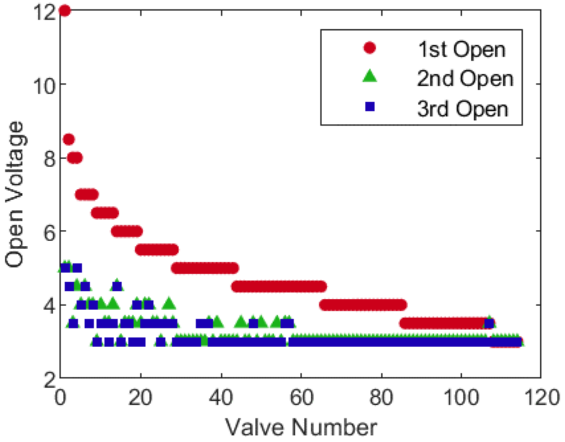
Contributing Causes

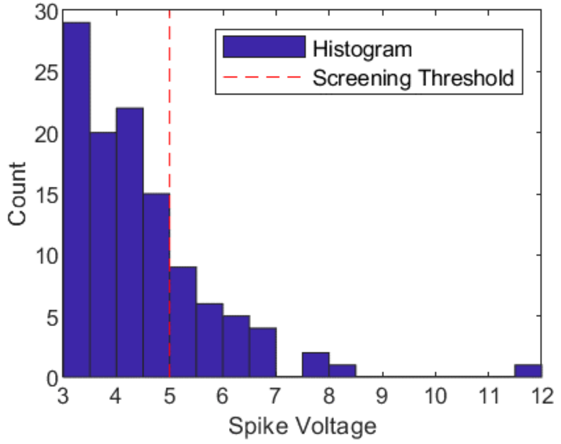
- Insufficient solenoid actuation energy from heritage circuit
- Variability of COTS valves
- Material/process incompatibility

Mitigations

- Increased solenoid spike voltage and duration
- Screened valves for minimum cold open voltage
- Eliminated a cleaning step
- Prepared an on-orbit priming function







High Leak Rate

Symptoms

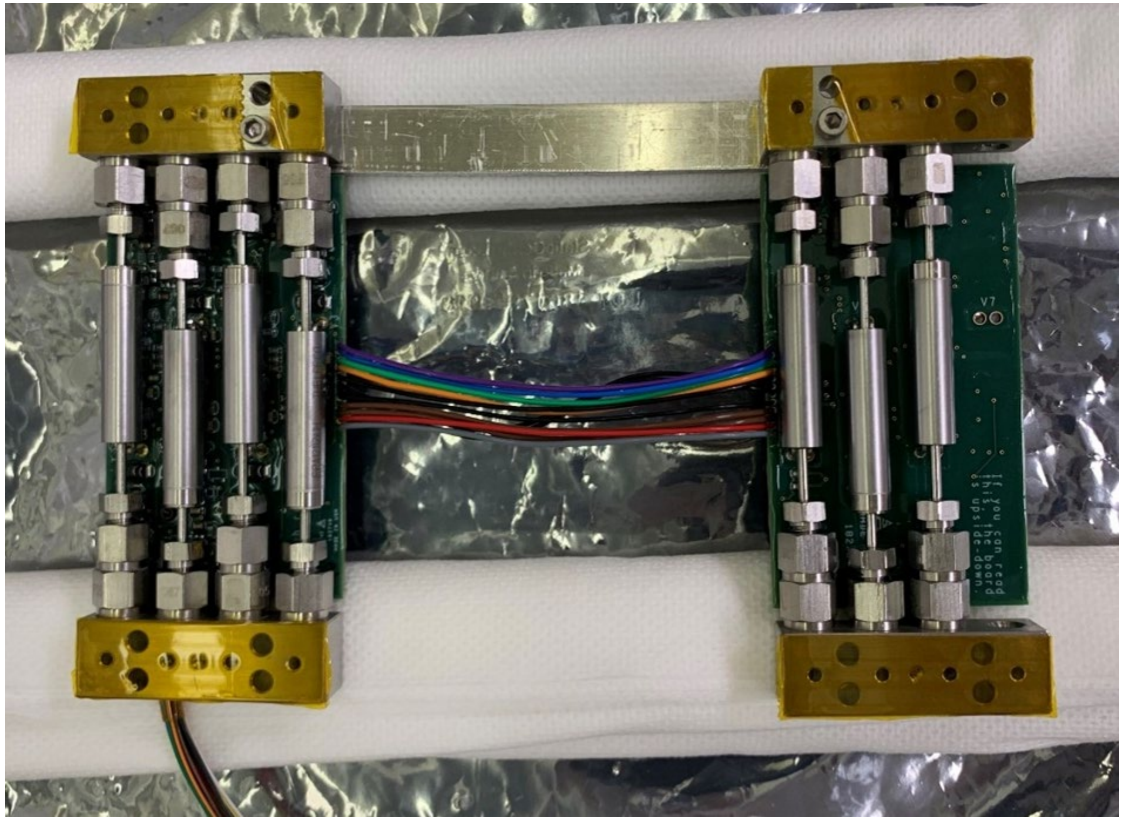
- High leak rates measured after initial assembly

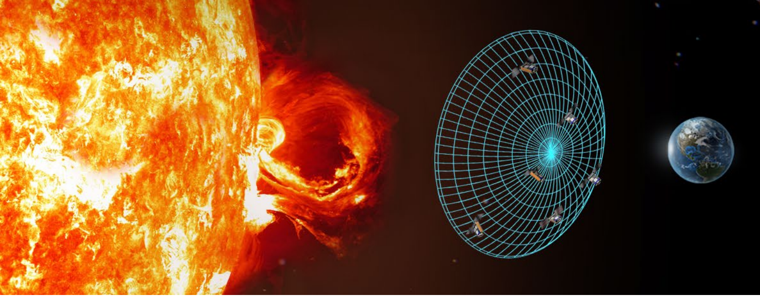
Contributing Causes

- Compression fittings
- Internal valve seals
- Thermal/mechanical overconstraint

Mitigations

- Implemented qual-style assembly process test program for compression fittings
- Screened valves for leaks
- Designed backup manifolds without compression fittings
- Designed backup manifolds with thermal strain relief





Filter Selection & Loading

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Symptoms

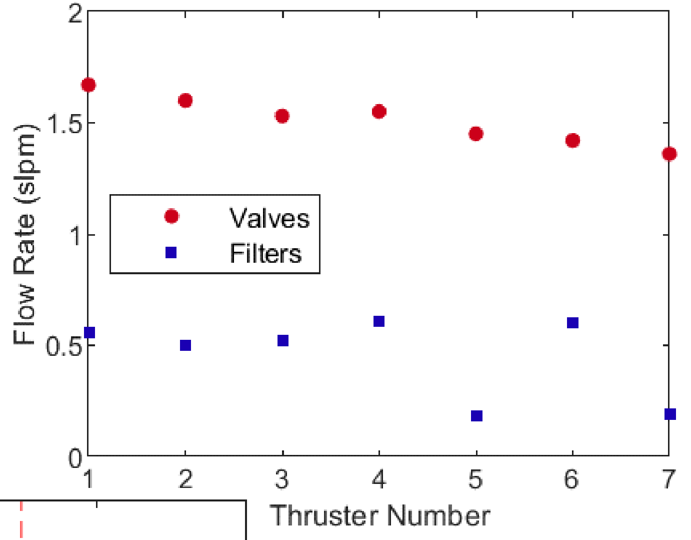
- Highly variable flow rate through sintered filters
- Filters load quickly, 1 mg coarse test dust

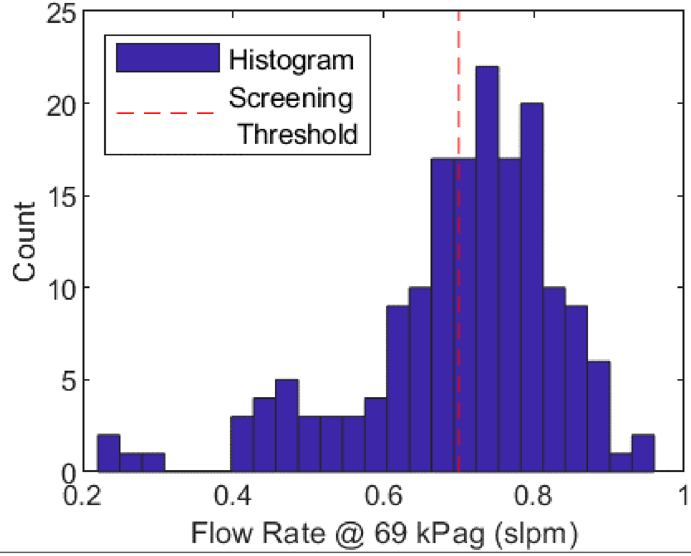
Contributing Causes

- Excessive flow restriction
- Insufficient end-of-life filter capacity
- High variability of COTS filters from factory
- Lack of cleanliness program

Mitigations

- Screened filters for flow rate
- Certified PCL100 cleanliness for all wetted parts





Additive Manufacturing & Materials

Symptoms

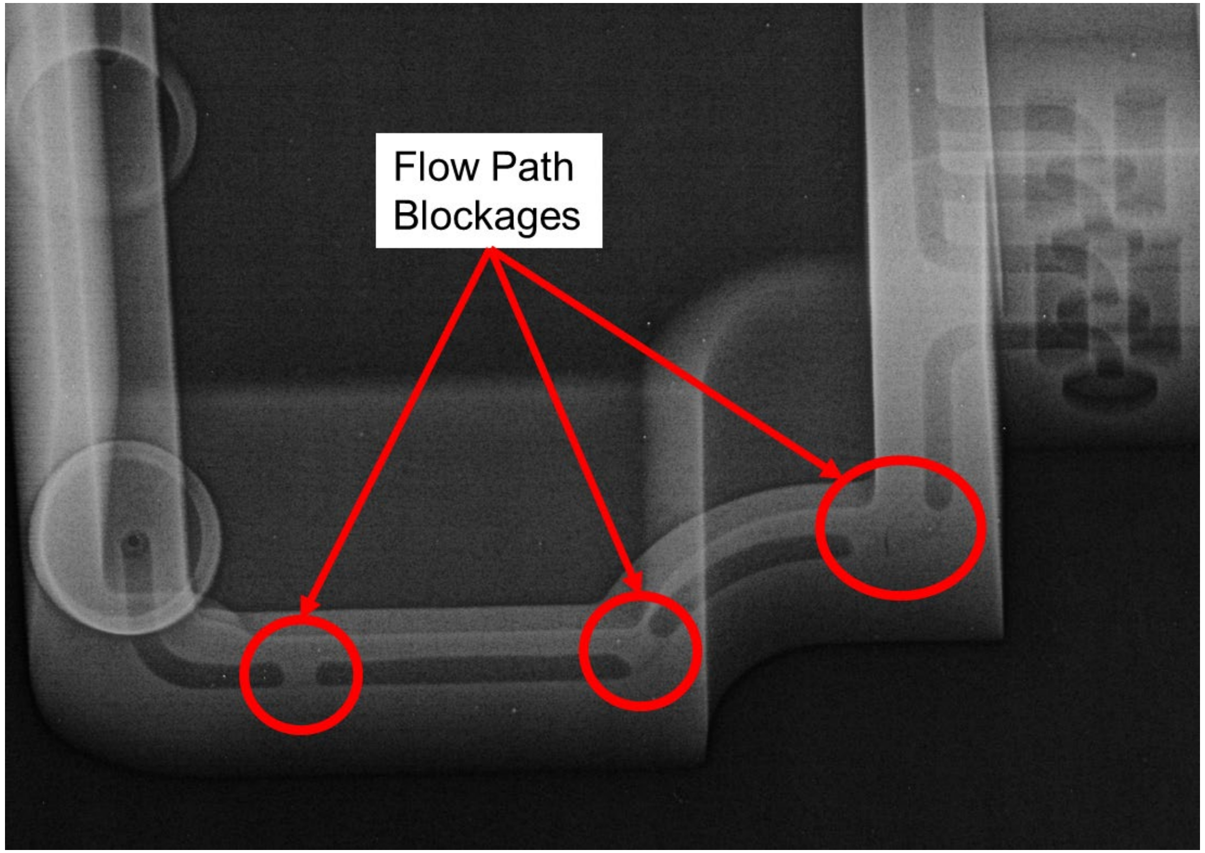
- Blocked flow in fluid passages
- Low tank yields
- Vibration mode shifts during testing

Contributing Causes

- Lack of project communication/training with vendor
- Insufficient resin removal processes
- Material creep

Mitigations

- Developed better resin removal processes with vendor, trained onsite at vendor
- Implemented multi-step torque application process



Propellant Phase Management

Symptoms

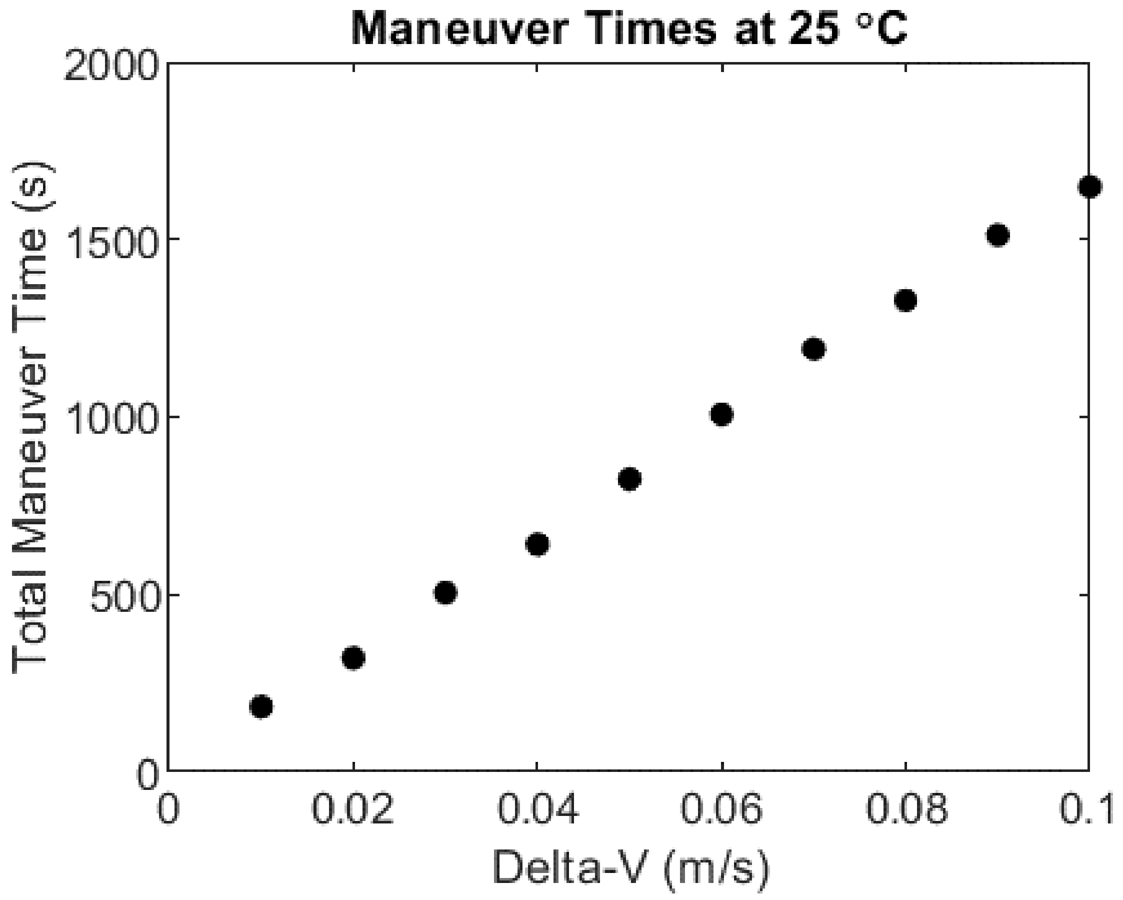
- Liquid phase observed in plenum during testing

Contributing Causes

- Lack of phase management feature in system architecture

Mitigations

- Implemented delay-based refill controller, accepted ~1% duty cycle as a result
- Reduced maximum single-maneuver delta-V magnitude
- Recommend using plenum heater or other phase-management device for future missions



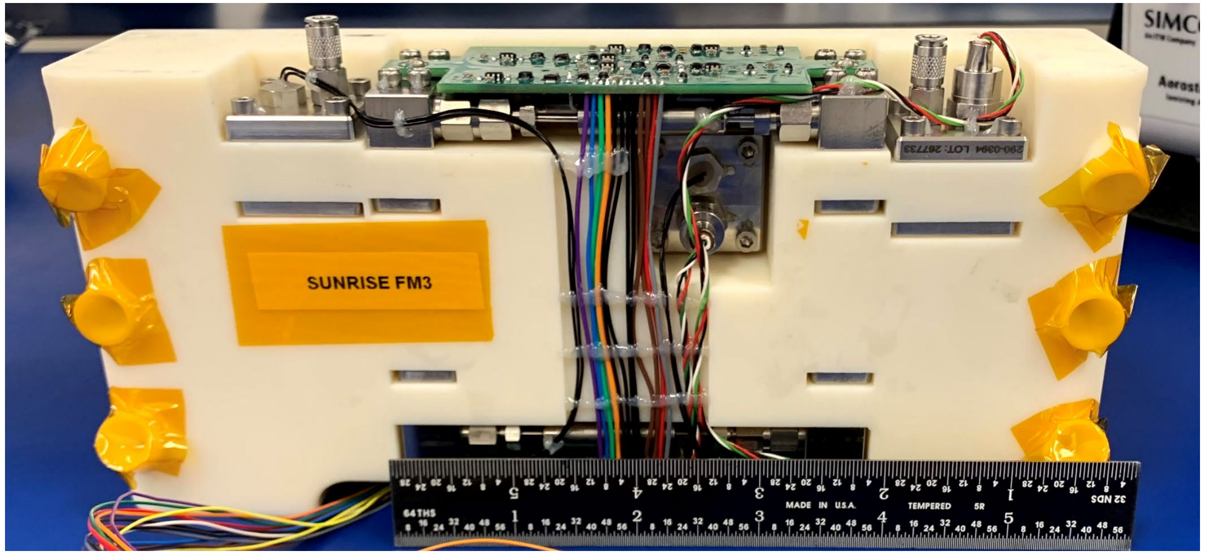
Conclusion

Other Lessons Learned Topics

- Leak rate measurement
- COTS parts challenges
- Sensor usage
- Propellant handling
- Requirement changes
- Storage protocols
- See paper for additional context and details

SunRISE Status

- Resolved or mitigated risk for all propulsion issues
- Built and tested seven flight units within ~six months, including issue resolution time
- Preparing for storage, launch expected Q4 2024



SunRISE

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