Distributed Attitude Control and Maneuvering for Deep Space SmallSats

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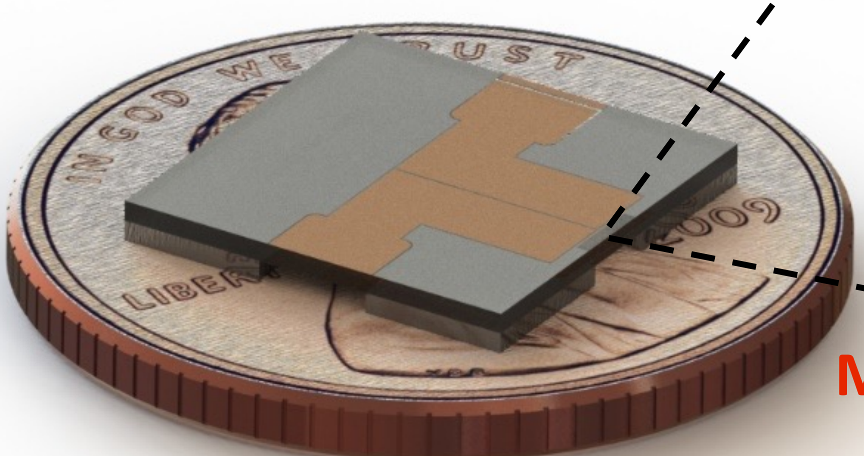
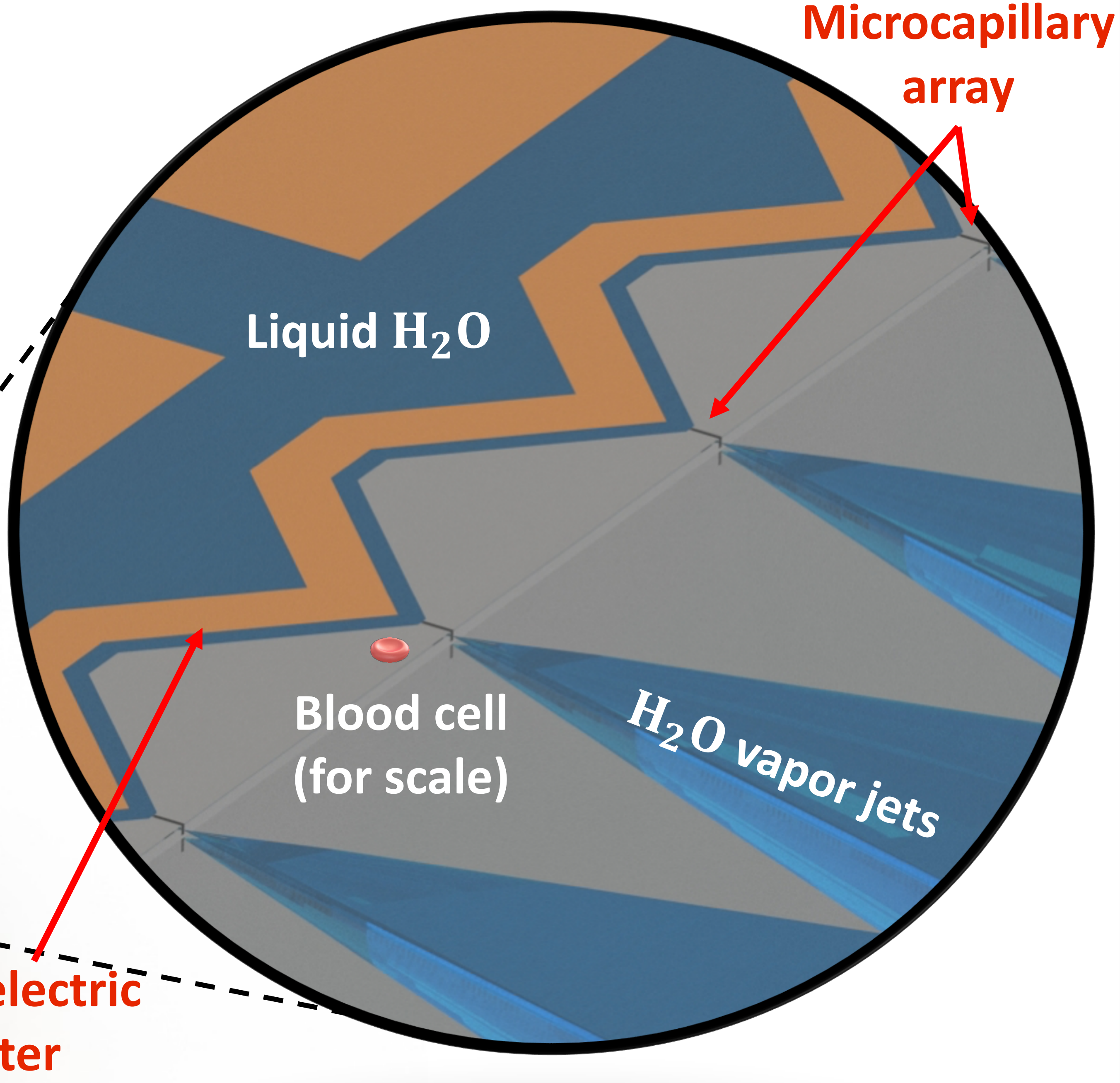
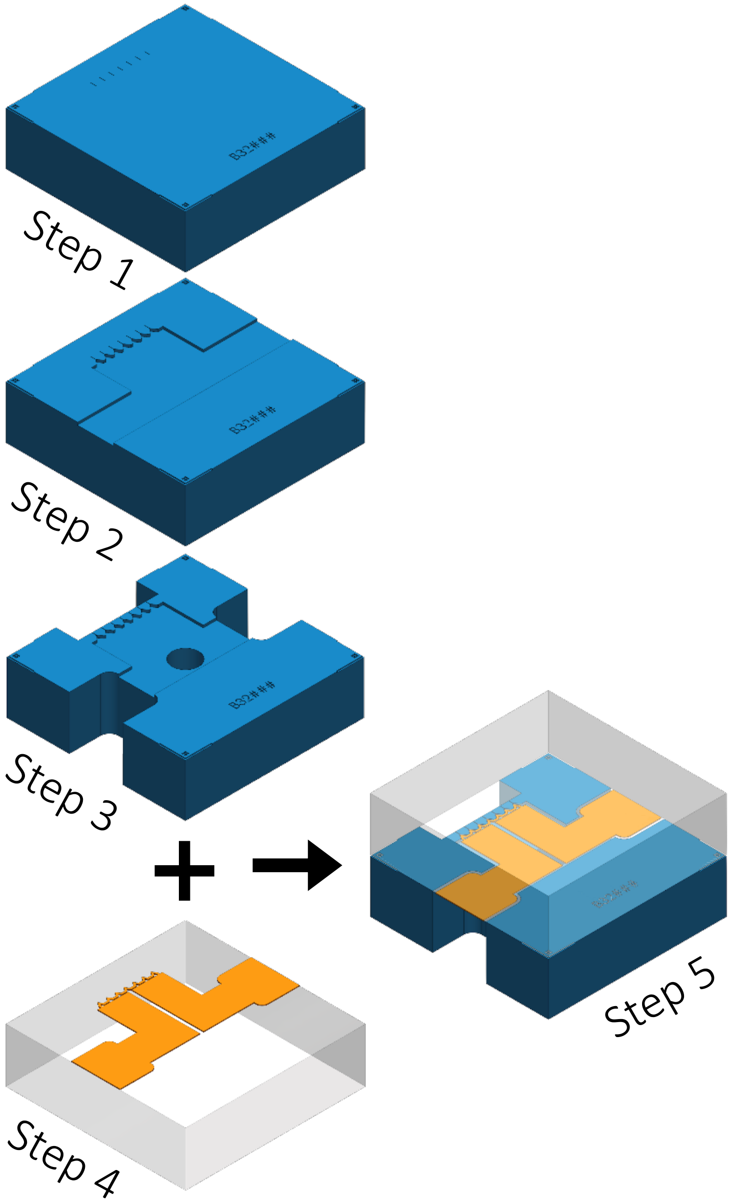
FEMTA Micro-thruster

250 $^{\mu N}/_{W}$ electrical power	< 1 W
Ultra-pure DI water as safe and abundant propellant	H_2O
High total impulse due to dense propellant	90 s
Thrusters fabricated on 1 cm^2 x 1 mm silicon chips	200 mg





FEMTA Microfabrication

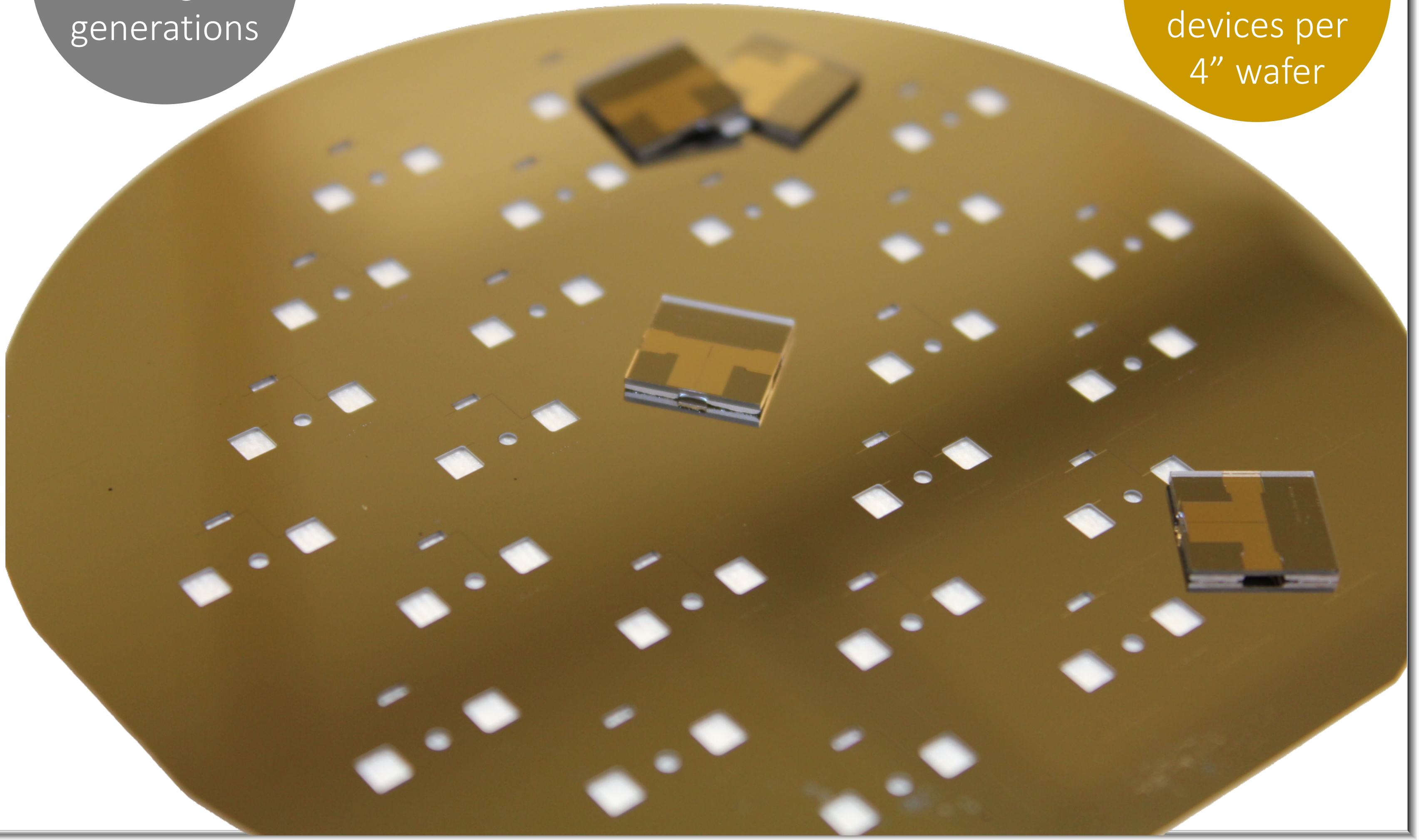


6
design generations

$35
per thruster

> 500
successfully fabricated

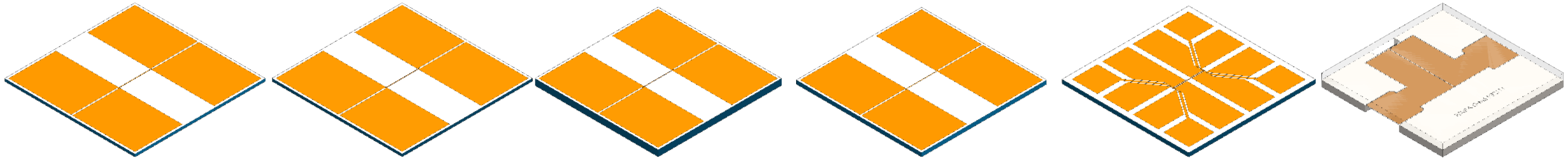
48
devices per 4” wafer



Thruster Development

Patents

Gen1-5: US20170159847A1
Gen6: Pending

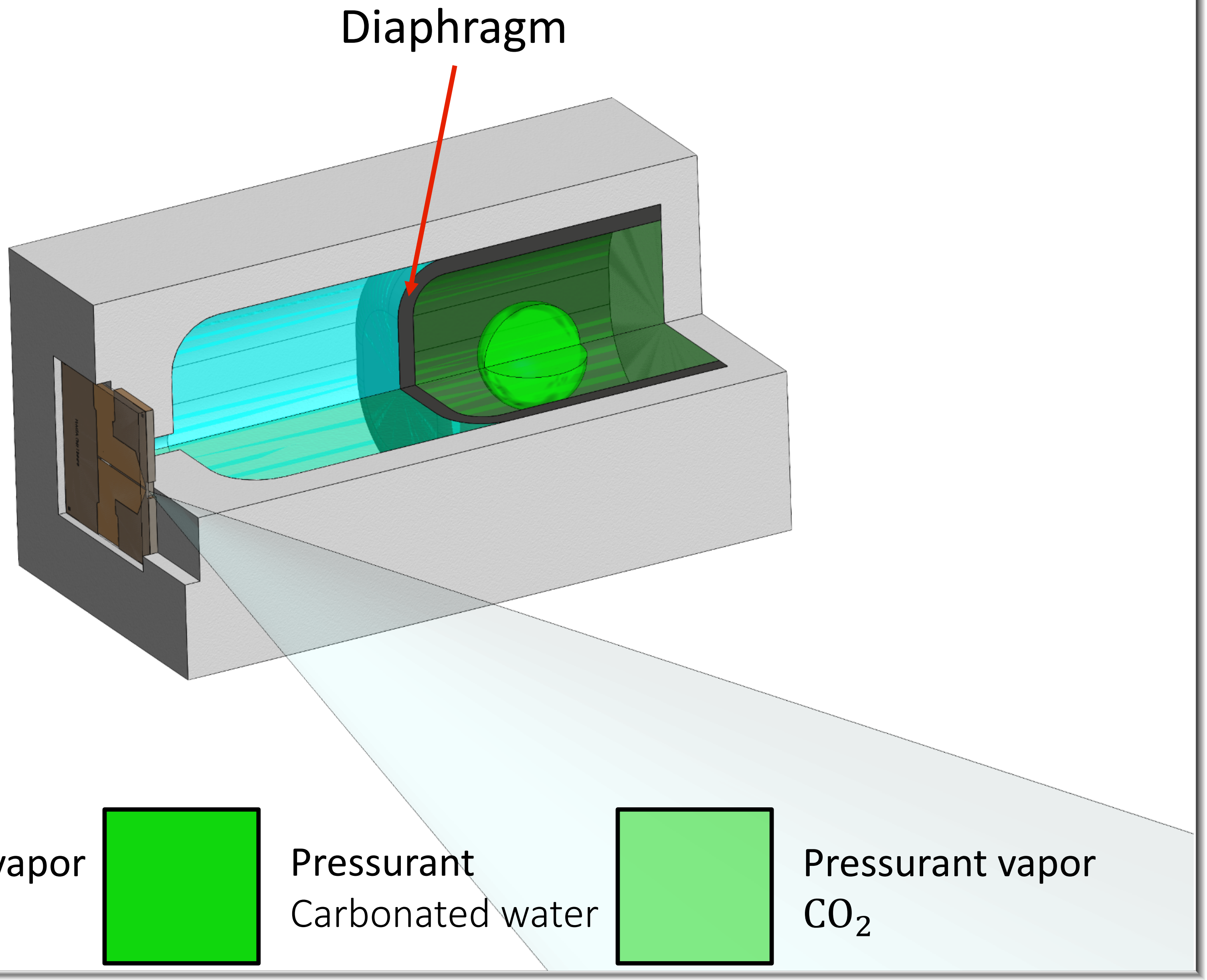


	Gen1 *2013*	Gen2 *2014*	Gen3 *2015*	Gen4 *2016*	Gen5 *2017*	Gen6 *2020*
Efficiency Specific impulse	65 s	65 s	70 s	72 s	72 s	90 s
Life-span Background thrust	35 µN	30 µN	25 µN	15 µN	15 µN	0.2 µN
Power Thrust/power ratio	750	750	500	350	350	250

Propellant Management

Patent: US20200109722A1

No power is required	0 W
Pressurant liquid is not hazardous	CO_2
Propellant pressure is between 20 – 100 kpa	1 atm
High prop mass fraction due to simple design	> 95%



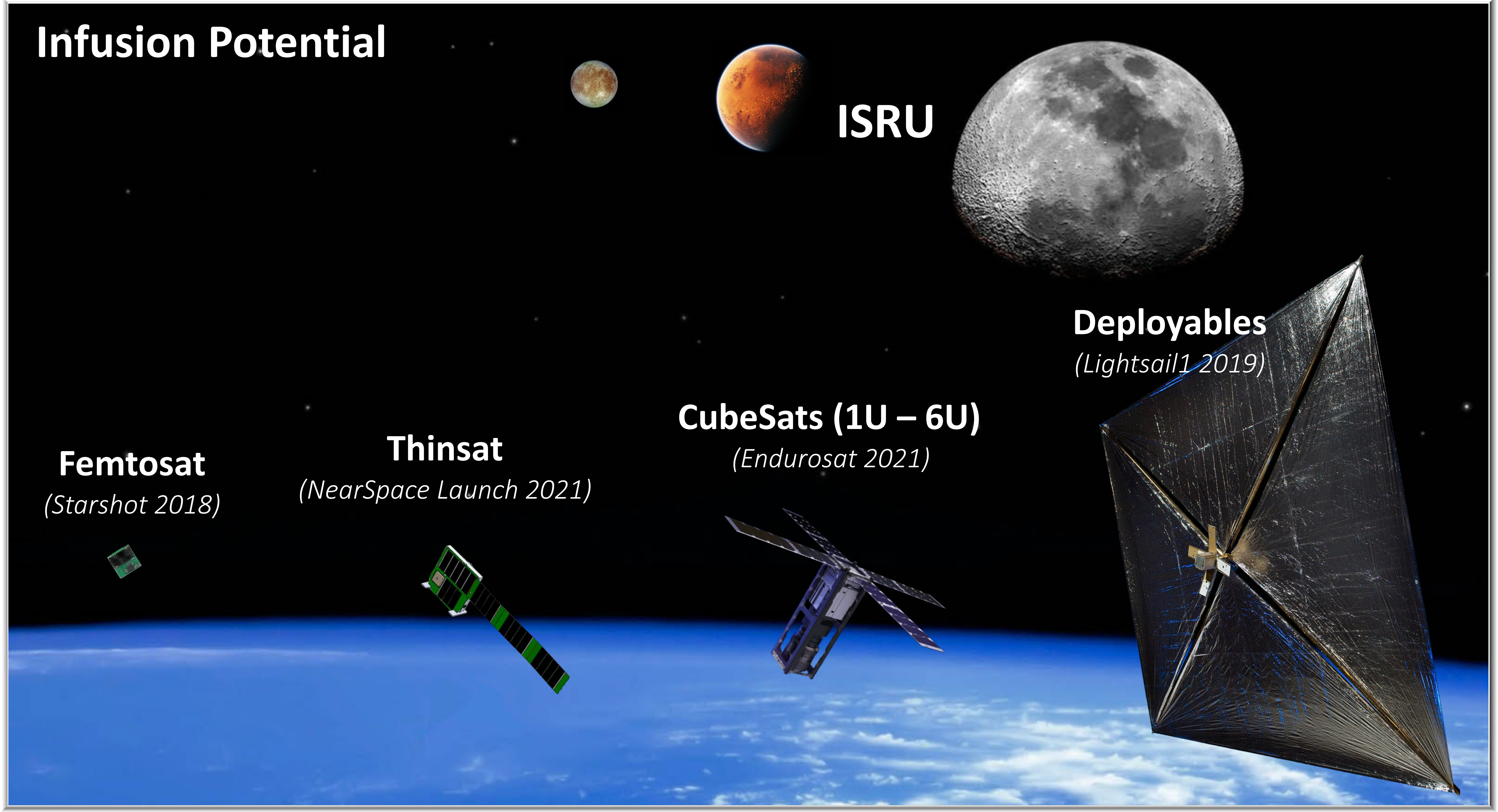
Propellant H_2O

Propellant vapor H_2O

Pressurant Carbonated water

Pressurant vapor CO_2

Infusion Potential



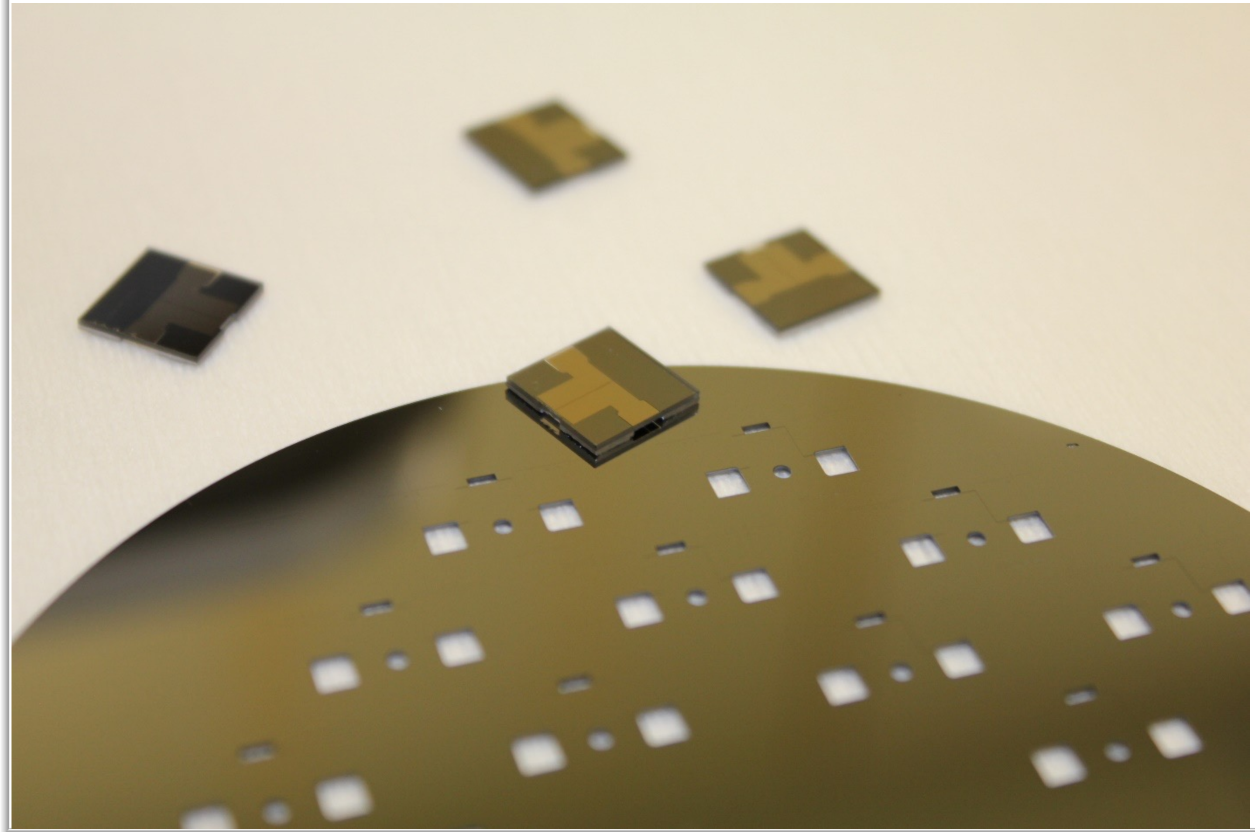
Current Results – Gen6 Thruster

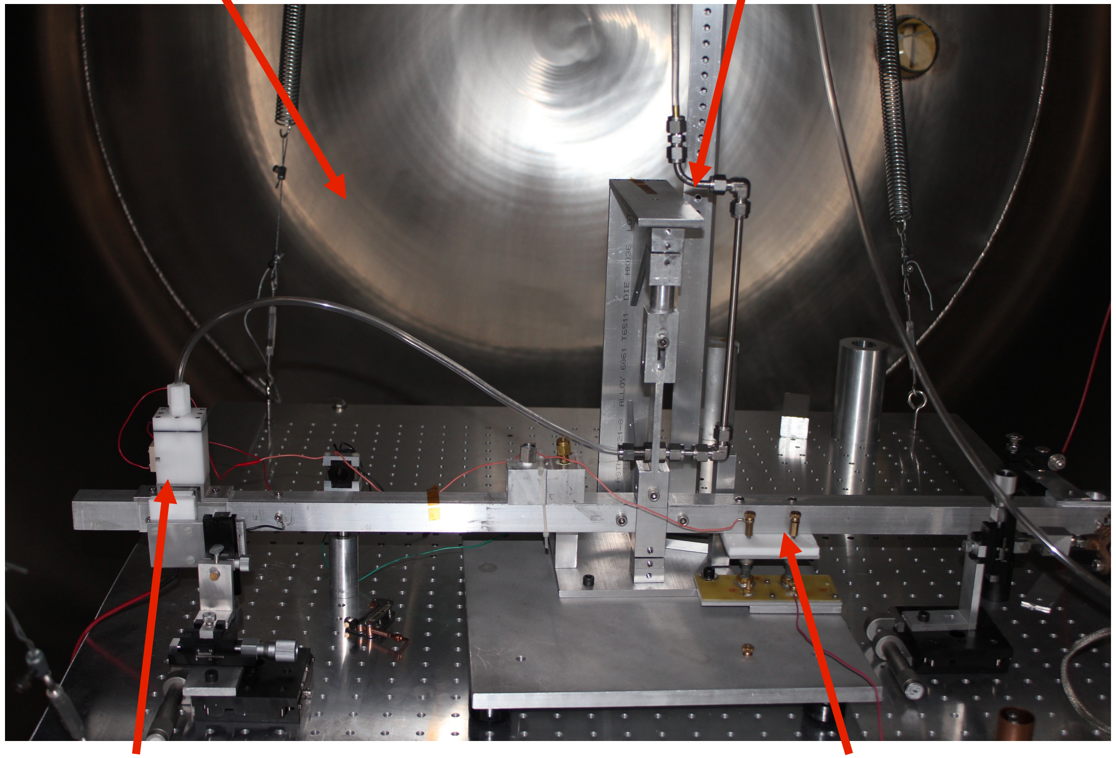
24
design revisions

> 900
fabrication samples

> 80%
fabrication yield rate

6
thrust tested





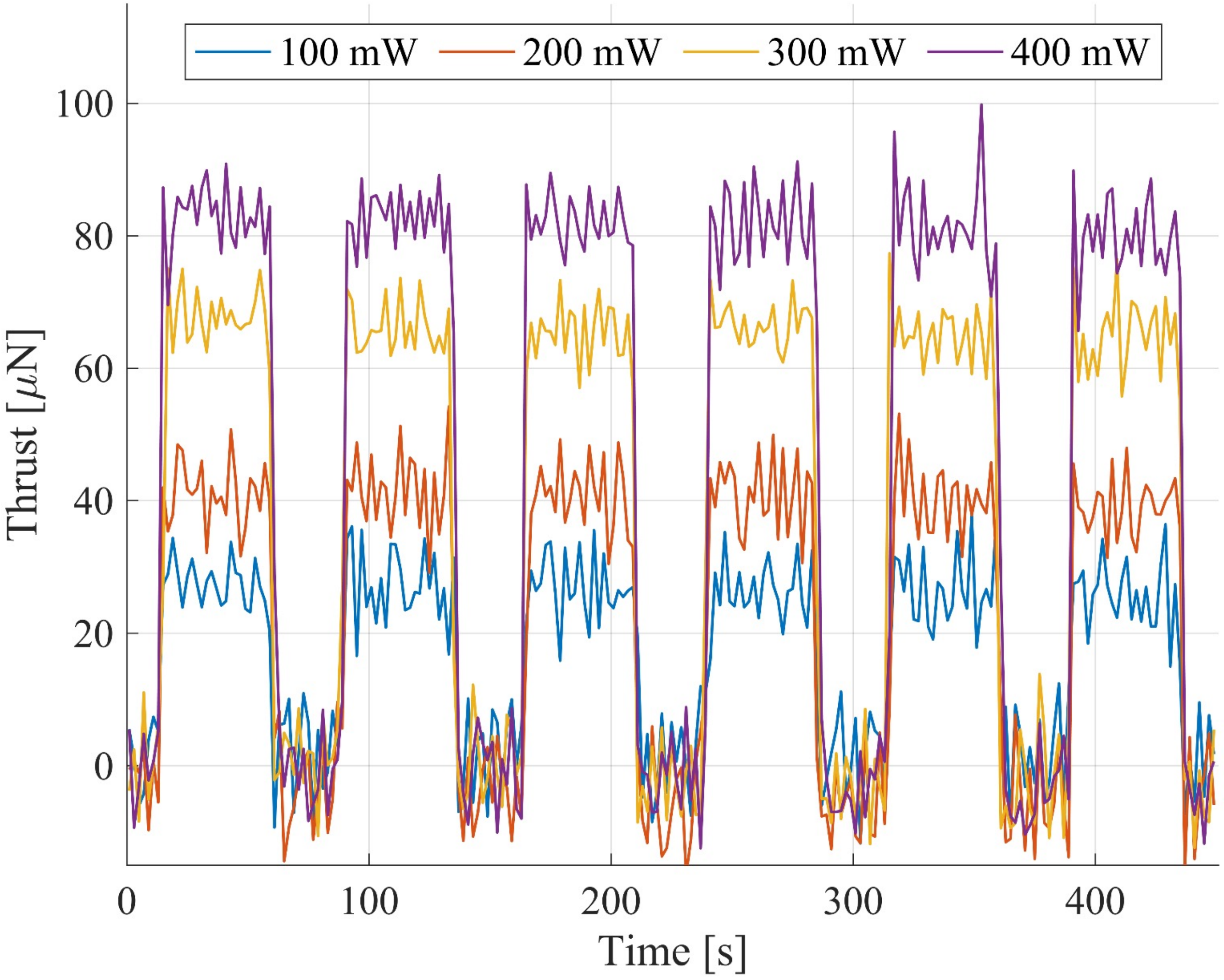
Current Results – Gen6 Thruster

Repeatable transient thrust response of 170 $^{\mu N}/_{s}$ | **< 100 µN-s**

Thrust is independent of propellant pressure > 20 kPa and < 100 kPa

TPR decreases linearly with thrust | **250 $^{\mu N}/_{W}$**

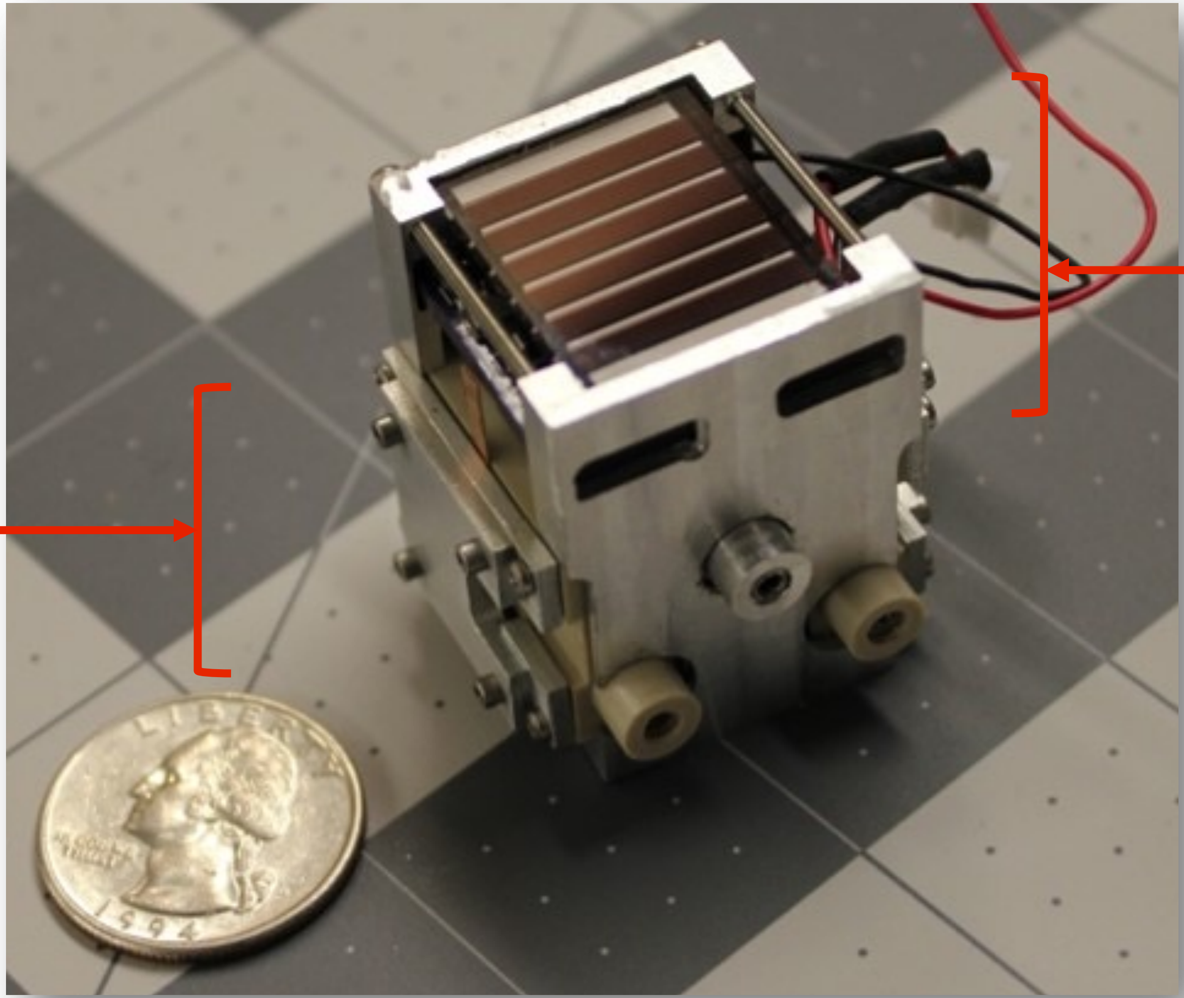
Heater dry tested up to 1W without melting | **> 200 µN**



Current Results – Compact Module

Onboard power generation and storage	5 W	
Zero-g prop management and 2 FEMTAs	1.72 Ns	
Compact and modular design	1.5 in^3	

Zero-g Propellant Management
- 2 g of water
- 2 gen6 FEMTAs



Power and Control
- Bluetooth
- 5W solar cell
- Battery

Test Campaign – Suborbital Flight Test

NASA REDDI Flight Opportunity

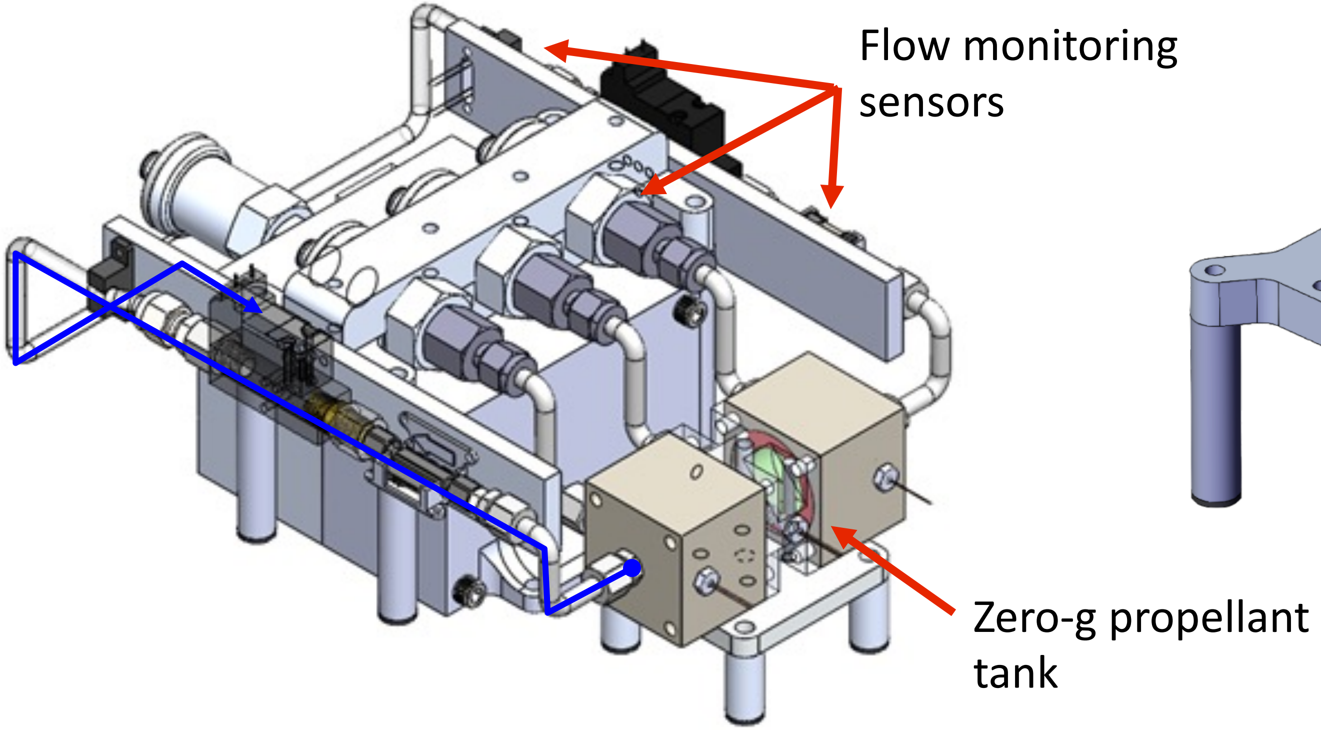
80HQTR18NOA01-18FO-F1

Payload location

- Vacuum
- Micro-g (2.5 min)

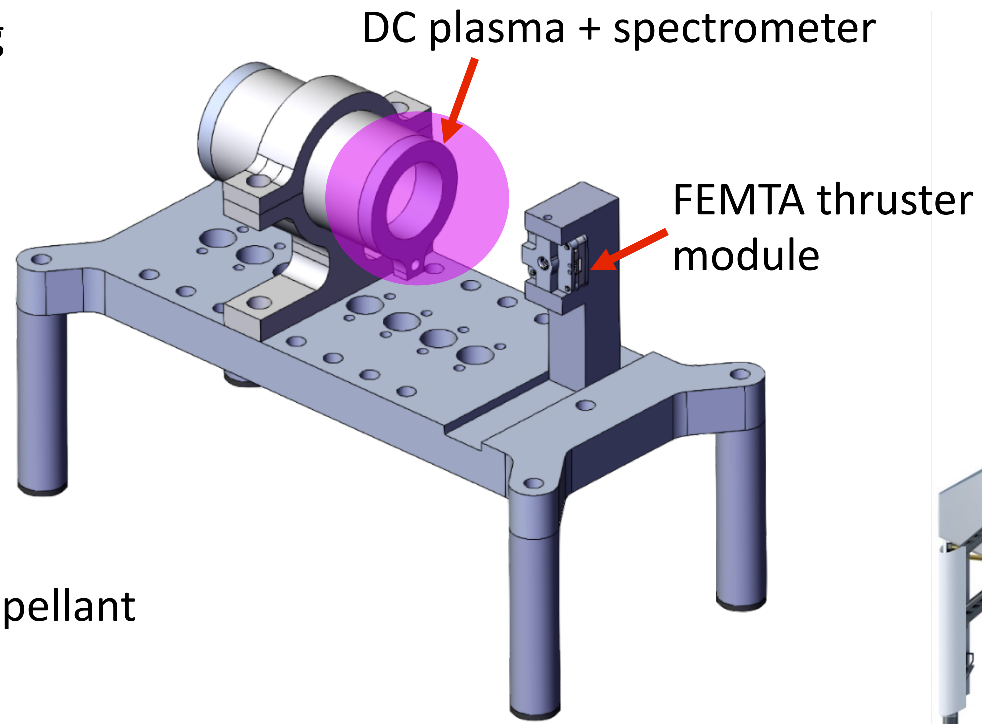
Propellant Management Exp

- Monitor flow characteristics of zero-g tank in micro-gravity



FEMTA Thruster Exp

- Use plasma spectroscopy to measure FEMTA thrust

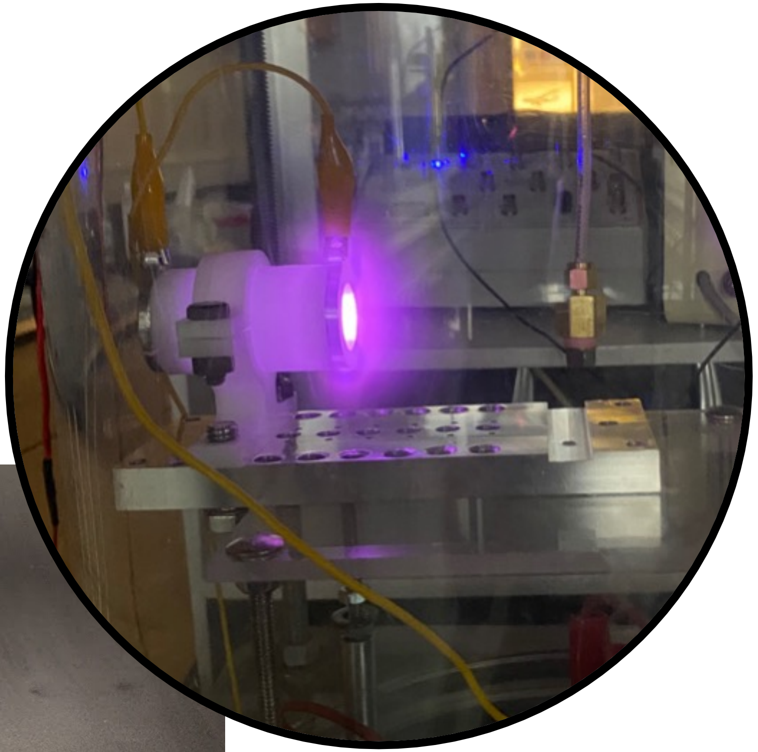


Test Campaign – Suborbital Flight Test

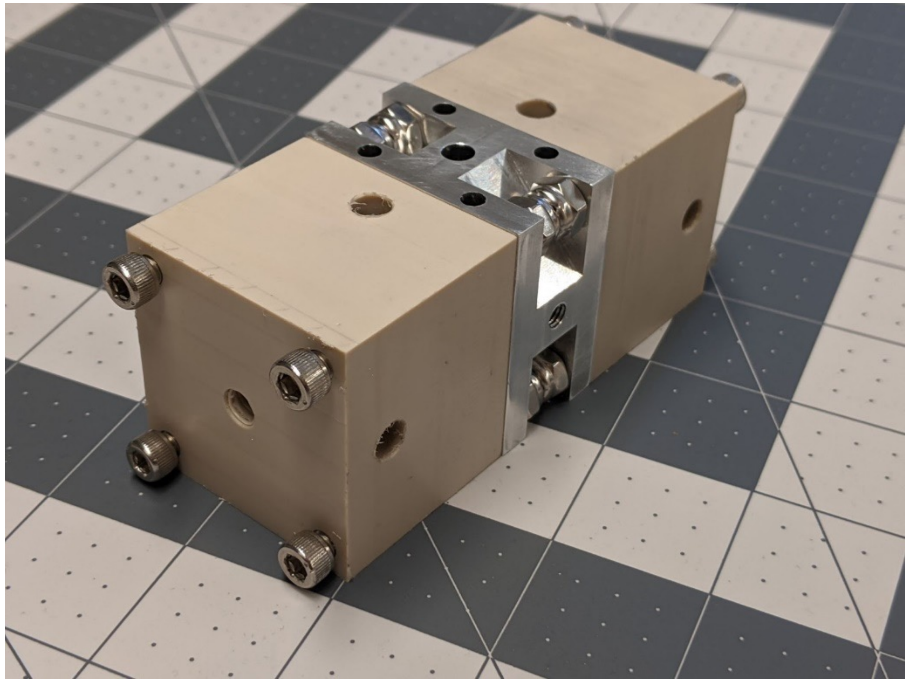
NASA REDDI Flight Opportunity

80HQTR18NOA01-18FO-F1

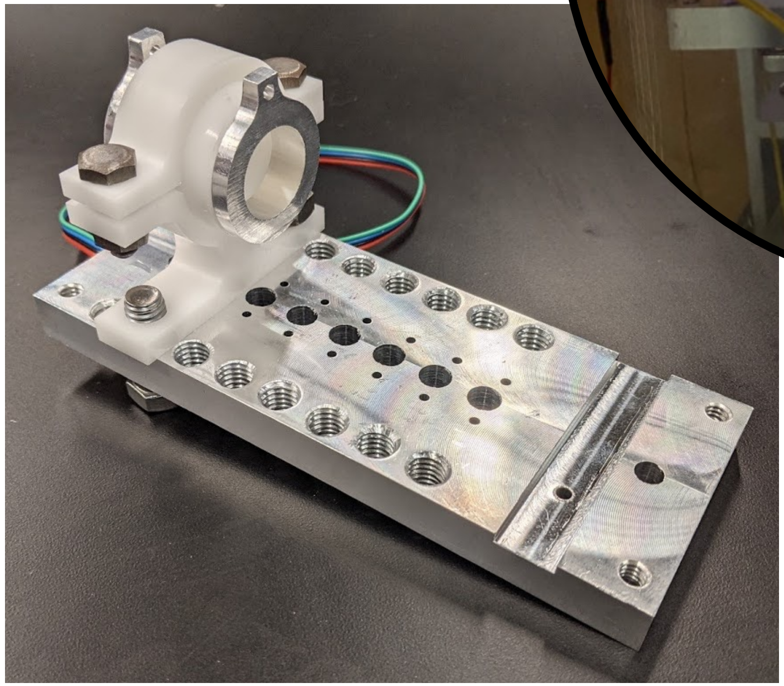
Current	Q3-4 2021	Q3 2022
Flight Hardware Fabrication	**Qualification Testing**	**Launch**



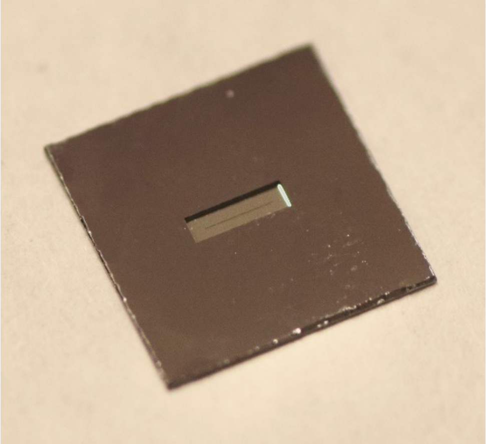
Zero-g propellant tank

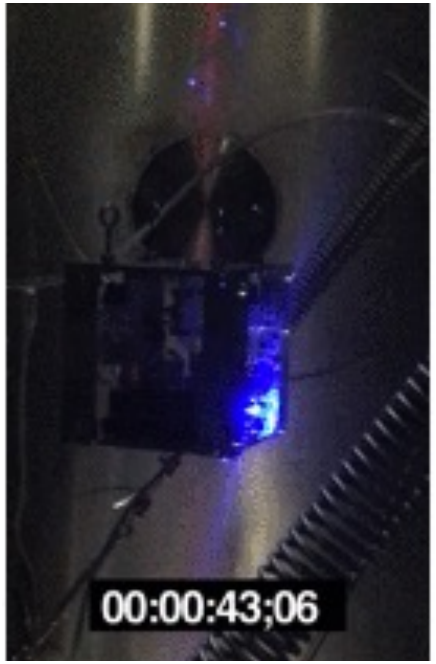


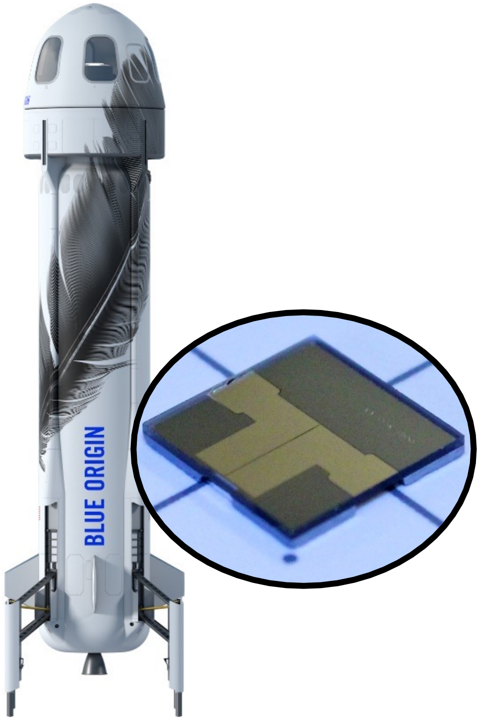
Plasma Source



Development Timeline







TRL 3

- **2015:** Gen1-3 fabrication and vacuum thrust testing

TRL 4

- **2017:** Gen4 1U CubeSat prototype

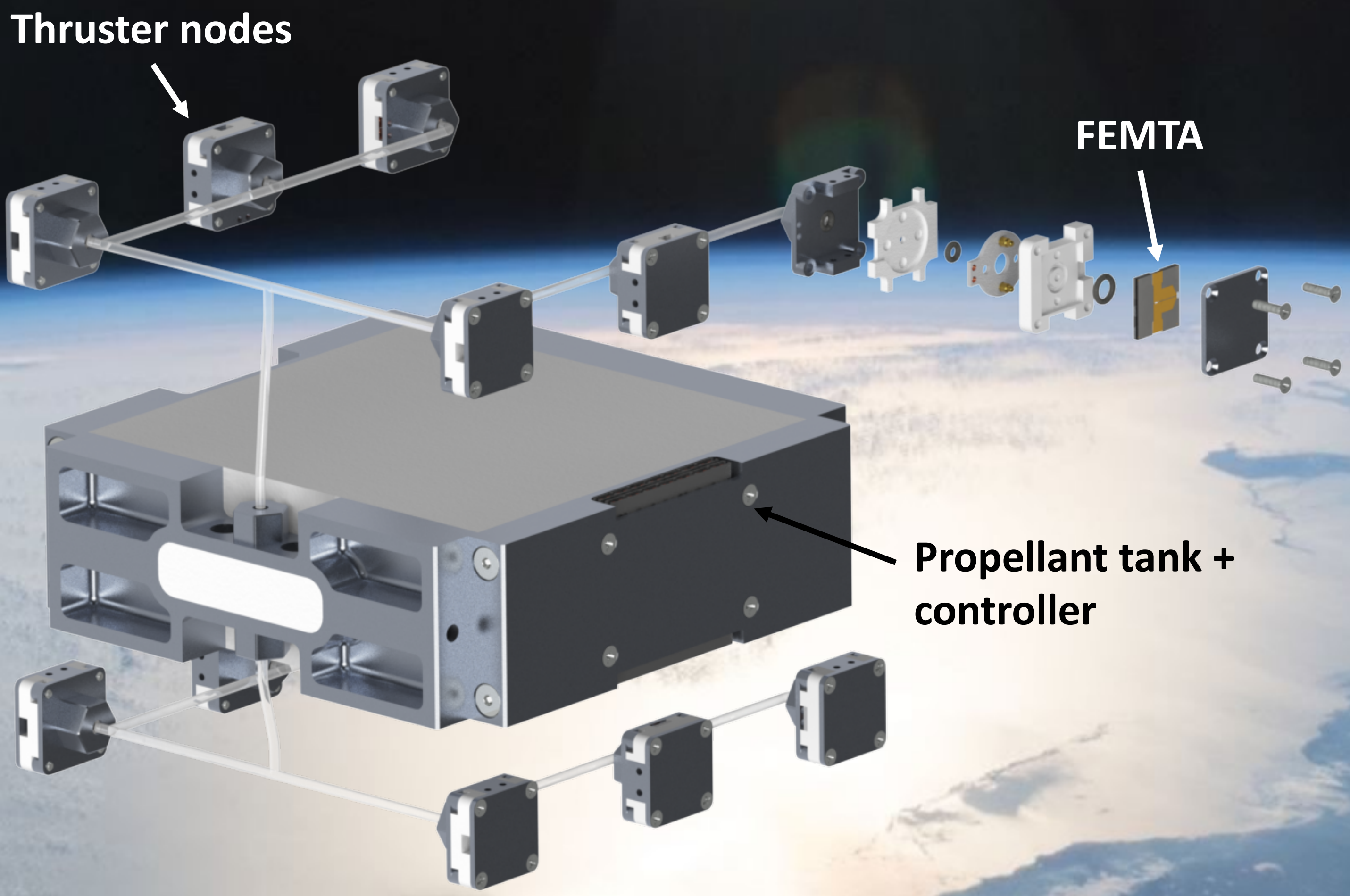
TRL 6

- **2022:** Suborbital flight test w/ Gen6 thruster

TRL 7/8

- **2024:** Orbital demonstration

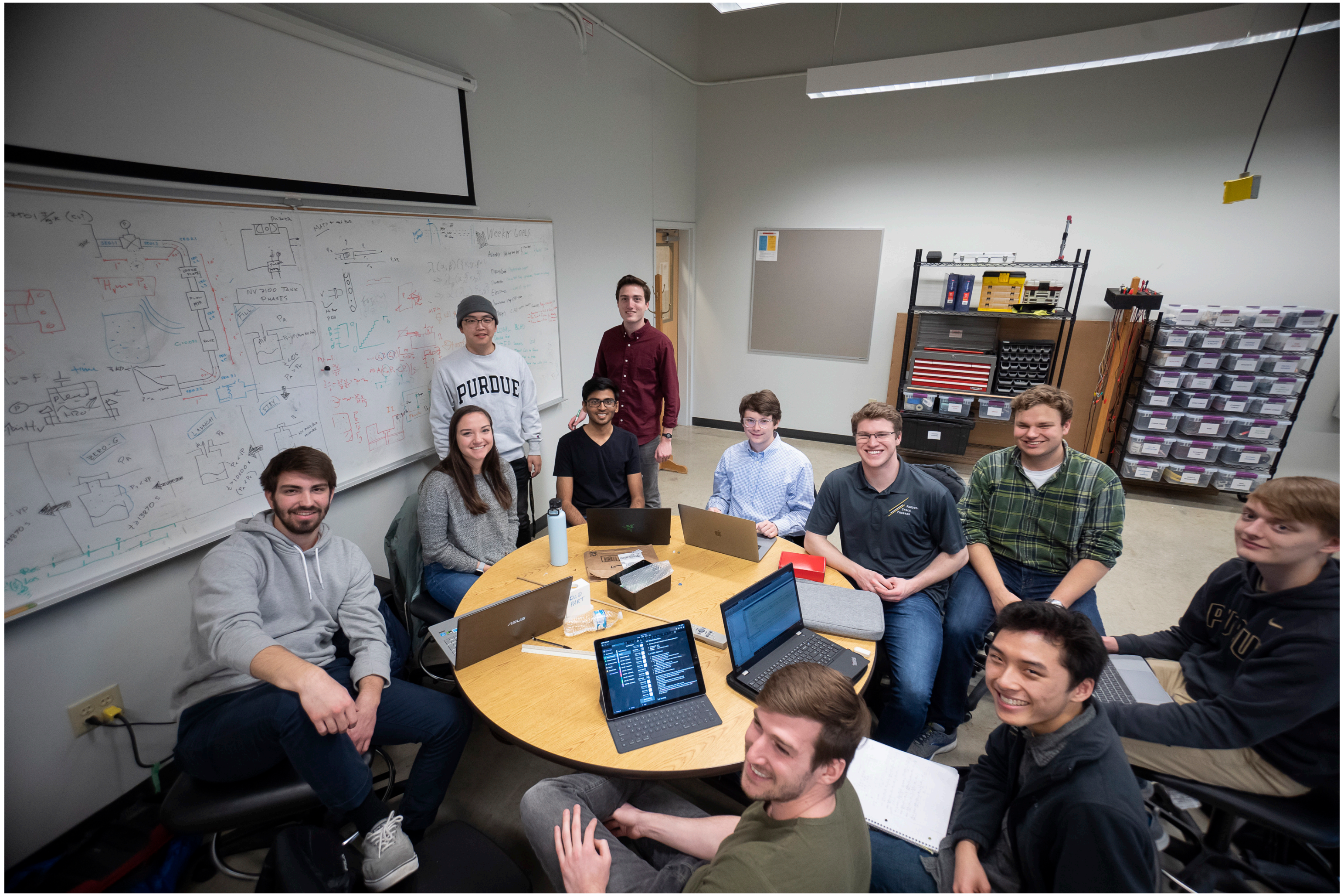
Future Orbital Demonstration



Propellant storage sized for multiyear operation	**4 yr**
Propellant storage can be scaled arbitrarily	**400** $\frac{Ns}{U}$
Thruster nodes can be added to meet demand	**12+**
Full scale 1U system requires < ¼ of CubeSat volume	**1/4 U**

Thanks you

QUESTIONS?



2020 Purdue FEMTA Suborbital Undergraduate Team

References

Patents

- Vapor pressure drive pump: US20200109722A1
- Microelectronic thermal valve: US20170159847A1
- Tunable Water-based MicroThruster Array: (pending)

Publications

1. Pugia S., Cofer A., Alexeenko A., (2020). "Characterization of Film-Evaporating Microcapillaries for Water-based Microthrusters". Acta Astronautica. 10.1016/j.actaastro.2020.09.011.

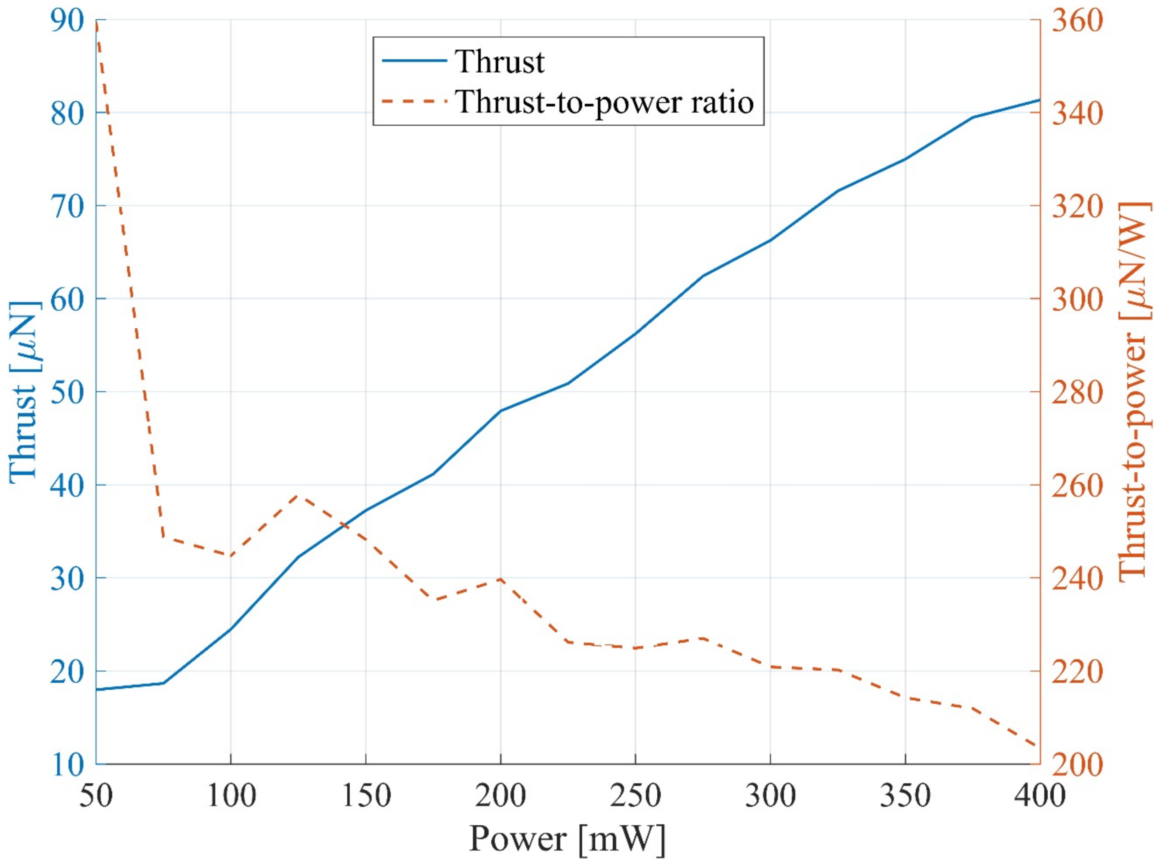
2. Fowee, K., Pugia, S., Clay, R., Fuehne, M., Linker, M., Cofer, A., Alexeenko, A. (2017). “Quad-Thruster FEMTA Micropropulsion System for CubeSat 1-Axis Control”. Proceedings of the 31st AIAA/USU Conference on Small Satellites, Logan, UT. SSC17-WK-48.

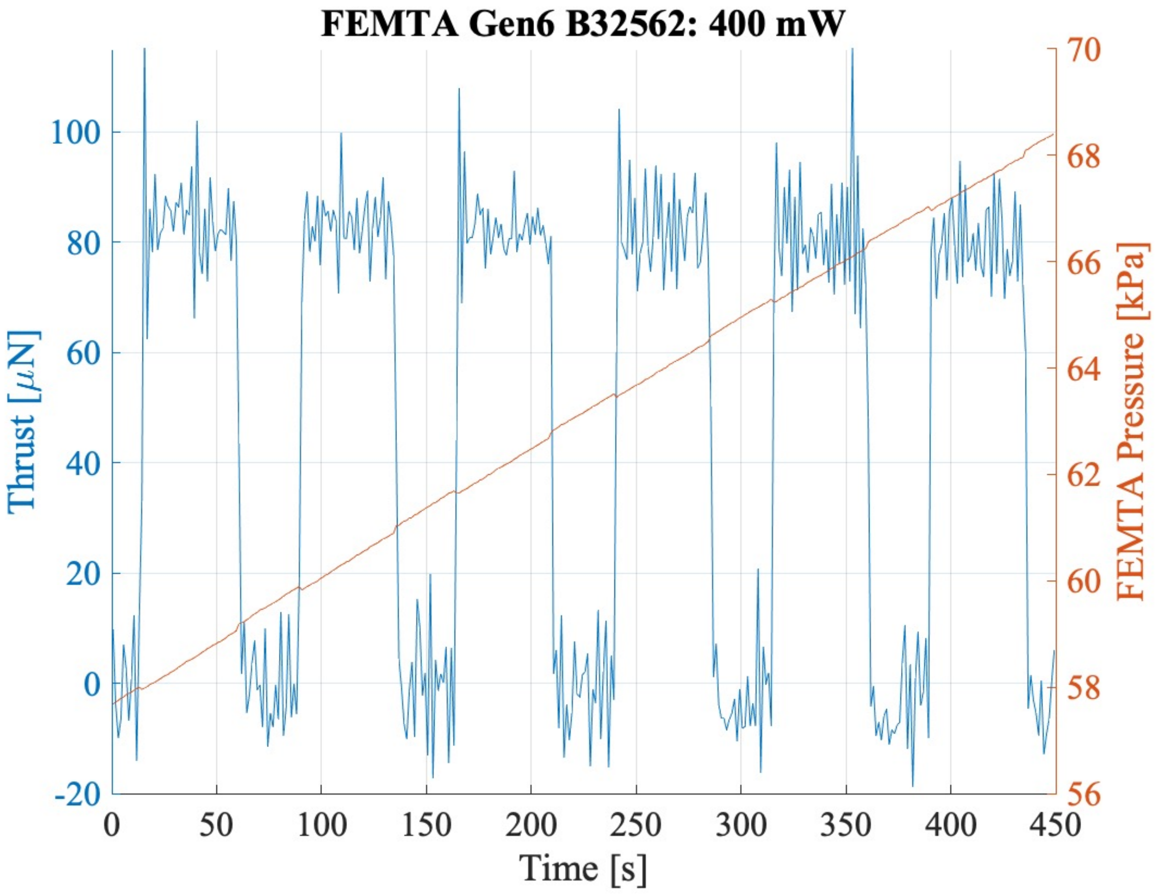
3. Cofer A., O’Neill W., Heister S., Alexeenko A. (2015), “Film-Evaporation MEMS Tunable Array for Low-Mass SmallSat Propulsion: Design Improvement and Thrust Characterization”. AIAA Joint Propulsoin Conference, Orlando, FL.

4. Collicott S., Alexeenko A., Pugia S. (2019). "Propulsion Testing in Commercial Re-usable Sub-orbital Rockets". AIAA Joint Propulsion Conference, Indianapolis, IN. 10.2514/6.2019-4354.

BACKUP

Current Results – Gen6 Thruster





Plasma Spectroscopy Preliminary Results