

Distributed Attitude Control and Maneuvering for Deep Space SmallSats

Purdue University

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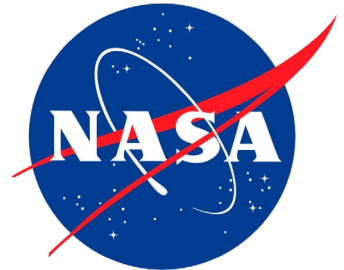
NASA Goddard

Khary Parker

Carl Kotecki

Manuel Balvin

NNX18035512



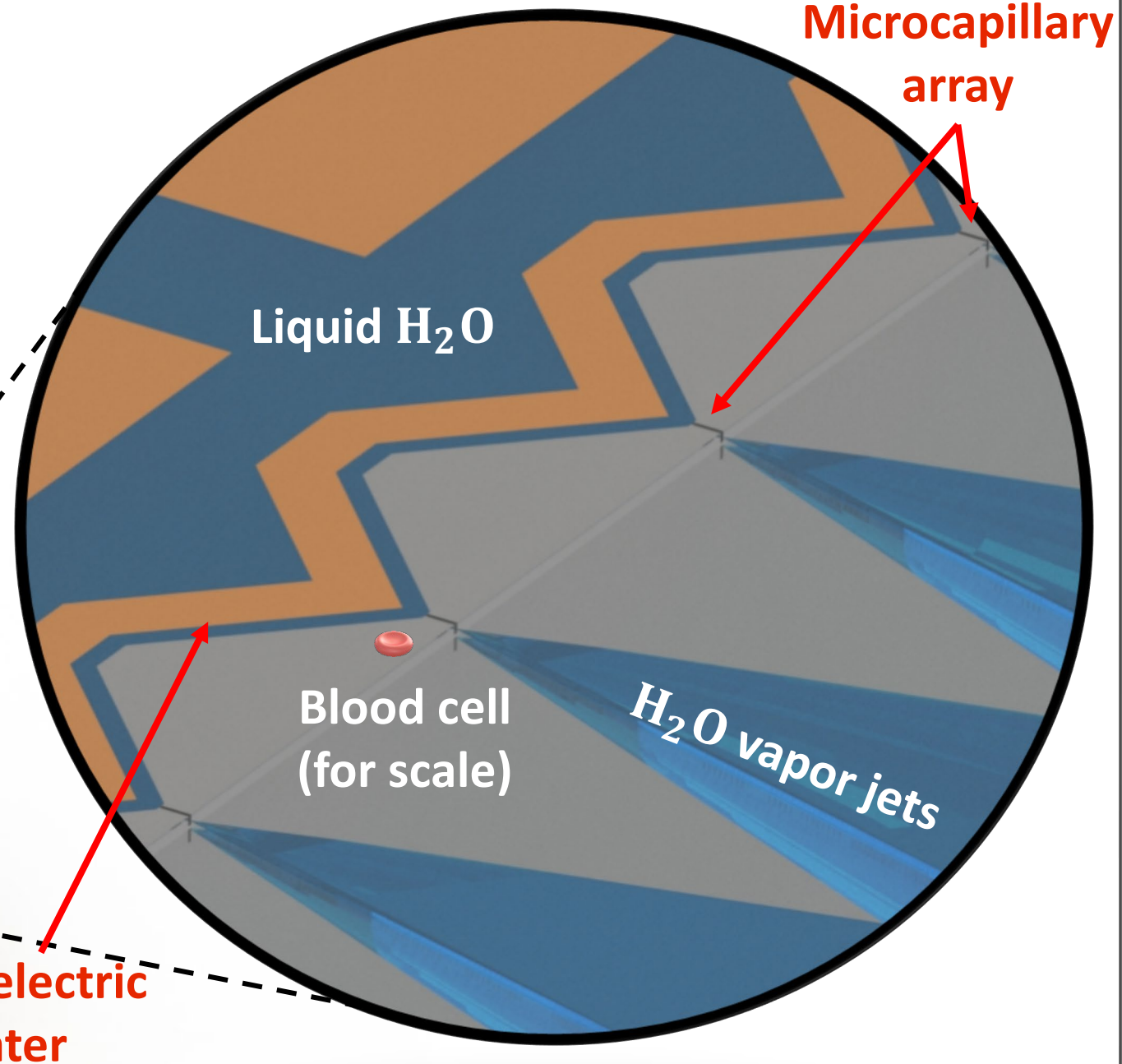
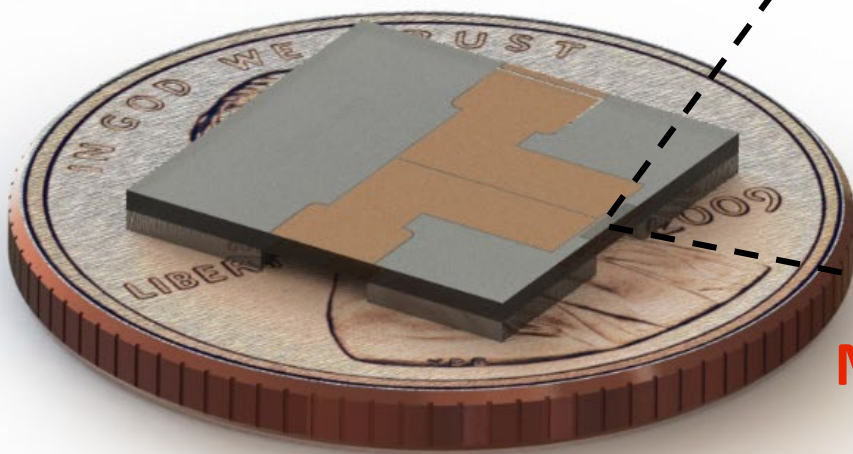
FEMTA Micro-thruster

 $250 \mu\text{N}/\text{W}$ electrical power | $< 1 \text{ W}$

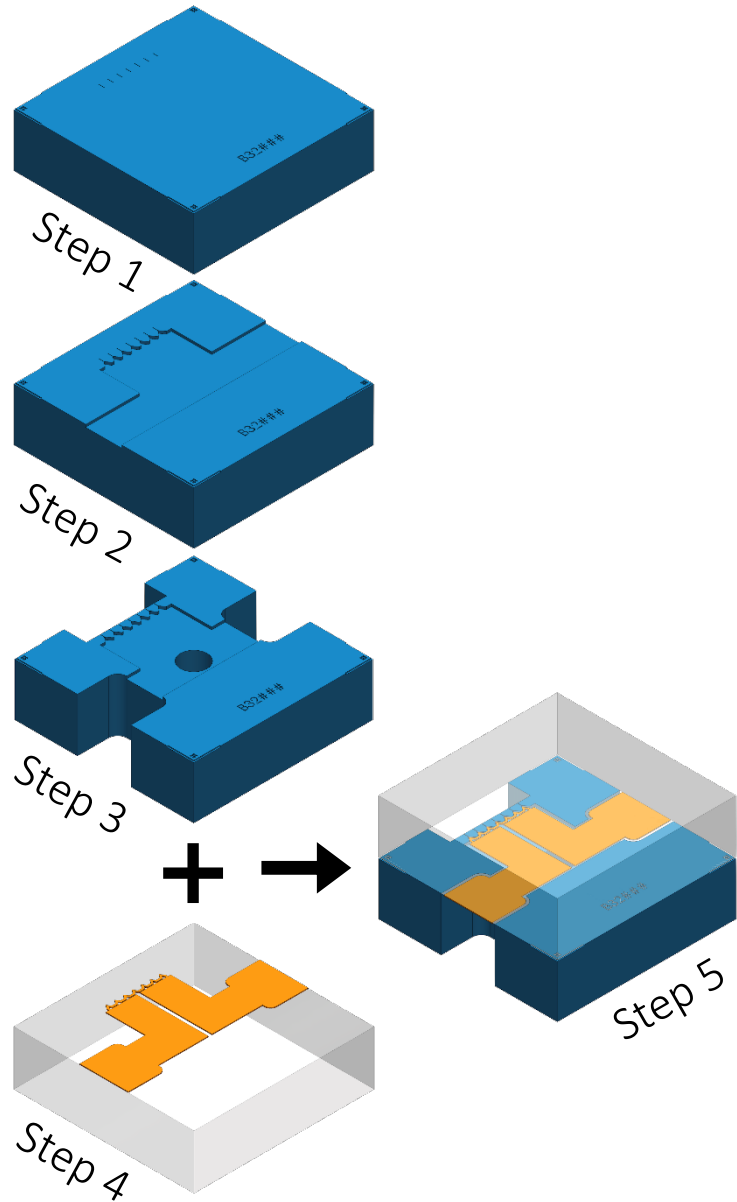
 Ultra-pure DI water as safe and abundant propellant | H_2O

 High total impulse due to dense propellant | 90 s

 Thrusters fabricated on $1 \text{ cm}^2 \times 1 \text{ mm}$ silicon chips | 200 mg



FEMTA Microfabrication

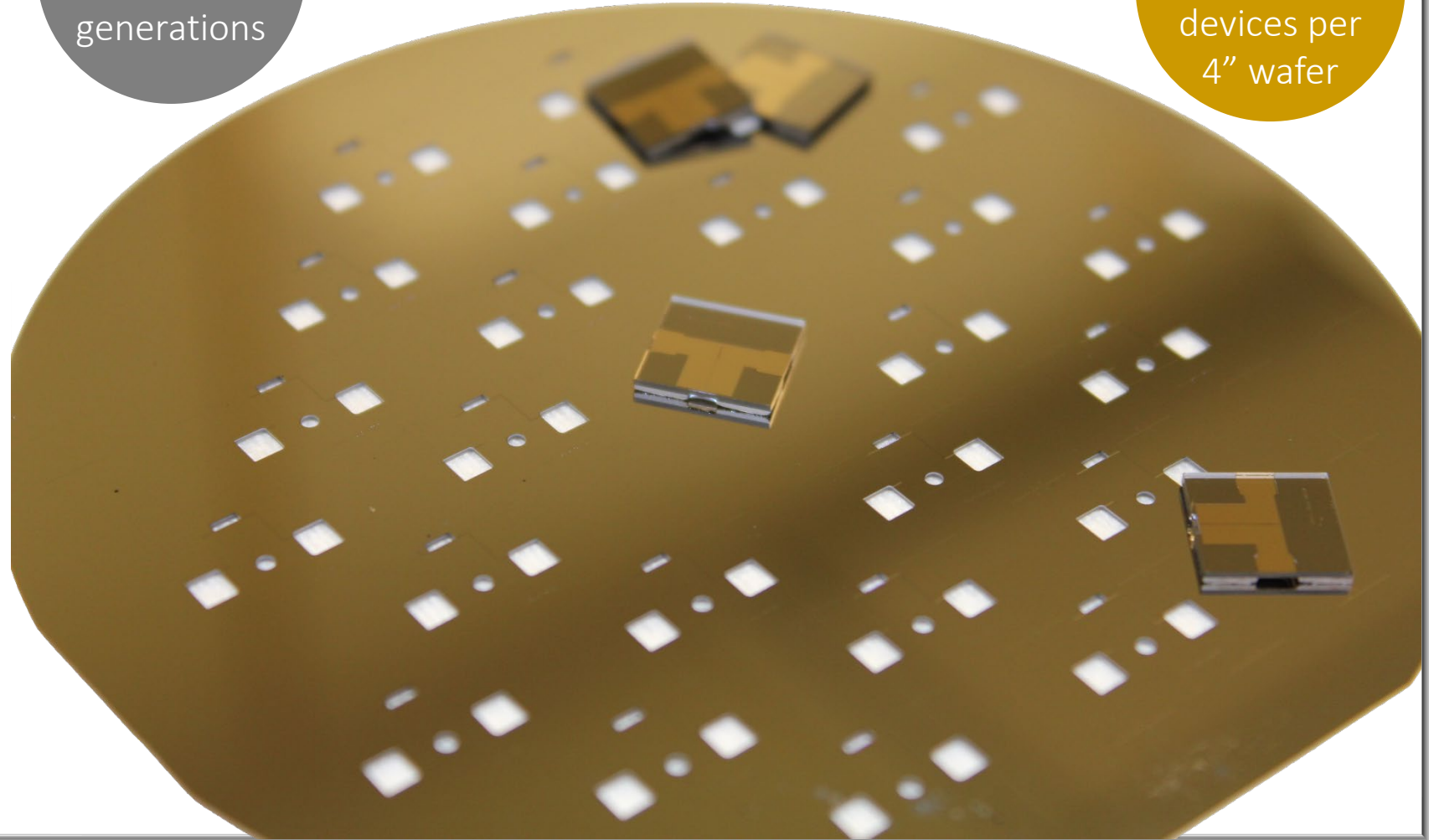


6
design
generations

\$35
per thruster

> 500
successfully
fabricated

48
devices per
4" wafer



Thruster Development

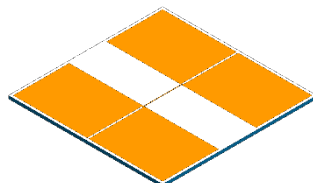
Patents

Gen1-5: US20170159847A1

Gen6: Pending

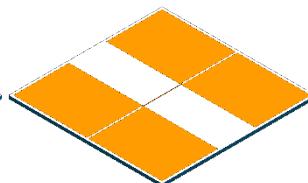
Gen1

2013



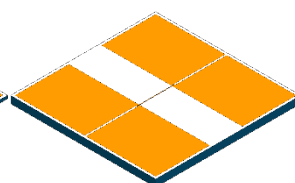
Gen2

2014



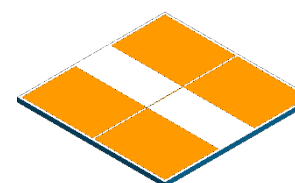
Gen3

2015



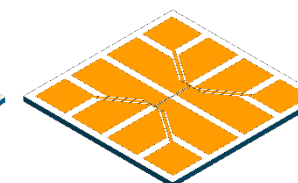
Gen4

2016



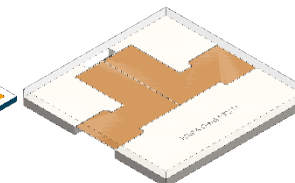
Gen5

2017



Gen6

2020



Efficiency
Specific impulse

65 s

65 s

70 s

72 s

72 s

90 s



Life-span
Background thrust

35 μ N

30 μ N

25 μ N

15 μ N

15 μ N

0.2 μ N



Power
Thrust/power ratio

750

750

500

350

350

250

Propellant Management

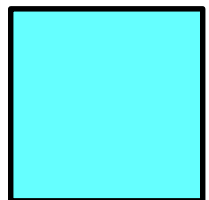
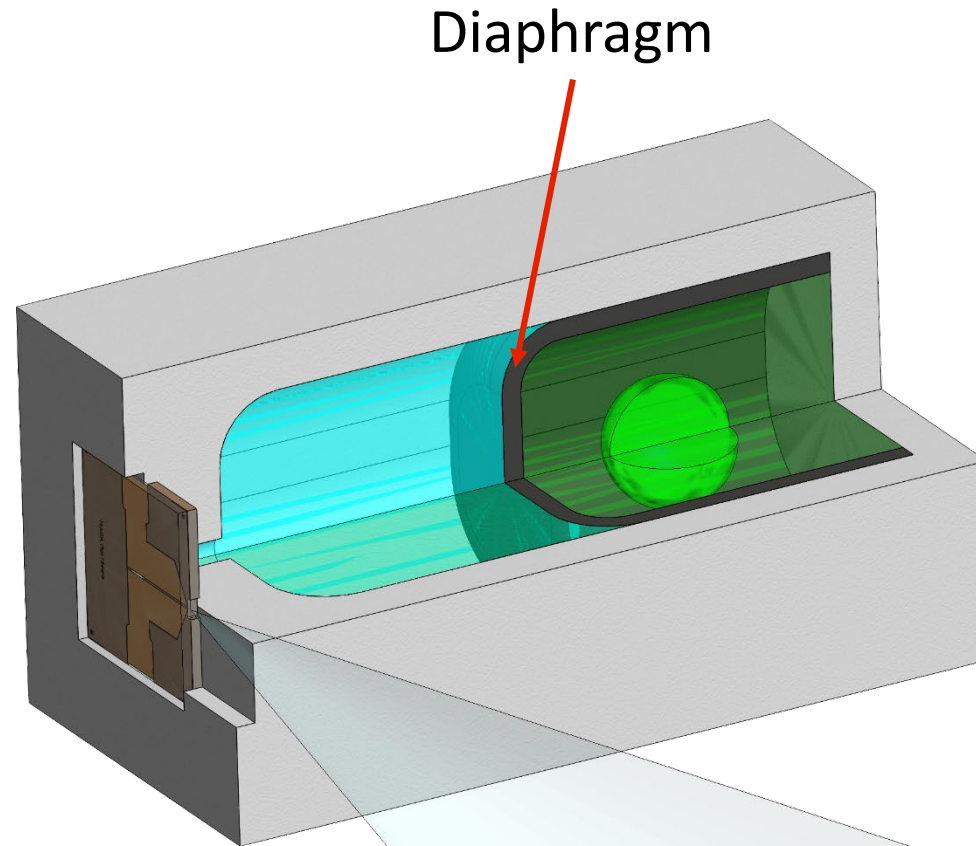
Patent: US20200109722A1

 No power is required | **0 W**

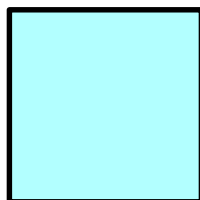
 Pressurant liquid is not hazardous | **CO₂**

 Propellant pressure is between 20 – 100 kpa | **1 atm**

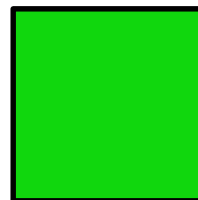
 High prop mass fraction due to simple design | **> 95%**



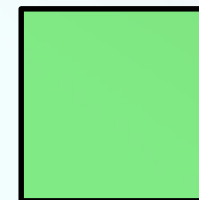
Propellant
H₂O



Propellant vapor
H₂O



Pressurant
Carbonated water

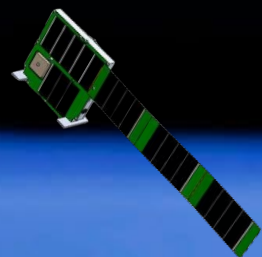


Pressurant vapor
CO₂

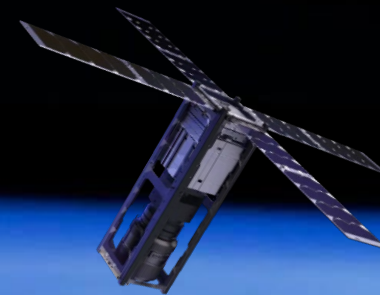
Infusion Potential



Femtosat
(Starshot 2018)



Thinsat
(NearSpace Launch 2021)



CubeSats (1U – 6U)
(Endurosat 2021)



ISRU



Deployables
(Lightsail1 2019)



Current Results – Gen6 Thruster

24

design
revisions

> 900

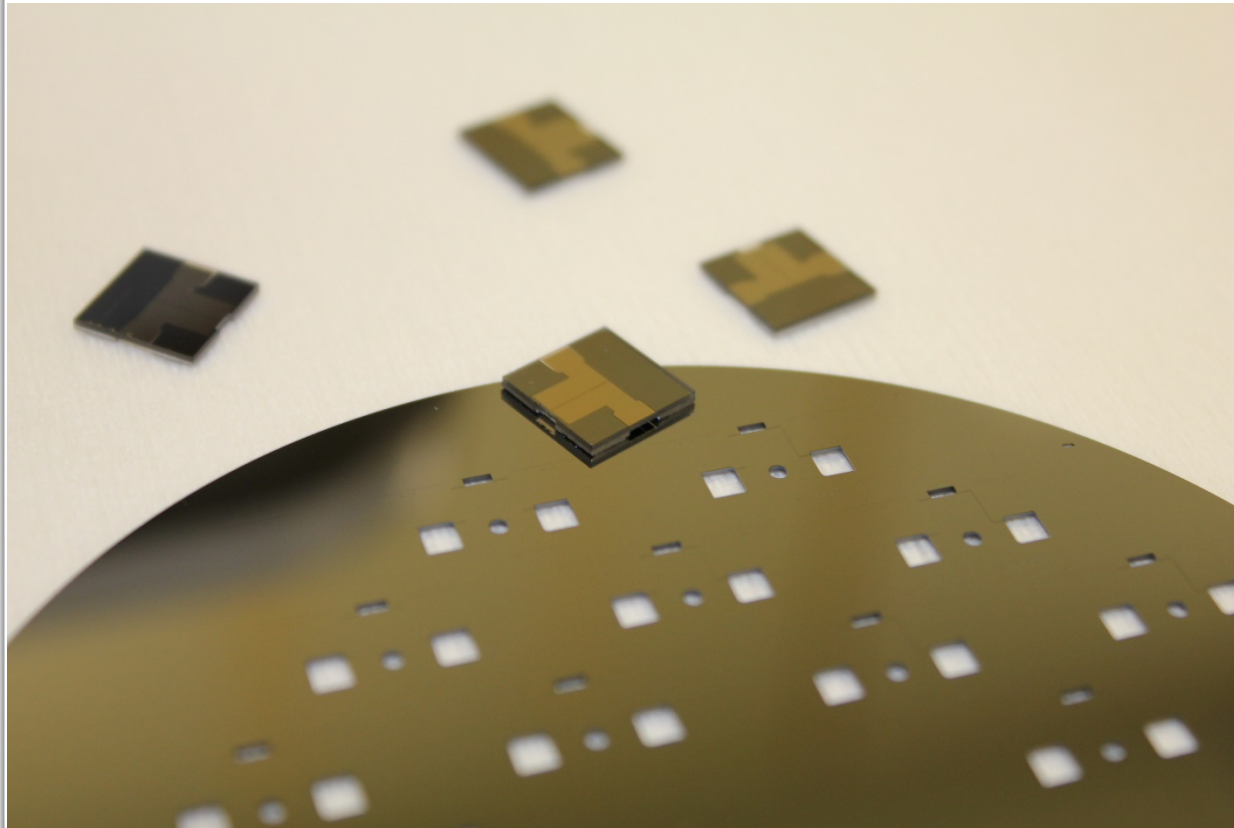
fabrication
samples

> 80%

fabrication
yield rate

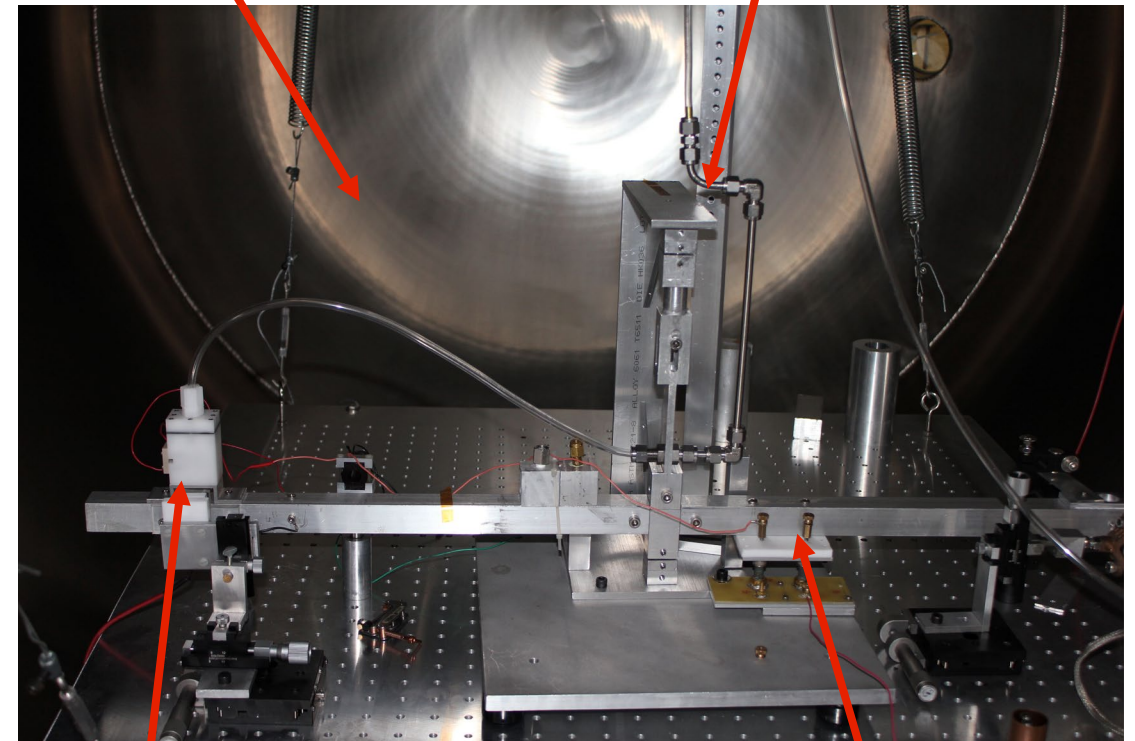
6

thrust tested



Vacuum chamber

Propellant pressure control line



Gravity-fed FEMTA thrust cell

μ N torsion stand

Current Results – Gen6 Thruster



Repeatable transient thrust
response of $170 \mu\text{N}/\text{s}$

$< 100 \mu\text{N}\cdot\text{s}$



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



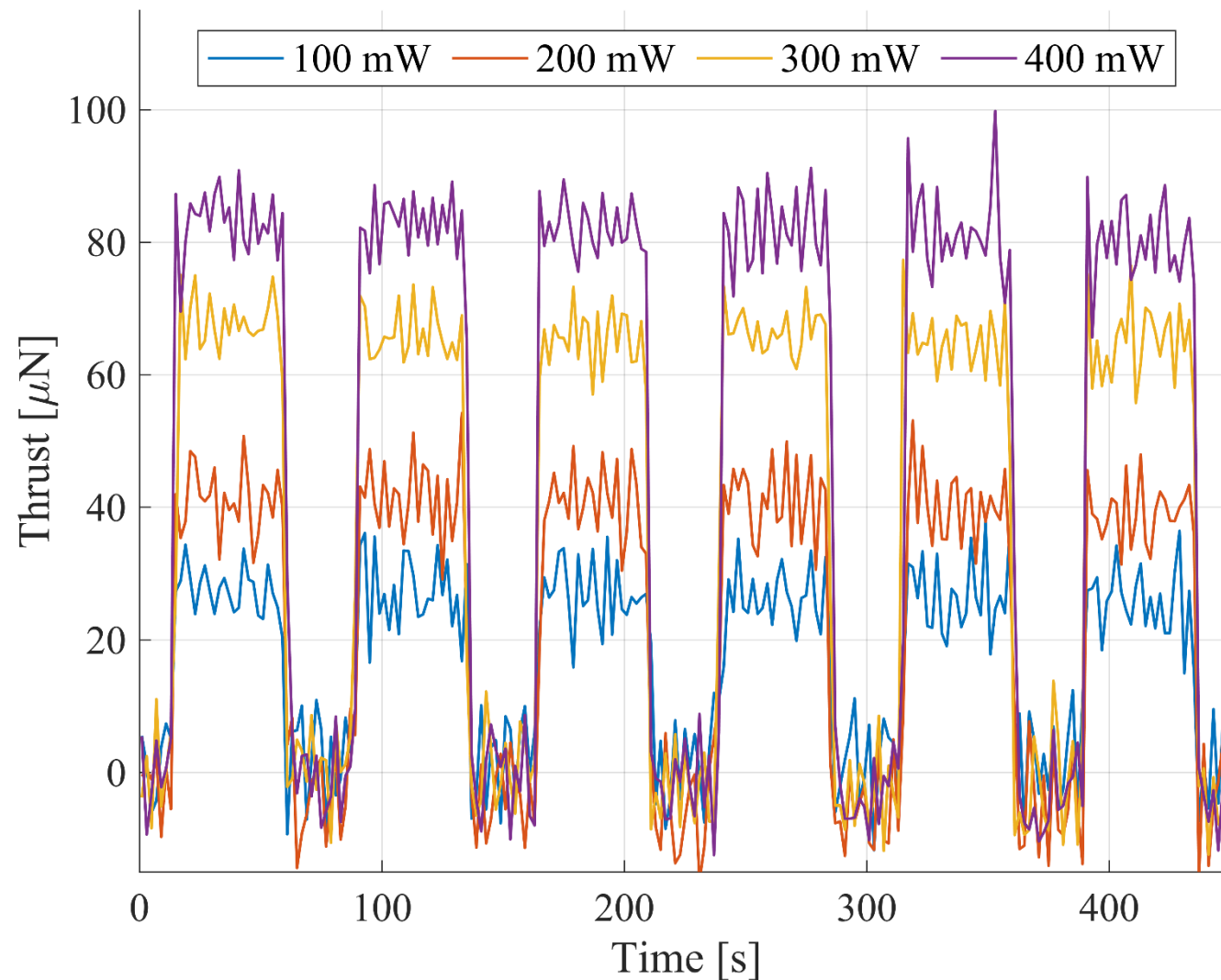
TPR decreases linearly with
thrust

$250 \mu\text{N}/\text{W}$



Heater dry tested up to 1W
without melting

$> 200 \mu\text{N}$



Current Results – Compact Module



Onboard power
generation and storage

5 W



Zero-g prop management
and 2 FEMTAs

1.72 Ns

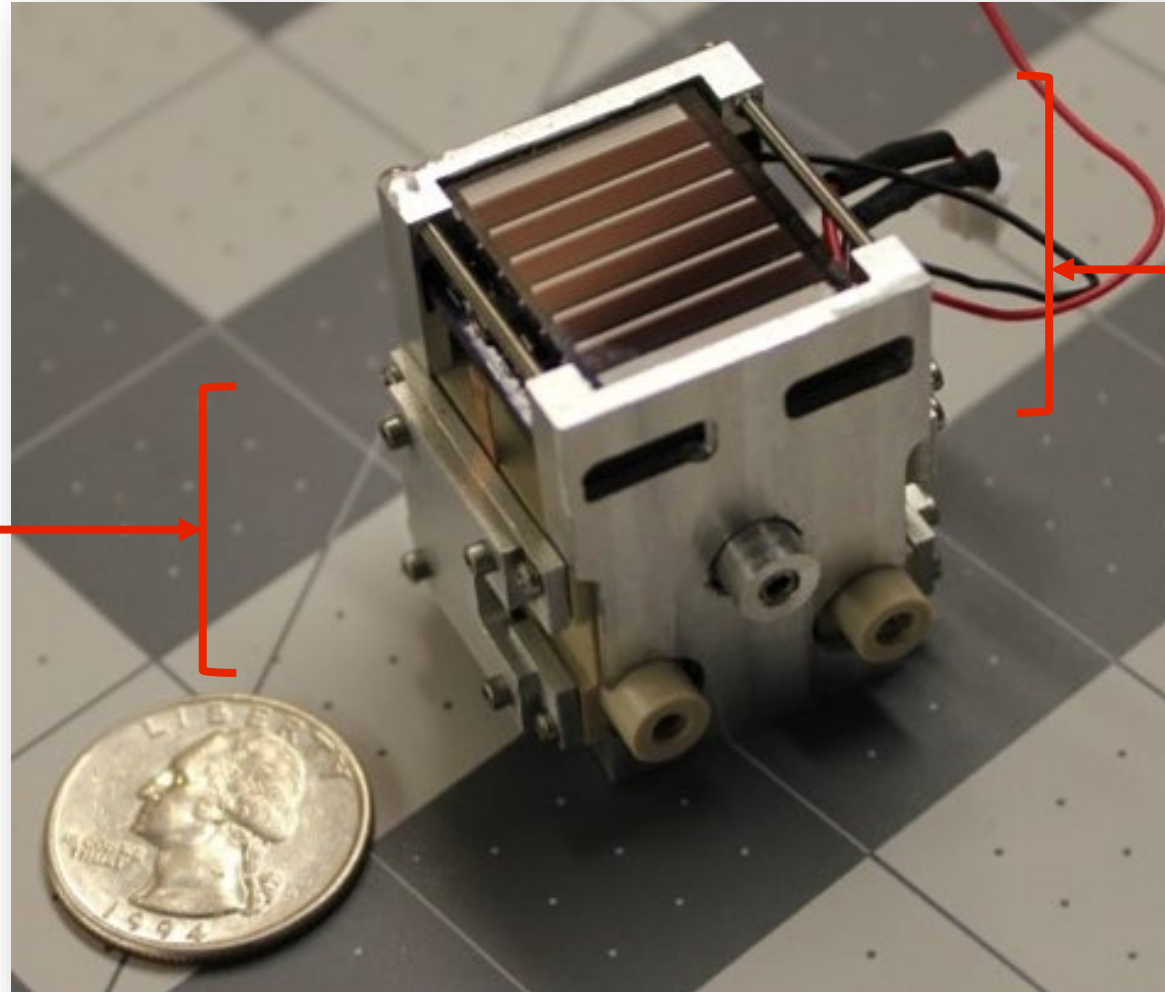


Compact and
modular design

1.5 in³

Zero-g Propellant Management

- 2 g of water
- 2 gen6 FEMTAs



Power and Control

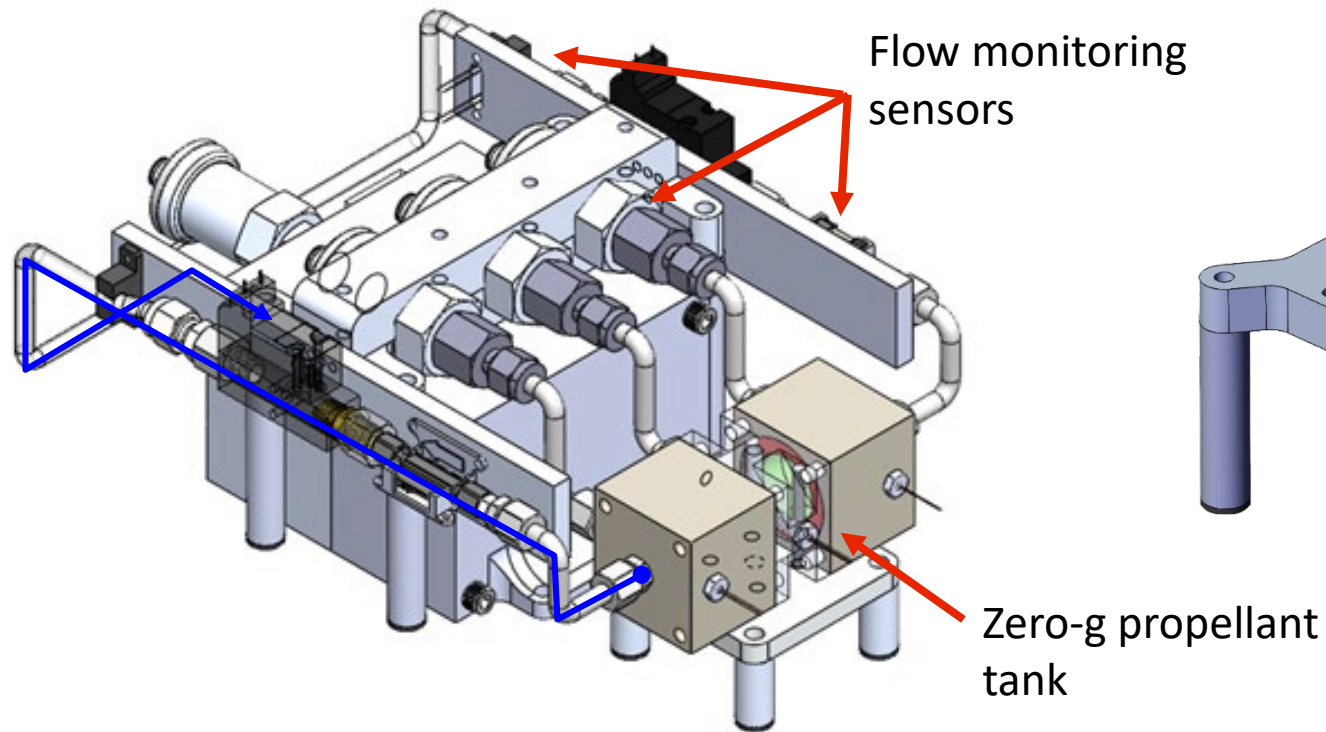
- Bluetooth
- 5W solar cell
- Battery

Test Campaign – Suborbital Flight Test

NASA REDDI Flight Opportunity
80HQTR18NOA01-18FO-F1

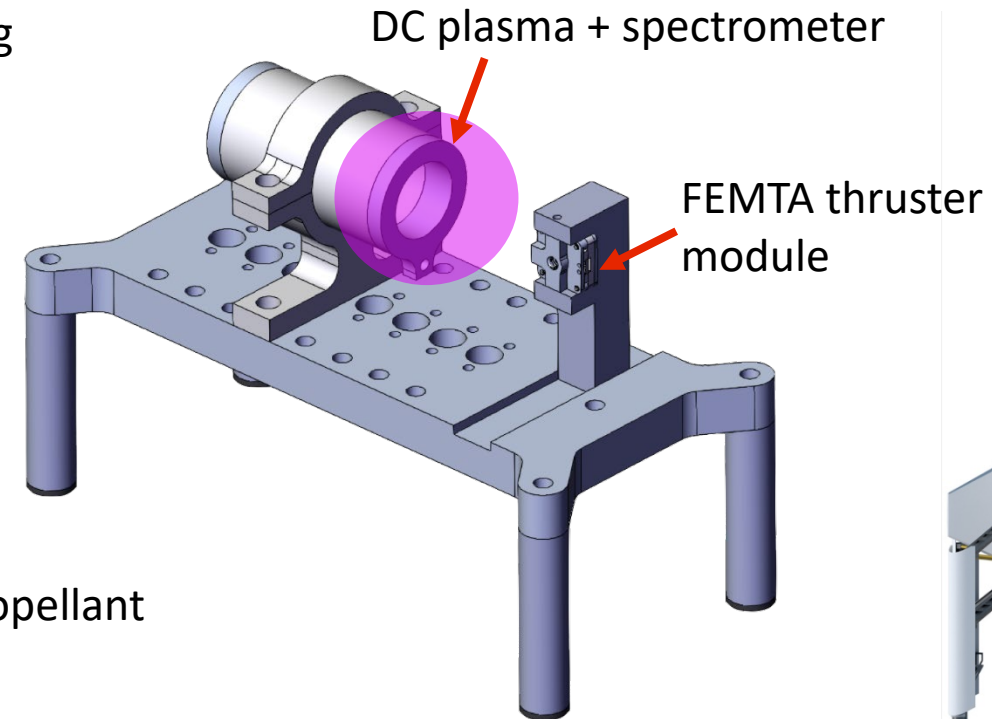
Propellant Management Exp

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



FEMTA Thruster Exp

- Use plasma spectroscopy to measure FEMTA thrust



Payload location

- Vacuum
- Micro-g (2.5 min)



Test Campaign – Suborbital Flight Test

NASA REDDI Flight Opportunity

80HQTR18NOA01-18FO-F1

Current

Flight Hardware
Fabrication

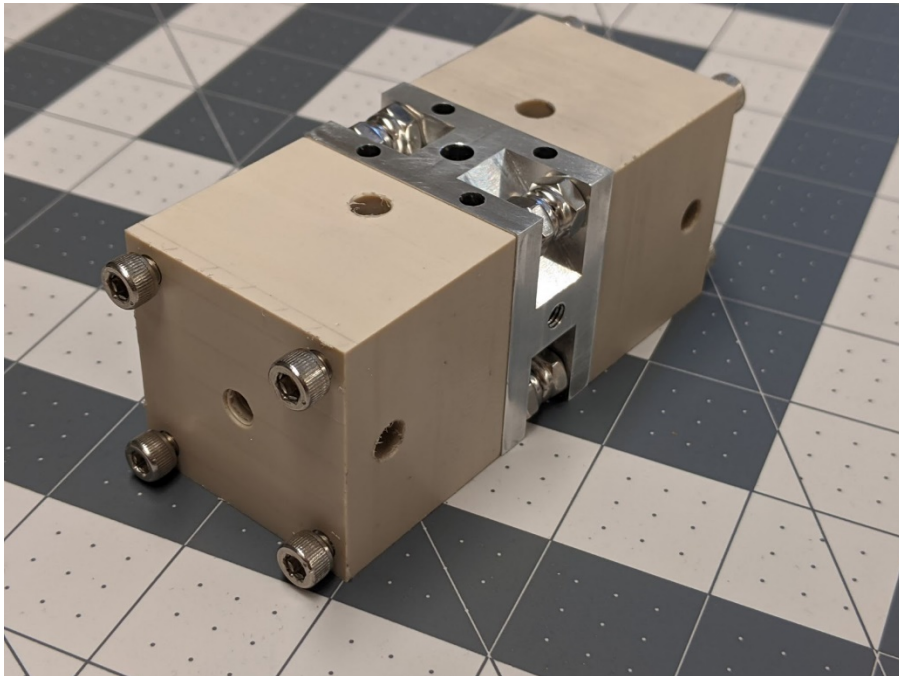
Q3-4 2021

Qualification
Testing

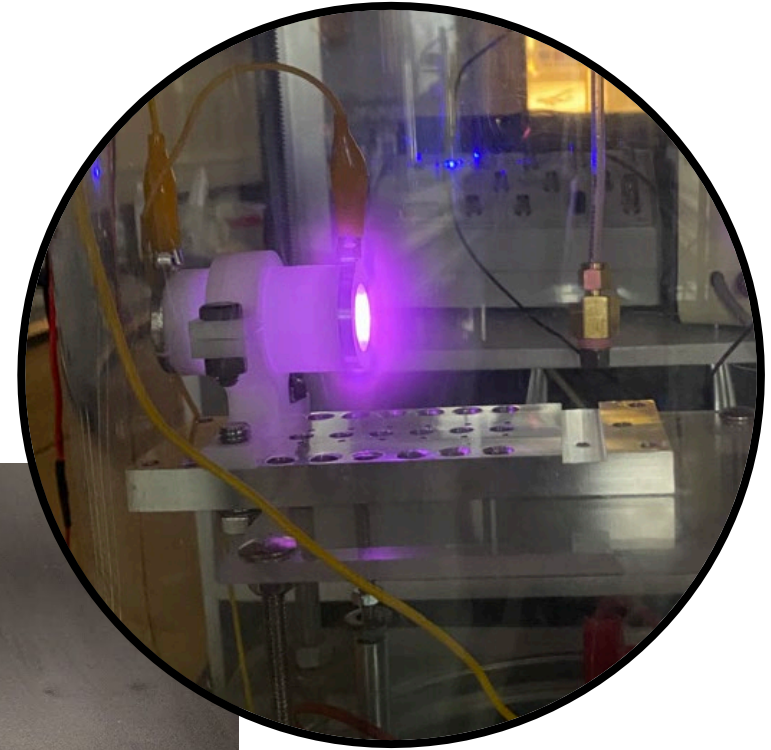
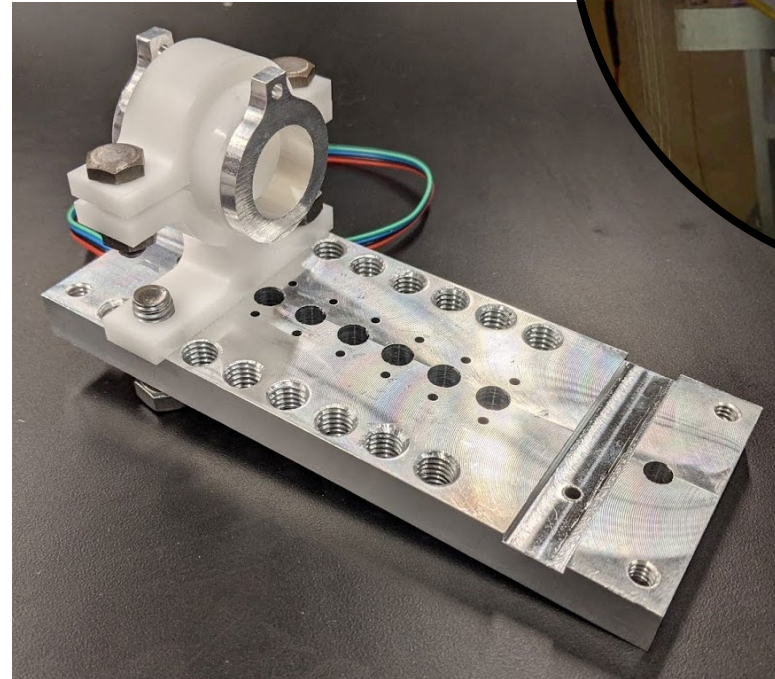
Q3 2022

Launch

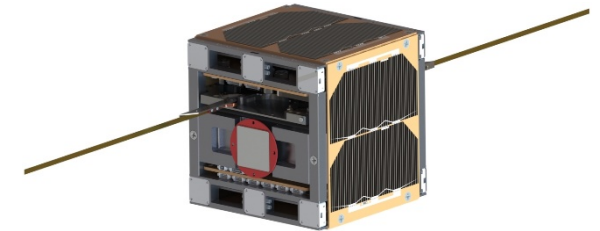
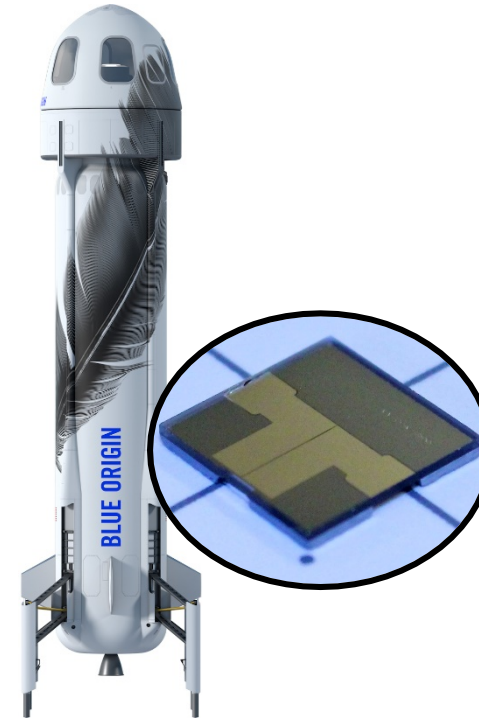
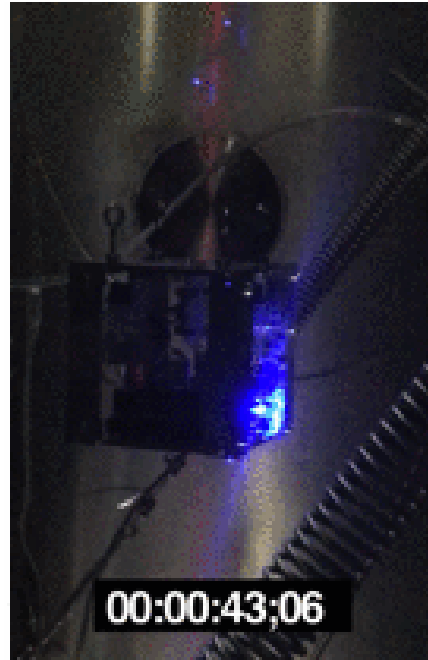
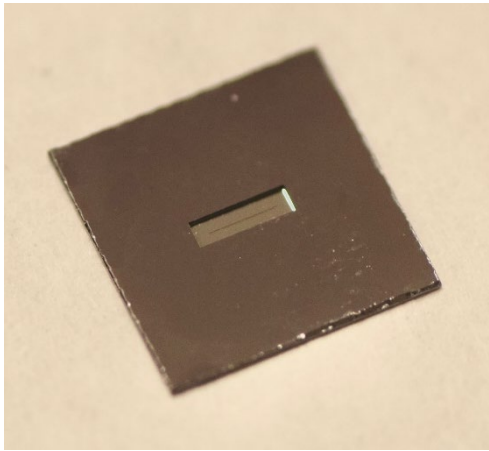
Zero-g propellant tank



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

Thruster nodes

FEMTA

Propellant tank +
controller



Propellant storage sized for
multiyear operation

4 yr



Propellant storage can be
scaled arbitrarily

400 $\frac{\text{Ns}}{\text{U}}$



Thruster nodes can be
added to meet demand

12+



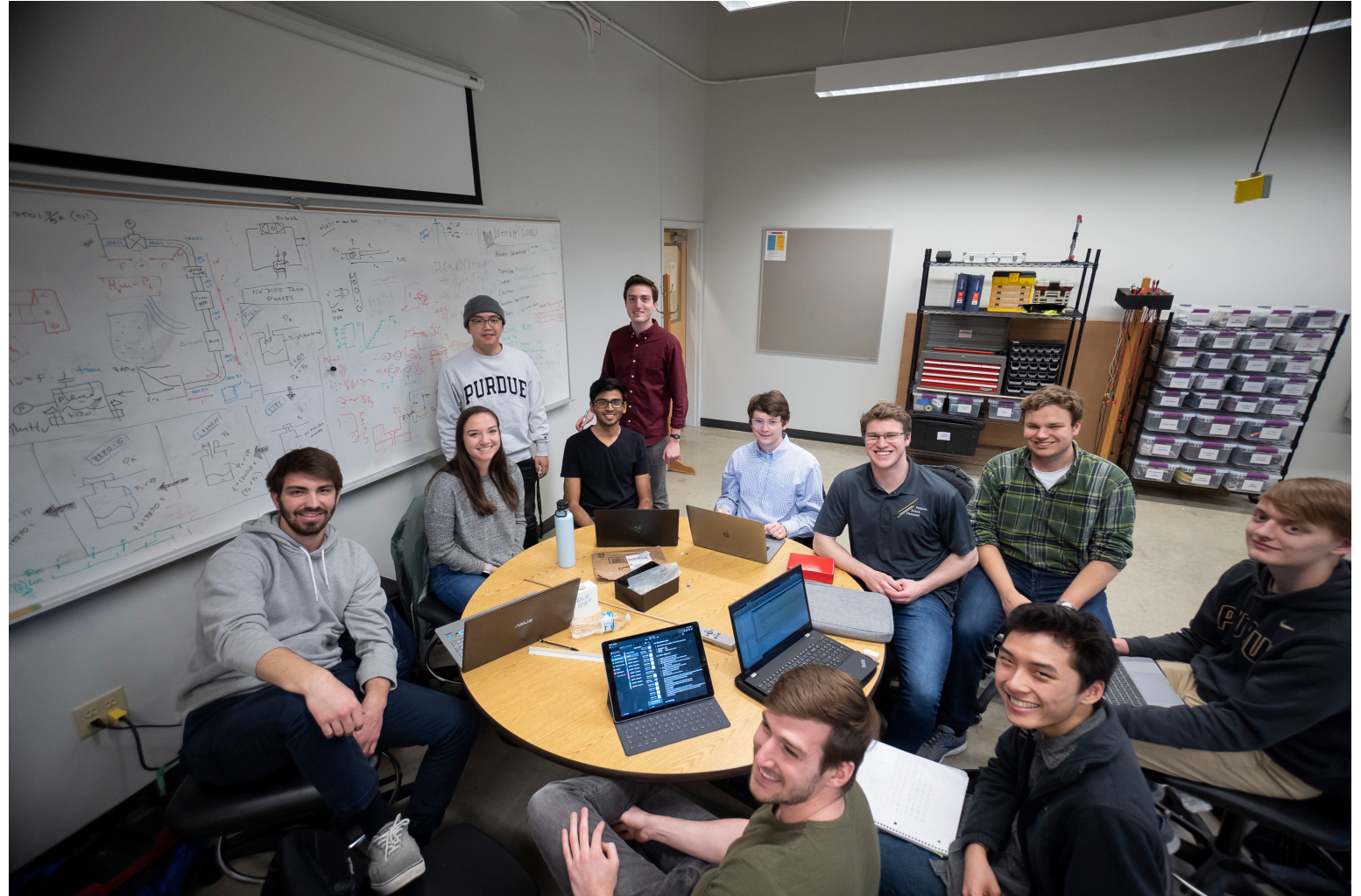
Full scale 1U system requires
< 1/4 of CubeSat volume

1/4 U



Thanks you

QUESTIONS?



2020 Purdue FEMTA Suborbital Undergraduate Team

References

Patents

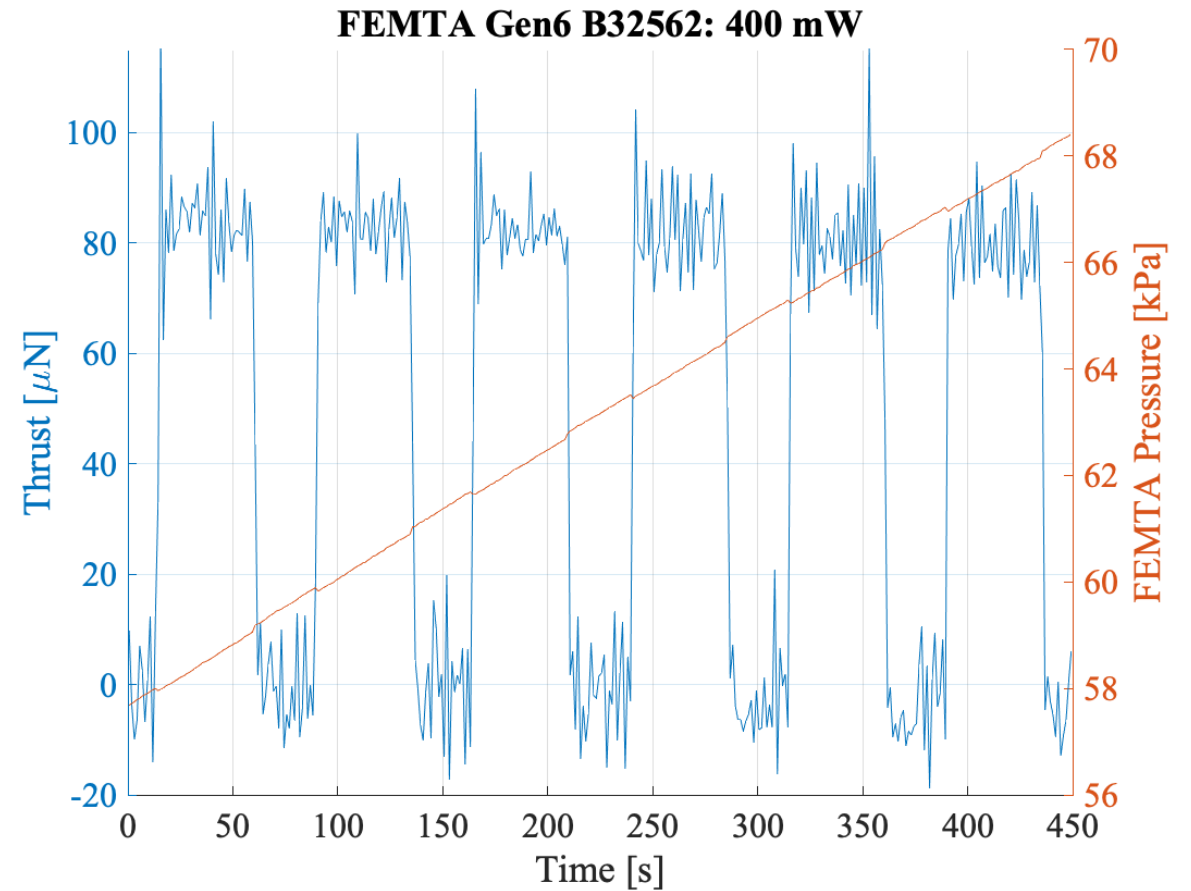
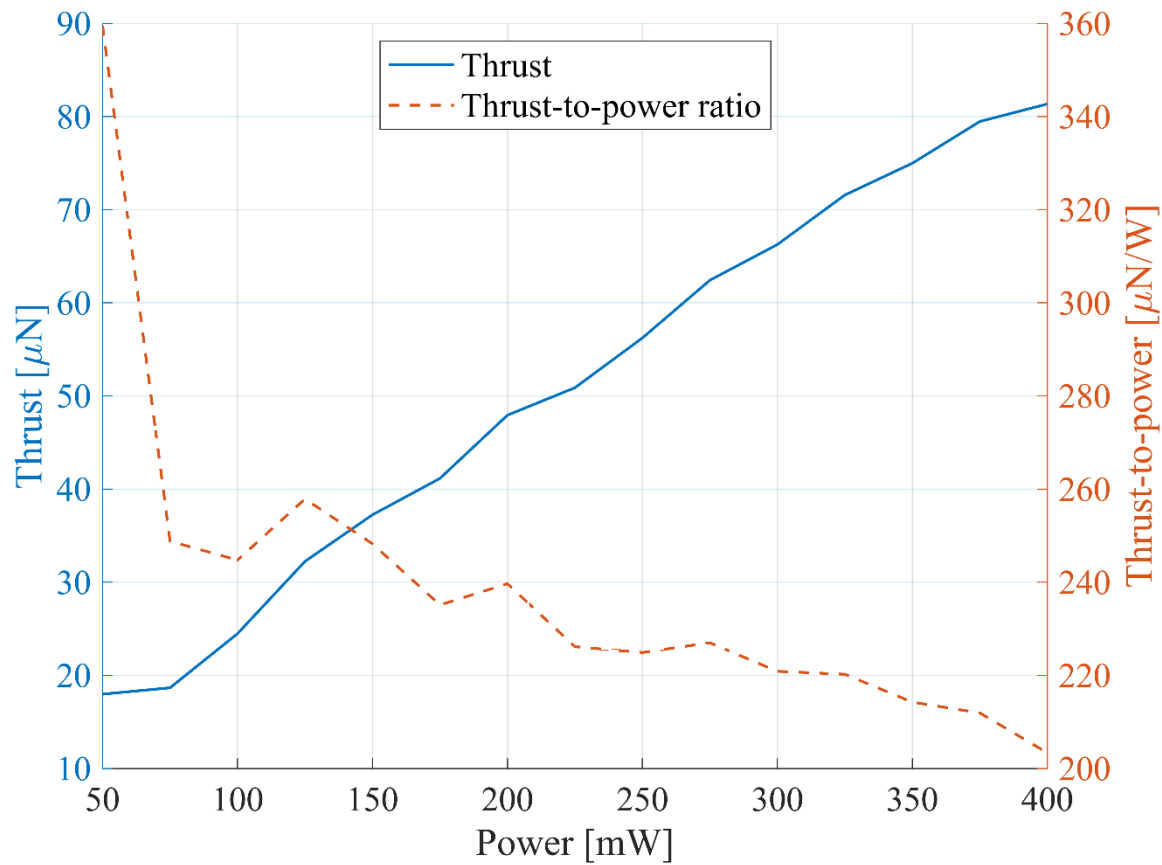
- Vapor pressure drive pump: US20200109722A1
- Microelectronic thermal valve: US20170159847A1
- Tunable Water-based MicroThruster Array: (pending)

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 Propulsion 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

