# FEEP Electric propulsion systems for small satellites

*David Krejci and Alexander Reissner* ENPULSION

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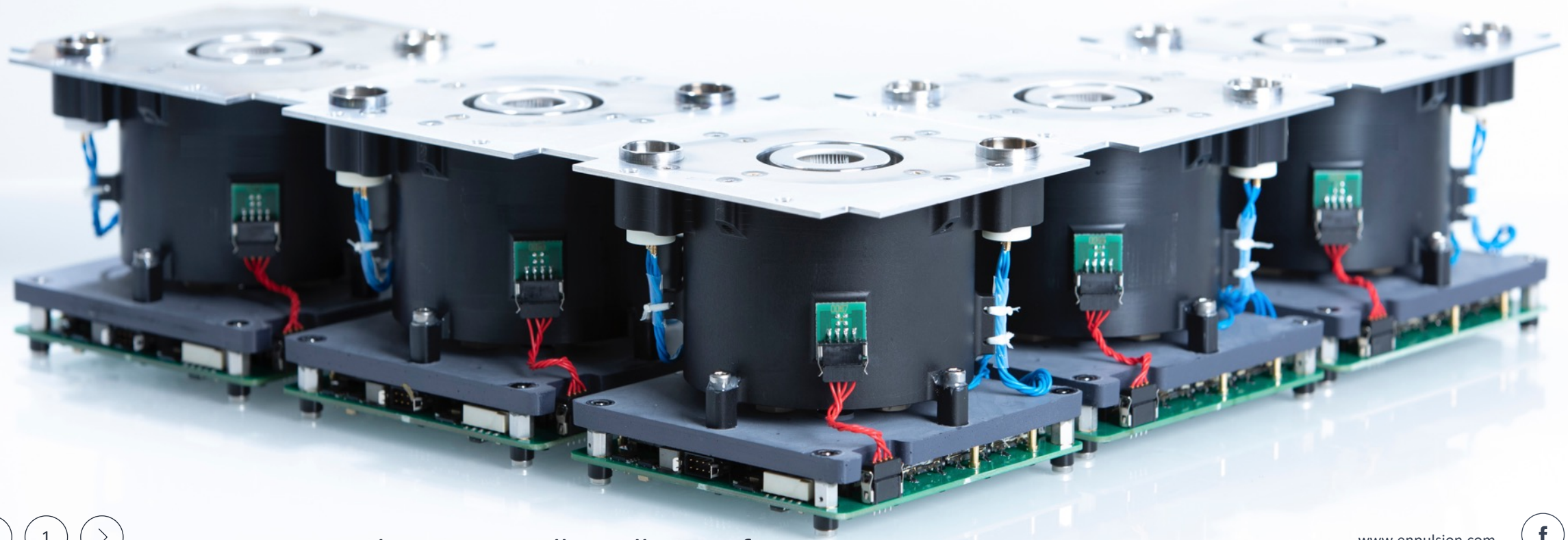
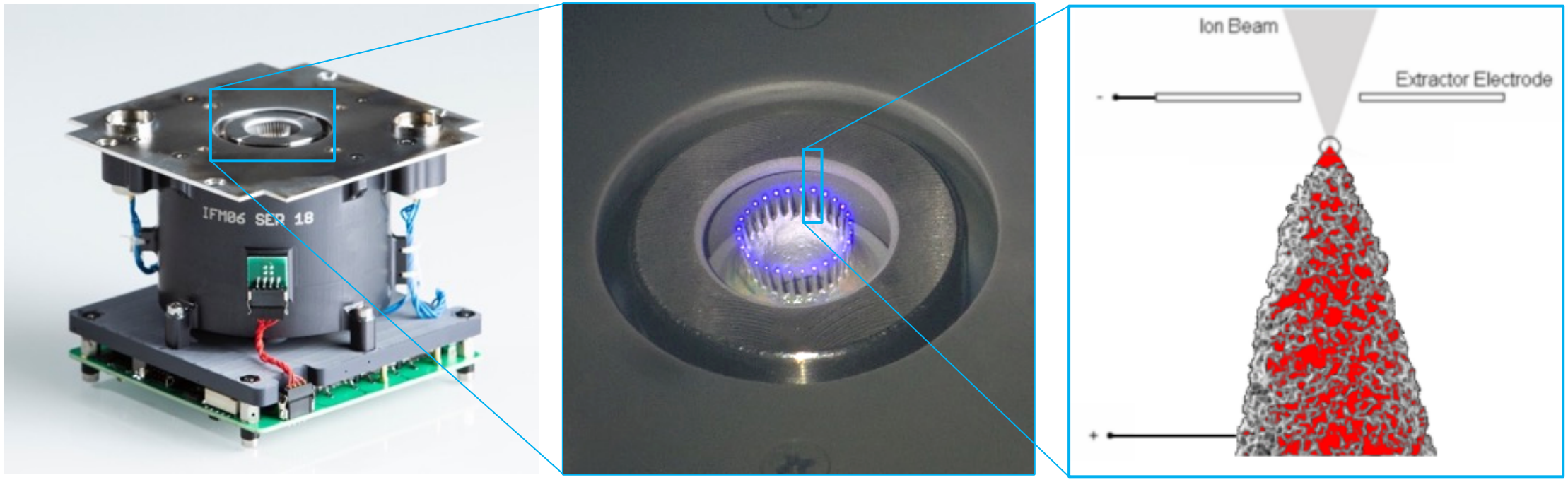


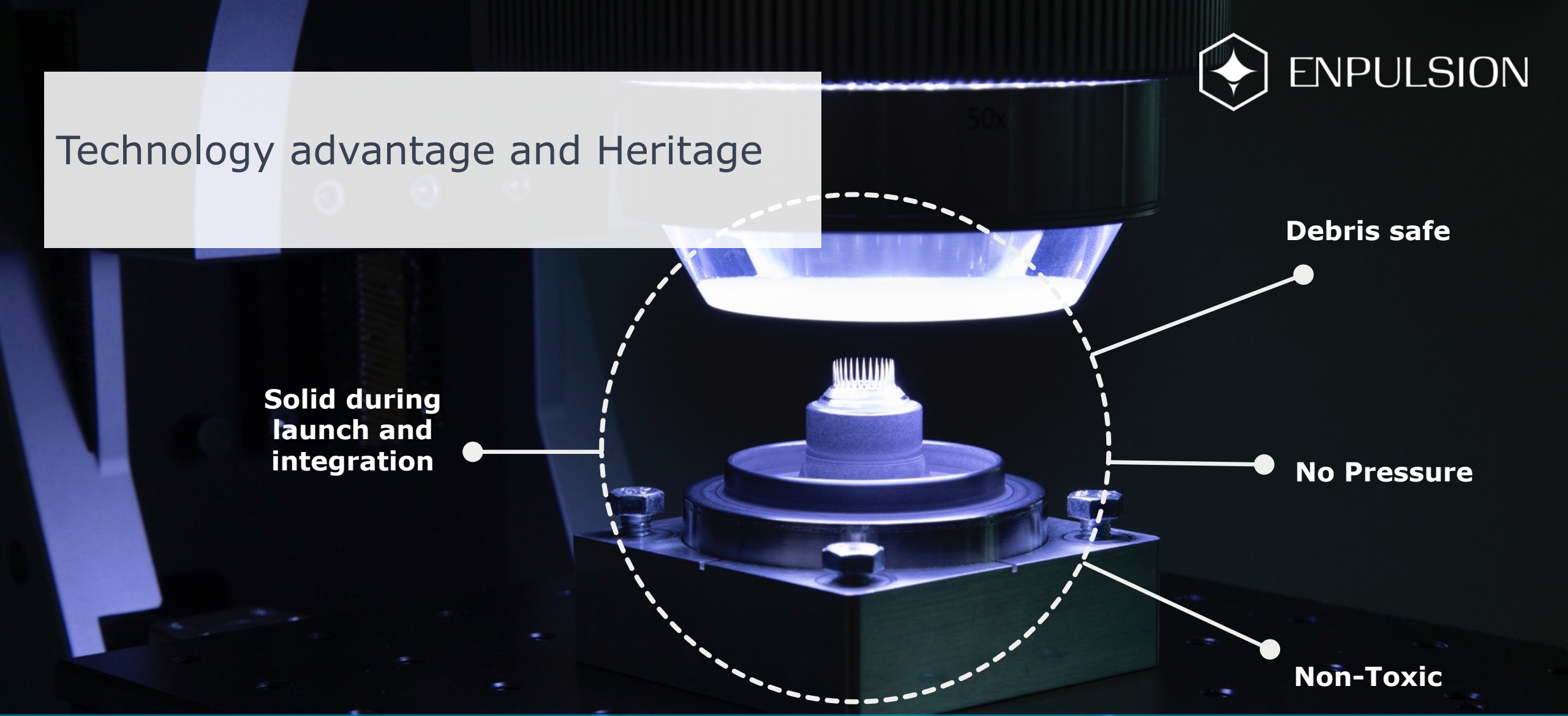
# FEEP Technology

Electrostatic ion emission and acceleration from a Taylor cone

Operation at different Thrust and Specific impulse setpoints



# Technology advantage and Heritage




Ion emitter validated in ongoing lifetime test, surpassed 30,000h of operation (>4x the lifetime of the IFM Nano Thruster emitter)

# Heritage in science missions

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**>25 years of flight heritage in LMIS**

The FEEP technology was developed at AIT (now FOTEC) for > 25 years for scientific missions, support through ESA

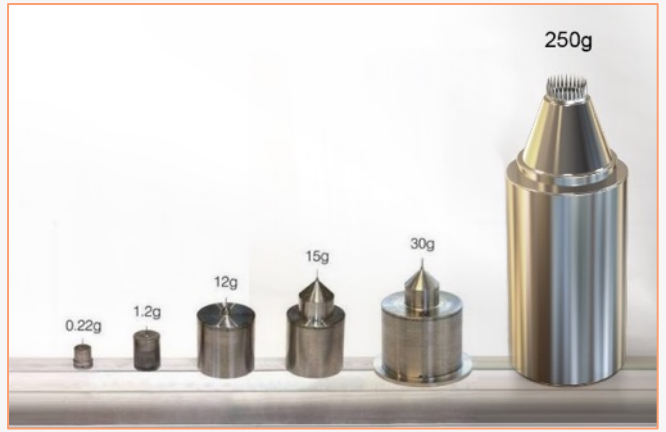
The IFM Thruster technology was developed by Fotec based on this heritage

FOTEC Research Subsidiary of — FH Wiener Neustadt —

## AIT/FOTEC Liquid Indium emitter flight missions

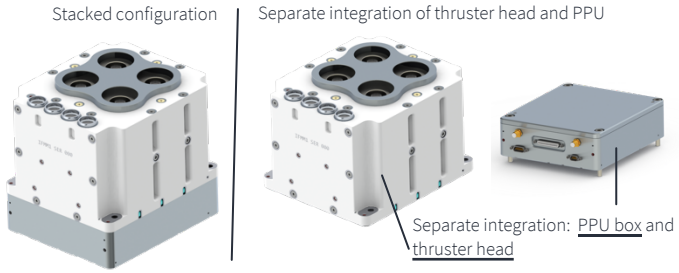
| Experiment | Function | Spacecraft | No. of LMIS | Operation Time |
|---|---|---|---|---|
| **LOGION** | Test of LMIS in µ-Gravity | MIR | 1 | 24 h (1991) |
| **MIGMAS/A** | Mass Spectrometer | MIR | 1 | 120 h (1991-94) |
| **EFE-IE** | S/C Potential Control | GEOTAIL | 8 | 600 h (1992 -) |
| **PCD** | S/C Potential Control | EQUATOR-S | 8 | 250 h (1998) |
| **ASPOC** | S/C Potential Control | CLUSTER | 32 | Ariane 5 Launch Failure 1996 Still operational after Crash |
| **ASPOC-II** | S/C Potential Control | CLUSTER-II | 32 | 6516 (2000 -) |
| **COSIMA** | Mass Spectrometer | ROSETTA | 2 | 2004 - 2014 |
| **ASPOC/DSP** | S/C Potential Control | DoubleStar | 4 | 8979 h (2004 – 2007) |
| **MMS ASPOC** | S/C Potential Control | MMS | 32 | Commissioned successfully in 2015 |

AIT AUSTRIAN INSTITUTE OF TECHNOLOGY → FOTEC Research Subsidiary of — FH Wiener Neustadt —



# Products

IFM Nano Thruster




IFM Micro Thruster

| | IFM Nano Thruster | IFM Micro Thruster |
|---|---|---|
| **Dimensions** | 100 x 100 x 82.5 $mm^3$ (<1U) | 140 x 120 x 98.6 mm (thruster)<br>140 x 120 x 34.0 mm (PPU) |
| **Mass (dry / wet)** | 0.67 / 0.9 kg (incl. PPU) | 2.6 / 3.9 kg (incl PPU) |
| **Total input power to PPU @ nominal thrust** | 40 W incl. neutralizer | 100 W incl. neutralizer |
| **Thrust range (Nominal thrust)** | 10-400 µN (350 µN) | 75 – 1,450 µN (1,000 µN) |
| **Specific impulse** | 2,000 – 6,000 s | 1,500 – 6,000 s |
| **Total impulse** | > 5 kNs | > 50 kNs |
| **Command interface** | RS422 / RS485 | RS485 |
| **Input voltage** | 12 V / 28 V / Others | 28 V / Others |
| **STATUS** | 28 in space | First FM delivery Q2 2020 |

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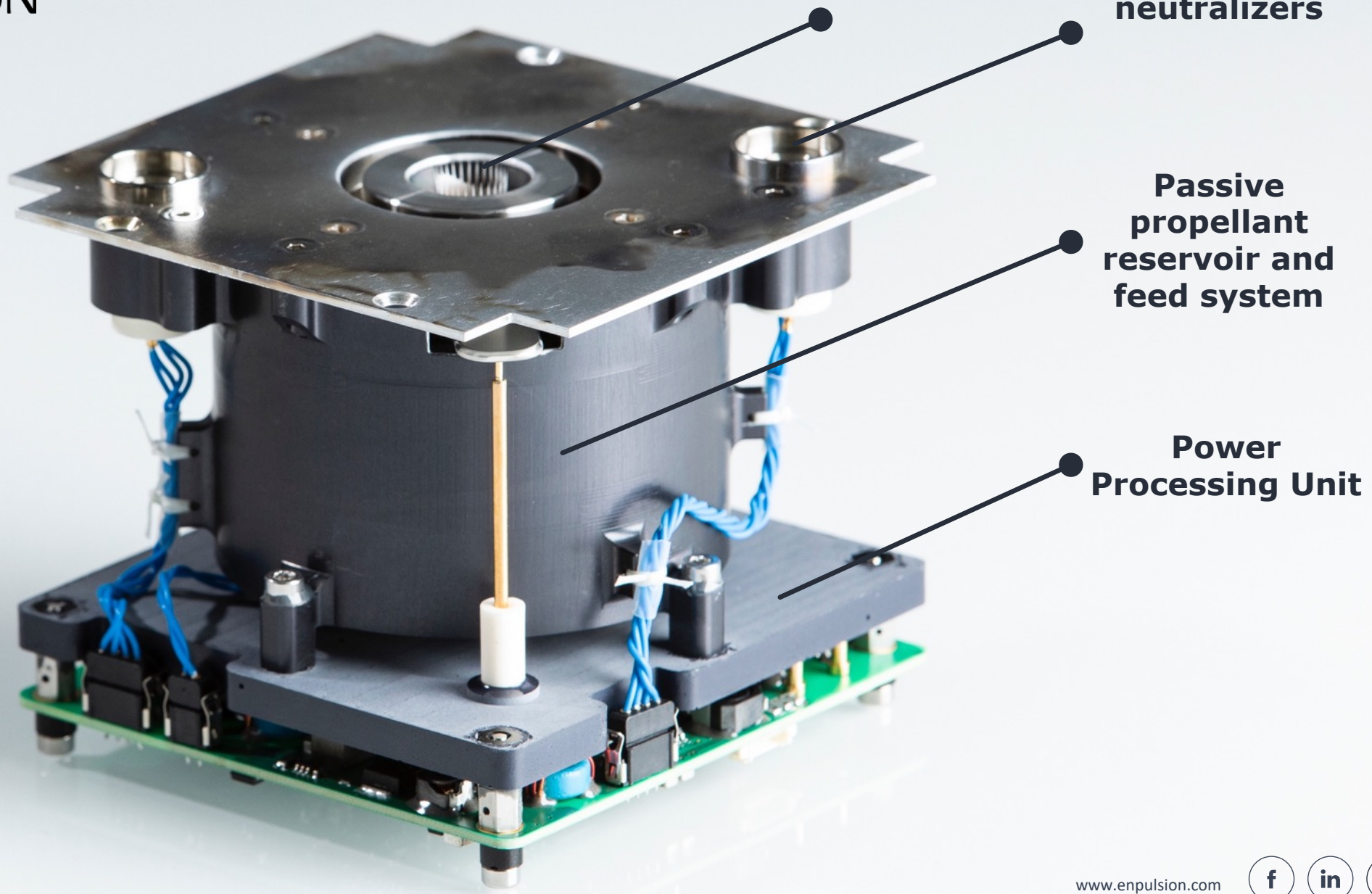
Porous crown emitter
Cold redundant neutralizers
Passive propellant reservoir and feed system
Power Processing Unit

# Launched on…

>100 IFM Nano Thruster built

28 in space at the moment

IOD in 2018 on a 3U Cubesat

In case of undisclosed customers, sample images are shown

# IFM Nano Thruster in Numbers

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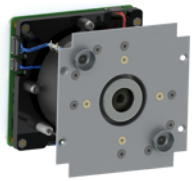

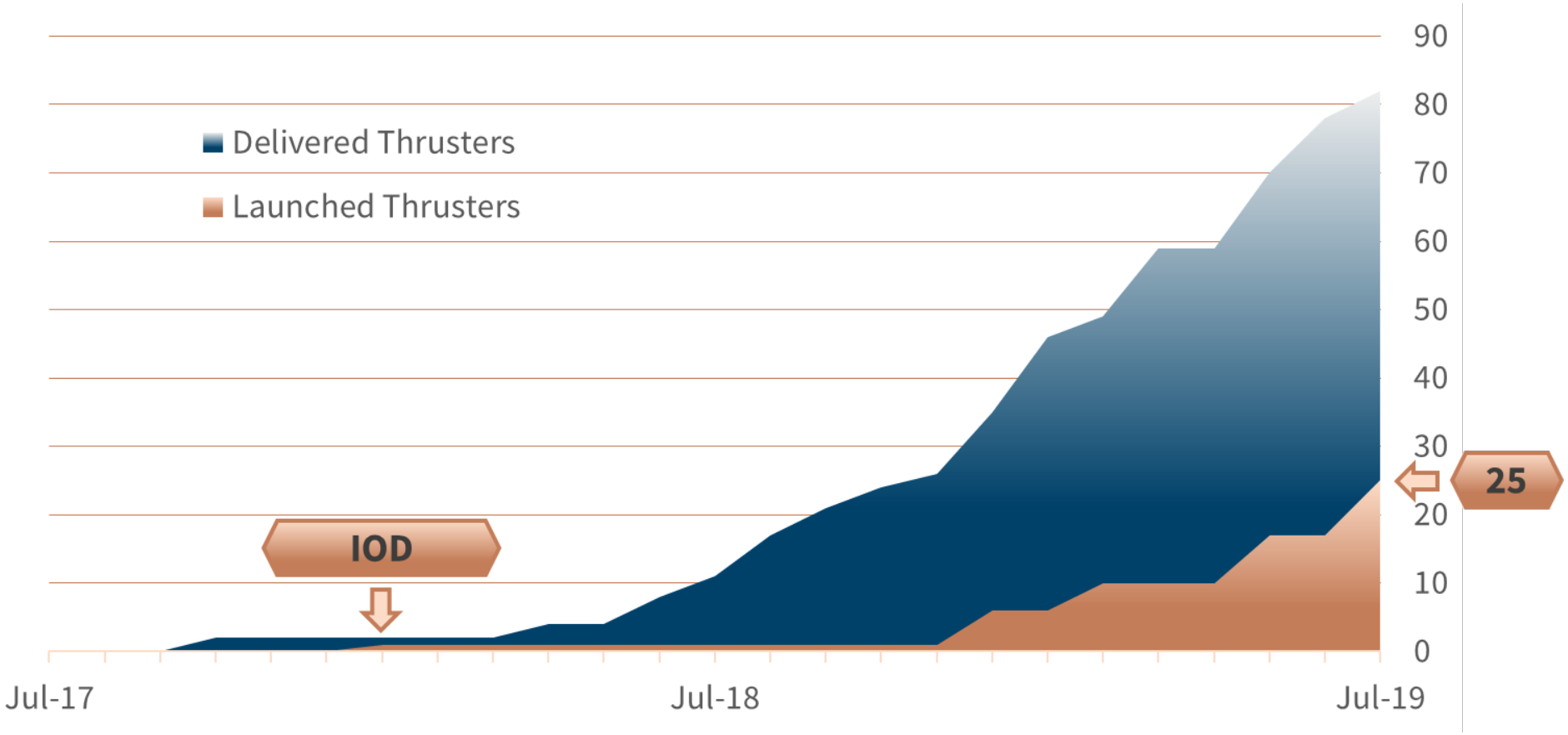

# IFM Nano Thruster Status update

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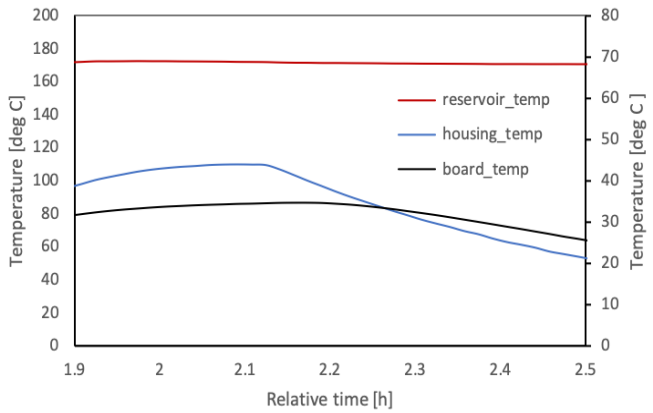
## In-orbit data analysis

Serial Production ongoing
Flight unit delivery at constant rate since 2018
Multiple constellation contracts ongoing

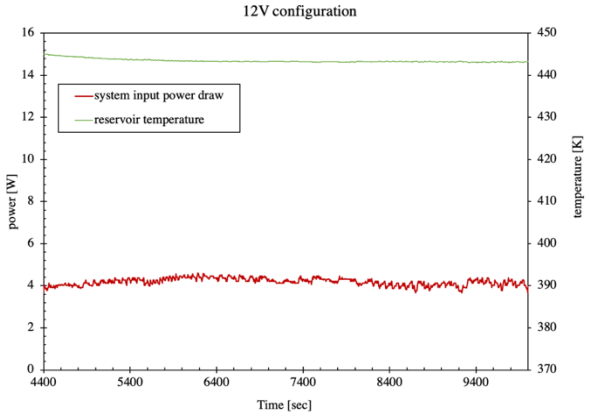
- Learning from advanced number of units in orbit
- Close cooperation with customers to optimize individual missions
- Introducing advanced testing into Acceptance testing

Updating the design for improved radiation tolerance: COTS+

Thruster capability to control propellant temperature in changing thermal environment entering eclipse




Hot-standby power draw of thruster in 500km LEO orbit



# 100 thrusters: acceptance data

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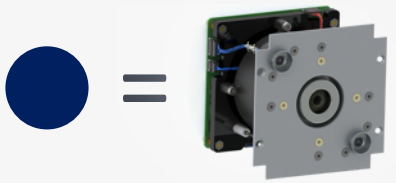
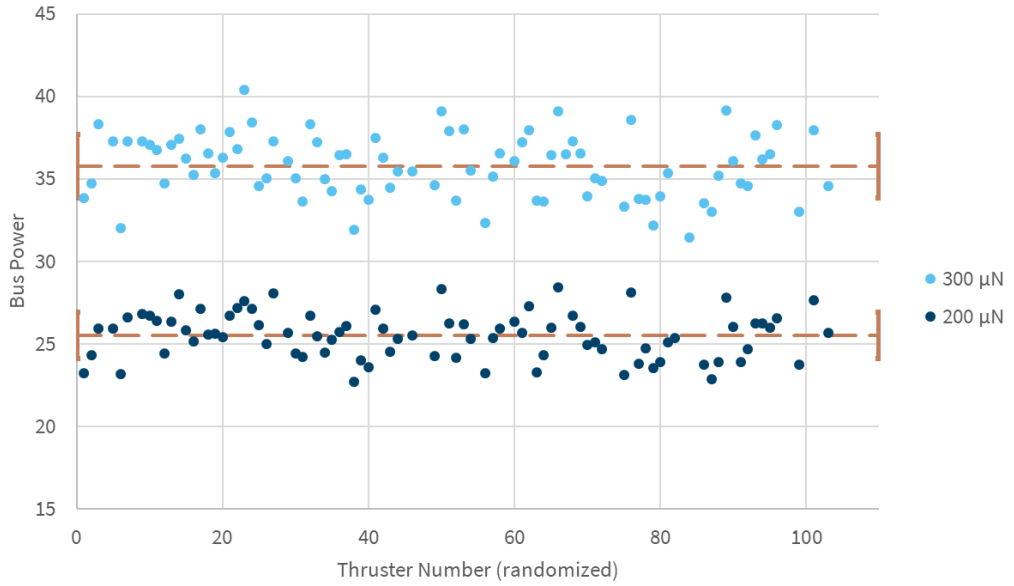
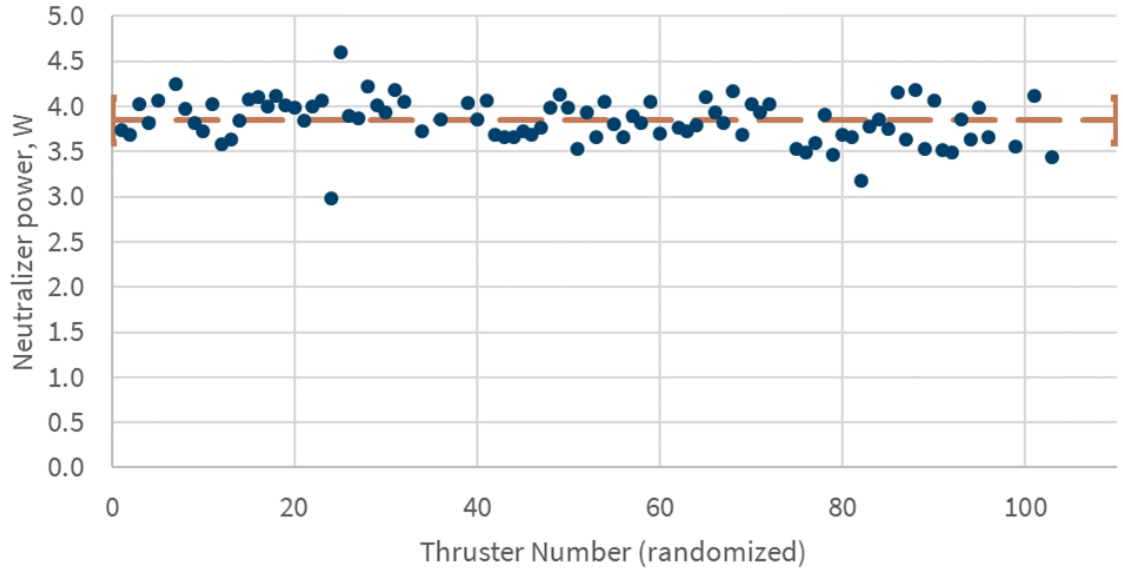
## Acceptance data statistics

Large number of thrusters allows to leverage statistical tools

Each data point represents a flight model





# IFM Micro 100 Thruster Status

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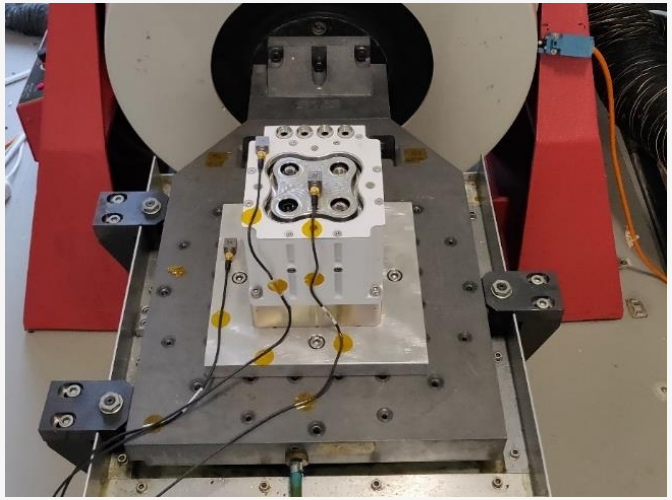
**Qualification started**

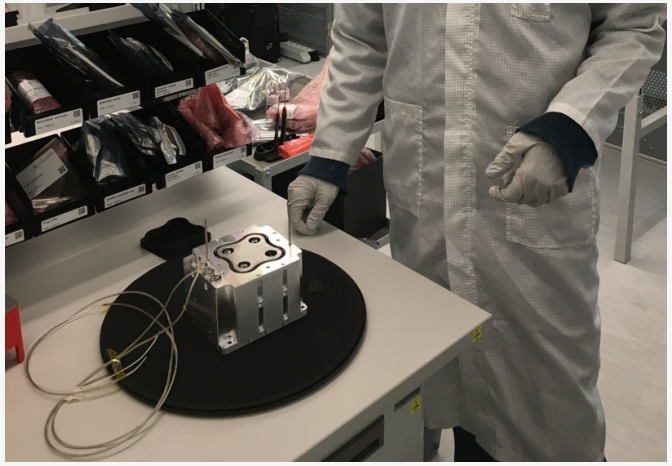
Qualification models built

COTS+ PPU in stacked configuration

Design verified:
- Vibration testing
- Shock testing
- Thermal design during heat-up and hot standby
- High voltage insulation
- Functional coupling testing with COTS+ PPU
- Beam diagnostics

First flight module delivery to customer
in Q2 2020





# IFM Nano Thruster Flight Data

# Independent orbit verification

**3U Cubesat**
**SSO orbit**

Thrust calculated by PPU (based on emission current and potentials) compared to GPS data provided by spacecraft operator

Independent orbit change verified within uncertainties of measurement

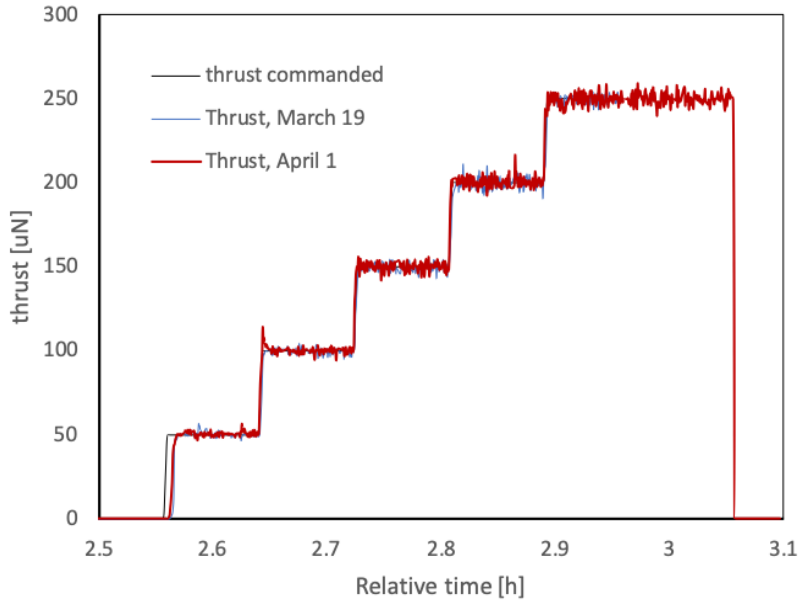
Table 1. Change in average spacecraft semi-major axis due to thrust maneuver, measured from GPS data and calculated from propulsion telemetry

| Maneuver parameters | Average change in semi-major axis [m] | |
|---|---|---|
| | Calculated from thruster telemetry | GPS measurements |
| *Test 1:* $I_{em}$=2mA, 15 min | 72 | 70 ± 5 |
| *Test 2:* $I_{em}$=2mA, 30 min | 115 | 116 ± 5 |

From: Krejci et al: *Demonstration of the IFM Nano FEEP Thruster in Low Earth Orbit*, 4S symposium, 56, Sorrento, IT, 2018.

1 year after commissioning

- Thrust steps with controlled transients
- Reproducability of thrust profiles
- High Isp operation



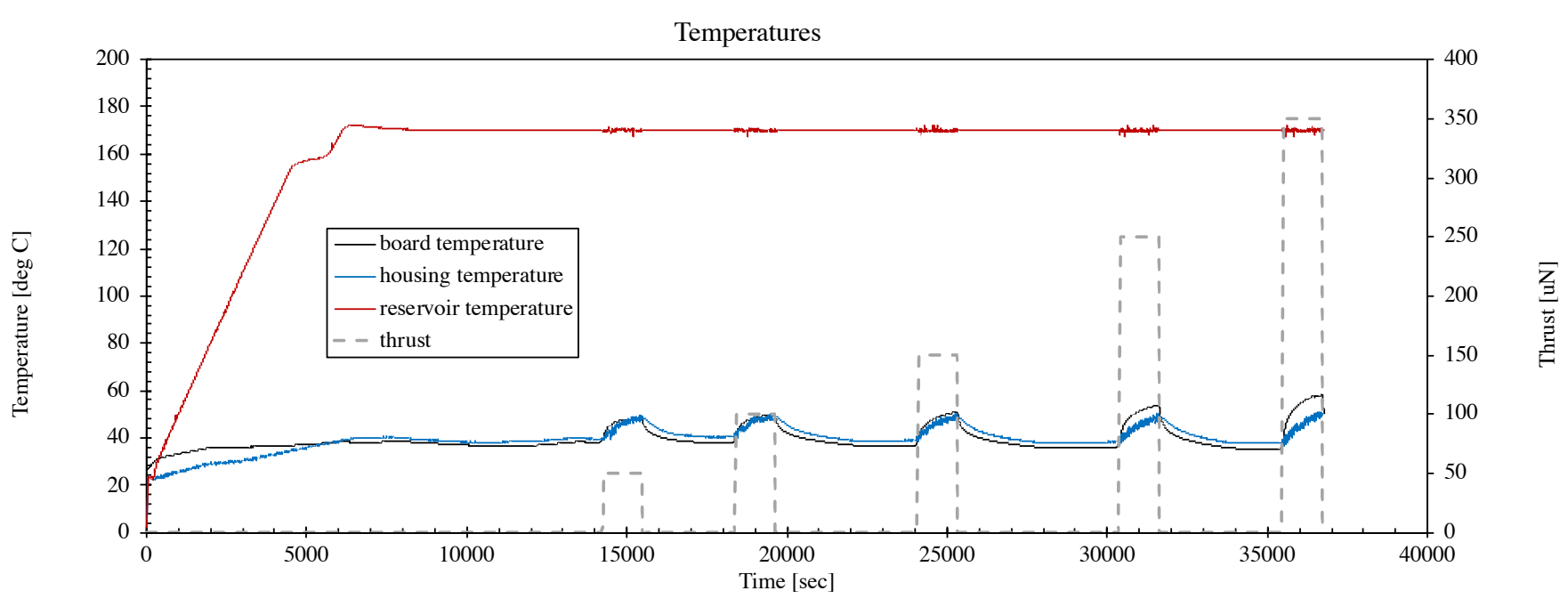
# Different thrust levels, remaining in hot-standby mode

**Smallsat launched in 2018**

**Carrying 4 IFM Nano Thruster**

Thermal data of IFM06.03

- Propellant liquification
- Hot-Standby
- Firing sequences with increasing thrust levels



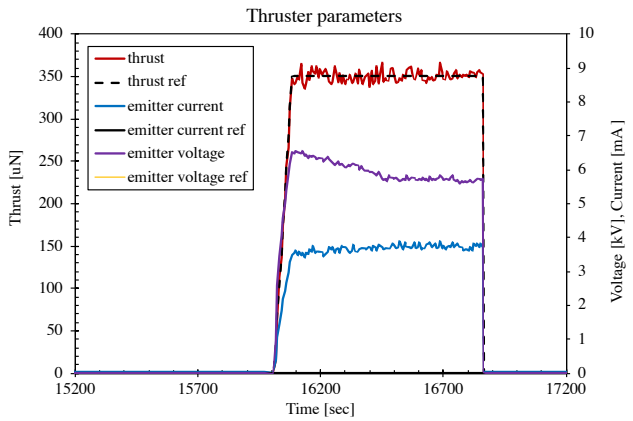

From: Krejci, Reissner, Schönherr, Seifert, Saleem, Alejos: Recent flight data from IFM Nano Thruster in a low earth orbit, IEPC-2019-A724, 36th International Electric Propulsion Conference, Vienna, Austria, Spt 2019

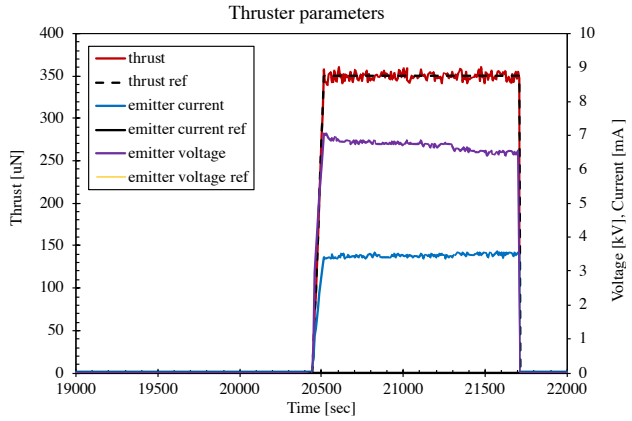
# Nominal operation point confirmation

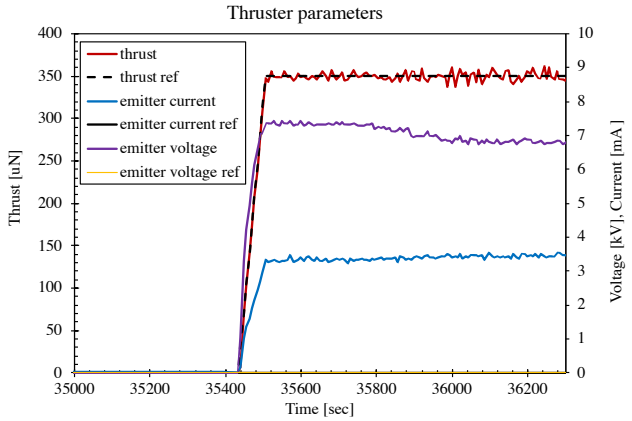
**Smallsat launched in 2018**

**Carrying 4 IFM Nano Thruster**

Firing with increasing thrust levels: 150µN, 250µN, 350µN

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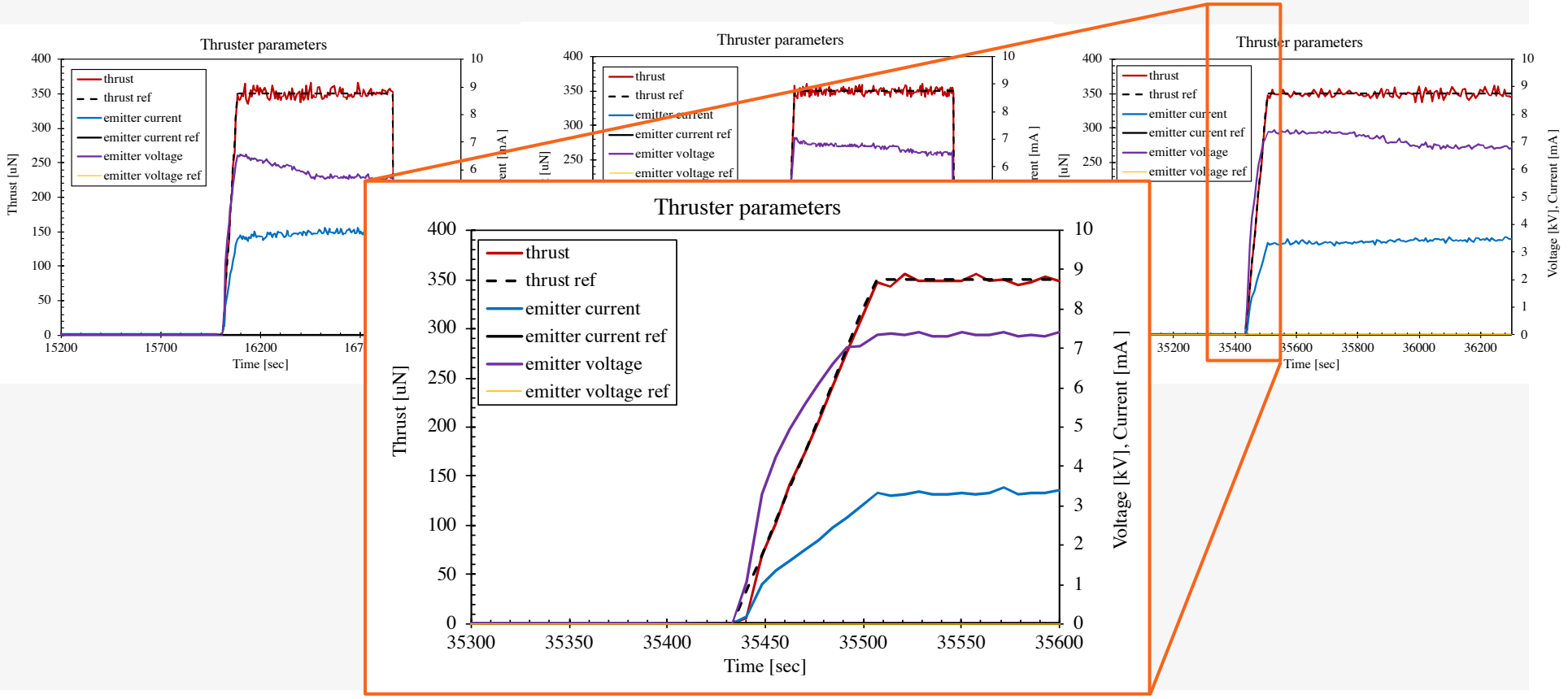




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# Conclusion

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| | |
|---|---|
| High rate | Multiple thrusters per week shipped to customers, enabled by standardization and batch testing |
| In-orbit data | Double digit number of thrusters in space now, firing tests presented show good controllability of thrust. Data is used to improve propulsion system and optimize missions together with customers |
| Introducing the IFM Micro 100 Thruster | IFM Micro 100 Thruster becoming available, with first customer deliveries in Q2 2020. Design verified by testing. |


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