DESIGNING THE NEXT GENERATION FEEP PROPULSION SYSTEMS BY UTILIZING THE FLIGHT HERITAGE FROM 163 THRUSTERS

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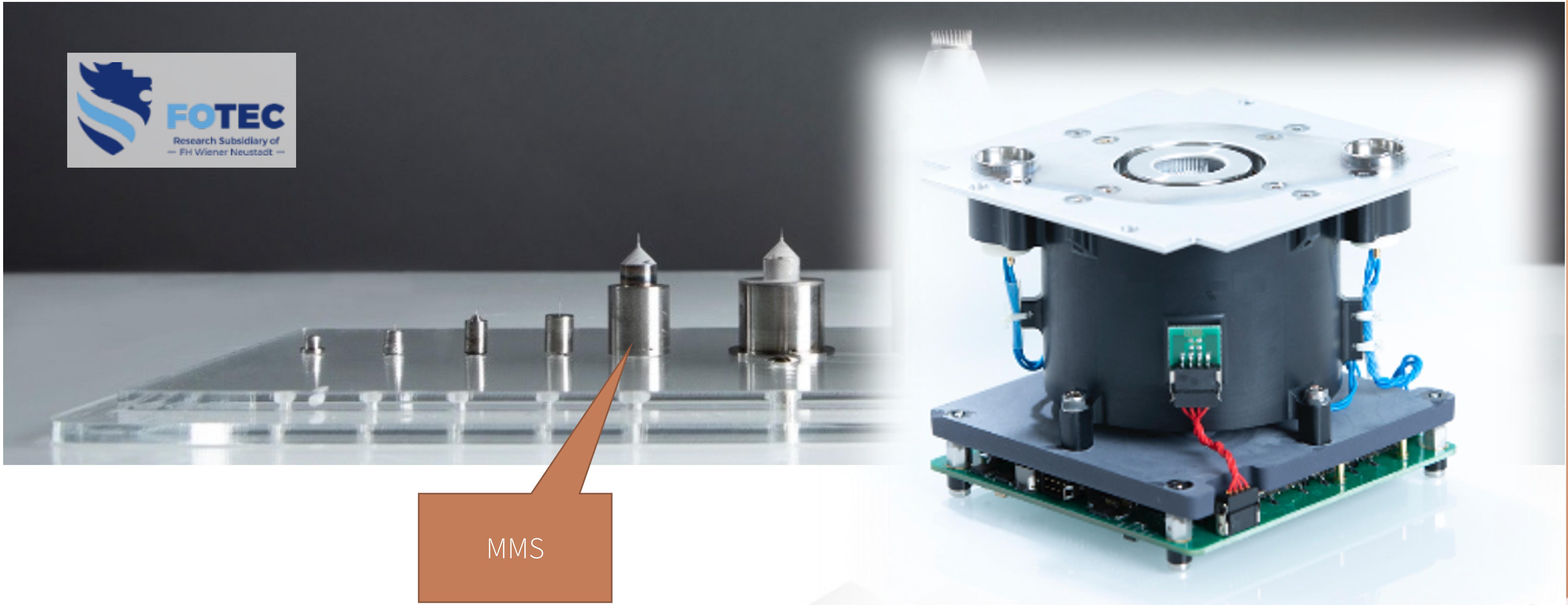
EPIC

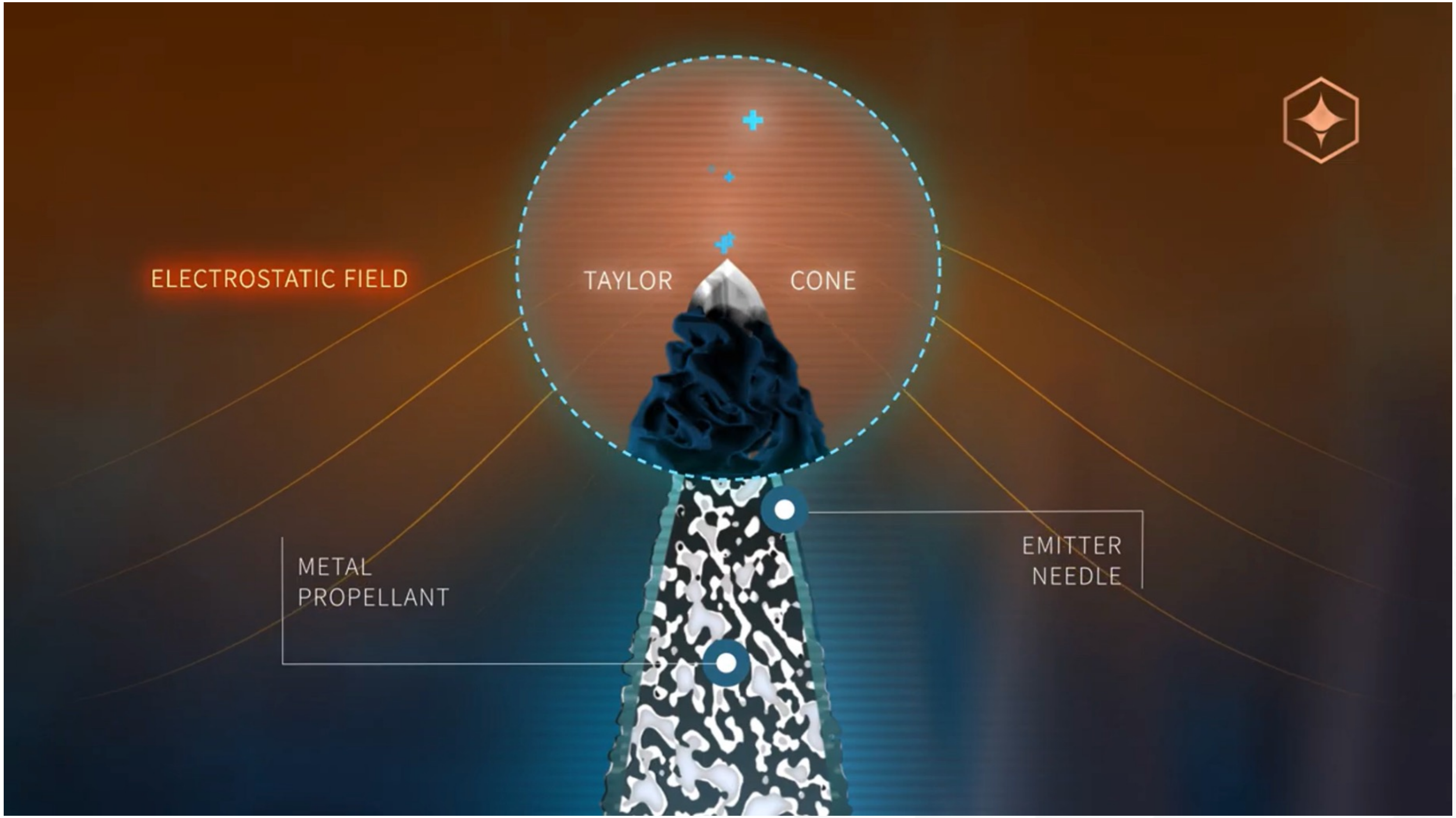
2023

BUILDING ON 30 YEARS OF DEVELOPMENT AT AIT/FOTEC

More than 20 years of heritage on NASA/ESA missions, including Rosetta, MMS, Cluster-II



FEEP TECHNOLOGY – HOW IT WORKS



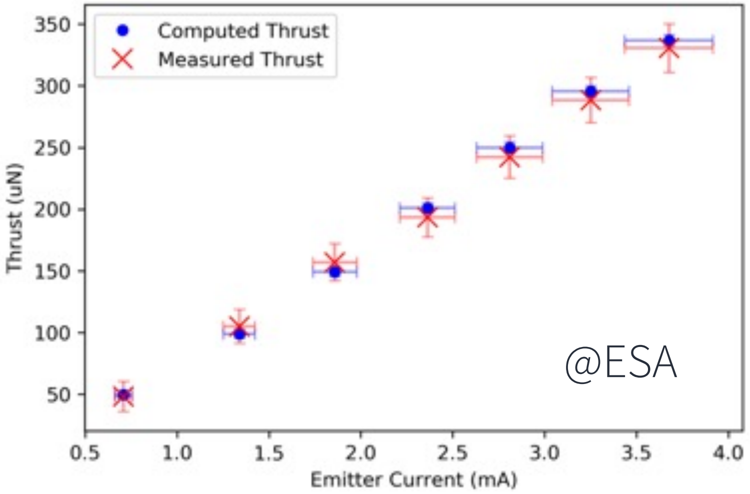
FLIGHT HERITAGE PROPULSION SYSTEMS

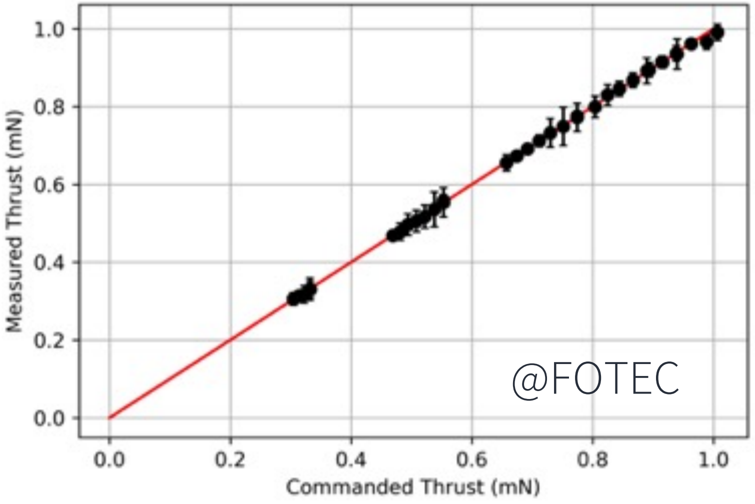
HERITAGE NANO

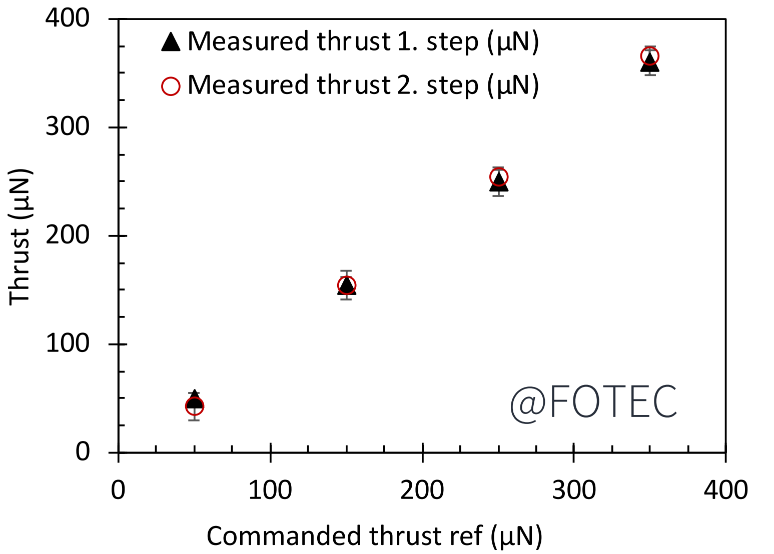
Heritage NANO

MIRCO R3

NANO AR3 / R3







FLIGHT HERITAGE PROPULSION SYSTEMS

ENPULSION

HERITAGE NANO

Heritage NANO

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.

LAUNCH STATISTICS

NANO, MICRO R^3 AND NANO AR^3

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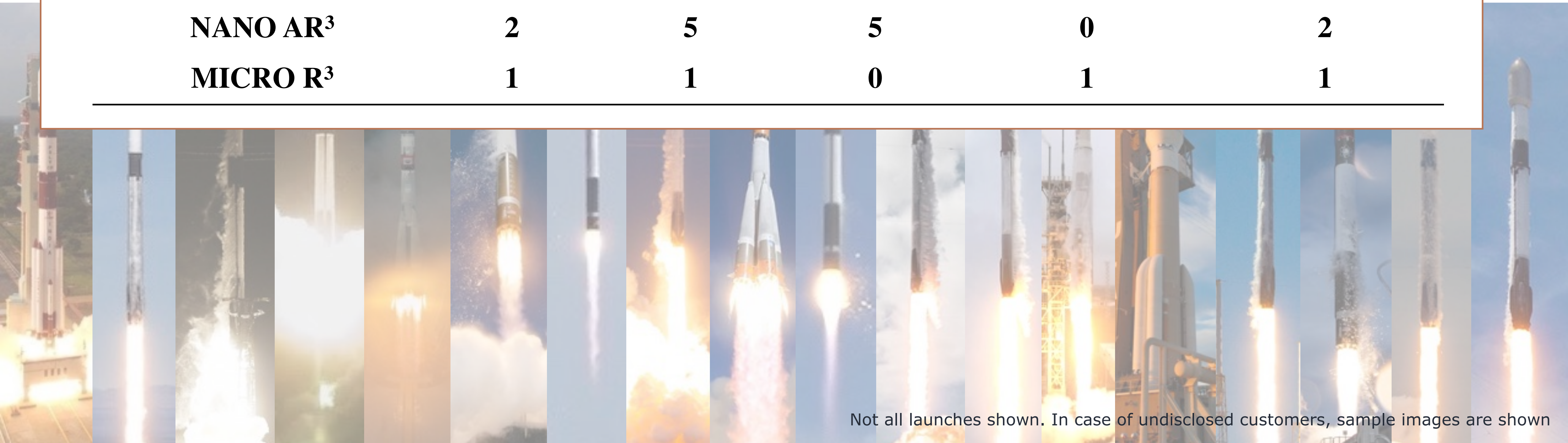
Propulsion System	Number of s/c	Number of Thruster	Thrusters on Cubesats	Thrusters on ESPA class s/c	Different launches
NANO	74	161	29	132	21
NANO AR^3	2	5	5	0	2
MICRO R^3	1	1	0	1	1

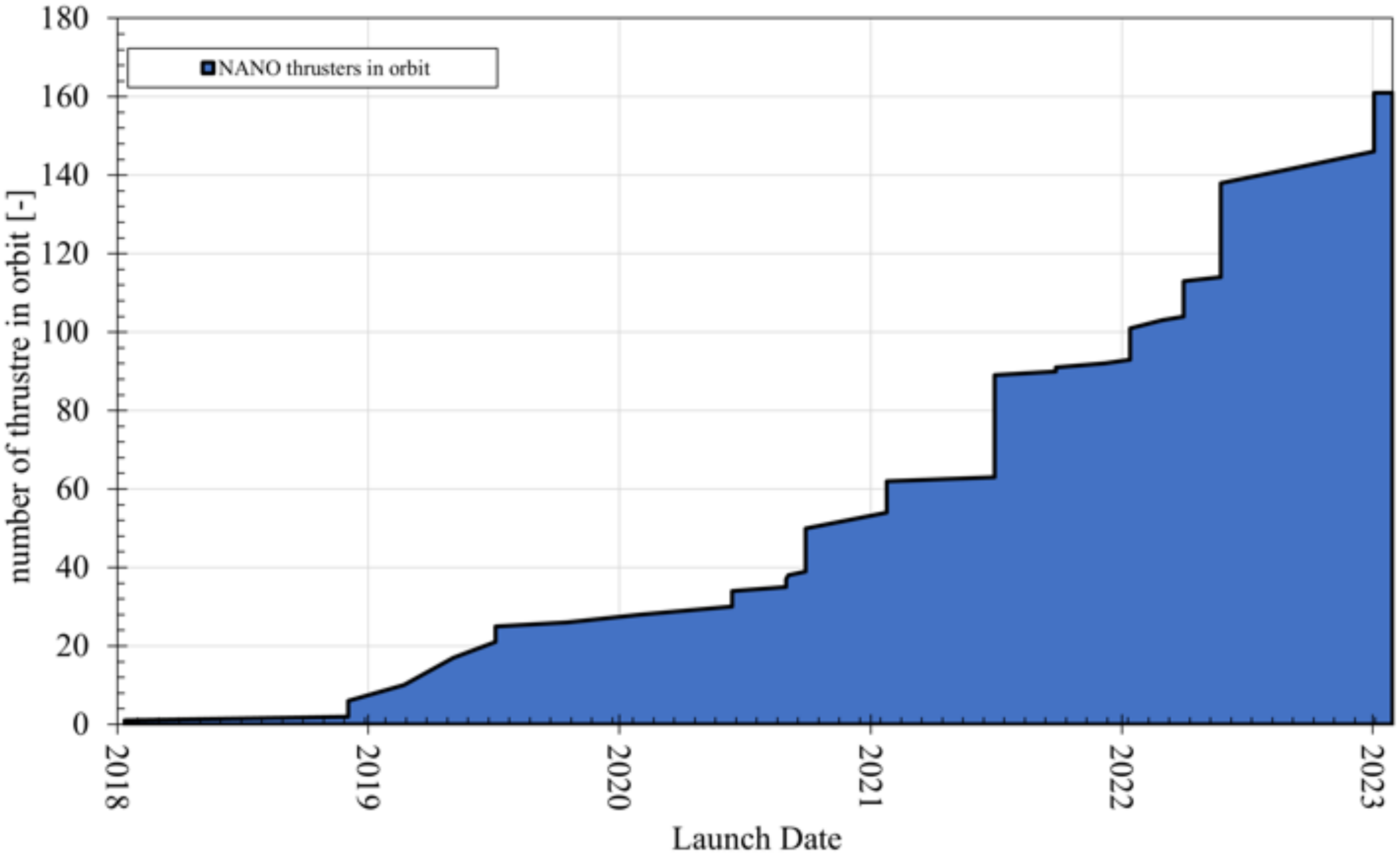


Not all launches shown. In case of undisclosed customers, sample images are shown

LAUNCH STATISTICS

NANO, MICRO R³ AND NANO AR³

Propulsion System	Number of s/c
NANO	74
NANO AR^3	2
MICRO R^3	1



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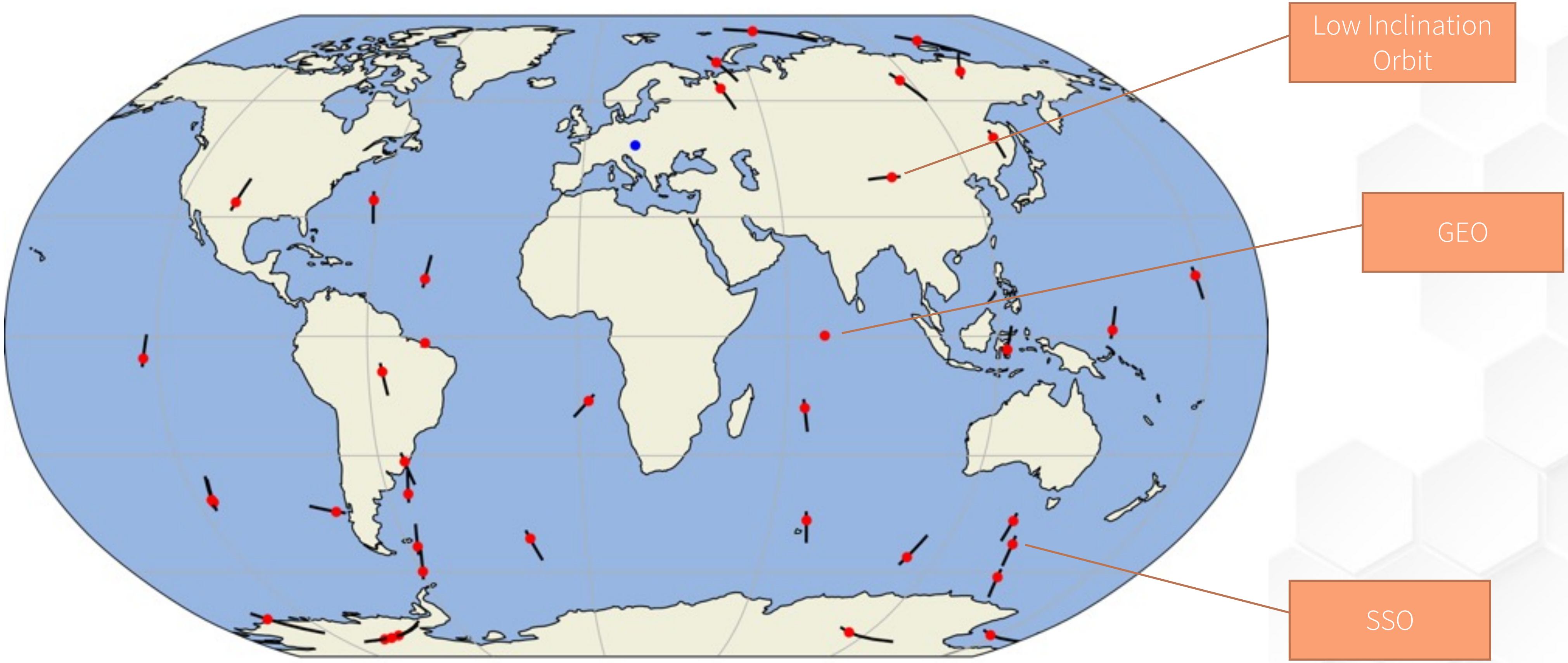
ENPULSION IN SPACE

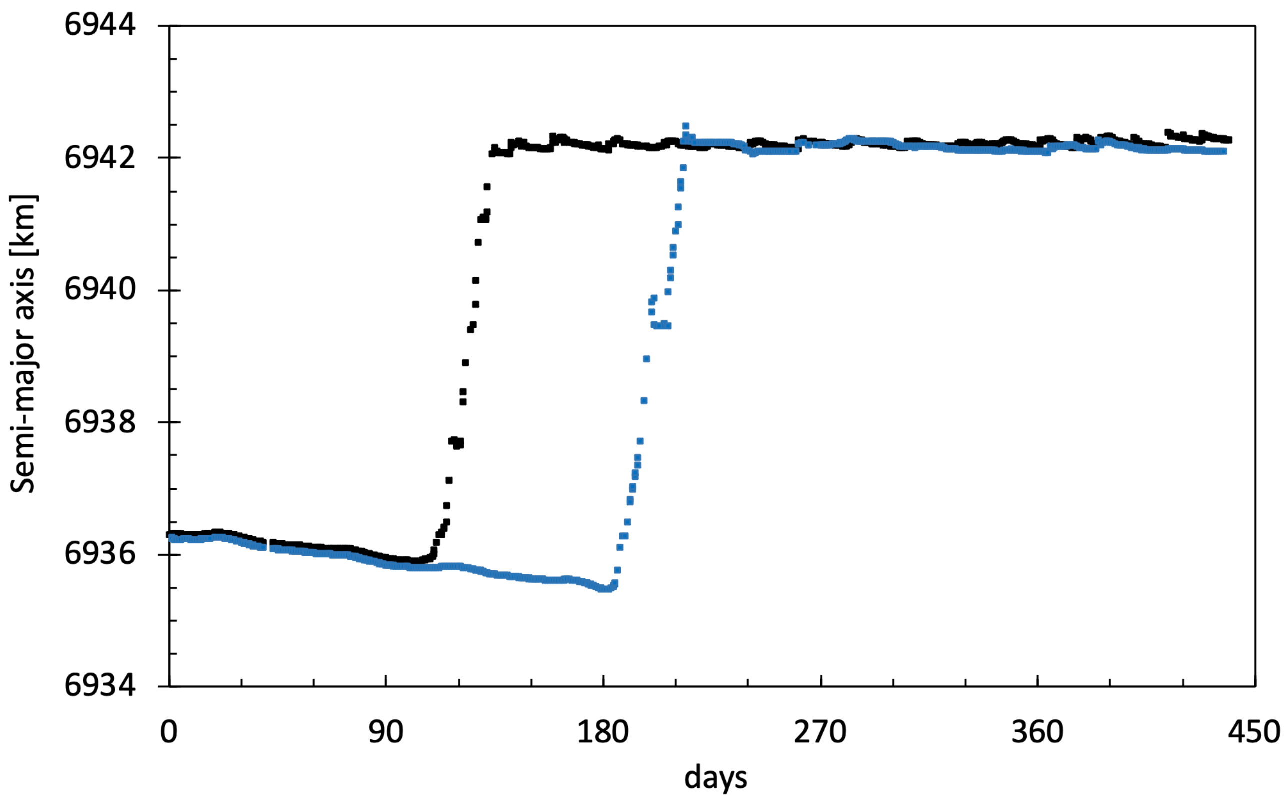
ENPULSION



39 out of 77 spacecrafts are shown, due to lack of orbital information or confidenciality reasons

Application examples

- NANOs have been used so far for a variety of different applications
  - bring into target orbit, in conjunction with ride share
  - formation and cluster initiation
  - maintenance of precise orbits to improve ground track
  - constellation rollout
  - deorbiting

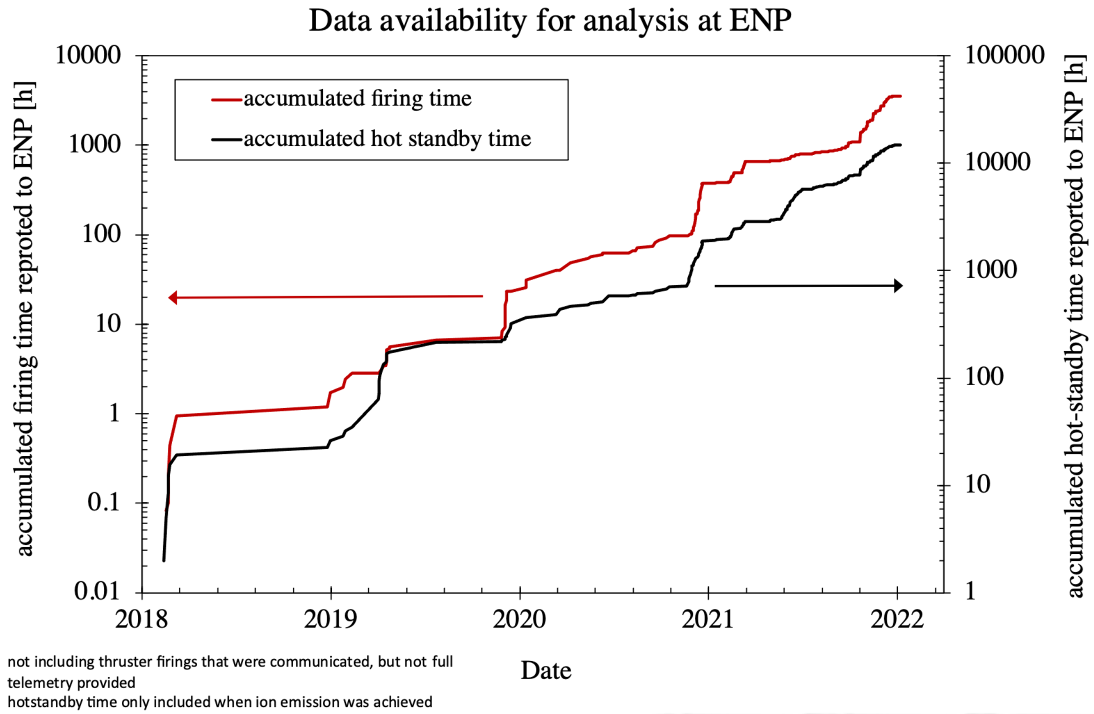


Spacecraft A & B: Average semi-major axis evolution of two spacecraft using multiple ENPULSION NANOs for orbit transfer each, arbitrary relative time in days: natural decay before thruster usage, followed by orbit acquisition, followed by precise orbit keeping during operational mission. Both spacecraft were launched on the same rideshare, data shows drifting separation. Data taken from publicly available sources

ENPULSION NANO data availability

Enabling statistical analysis across missions, platforms and use cases

- Goldmine of onorbit data available at ENP
  - Allows for statistical evaluation **across missions, customers, platforms, orbits, and use cases**
  - Large sample data for lessons learnt
- Limiting factor remains how much data we can get visibility on, not how much is accumulated onorbit
- Often problems are reported, while uneventful thrusting is not, skewing the data/preventing derivation of real probability numbers



NANO data availability for analysis at ENPULSION: Accumulated firing time and hot standby time for which full telemetry was made available to ENPULSION. The scaling of hot standby time with firing time indicates that the data shown is limited by data visibility, and accordingly represents minimum accumulated times, with true on-orbit times likely higher, based on customer communication.

ENPULSION NANO data availability

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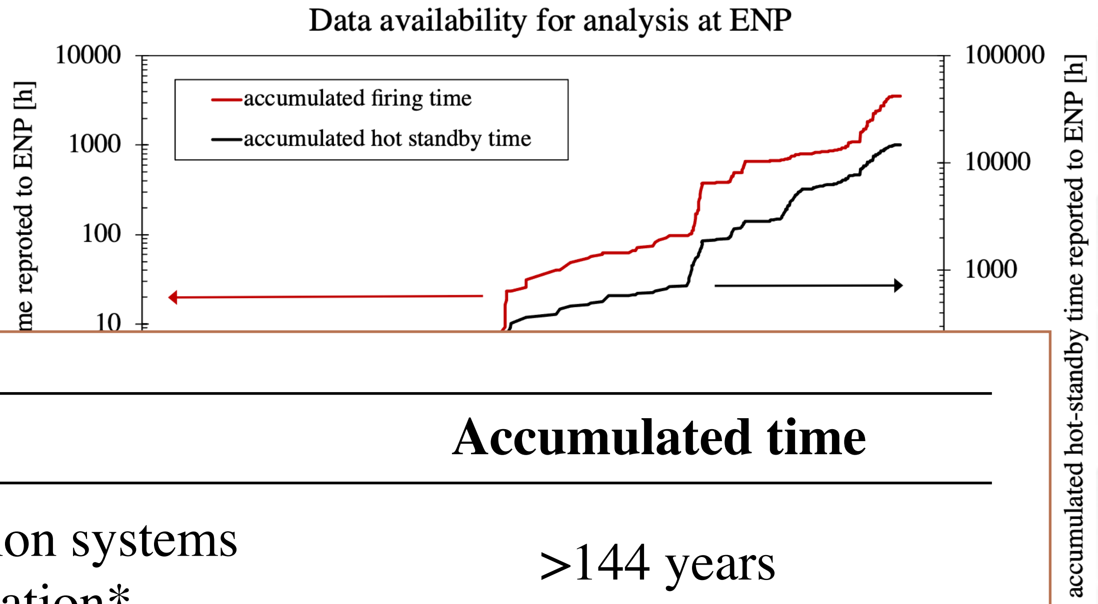

	Accumulated time
Accumulated orbit life for all operational propulsion systems where ENPULSION has visibility on thrust generation*	>144 years
Longest accumulated firing time on a single ENPULSION NANO (launched in June 2021)	> 650 hours

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* note that this includes time accumulated between the last telemetry was made available to ENP and the now, assuming that during normal operations, any anomaly would be reported to ENP

INFORMING THE DESIGN OF FUTURE SYSTEMS

NEXT GENERATION PROPULSION SYSTEMS

ENPULSION

- **CUSTOMER NEED** Strong interaction over all mission phases, including operational missions, defining the next generation propulsion requirements.

- **LESSONS LEARNT** in actual application environment, and actual operational application, are infused in the design.

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ENPULSION NEO

DURABLE AND POWERFUL

The Enpulsion NEO is the next step in FEEP technology evolution. By stepping up the number of ion emission sites by an order of magnitude compared to previous FEEP thrusters it allows high power and high thrust operation.

REDUNDANCY With approximately two thousand ion emission sites the thruster is inherently resilient to micro-damages. The electronics architecture is also designed around parallel high voltage supplies to increase system robustness.

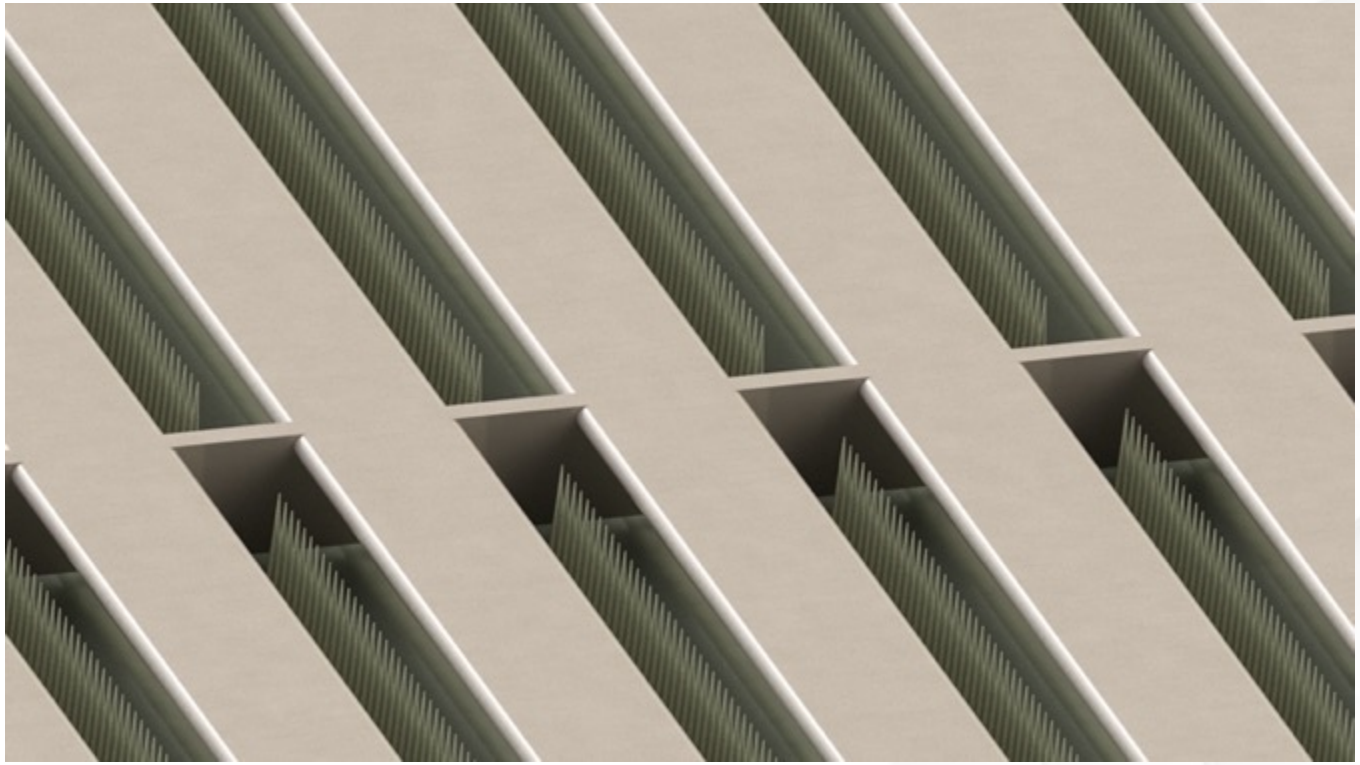
HIGH SPECIFIC IMPULSE FOR LOW SYSTEM MASS With its high specific impulse (>2500s) and propellant density 4 times higher than xenon the NEO thruster system is both more compact and lighter than traditional EP systems.

HIGH THRUST TO POWER RATIO By scaling up main beam power and optimizing the operation point the efficiency and power thrust ratio are greatly improved compared to ENPULSION's lower power propulsion systems.

NOMINAL THRUST[1]	20 mN
SPECIFIC IMPULSE[1]	~ 2,500s
PROPELLANT MASS[1]	23kg
TOTAL IMPULSE[1]	> 550 kNs
TOTAL SYSTEM POWER[1]	800 W
DIMENSIONS Thruster head including tanks	⌀ 340 x 150 mm
MASS (DRY / WET) Thruster head including tanks[1]	7 kg / 30 kg
HOT STANDBY POWER[1 2]	40 to 60 W

NEO design concept

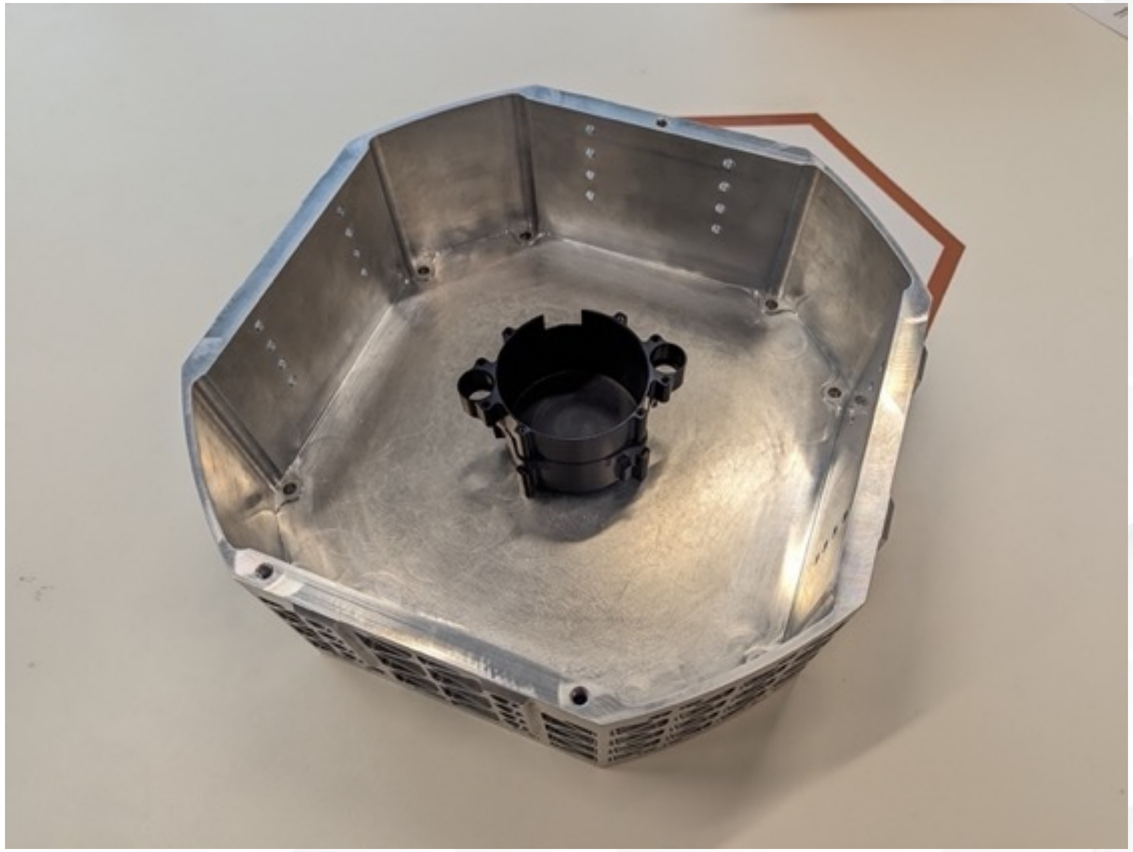
- Designed for ESPA and ESPA Grande Spacecraft
- Keep the advantages of FEEP for integration, operation and flexibility
- 400W to 1KW Power input
- Increase thrust to power ratio



NEO design

Development with FOTEC

- Line-emitters
- Impulse density

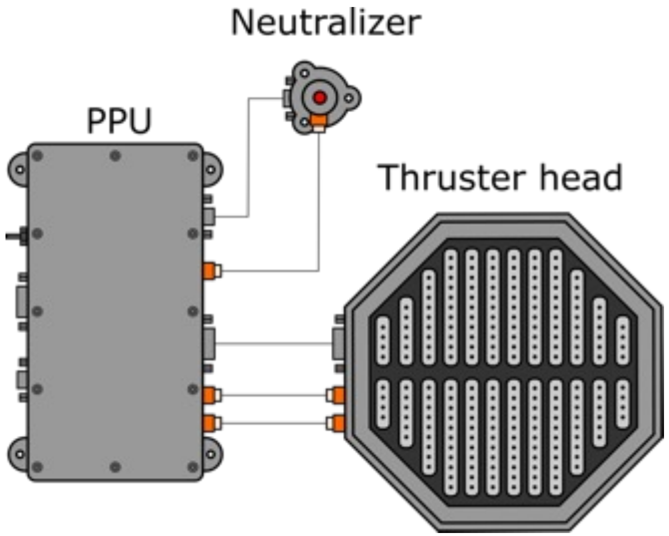


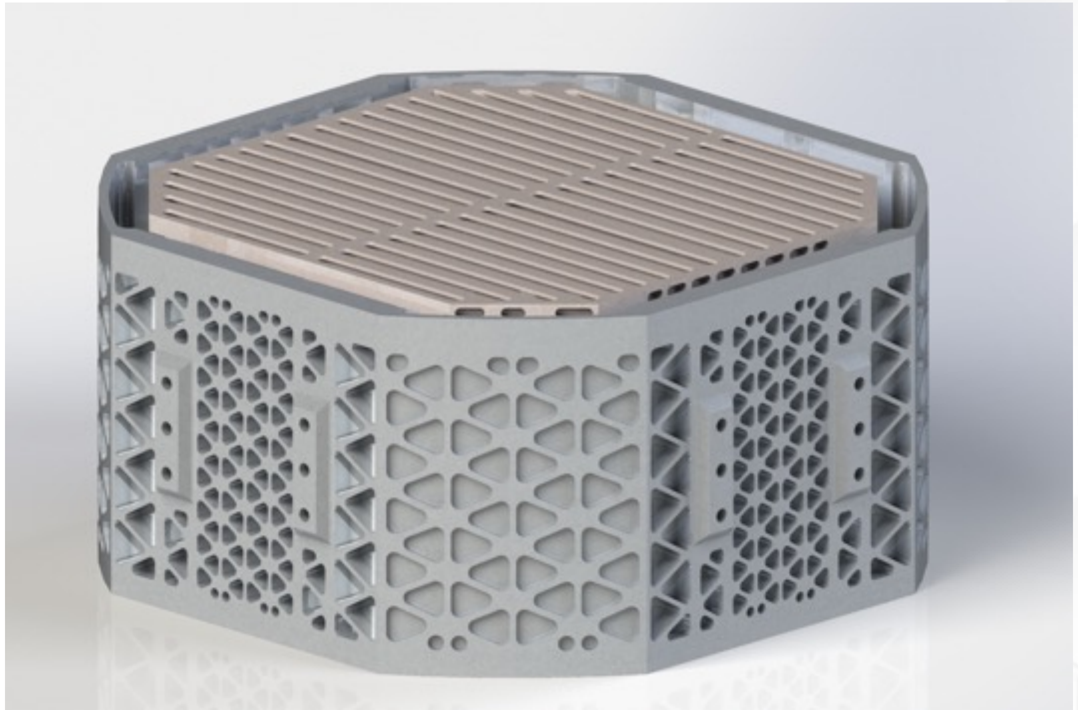
Comparison of thruster housing NEO to NANO

NEO design concept

Sub-elements

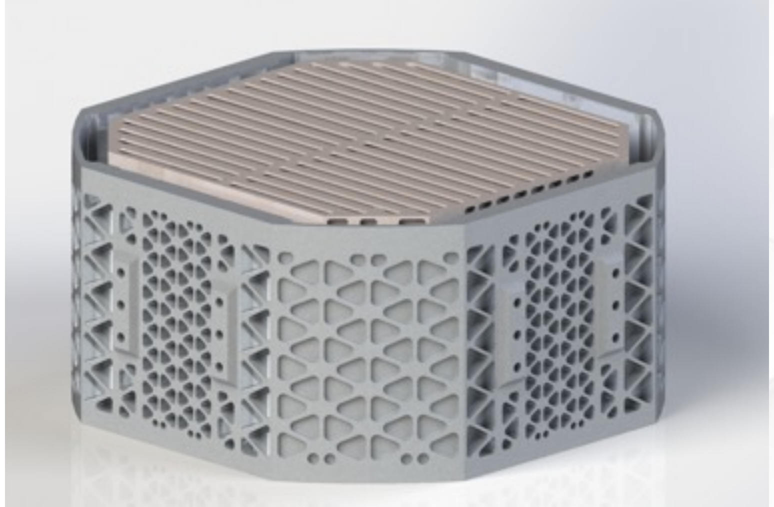
- Thruster head:
  - Panel mounted
  - Fits within a 15 inch separation ring
  - >20kg of propellant
  - ~6kg dry mass
  - No cooling required
  - ~2000 individual ion emission sites





Performance

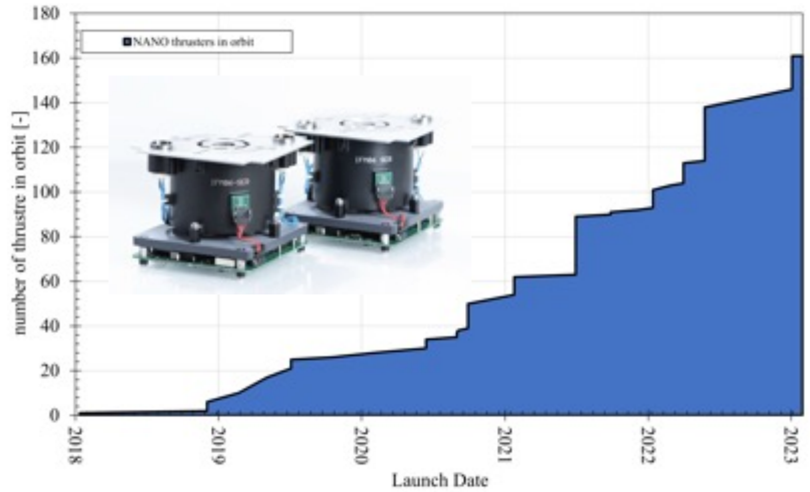
- Integration
  - Shipped full, no filling operation at customer facilities
  - Simple “bolt on” design, no fluid connections or leak test necessary
  - Pure electrical testing, no moving parts
  - No stored energy (chemical or high pressure)



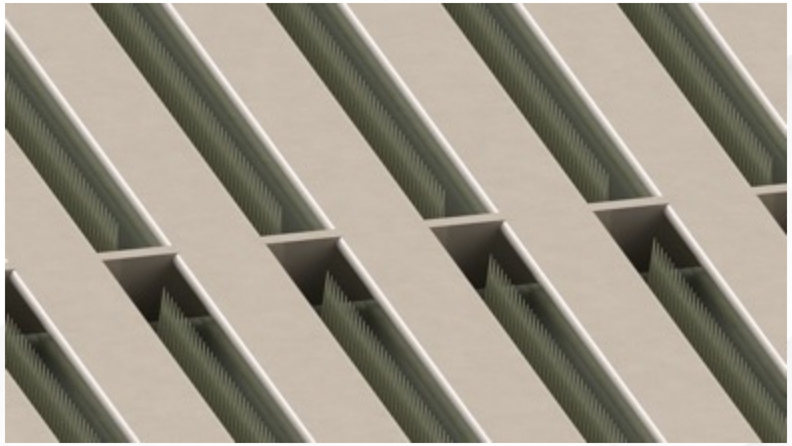
- Operations:
  - Hot standby startup under 1min
  - Operating point (thrust, input power) adjustable on the fly
  - Controlled directly in thrust with closed loop system.

Conclusion

- 167 propulsion systems in space
  - >144 years accumulated
  - 3 propulsion systems have flight heritage
  - Large variety of different applications, missions ranging from 3U Cubesat to >100kg s/c
  - Across mission improvement via unified user manual



- NEO:
  - Based on lessons learnt from heritage
  - 20mN thrust point, 800W nominal
  - Inert at launch



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DRIVING YOUR ADVANCE