IFM NANO THRUSTER: HIGH TOTAL IMPULSE PROPULSION FOR SMALL- AND NANOSATELLITES ENABLING INTERPLANETARY MISSIONS

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THE FEEP TECHNOLOGY

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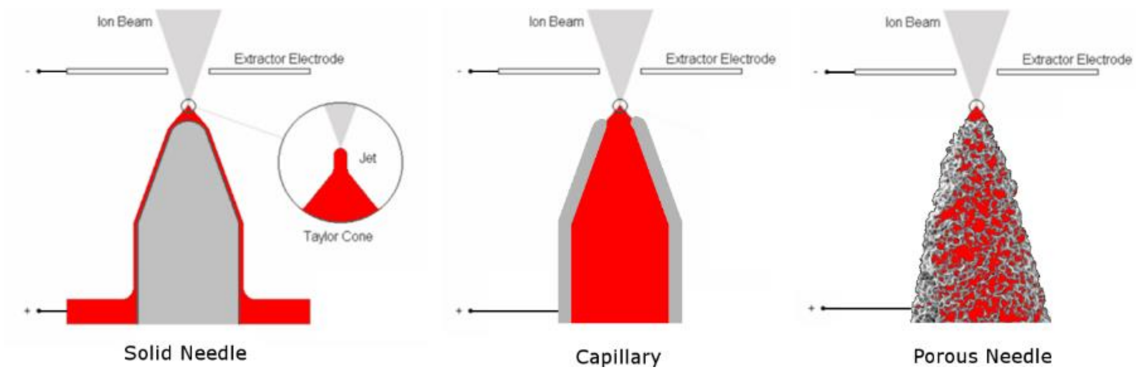
- Field emission electric propulsion
- Indium is molten in a reservoir
- Capillary forces transport In to a sharp tip
- High electric fields extract and accelerate ions
    - Taylor cone formation



- 28 emitters in parallel to increase emission current and thrust

THE FEEP TECHNOLOGY – HOW IT WORKS

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- Liquid metal ion sources
- >25 years of heritage at Fotec, AIT/ARC Seibersdorf

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

THE FEEP TECHNOLOGY – A HISTORY

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AUSTRIAN INSTITUTE OF TECHNOLOGY

FOTEC
Research Subsidiary of
— FH Wiener Neustadt —

1985 — 2011 — 2016

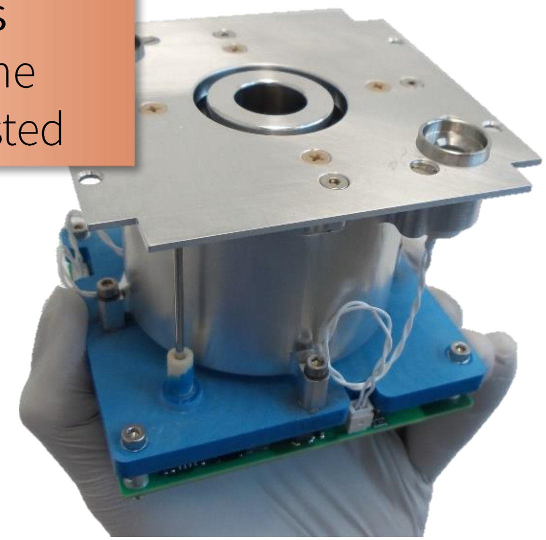
1991
Austro
MIR

2000-
2016
ROSETTA
ESA

2015-
2017
MMS
NASA

2020
NGGM
ESA

Developed for ESA Science Missions
- >17.000 h Lifetime
- >100 Emitter Tested



THE FEEP TECHNOLOGY – A HISTORY

ENPULSION

FOTEC
Research Subsidiary of
– FH Wiener Neustadt –

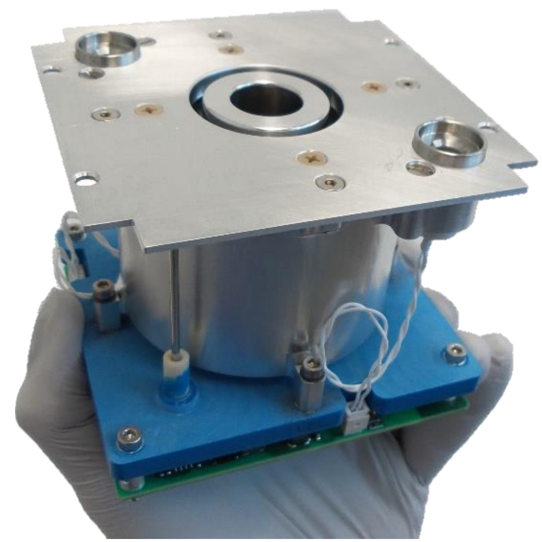
Research & Development → Commercialization

1991
Austro
MIR

2000-
2016
ROSETTA
ESA

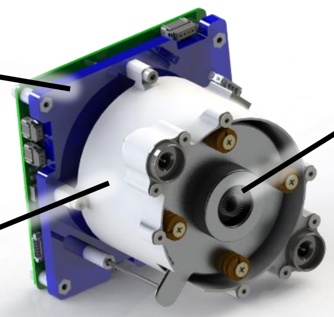
2015-
2017
MMS
NASA

2020
NGGM
ESA



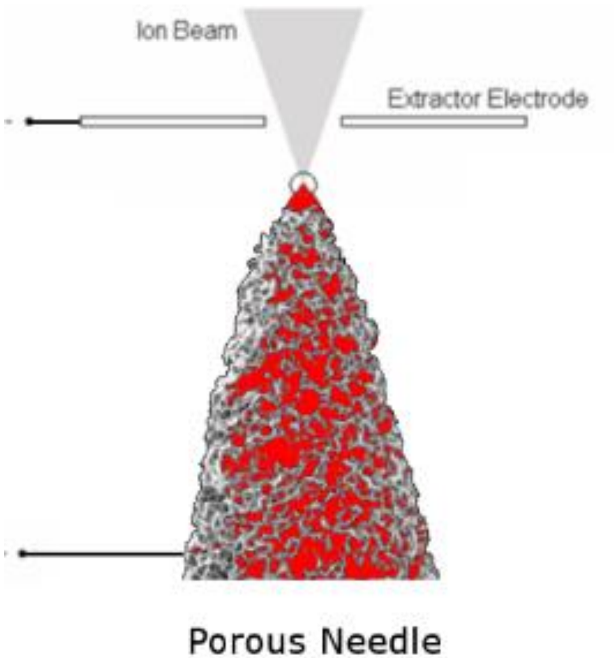
THE IFM NANO THRUSTER

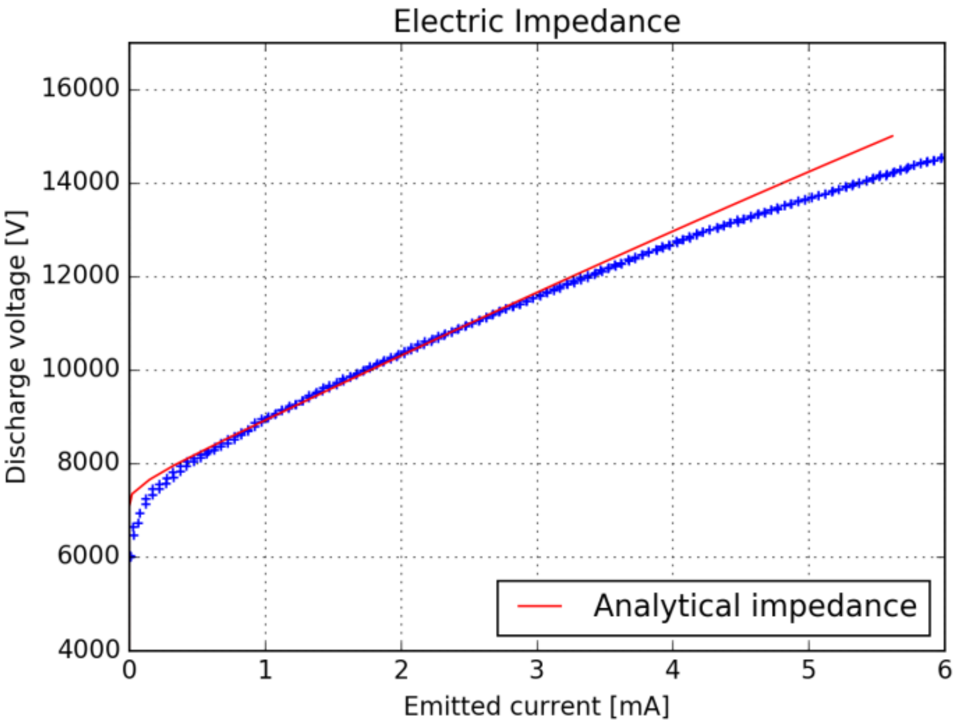
ENPULSION



- No active propellant management
- Inert at launch
- Highest ISP
- Solid propellant

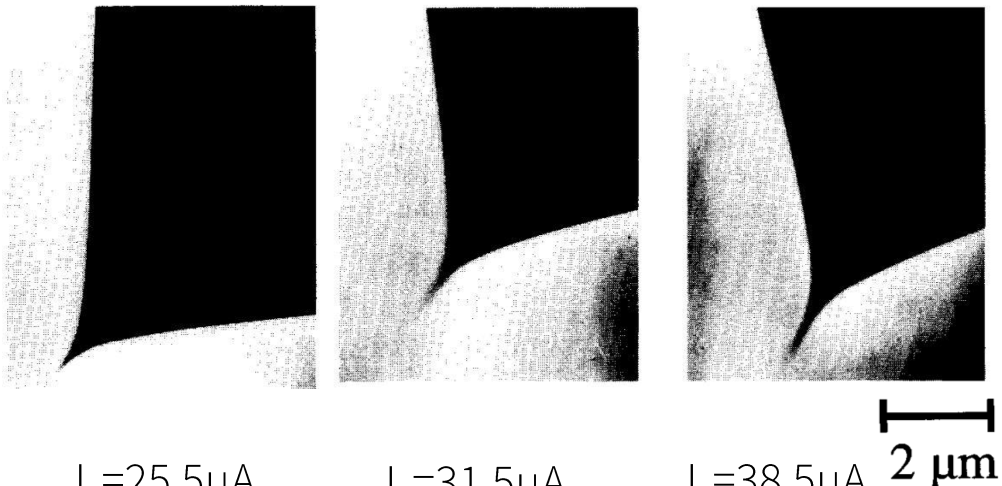
- FEEP technology is a well understood physical process
  - Architecture with multiple emitters enables wide throttle range





IFM NANO PERFORMANCE

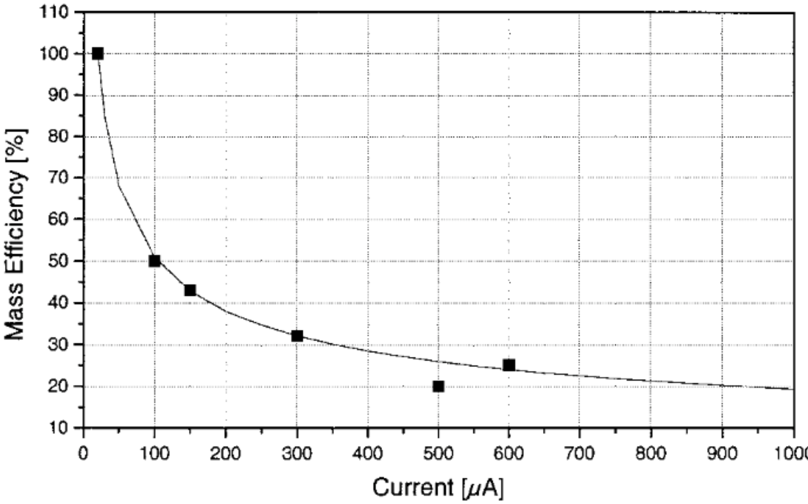
- IFM Nano: Operation below 100% mass efficiency



I_e=25.5µA I_e=31.5µA I_e=38.5µA

HV-TEM in-situ

From: Praprotnik, Driesel, Dietzsch, Niedrig: HV-TEM in-situ investigations of the tip shape of indium liquid metal ion emitter, Surface Science 314, 1994, pp. 353-364



Single needle mass efficiency

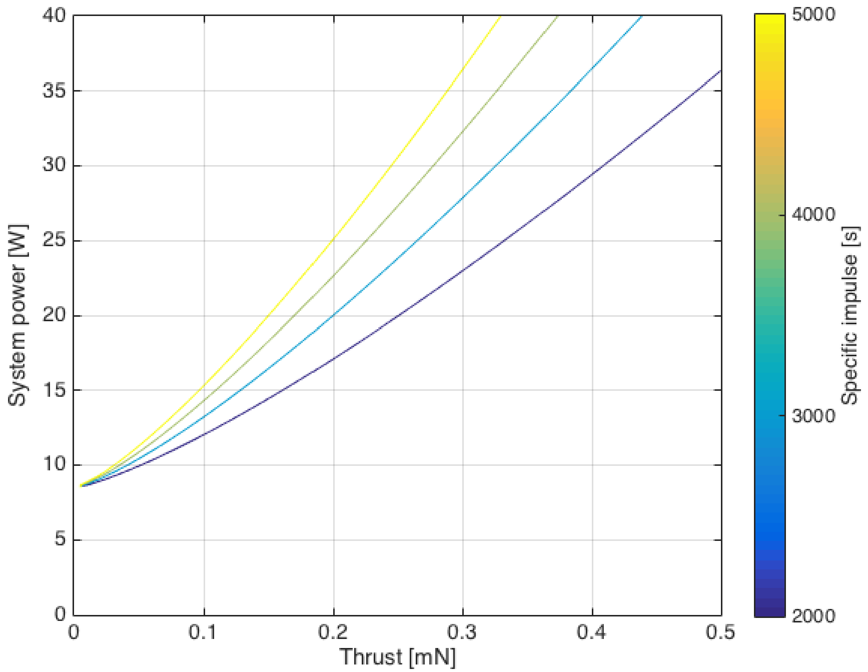
From: Tajmar, Genovese, Steiger: Indium Field Emission Electric Propulsion Microthruster Experimental Characterization, Journal of Propulsion and Power, Vol. 20, No. 2, 2004, pp. 211-218.

IFM NANO PERFORMANCE MODEL

- Operational envelope
  - Mass efficiency of η=.35
  - 250mg tank

$$F = \dot{m}_{ion} v_{ion} = \frac{\dot{m}_{ion}}{\dot{Q}} I\, v_{ion} = I\sqrt{\frac{2V_e m}{q_e}} f$$

$$I_{SP} = \frac{F}{g_0 \dot{m}_t} = \frac{\sqrt{\frac{2V_e q_e}{m}}\eta f}{g_0}$$



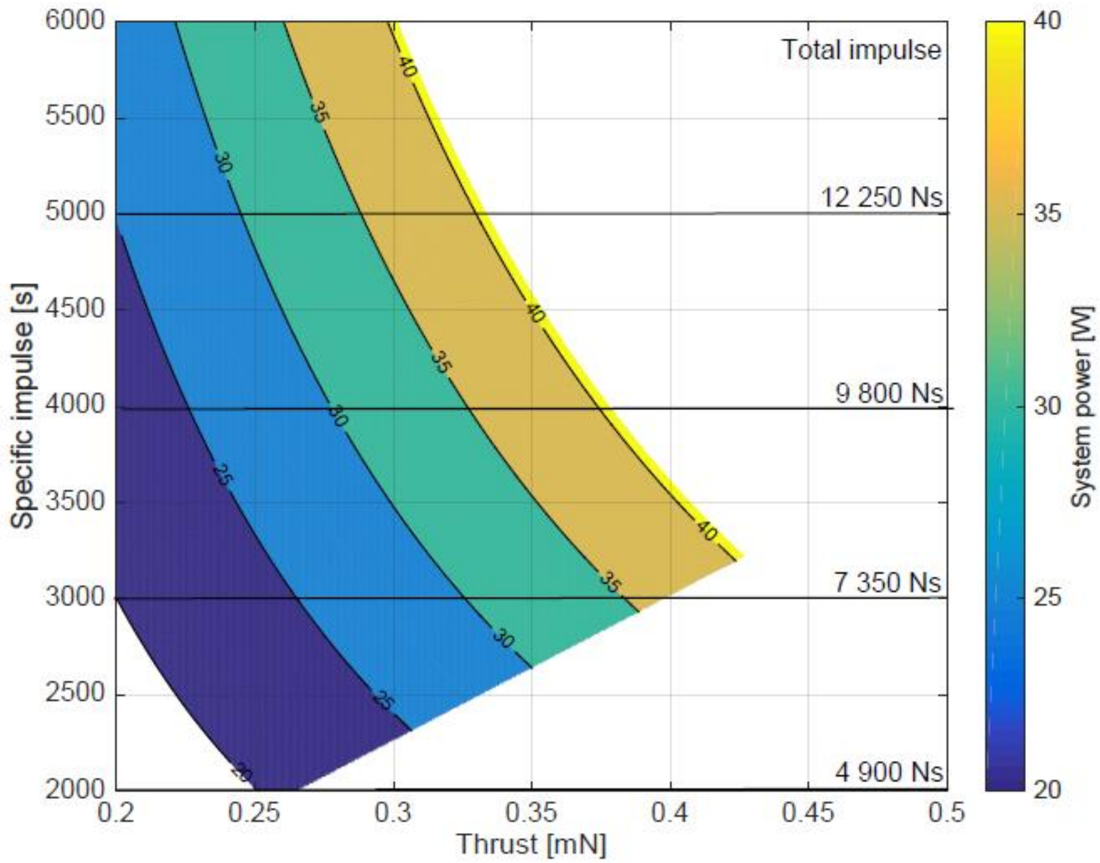
V_e ...emitter potential

$\dot{m}_t$ ...total mass flow rate

f ...beam spreading

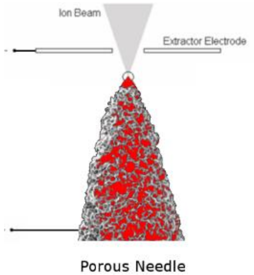
IFM NANO PERFORMANCE MODEL

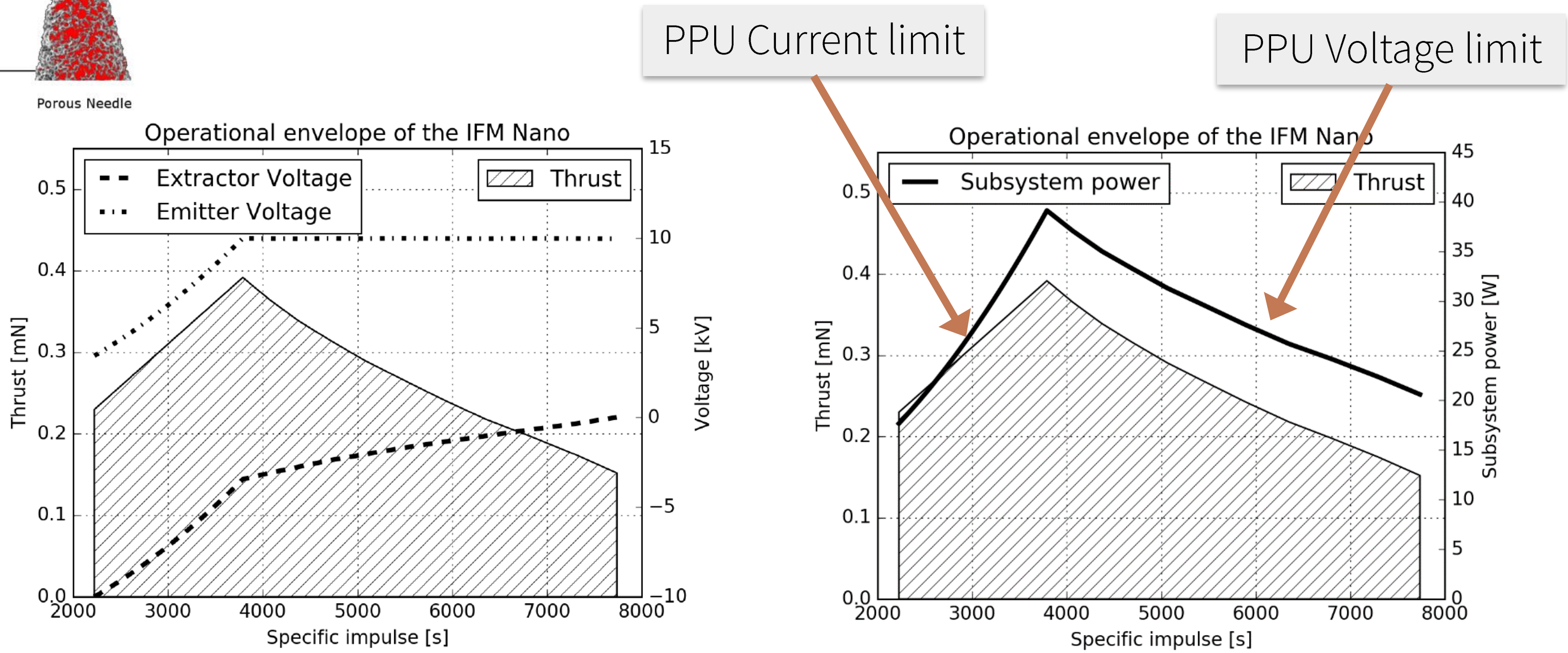
- Operational envelope
- System power includes all HV conversion efficiencies and neutralizers



ENPULSION

IFM NANO PERFORMANCE OPERATION





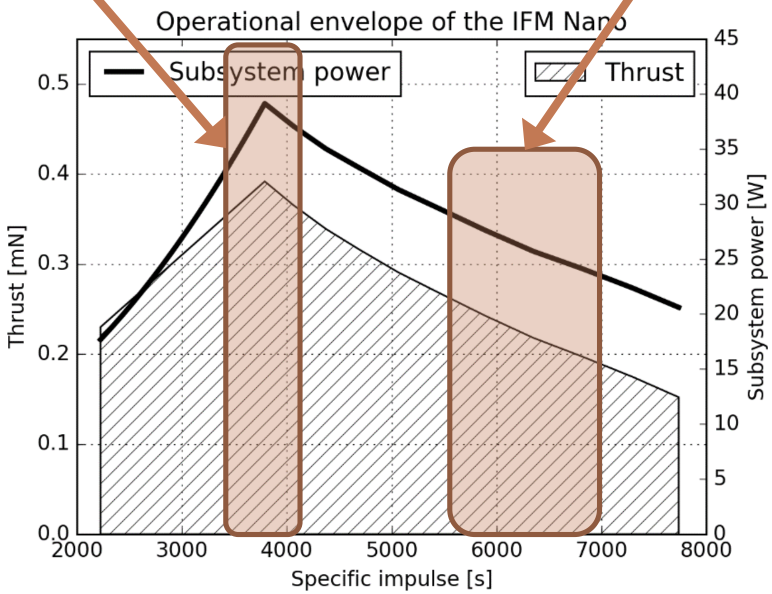
From: David Jelem: Development of a performance model for a Field Emission Electric Propulsion system, Master thesis, University of Applied Sciences Wiener Neustadt, Austria , 2016.

IFM NANO PERFORMANCE OPERATION

Choose performance parameters within operational envelope

Sample mission scenario:

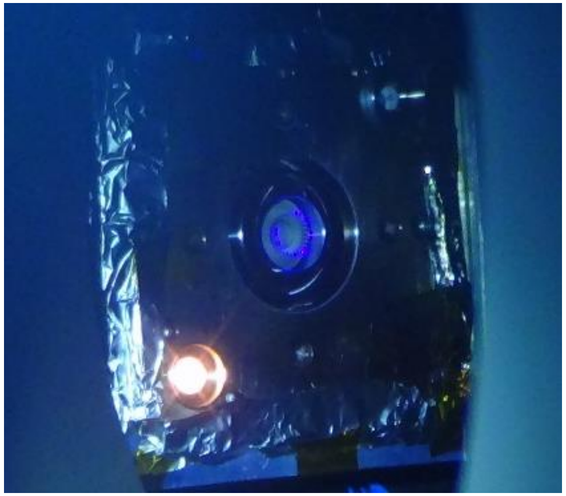
High thrust (orbit positioning) followed by High Isp (drag makeup)

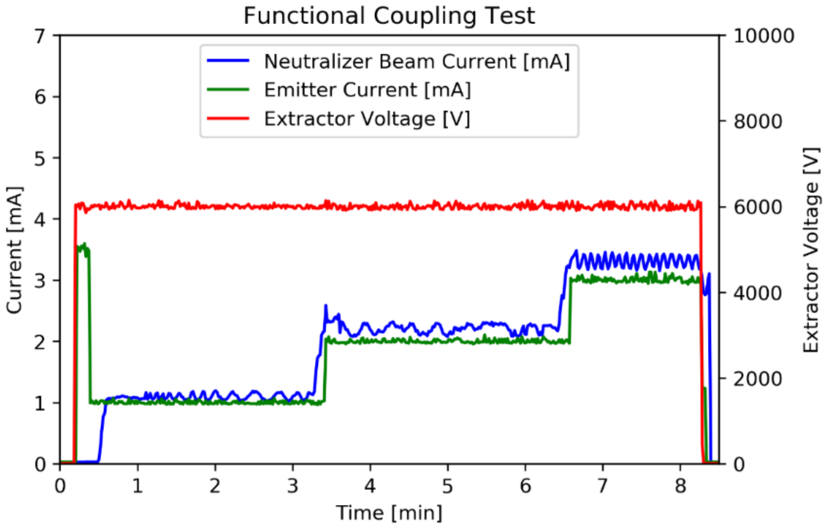


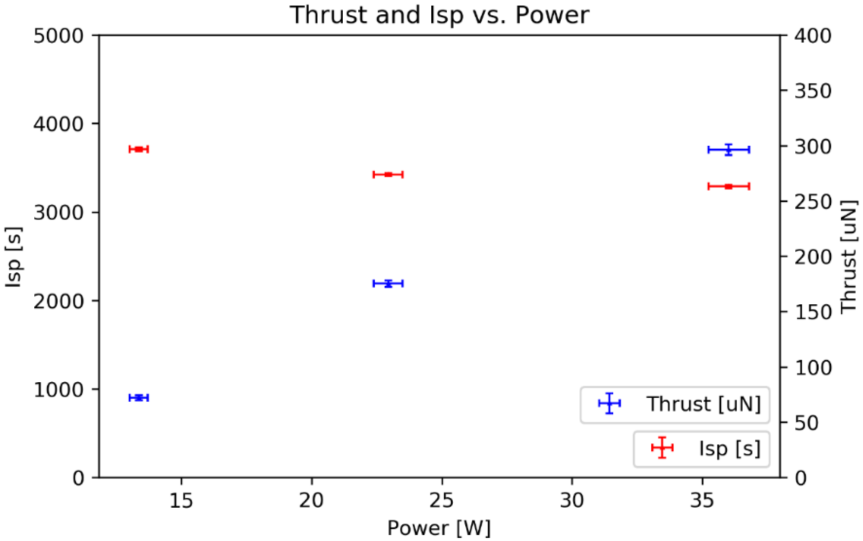
IFM NANO PERFORMANCE TESTING

- IFM Nano Thruster IOD acceptance test data
- Fully integrated system incl. neutralizers

- Fixed I_{sp} mode:

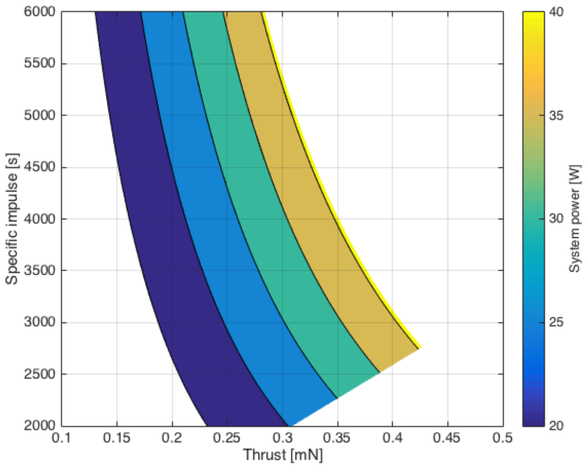




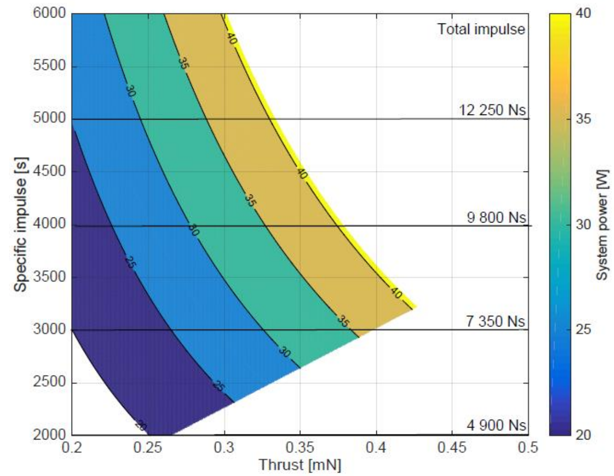


IFM NANO PERFORMANCE MODEL

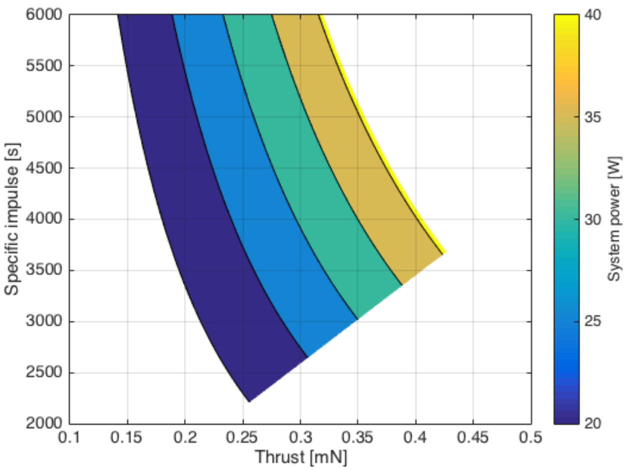
– Dependency on mass efficiency



η=0.3 @ 4mA



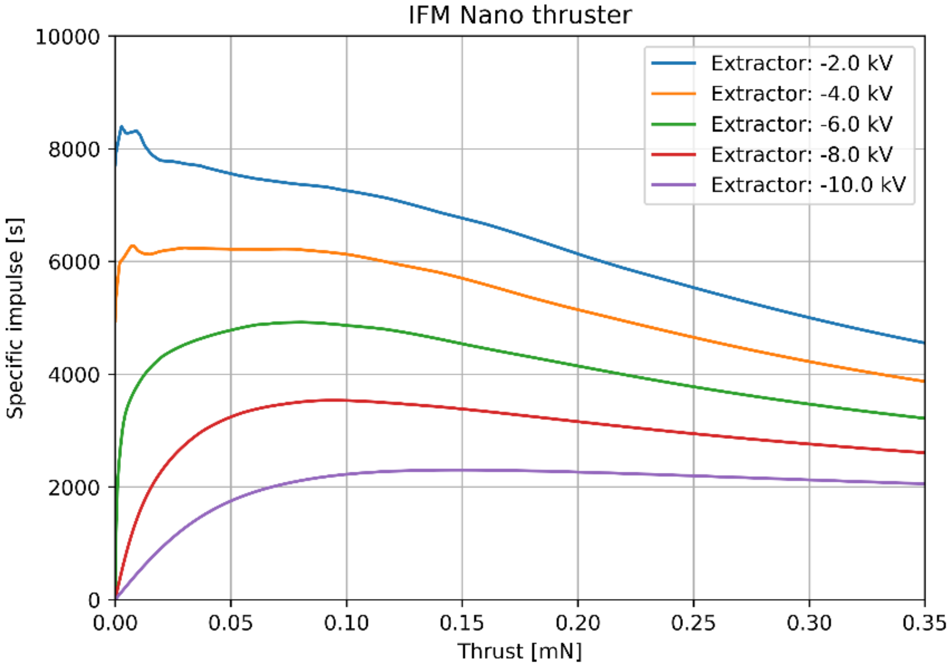
η=0.35 @ 4mA



η=0.4 @ 4mA

IFM NANO PERFORMANCE MODEL

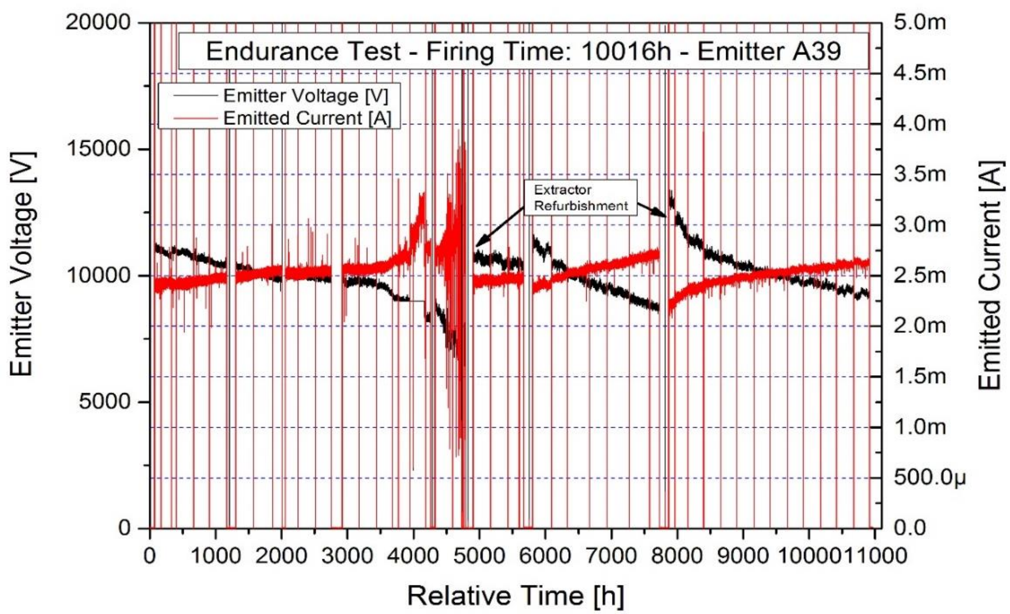
- Trade-off specific impulse vs thrust and system power



IFM EMITTER LIFETIME TESTING

Ongoing test, currently >17,500h, no emission degradation observed

- Identical emitter as in IFM Nano Thruster
- Tested in a previous version packaging (no PPU, neutralizer)



First 10 000h of FOTEC lifetime test conducted within ESA funded project

QUALIFICATION MATRIX

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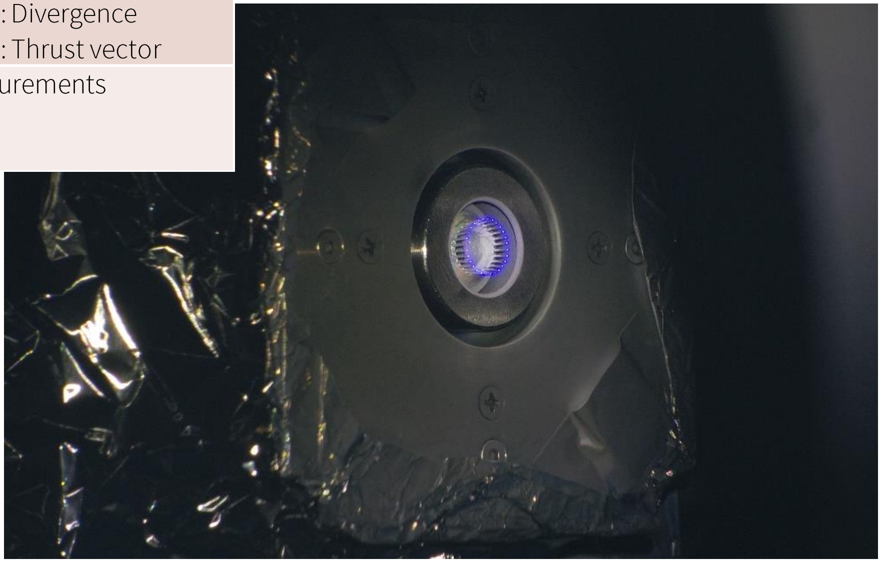
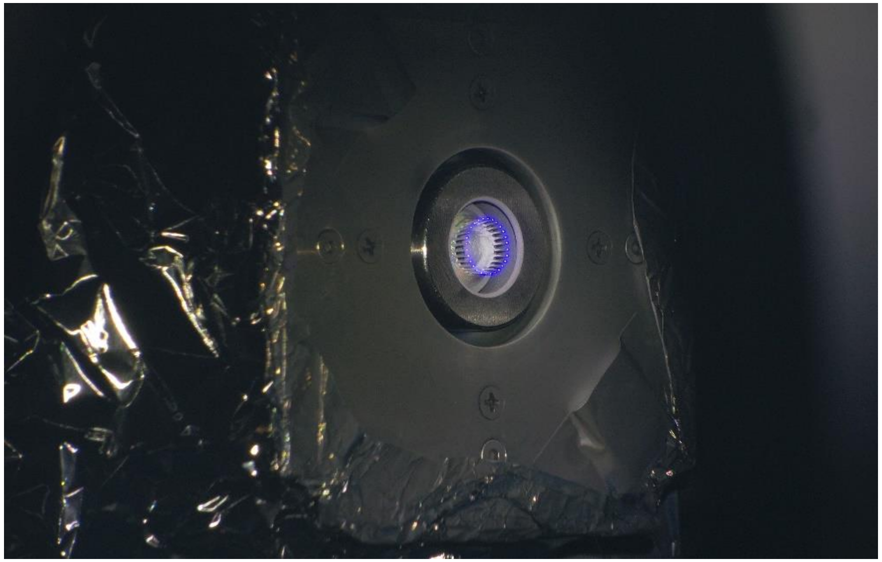
– Qualification of the IFM Nano Thruster will be completed within 2018

	Successfully Passed	Planned within (already performed with BBs)
Mechanical load tests	Sinusoidal vibration Random vibration Shock	
Thermal vacuum tests	High load/hot test Cold start test Non operational envelope Thermal cycling	Thermal endurance
Emitter tests	On/Off cycles	Plume Diagnostics: Divergence Plume Diagnostics: Thrust vector
Functional (coupling) test	Emitter firing test Neutralizer firing test Floating test	Direct thrust measurements



- In-orbit Demonstration on a 3U Cubesat launched in Jan 2018 ongoing



ENPULSION

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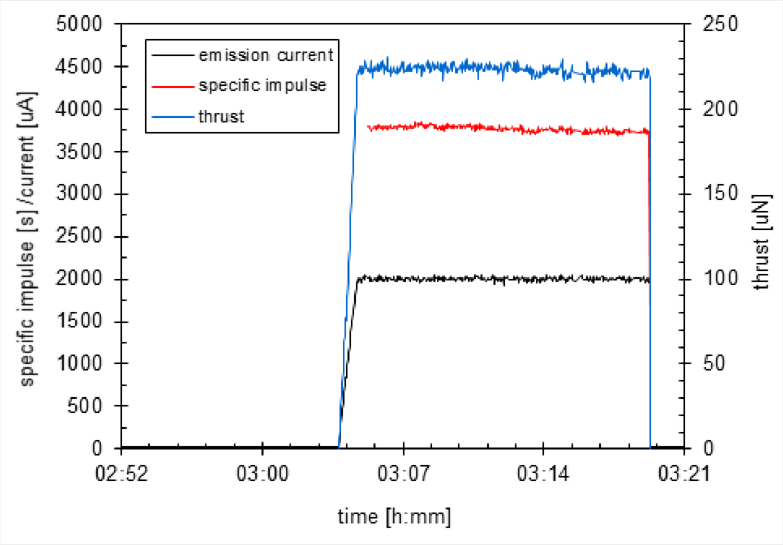

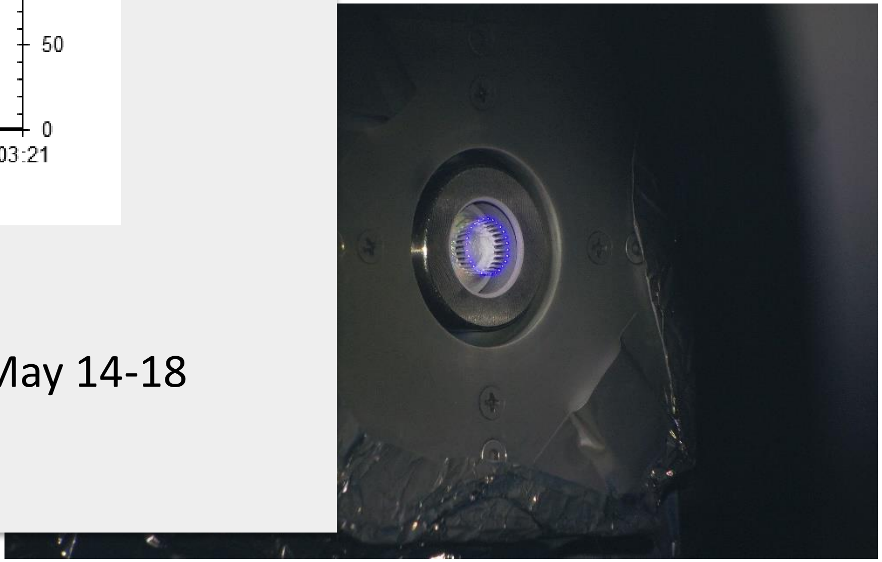

→ First results will be disseminated at

Space Propulsion Conference, Seville, May 14-18

4S Symposium, Sorrento, May 28-Jun 1

IFM NANO THRUSTER CAPABILITY

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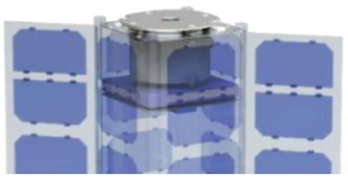
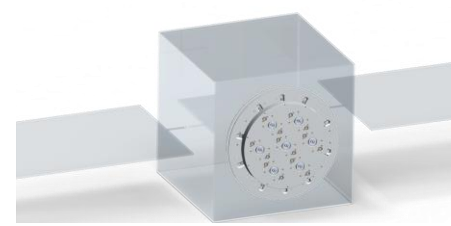
– Estimates for low specific impulse operation (high thrust)





Number of Modules	1	2	3	4	5	6	7
Total Impulse	> 5000 Ns	> 10000 Ns	> 15000 Ns	> 20000 Ns	> 25000 Ns	> 30000 Ns	> 35000 Ns
System Mass (wet)	1 kg	2* kg	3* kg	4* kg	5* kg	6* kg	7* kg
System Volume	0.6 dm³	1.2 dm³	1.8 dm³	2.4 dm³	3 dm³	3.6 dm³	4.2 dm³

* Additional mass for brackets or housings might be necessary depending on the accomodation of the thruster modules on the spacecraft.

Δv [m/s]

Spacecraft Mass [kg]	1	2	3	4	5	6	7
2	2879						
3	**2141**	3480					
5	1415	2456	3254	3886			
10	766	1415	1972	2456	2879	3254	3587
15	525	993	1415	1795	2141	2456	2744
20	399	766	1103	1415	1703	1972	2222
30	270	525	766	993	1209	1415	1610
40	204	399	586	766	938	1103	1262
50	164	322	475	623	766	904	**1038**
70	118	232	344	453	560	664	766
100	83	164	244	322	399	475	549
150	55	110	164	217	270	322	374
200	42	83	123	164	204	244	283