SITAEL

LOW POWER ELECTRIC PROPULSION AT SITAEL

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International Workshop on Ion Propulsion and Accelerator Industrial Applications

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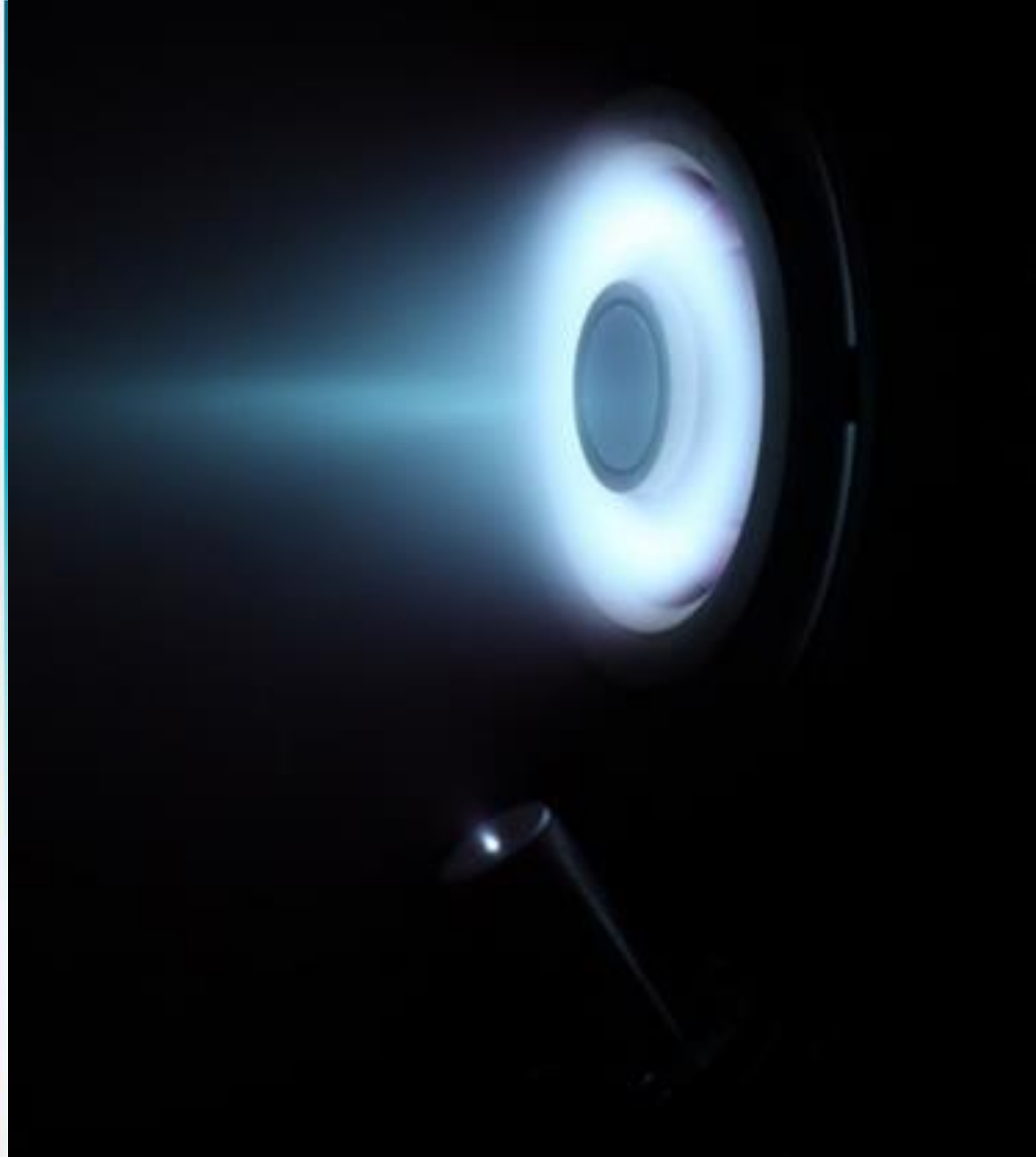
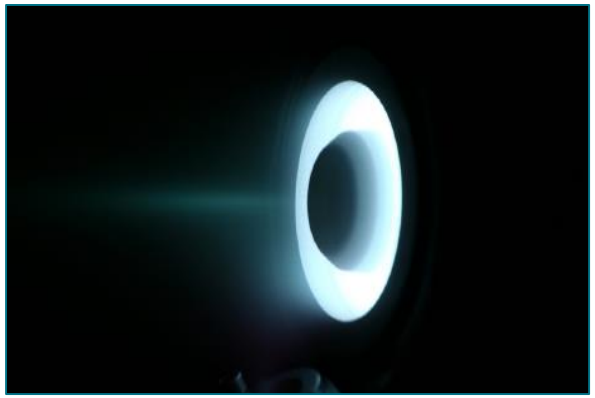


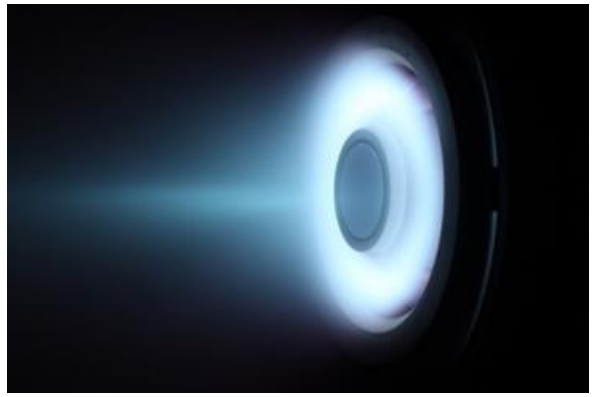
Outline

- Low Power Hall Thruster development at SITAEL
- Why Low Power EP? (potential applications)
- Main ongoing programmes at SITAEL and next steps

SITAEL Low Power Thrusters



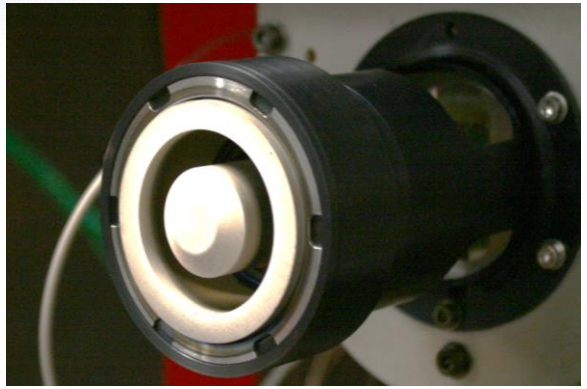
HT100	
Nominal Power	175 W
Thrust Range	5 - 15 mN
Max. I_{sp}	1350 s
TRL	6
Extensively tested in the past two years, HT100 is Sitael's baseline and most advanced electric thruster	



MSHT100	
Nominal Power	175 W
Thrust Range	5 - 14 mN
Max. I_{sp}	1250 s
TRL	3/4
First prototype tested in Autumn 2016	

HT400	
Nominal Power	400 W
Thrust Range	20 - 50 mN
Max. I_{sp}	1800 s
TRL	5
Estimated lifetime 5000 hrs Power can go up to 800W with no thermal problems; intended for satellites up to 500kg	

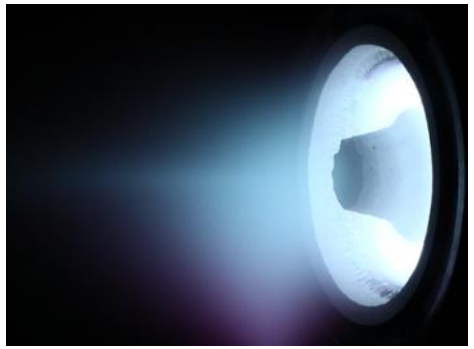
HT100: Development Status



HT100 is the lowest power Hall Effect Thruster ever developed in Europe, with a nominal operating power of 175 W and a minimum operating power of 100W.

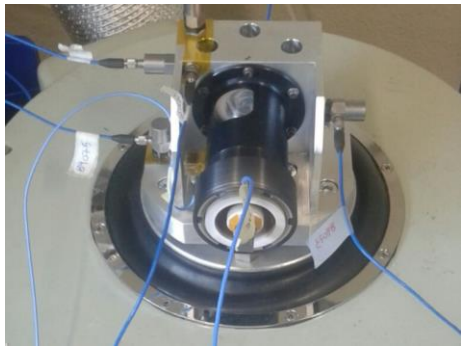
With a design based on **permanent magnets** and a total mass lower than 470 g, HT100 is also the most lightweight Hall thruster of this class.

HT100	
Nominal Power	175 W
Thrust range	5 -15 mN
Specific Impulse	up to 1350 s
Total Efficiency	up to 35%
Operating Voltages	250 - 350 V
Demonstrated lifetime	2250 hrs
Thruster mass	<500 g



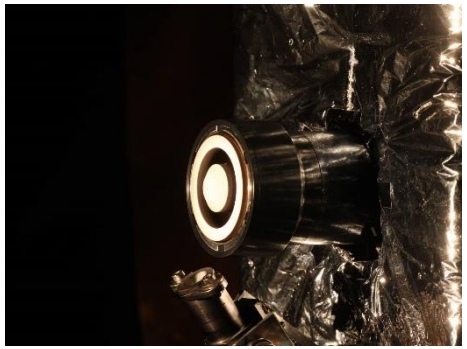
Extended Endurance Test

2250 hrs of operation.
Total impulse > 75 kNs



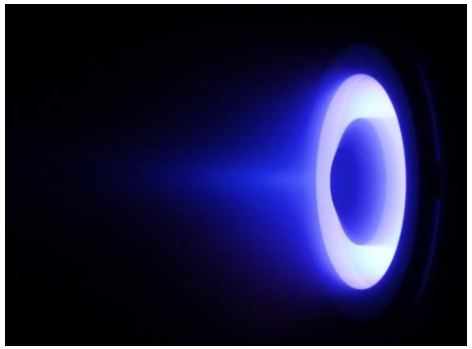
Full Structural Tests (Shock & Vibration)

Successfully withstands typical launch loads



Thermal Vacuum Test

8 thermal cycles
[-25° C and 110° C]
Hot & Cold starts
[-25° C and 250° C]

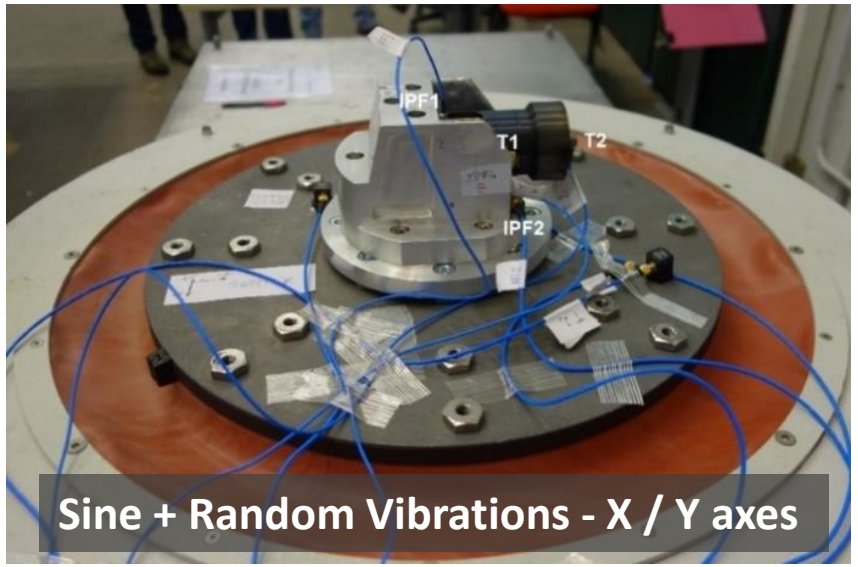


Test with Krypton as propellant

Efficiency up to 33%.
Anode specific impulse exceeding 1800s

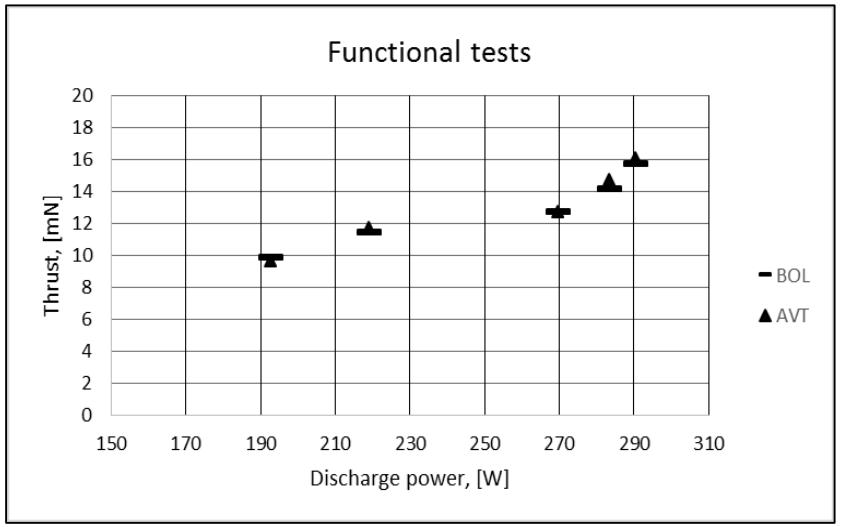
HT100: Structural Analysis and S&V Test

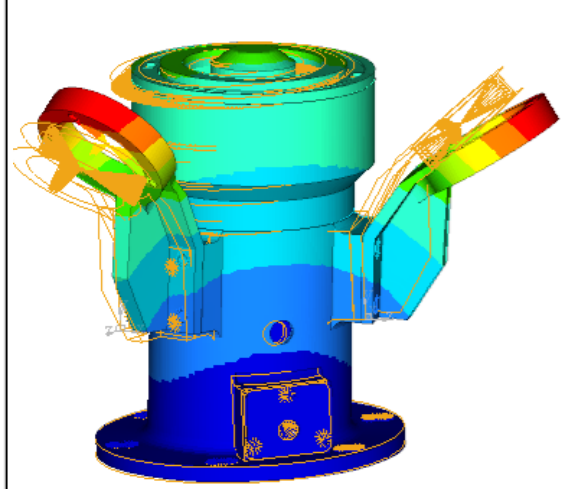
Sine + Random Vibrations - Z axis



Sine + Random Vibrations - X / Y axes


2000 g Shock Test - Z axis





Design of the anode-cathode bracket

Anode support structure modifications to:

- ✓ Optimize the resonant frequency (> 450Hz)
- ✓ Withstand high shock loads at the thruster interface

Thruster body weight: 440 g → **490 g**
Total weight (incl. cathodes): **680 g**

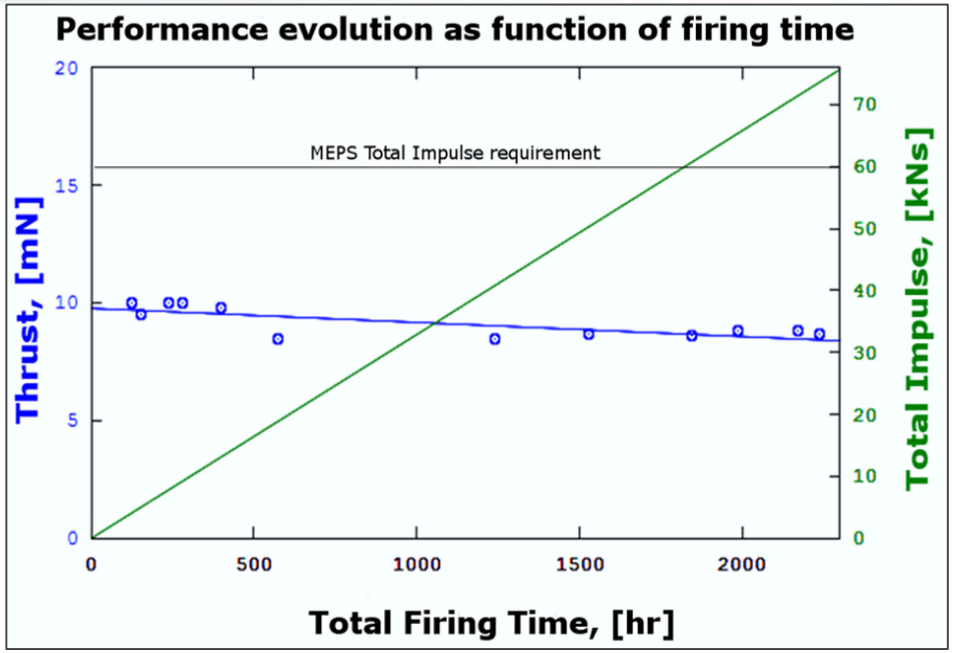
HT100: Endurance Test Results

Thruster was operated at a fixed operating power level of 210W, resulting in a slightly accelerated lifetest

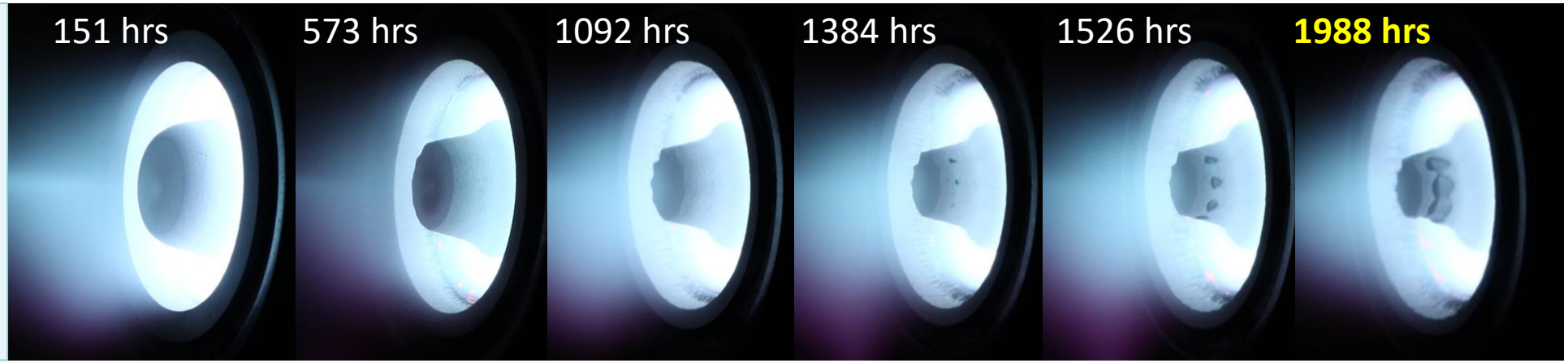
The HT100 at BOL provided a thrust of 10mN; at the end of the test, after a total firing time of 2240h, the value was 15% lower.

The **total impulse** cumulated at the end of the test was approximately **75 kNs**

The beam remained focused and no major variations of its orientation were detected



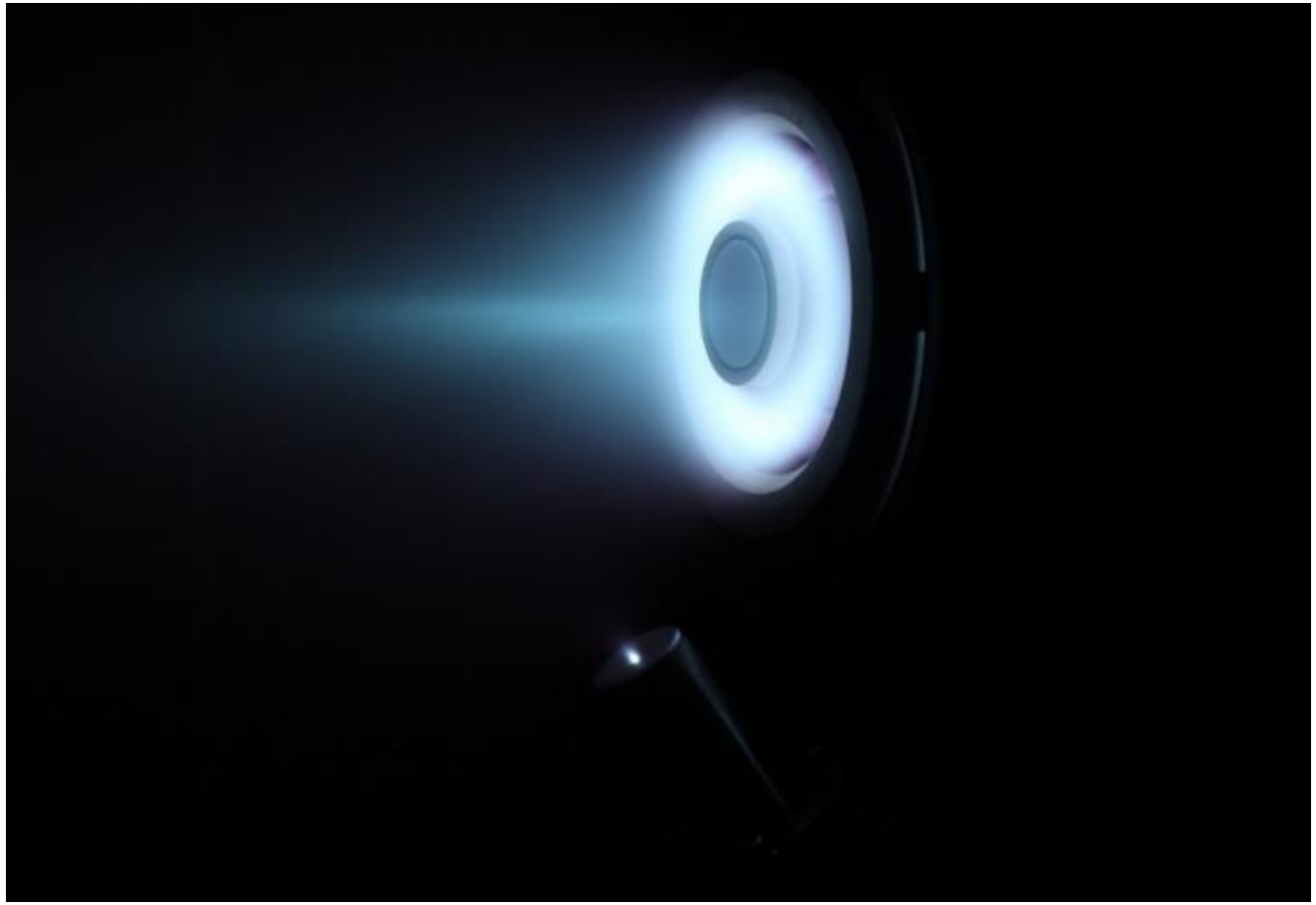
- ✓ Ceramic cap detached after 2000 hours of operation
- ✓ HT100 continued to operate with unaltered performance (test was stopped @ **2250 hrs**)



MSHT100, Improving Lifetime Through Magnetic Shielding

The new version of HT100, named **MSHT100** (Magnetically Shielded HT100), is again based on permanent magnet but with a new magnetic field topology that limits the walls erosion and **increments the thruster lifetime**.

MSHT100 Specifications	
Propellant	99.996% Xenon or Krypton
Power	100-350 W
Thrust	5-14 mN
Isp	900-1450 s
Efficiency	Up to 35%
Operating voltage	150 – 400 V
Thruster mass	~640 g (without cathode)
Thruster envelope	Ø 75 x 101 mm (I/F included, cathode excluded)
Lifetime	> 7000 hours [estimated]
ON/OFF cycles	> 10000 [estimated]

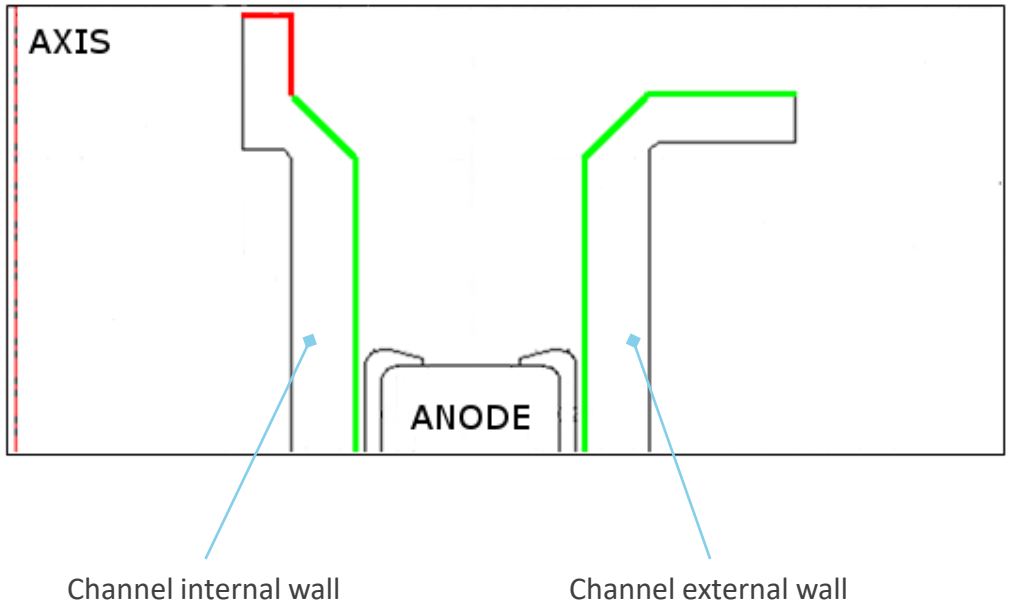


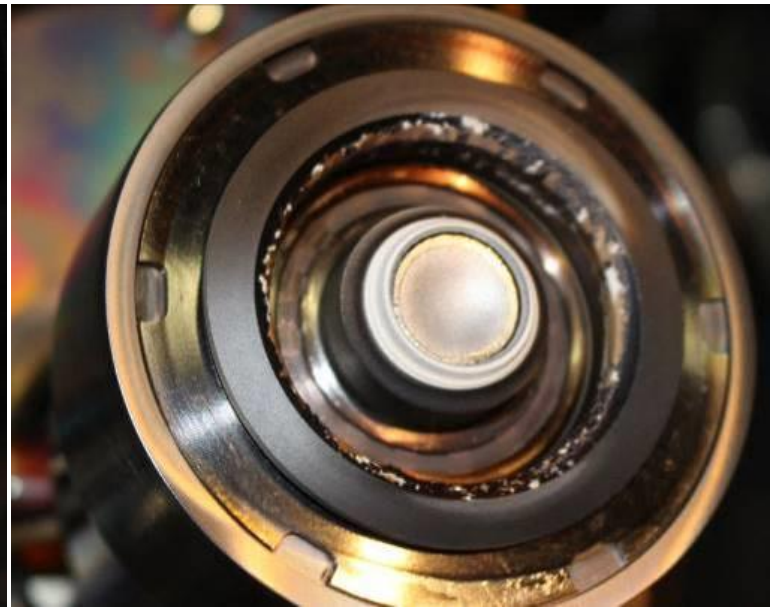
MSH100 Prototype: Erosion after 360 hrs of Operation

First prototype has been **operated continuously for 360 hours**, showing no erosion on the protected walls

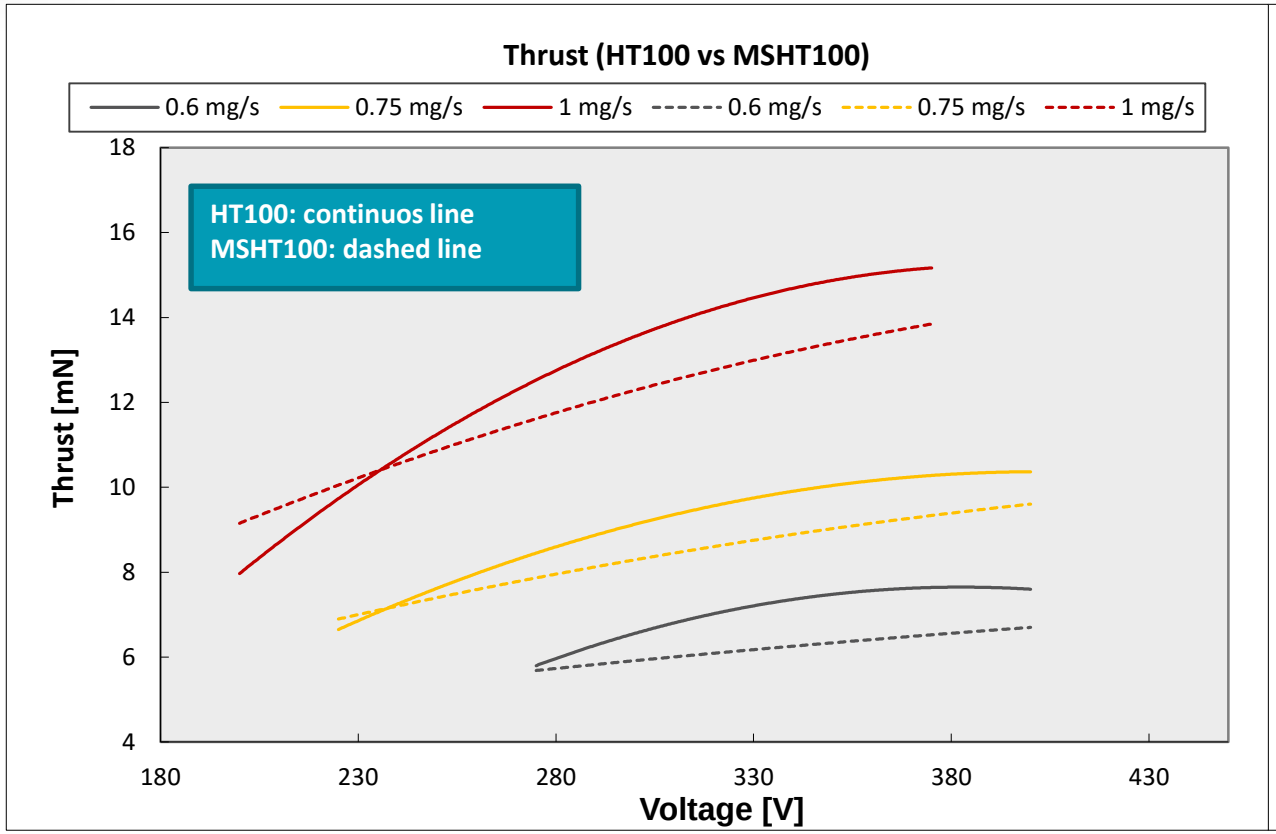
New magnetic field topology is completely shielding the outer wall and partially shielding the inner wall (see bottom-left picture: green lines indicate shielded areas, red lines indicate unshielded ones)

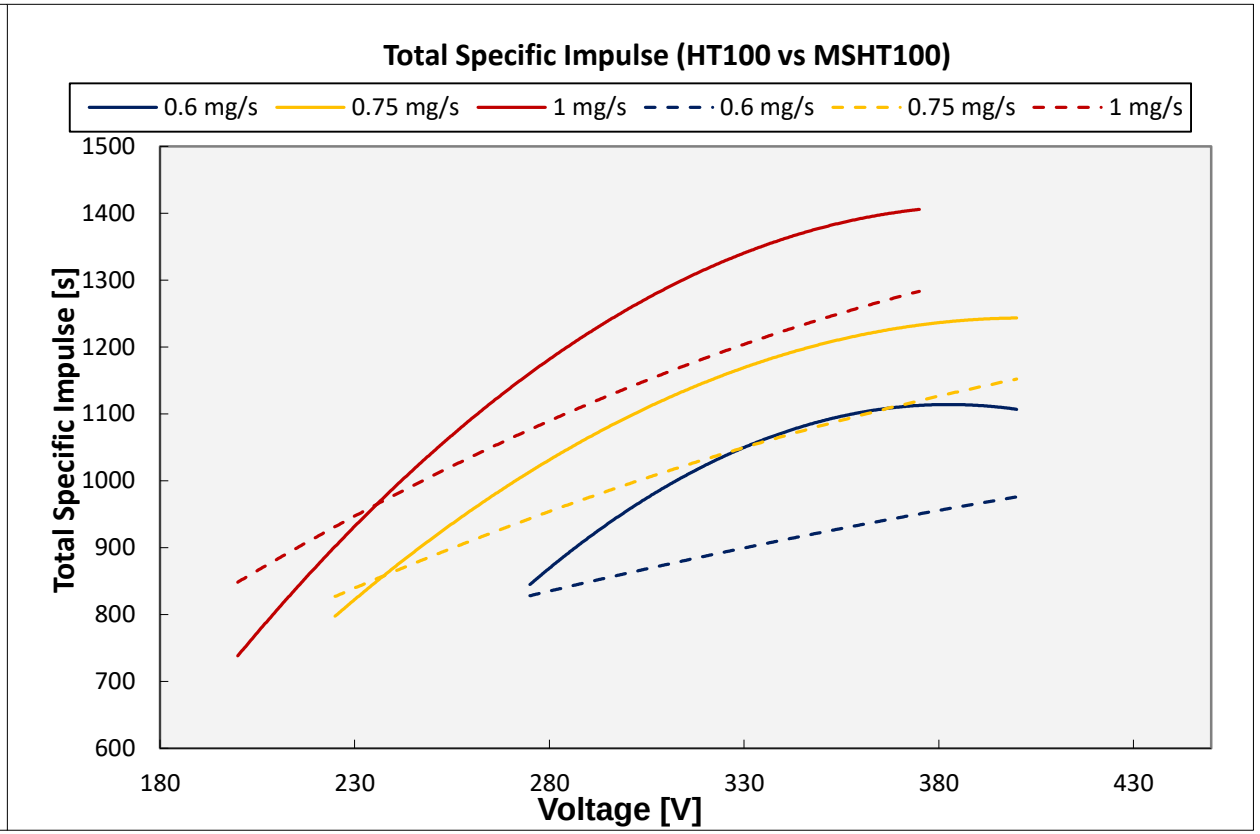
Suppression of channel erosion stabilizes the thruster performance (e.g. thrust, beam divergence) along its lifetime





Performance: HT100 vs MSHT100

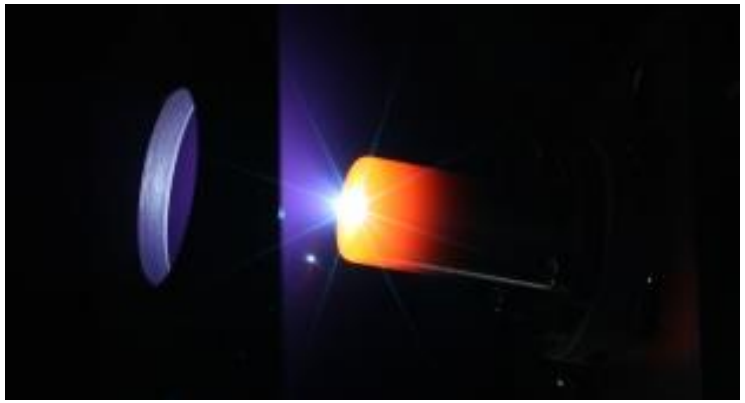




- ✓ Thrust reduction should be more than compensated by the extended lifetime (difficult to be estimated as theoretical models developed for HT100 do not apply to MSHT100, but expected to be at least 2-3 times longer than HT100's)
- ✓ Performance gap is negligible at lower power levels (<150W)

HC1, 1A Hollow Cathode

HC1 is a hollow cathode for the **100 W-class Hall thrusters** that has been developed to provide **0.3-1 A discharge current**. The cathode operates at mass flow rates in the range 0.08-0.5 mg/s Xe, with an expected lifetime in excess of 4000 hours. The HC1 cathode has been coupled with both **HT100** and **MSHT100** thrusters, using Xe and Kr as propellants.

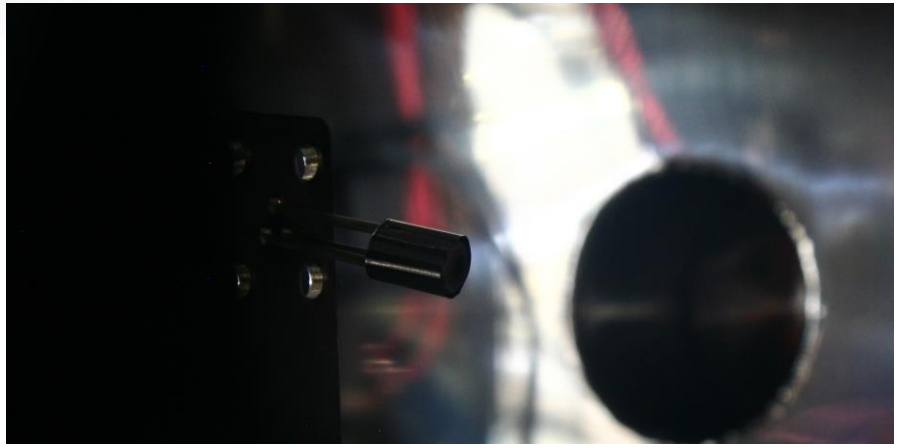


Discharge current	0.3 – 1 A
Mass flow rate	0.08 – 0.5 mg/s
Heater power	< 25 W
Cathode mass (w/o harnesses)	30 g
Cathode dimensions	ϕ 35 x 50 mm
Expected lifetime	> 4000 h

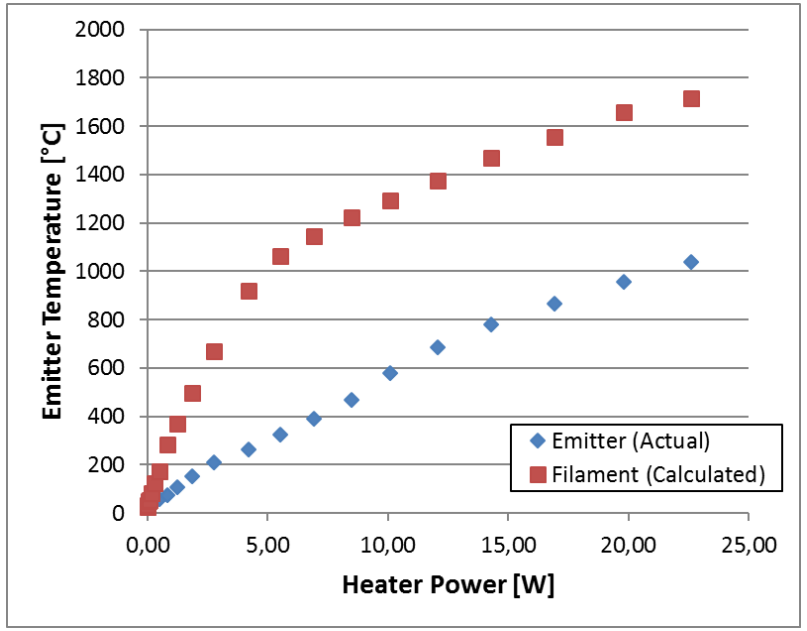
Ignition parameter	Heated	Heaterless
Keeper voltage	300 V	700 V
Mass flow rate, Xe	0.5 mg/s	1 mg/s
Heater power	< 25 W	N.A.

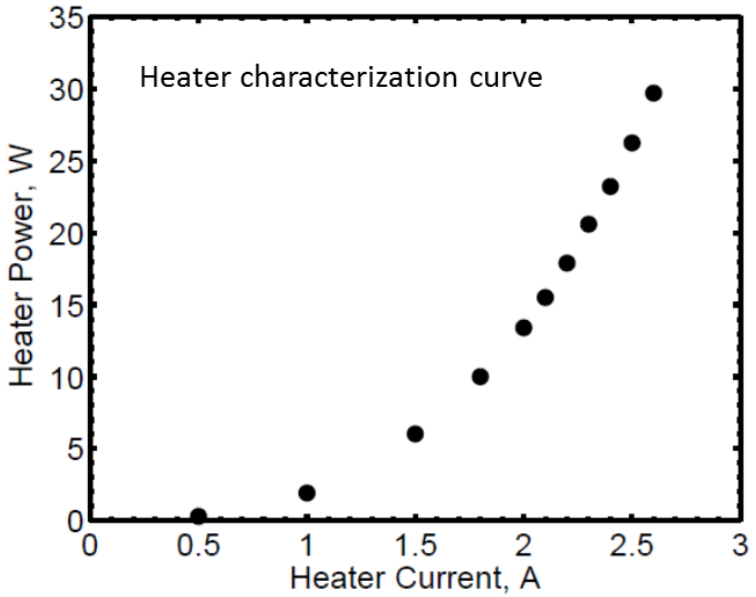
✓ More than **450 hours** of continuous operation
✓ More than **200 ignitions**

Cathode Heater Technology



Heater Characteristics	
Max. power	30 W
Max. filament temperature	1500 °C
Max. emitter temperature	~1200 °C

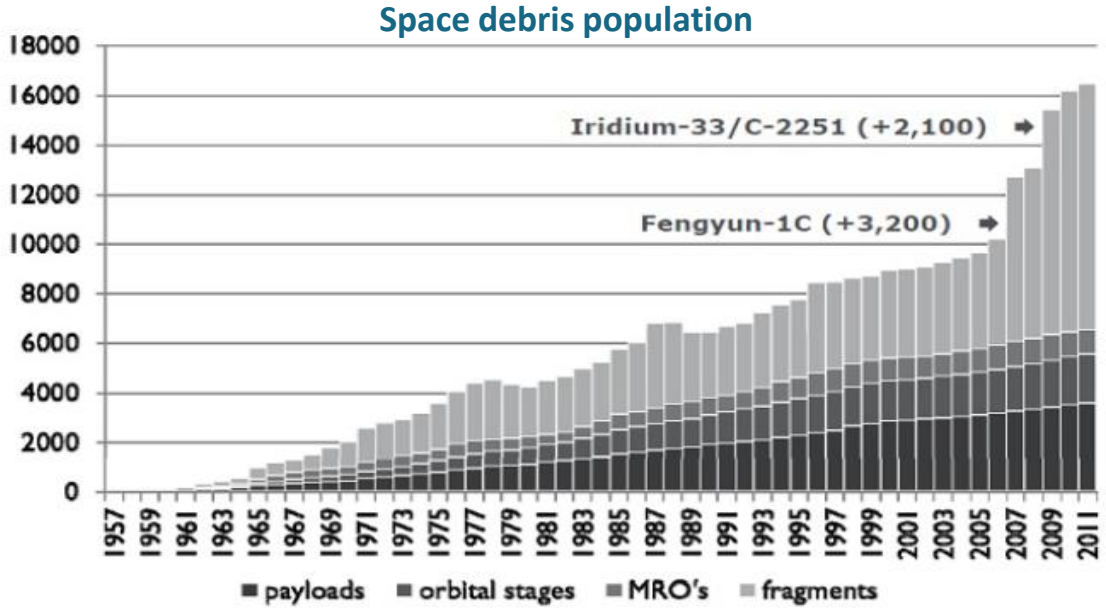




Low Power EP: Main Applications for Small Satellites

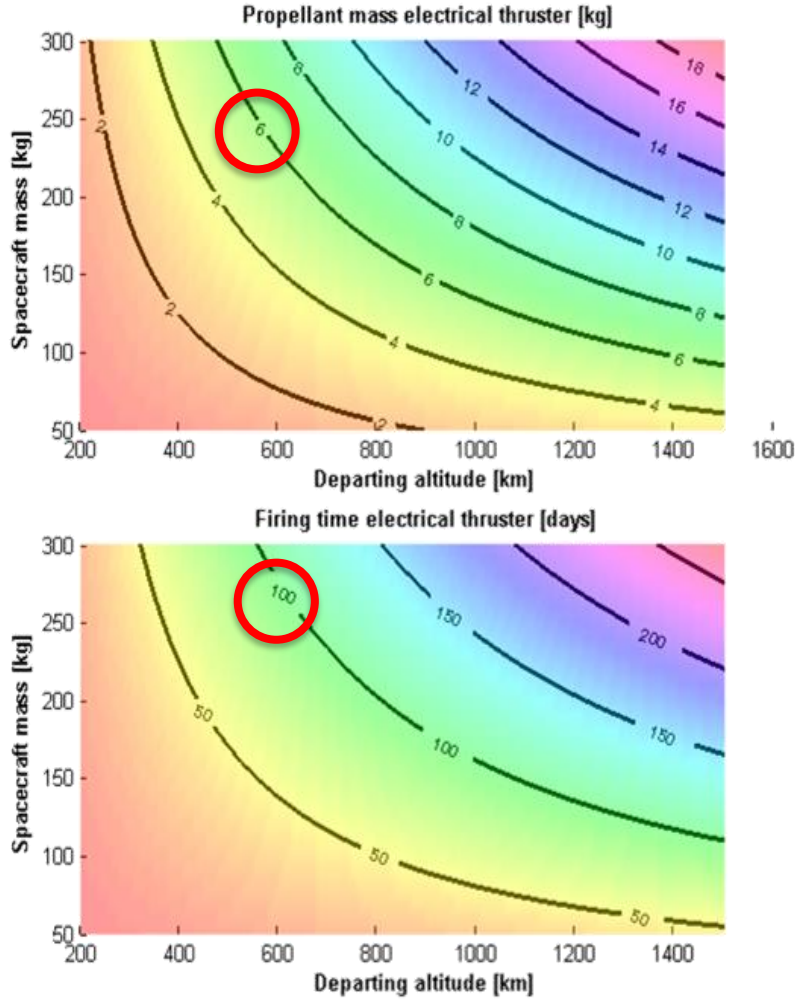
- ✓ Accurate final orbit insertion after separation from launcher
- ✓ Orbit transfers (e.g. from parking to active orbit, for constellation spare-satellites)
- ✓ Main propulsion system for large LEO constellations
- ✓ Spacecraft end-of-life disposal
- ✓ Orbit maintenance in Very-Low Earth Orbit (Drag-Compensation)

Satellite De-Orbiting



Using an EP System for de-orbiting (pros and cons):

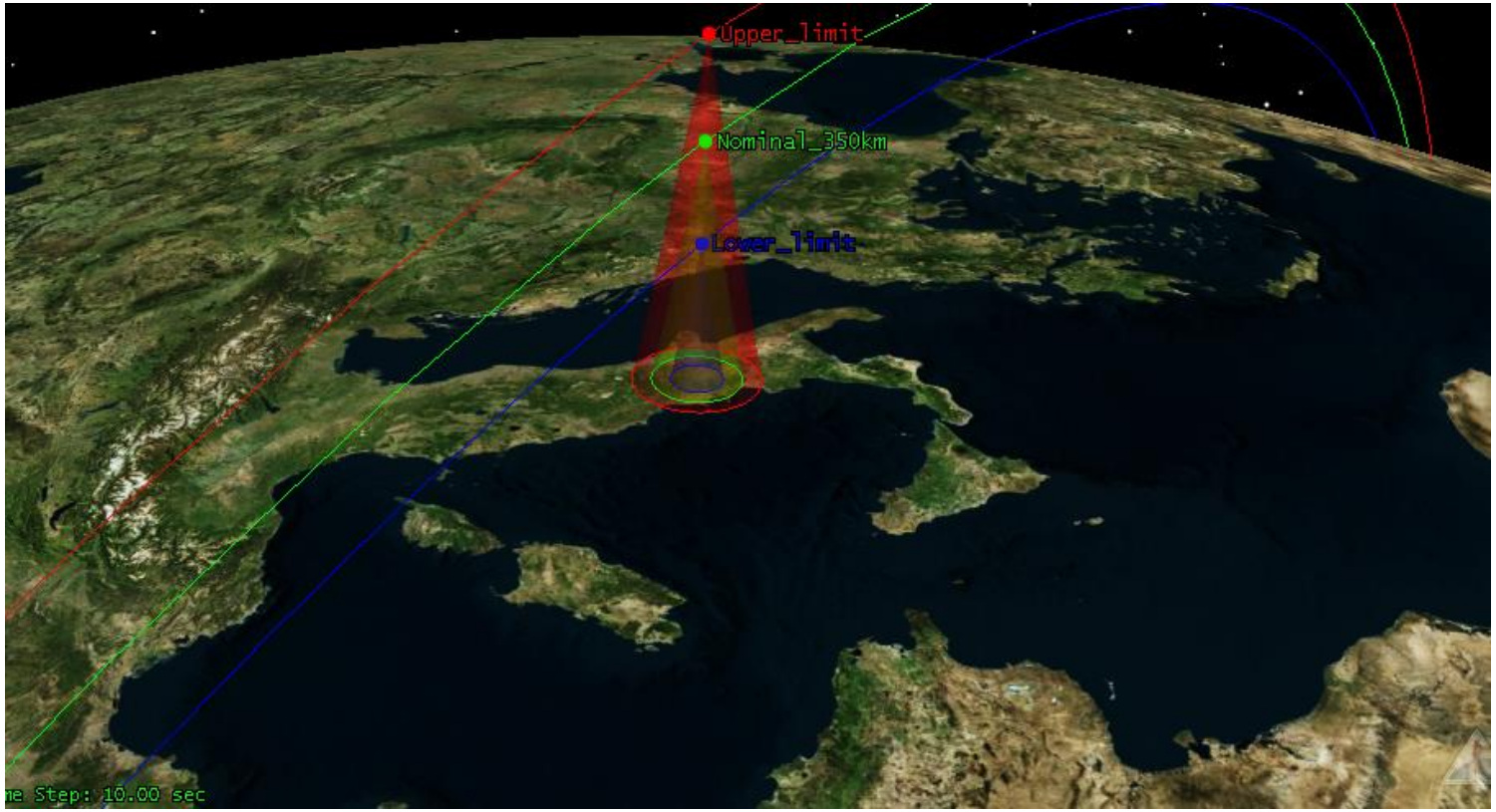
- Power availability at the EOL
- Semi-controlled re-entry
- Green, as it uses inert gases as propellant
- Flexibility (possibility of >2000 ignitions / thrust tuning)
- Significantly extends Small-sat capabilities during operational life
- High specific impulse (>1000s)

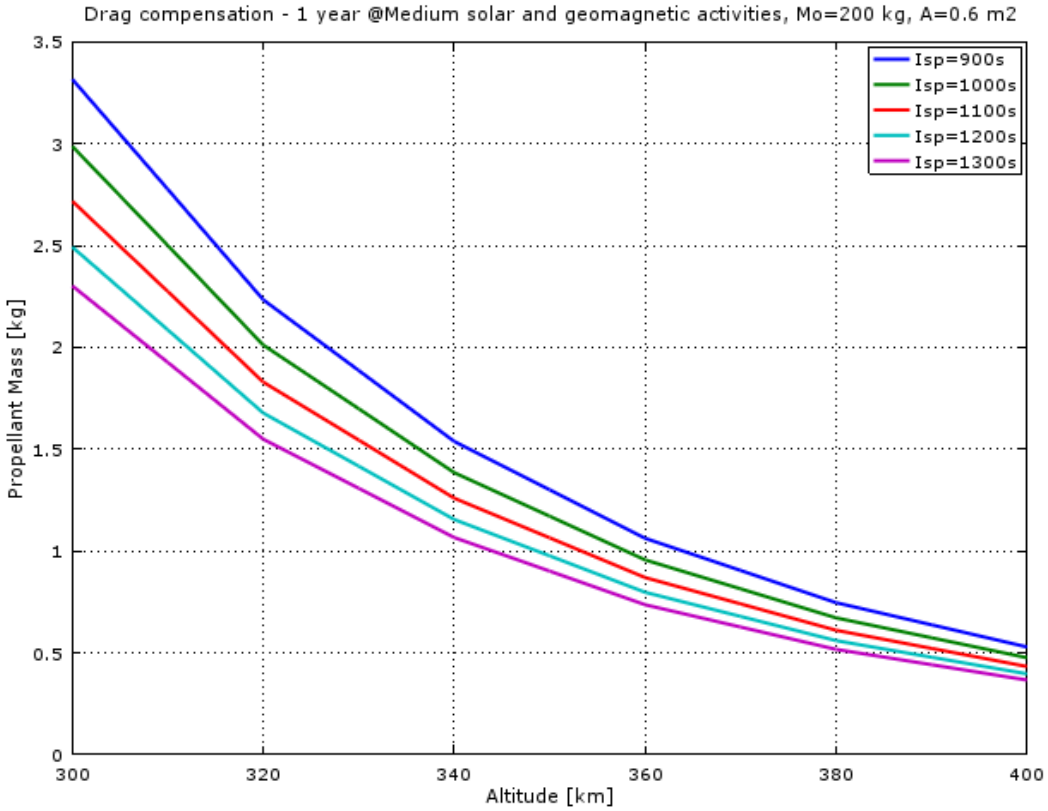


De-orbiting performance with HT100
Isp: 1100s / Thrust: 9mN / Target final orbit 100 km

Drag Compensation

- Earth observation missions in very-low Earth orbit (e.g. 350 km)
- 1 kg of Xe to maintain a Small Satellite @ 350km for one year using an HT100 based propulsion system





Low Power HETs: Main Ongoing Programs @ SITAEL

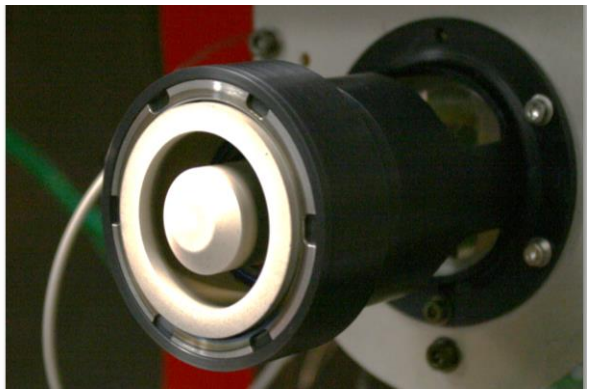
MEPS: Microsatellite Electric Propulsion System

Jointly supported by ESA and ISA, the project aims at the space qualification of a Low Power Electric Propulsion System.

Power level: up to 300W

Thrusters: HT100 / CAM200

Two thrusters onboard, full redundancy



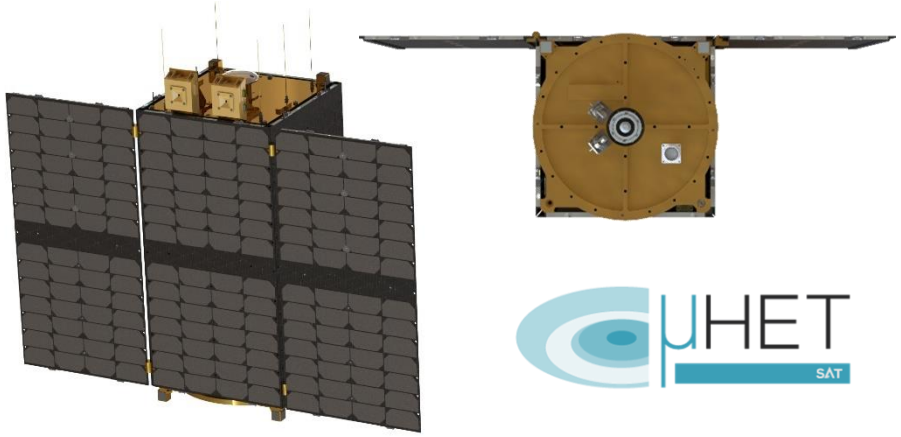
µHETSat: In-Orbit Validation Program

Supported by ESA and ASI, the project aims at validating in-orbit a low power propulsion system based on HT100.

Platform (SITAEL S-75) from ESEO programme

Power level: up to 200W

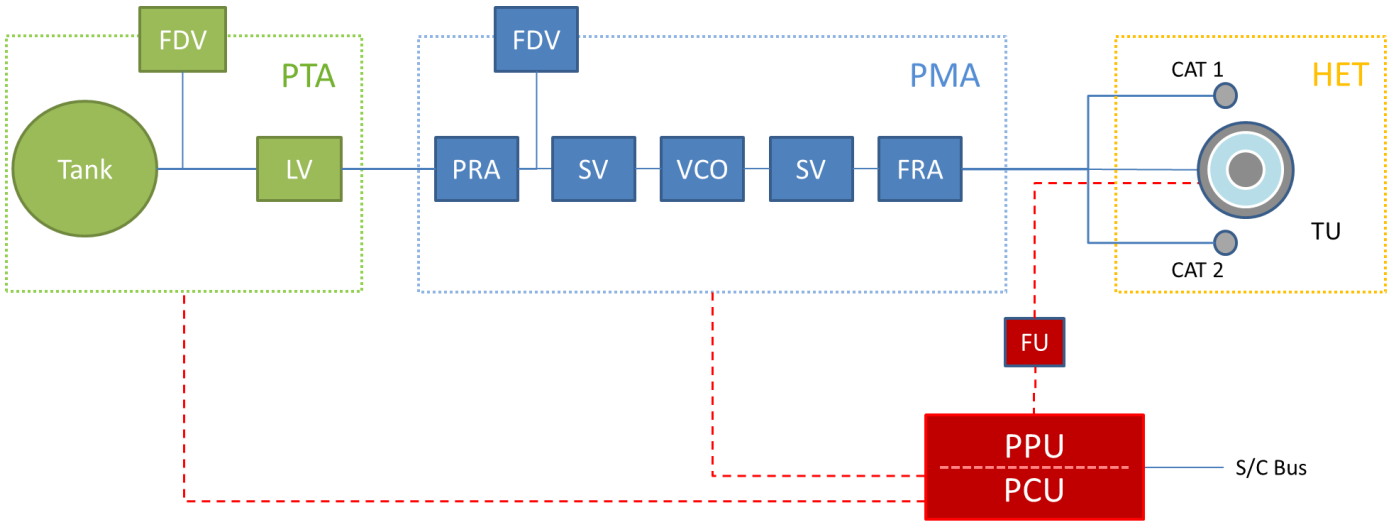
Target: 1000 hrs of HT100 operation in LEO



µHETSat: EP System Scheme & Mission Profile

IOV mission target: **cumulate 1000 hrs of thruster operation** while deorbiting the satellite (65 kg platform).

270 firing hours and less than 1kg of propellant are enough to lower the satellite orbit of 250 km (from 600 km to 350 km)



PTA: Propellant Tank Assembly
PMA: Propellant Management Assembly
HET: Hall Effect Thruster
PPU: Power Processing Unit
PCU: Power Control Unit
FDV: Fill and Drain Valve
LV: Latch Valve

PRA: Pressure Regulator Assembly
SV: Solenoid Valve
VCO: Valve COllector
FRA: Fine Regulation Assembly
TU: Thruster Unit
CAT: Cathode
FU: Filter Unit

µHETSat Mission Profile			
Orbit transfer [km]	**Firing time [hours]**	**Propellant mass consumption [kg]**	**Maneuver time [days]**
600 to 500	84.22	0.24	33
500 to 600	76.73	0.22	30
600 to 500	55.63	0.16	22
500 to 600	76.09	0.22	30
600 to 500	65.38	0.19	25
500 to 600	64.11	0.18	25
600 to 500	103.68	0.30	41
500 to 600	76.58	0.22	30
600 to 350	270.09	0.77	103
Sub-Total	**872.50**	**2.49**	**339**
Drag-comp.	162.00	0.46	~ 1 year
TOTAL	**1034.50**	**2.95**	~ 2 years

Conclusions

- ✓ Skipped

  (in order to get a 5% improvement in the information-transfer efficiency)

Conclusions (if Time Permits / for PDF Release)

Next Steps & Future Developments:

- Design, manufacturing and test of an MSHT100 at EM level
- Extended tests with alternative propellants as iodine or krypton
- Reduce EP system costs using COTS as much as possible (i.e. for PPU and PMA)
- Continue the development of HT400 thruster
- Scale down the thruster for Micro-Sats usage (target power range 50-100W, nominal power 80W)

Ongoing Programs (MEPS, uHETSat, CHEOPS):

- MEPS (ESA/ISA): fully redundant EP system qualification
- µHETSat (ASI/ESA): In-Orbit-Validation for an HT100 EP system
- CHEOPS (EU): development of a PPU and a hollow cathode for a 500W-class HET