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BB# 24

HT100 Deorbiting (Auxiliary) System

Tommaso Misuri
Tommaso.Misuri@sitael.com

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Outline

- Low Power EP: Rationale and Applications
- System description, BB24: HT100 De-orbiting System
- Propulsion System Performance
- Development Roadmap
    - Development activities to date
    - Incoming development activities
- Main Ongoing Programs @ SITAEL
- Effectiveness of low power Hall thrusters as de-orbiting systems

SITAEL: Company Info

- ✓ **Sitael**, 15+ years of heritage in electronics for space applications
- ✓ **Alma Space**, focused on small satellites
- ✓ **Alta**, 20+ years of heritage in Electric Propulsion

Introduction: EP System for De-Orbiting Tasks

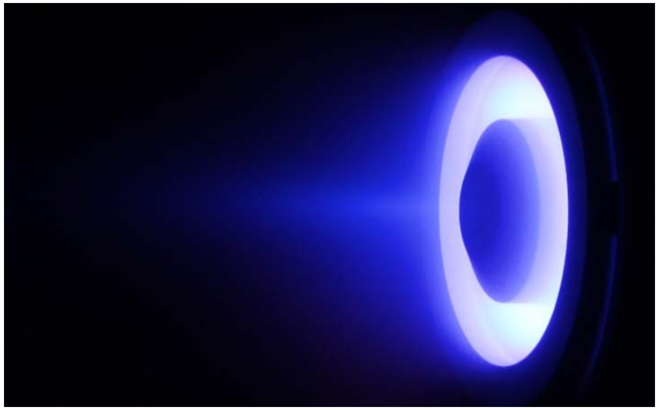
Using an EP System for de-orbiting (pros and cons):

- Power availability at the EOL
- Semi-controlled re-entry
- Green, as it uses inert gases as propellant
- Flexibility:
  - *thruster can be ignited thousands of times (typically >2000)*
  - *thrust can be tuned in-orbit (compatibly with the PPU capabilities and the available power)*
- Significantly extends Small-sat capabilities during operational life
- High specific impulse (>1000s)

HT100 Hall Effect Thruster

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.

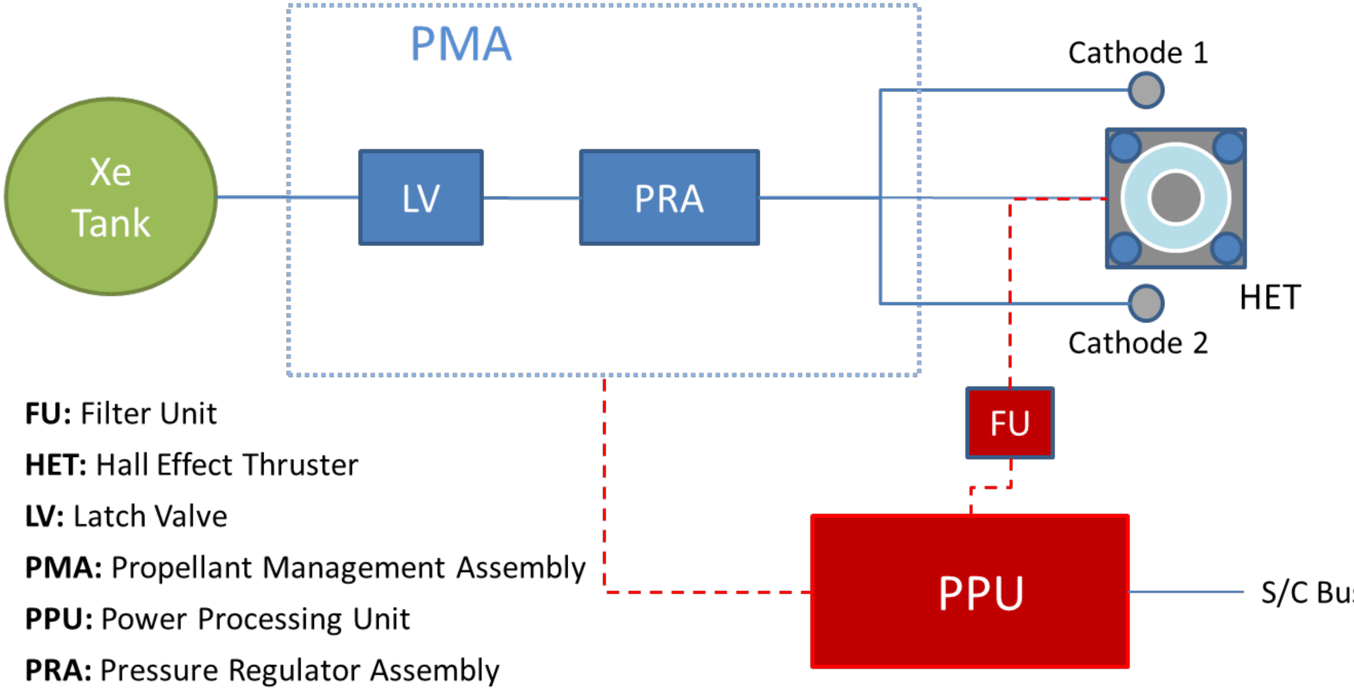
HT100 is also the most compact and lightweight Hall thruster of this class,



HT100 propulsion system is conceived with a design-to-cost approach and has been designed to **significantly extend the capabilities of mini satellites** operating in Low Earth Orbit. Typical applications are:

- ✓ Orbit maintenance of spacecraft in Low and Very-Low Earth Orbit
- ✓ Accurate final orbit insertion after separation from launcher
- ✓ Orbit transfers (i.e. from parking to active orbit, for constellation spare-satellites)
- ✓ Spacecraft end-of-life disposal

Building Block's Building Blocks

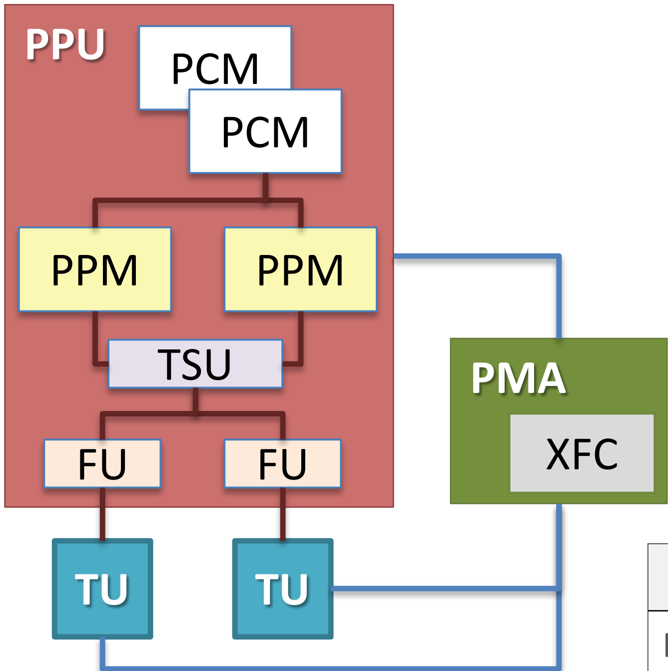


Main System Components:

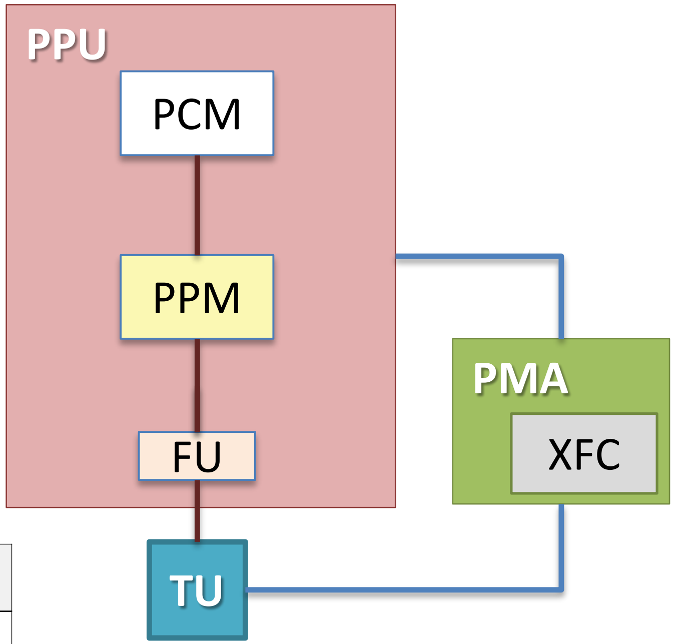
- ✓ *Thruster Unit (HT100) with two cathodes*
- ✓ *Power Processing Unit (PPU)*
- ✓ *Propellant Management Assembly (PMA)*
- ✓ *Xe Tank*

Target Performance	
Max. Input Power	300 W
Anodic Power	100 - 250 W
Thrust Range	6 - 18 mN
Specific Impulse	800 - 1400 sec
Lifetime	> 2000 h

HT100DS - System Configurations



PPU: Power Processing Unit
PCM: Power Control Module
PPM: PPU Power Module
TU: Thruster Unit
FU: Filter Unit
XFC: Xenon Flow Controller
PMA: Prop. Manag. Assembly
TSU: Thruster Switching Unit



System Dry-Mass	
Fully Redundant (left)	< 15 kg
Single Branch (right)	< 9 kg

Higher reliability and capability of extending mission life (firing both thrusters sequentially)

Vs.

Significant mass, size and cost reduction

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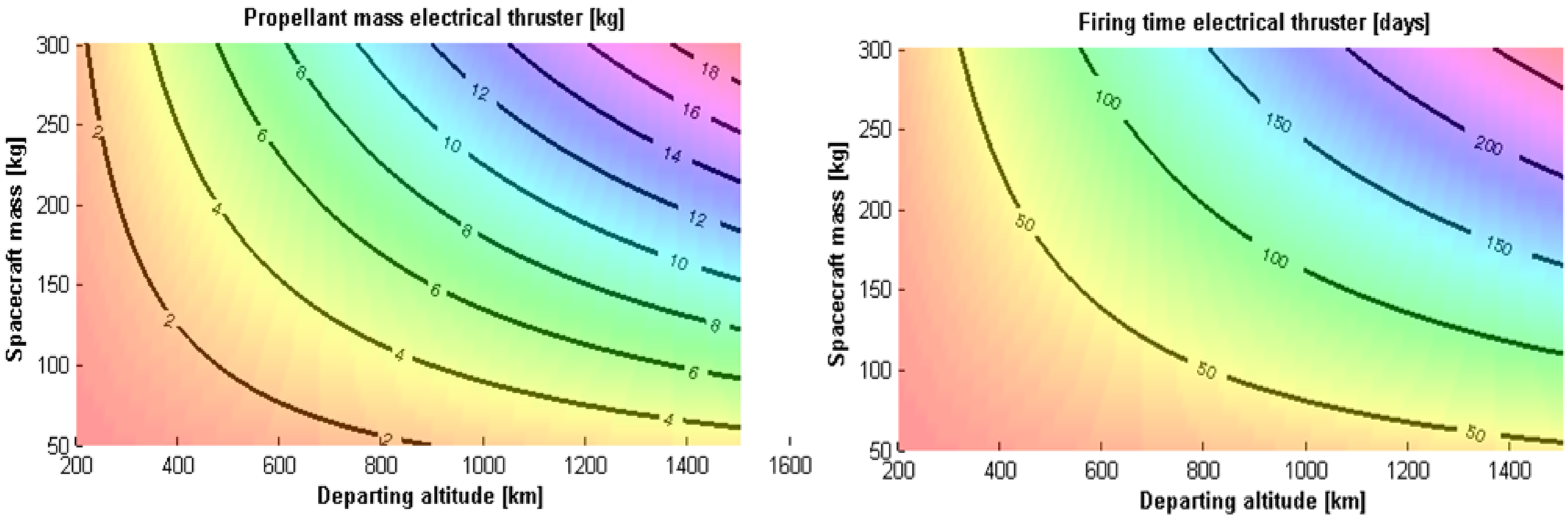
De-orbiting with HT100: Preliminary Mission Analysis

- Baseline applicability range: LEO orbit for satellites up to 500 kg



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

- System mass <10 kg (dry)
- Compact tank size (5 liters for ~8 kg of Xe stored in supercritical conditions)
- Required power will be in the order of 150-200 W

HT100 Propulsion System: Development Roadmap

Complete Structural Analysis vs Typical Launch Loads - Thermal Analysis - Magnetic Analysis
COMPLETED

↓

HT100 Full Performance Characterization
COMPLETED

↓

- **PPU-BB Manuf. & Test** — COMPLETED
  - ↓ **PPU-EM Manuf. & Test** — in progress
- **HC1 Cathode - Standalone Test** — COMPLETED
  - ↓ **HC1 - HT100 Coupling Tests** — in progress
- **Endurance Test (HT100_01)** — COMPLETED
- **Structural Tests (HT100_02)** — COMPLETED
  - ↓ **Full TV Tests (HT100_02)** — COMPLETED

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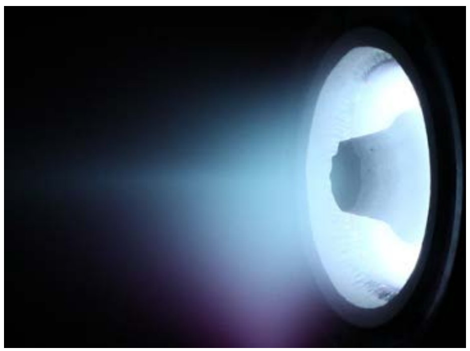
HT100 Thruster Unit: Development Status

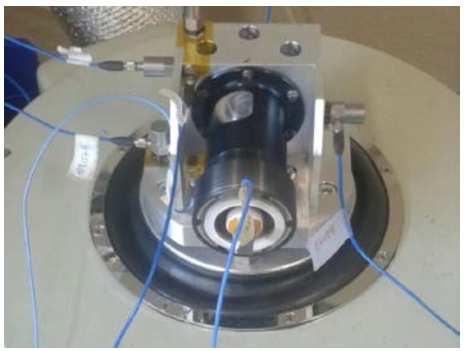
Thruster performance characterization:

Nominal Power	175 W	**Operating Voltages**	250 - 350 V
Thrust range	6 -18 mN	**Demonstrated lifetime**	2250 hrs
Specific Impulse	up to 1400 s	**Thruster mass**	440 g
Total Efficiency	up to 35%	**TRL**	6



Extended Endurance Test

2250 hrs of operation.
Total impulse > 75 kNs

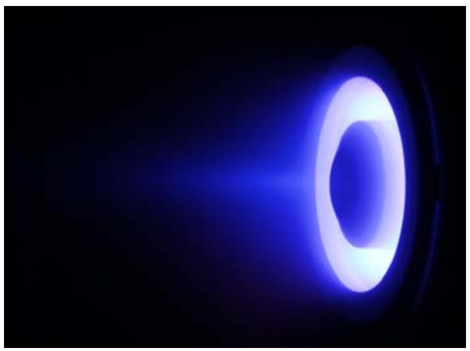


Full Structural Tests
(Shock & Vibration)

Successfully withstands typical launch loads

Thermal Vacuum Test

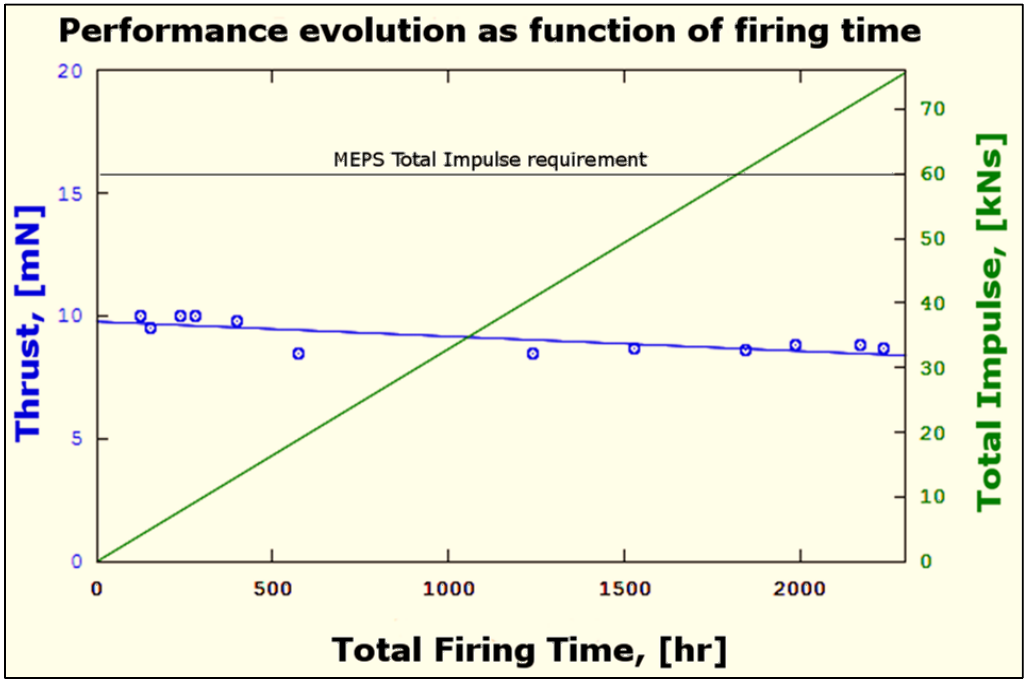
8 thermal cycles
[-25°C and 110°C]
Hot & Cold starts
[-25°C and 250°C]



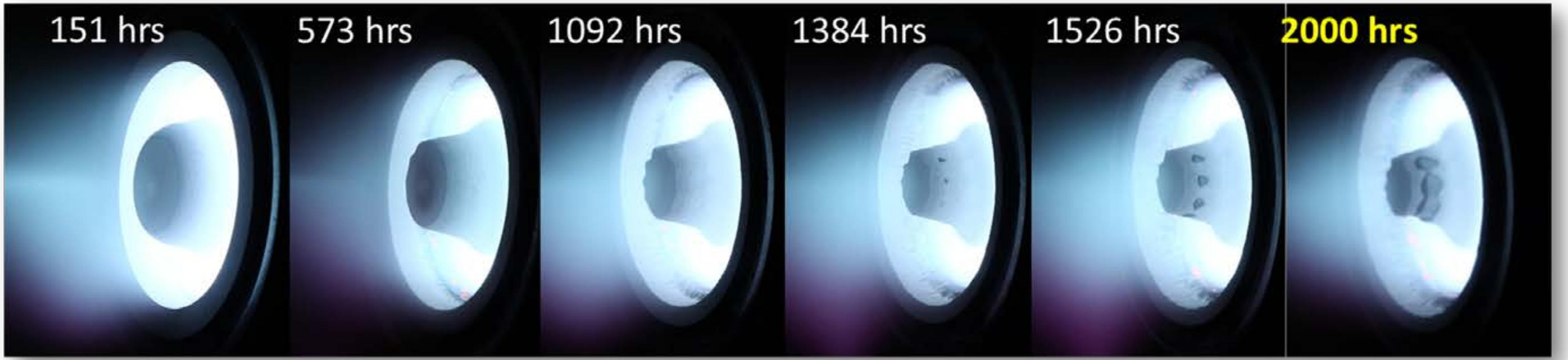
Test with Krypton as propellant

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

HT100 Endurance Test



- The HT100 at BOL provided a thrust of 10mN; at the end of the test, after a total firing time of 2250h, the value was 15% lower.
- Power level: **210 W ± 3%**
- 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



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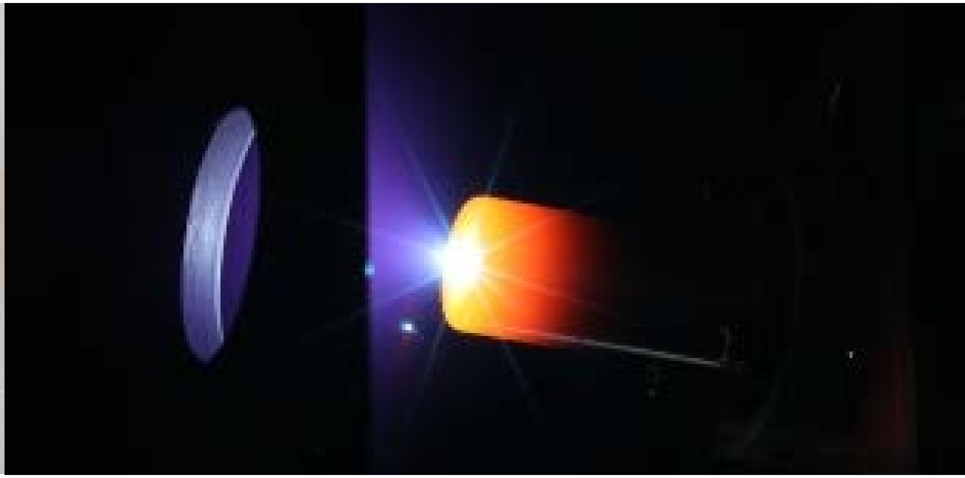
HC1 Low Current Cathode: Development Status



- ✓ **Current Range :** 0.3 - 1.5 A
- ✓ **Mass Flow Rate:** 0.08 - 1.5 mg/s
- ✓ **Ignition voltage:** < 300 V (heated)
  700 V (heaterless)
- ✓ **Cathode mass:** 30 g
- ✓ Heater designed / manufactured in-house

- ✓ **Hours of operation:**
  - predicted: 5000+ hrs
  - demonstrated: 300 hrs (>70 repeatable ignitions)
- ✓ **Total power consumption:**
  - < 30 W ignition phase
  - < 15 W operation, self-heating

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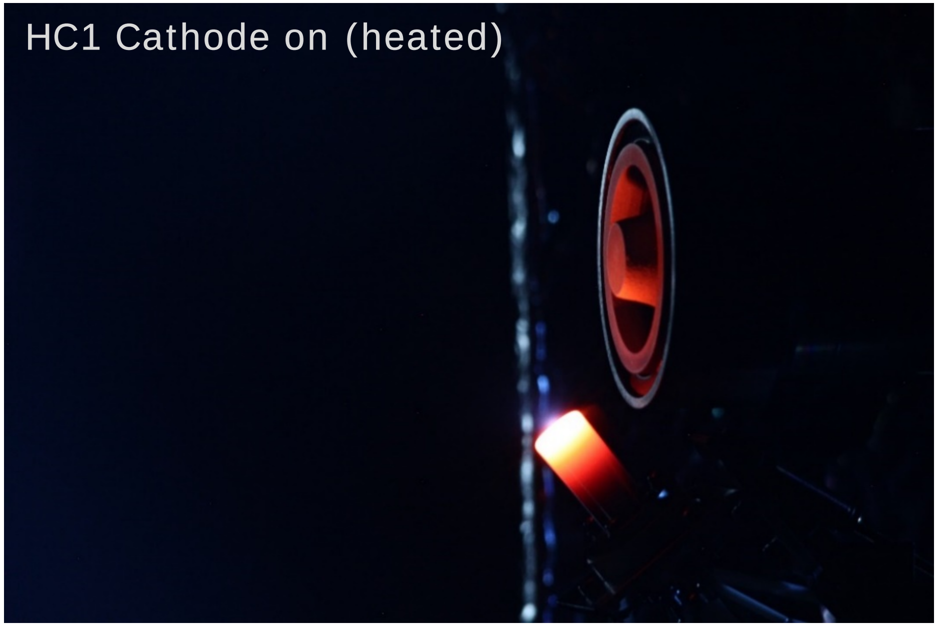
HT100 - HC1: Maiden Coupling Test

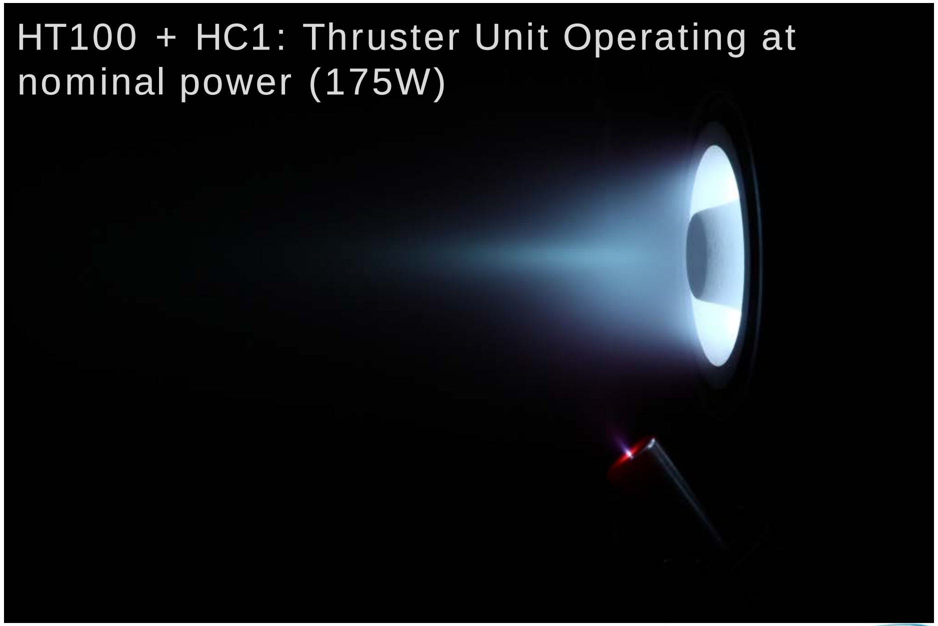
Carried out last Monday in our facilities in Pisa, HT100 Thruster has been operated for several hours in combination with HC1 Cathode.

Ignition was immediately successful and repeated precisely 16 times following the same procedure.

Full thruster unit characterization is ongoing (power range tested: 130-330W)



HC1 Cathode on (heated)



HT100 + HC1: Thruster Unit Operating at nominal power (175W)

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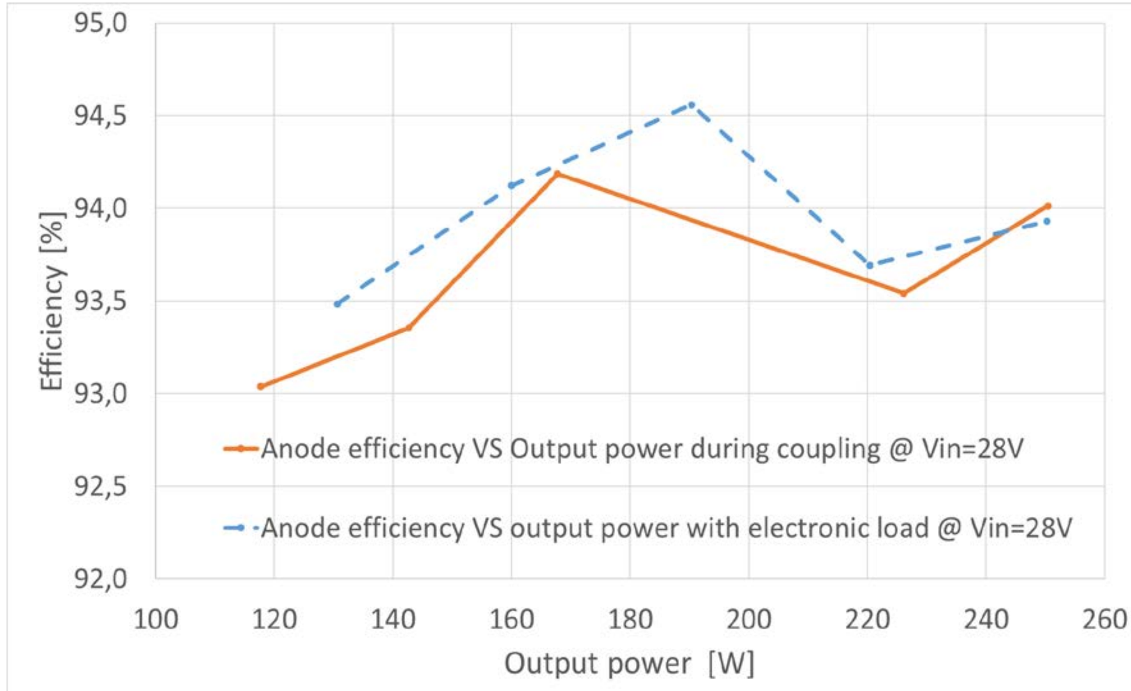
PPU Development

A PPU breadboard has been manufactured and it implements the modules necessary to drive the thruster (HT100) and the cathode (HC1, heated).

Coupled with HT100 thruster and heated cathode, it showed an efficiency (anode module) over 94%, in very good agreement with the measurements taken when testing vs. electronic loads.



PPU EM is presently under development in the framework of two different ongoing programs, which leads us to introduce our main frameworks for HT100 propulsion system future development….

Ongoing Development Programs

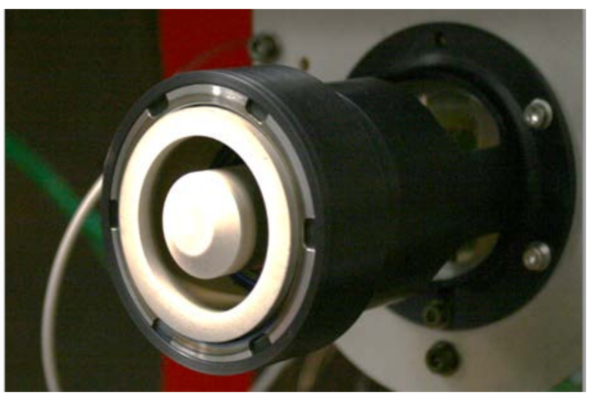
MEPS: Microsatellite Electric Propulsion System

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



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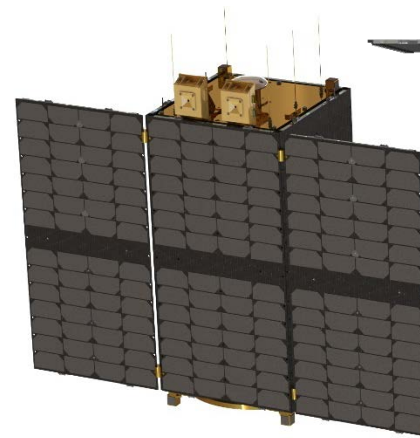
μHETSat: In-Orbit Validation Program

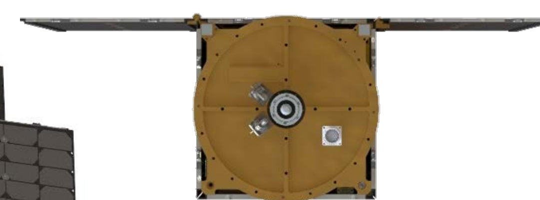
Supported by ESA and ASI, the project aims at validating in-orbit a low power propulsion system based on HT100.

Platform (SITAEL S-75) from ESEO programme

Power level: up to 200W

Target: 1000 hrs of HT100 operation in LEO





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μHETSat Mission Scenario

Assuming an initial orbit at 600 km (circular), IOV mission target is to cumulate 1000 hrs of thruster operation while deorbiting the satellite (65 kg platform).

DAS (NASA software) indicates as 575 km the maximum altitude (circular) for the spacecraft to deorbit within 25 years as required.

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)

Orbit transfer [km]	Final orbit	Firing time [hours]	Thruster ignitions	Propellant mass consumption [kg]	ΔV [m/s]	Maneuver time [days]
600 to 500	500 x 564	84.22	165	0.24	34.30	32.98
500 to 600	530 x 652	76.73	150	0.22	31.36	30.00
600 to 500	500 x 590	55.63	108	0.16	22.81	21.67
500 to 600	571 x 636	76.09	149	0.22	31.29	30.00
600 to 500	500 x 601	65.38	127	0.19	26.98	25.46
500 to 600	530 x 660	64.11	149	0.18	26.53	25.00
600 to 500	500 x 560	103.68	205	0.30	43.08	41.01
500 to 600	550 x 615	76.58	150	0.22	31.86	30.00
600 to 350	350 x 367	**270.09**	523	**0.77**	113.64	102.66
Total		**872.50**	1726	2.49	361.85	338.78

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Future Developments / Technical 'Challenges'

Present thruster / system design:

- Consolidate the techology and achieve full system qualification according to ECSS (MEPS) and in-orbit validation (uHETSat)
- Test of alternative propellants: **krypton** (already tested with HT100) and **iodine**
- Reduce costs using COTS as much as possible (i.e. for PPU)

Possible *thruster* design improvements (ongoing activities):

- Extend the Hall thruster lifetime through magnetic-shielding techniques
- Scale down the thruster (target power range 50-100W, nominal power 80W)

Possible *system* design improvements:

- Design of a Plug & Play System specific for de-orbiting missions (?)

Conclusions

Hall Effect electric propulsion for deorbiting small-sats:

- ✓ HETs are now mature enough also at low-power levels to be installed onboard smallsats
- ✓ Hall thrusters are green, as they rely on inert gases as propellant (typically Xe)
- ✓ De-orbiting system **wet-mass is extremely low**
- ✓ Hybrid de-orbiting maneuver if EP is already onboard (i.e. lowering the orbit height from 600 to 200 with EP and then using a high thrust device for controlled re-entry)
- ✓ HT100-based propulsion system just started an In-Orbit Validation programme with a mission scenario that includes a de-orbiting maneuver