C12

デブリ除去に向けた1kW級ホールスラスタシステムの研究開発

R&D status of JAXA 1-kW Hall Thruster System for Active Debris Removal

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JAXA では商業デブリ除去実証やその先のデブリ除去事業等を目指し、1kW 級ホールスラスタの研究開発を進めている。500 キログラム級の衛星により、数トン級のデブリの除去を実施するためには、MNs 級のトータルインパルスと、高い比推力が要求されるため電気推進の利用が望ましく、中でも推力電力比が高くミッション期間の制約を満たしやすいことから、1kW 級ホールスラスタが最有力候補と考えられる。ただし、同電力帯の既存ホールスラスタは一般に寿命が短く不足するため、JAXA では技術試験衛星 9 号機で実証される長寿命ホールスラスタ技術をベースとして、低コスト長寿命な小型ホールスラスタシステムの実現を目指している。ホールスラスタヘッドや中和器だけでなく、電源や流量制御器を含めた推進システムとしての研究開発状況を報告する。

JAXA is conducting R&D on a 1kW-class Hall thruster system for active debris removal. The Commercial Removal of Debris Demonstration (CRD2) phase II mission target is several tons of weight, which requires MNs-class of total impulse and high-specific impulse to accomplish. In addition, mission duration is also important from a commercial perspective. Therefore, electric propulsion, especially Hall thruster is the first candidate because of its relatively high thrust-to-power ratio. Since life-limit is challenging for conventional small Hall thrusters, JAXA is targeting low-cost long-life 1kW-class Hall thruster system, utilizing technologies to be demonstrated on JAXA ETS-9 satellite. Research and development status of the system is reported.

R&D status of JAXA 1-kW Hall Thruster System for Active Debris Removal
デブリ除去に向けた1kW級ホールスラスタシステムの研究開発

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(JAXA)

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Background

CRD2 (Commercial Removal of Debris Demonstration)

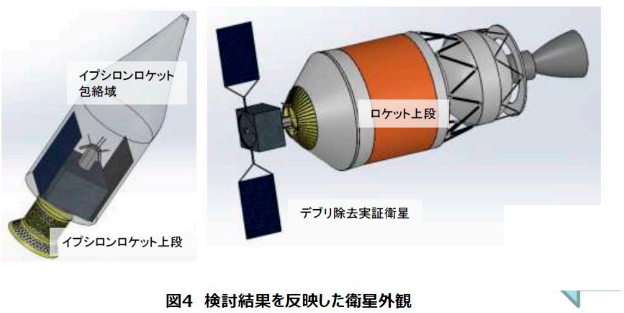

図4 検討結果を反映した衛星外観

イプシロンロケットへの搭載を可能とし、PAF1194のデブリに対応した衛星サイズ（航法センサの取り付け条件）を実現。
打上重量500kg以内での実現性の目途を得た。

Successor mission of TSUBAME (SLATS)

衛星配置（北極から見る）

- **Long-life, powerful, low-cost and robust EP system** demands for JAXA LEO missions
- FY2019, JAXA started research and development of 1-kW class Hall thruster system (in-house)

➡FY2021, initiating EM-phase
➡FY2024, FM ready
➡FY2025, CRD2 phase2 mission: satellite launch

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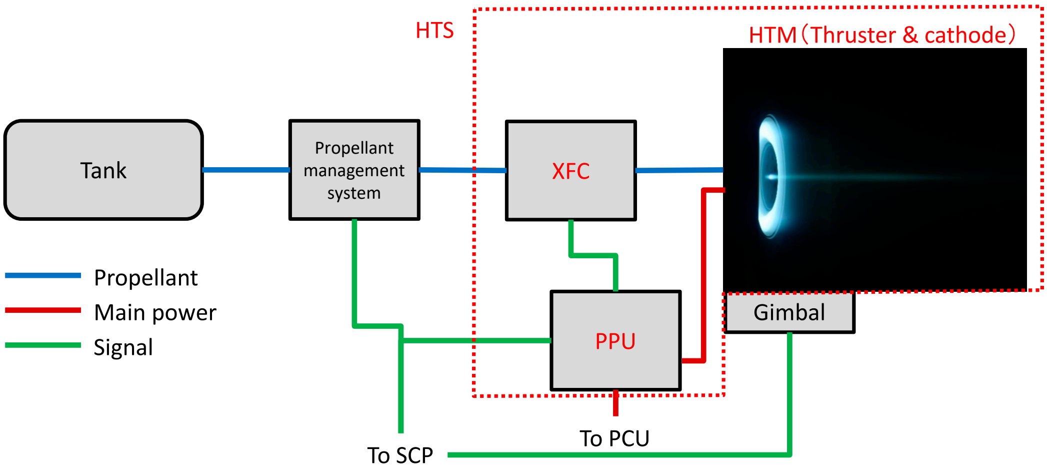
HTS(Hall thruster system) components



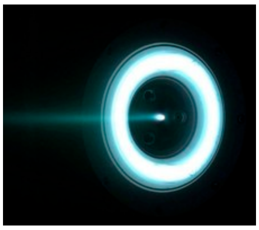
HTM（Thruster & cathode）
- **Life-test necessary.**

PPU（Power processing unit）
- **Mass & cost driver.**

XFC（Flow controller）
- **Important in terms of HTM/PPU interface.**

HTM key concepts

HTM-LM firing

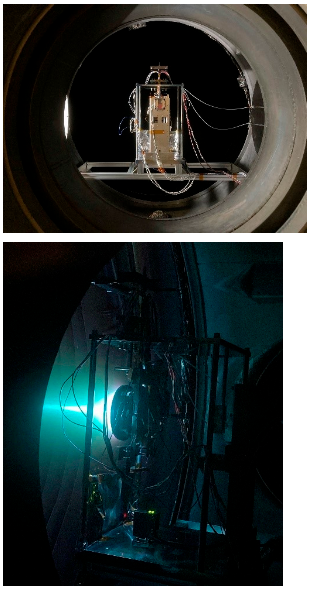


HTM-BBM image

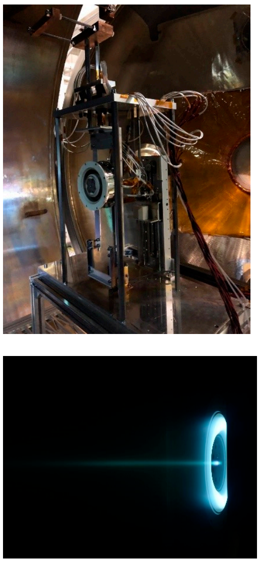
Advanced materials

- **Target**: Long life small Hall thruster **(10,000 hrs, 10,000 cycles)**
- Key technologies :
  -Internal mounted cathode
  -Low-erosion magnetic field topology
  -Radiative cathode heater
  will be demonstrated in JAXA Engineering Test Satellite-9's 6-kW Hall thruster
- **Unified design of Hall thruster with internal cathode**
- **Advanced materials and structures** (patents to be published)
- Fully utilization of **JAXA ion thruster neutralizer heritage**
- **Physics-based modeling** and design tools

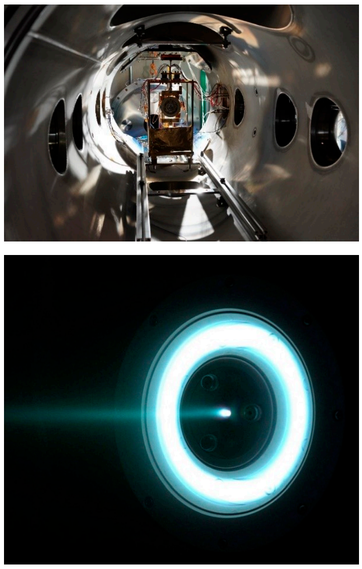
HTM Operations and setups in JAXA facilities



3m ion thruster chamber (Chofu)
3E-6 torr @1kW

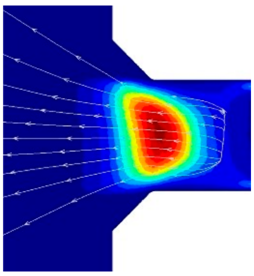


Space science chamber (ISAS)
4.5E-5 torr @1kW



Small EP chamber (ISAS)
3E-5 torr @1kW

Measurement & modeling: thrust performance



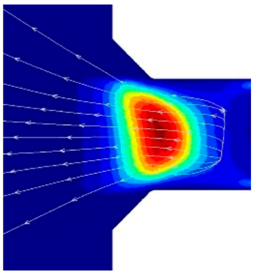
Mass, momentum, and energy conservation

- Plasma production
- Beam trajectories
- Thrust, discharge current, etc.
- Erosion due to sputtering
- Energy loss and deposition

Experiment VS simulation

	Experiment (ISAS)	PIC simulation
Background pressure	4.5E-5 torr	(input) 0 torr
Discharge voltage	300.8 V	(input) 300 V
Xe anode mass flow rate	3.5 mg/s	(input) 3.5 mg/s
Discharge current	2.9 A	2.7 A
Thrust	58.2 mN	57.9 mN
Anode Isp	1694 s	1689 s
Anode thrust/power ratio	66.2 mN/kW	71.3 mN/kW
Anode efficiency	55%	59%

Measurement & modeling: energy balance and thermal analysis



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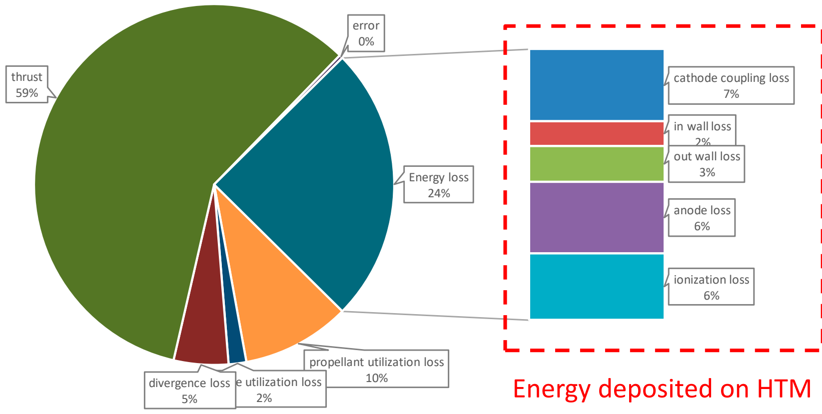
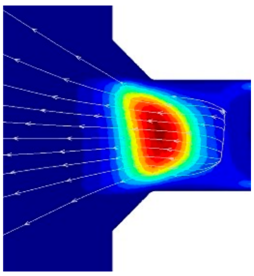
Energy balance



Energy deposited on HTM

Thermal analysis

Measurement & modeling: erosion and life estimation



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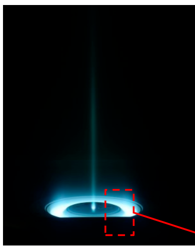
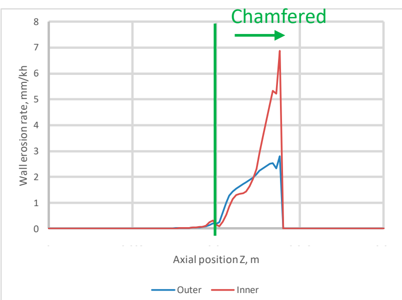


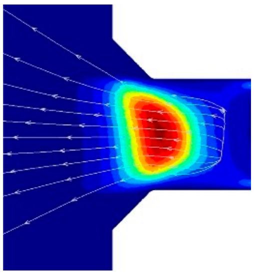
Channel observation after HTM operation



Simulated channel erosion rate

Life estimation

Measurement & modeling: beam divergence and interference



Mass, momentum, and energy conservation

- Plasma production
- Beam trajectories
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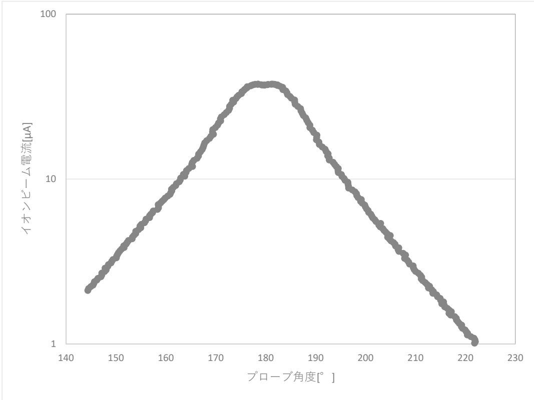
Engine model

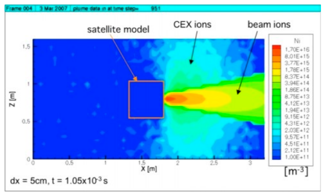
Ion beam measurement



- Measured by Faraday cup at 1.26 m downstream of HTM-BBM
- Beam divergence:
  27 deg (90% current)
  30 deg (95% current)
- Estimated error: ±3 deg

Satellite plume interference

Muranaka, IEPC-2007-197



Technology development status

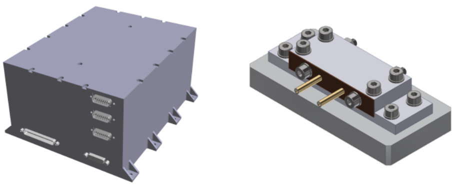


Image of PPU-EM (left) and XFC-BBM (right)

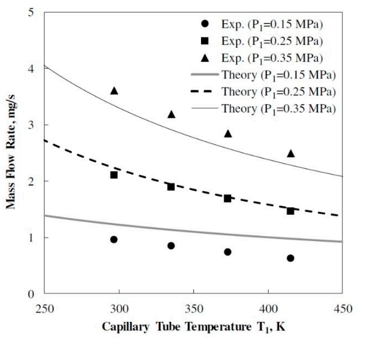


Fig. 14 Comparison of mass flow rates between experiment and theoretical estimation [turbulent case, Eq. (10)].

Flow control characteristics by capillary flow controller (Kinefuchi, JPP vol.36, No. 4, 2020)

HTM

- 240 hrs, 100 cycles completed by LM
- 20 hrs, 10 cycles completed by BBM
- Further BBM life-test planned
- Shock and random vibration analyzed. BBM mechanical tests planned

PPU

- Light-weighted, low-cost PPU
- Anode coupling test successfully completed with HTM-LM
- PPU-BBM coupling test with HTM-BBM planned

XFC

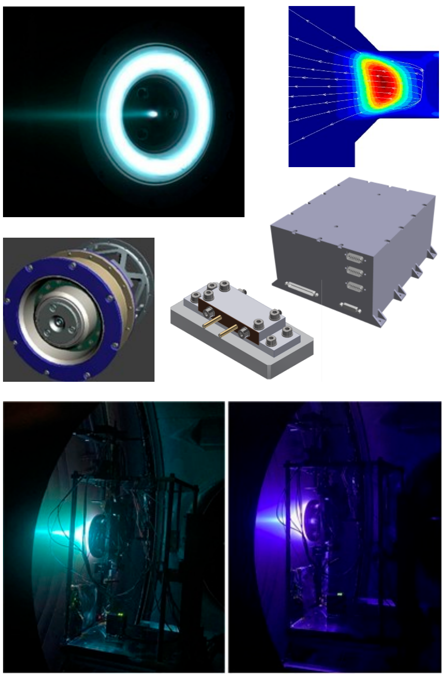
- Light-weighted, robust, low-cost capillary flow controller
  (based on journal publication)
- BBM Coupling test planned

➡Initiating EM phase in FY2021

HTS key specifications

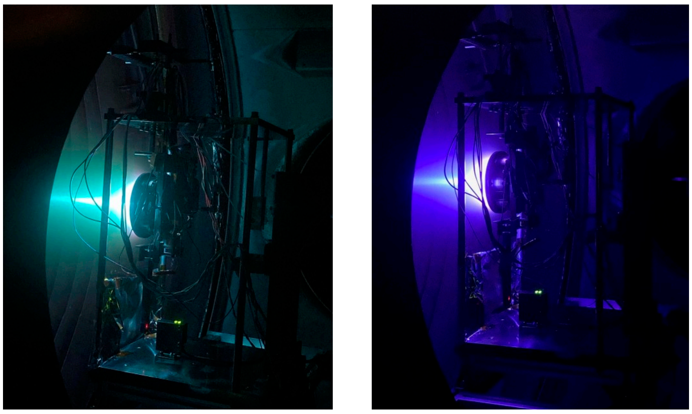
Items	Target (TBD)	BBM results (@HTM 887W, 3E-6 torr)
Total power [W]	≦1100	-
HTM power [W]	(1000)	887
Life [hrs]	≧10000	240 (LM) and 20 (BBM) completed
ON cycles	≧10000	100 (LM) and 10 (BBM) completed
Total Isp [s]	≧1600	1543
Total Thrust/power ratio [mN/kW]	≧61	65.6
Plume divergence [degree]	≦45	27 (90% current)
Total mass [kg]	≦15	~10

Summary: Novel 1-kW class Hall thruster system



- **Unified design of Hall thruster with internal cathode**
- **Advanced materials and structures** (patents to be published)
- **High performance**: Isp 1600sec, 65 mN/kW
- **Long life**: 10,000 hrs, 10,000 cycles(expected)
- **System friendly**: low-plasma oscillation, high-environmental resistance, beam divergence~30deg
- **Cost-effective, low-mass power supply and flow controller**
- **200 hrs operation completed** at JAXA ultrahigh-vacuum facility
- **Physics-based modeling** and design tools
- FY2019 project started. **FY2021 initiating EM phase**

THANK YOU FOR LISTENING



Xe (left) and Kr (right) operation