Development and In-Flight Testing of an Iodine Ion Thruster

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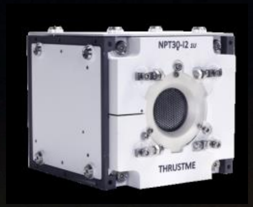
NPT30-I2: First to fly iodine ion thruster

Iodine ion propulsion system

- RF ICP discharge for ionization
- Two-grid ion acceleration
- Waste heat recirculation
- Complete system
- Onboard flight controller
- Built-in self test

NPT30-I2-1U



<u>Specifications</u>

Thrust: 0.4-1.2 mN
Isp: up to 2450 s
Input power (10-36V dc): 35-65 W
Total impulse: up to 5500 Ns
Mass/Volume: 1.2 kg, 1U

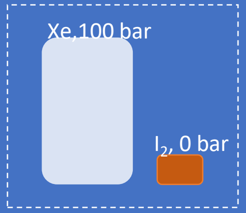
<u>Chronology</u>

Development: 2014-2020
Qualifications: (04-06) 2020
Integrated to satellite: 09/2020
Launched: 11/2020
First maneuver: 12/2020

Iodine ion thruster: motivation

Iodine specifics

- Unknown reaction cross-sections
- Surface properties (secondary emission, work function)
- Basic properties (thermal conductivity at high temperatures)
- Corrosion-related data
- General data is very scarce



Reasons for using iodine

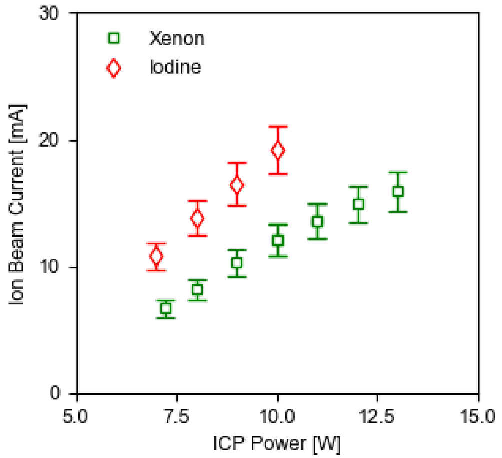
- Same or lower ion energy cost as with Xe
- Pressure <<1 Bar, solid
- Storage density up to 4.9 g/cm^{-3}
- No chemical energy stored

Starting point of the development

- Heritage with first iodine-based cold gas thruster I2T5 (launched 2019)
- Extensive studies on iodine chemistry and fundamental properties starting from 2014

Problems to keep in mind

- Moderate corrosion and toxicity
- Lack of fundamental data
- Ease of solid-gas phase transition
- Molecular propellant with more requirements for accurate modelling



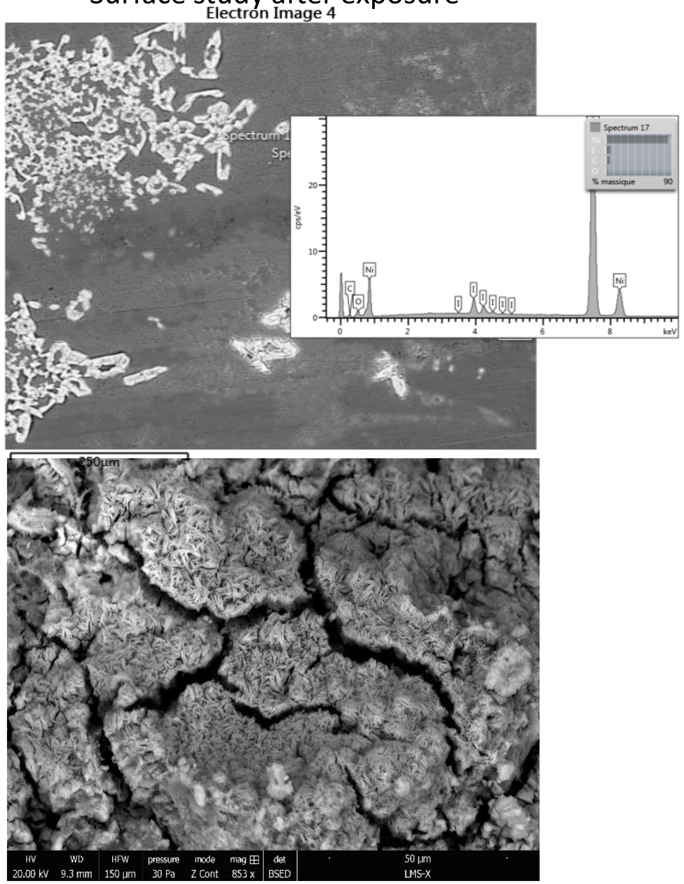
Iodine for EP: challenges

Iodine specific problems

- Lines clogging
- Corrosion
- Scarce data

Corrosion studies:

Surface study after exposure

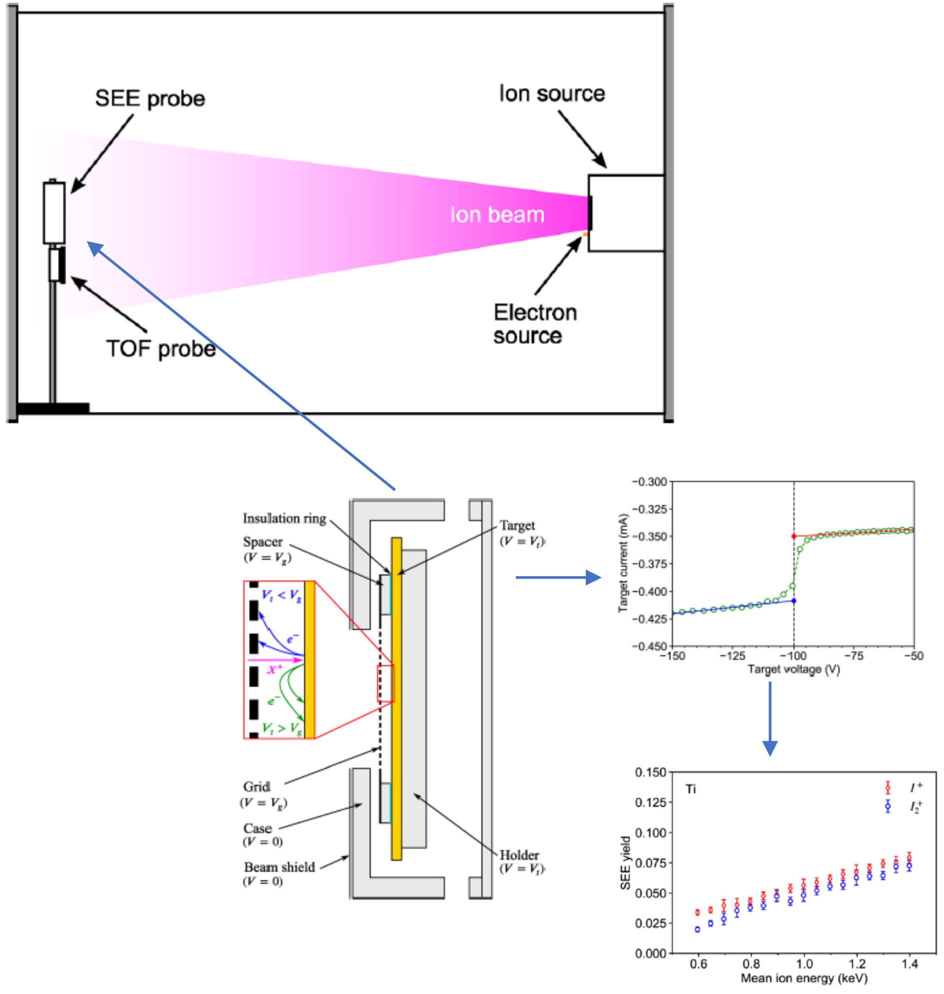


>25 materials studied, including metals and their alloys, ceramics, polymers

Short list of compatible materials identified

Fundamental studies:

First ever measurements of secondary electron emission yields (J. Appl. Phys. **129**, 153302 (2021))



Read more: IEPC 2019-811

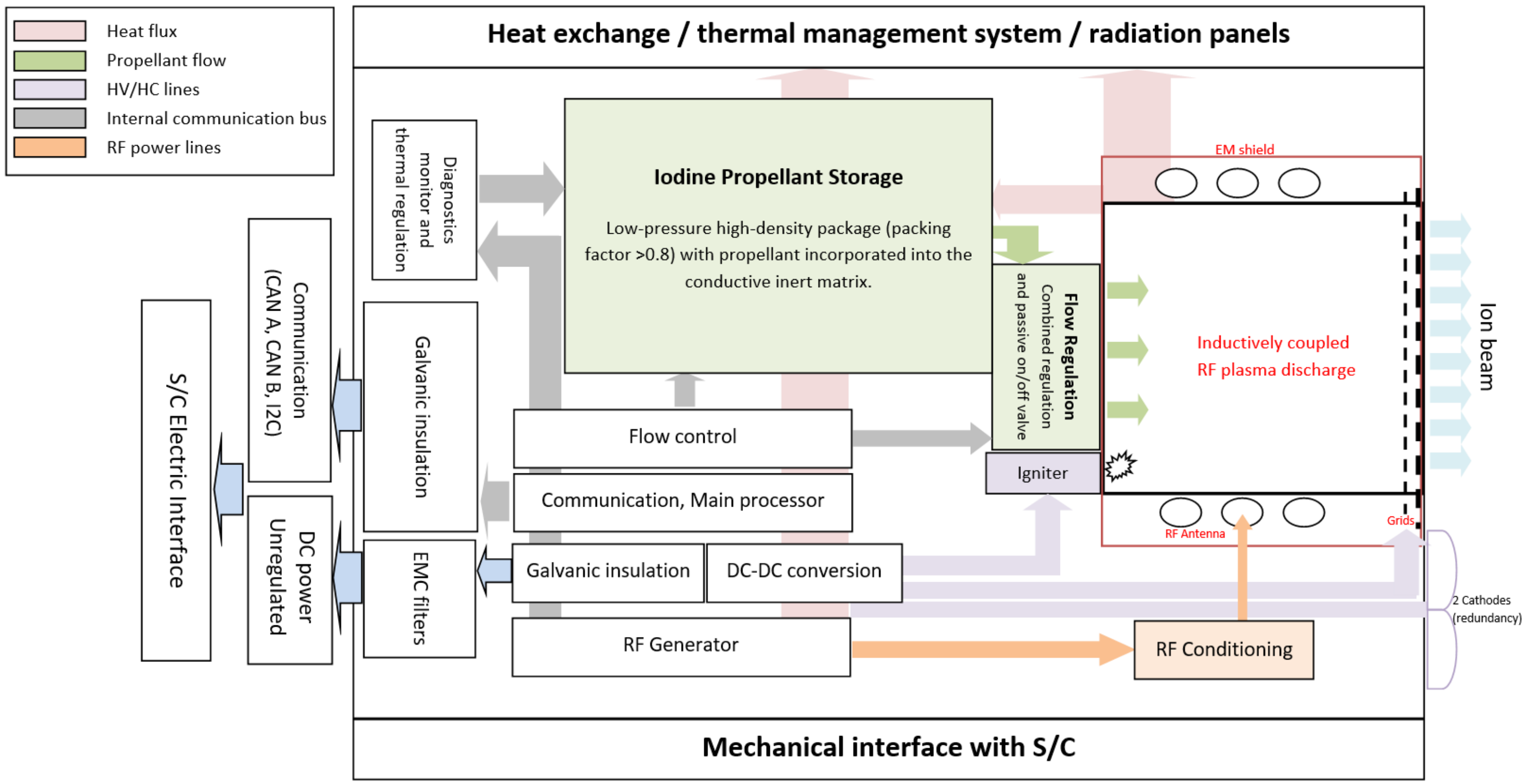
NPT30-I2: System architecture

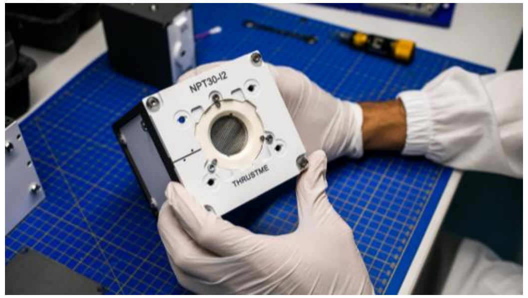
Need to rethink the entire system for operating with iodine

NPT30-I2
Iodine ion thruster

- Integrated tank
- Direct sublimation control
- Fully autonomous system
- Filament neutralizer

NPT30-I2 architecture: internal schematics (simplified)





NPT30-I2: System development and testing

NPT30-I2

Iodine ion thruster

- Integrated tank
- Direct sublimation control
- Fully autonomous system
- Filament neutralizer

Basic studies (2014-2019)

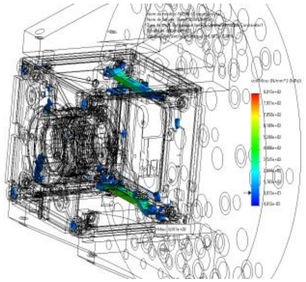
Re-adaptation of *Xe* version to I_2 (2019)
- Initially I_2 oriented NPT30-Xe thruster head
- Propellant storage and management from I2T5

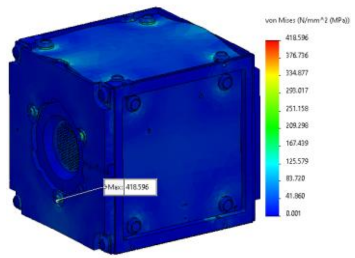
Operational testing (2019-2020)
- 2 test units (generic prototype and EQM)
- ~150 hrs of operation, 126 firing cycles
- Lifetime assessment, performance mapping

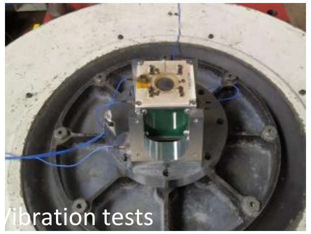
Launch qualifications and flight testing (2020-2021)
- Vibration, Shock
- Thermal ambient, TVAC cycling
- EMC
- Orbital maneuvers

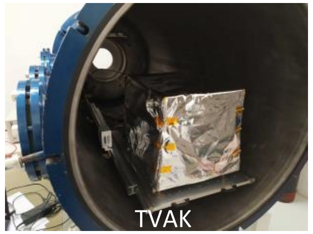
Industrialization and upscaling (2021)
- 3 deliveries in 2020
- >20 deliveries in 2021

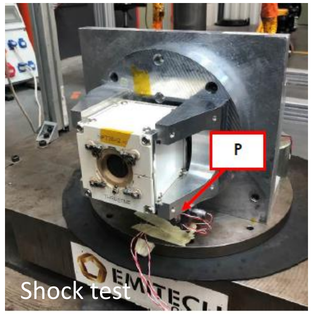

EQM operational testing

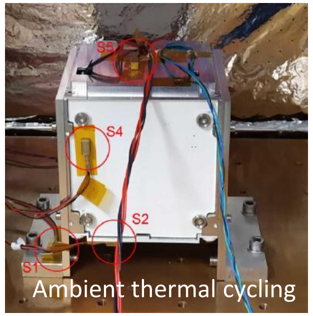





Vibration tests


TVAK


Shock test

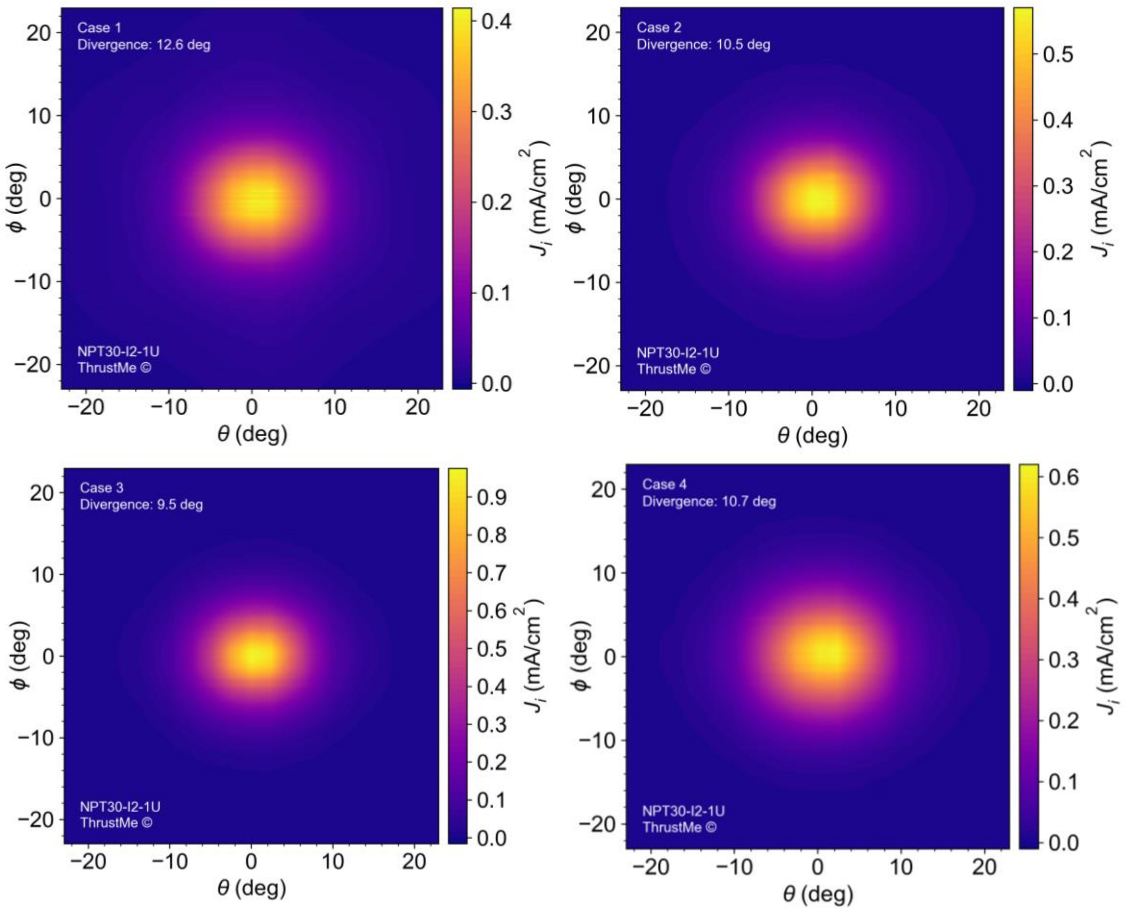

Ambient thermal cycling

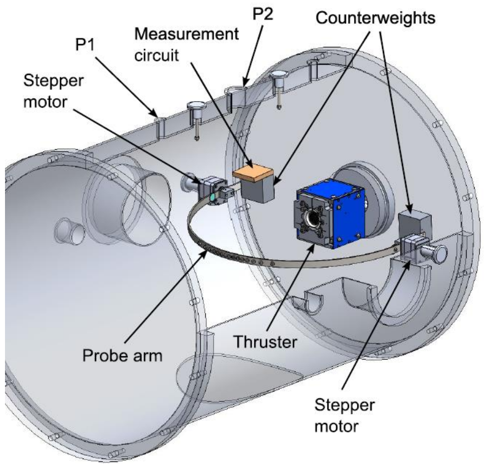
Iodine for EP: system development

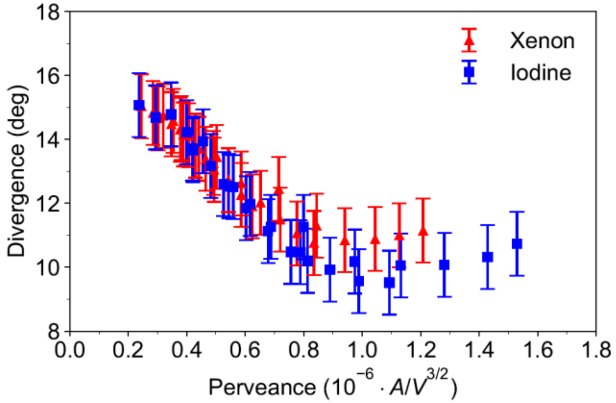
Iodine ion thruster characterization:

- Ion beam composition
- Ion beam profiles
- Thrust correction coefficients
- Performance mapping

Ion beam divergence with iodine:







Review of Scientific Instruments, *91*(9), 093501

Ion beam divergence is similar to xenon

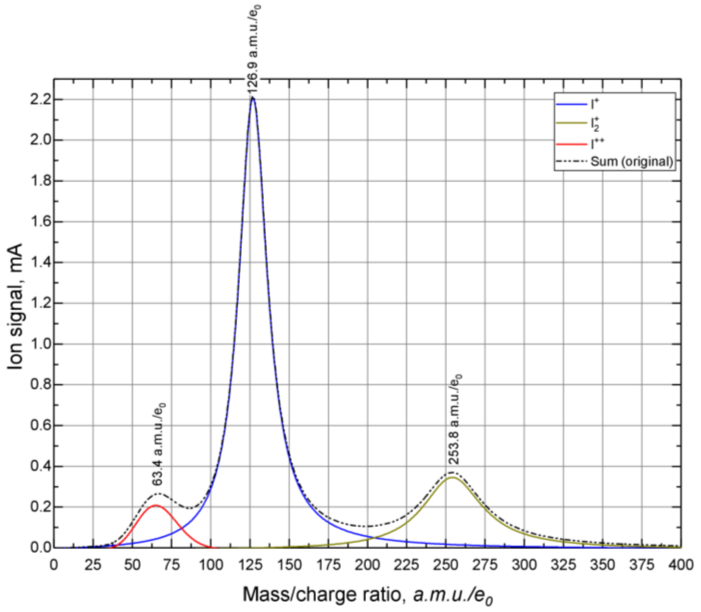
Iodine for EP: Fundamental problems

Iodine ion thruster characterization:

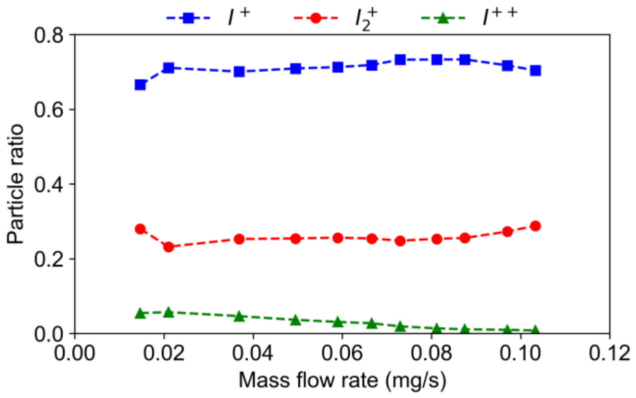
- Ion beam composition
- Ion beam profiles
- Thrust correction coefficients
- Performance mapping

Dissociation rate may lead to large impact on a thrust:

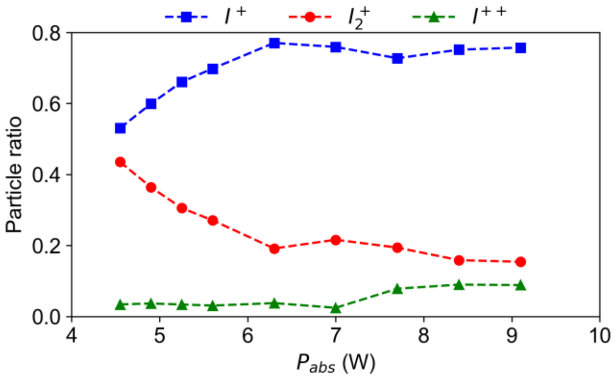
Time-of-flight mass spectrometry:



Dissociation: Evolution with flow rate



Dissociation: Evolution with discharge power



- Xenon ion beam is typically composed of Xe^+ and small fraction of Xe^{++}
- Iodine has complex dissociation processes

Iodine for EP: Fundamental problems

Iodine ion thruster characterization:

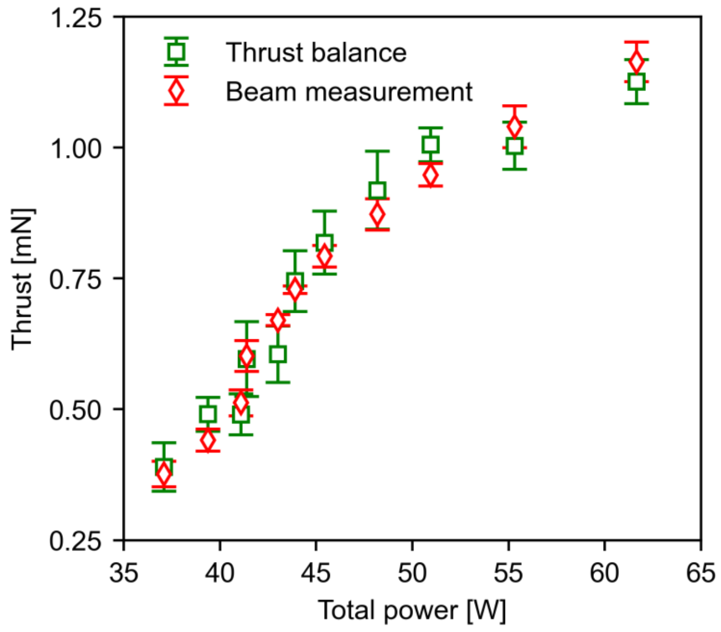
- Ion beam composition
- Ion beam profiles
- Thrust correction coefficients
- Performance mapping

Thrust: $T = \alpha\gamma\sqrt{\frac{2M_i}{e}}I_i\sqrt{V_{acc}}$

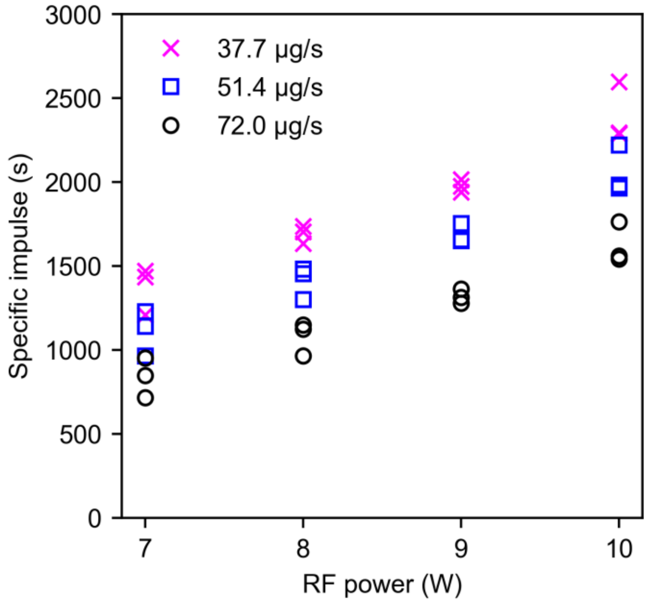
Divergence correction: $\gamma = cos\Theta_{div}$

Composition correction: $\alpha = \beta_{I+} + \sqrt{2}\,\beta_{I_2+} + {}^{1}/_{\sqrt{2}}\,\beta_{I^{++}}$

Thrust with correction coefficients applied:



Isp vs RF power, flow rate and acceleration voltage

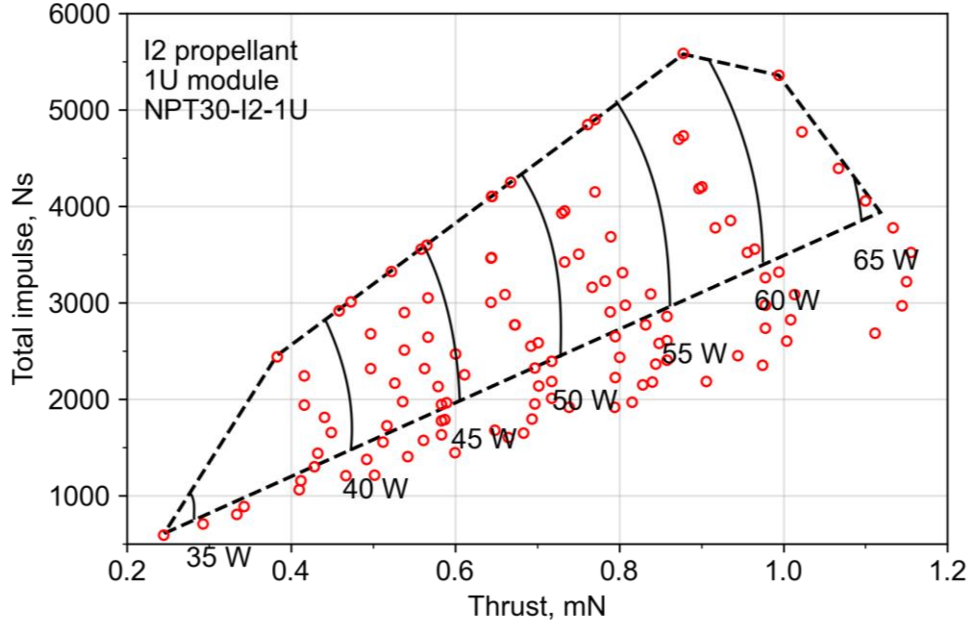


NPT30-I2: performance mapping

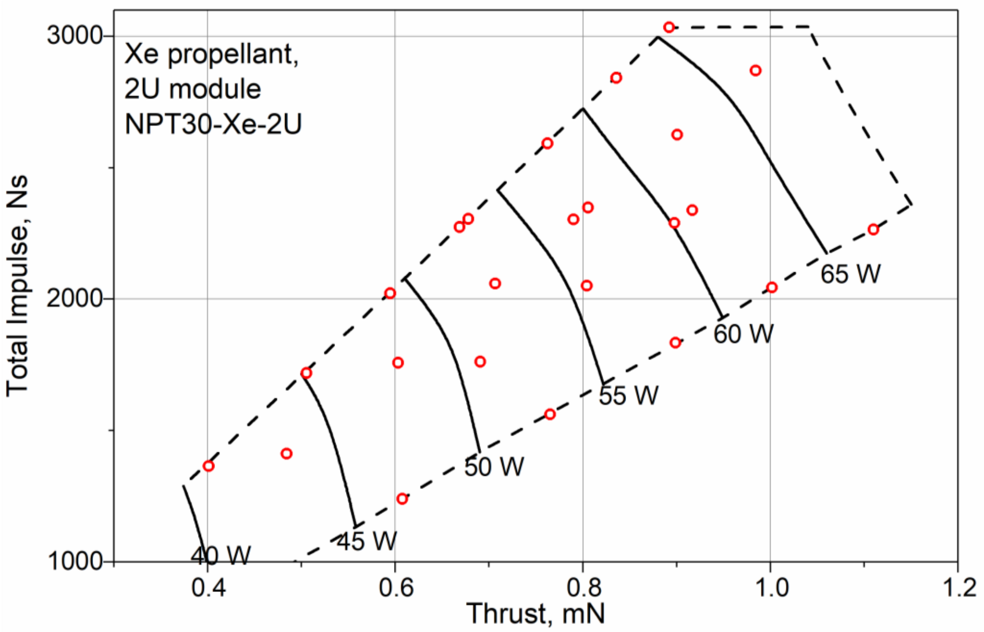
Iodine ion thruster characterization:

- Ion beam composition
- Ion beam profiles
- Thrust correction coefficients
- Performance mapping

Iodine:

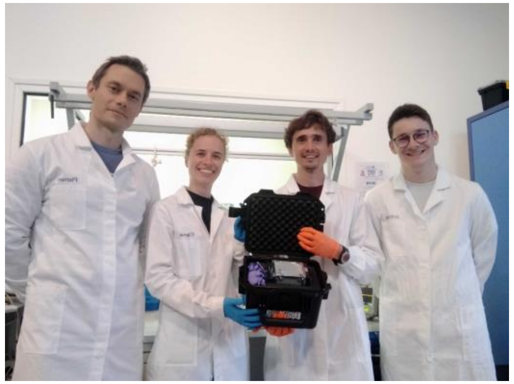


Xenon:

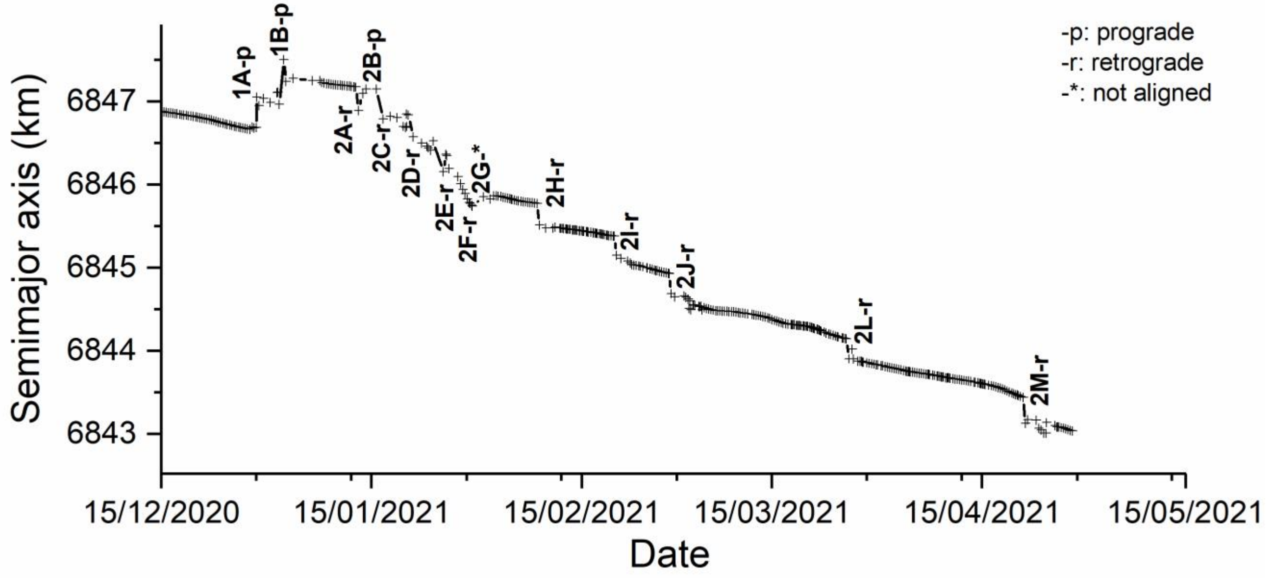


NPT30-I2: Space flight

Launch: 6th of November 2020 onboard 12U Beihangkongshi-1 (SpaceTy)



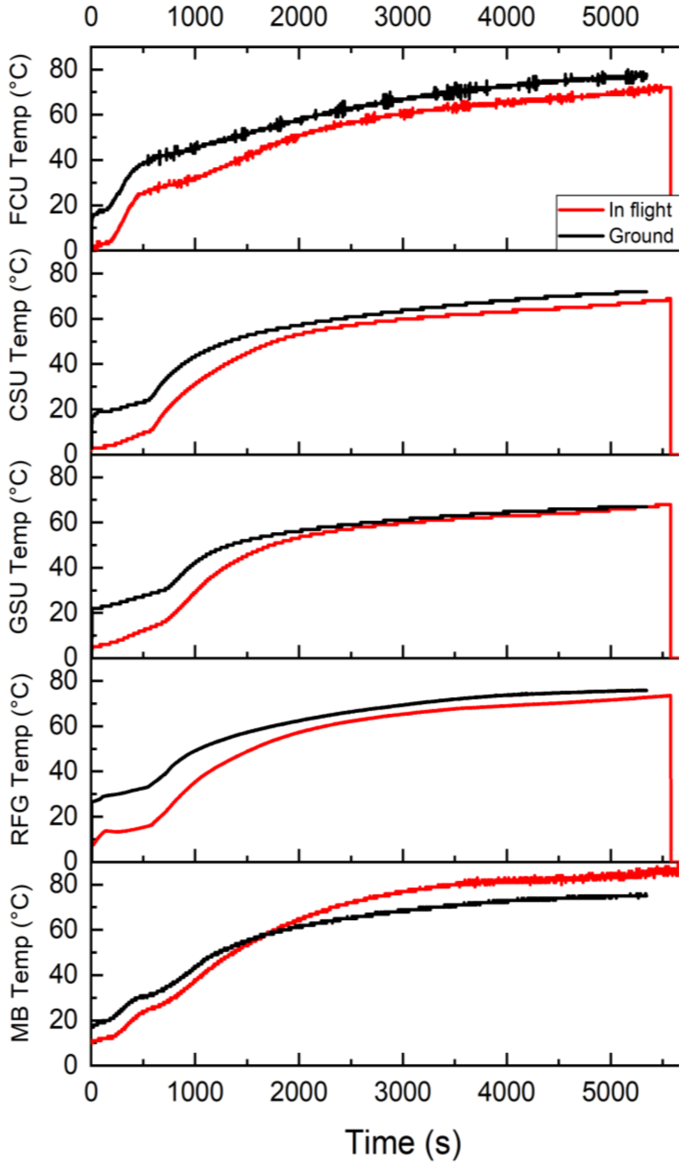
Maneuvers



Mean semi-major axis of the Beihangkongshi-1 satellite as a function of time obtained with Space-Track data. The arrows and labels indicate different NPT30-I2 firing tests.

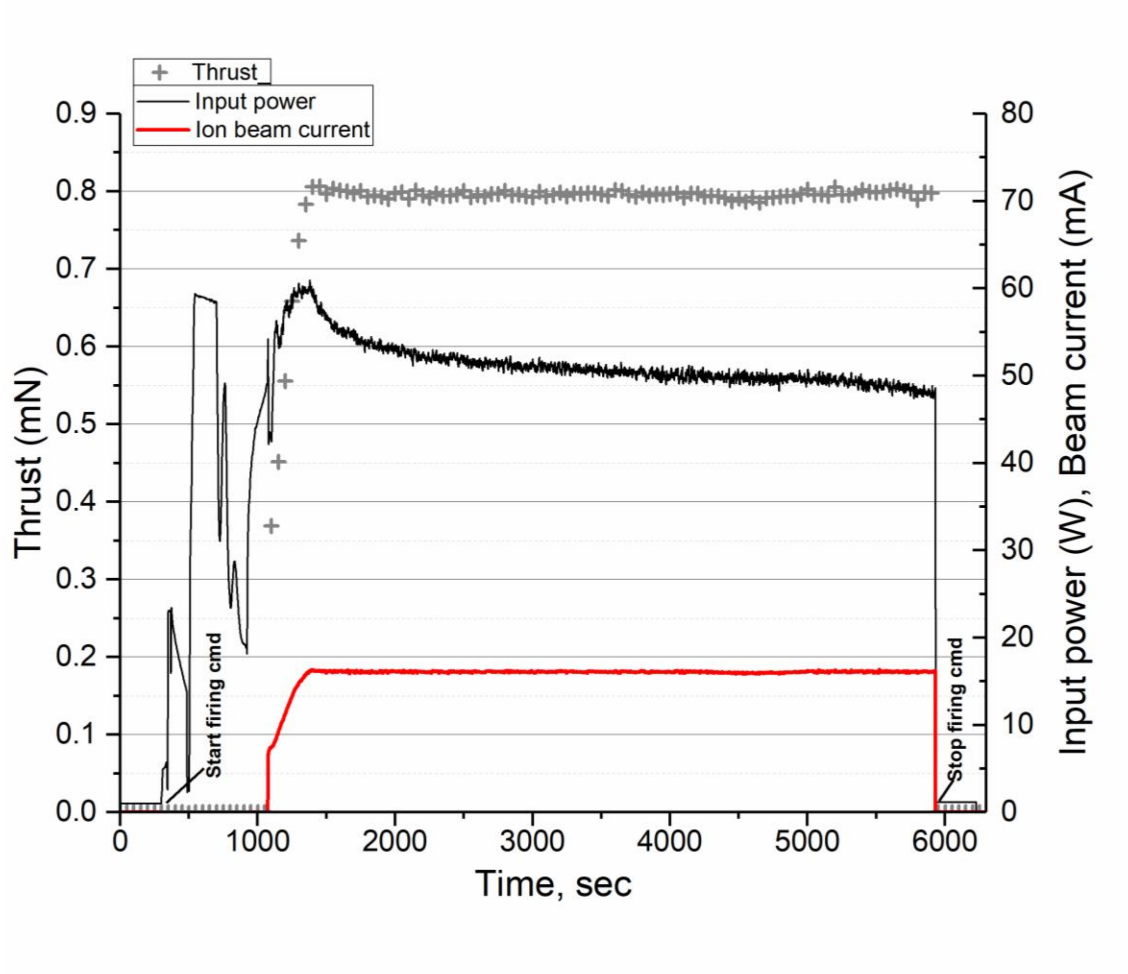
14 firings, about 4 km altitude change (mission success criteria – 1.5 km orbit change)

Thermal validation

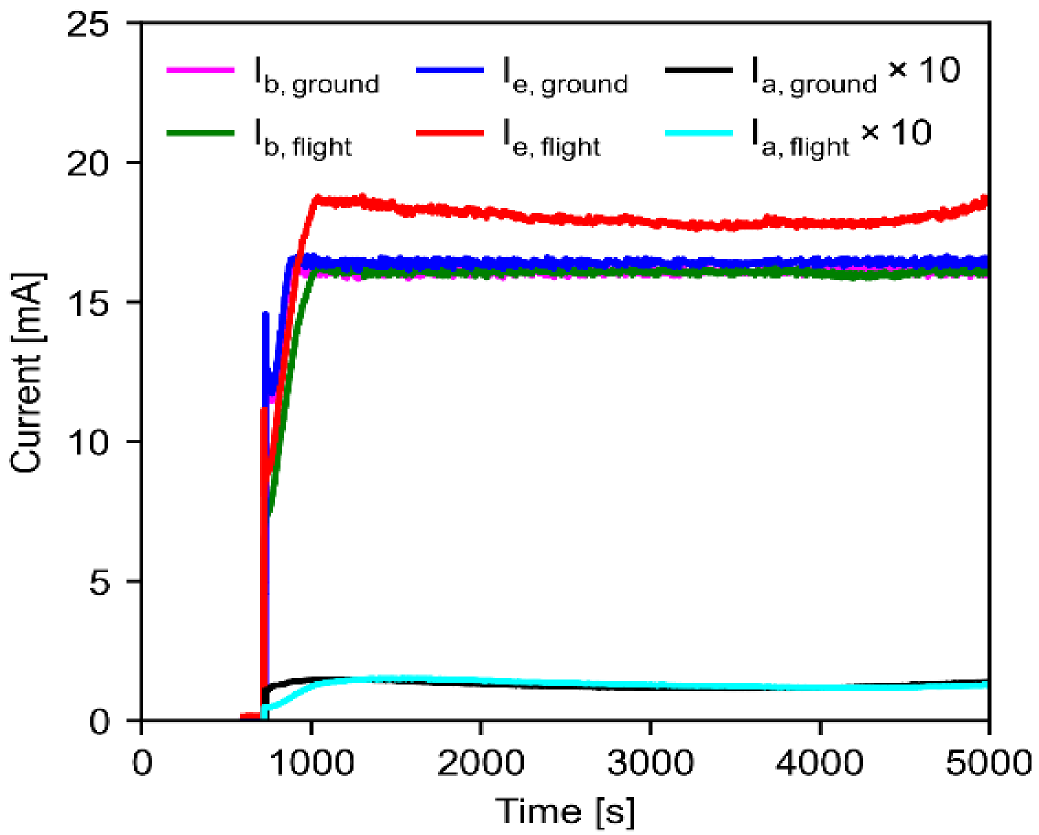


NPT30-I2: Space flight

Firing cycle example:
thrust, ion beam current and power

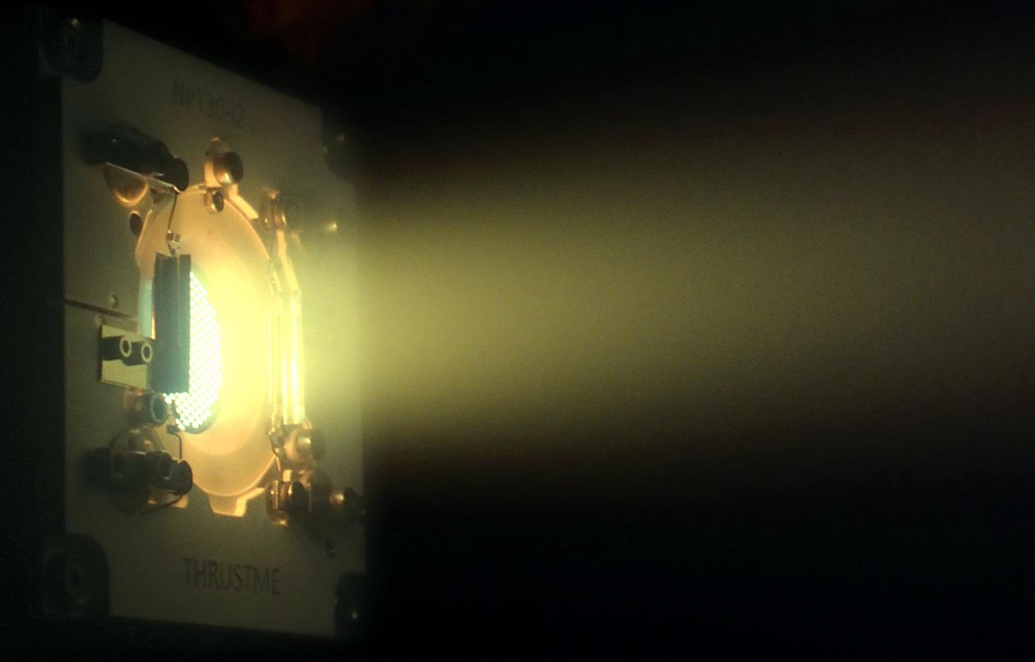


Grids and cathode currents, flight vs ground testing



Further steps

- Alternative solutions for a filament cathode
- Full scale lifetime testing
- Extending radiation range



Conclusions

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- Use of iodine for electric propulsion is successfully demonstrated in space
- 14 maneuvers with about 4 km altitude change
- System behaviour agrees with ground testing data

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CNES: INODIN grant, R&T action R-S19/PF-0002-108-92
SpaceTy: IOD provider