



THRUSTME

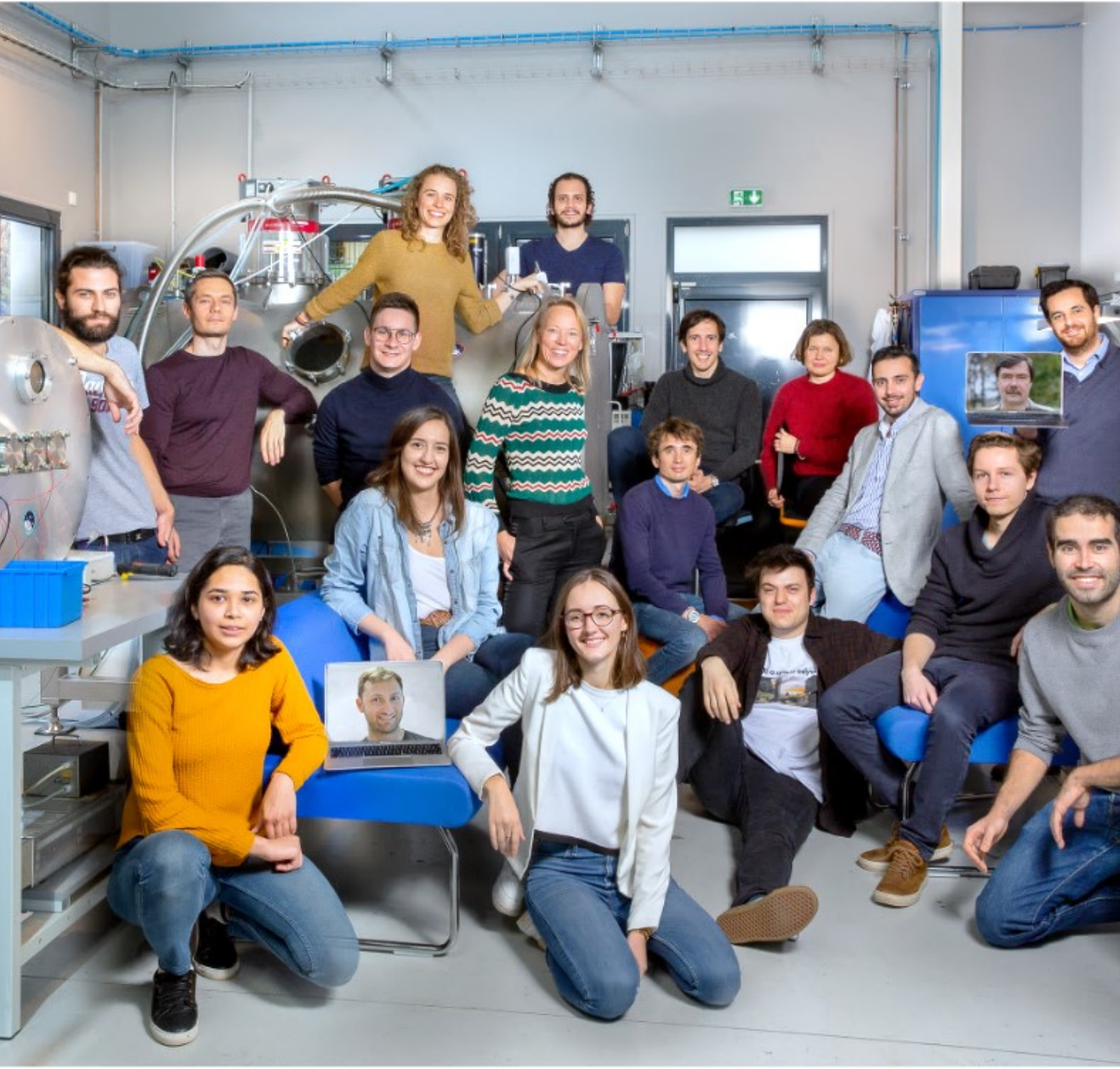
Using ions to maneuver satellites in space

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November 8, 2021

About ThrustMe



Overview

- Created in 2017
- Spin-off from LPP / CNRS
 - Plasma physics background
 - Plasma-based propulsion
 - 25+ years of research
- 20 employees
- Development of integrated space propulsion systems for **small/medium sized satellites**
 - Mainly **Gridded Ion Thrusters**
 - More... (Cold gas, resistojet, etc)

About ThrustMe

Based in Verrières-le-Buisson

12 km from Paris

5 km from Palaiseau



08/11/2021

Main lab



ThrustMe II vacuum system

- 7000 l/s pumping speed
 - 2 turbomolecular pump
- Dimensions:
 - 1.5 x 2.5 m
 - 2 sub-chambers
- Used for xenon, water and other experiments

PEGASES vacuum system

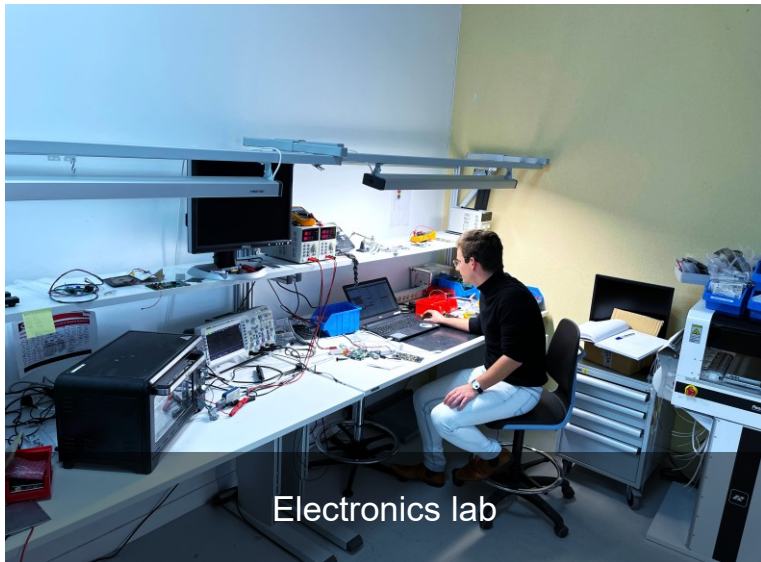
- 2500 l/s pumping speed
 - 1 turbomolecular pump
 - 1 cryogenic pump
- Dimensions:
 - 0.6 x 0.83 m
- Iodine R&D
- Used for qualifications



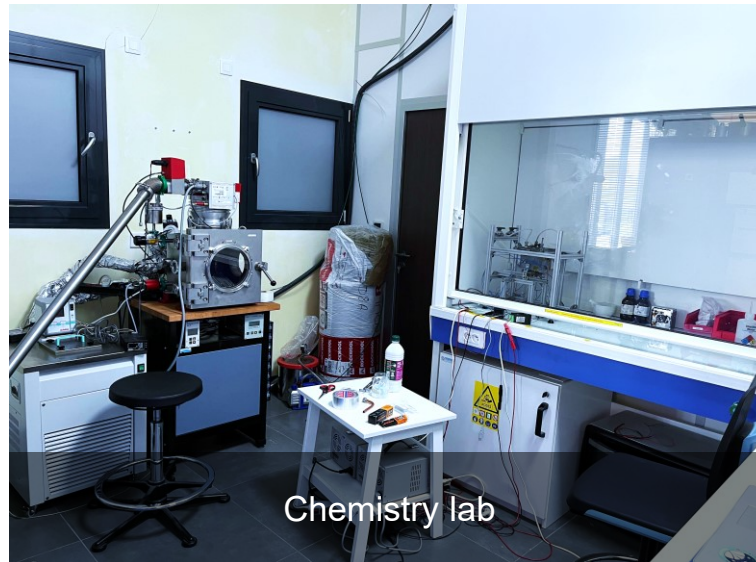
Mechanical workshop



Clean room



Electronics lab



Chemistry lab

Other facilities

Products overview



I2T5

- Cold gas thruster
- Iodine
- Very-low power solution (<15 W)
- **Flown**



NPT30

- Gridded ion thruster
- Iodine or xenon
- Fully autonomous
- 1U or 1.5U form
- Mid-power range (30-65 W)
- **Flown**



NPT30 cluster

- >2 thrusters
- Iodine
- Fully autonomous
- Integrated interface



NPT300

- Gridded ion thruster
- Iodine
- Fully autonomous
- High-power solution (>300 W)

Background

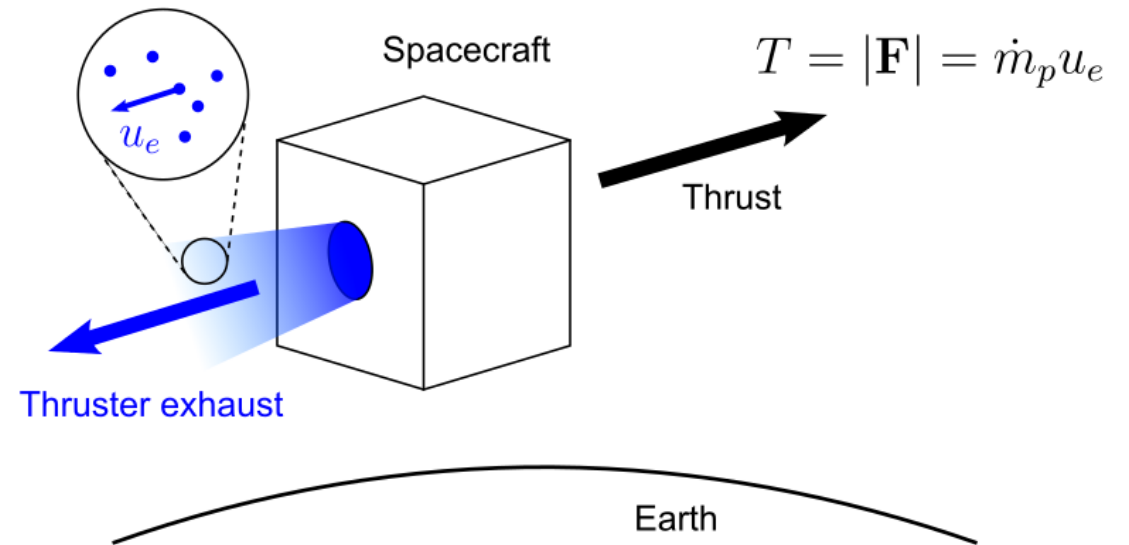
Space propulsion

- Device installed onboard the satellite / spacecraft
- Generation of thrust (**force**) on a satellite
- Just conservation of momentum
- Tsiolkovsky rocket equation:

$$\Delta v = u_e \ln \frac{m_0}{m_f}$$

$$m_0 = m_f + m_p \rightarrow \boxed{\frac{m_p}{m_0} = 1 - \exp\left(-\frac{\Delta v}{u_e}\right)}$$

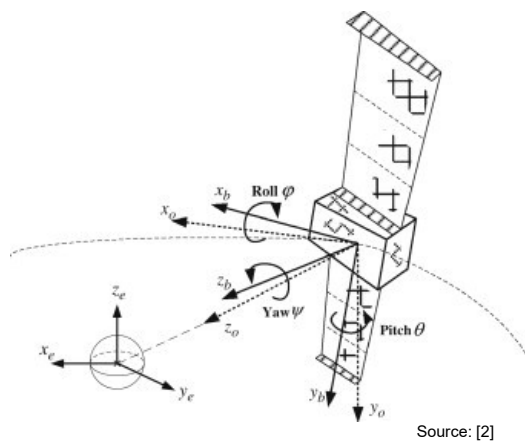
Propellant mass fraction



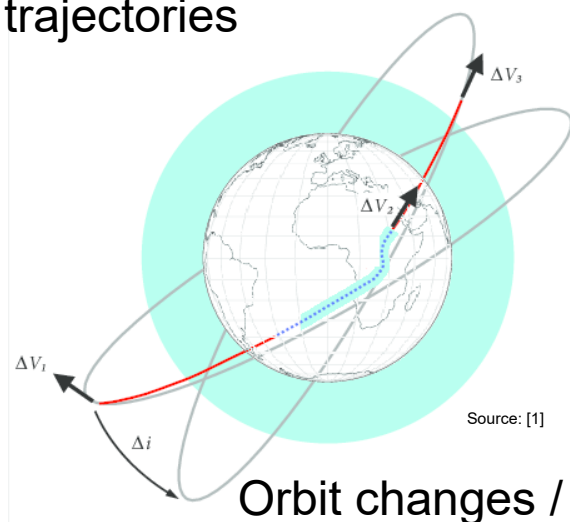
Space propulsion (why?)



Deep space trajectories



Attitude control

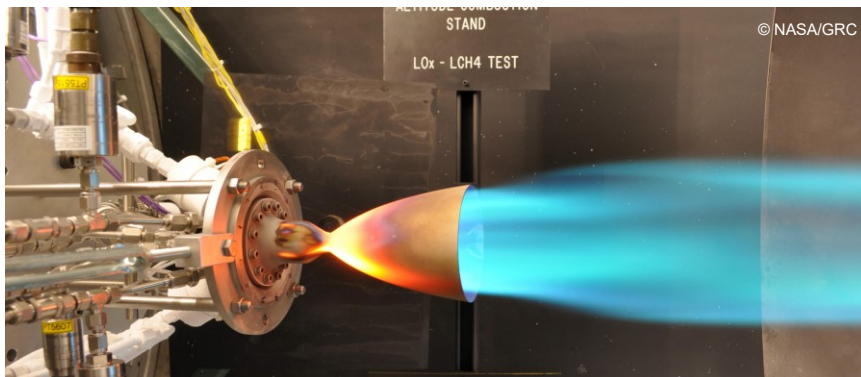


Space propulsion



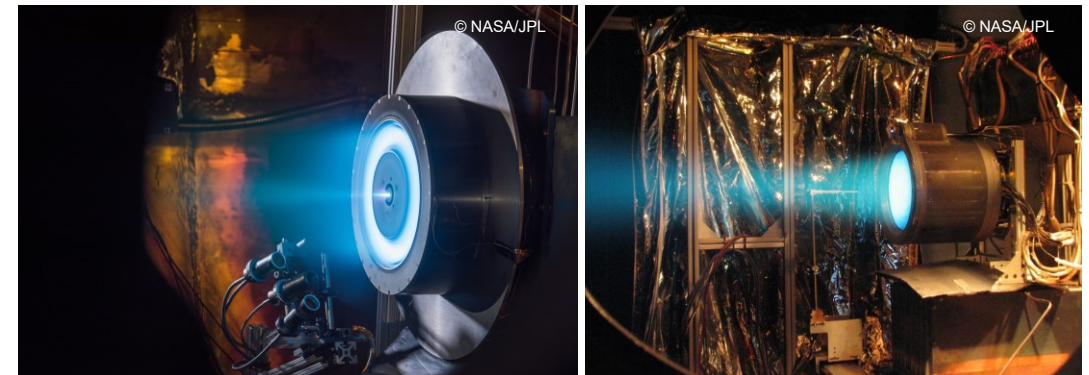
Main types

Chemical thrusters



- High thrust (1 N – 1 kN)
- Low exhaust velocity (1 – 5 km/s)
- Energy from chemical bonds
- Acceleration from thermal expansion

Electric (plasma-based) thrusters



- Low thrust (< 100 mN)
- High exhaust velocity (10 – 50 km/s)
- Energy from solar power
- Acceleration from electromagnetic fields

Why we need EP



Pros

- Less propellant required

For $\Delta v \approx 1 \text{ km/s}$

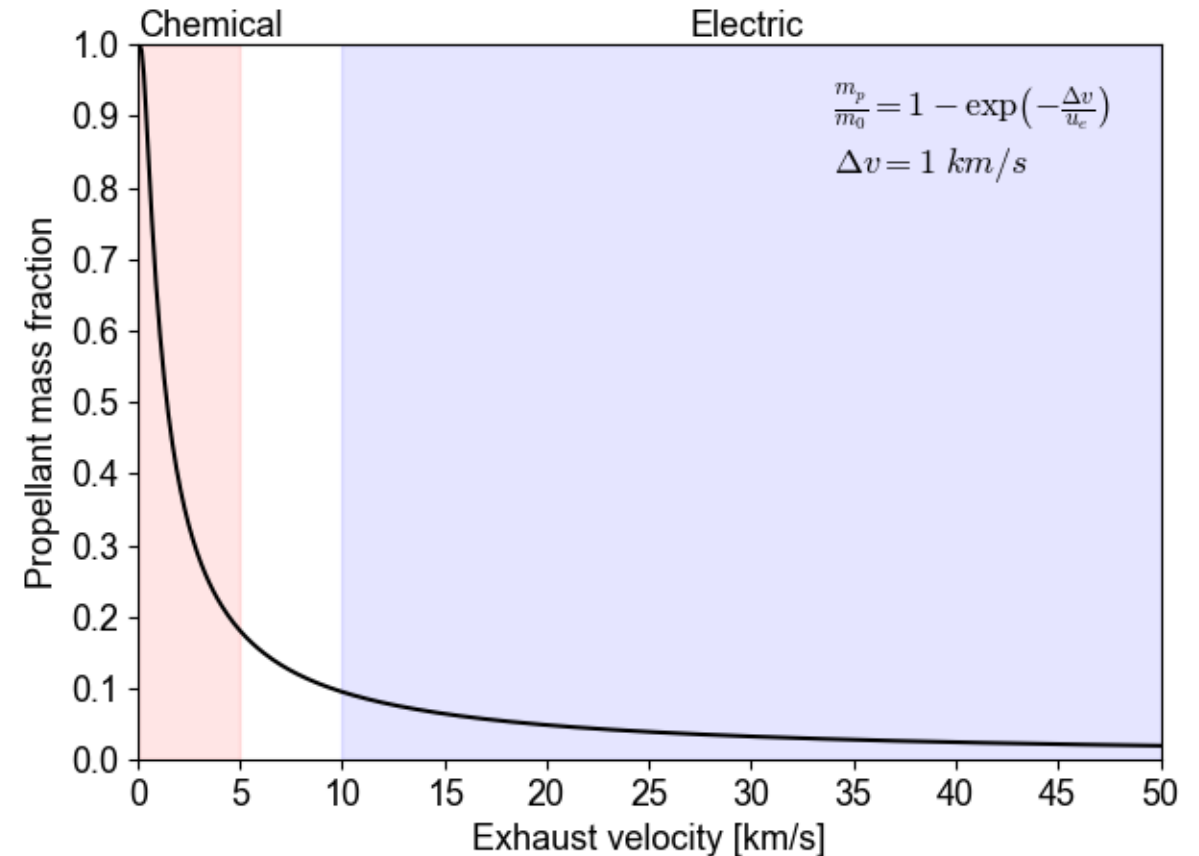
Chemical: $u_e \approx 3.5 \text{ km/s} \rightarrow \frac{m_p}{m_0} \approx 0.25$

Electric: $u_e \approx 20 \text{ km/s} \rightarrow \frac{m_p}{m_0} \approx 0.05$

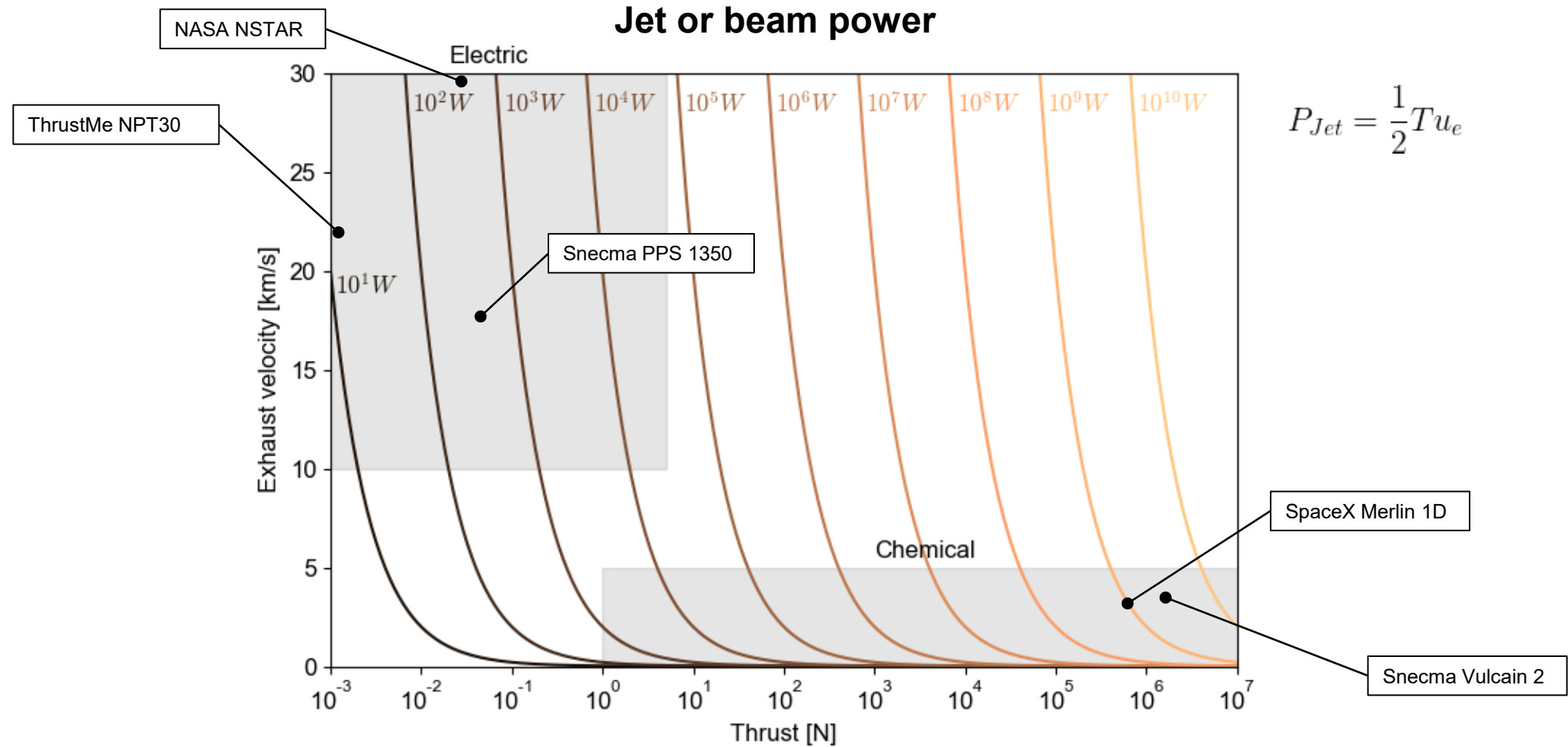
- Energy not stored (stored in the sun)
- Flexibility of propellants (Xenon, krypton, water, ...)

Cons

- Maneuvers take much more time (lower thrust)
- Spend power from satellite
- Require power hardware

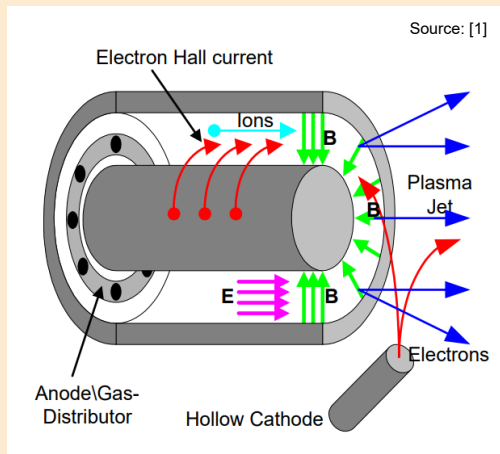


Why not always EP ?



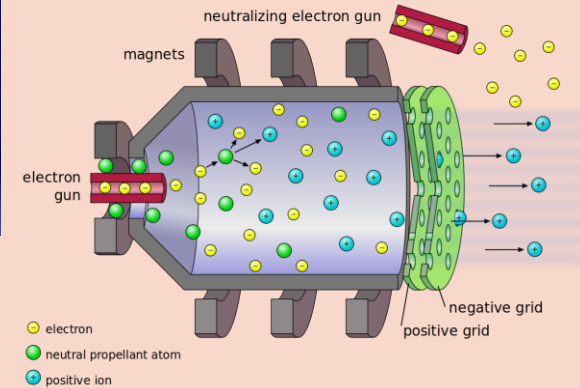
Main types

Hall thrusters



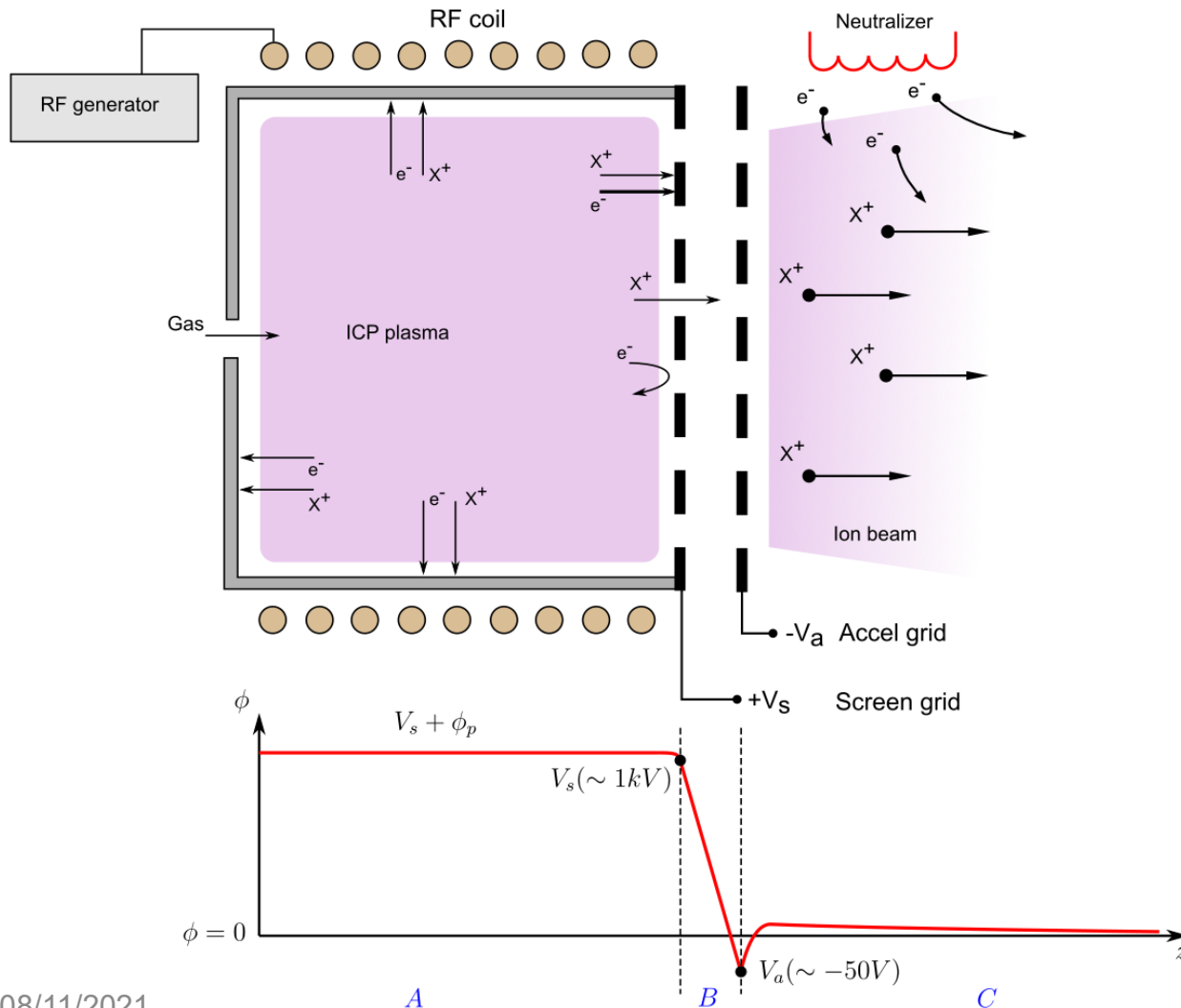
- Higher thrust
- Lower exhaust velocity (10 – 20 km/s)
- Coupled plasma generation / acceleration
- ExB electron bombardment ionization

Ion thrusters



- Lower thrust
- Higher exhaust velocity (10 – 45 km/s)
- Decoupled generation / acceleration
- Ionization: e⁻ bombardment, RF, Microwave, etc.

Ion thruster



- Approximate ion energy

$$E_i \approx V_s$$

- Average u_e

$$u_e \approx \sqrt{\frac{2eV_s}{m_i}}$$

- Average thrust

$$T \approx \dot{m}_i u_e \approx \alpha I_b \sqrt{\frac{2m_i V_s}{e}}$$

- Ion beam current (depends on power)

$$I_b \propto n_i \sqrt{T_e}$$

- α is a correction factor (divergence, doubly charged ions, ionization efficiency, etc.)

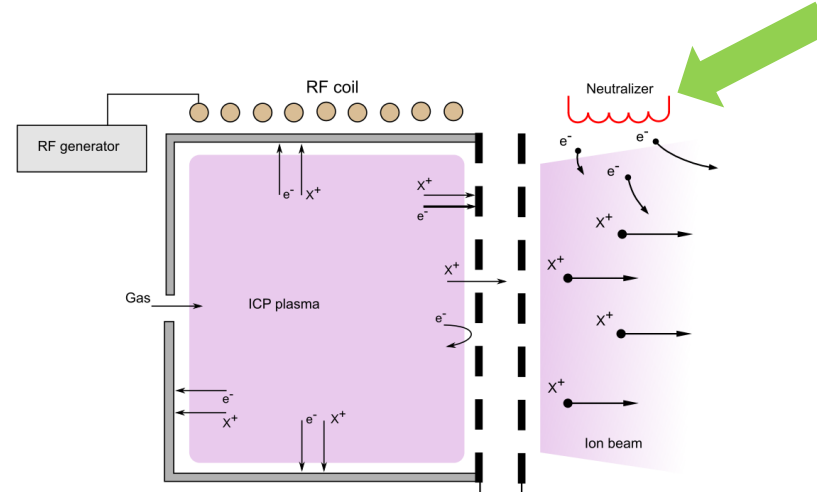
- Beam power

$$P = I_b V_s$$

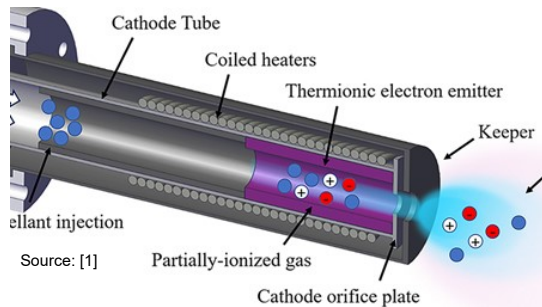
Neutralizer

Avoid:

- Spacecraft charging
- Ion beam stalling
- High plume potential



Hollow cathode

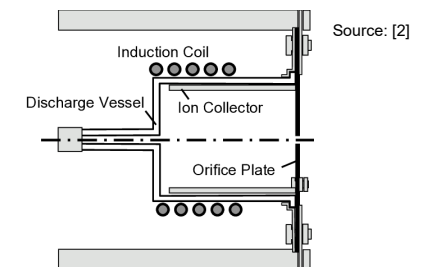


Source: [1]

© HeatWave Labs



Plasma/RF cathode



Source: [2]

Propellants



Early EP era

- Cesium
 - 3.89 eV
 - 132.9 u
 - Solid (melting: 28.4 °C)
- Mercury
 - 10.4 eV
 - 200.6 u
 - Liquid (melting: -38.3 °C)

Important factors

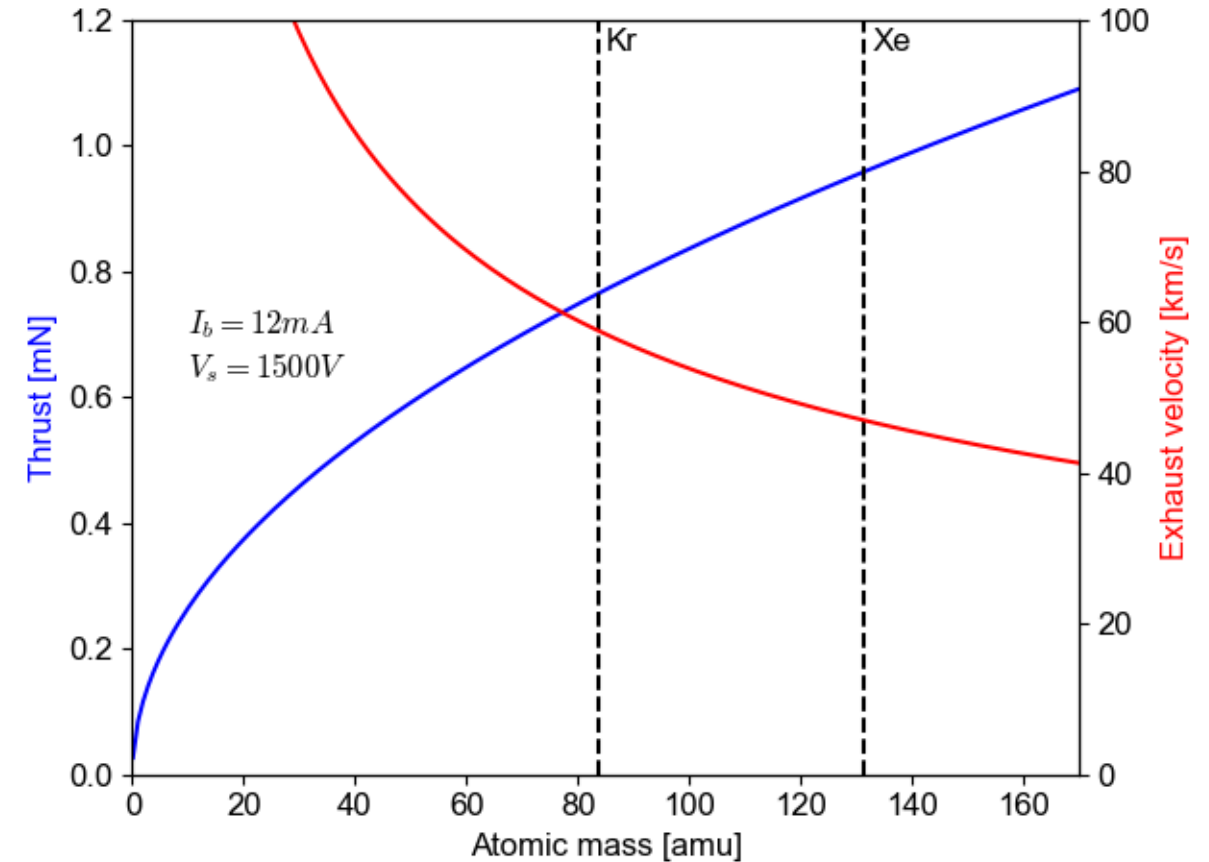
- Ion mass
 - Thrust / time
- Ionization potential
- Molecular dynamics
- Storage (density) / pressure
- Price

Most used now

- Xenon
 - 12.1 eV
 - 131.2 u
 - Gas
- Krypton (Starlink / HT)
 - 13.9 eV
 - 84 u
 - Gas

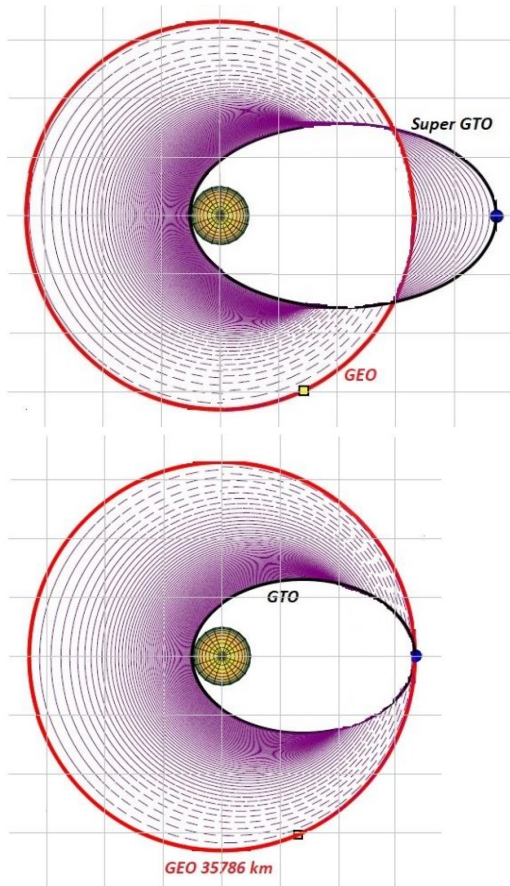
Main problems

- Xenon
 - Price
 - Pressure tank (~150 bar)
- Krypton
 - Low mass
 - Pressure tank (~150 bar)

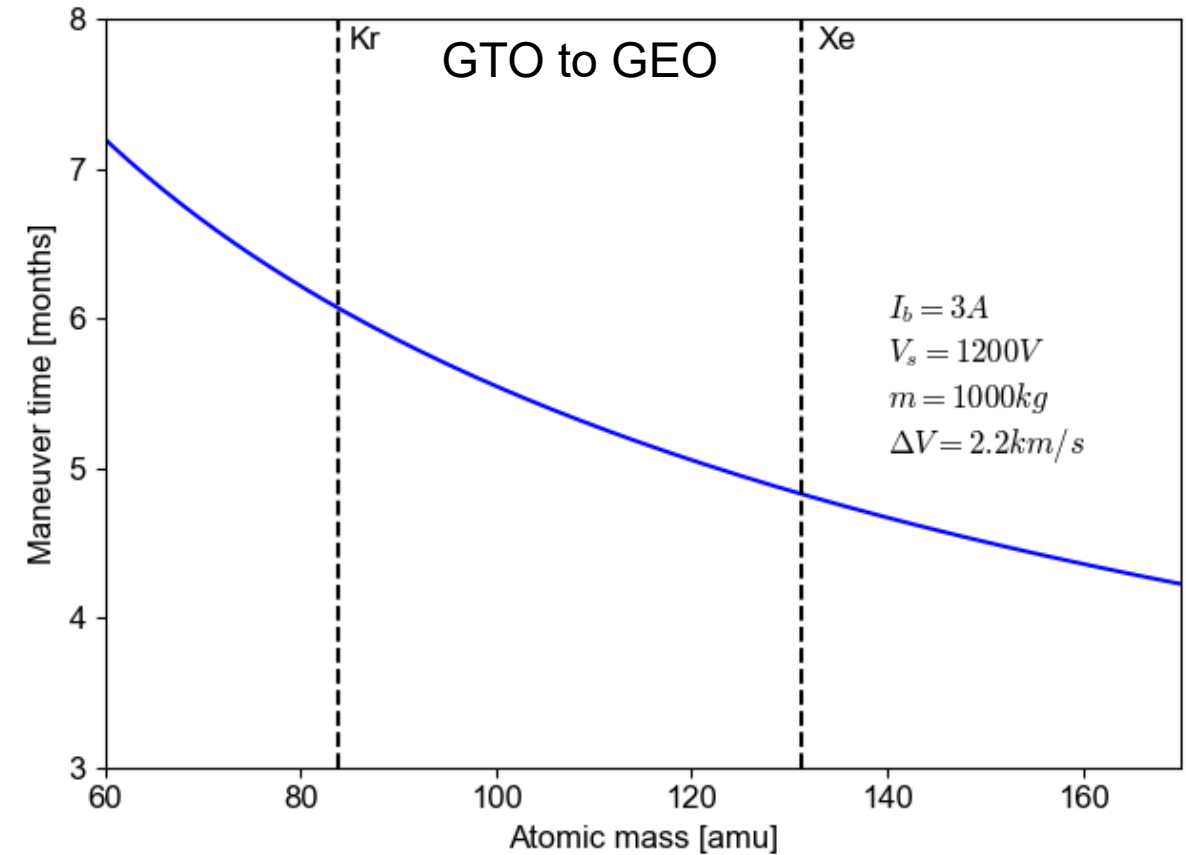


$$u_e \approx \sqrt{\frac{2eV_s}{m_i}} \quad T \approx \dot{m}_i u_e \approx \alpha I_b \sqrt{\frac{2m_i V_s}{e}}$$

Propellants



- Ion mass impacts thrust / exhaust velocity
- Time is critical
- Minimize maneuver time
- Chemical thruster:
 - GTO-GEO: < 1 month



Source: [1]

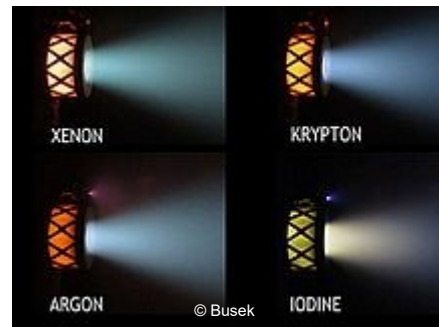
Iodine

Pros

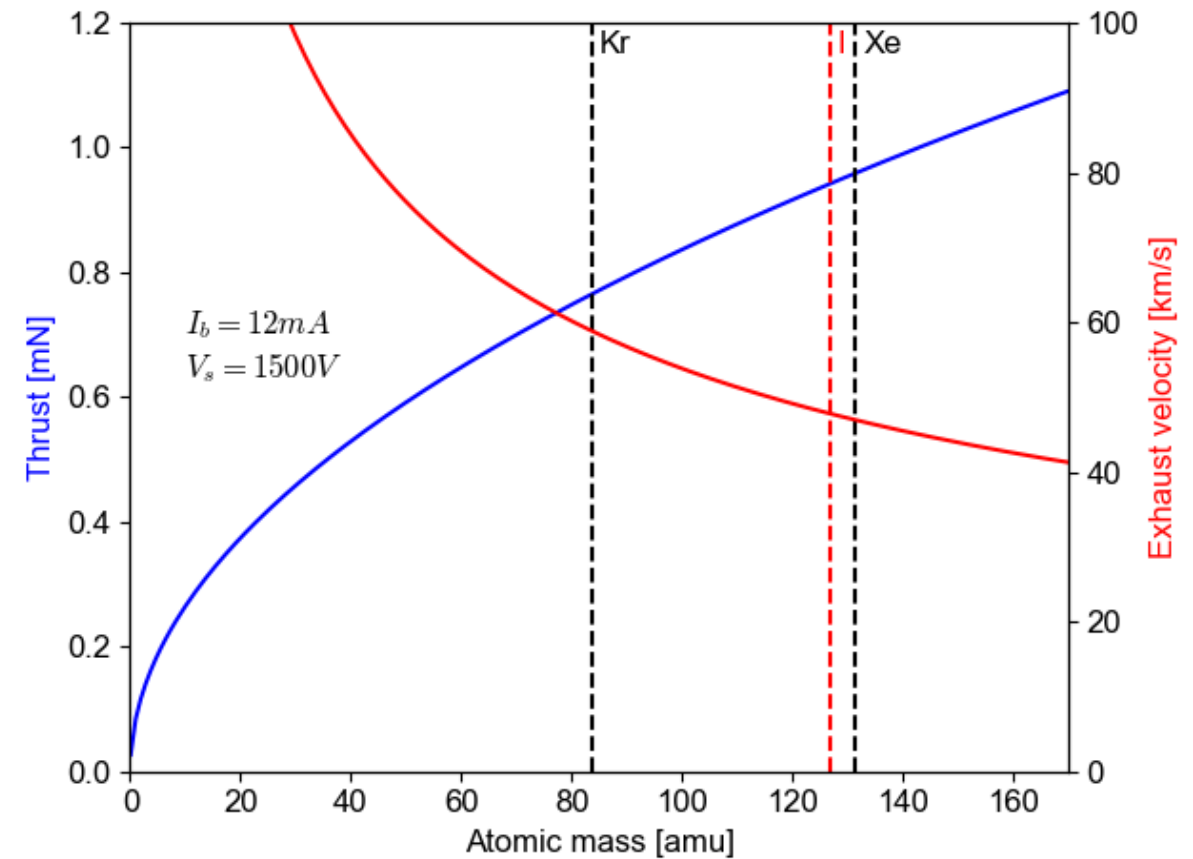
- Atomic mass: 126.9 u
- Ionization energy: 10.45 eV
- Solid-state / high-density
- Possibility of having molecular ions (I_2^+)

Cons

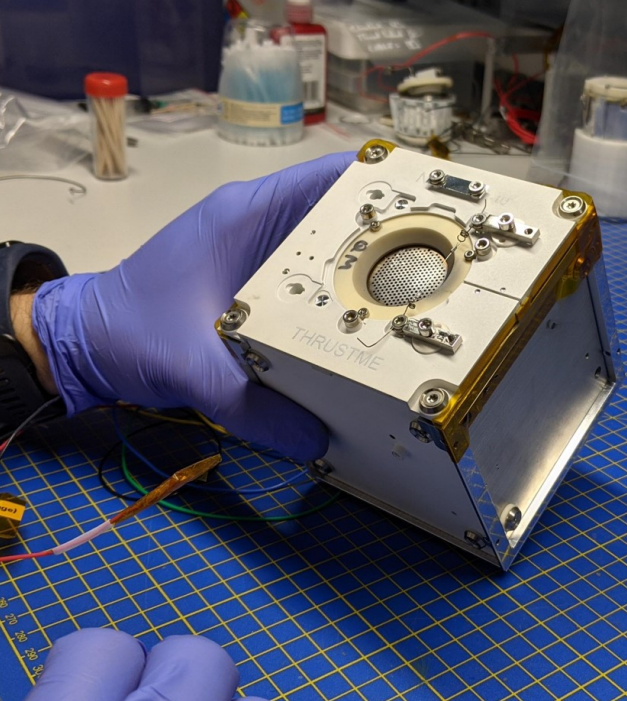
- Lack of fundamental data
- Complex chemistry and physical processes
- Engineering challenges because of corrosion



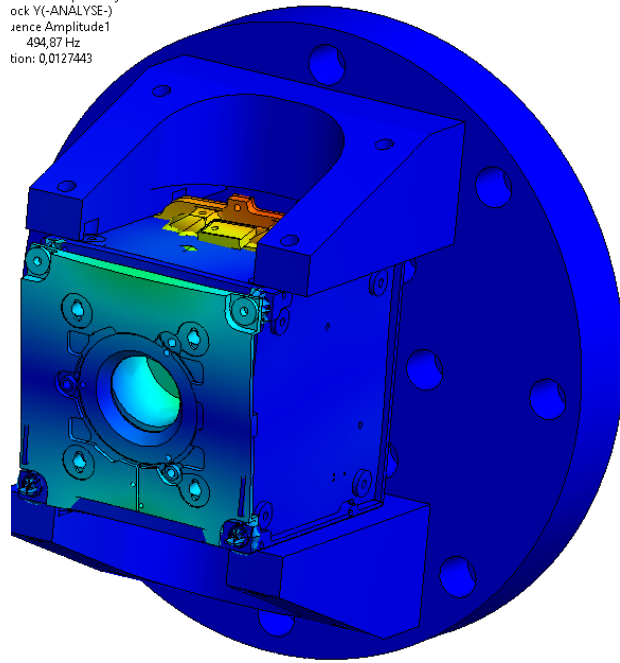
Source:
https://commons.wikimedia.org/wiki/File:RF_Ion_Propellants.jpg





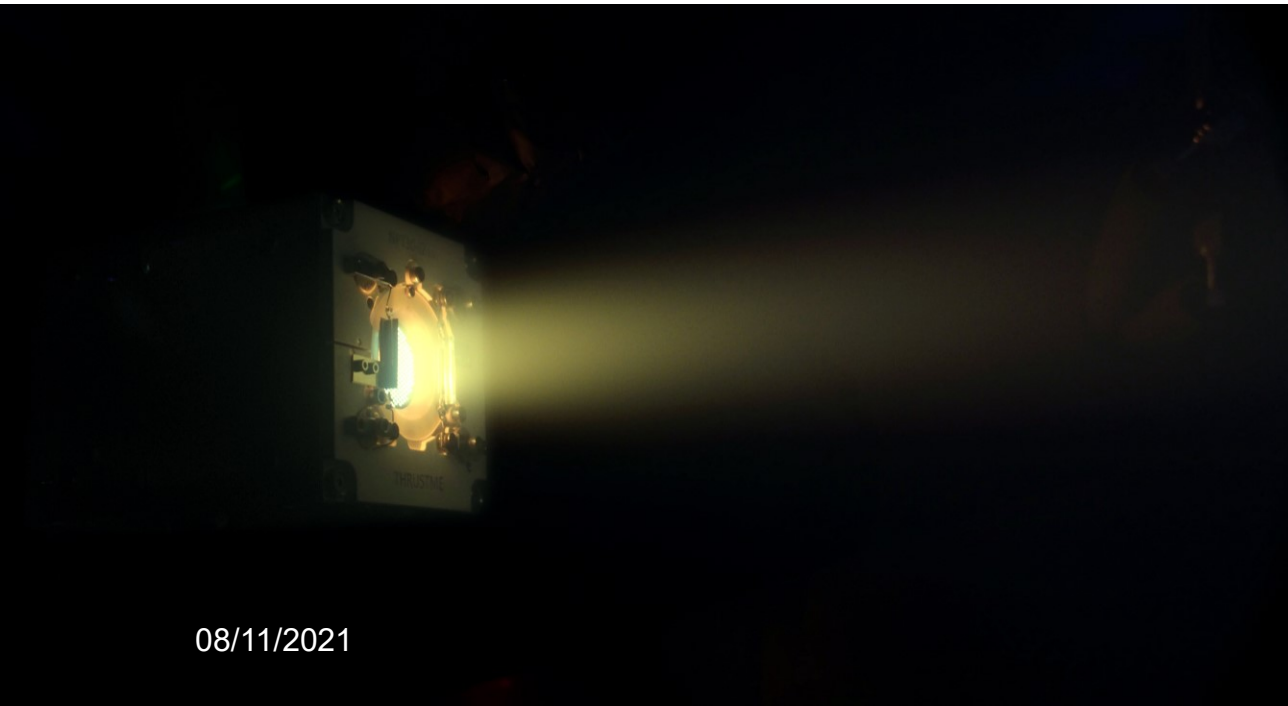


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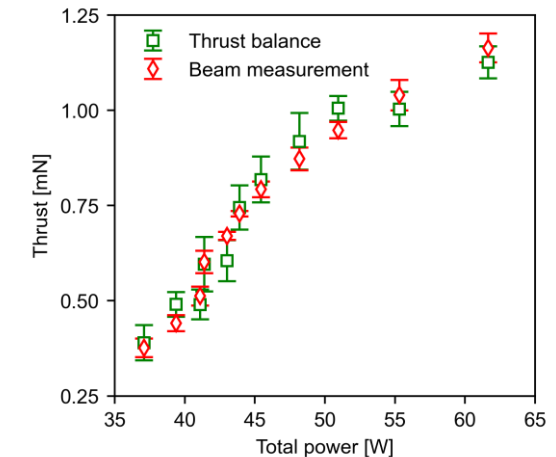
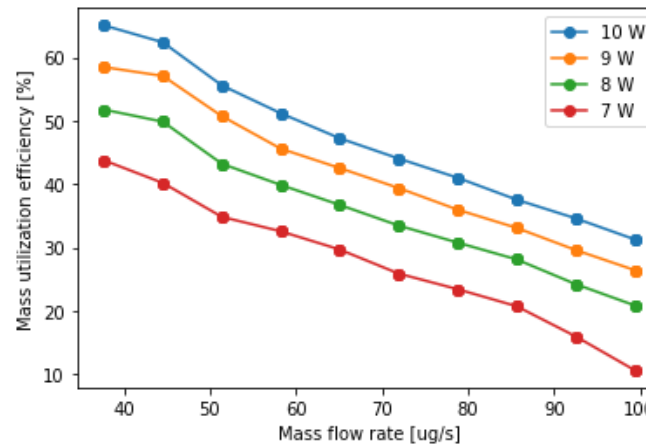
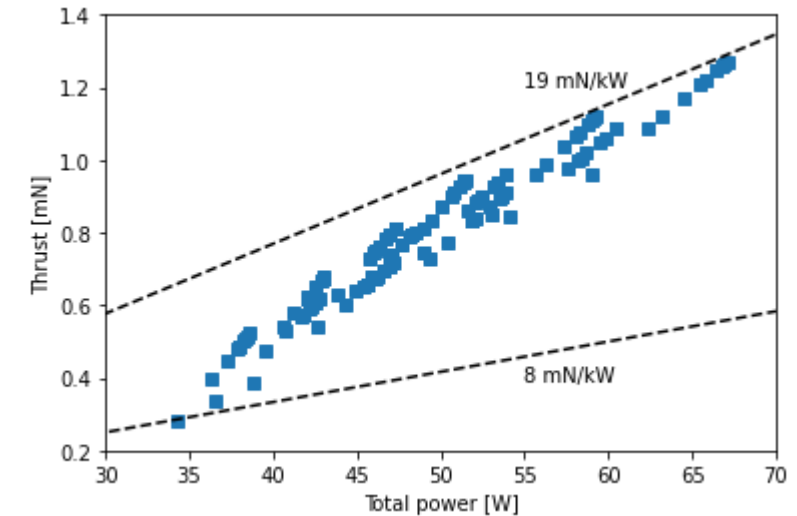
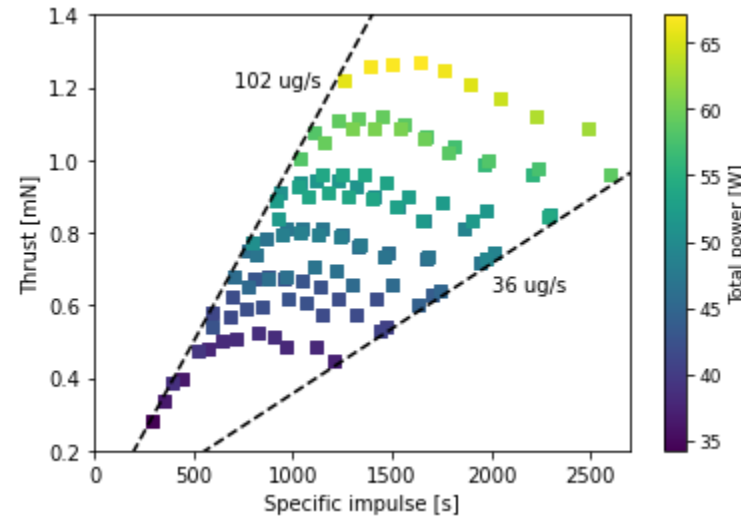
Overview

- Miniaturized propulsion system
- Sizes: 1U and 1.5U (CubeSat form factor)
- Based on an RF **ion thruster**
- Propellants: Xenon and Iodine



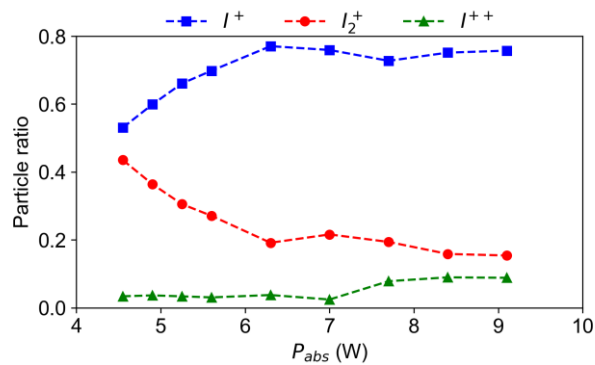
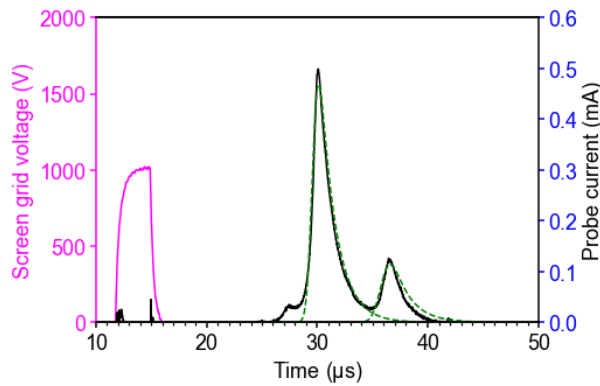
Key results

- **Thrust:** 0.25 – 1.3 mN
- **Total power:** 35 – 67 W
- **Exhaust velocity:** 2.5 – 25 km/s
- **Mass utilization eff.:** up to 63%
- **Thrust-to-power ratio:** 8 – 19 mN/kW
- Validation by **direct thrust measurement**
 - **Needs complex thrust measurement system**

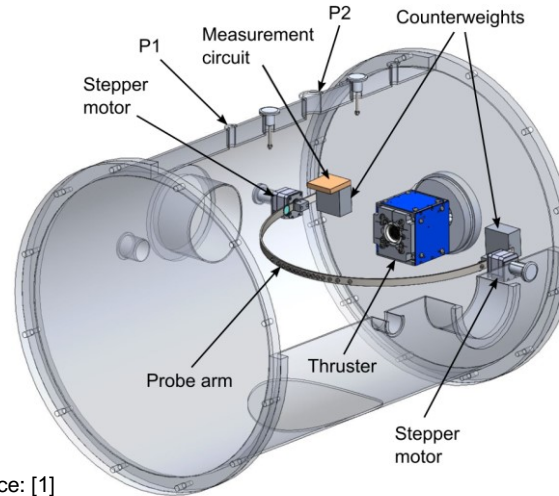


Key results

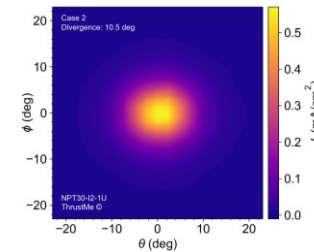
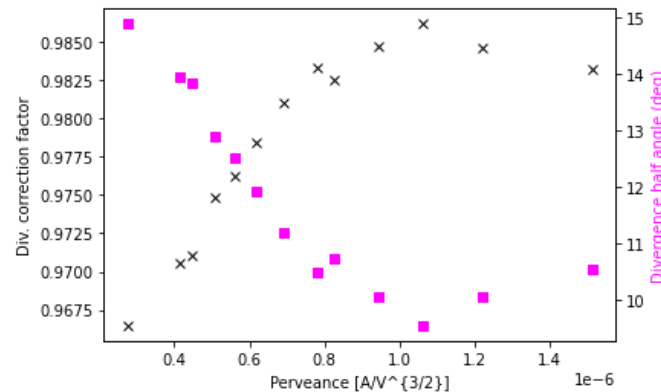
TOF/Composition



Beam divergence



Source: [1]



Thrust estimation

$$T = \overbrace{k_{div}^{\alpha} k_c}^{\alpha} I_b \sqrt{\frac{2m_i V_s}{e}}$$

- Divergence factor:

$$k_{div} = \cos \theta_{div}$$

- Beam composition factor:

$$k_c = \frac{I_{I^+}}{I_b} + \sqrt{2} \frac{I_{I_2^+}}{I_b} + \frac{1}{\sqrt{2}} \frac{I_{I^{2+}}}{I_b}$$

[1] L. Hahl, D. Rafalskyi, and T. Lafleur, "Ion beam diagnostic for the assessment of miniaturized electric propulsion systems," *Review of Scientific Instruments*, vol. 91, no. 9, p. 093501, Sep. 2020, doi: [10.1063/5.0010589](https://doi.org/10.1063/5.0010589).

A spin-off (I2T5)



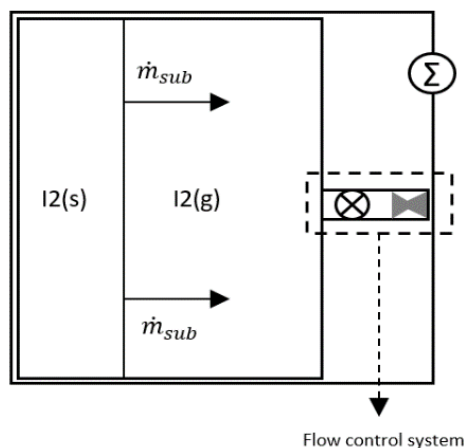
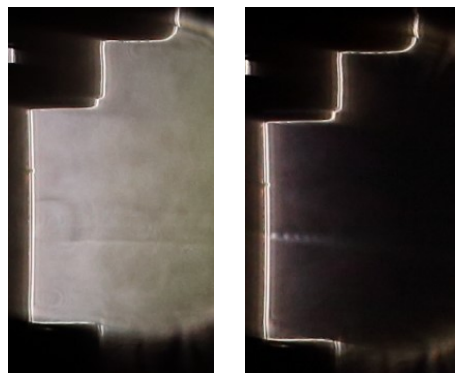
- NPT30 tank → Cold gas thruster
- Used as proof-of-concept for NPT30
- Low-cost solution for very small satellites

PERFORMANCE & SPECIFICATIONS

Thrust	up to 0.35 mN
Total impulse	up to 75 Ns
Form factor	0.5 U
Total wet mass	0.9 kg
Power consumption	<1 W standby 5 W in steady state firing
Start-up time	10 min

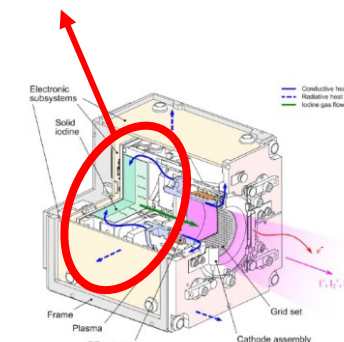
INTERFACE

Input Voltage	12 – 28 V
Bus interface	I ² C, CAN



EXAMPLE

Platform	Form Factor	3 U
	Total Mass	4 kg
Environment	Altitude	400 km
	Avg. Atm. Density	3.04E-12 kg/m ³
I2T5	x2 Collision Avoidance 1km	0.57 m/s
Propulsion	Drag compensation	17.61 m/s

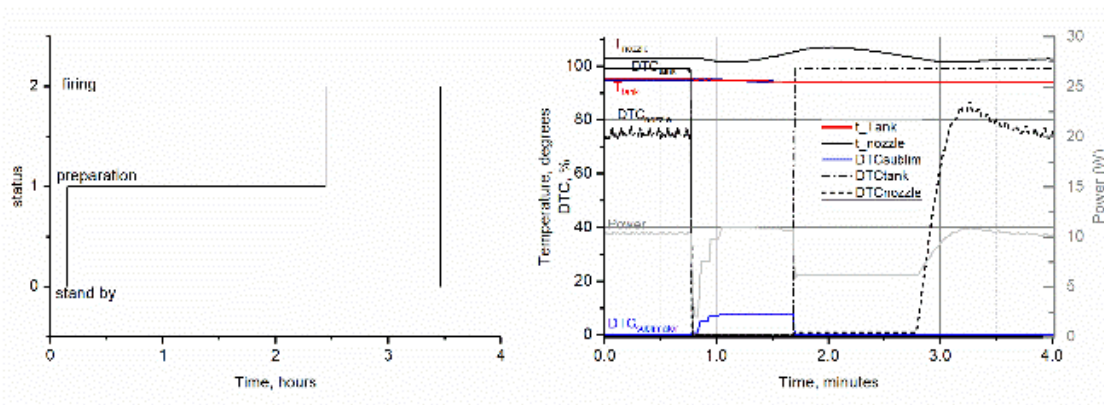


In-orbit demonstrations

I2T5 demonstration

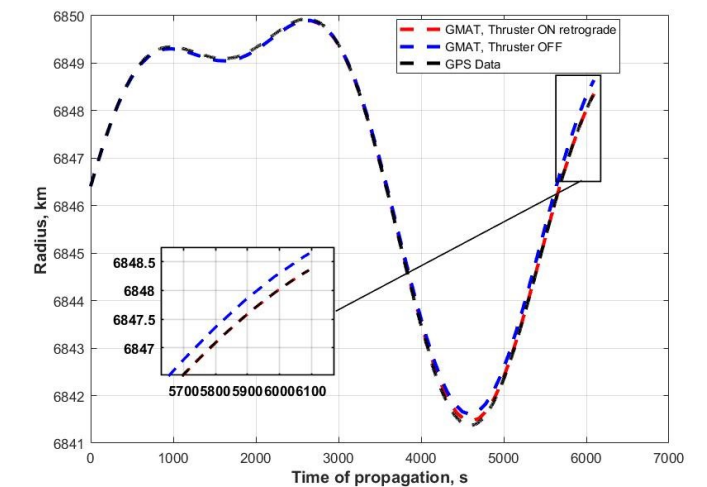
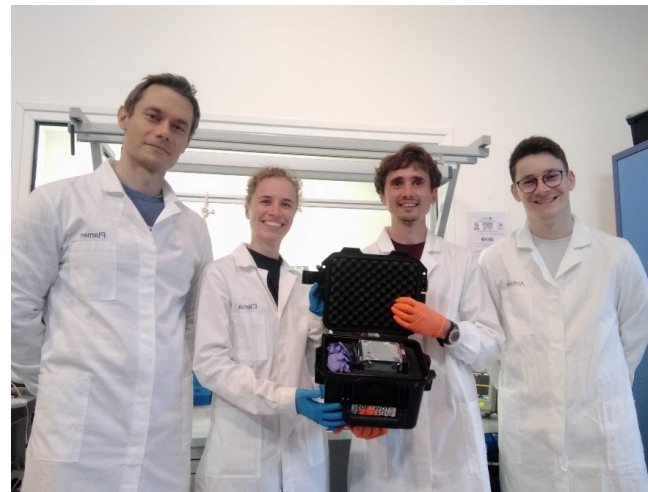


- Mission Robusta-3A
- University of Montpellier
- Launched on November 6, 2019
- 3U CubeSat
- Used for life-time extension
- Successful demonstration of I2T5



NPT30 demonstration

- Launched on 6 November 2020
- Long March 6 rocket
- **Beihangkongshi-1** satellite by SpaceTy
- 480 km sun-synchronous orbit

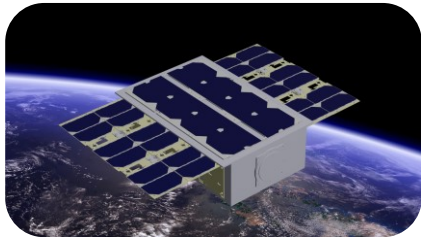


Next (public) missions



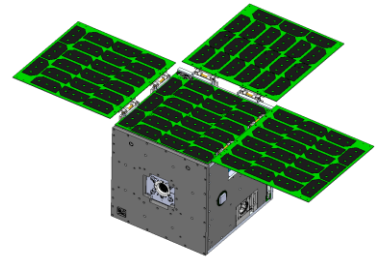
NPT30-I2 IONSAT

6U CubeSat
Student education mission
➤ VLEO demonstration



NPT30-I2 INSPIRESAT-4

27U CubeSat
Ionospheric research mission
➤ Controlled orbit decay
from 500kg to <300 kg



I2T5 NAPA-2

6U nanosat
Earth Observation
➤ Small orbit changes



NPT30-I2 GOMX-5

12U nanosat ~20 kg
➤ Large orbit raising
maneuvers for future
constellation deployment



NPT30-I2 NORSAT-TD

Microsatellite 35 kg
Tech demo and SSA
➤ Low thrust collision
avoidance maneuvers



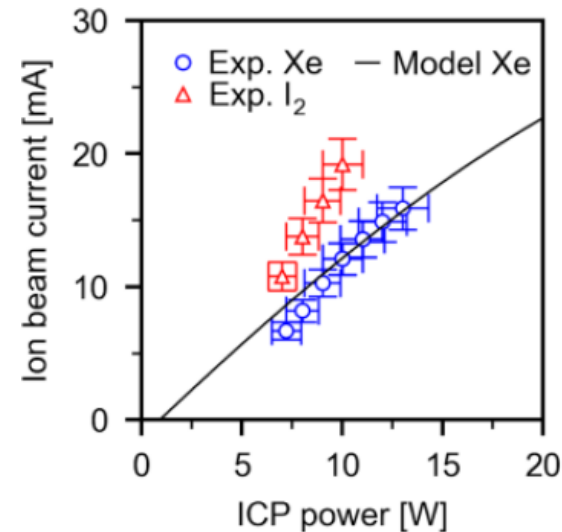
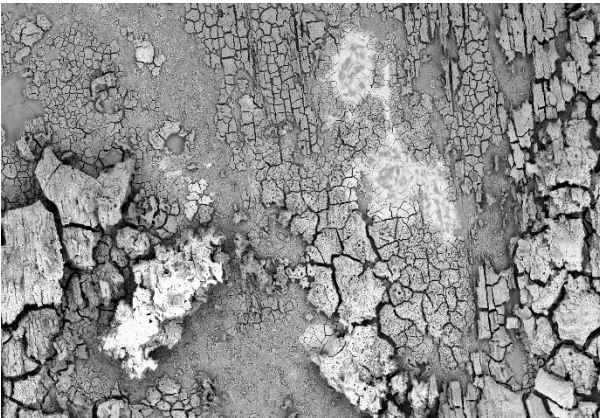
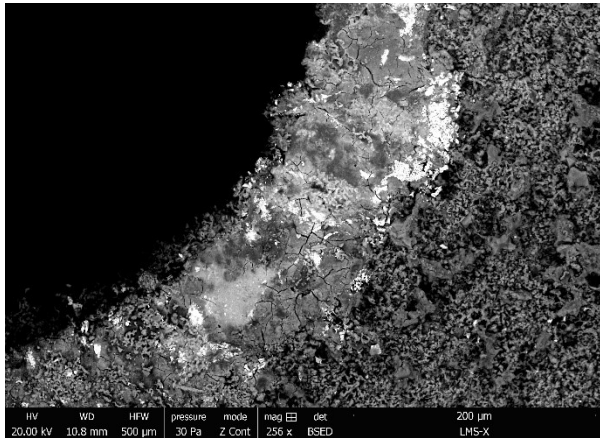
Future

Research and development

Iodine fundamental research



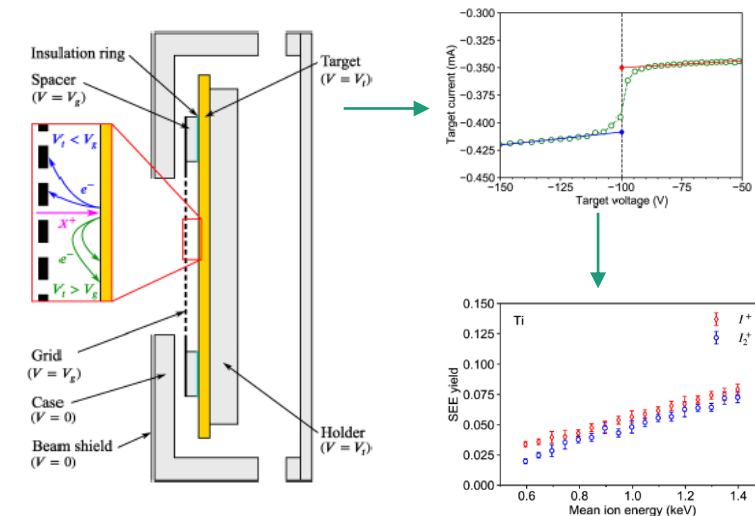
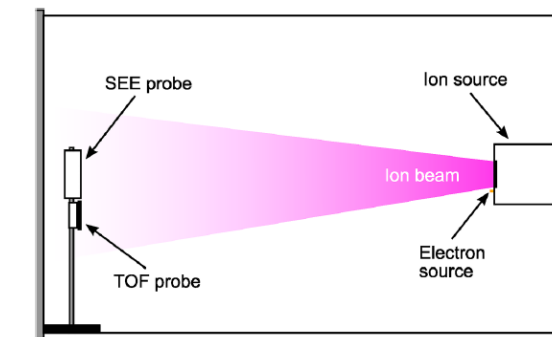
Iodine surface chemistry



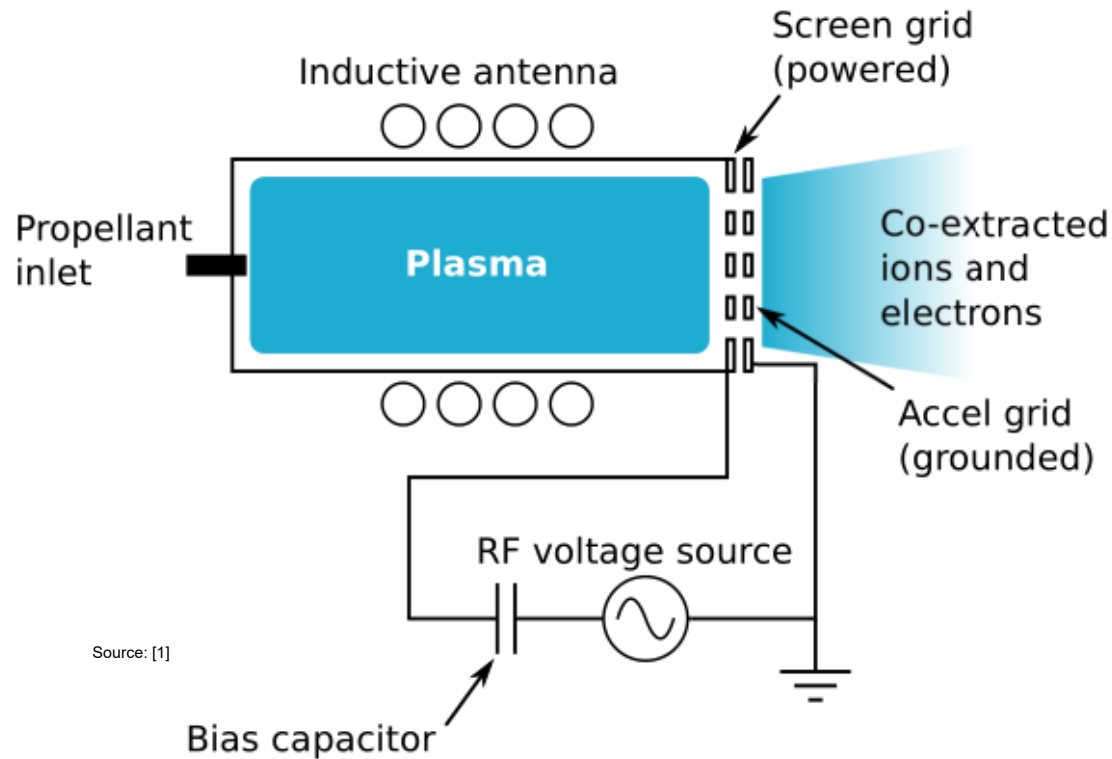
Simulation of iodine plasmas
currently it's more reliable to
simulate the xenon case and
perform empiric fits.

First ever measurements of secondary electron emission yields in 2021.

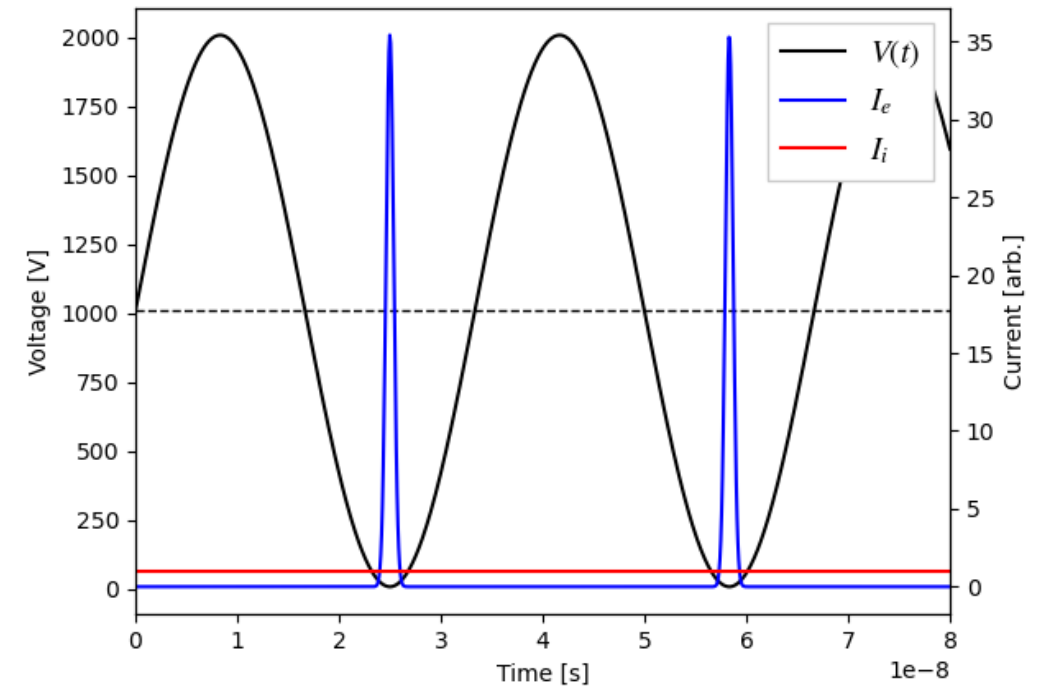
J. Appl. Phys. **129**, 153302 (2021)



RF acceleration



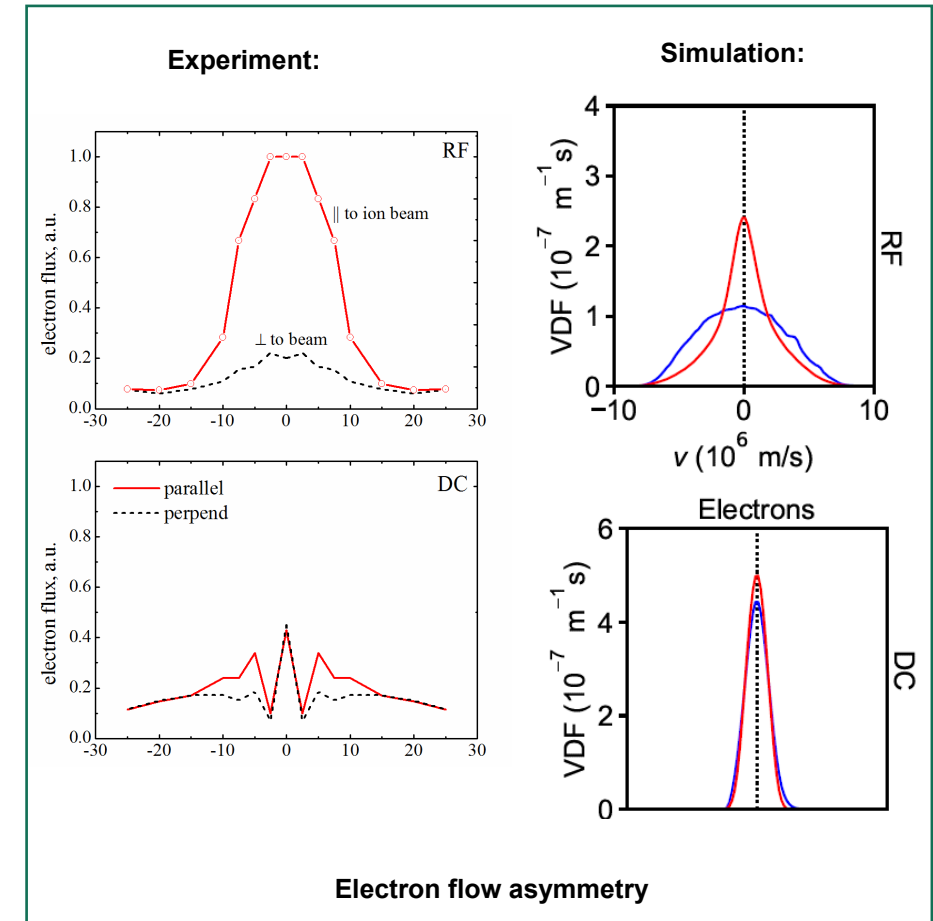
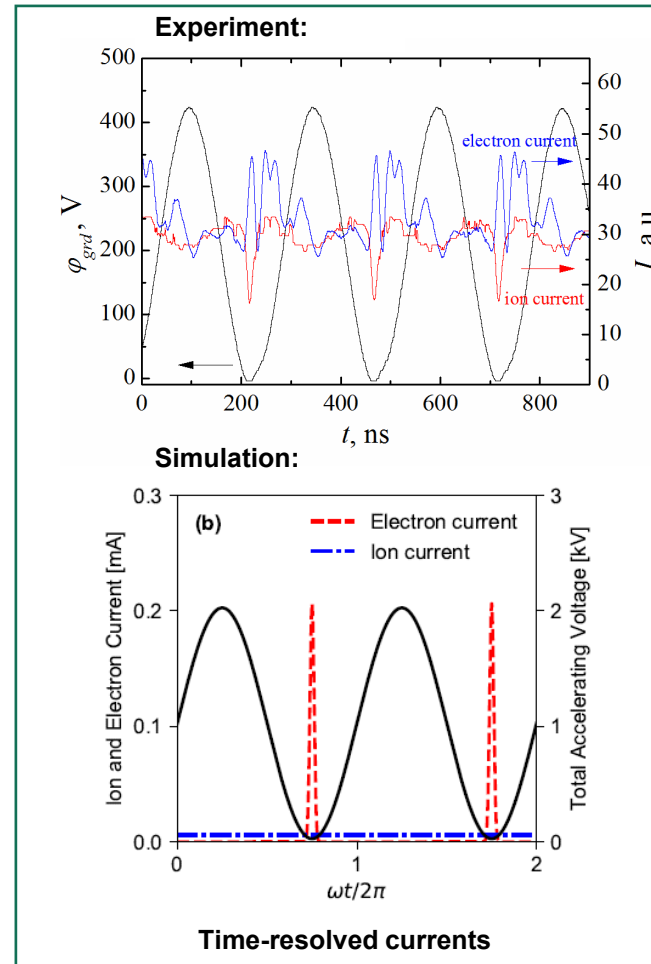
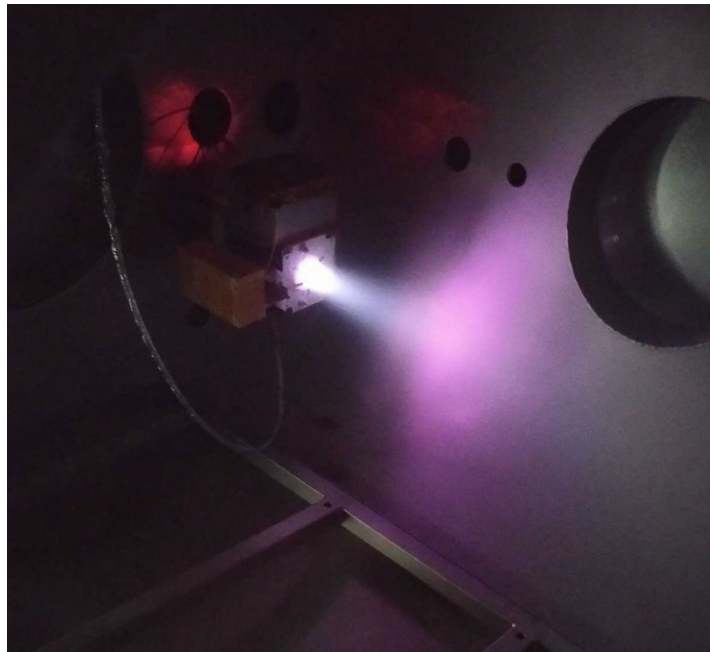
Source: [1]



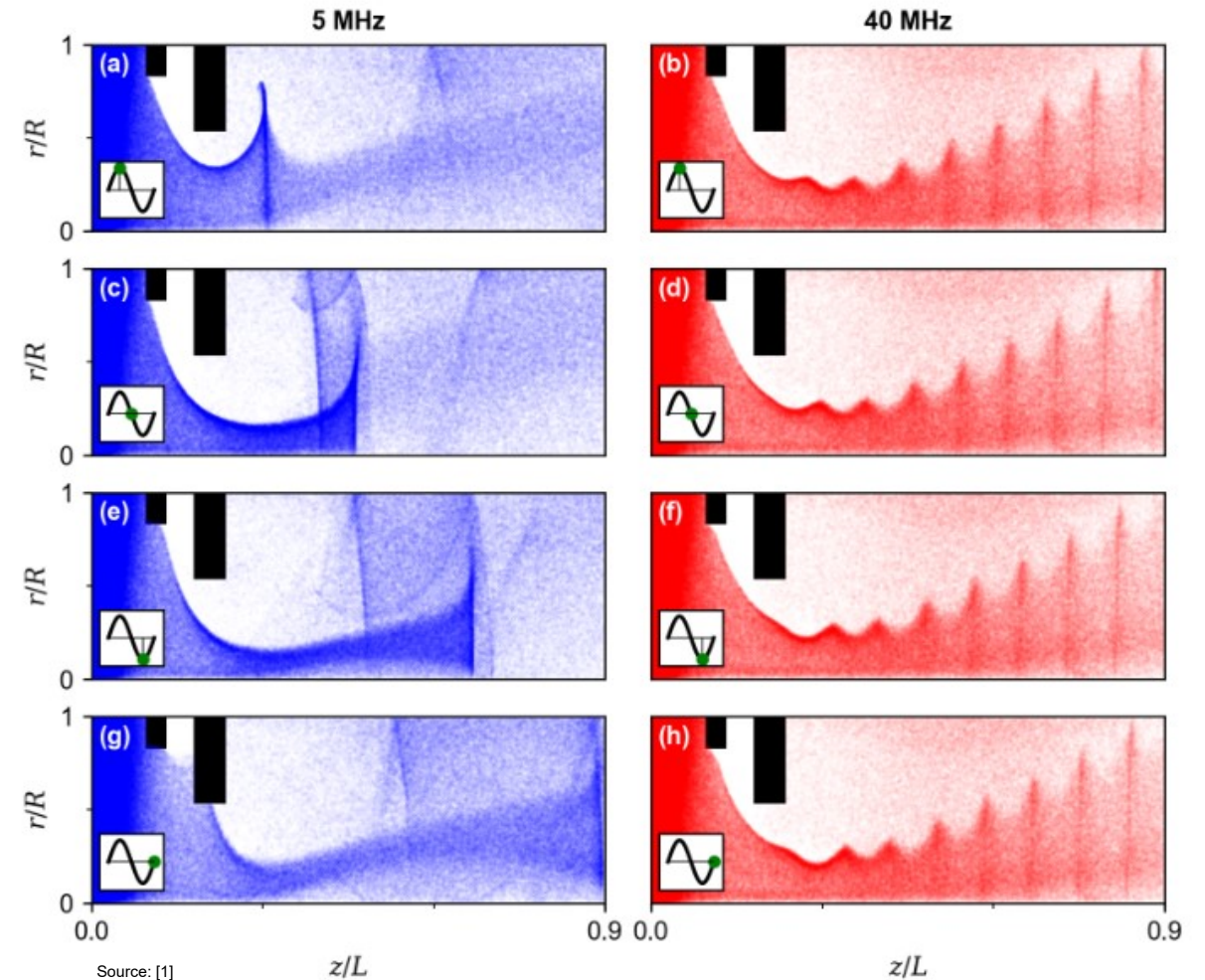
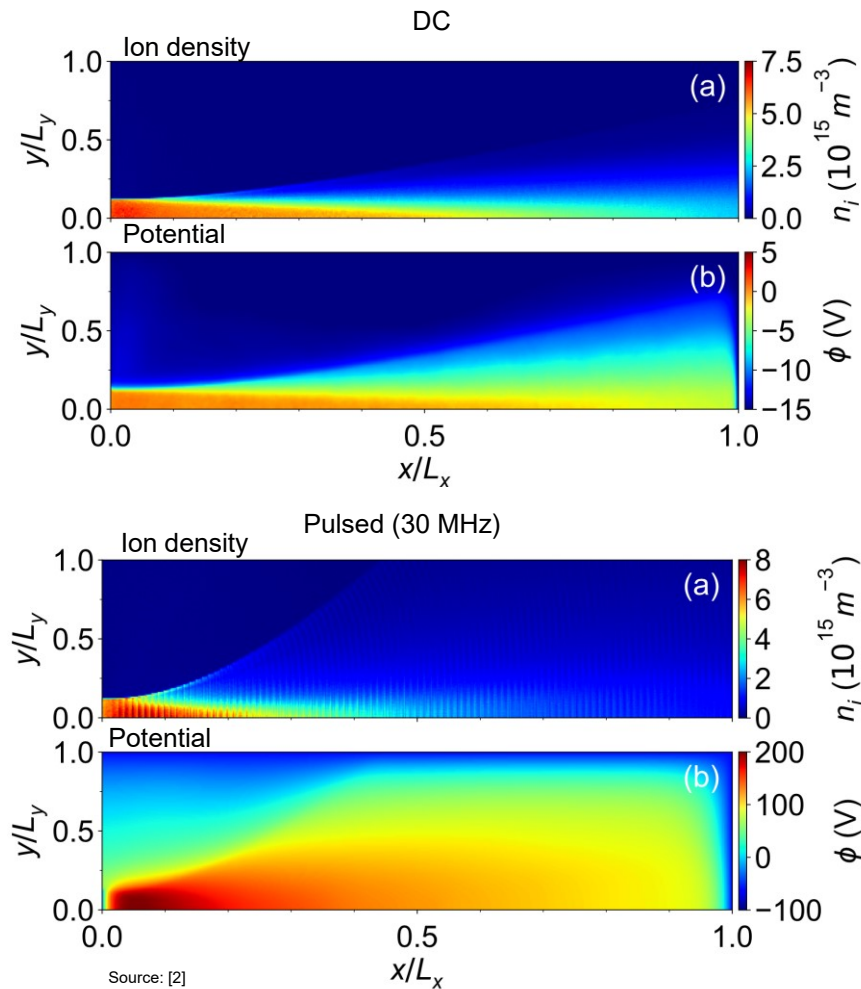
- No neutralizer
- Demonstrated experimentally
- Numerical work was mostly on particle focusing
- Plume dynamics are still unexplored

[1] T. Lafleur, D. Rafalskyi, and A. Aanesland, "Radio-frequency biasing of ion thruster grids," presented at the 36th International Electric Propulsion Conference, 2019.

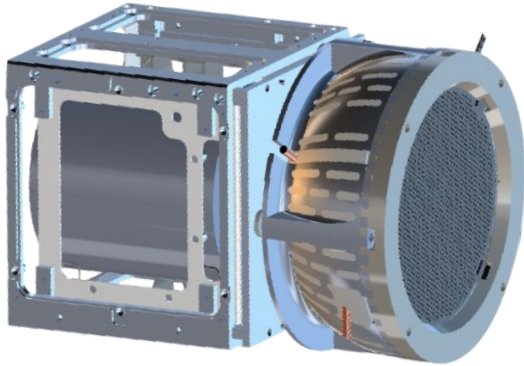
RF acceleration



RF acceleration



NPT300

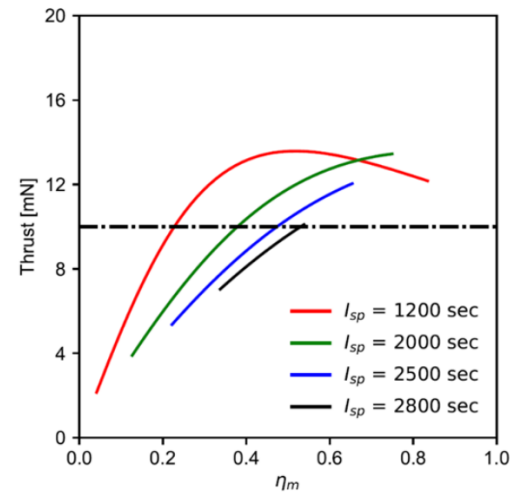


PERFORMANCE & SPECIFICATIONS

Thrust	8 - 14 mN
Isp	1200 – 3000 s
Total impulse	> 50 kNs*
Total wet mass	< 10 kg
Total power	200 – 500 W

PERFORMANCE ESTIMATION

For the NPT300 operating at 400 W



Thrust as a function of propellant utilization for different specific impulses. The dotted horizontal line indicates 10mN.

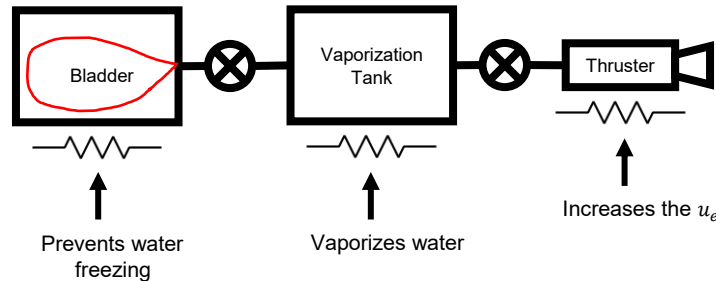


Water propulsion

- Electrothermal thruster (resistojet)
- Reaction control system
- Multiple customizable nozzles

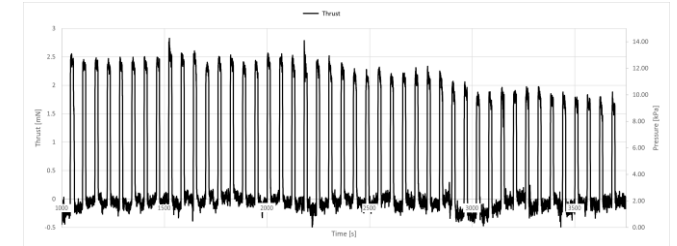


Water Reaction Control System 3D Mockup

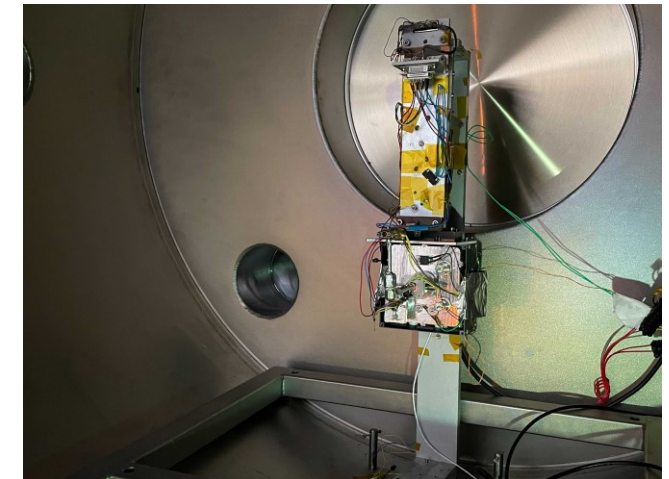


Predicted performance

Thrust	1 – 4mN (per thruster)
Exhaust velocity	1 – 1.2 km/s
Total impulse	> 400 Ns*
Total wet mass	< 1 kg
Total power	10 – 30 W
Impulse speed	50 ms



Direct thrust measurement



Thruster Functional Prototype

Conclusions

Conclusions

- EP is a great way to make spacecraft maneuvers
- Iodine-fuelled EP can help thrusters more available
- New innovations are needed:
 - Improve the efficiency (mass and power)
 - Decrease cost (small satellites/projects)
 - Increase reliability (need to work for 1-10 years)

Do we have solutions for sustainable space exploration?

What's next?

Factors slowing down innovations in space



- System complexity and qualifications
- “Heritage” approach
- Over-engineering and over-qualifications
- Approach of infinite resources availability (time/cost)
- Unit-by-unit “unique” production

“*New space*” paradigm vs classical approach

- **238** hall thrusters in total launched from 1960s to 2008 (40 years).
- **1700+** hall thrusters launched just by SpaceX in 2019-2021 with Starlink
- Space propulsion is the field with huge potential of growth with a lot of science-dense topics
- New ideas and approaches are highly demanded



Thank you!