Experimental activities at the Plasma and Space Propulsion Team (EP2-UC3M)

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EPIC Workshop 2023
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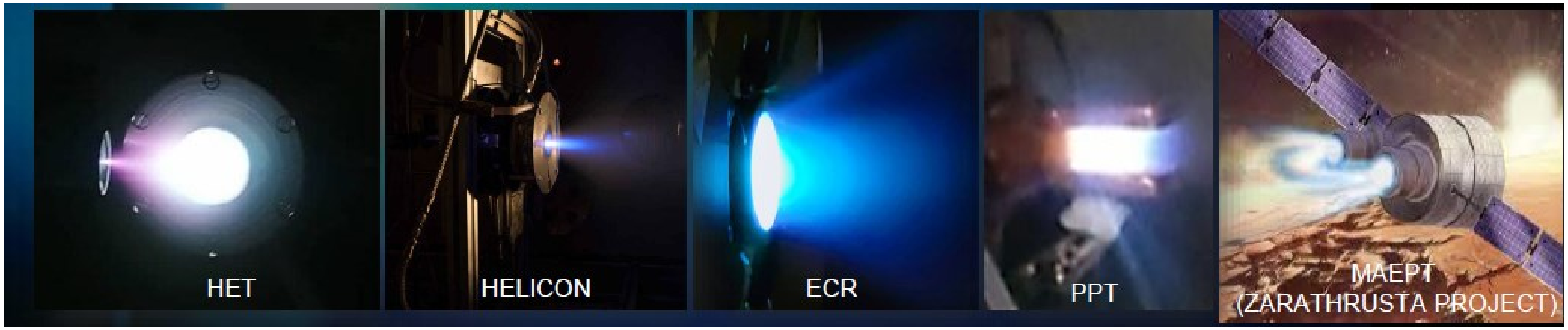
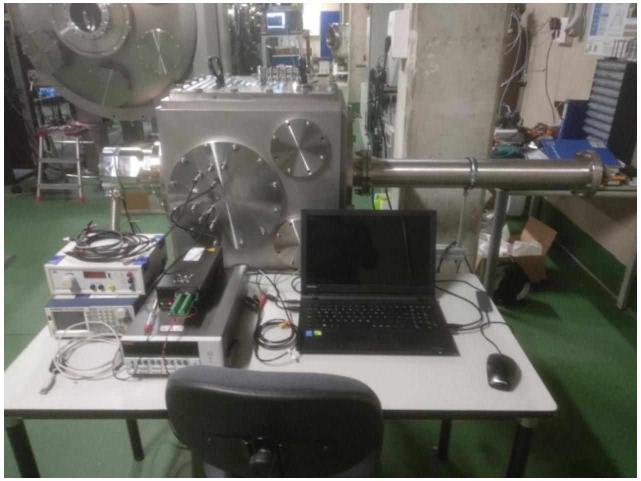


Facilities

- Main chamber:
  - Steel 304 vessel, 1.5 m diameter, 3.5 m long
  - Vacuum technology
    - Mechanical roughing pump (Leyvac LV80)
    - 2 turbomolecuar (MAGW2).
    - 3 interchangeable cryopanels, Leyvac 140 T-V
  - Ultimate dry pressure 10^{-7} mbar.
  - Pumping speed:

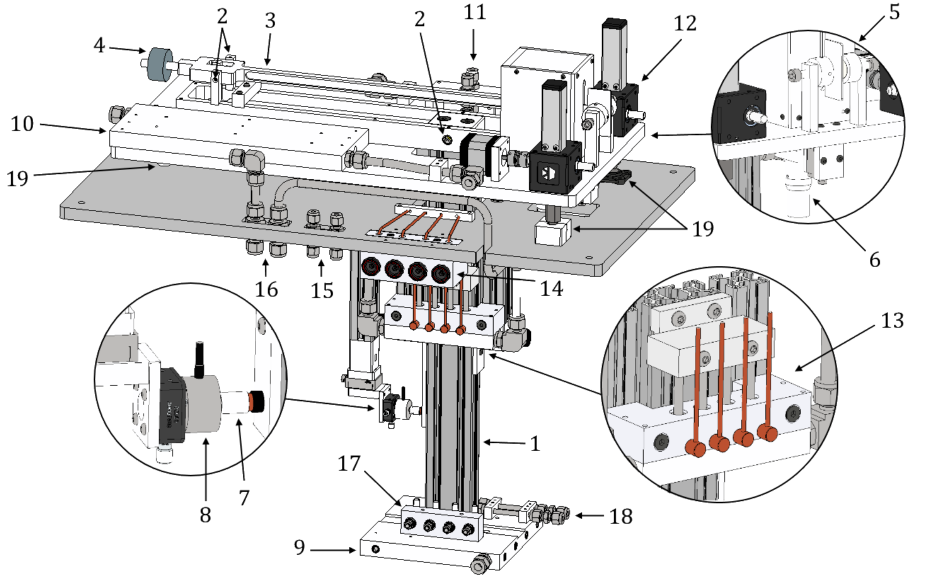
    33,000 l/s of Xe at $2 \cdot 10^{-5}$ mbar

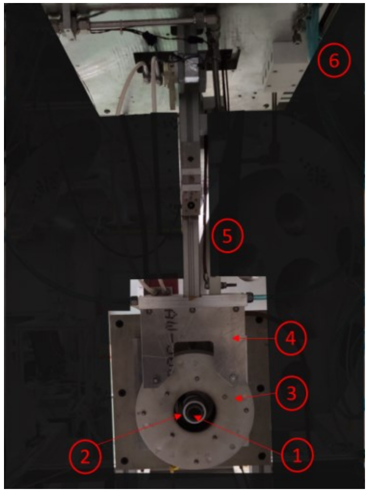
    (cont. operation 5 days x 20 sccm Xe).
- Small Vac chamber
  - Volume: (0.125 m^3)
  - Dry scroll pump: 3.2 L/s (11.4 m^3/h)
  - Turbomolecular pump: 400 L/s
  - Ultimate dry vacuum: 10-6 mbar
- Others:
  - 1,5 m x 1 m chamber (1,5 m^3)
  - Small plasma reactor.

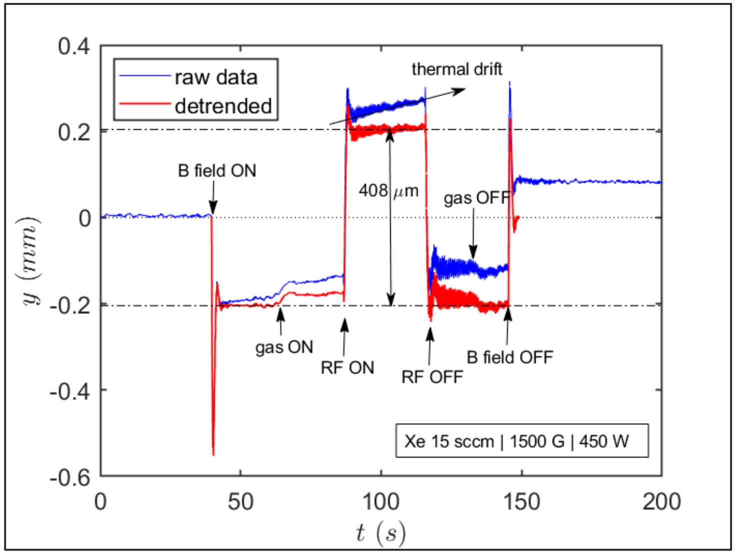


DIAGNOSTICS

- Thrust balance
  - 0-100 mN
  - 0.1 mN resolution
  - Thruster mass, up to 50 kg
  - Cooled, adjustable damping, Remote calibration (voice coil and Calibrated weights)
  - Optical sensor for the displacement







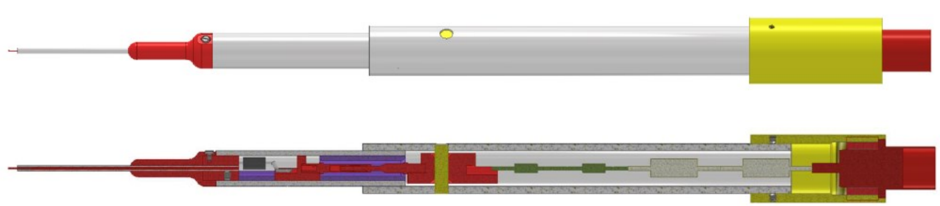
EXAMPLE: Thrust measurements in HPT, *M. Wijnen, PhD Thesis 2023, DIAGNOSTIC METHODS FOR THE CHARACTERIZATION OF A HELICON PLASMA THRUSTER.*

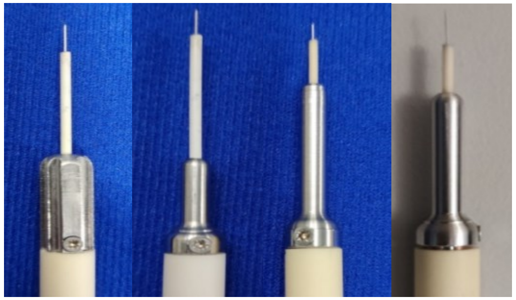
DIAGNOSTICS

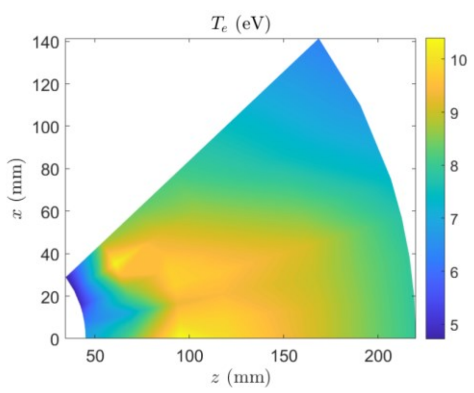
- RF compensated LP and Faraday Cups/Probes
  - Latest advances in the frame of the ***Diagnosis Toolkit for Plasma thrusters*** project.
  - RFCLP with plug-&-play interchangeable electrodes for highly rarefied plasmas.
  - High resolution in the 2D maps of plasma properties.
  - **Modular Faraday Cups.**
  - **Robotic Arm system:** polar coordinates 0-400 mm and -90, +90 deg.

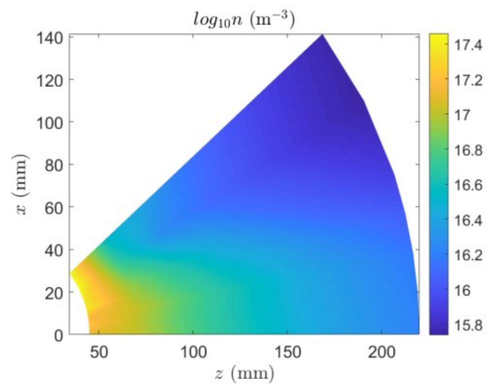
esa

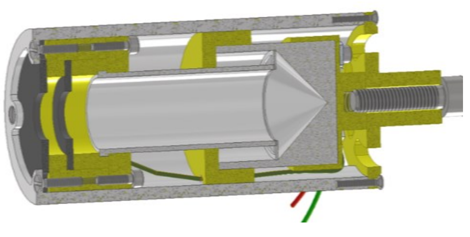
DTK
iagnosis ToolKit for Plasma Thrusters











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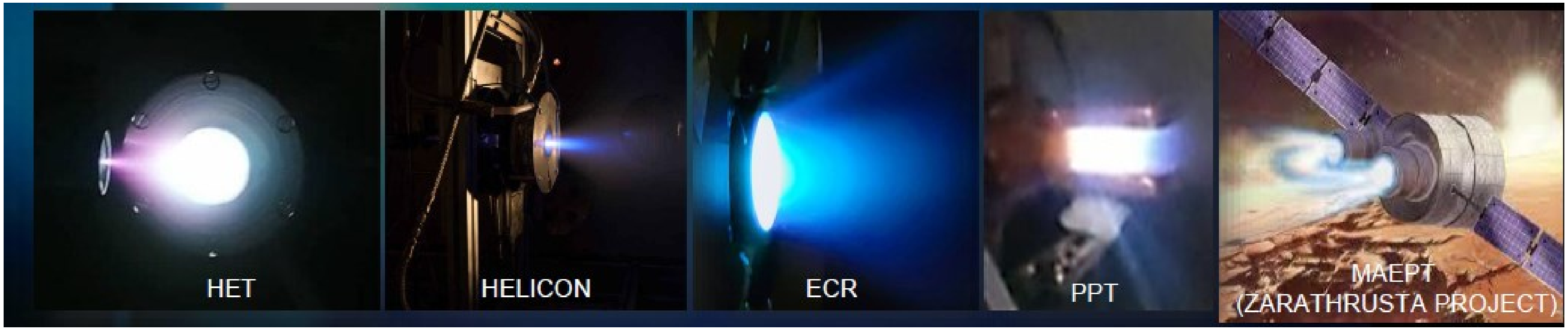
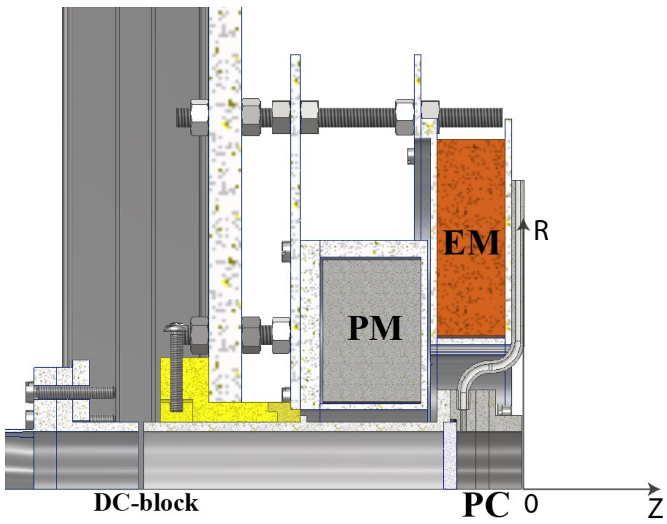
   - MAEPT, presented in Zarathrusta poster

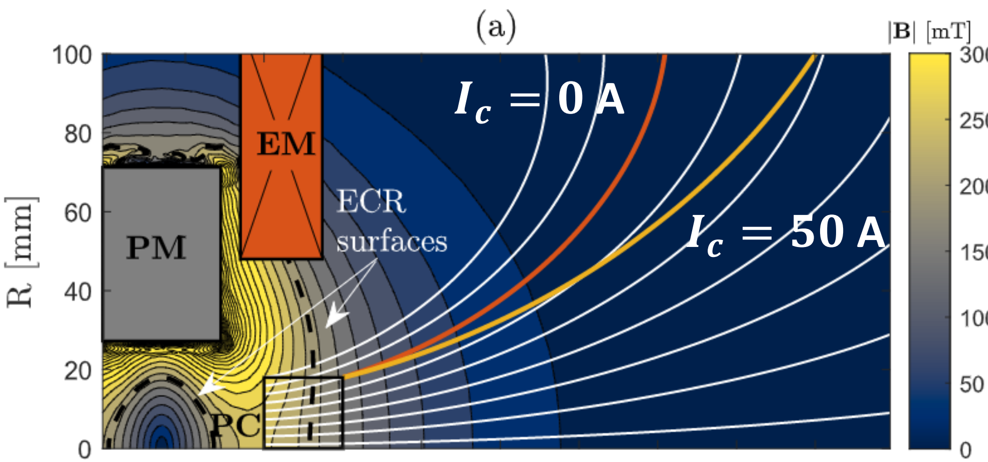


WAVEGUIDE ECRT DESIGN

- Modular approach for easy design iterations.
- 5.8GHz microwaves for smaller plasma chamber and lower power and mass flow rate requirements.
- Stainless steel plasma chamber (PC) separated from the waveguide.
- Magnetic field generator: permanent magnet (PM) + electromagnet (EM) for resonance position tuning and nozzle divergence control.
- Thruster left floating by using a waveguide “vacuum-gap” DC-Block.
- Radial propellant injection.



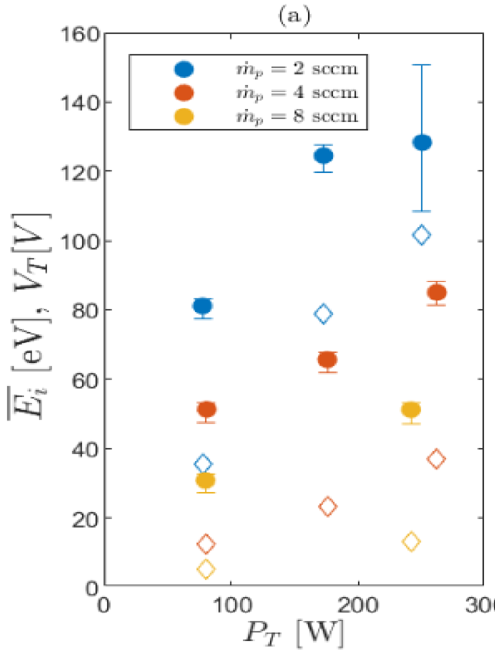
Plasma Chamber Dimensions: Radius, Length	18mm, 20mm
Microwave Power	50-300 W
Mass flow rate (Xe)	1-40sccm
MW frequency	5.8 GHz
B resonance	2070 G
Magnet type	Sm-Co YXG-32
Max electromagnet power	500 W
Electromagnet max B field	900G

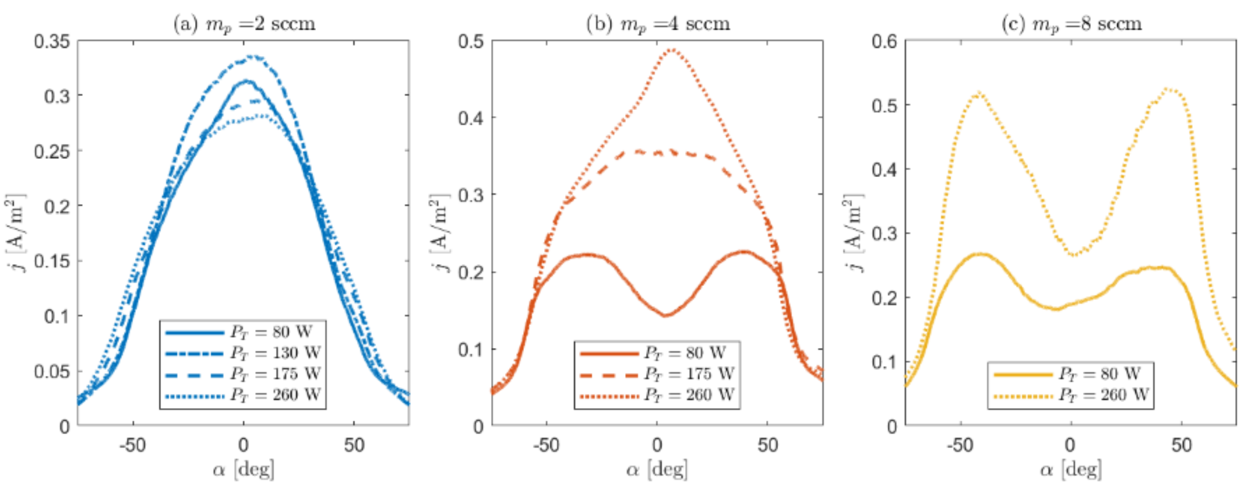


[1] M. R. Inchingolo, M. Merino, J. Navarro-Cavallé; Plume characterization of a waveguide ECR thruster. *Journal of Applied Physics* 21 March 2023; 133 (11): 113304.

ECRT PLUME MEASUREMENTS

- Ion energies measured with a Retarding Potential Analyser (RPA). Energies up to 200 eV were found with an average energy up to 130 eV.
- Plume shape and ion energies are strongly affected by the free parameters: input power, mass flow rate and coil current.
- A hollow plume arises for low values of mass flow rate to input power ratio, the plume divergence is strongly affected.
- The plume divergence is reduced when the coil is turned on (less divergent magnetic field).
- High energy electrons were found in the plume with energies up to 300 eV. [2]

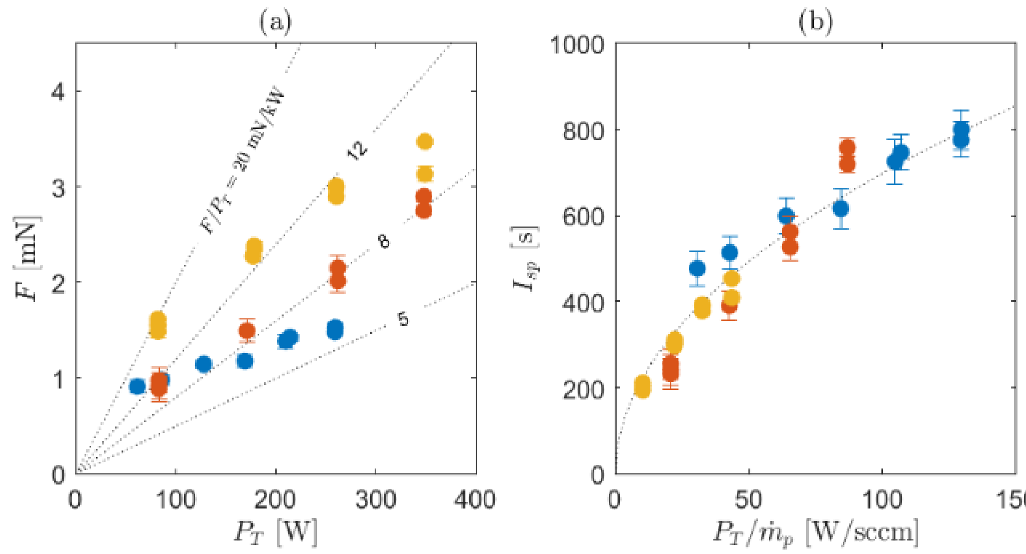




[2] M. R. Inchingolo, M. Merino, J. Navarro-Cavallé; Direct Thrust Measurements of a circular waveguide Electron Cyclotron Resonance Thruster. IEPC 2022.

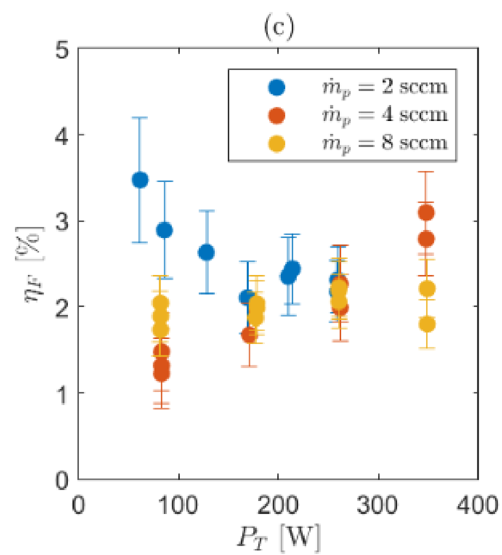
ECRT PERFORMANCE – TB MEASUREMENTS

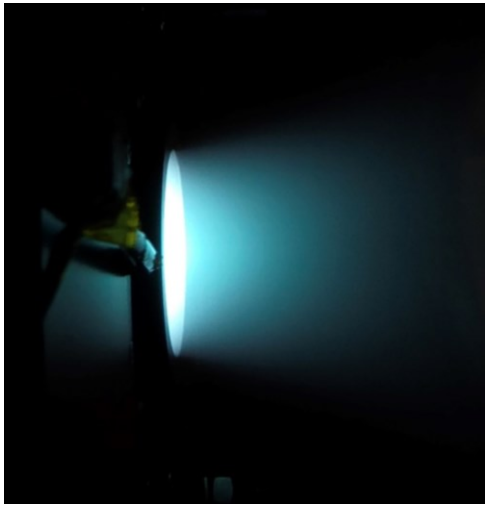
- Propulsive performance characterized on the EP2 amplified displacement pendulum thrust balance.
- Three mass flow rates studied for different power levels
- Thrust ranging 1 – 3.5 mN
- Isp between 200 – 800 s
- Efficiencies found between 1 – 3.5 %



FUTURE REASEARCH

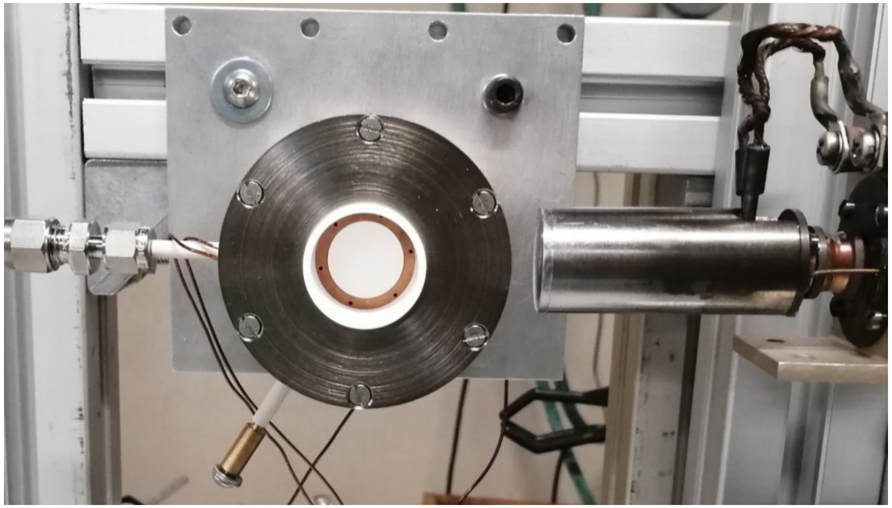
- Investigate the role of power coupling on the plume shape and address how the hollow plume is formed.
- Role of high energy electrons on the plume expansion and ion acceleration.
- Multiple charged ions are thought to be present in the plume, ExB measurements are planned to quantify their amount.



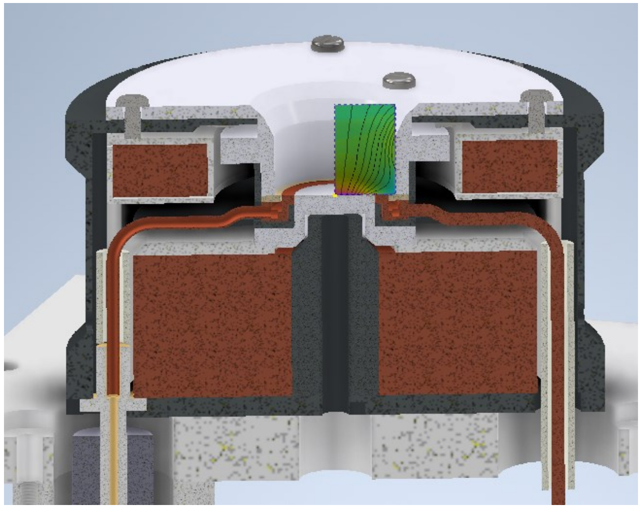


Cylindrical Hall thruster development

- 200 W prototype: tested and characterized
  - Fully cylindrical BN channel
  - Injection through anode
    - 6 injectors
  - 2 electromagnets, pure ion circuit
  - Direct magnetic topology
  - Hollow cathode

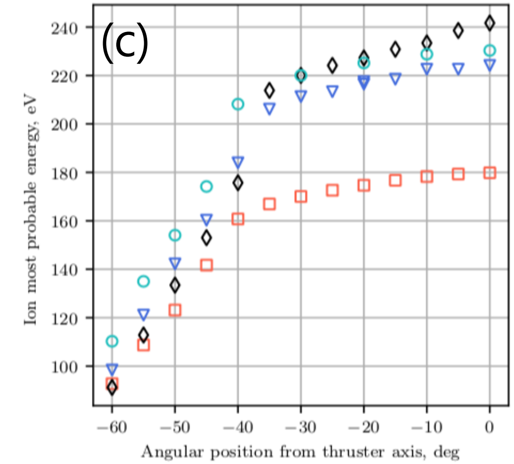


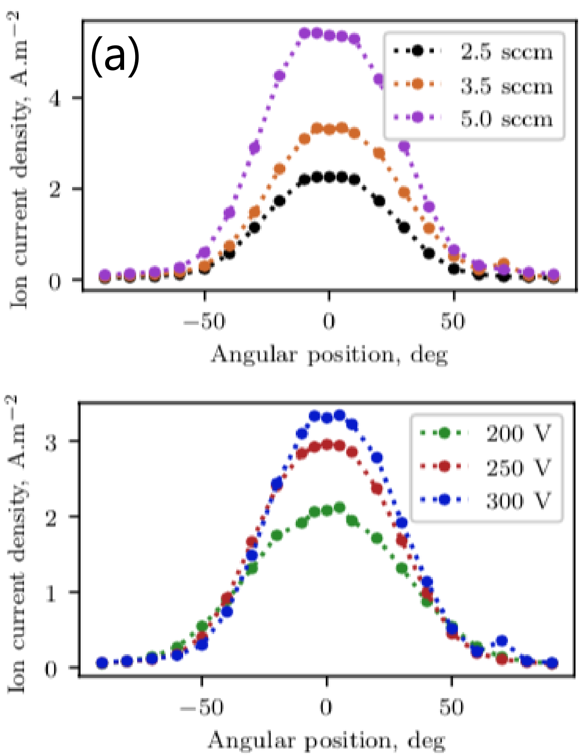
- 100 W prototype: in procurement
  - Downscaled and improved from 200 W
  - Fully cylindrical BN channel
  - Injection through anode
    - Continuous slot or porous injector
  - 2 electromagnets with pure ion circuit
  - Magnetic shielding
  - Alternative neutralizers

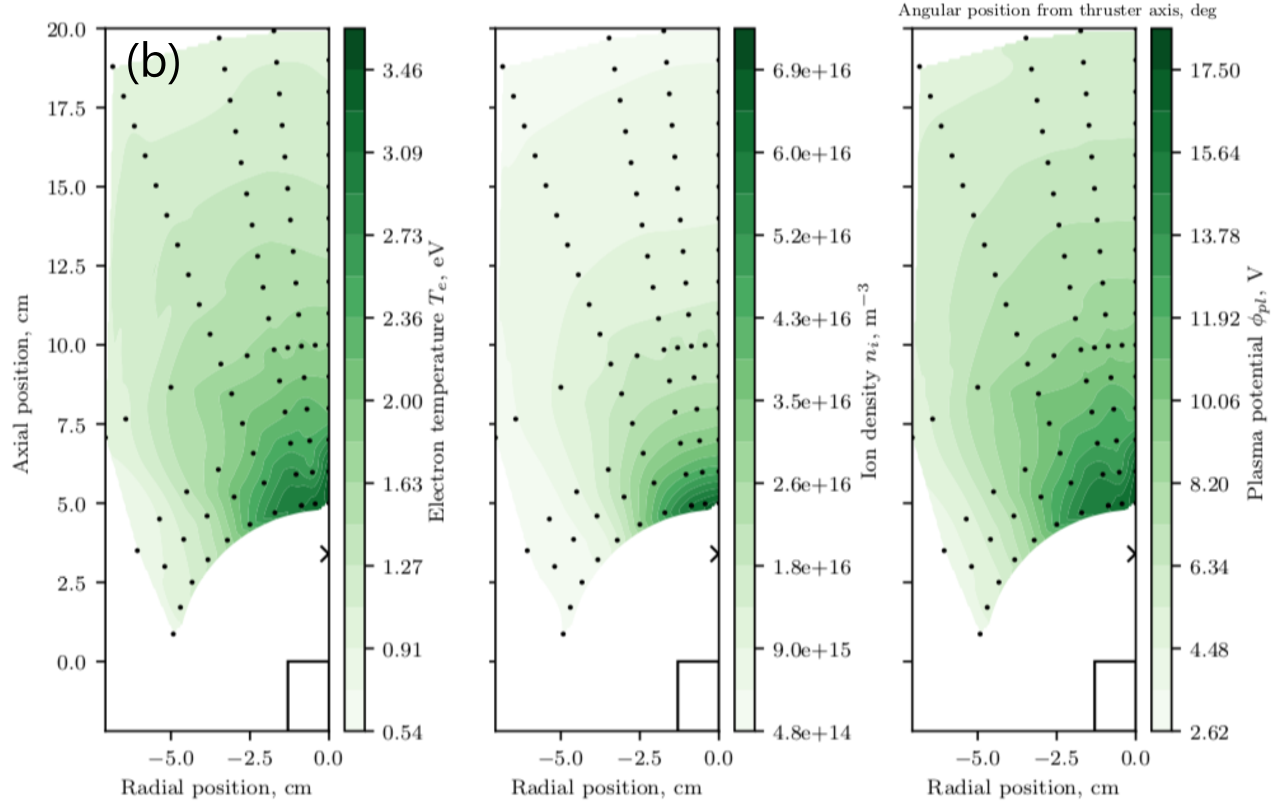


200 W CHT Experimental results

- Ignition tests: in colaboration with
- Operating envelope
  - 30-300 W, 150-350 V, 2.5-6.5 sccm Xe
- Electrostatic diagnostics
  - Faraday cup (a), Langmuir probe (b), RPA (c)

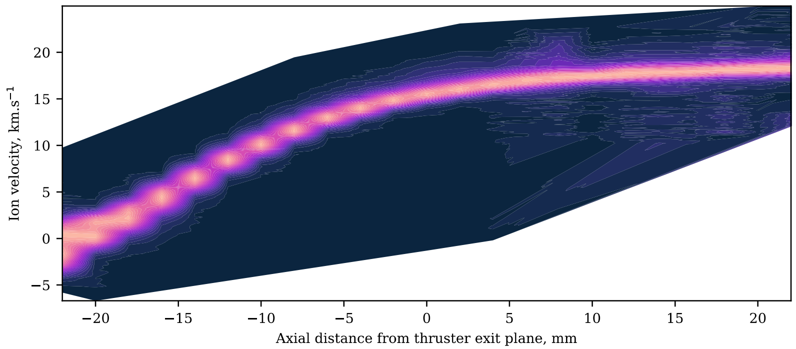


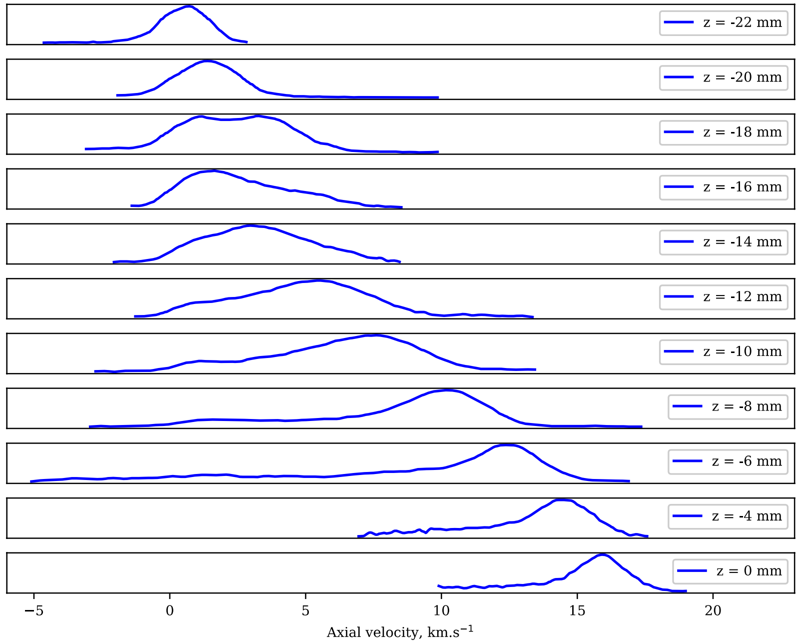




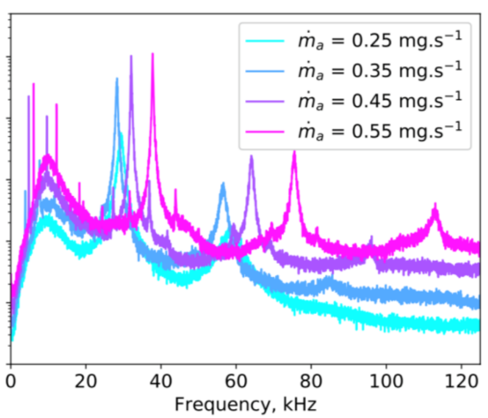
200 W CHT Experimental results

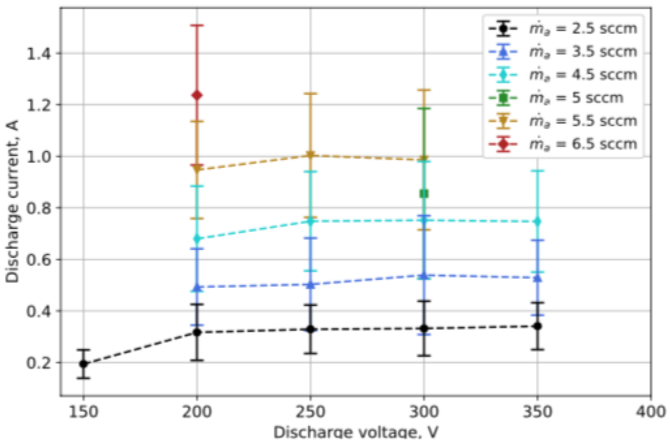
- Optical diagnostics
  - LIF spectroscopy
  - Xe ions and atoms





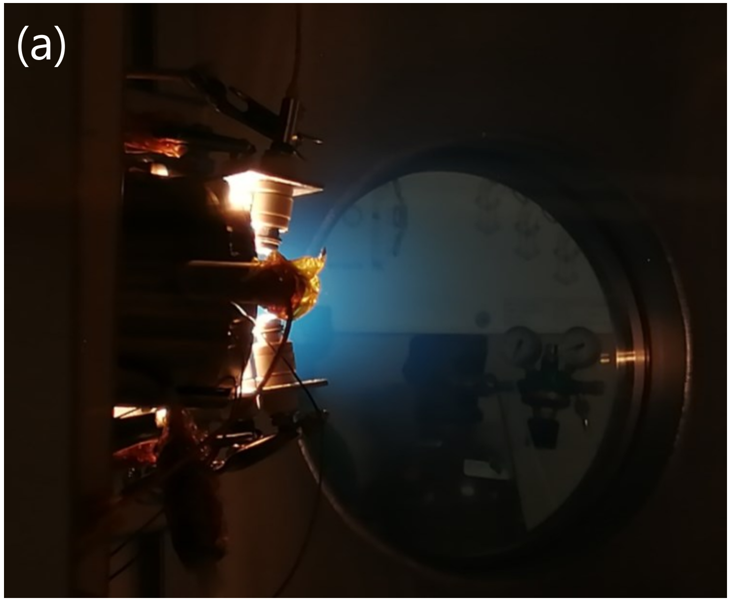
- Discharge current oscillations

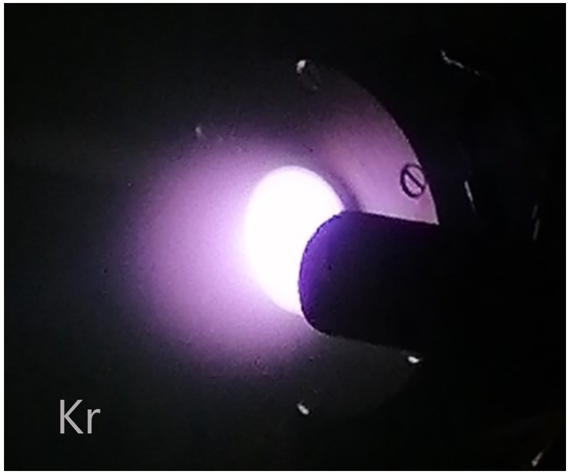


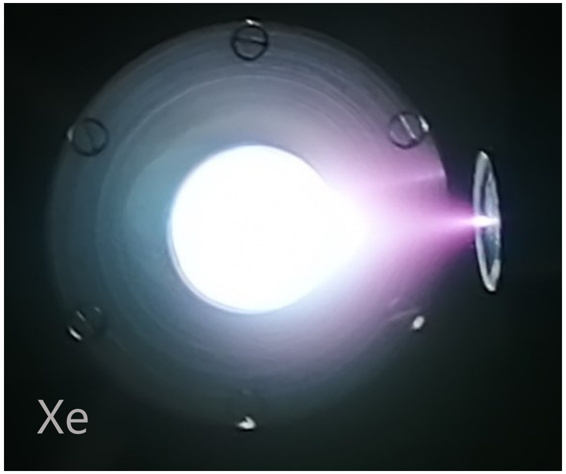


Future research on CHT

- Characterization of 100 W CHT
  - Discharge and plume properties
- Cathode study
  - Alternative cathodes tests with 100 W CHT
    - Hollow cathode, dry (a), power-free
  - Hollow cathode coupling with 200 W CHT
  - Cathode-related plasma oscillations
- Direct thrust measurements
- Alternative propellants testing:
  - Kr
  - Xe, others







PPT development

- For CubeSat applications, Impulse bit: 10-100 uNs
- Analysis of spark-plug / channel electrical discharge for different Vo, C.

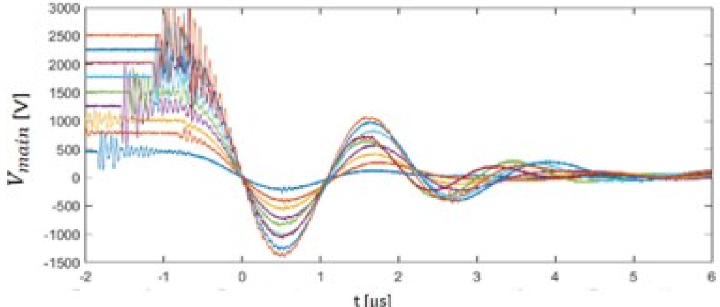
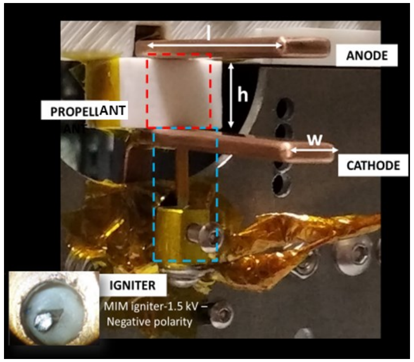
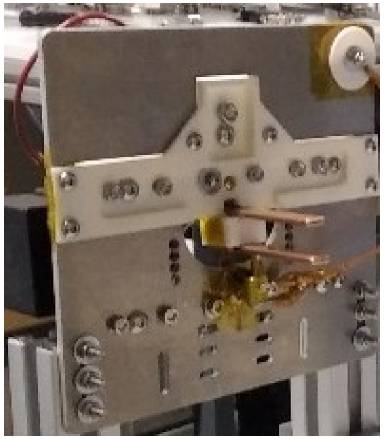
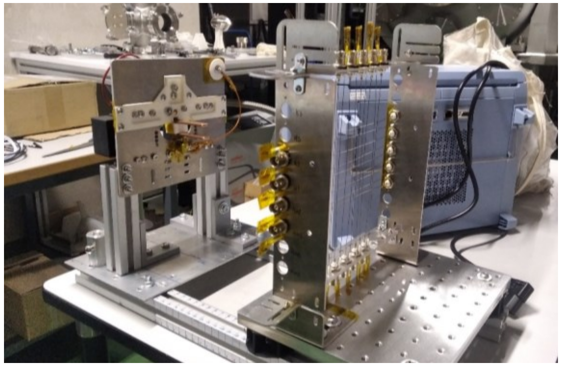


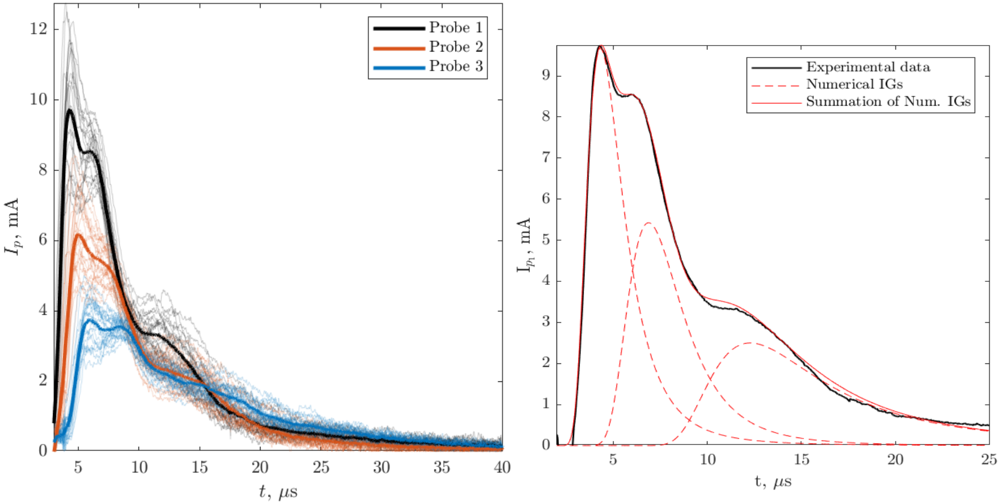
Fig. 1. Electrode voltage (unfiltered) waveform as a function of the initial voltage. [1]





- Time-of-flight measurements
  - Identification of different ion group velocities
- Next steps:
  - Characterization of the plasma beam cross-section





Ion saturation current: unfiltered vs mean current with Gaussian fitting.

Thank you!

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