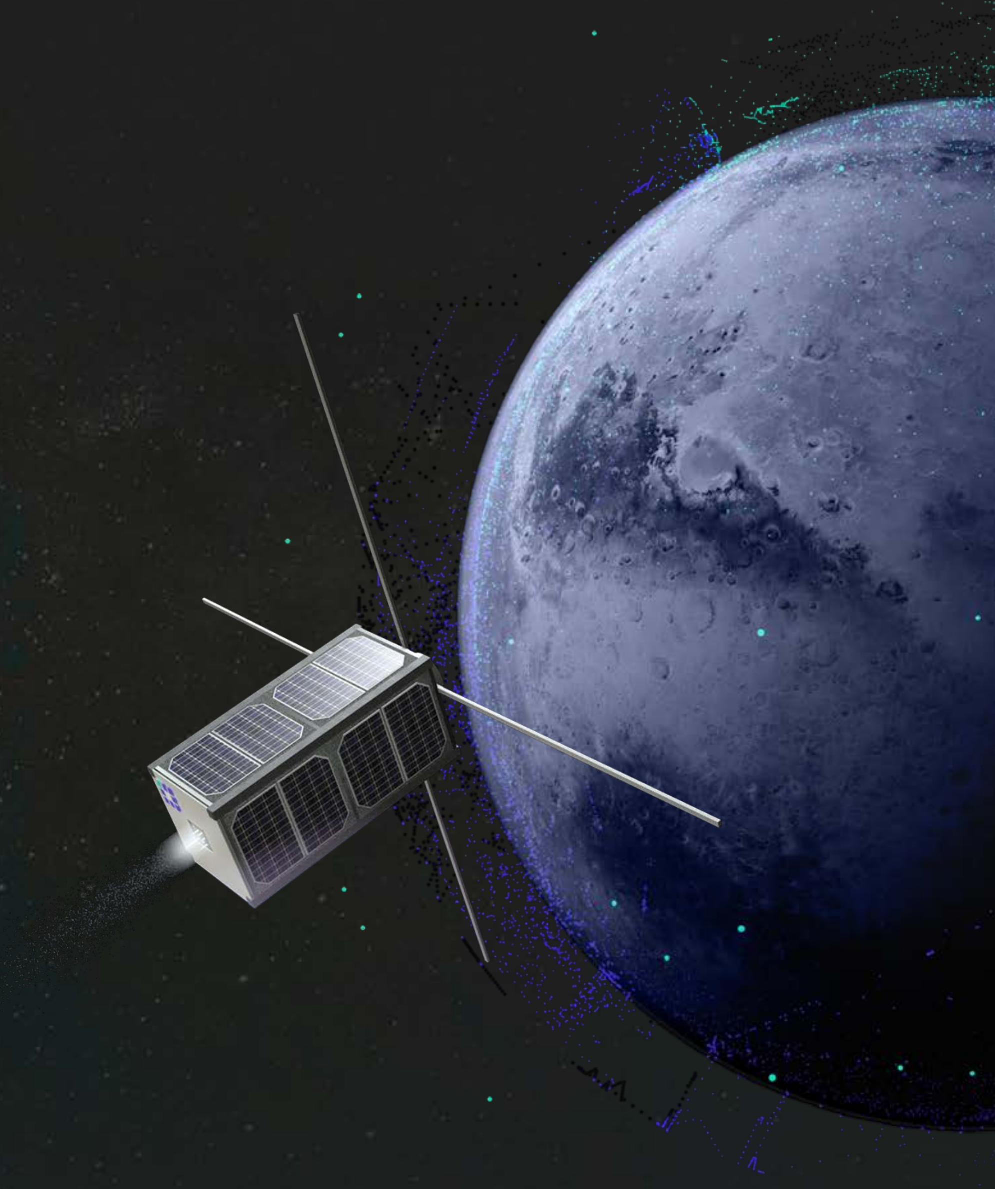
Performance of ATHENA using different ionic liquids



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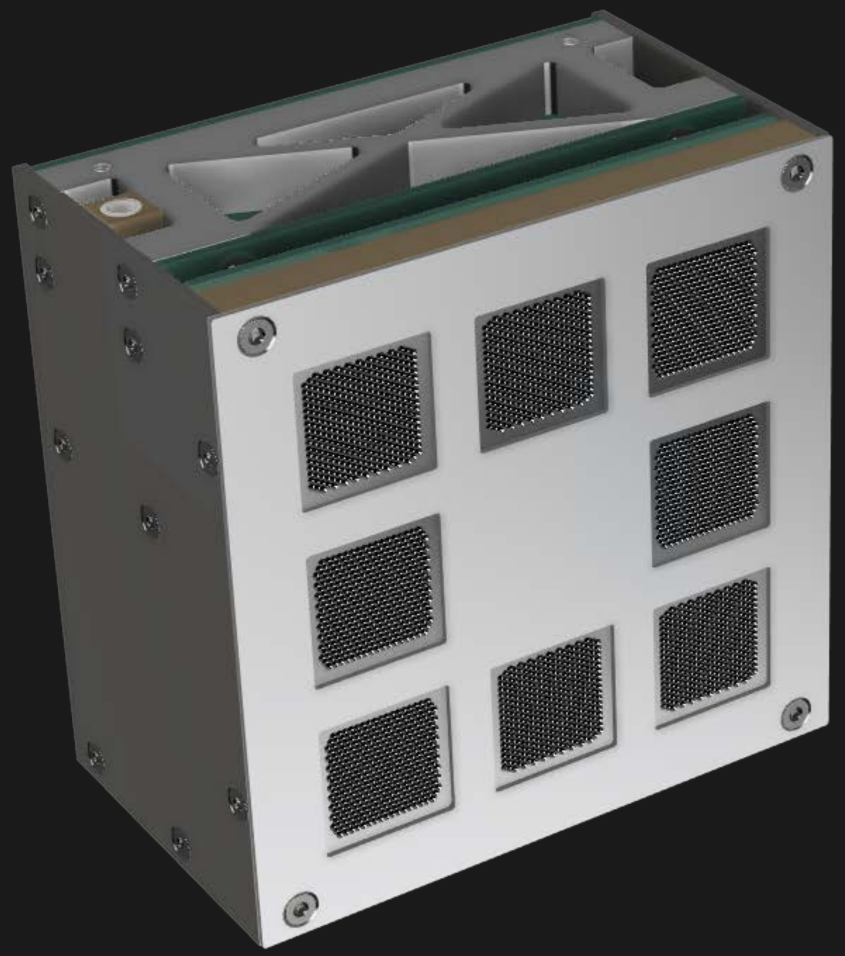
1.0

ELECTROSPRAY - ATHENA

1.1 A BREAKTHROUGH PROPULSION SOLUTION

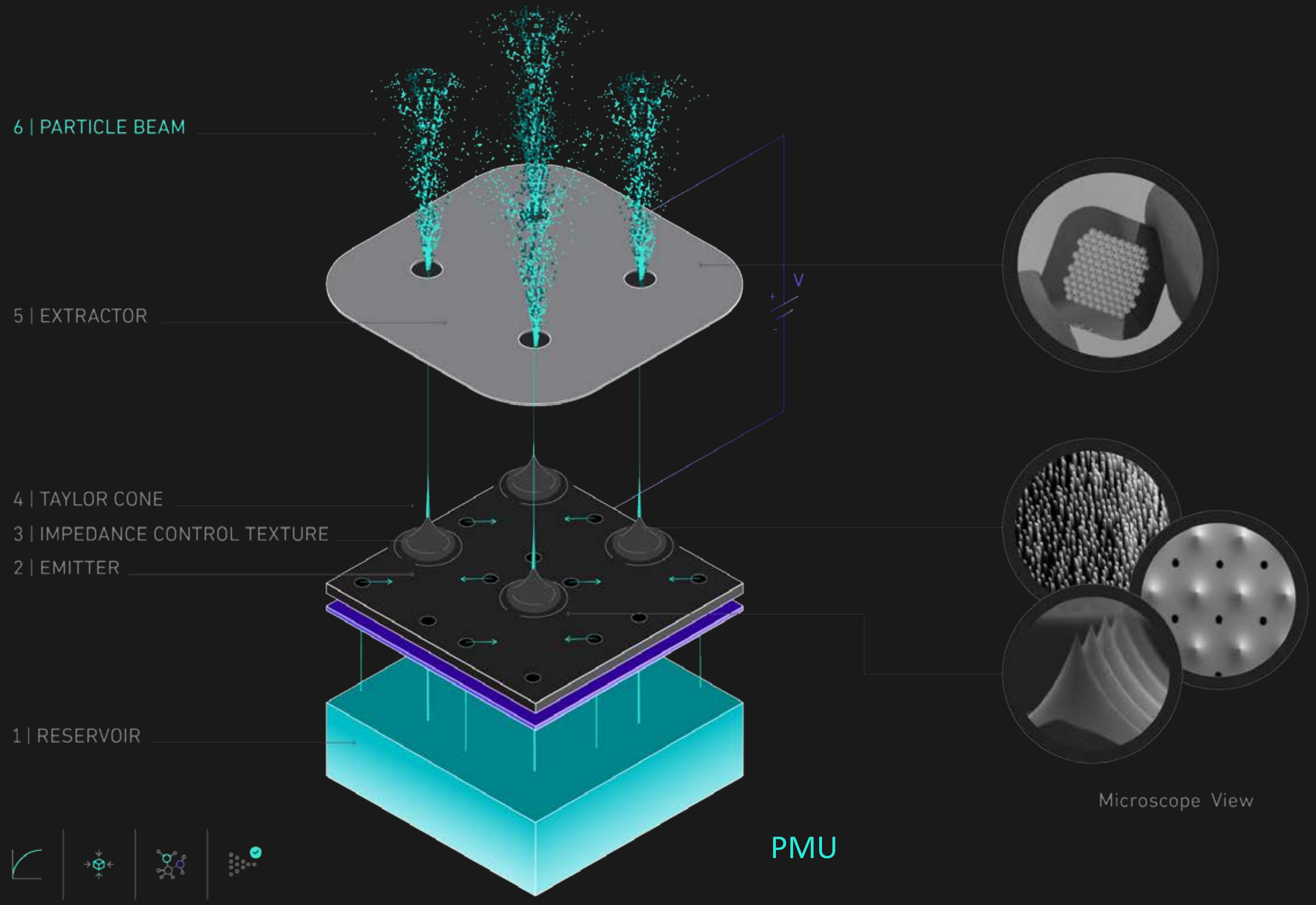


Next generation Electric Propulsion, based on Electrospray technology.

- High Efficiency.
- High Thrust-to-Power.
- High Compactness.
- Low thermal loads.
- Total impulse customizable.
- Total thrust selectable.

1.2 WORKING PRINCIPLES

How do Electrosprays work?



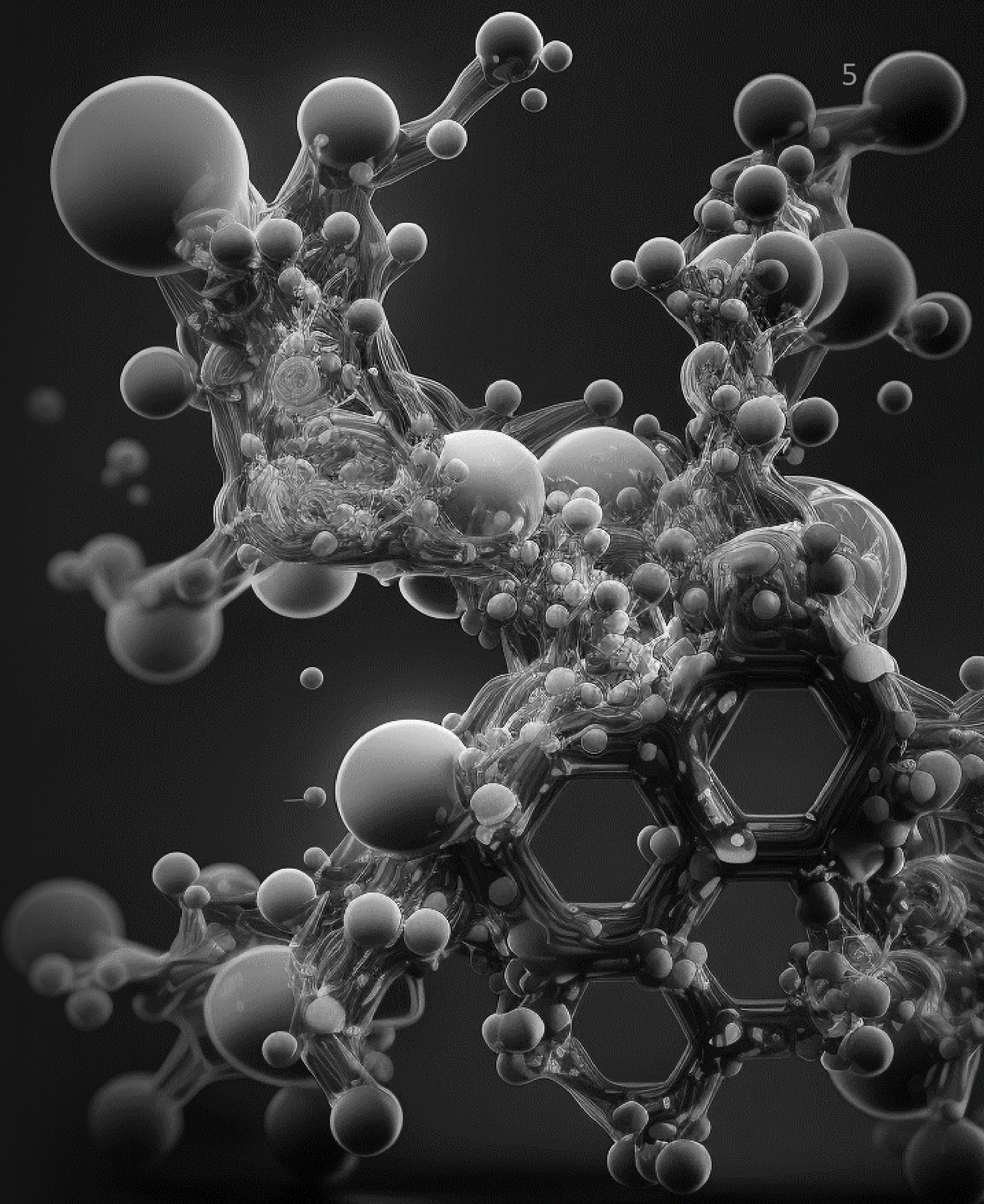
ATHENA by IENAI

Adaptable
THruster based on Electrospray
powered by NAnotechnology

1.3 IONIC LIQUIDS

Benefits of electrospray using Ionic Liquids

- Self neutralizing
- Purely electrostatic
- Stable in vacuum
- Negligible losses
- Safe handling
- Propellant accessibility



1.3 IONIC LIQUIDS

EMI-Im ATHENA baseline

- ✓ Flight heritage
- ✓ Widely understood in electrospray community
- ✓ Less hygroscopic than EMI-BF_4
- ✓ Performance meets requirements

- ✗ Disparity between positive and negative emitted current
- ✗ "Low" conductivity → less emission
- ✗ Droplet presence during negative emission

IONIC LIQUID	ANION MASS [Da]	SURFACE TENSION [mN/m]	CONDUCTIVITY [S/m]	VISCOSITY [mPs]
EMI-Im	282	37	0.8	39
EMI-OTf	150	41	0.8	51
EMI-SCN	58	49	1.8	28
EMI-TFA	114	-	1.0	40

EMI 112

2.0

DIAGNOSTICS

2.1 TIME-OF-FLIGHT MASS SPECTROMETRY

How does Time-of-flight mass spectrometry work?

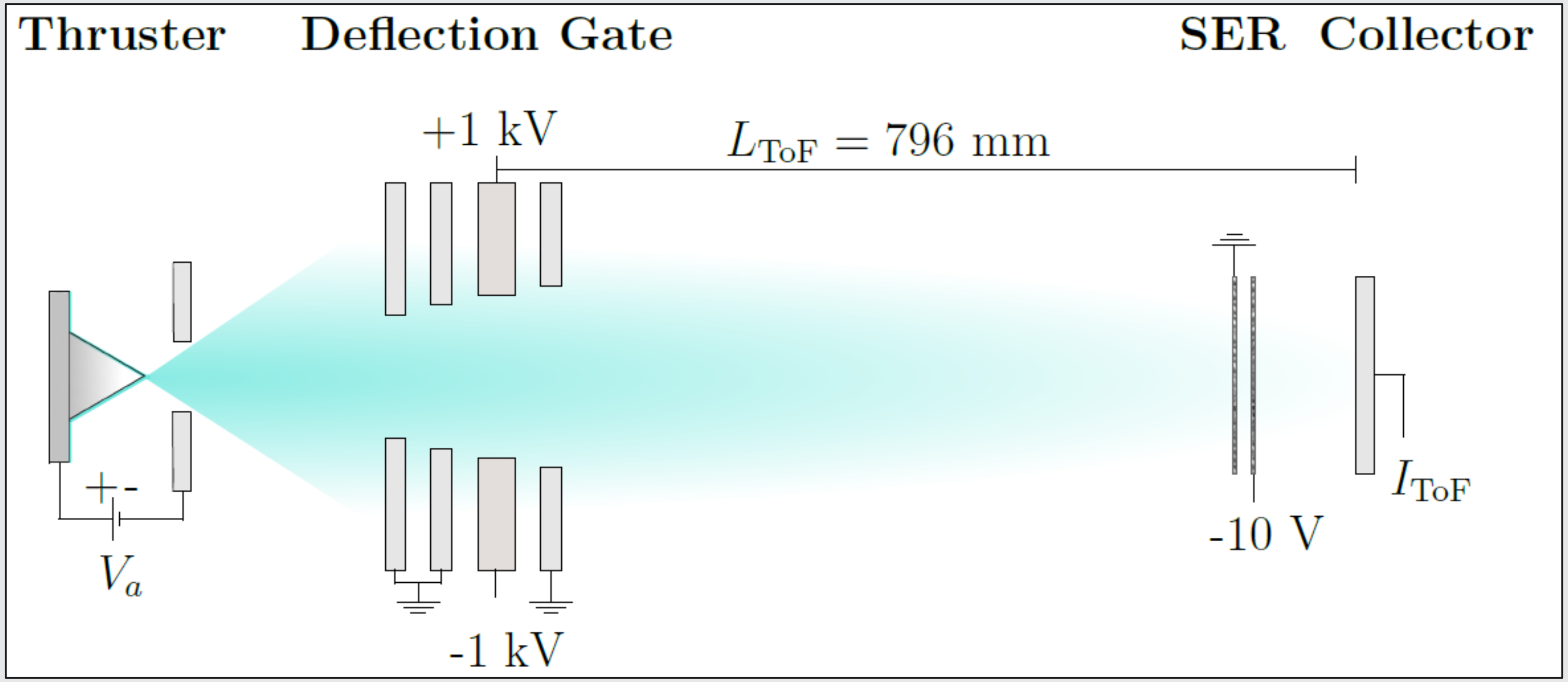


Figure 1. Time-of-flight schematic.

2.1 TIME-OF-FLIGHT MASS SPECTROMETRY

How does Time-of-flight mass spectrometry work?

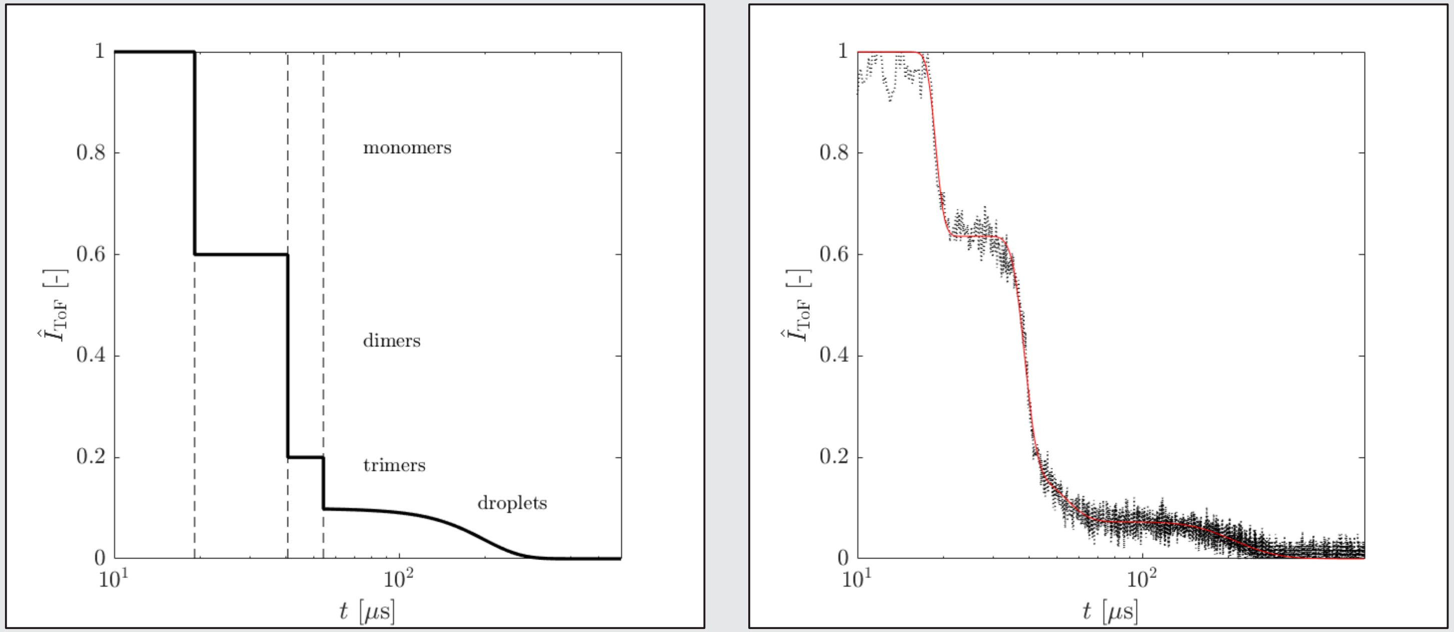


Figure 2. Ideal (left) arbitrary ToF curve and measured (right) curve with fitted curve.

2.1 TIME-OF-FLIGHT MASS SPECTROMETRY

Which parameters are estimated?

- Operation regime
- Thrust and mass flow rate

$$F_{ToF} = \frac{2V_a I_e}{L_{ToF}} \int \hat{I}_{ToF}(t)dt$$

$$\dot{m}_{ToF} = \frac{4V_a I_e}{L_{ToF}^2} \int t\hat{I}_{ToF}(t)dt$$

- Specific impulse

$$I_{sp_{ToF}} = \frac{F_{ToF}}{g_0 \dot{m}_{ToF}}$$

- Polydispersive efficiency

$$\eta_p = \frac{F_{ToF}^2}{2\dot{m}_{ToF} I_e V_a}$$

- Thrust efficiency (using other efficiencies)

$$\eta_T = \eta_\theta \eta_p \eta_E \eta_x^2$$

2.2 SETUP AND PROTOTYPE

TESTING FACILITIES

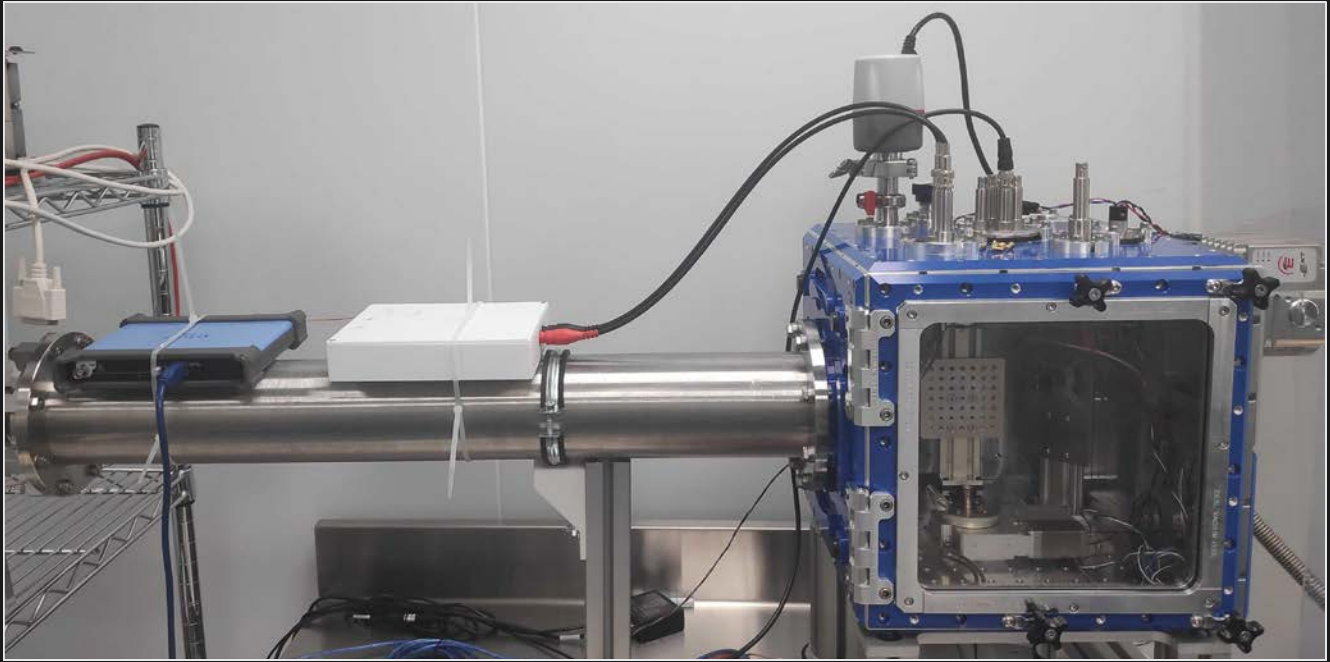
- 0.125 m^3 cube chamber
- 0.75 m extension tube
- Edwards nEXT85H

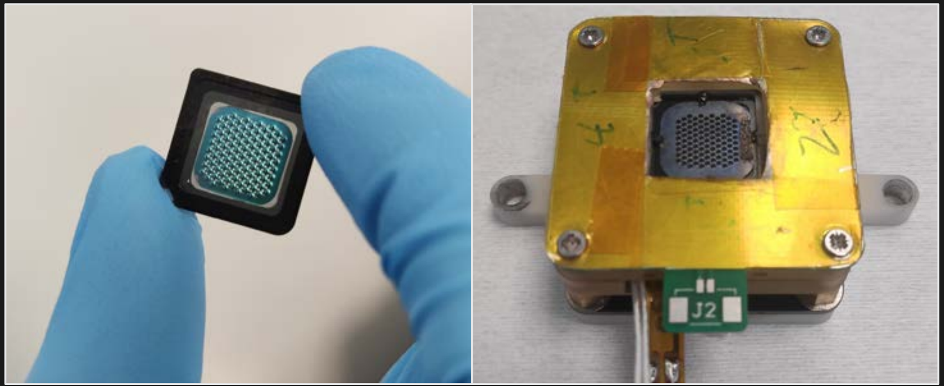
ATHENA PROTOTYPE

- 101 emission sites (1 cm^2)

PROCEDURE

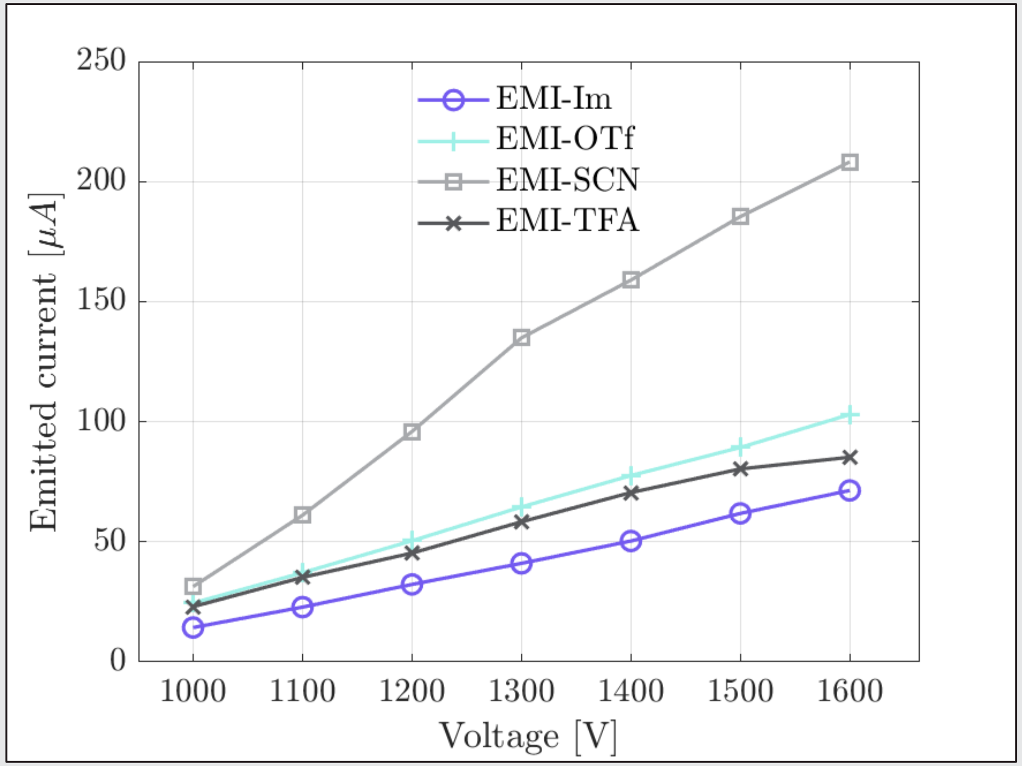
- Chamber pressure 10^{-5} mbar
- TOF and FP for 4 ionic liquids at different applied voltages (from 1000 to 1600 V in steps of 100 V)



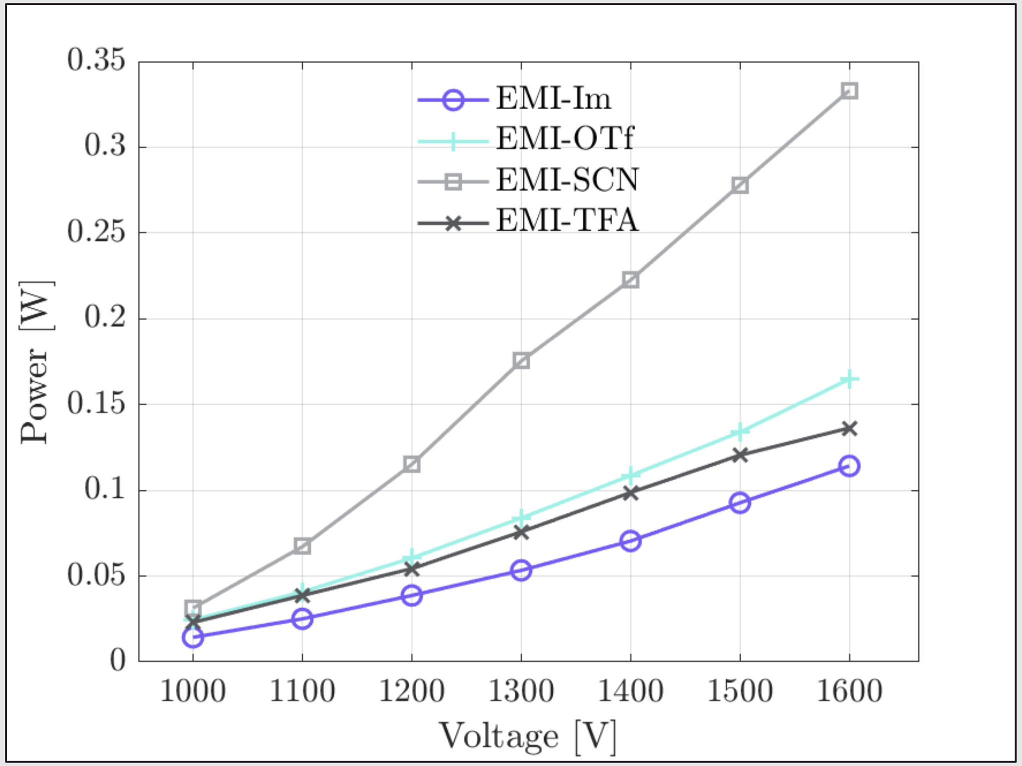


3.0 PERFORMANCE RESULTS

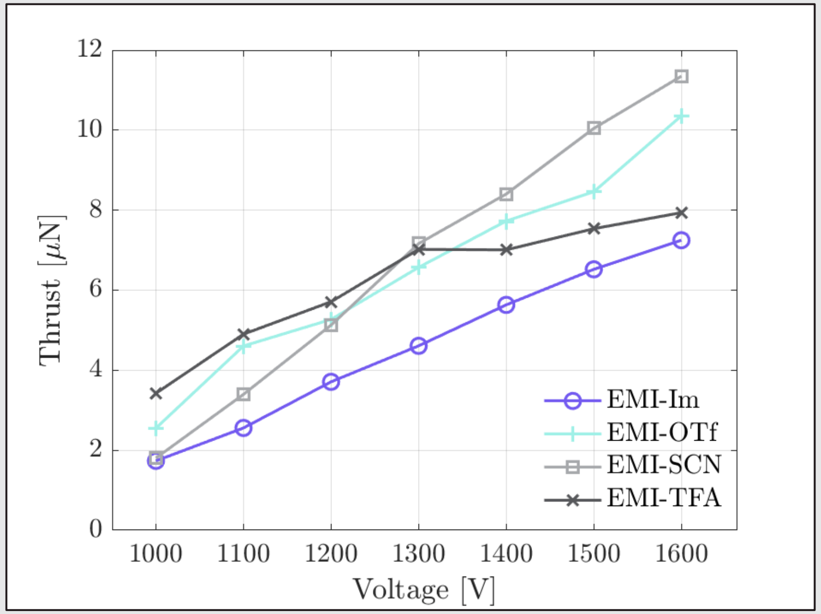
EMITTED CURRENT



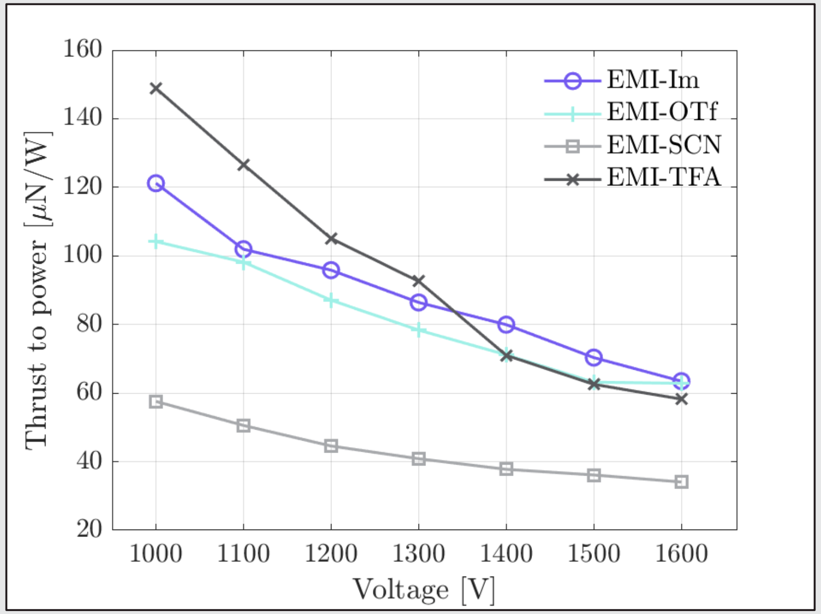
EMITTER POWER



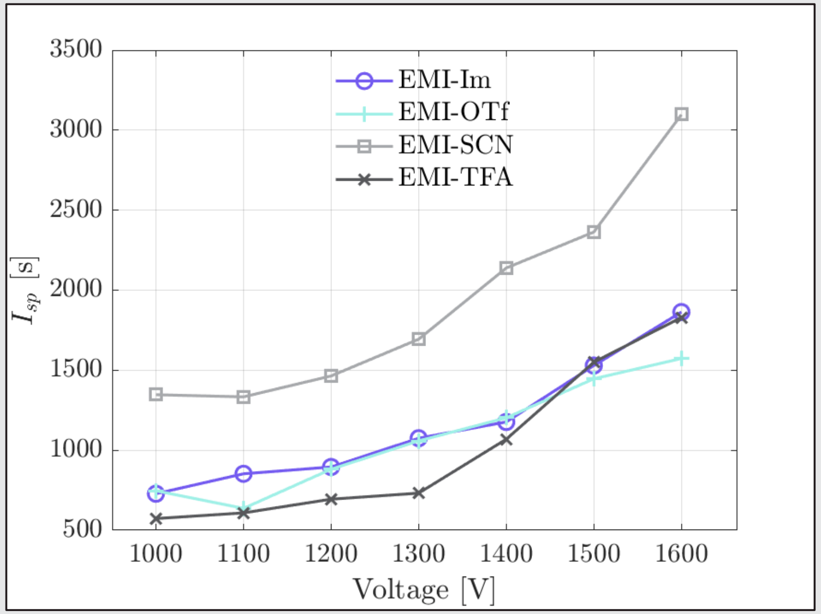
THRUST



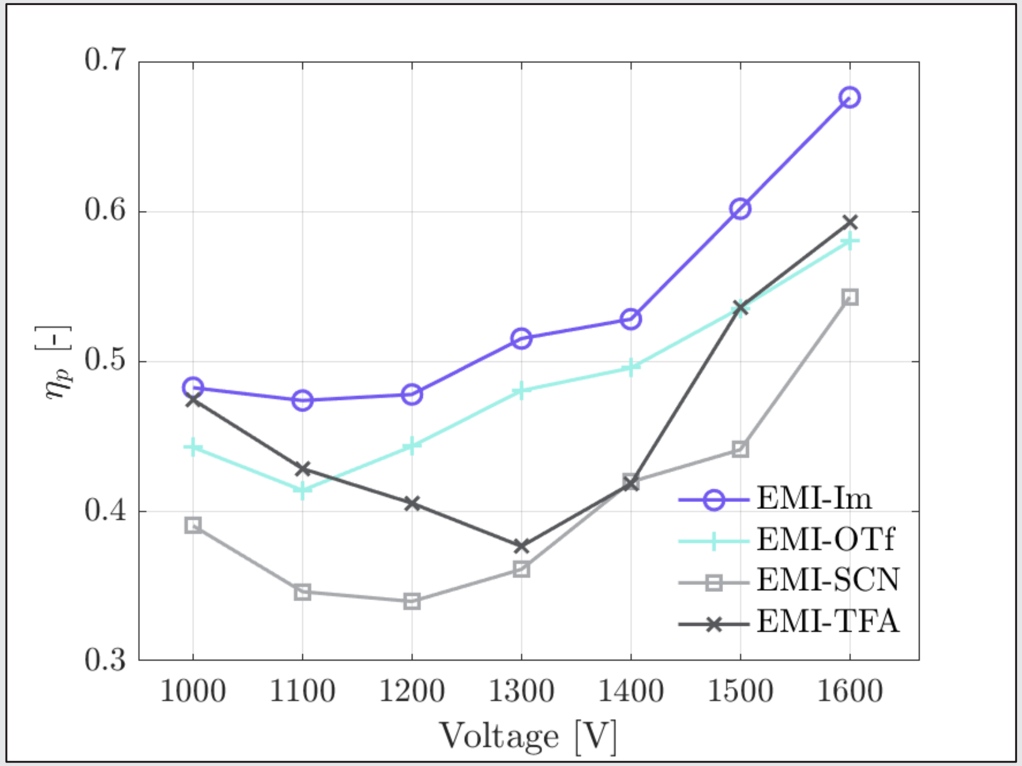
THRUST TO POWER



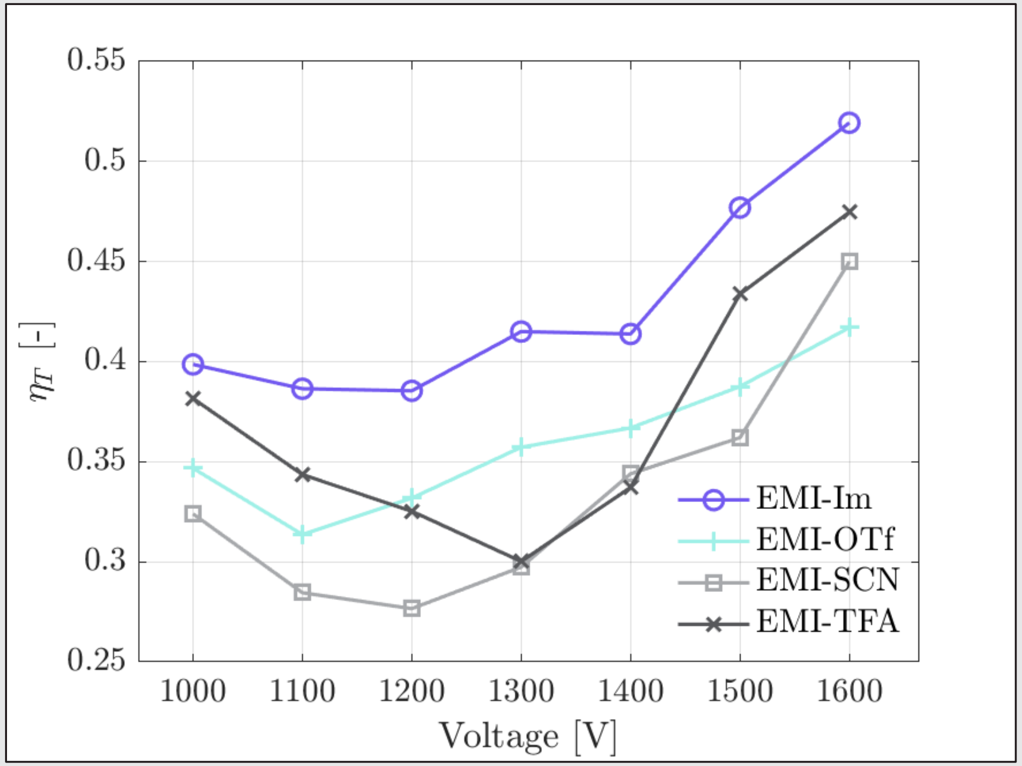
SPECIFIC IMPULSE



POLYDISPERSIVE EFFICIENCY



THRUST EFFICIENCY



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4.0 CONCLUSIONS

- EMI-Im has the highest thrust efficiency of the liquids tested, but lacks thrust due to the lower emitted current.
  - Increase the electric field.

- EMI-SCN has the highest thrust and specific impulse, but lowest thrust efficiency.
  - Increase fluidic impedance.

- EMI-OTf and EMI-TFA show similar performance. They are close in thrust and specific impulse to EMI-Im, but fall short in thrust efficiency.

- Easiness and quickness to test different propellants with the same thruster.
  - Is there a better option than EMI-Im?
  - Emitter needs to be tailored to the ionic liquid for optimizing the performance.
  - Material compatibility and temperature behavior.

- Hybrid propulsion concept using green propellant (hypergolic liquids like EMI-SCN).

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THANK YOU !

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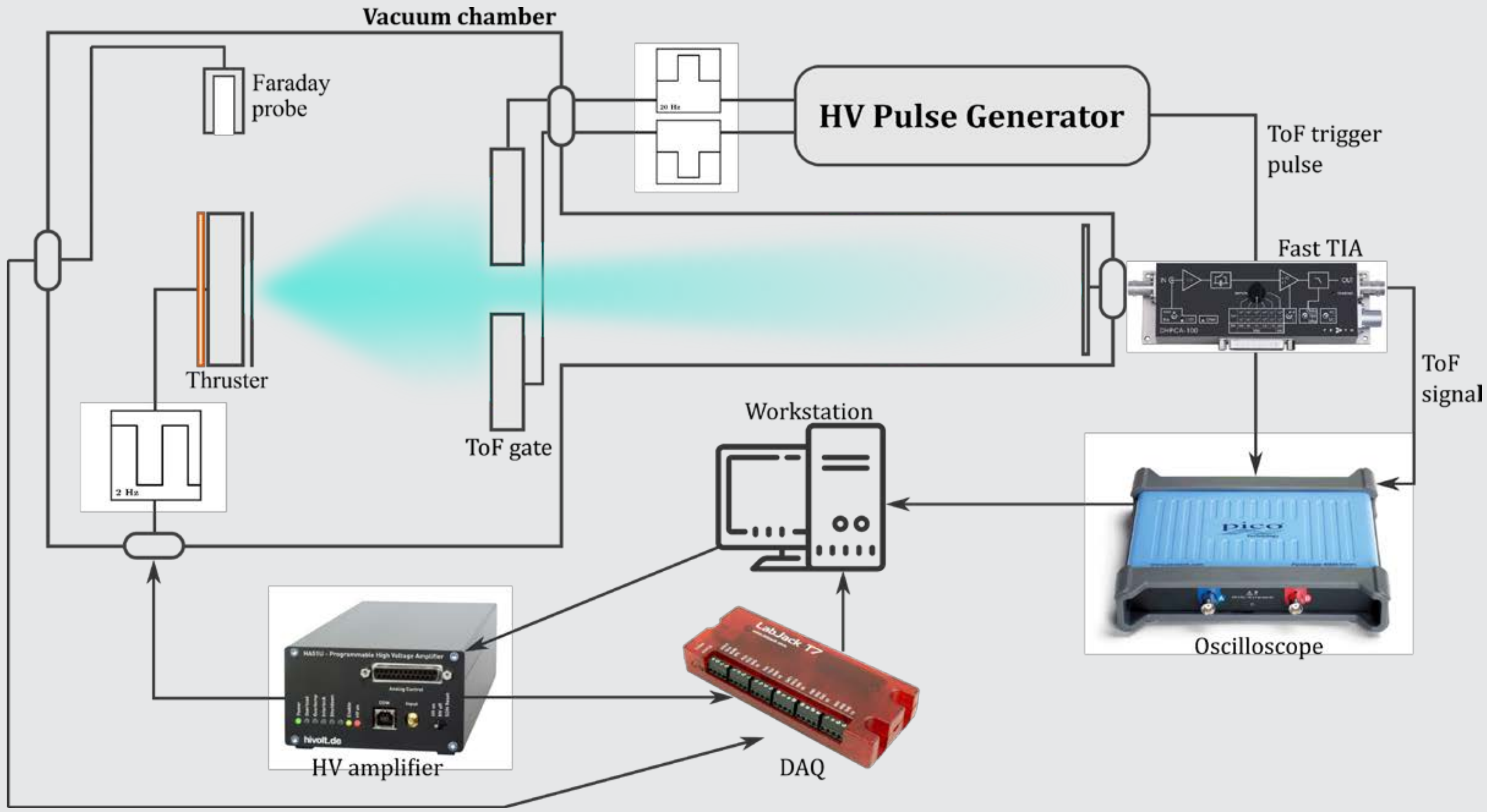
VACCUM CHAMBER AND SETUP SCHEMATIC



EQUATIONS

ToF Thrust

$$F_{ToF} = \frac{2V_a I_e}{L_{ToF}} \int \hat{I}_{ToF}(t)dt$$

Mass flow

$$m_{ToF} = \frac{4V_a I_e}{L_{ToF}^2} \int t\hat{I}_{ToF}(t)dt$$

Polydispersive

$$\eta_p = \frac{F_{ToF}^2}{2\dot{m}_{ToF} I_e V_a}$$

Specific impulse

$$I_{sp_{ToF}} = \frac{F_{ToF}}{g_0 \dot{m}_{ToF}}$$

Angular efficiency

$$\eta_\theta = \left(\frac{\int_0^{\pi/2} \hat{I}(\theta) \cos\theta \sin\theta \, d\theta}{\int_0^{\pi/2} \hat{I}(\theta) \cos\theta \, d\theta} \right)$$

Thrust

$$F = F_{ToF} \eta_x \sqrt{\eta_\theta \eta_E}$$

Specific impulse

$$I_{sp} = I_{sp_{ToF}} \eta_x \sqrt{\eta_\theta}$$