Experimental Characterization of Indium FEEP Microthrusters

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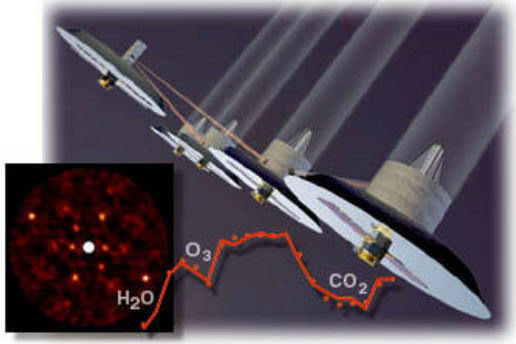
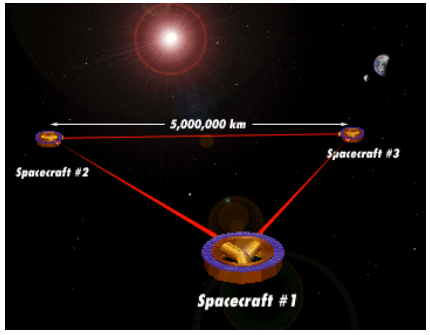
Space Propulsion

Austrian Research Centers Seibersdorf

NASA Advanced Propulsion Workshop, MSFC, April 2001

NASA Origins Program - ESA Fundamental Physics Missions





Starlight (ST-3) **Terrestrial Planet Finder** **LISA** **DARWIN**

European Missions in Progress: Microscope, GOCE, DIVA, SMART-2, ...

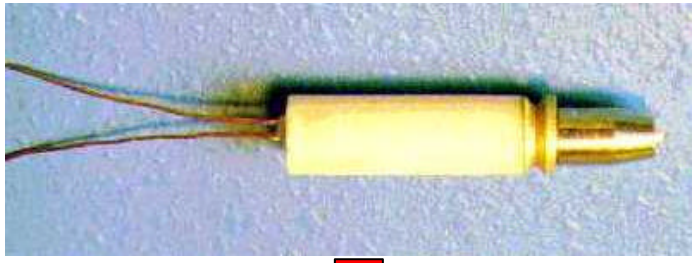
Challanging Requirements

- Highly Controllable µN Thrust
- Very low Thrust Noise
- No Contamination Risk

Ultraprecise Indium FEEP Thrusters

Development of Indium Liquid-Metal-Ion-Source (LMIS)

20 years of development at ARCS ...



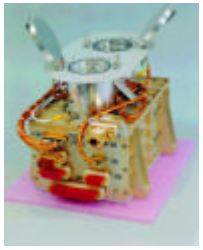
... 10 years involved in space programs

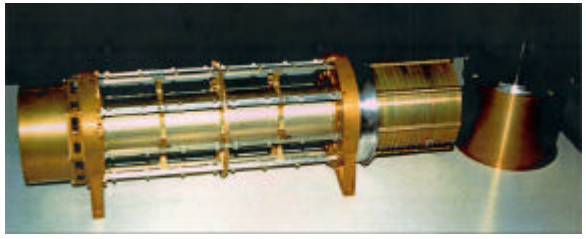
Mass Spectrometer

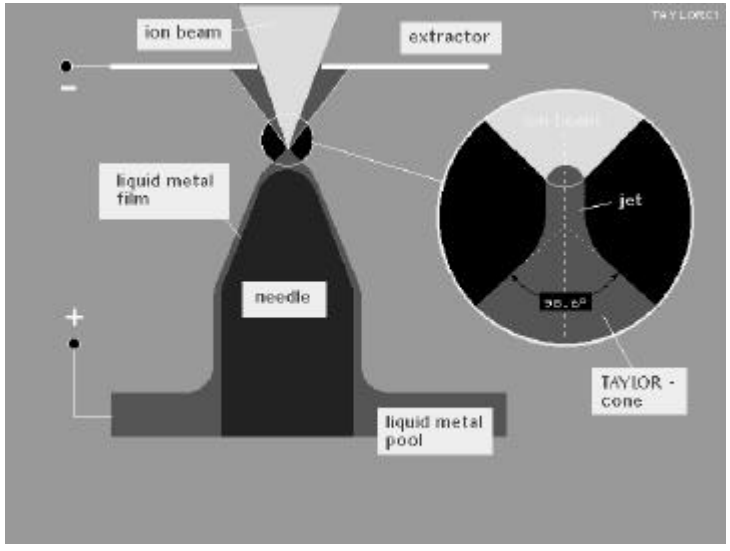
S/C Potential Control

FEEP Thruster

Experiment	Spacecraft	Operation Time
EFD-IE	GEOTAIL	600 h ('92 -)
PCD	EQUATOR-S	250 h ('98)
ASPOC	CLUSTER	Launch Failure '96
ASPOC-II	CLUSTER-II	170 h ('00 -)







Indium FEEP Thruster Overview

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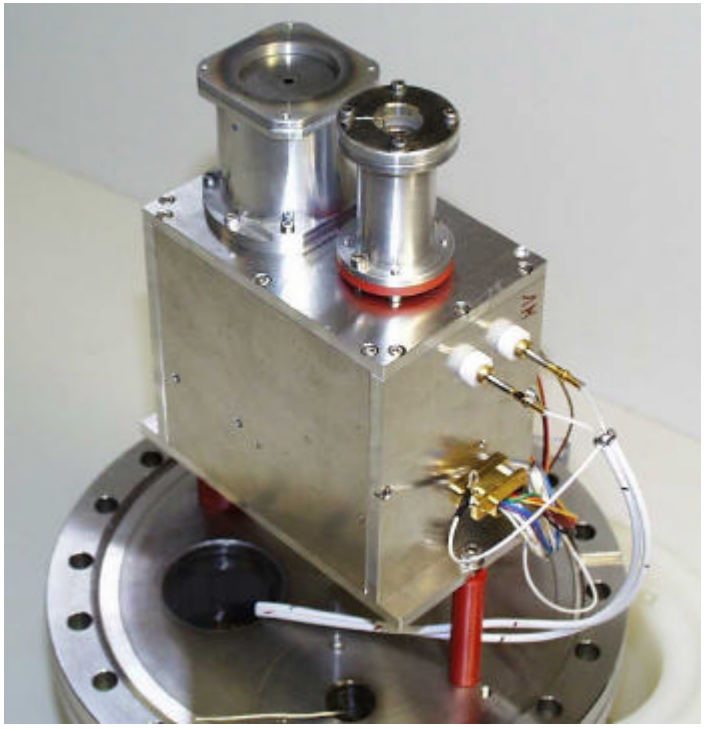


Engineering Model available 2001, FM-QM in 2002

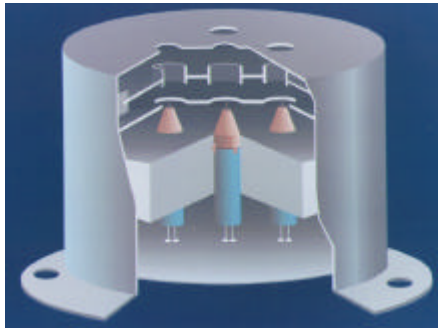
Complete In-FEEP Thruster Lab-Model (incl. Neutralizer & Power Supplies)

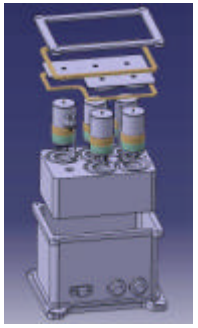
Specifications	InFEEP-25	InFEEP-100
Propellant:	Indium	Indium
Thrust range (µN)	1 – 25	1 – 100
Thrust resolution (µN)	< 0.01	< 0. 1
Thrust noise (µN)	< 0.1**	< 0.1**
Minimum Impulse bit (nNs)	< 5	< 10
Specific Impulse (s)	10000	10000
PCU Input power (Thruster+Neutr.) (W)	5*	13*
Mass (Thruster+Neutralizer+PCU) (kg)	2*	2.5*
Overall dimensions	260x140x200*	260x160x210*
Status	all parameters experimentally verified	

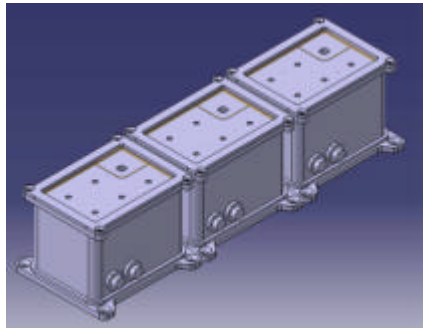
* estimated

** over periods of more than 100 s

Needles can be clustered to achieve up to 1.5 mN or more







Beam Diagnostics

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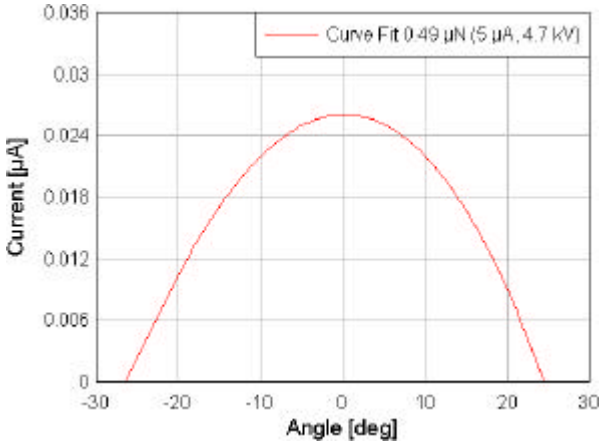
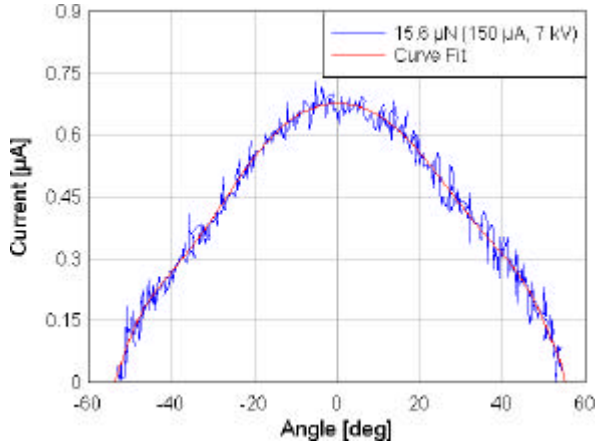
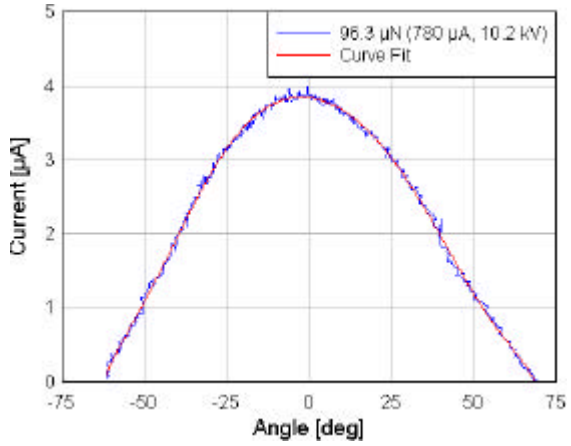
0.47 µN



20 µN



96 µN

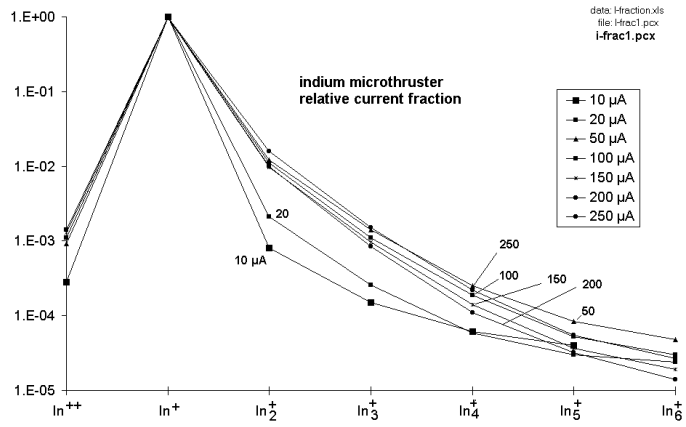


Derive Thrust from Electrical Parameters

$$F \propto I \cdot \sqrt{U} \cdot f\left(\text{Beam Divergence}\right)$$

Confirm Thrust Equation with Direct Pendulum Measurements

Mass Distribution



Direct Thrust Measurements

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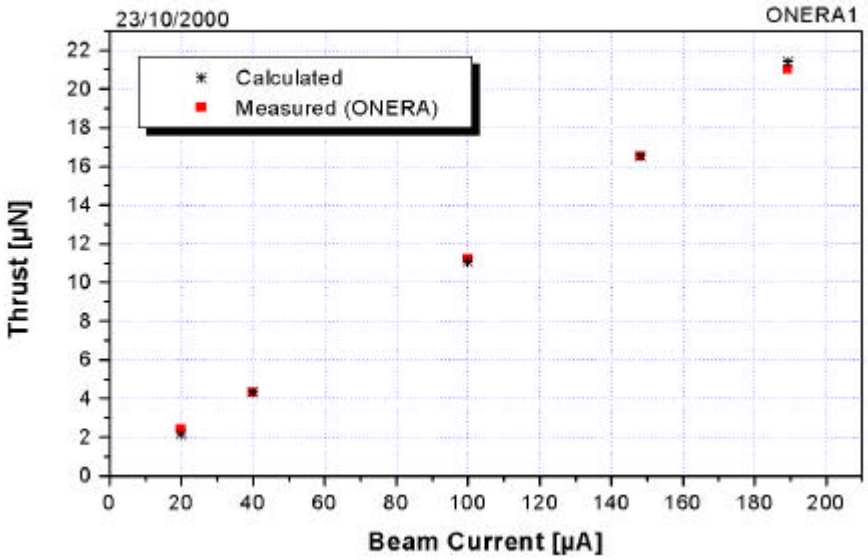
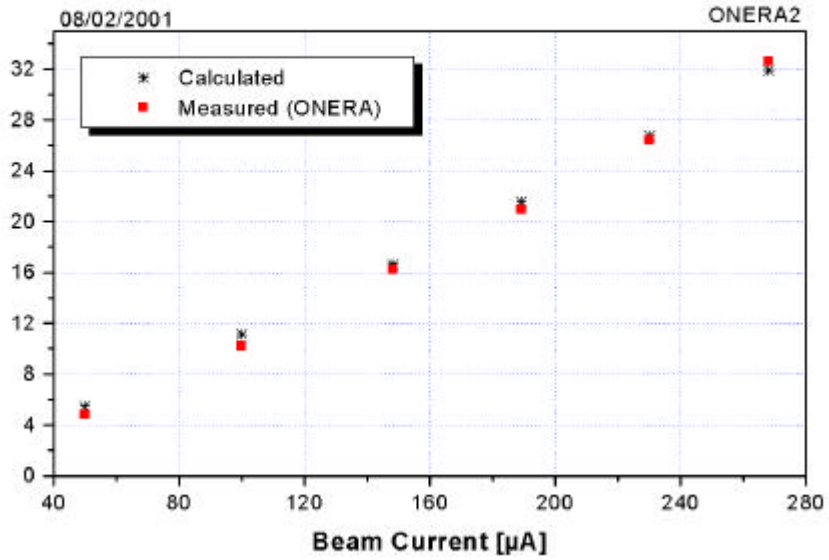
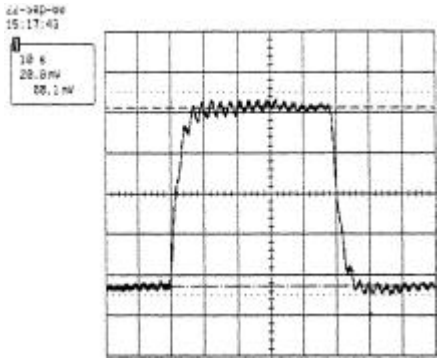
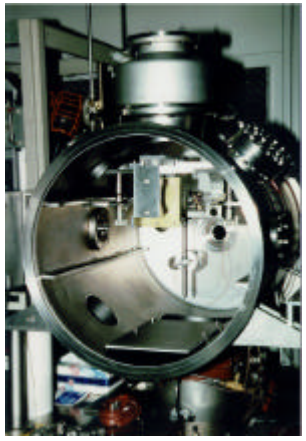






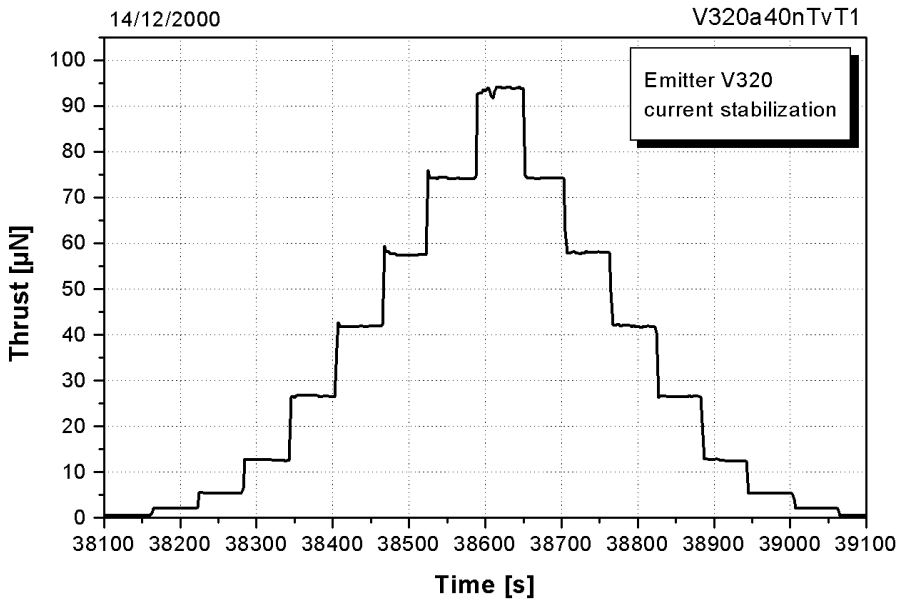
20 µN Impulse



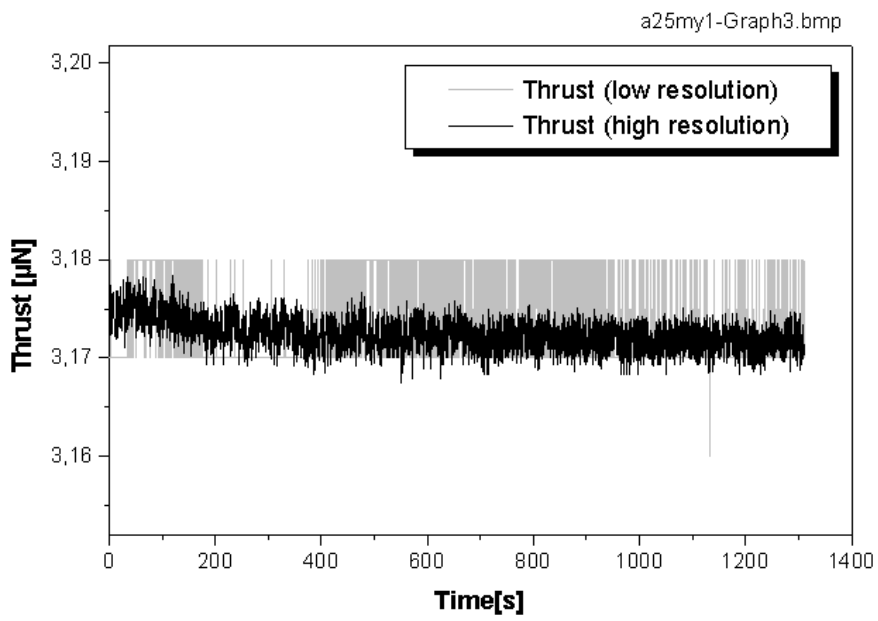
ONERA Chamber

- World first µN direct thrust measurement of Indium FEEP thruster at ONERA
- Performance as expected from 2 - 32 µN ⇒ Thrust Equation ✓
- Further direct thrust testing together with NASA JPL and GSFC

Thruster Response 0.5 - 100 µN



Thrust Resolution



Resolution < 10 nN !

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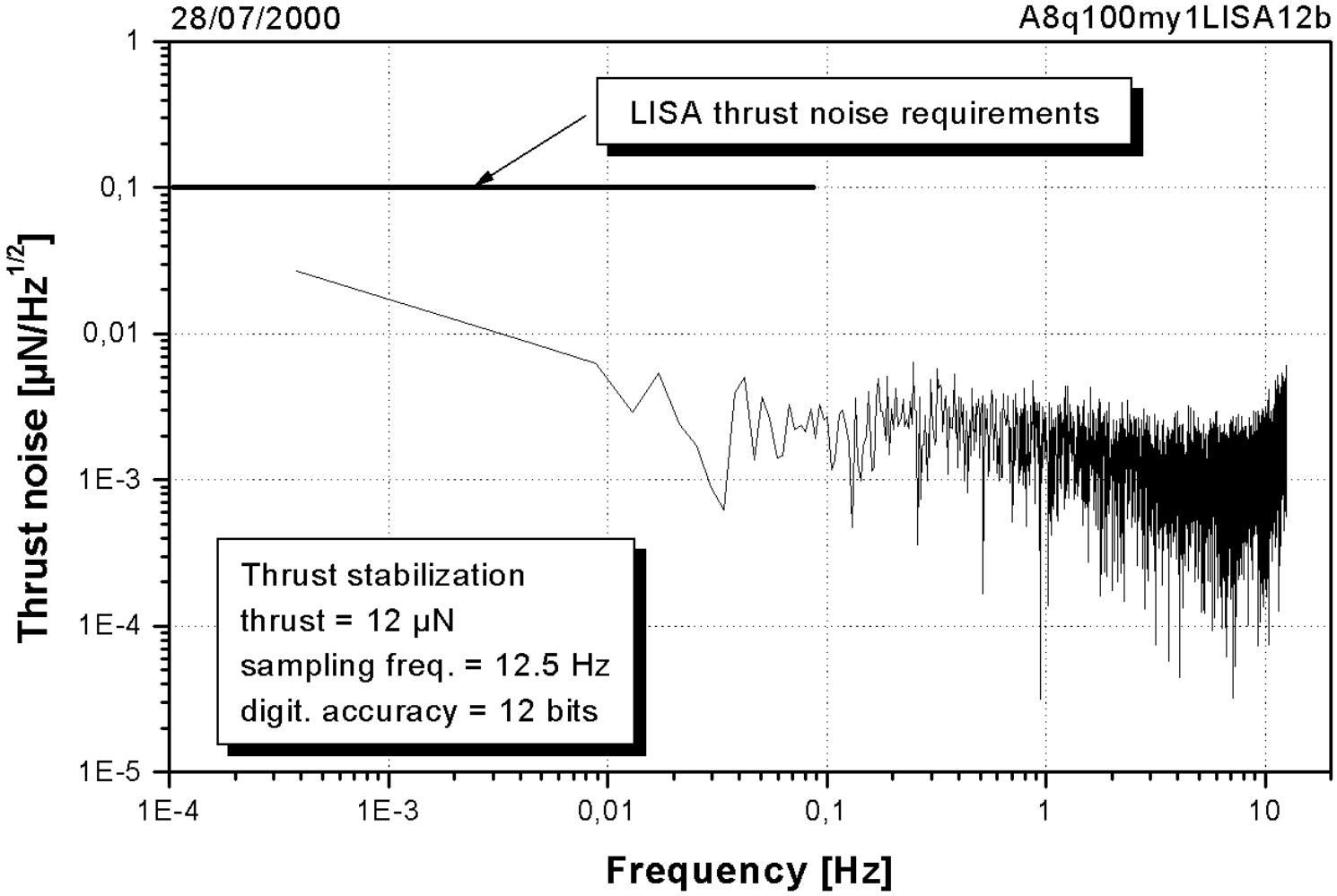
Already One Order of Magnitude below LISA Requirements !



Robustness

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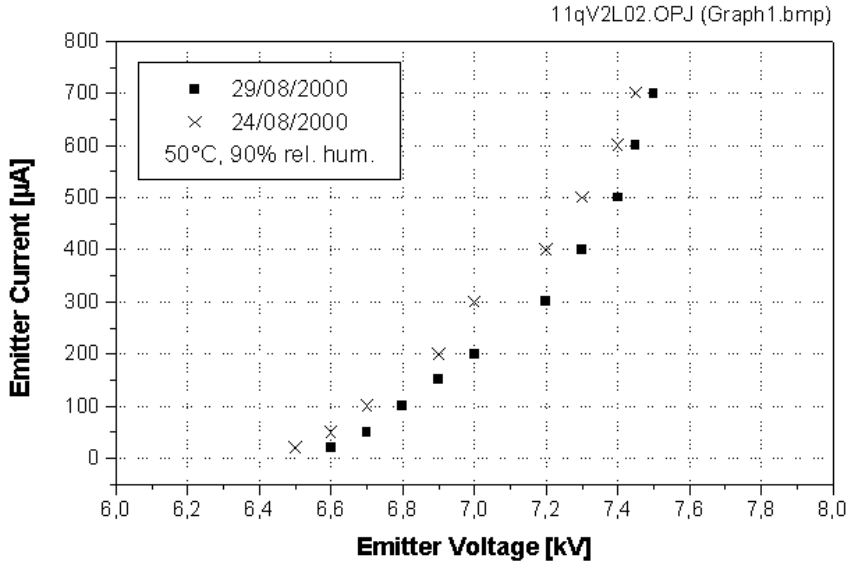
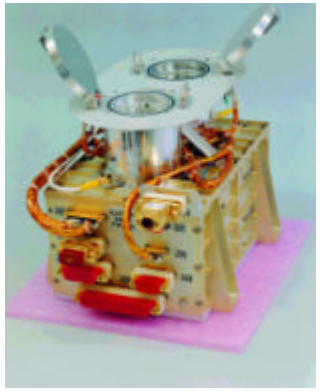
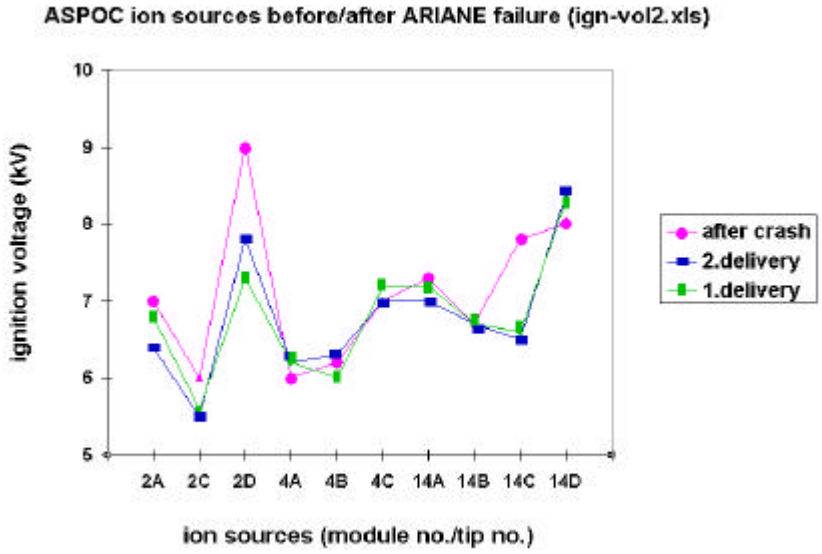




ASPOC Before ... **... and After Launch Failure**

Test of an Indium Ion Emitter after 5 days at 50°C and 90% rel. humidity



Lifetime Testing

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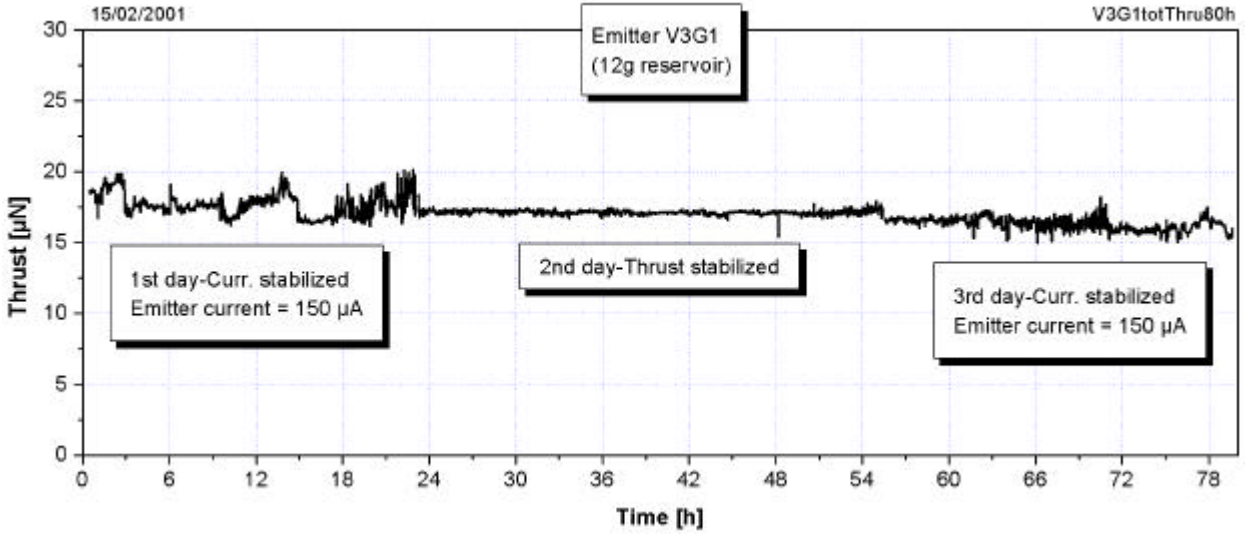
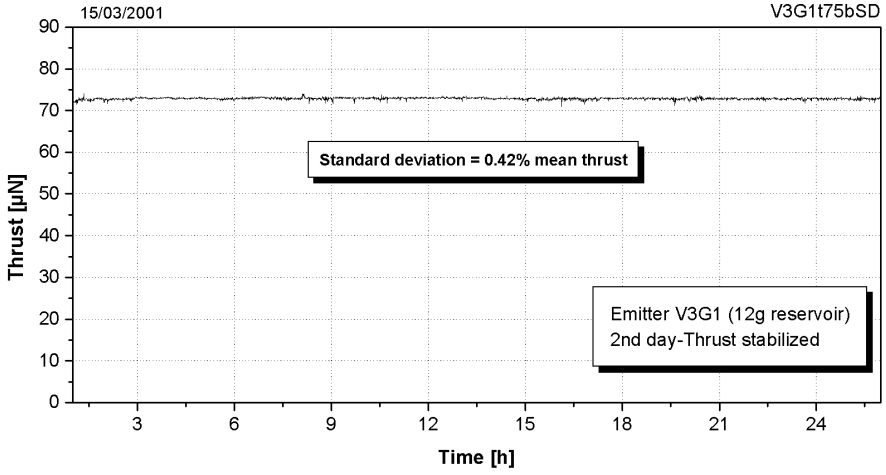
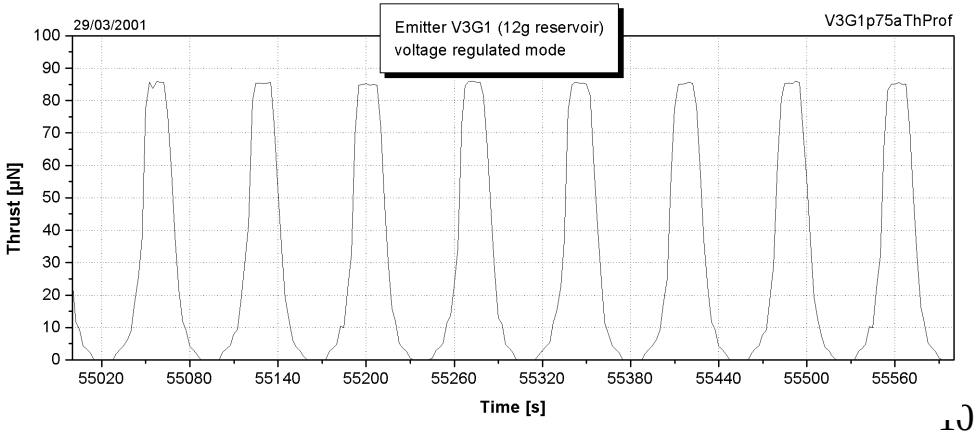
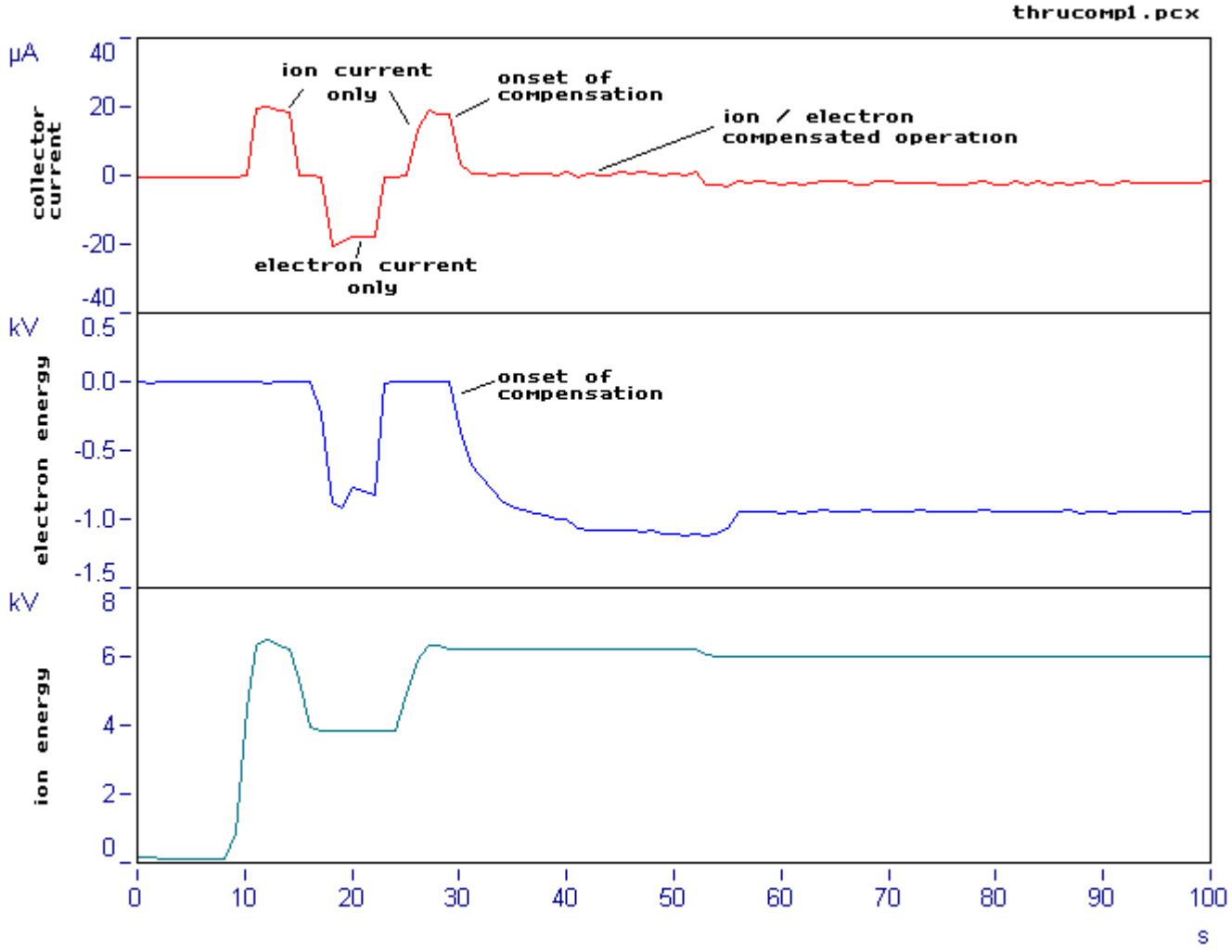
- > 1200 hours in space
- 4000 h Endurance Test at 1.5 µN
- 100 hours at 15 µN
- 50 hours at 75 µN, 100 hours at 75 µN sinus profiles (still going on)

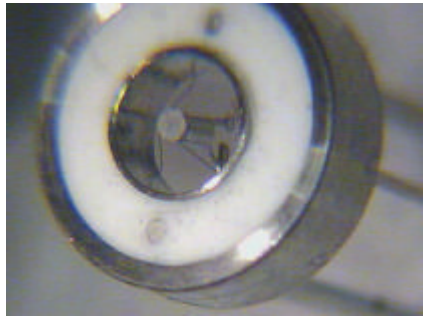


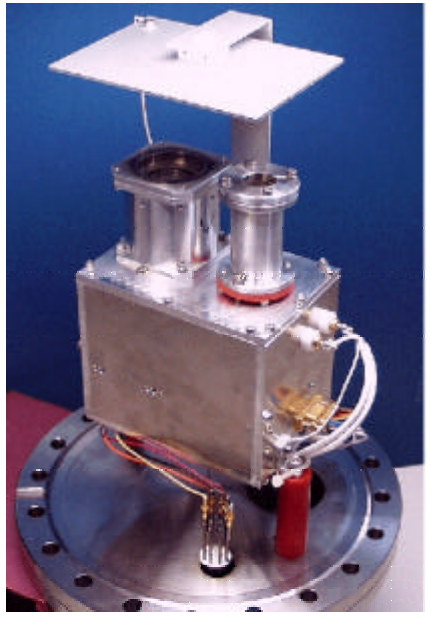




Low-Power Thermionic Cathode - Combined Neutralizer Operation







Numerical Simulation

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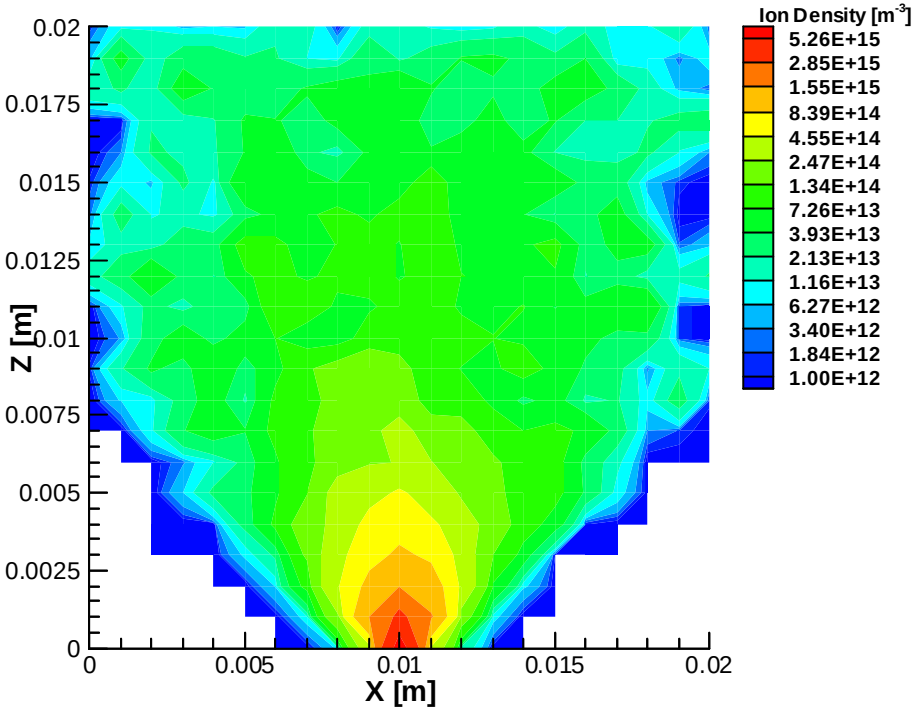

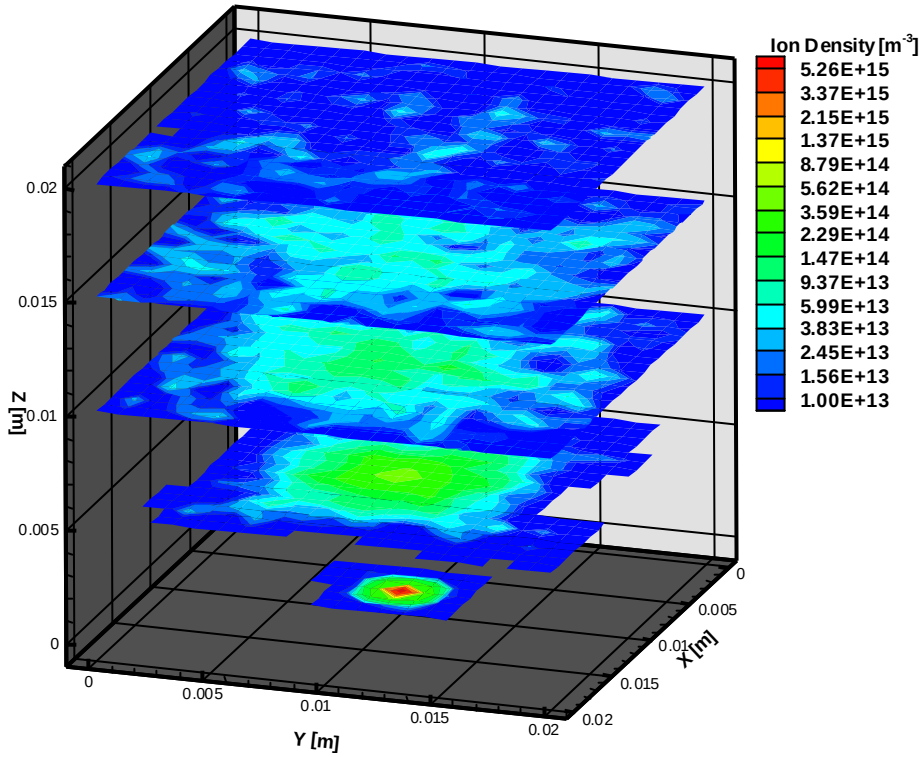

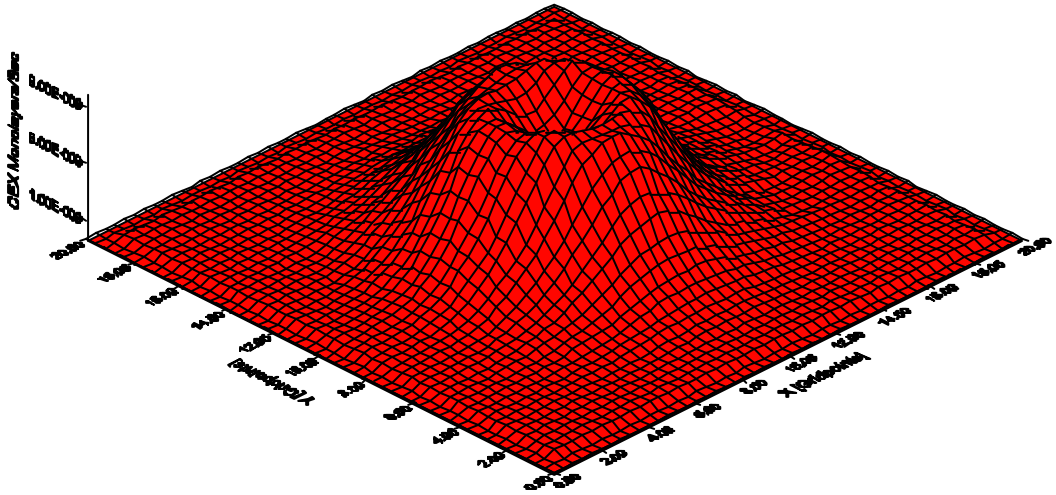

- 3D PIC-MCC Simulation Developed
- Neutralization Issues
- Clustering
- CEX Contamination (backflow below 10^{-8}% !)

New High Current Emitter Designs

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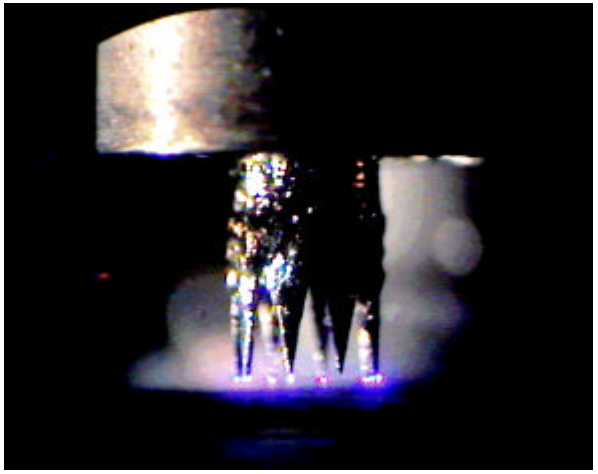
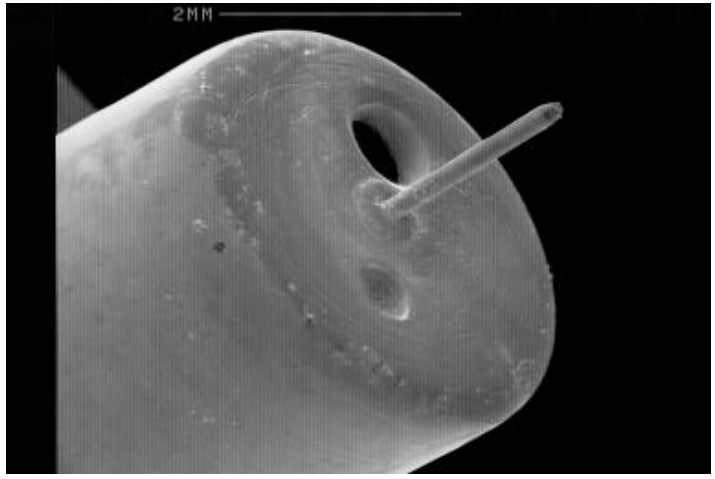
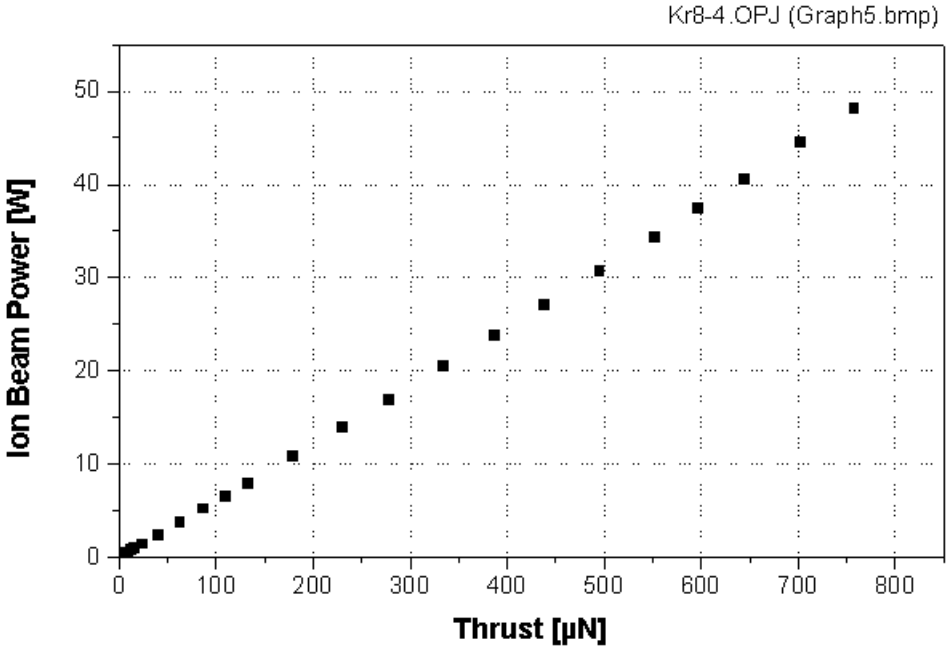


8 Tip Crown Emitter

Porous Ring Emitter



Capillary Tube Emitter



Blade Emitter

FEEP Thruster based on an Indium LMIS

- Demonstrated flawless performance after exposure in humid and hot environment
- Fulfill all challanging µN thruster requirements
- Neutraliser compensates charge on collector
- No contamination expected to spacecraft

Present Activities

- Continuation of Endurance Testing for 1070 hours
- Large Reservoir Implementation (1600 Ns per emitter)
- Cluster Testing of Module with 3 Emitters
- Thrust Vector Stability for Long Periods