Passive Propellant Feeding in Electrospray-Ion Microthrusters

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lmts.epfl.ch
http://lmts.epfl.ch/MEMS-ion-source

EPFL, Switzerland

9th ESA Round Table on Micro and Nano Technologies for Space Applications, Lausanne • Switzerland, June 12-15, 2014

Electric propulsion for in-space maneuvers

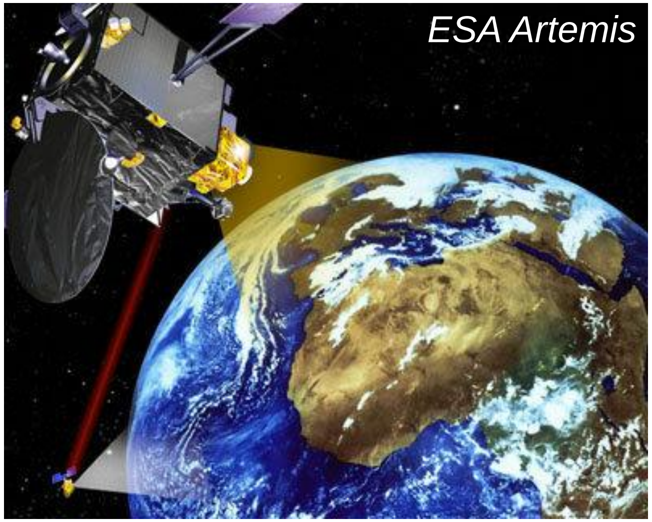
Low thrust propulsion systems

- ✓ In-space orbital maneuvers
- ✓ Station keeping
- ✓ Attitude control

Low system mass/size is enabling

EPFL "Clean Space One"

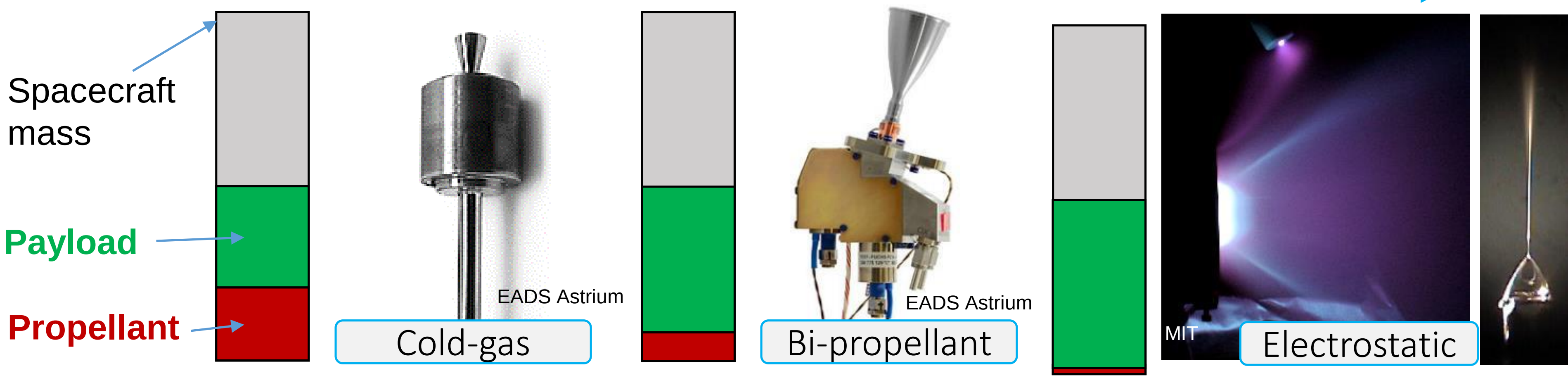
JAXA Hayabusa



ESA Artemis

Propellant-efficient electric propulsion

Increasing exhaust velocity (*specific impulse*) : More **Payload**, Less **Propellant**



Propellant-efficient electric propulsion

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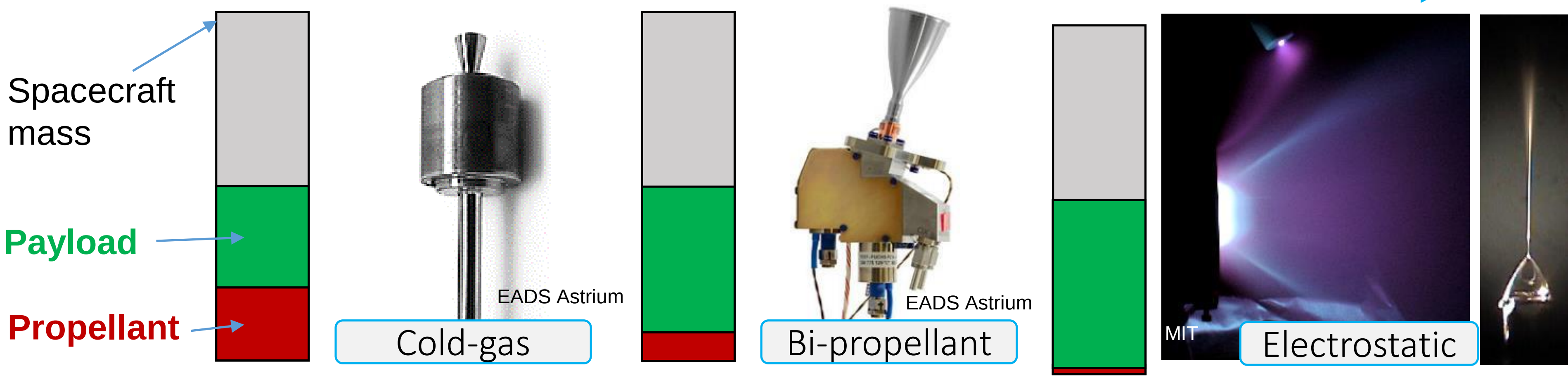
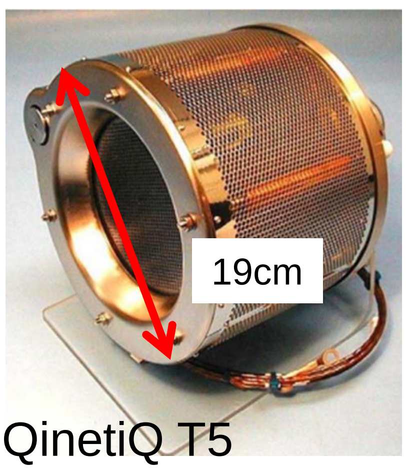
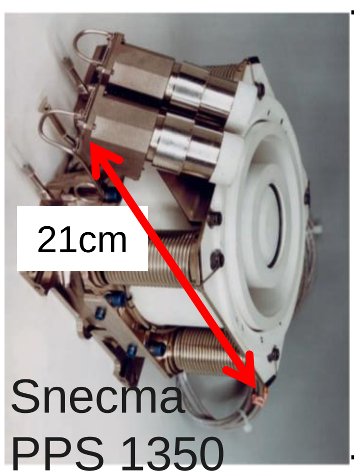


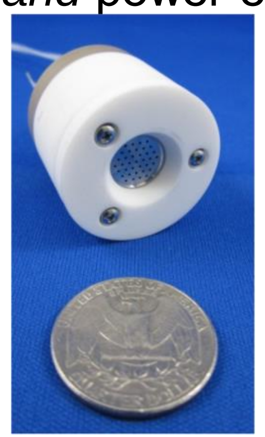
Electrostatic Propulsion : ***Ideally*** High specific impulse (Isp) *and* power efficiency (η)





Isp > 1500s
η> ~50%

Miniaturize



Busek BFRIT-1

Isp > 1800s
η< ~10%

Propellant-efficient electric propulsion

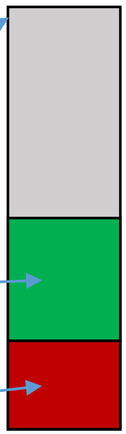
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

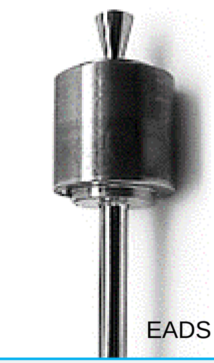
Increasing exhaust velocity (*specific impulse*) : More **Payload**, Less **Propellant**

Spacecraft mass

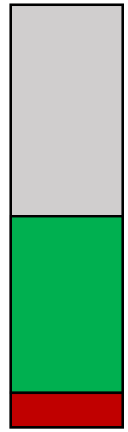
Payload

Propellant

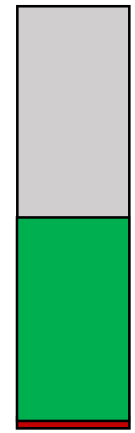


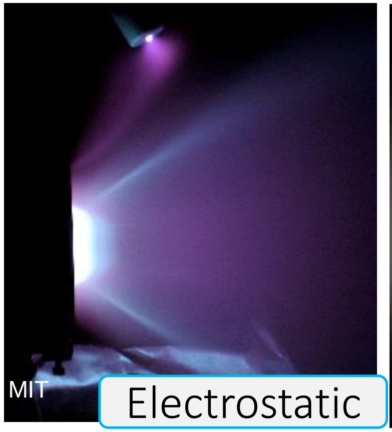


Cold-gas



Bi-propellant



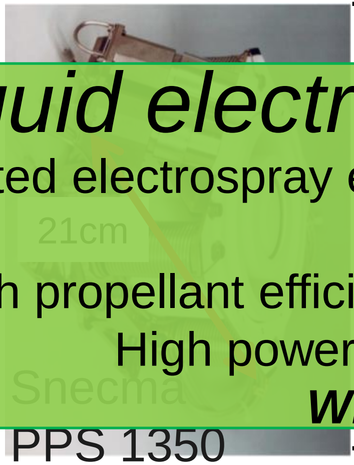


Electrostatic

Electrostatic Propulsion : ***Ideally*** High specific impulse *and* power efficiency

19cm

QinetiQ T5



21cm

Snecma PPS 1350

Isp > 1600s

η> ~50%

Miniaturize

Busek BFRIT-1

Isp > 1800s

η< ~10%

Ionic liquid electrospray propulsion

Microfabricated electrospray emitter arrays

High propellant efficiency

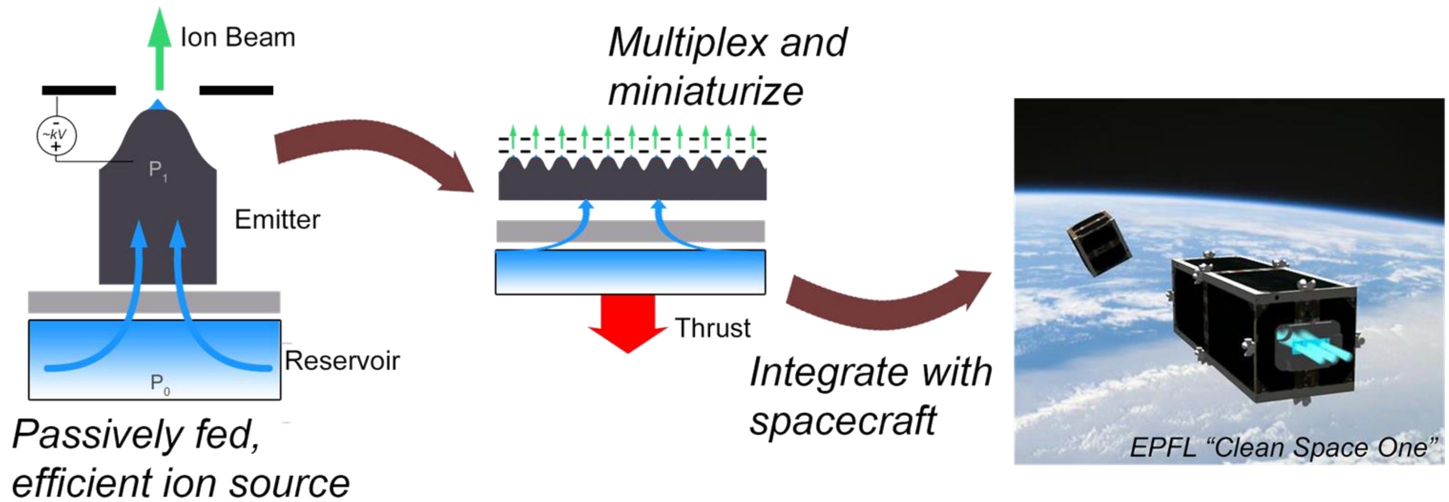
High power efficiency

Within compact device

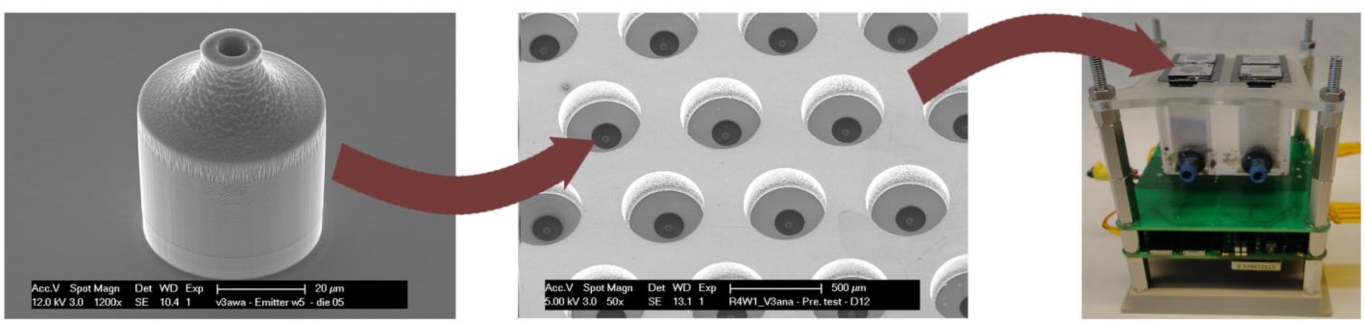
FP7 MicroThrust

Ionic Liquid Electrospray Propulsion Presentation Overview

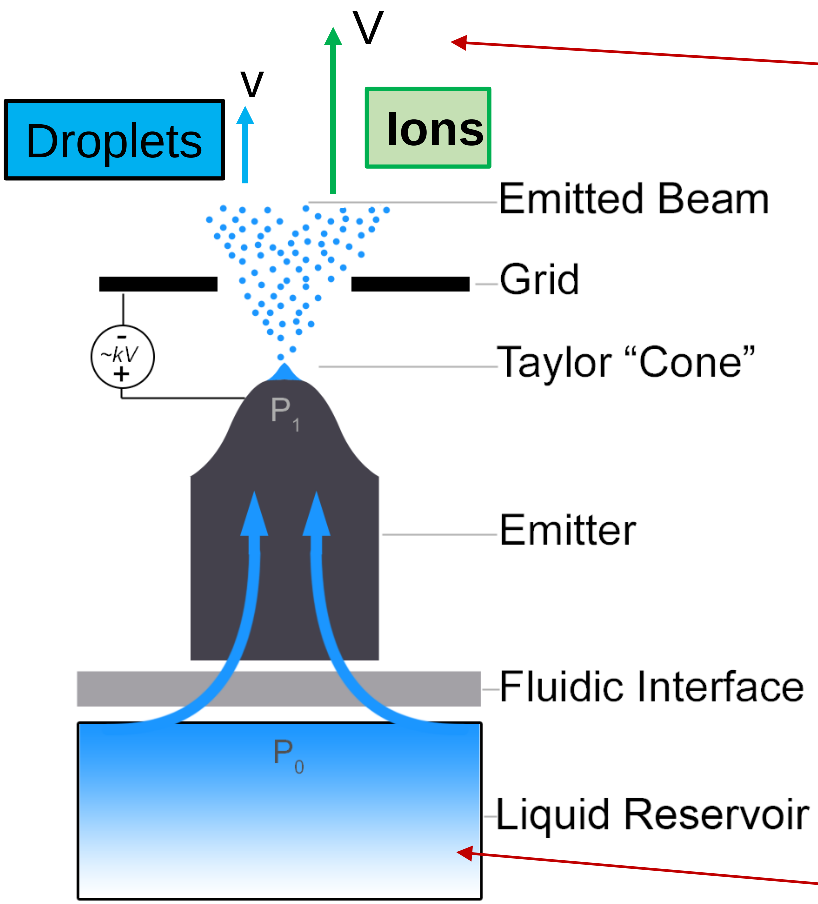
1. Concept motivation:
   Benefits of passively fed ionic liquid ion source thrusters



2. Technology status:
   FP7 MicroThrust Program, overview and results

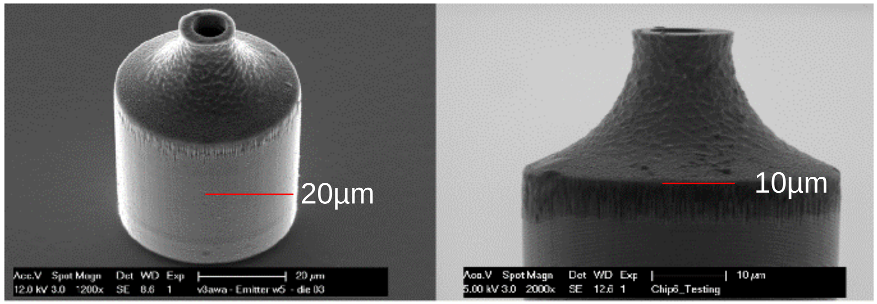


Purely ionic emission and passive propellant transport in electrospray propulsion



Ion emission yields high beam velocities
→*Low propellant mass per mission*

Purely ionic emission
→Propellant and *power* efficient
→V. low thrust per emitter, *arrays are required*
→Targeted at EPFL through narrow *microfabricated* emitters



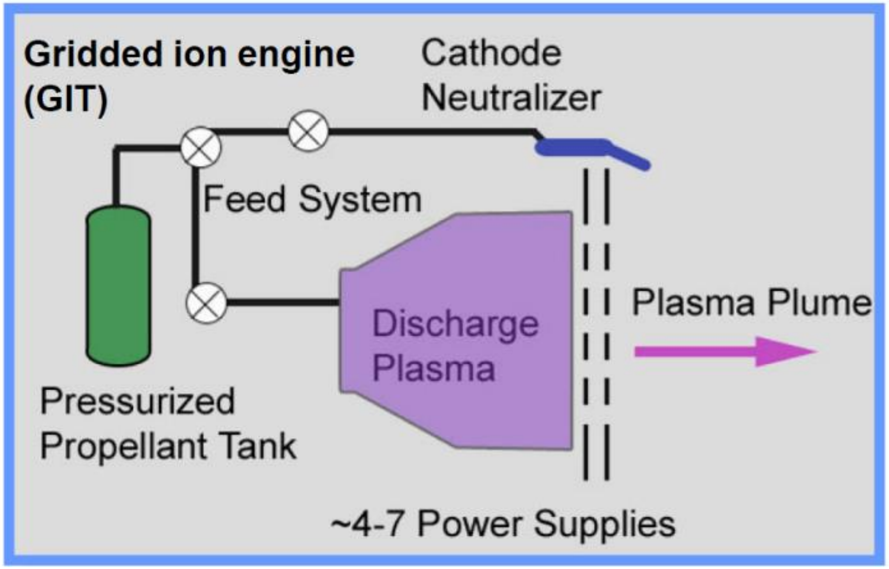
Passive / Zero-G Compatible Feeding

Fluid transport by capillarity / wicking

Many system benefits (discussed here)

Limited demonstration to date

Why passivize IL feeding?
Simplicity



Plasma (Hall/GIT) thrusters
High performance but difficult to miniaturize systems

Propellant stored as gas (typically)
- Heavy storage tank
- Power, mass and volume consuming valves

Discharge chamber
- On-orbit ionization
- Potentially complex

Positive beam emissions
- Require external neutralizer
- Resource and performance loss

Why passivize IL feeding? Simplicity

Passively fed IL-Electrospray

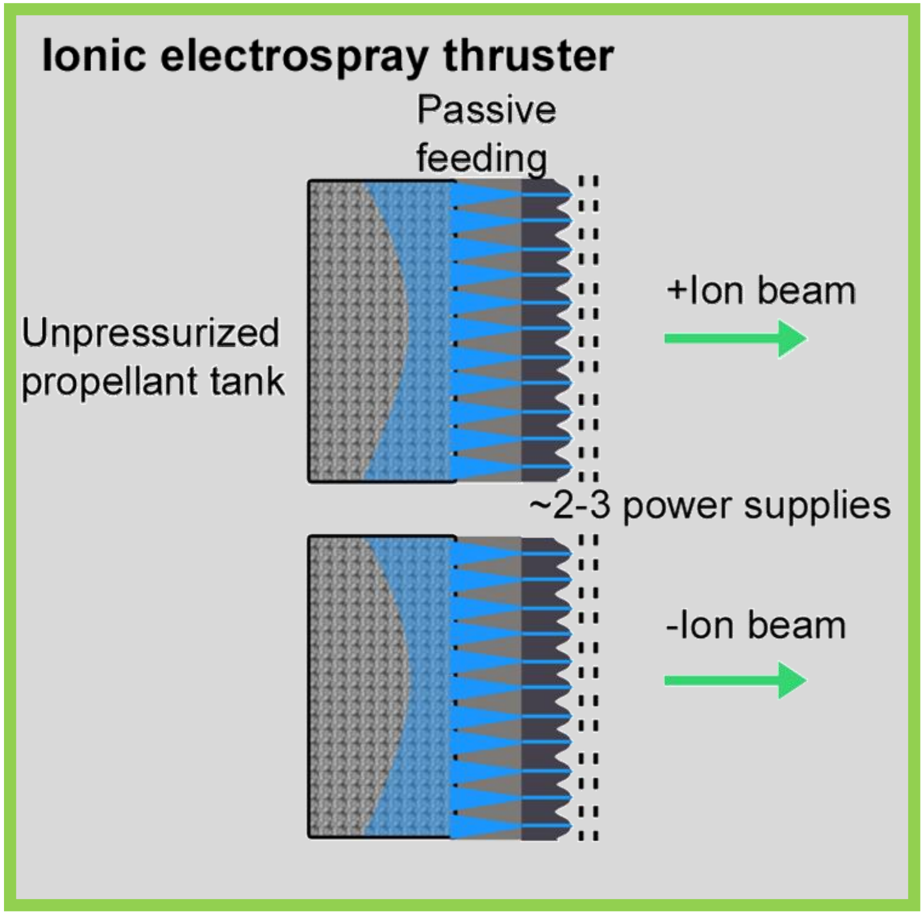
Propellant stored as liquid
- **IL has *zero* vapour pressure**
- *Stored as liquid in vacuum*

Passive feeding
- No valves or regulators

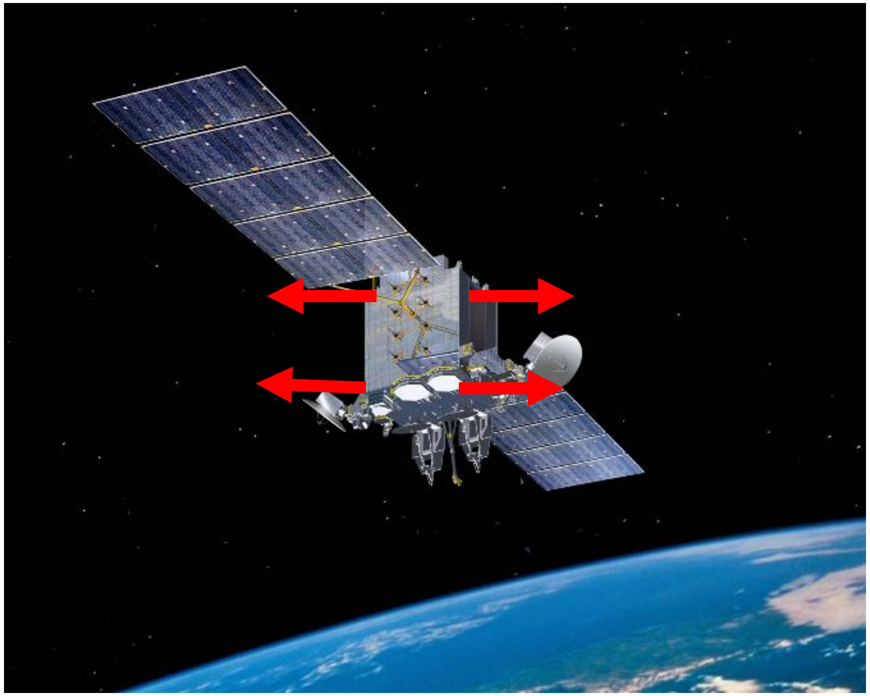
Solvent free 'ionic liquid'
- Plasma in bottle, direct field emission

Bi-polar field emission
- Simultaneous +/- emissions neutralize and contribute to thrust

✓ Simple



Why passivize IL feeding?
Scalability

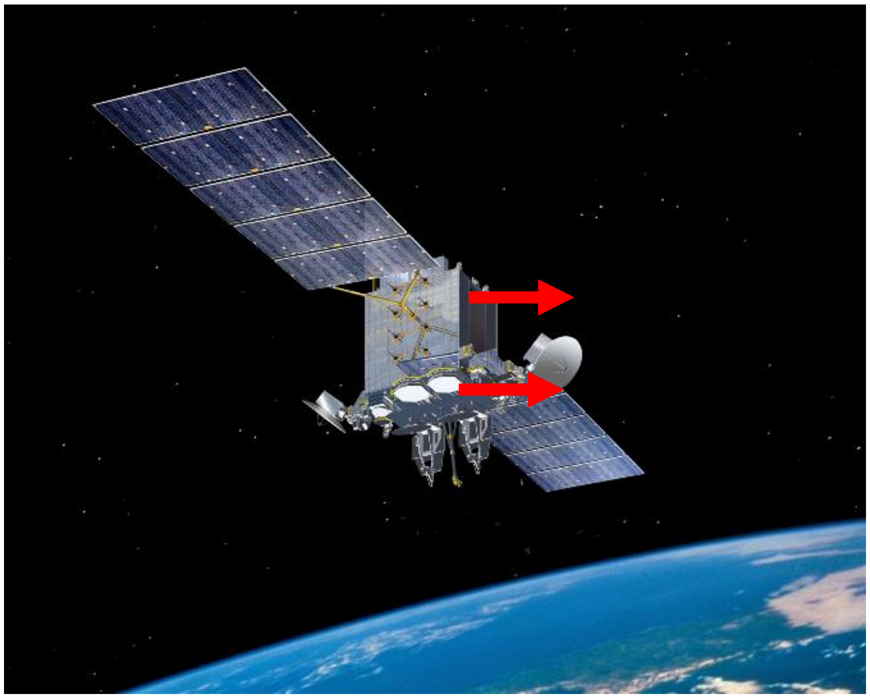


Geostationary SGDC satellite (aviationnews.eu)

Spacecraft
w/ distributed thrusters

✓ Simple

Why passivize IL feeding?
Scalability



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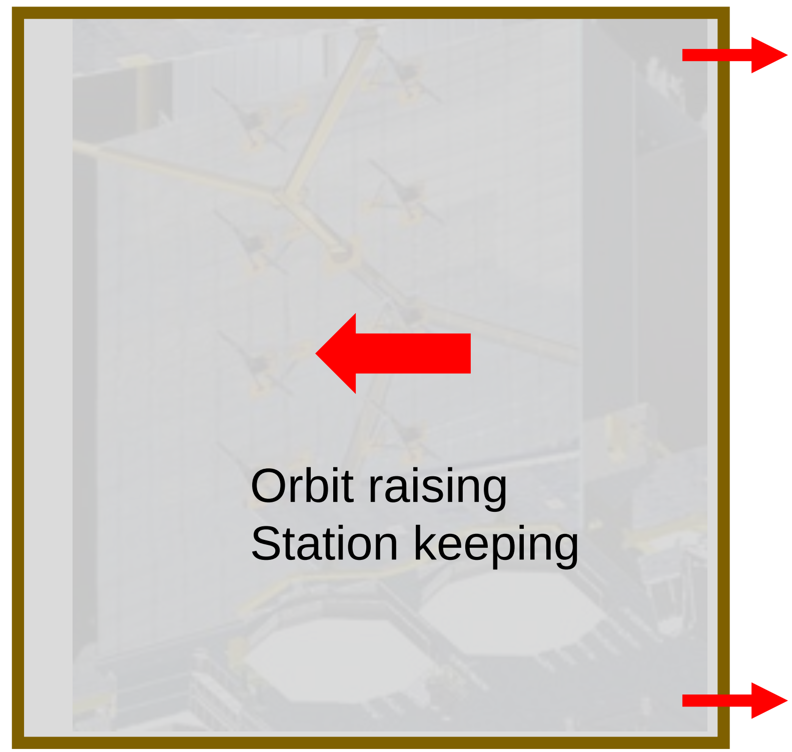

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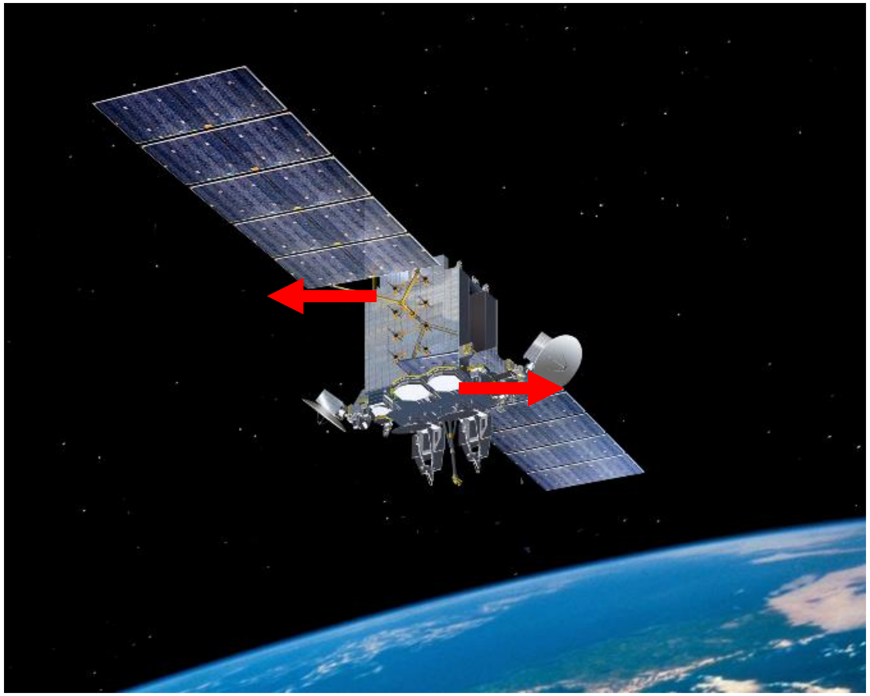

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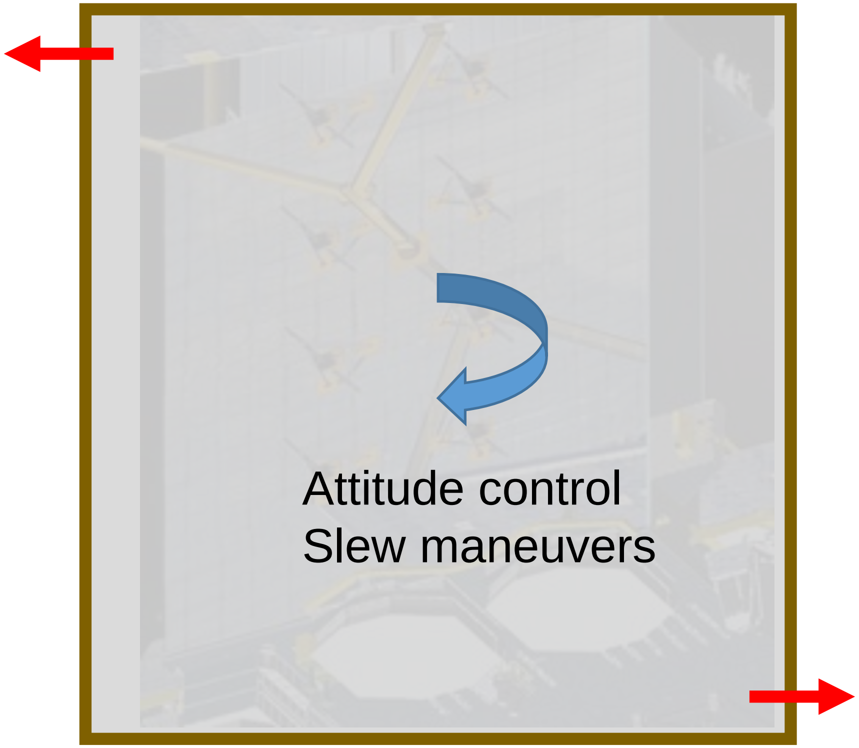
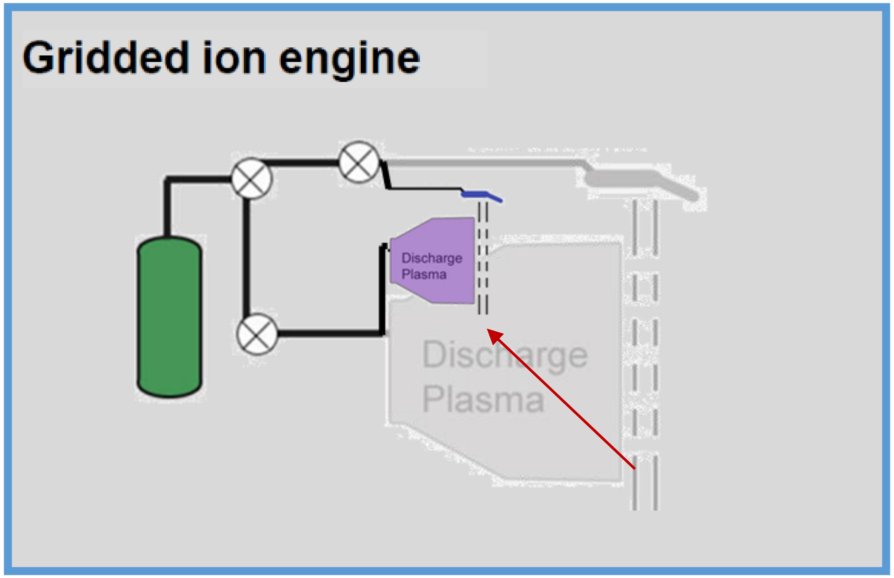


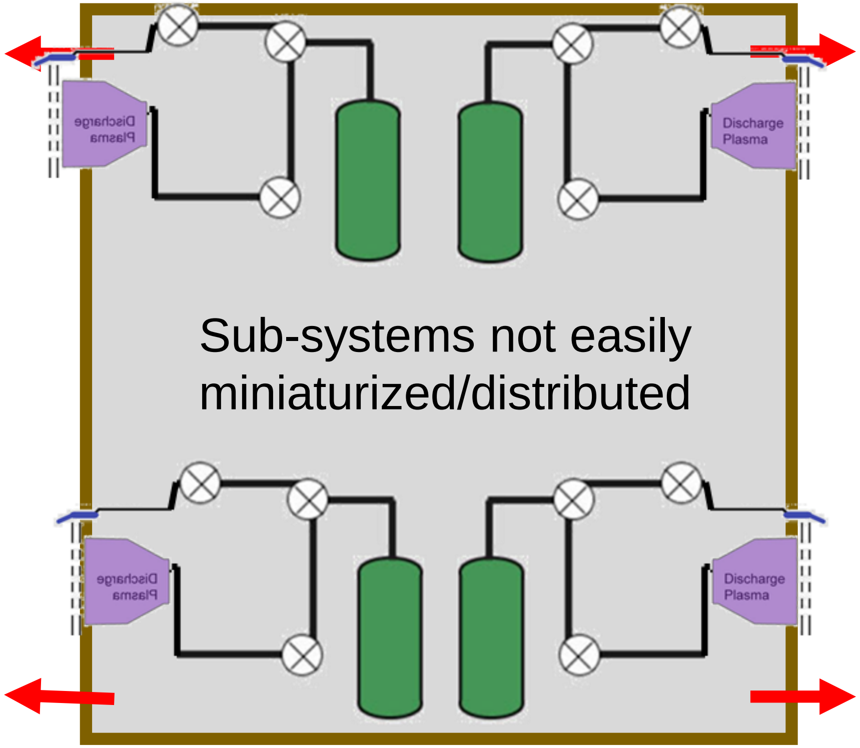
✓ Simple

Why passivize IL feeding? : Scalability of plasma EP

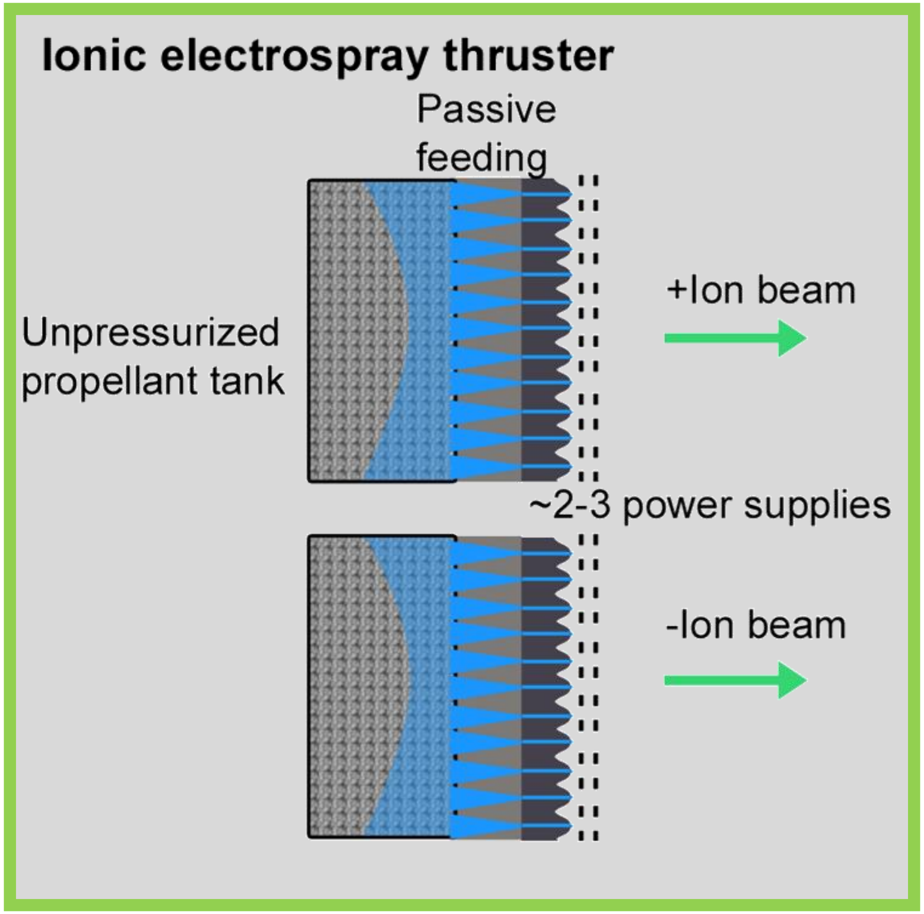


Shrink thruster :
Performance losses

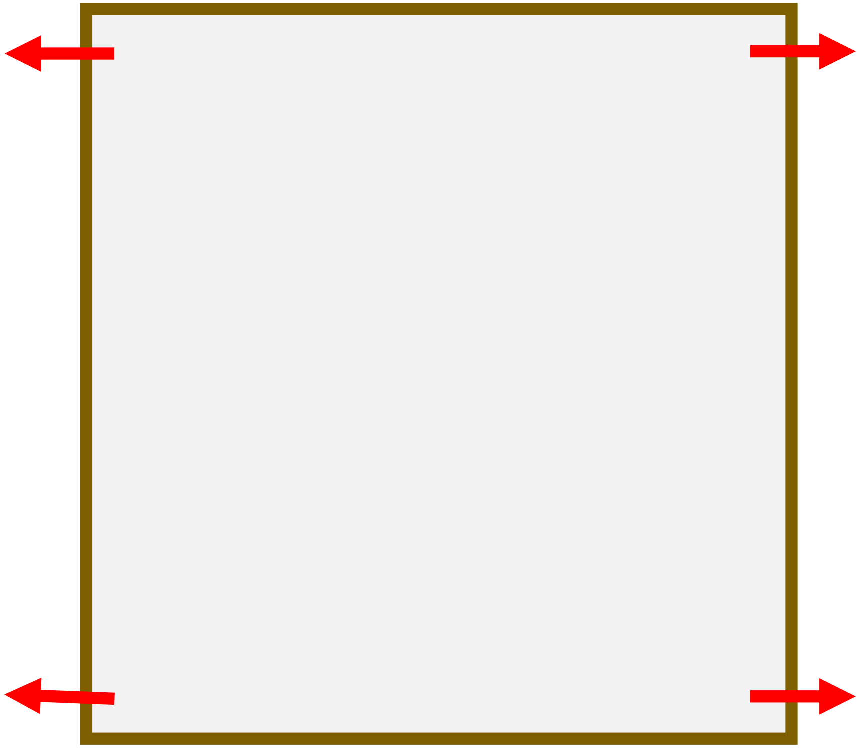
Spacecraft
w/ distributed thrusters



Why passivize IL feeding? : Scalability of IL electrospray EP

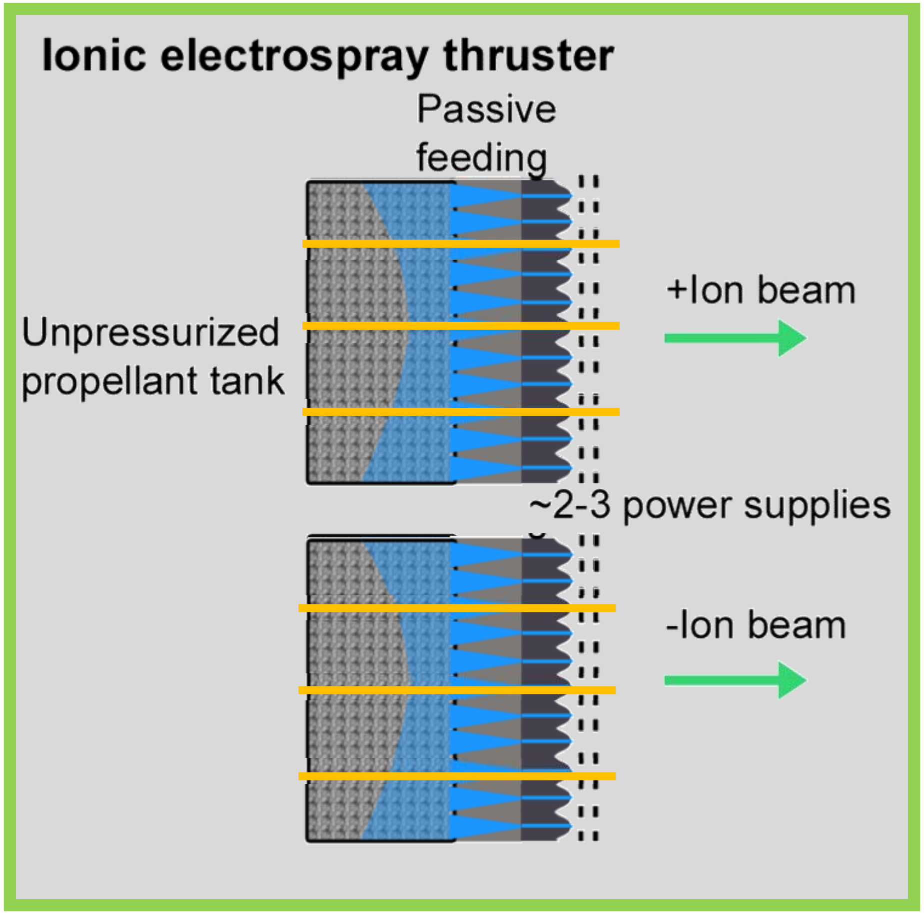


Spacecraft
w/ distributed thrusters

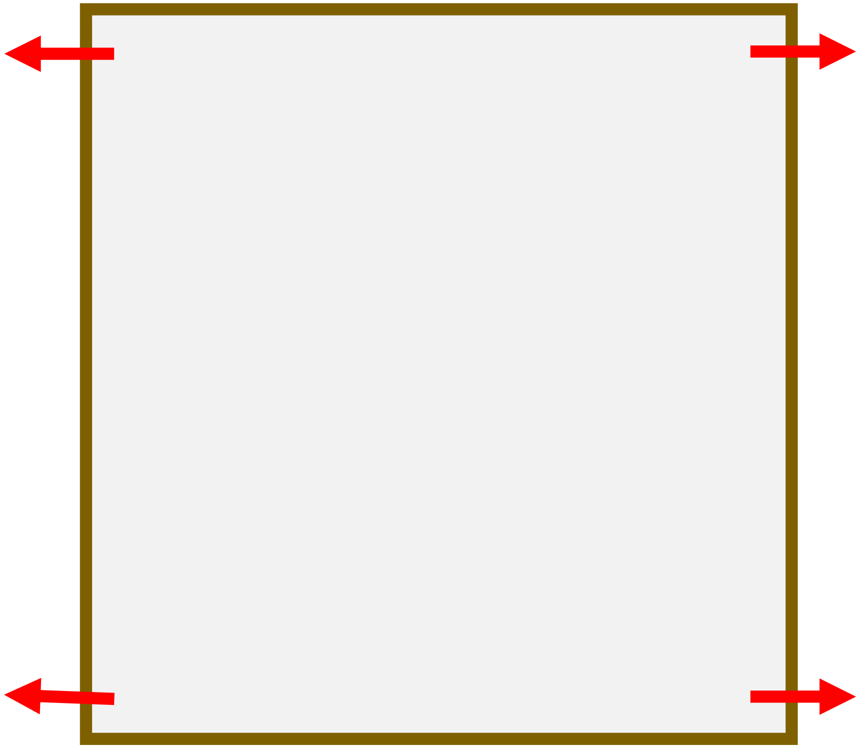


✓ Simple

Why passivize IL feeding? :
Scalability of IL electrospray EP



Spacecraft w/ distributed thrusters



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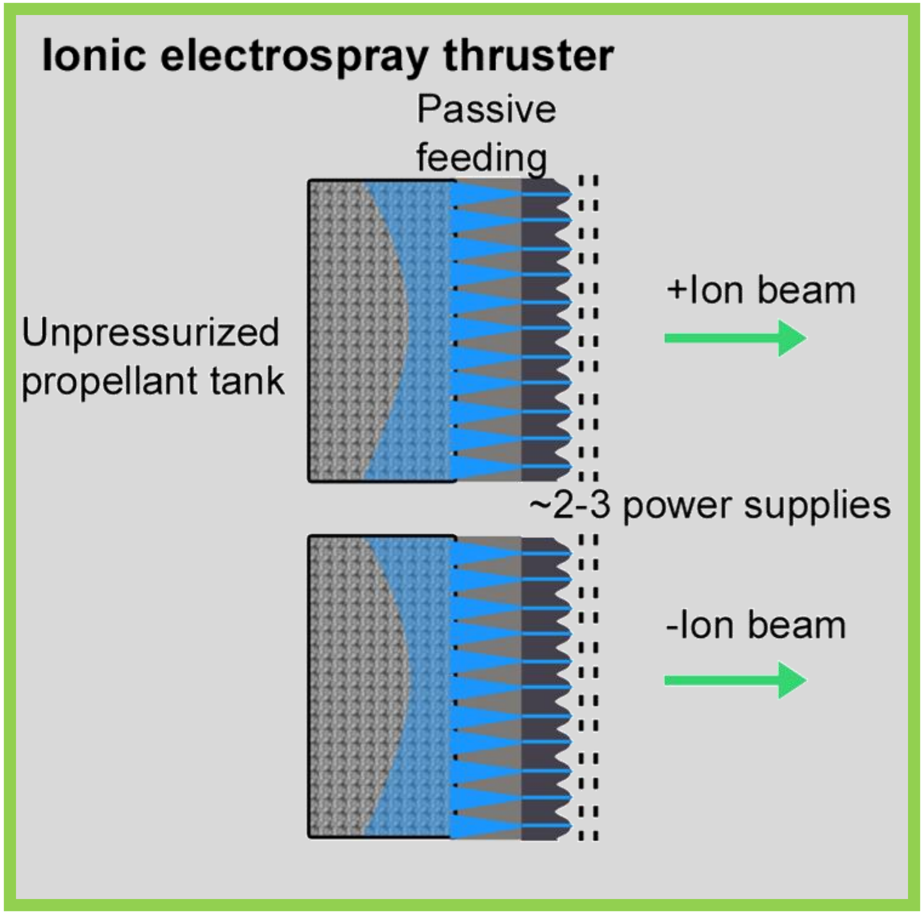
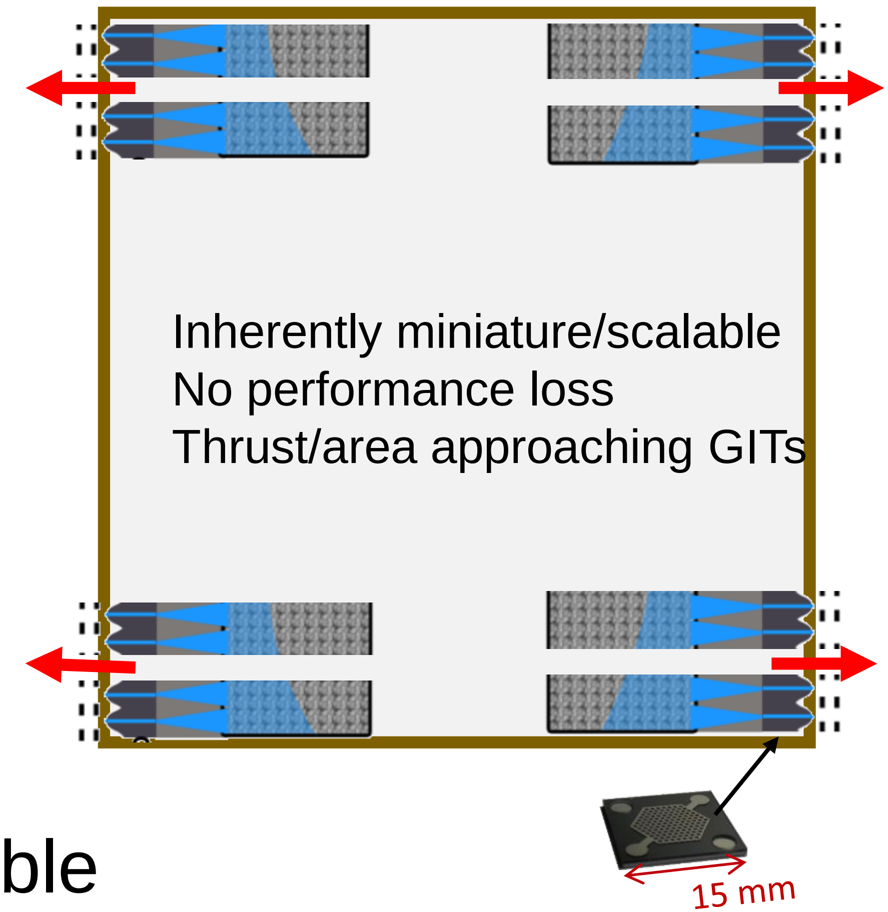


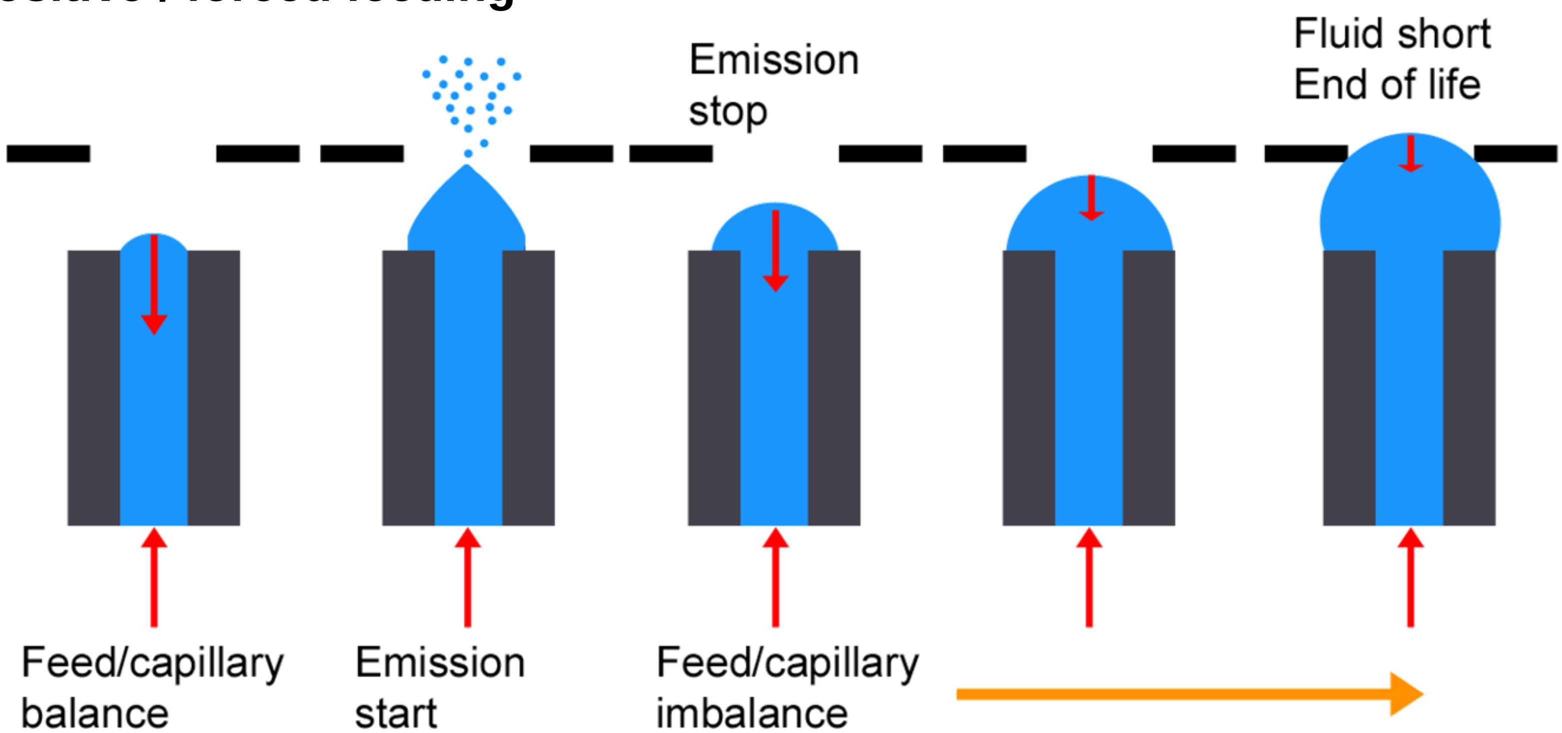
Spacecraft
w/ distributed thrusters



✓ Simple ✓ Modular / scalable

Why passivize IL feeding? : Liquid shorts in pressure fed devices

Positive / forced feeding



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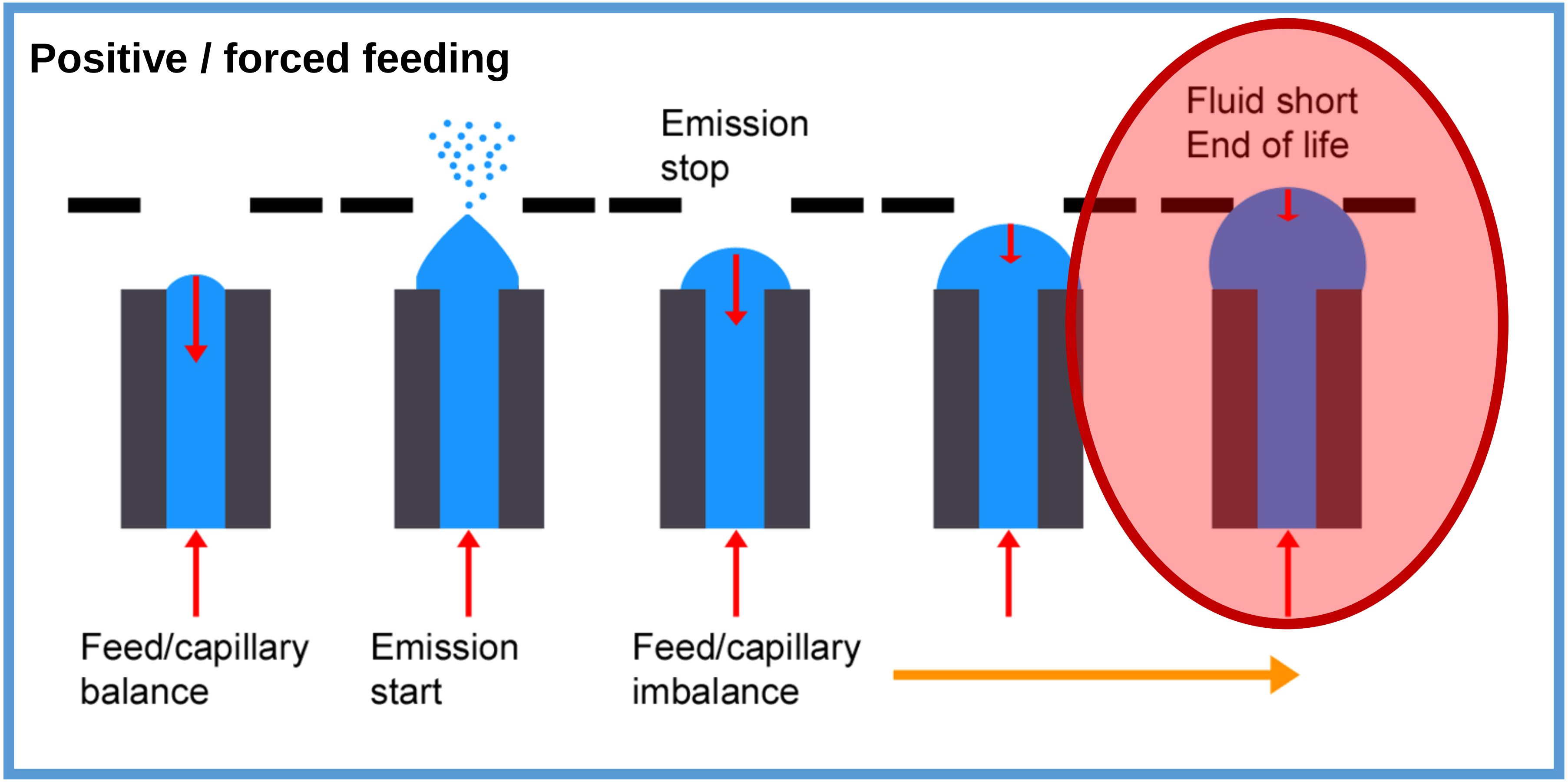
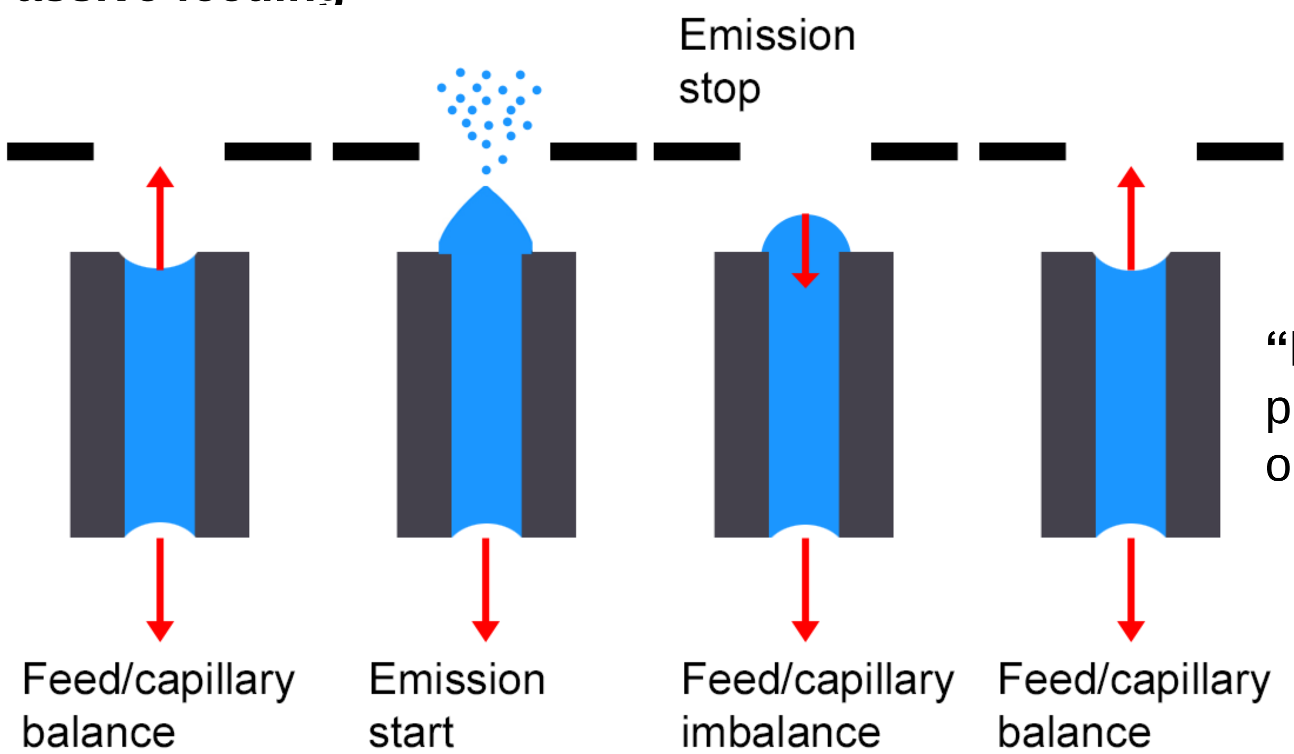
Why passivize IL feeding? : Liquid shorts in pressure fed devices



✓ Simple ✓ Modular / scalable

Why passivize IL feeding? : Prevention of liquid shorts

Passive feeding

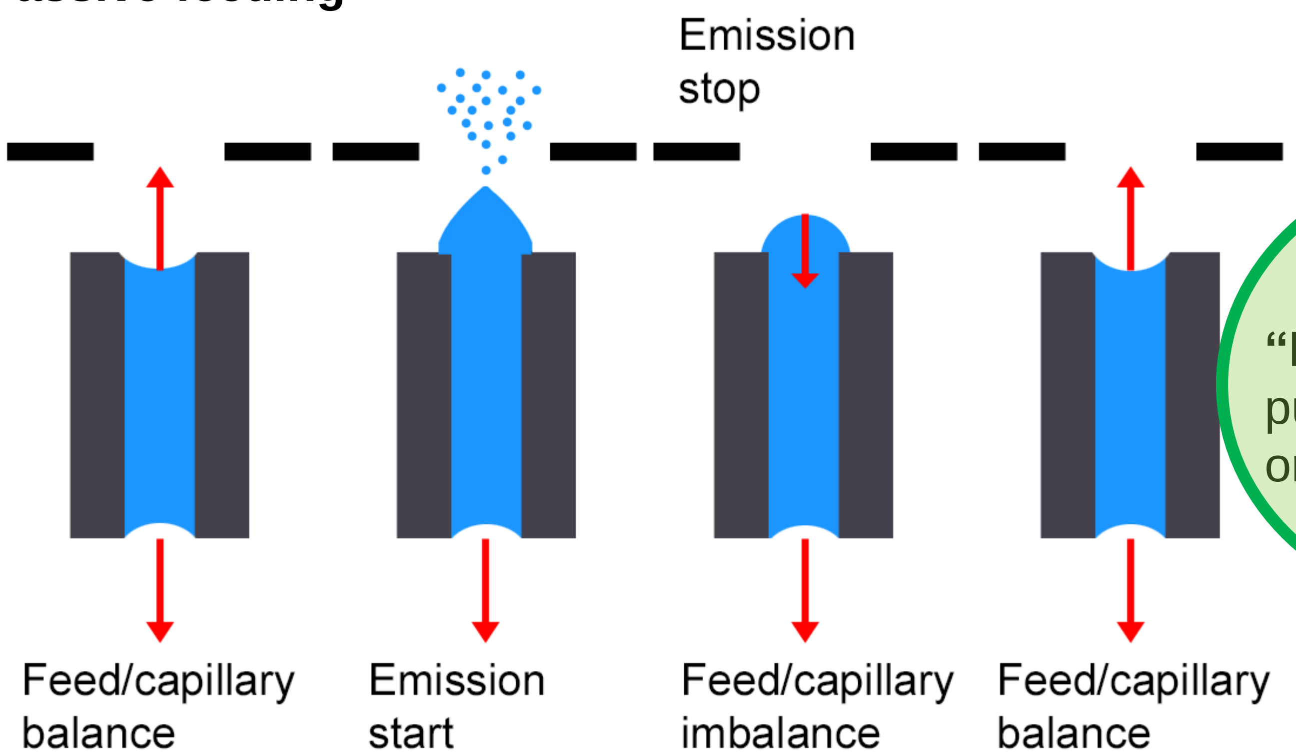


"Negative" pressure pulls liquid back to original state

✓ Simple ✓ Modular / scalable

Why passivize IL feeding? : Prevention of liquid shorts

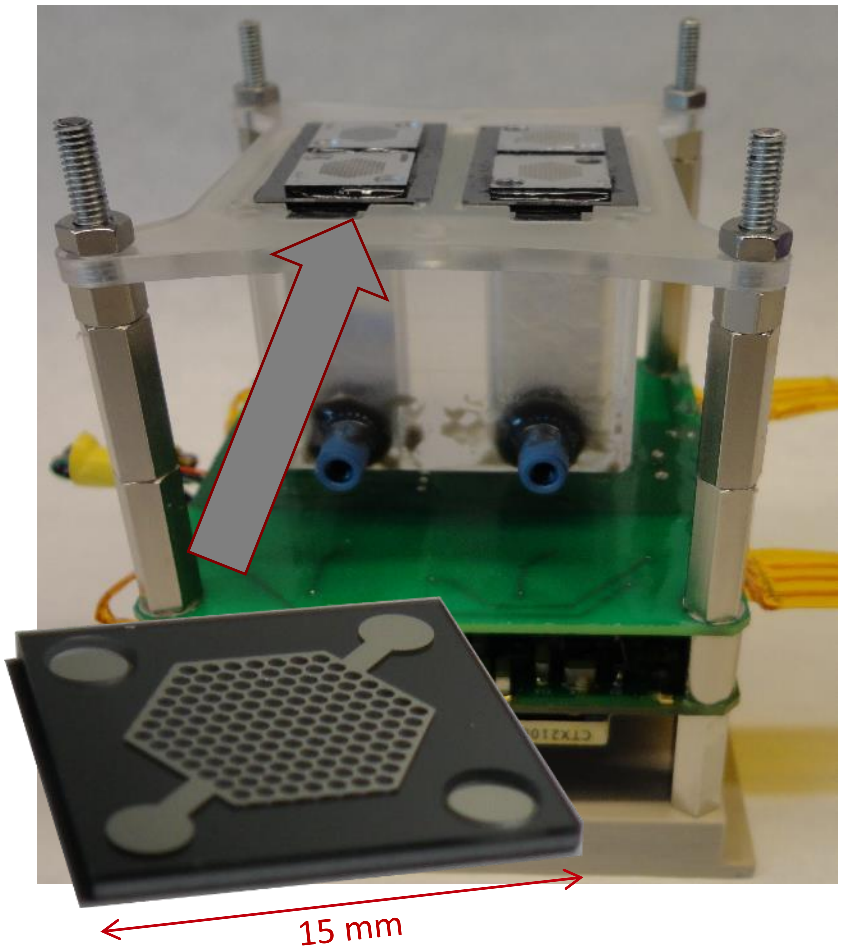
Passive feeding



“Negative” pressure pulls liquid back to original state

✓ Simple ✓ Modular / scalable ✓ Safe / reliable

MicroThrust:
Electrospray propulsion system for small spacecraft



[MicroThrust : An FP7 Project]

Microfabricated arrays of IL electrospray

- Up 127 emitters per array in first phase

Complete module (*concept*):

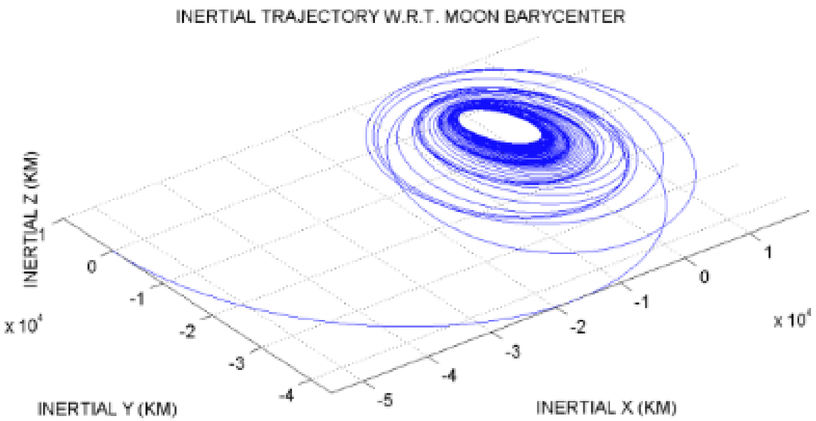
- Wet mass: < 300g / kg of launch (30%)
- Power: <5 W @ 3.5 kV
- Dimensions: < 10cm x 10cm x 10cm

- Isp: > 3000s
- Thrust: 20 µN/W
- ΔV: 5 km/s

Partners:

- EPFL (Switzerland)
- Queen Mary University of London (UK)
- Nanospace (Sweden)
- TNO (Netherlands)
- SystematIC (Netherlands)

Mission optimizations performed by partners : [Swiss Space Center](EPFL)(EPFL)



GTO to Lunar orbit mission

Enabled by MicroThrust high density fabrication

→8 Emitter arrays,

→2300 emitters per chip

→Purely ionic emission

~2.5 year transit

~65% payload mass ratio

Clean Space One

Retrieve and de-orbit *SwissCube*

ΔV>~650m/s required

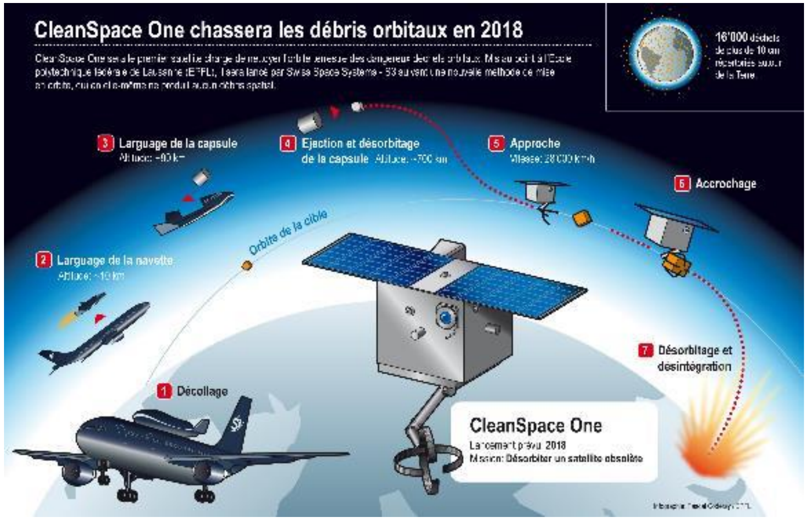
Enabled by MicroThrust high density fabrication

→ 4 Emitter arrays,

→ ~3000 per chip

→ Mixed ion/droplet mode

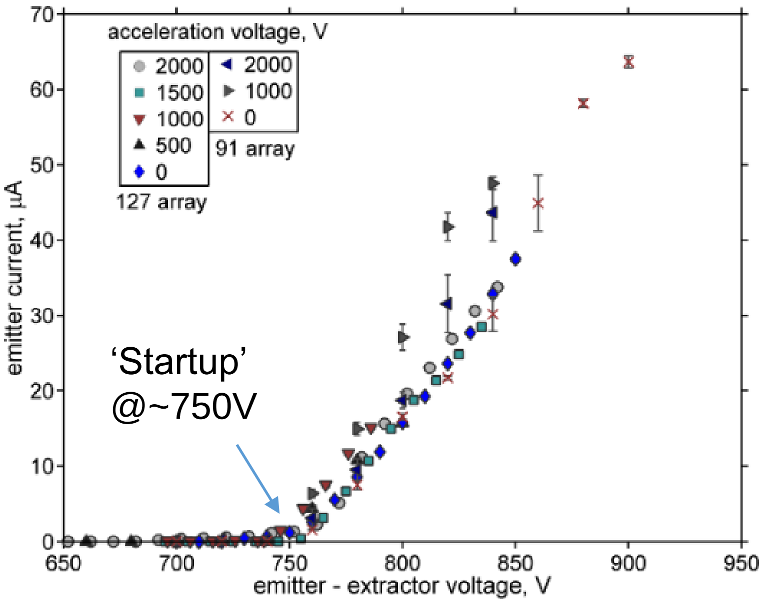
~85% payload mass fraction



MicroThrust results:
Performance status and beam focusing capability

Queen Mary University of London

Measurements by QMUL

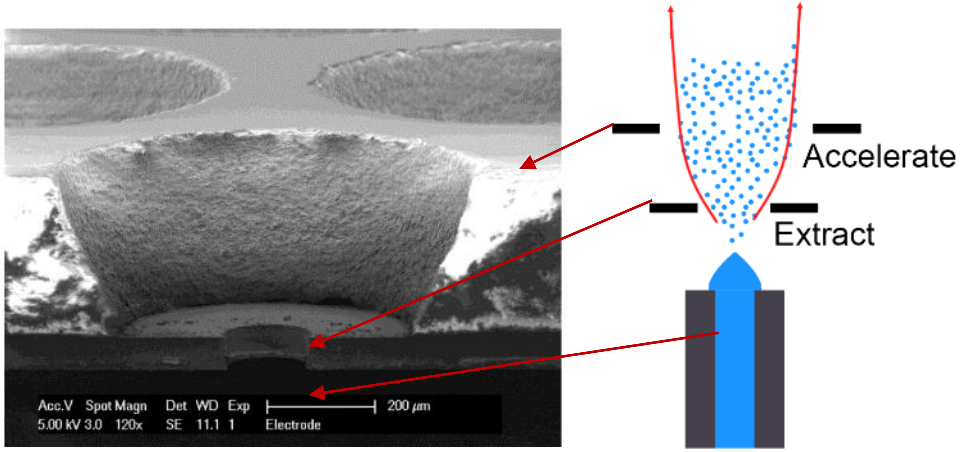


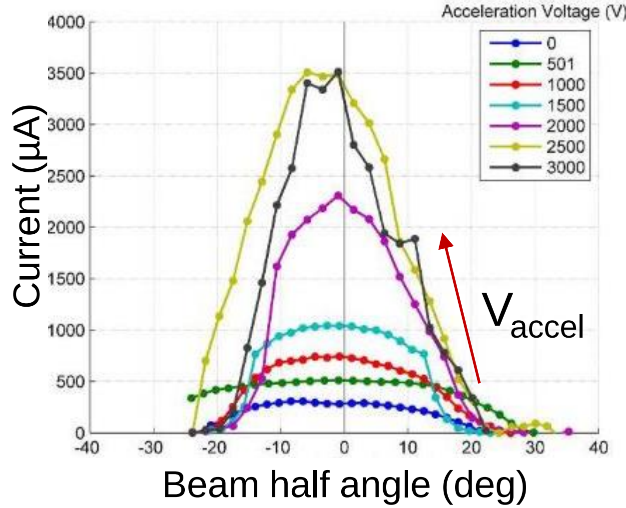
Many 10's of µA from 127 emitter array
No saturation condition reached

Up to 95% ionic emission
→ Isp~1000s

Thrust levels up to ~7µN per chip
~30µN per MicroThrust breadboard

Downstream beam focusing
With integrated extractor grid (next pres.)

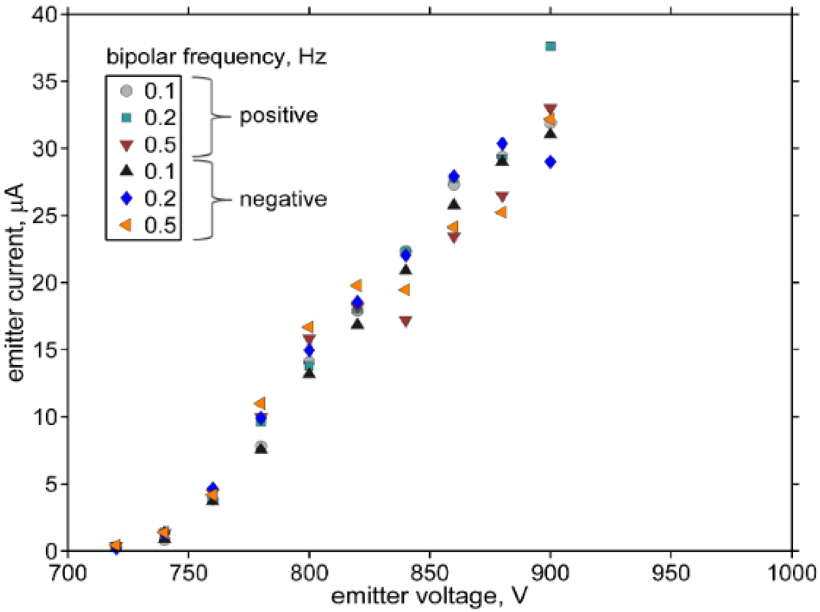




Acceleration grid gives
Focusing
→Improved power efficiency
and
Exhaust velocity control
→Mission optimization

MicroThrust Results:
Bi-polar operation for long durations

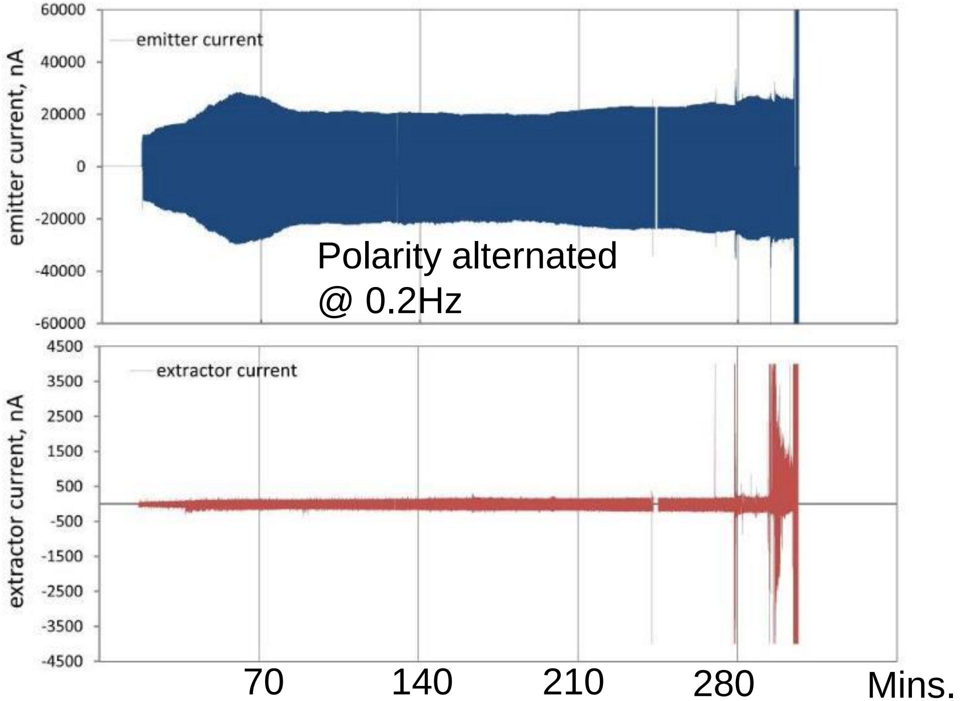
Bi-Polar Emission:
Removes external neutralizer and suppresses reactions



Symmetric emission currents
Minimizes charge build up at alternating potential

Continuous bi-polar operation for>4.5 hours
Missions will require >800 hours of operation

Typically failed due to fluid bridge:
To be addressed with passive feeding



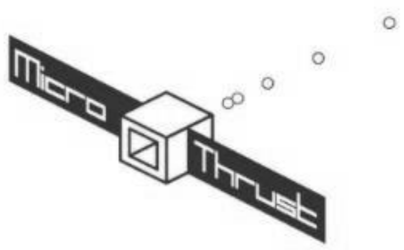
Summary and Next Steps

- Ionic Liquid electrospray ion propulsion with passive feeding

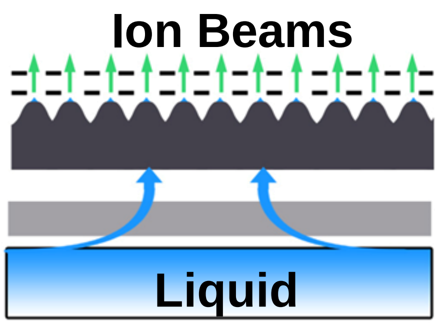
  High propellant and power efficiency *and:*

  ✓ Simple ✓ Modular / scalable ✓ Safe / reliable

- MicroThrust (completed Dec. 2013)
  - Novel microfabricted emitters
  - Integrated extraction and acceleration electrodes (details in following presentation)
  - Promising preliminary performance measurements



- Next : A focus on fluid feeding
  - Expand hydraulic features of MicroThrust devices (next presentation)
  - New developments focused on reservoirs
  - Study impact of upstream flow on performance



Thank You

Thank you to MicroThrust partners

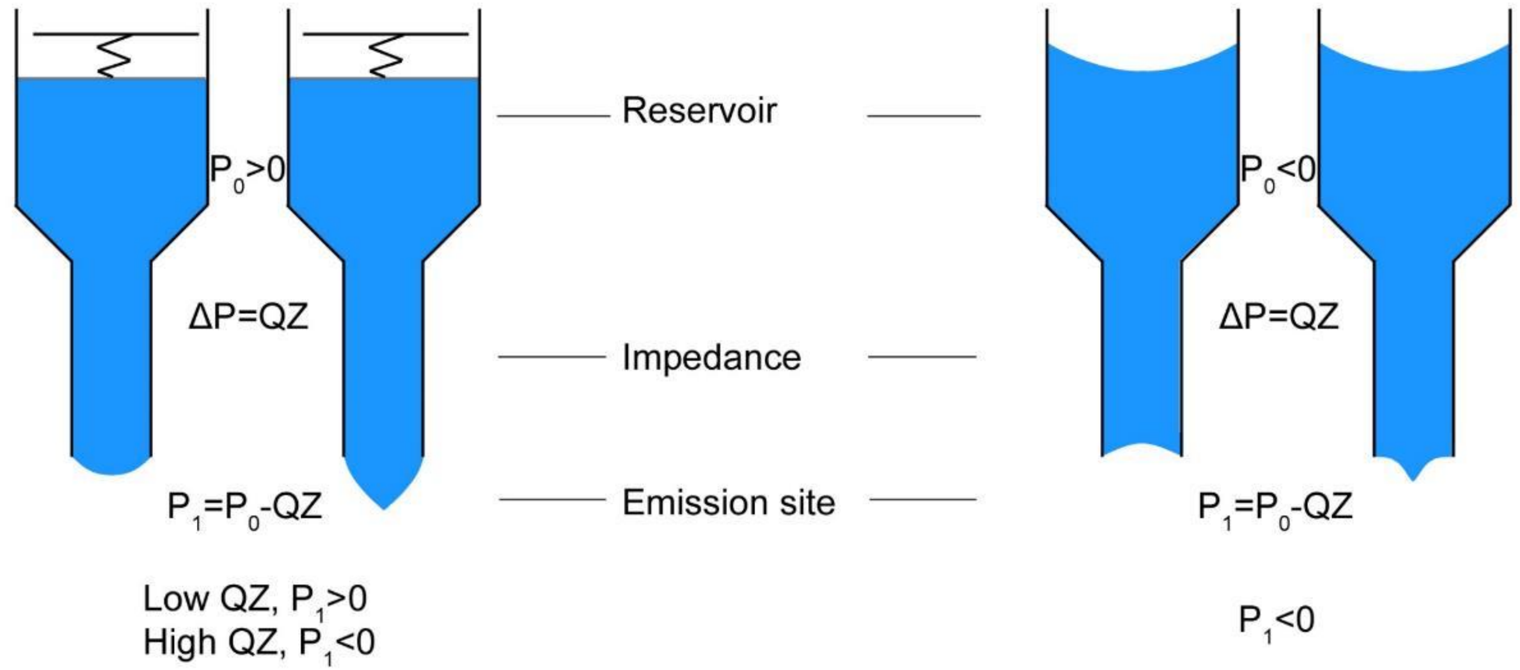
SSC, QMUL, TNO, SystematIC, NanoSpace

MicroThrust was an EU-FP7 Program

Work currently supported by ESA-NPI #4000109063/13/NL/PA

What is passive feeding?

Active / Pressure Fed | **Passive/Capillarity Driven**



Active / Pressure Fed	Passive/Capillarity Driven
Liquid forced through emitters	No valves or active controls : **Typically porous material**
Liquid meniscus at ***positive pressure***	Liquid pulled into device due to ***"negative" pressure***
Devices tend to operate in droplet or mixed regime	**Devices tend to operate in purely ionic regime**