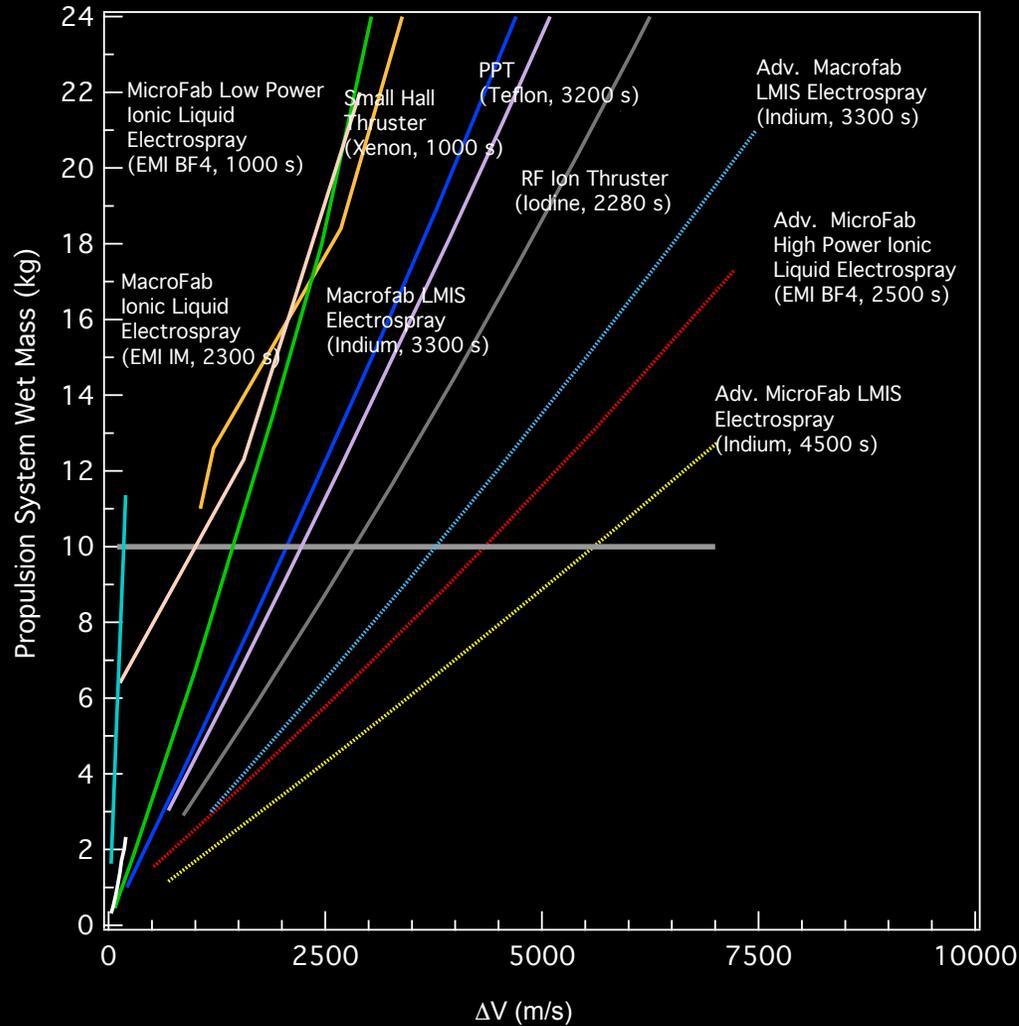


Electrospray Thrusters for Smallsat Missions

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EP system wet mass for 35 kg dry mass high ΔV spacecraft

ELECTRIC PROPULSION (EP) ENABLES LARGE ΔV SMALLSATS

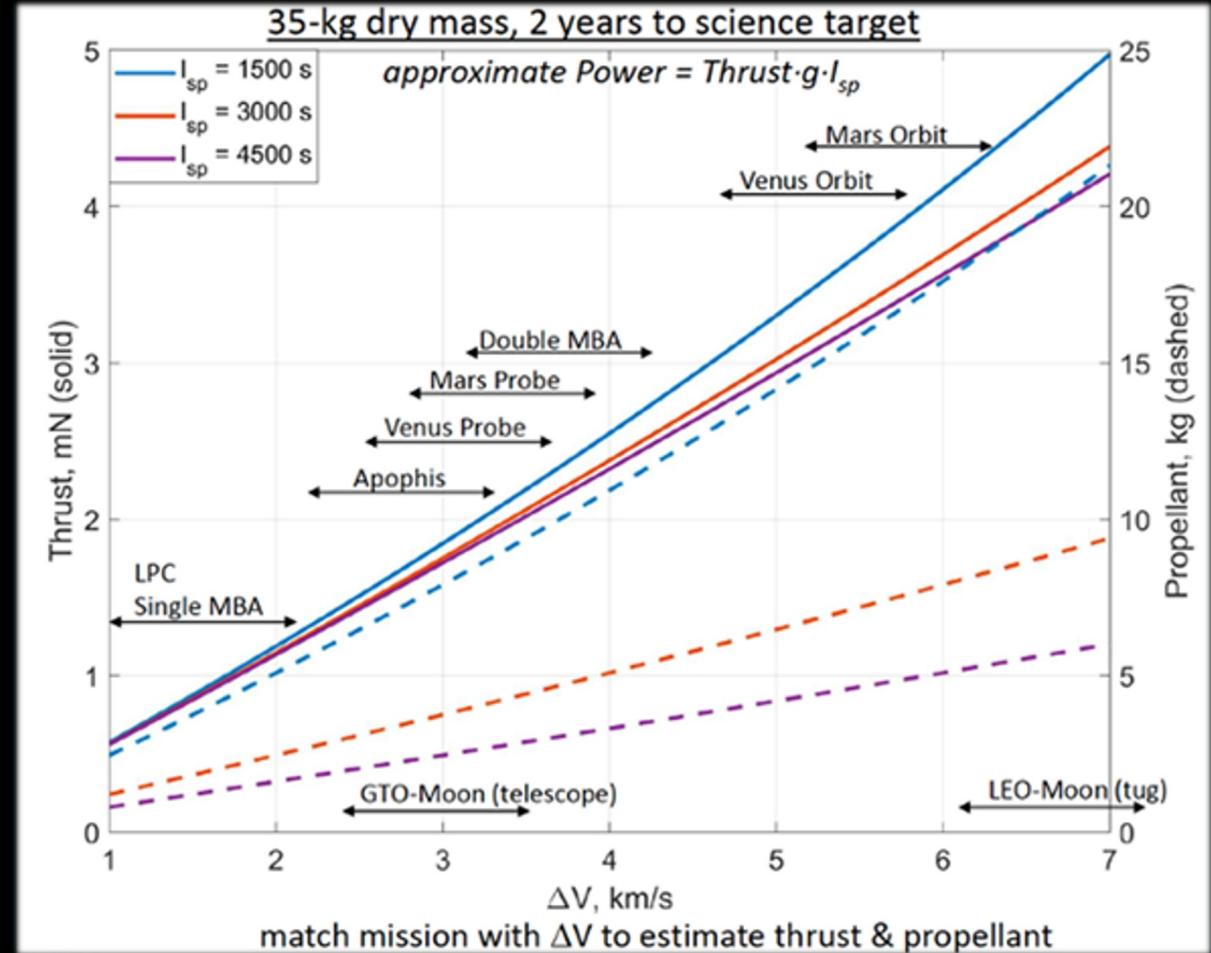
ELECTROSPRAY PROPULSION ALSO ENABLES LARGE ΔV CUBESATS BECAUSE OF LOW WET MASS:

- High specific impulse for low propellant mass
- Liquid or solid metal propellants for low tank volume and mass
- Some electro spray propulsion systems have a capillary force driven feed system with very little to no mass
- Some electro spray propulsion systems have microfabricated components with very low mass

EP ENABLES SMALLSATS WITH HIGH ΔV FOR A BROAD RANGE OF INTERPLANETARY MISSIONS:

- NEO Orbiter/Lander/Hopper
- Long Period Comet Flyby
- Potentially Hazardous Asteroid Flyby
- Mars Orbiter/Lander
- Venus orbiter/lander
- Lunar Orbiter
- NEO Orbiter/Lander/Hopper
- Titan Lander
- Main Belt Asteroid Flyby, Orbiter, Lander, Hopper
- Asteroid/Phobos/Deimos/Lander/Hopper
- Asteroid/Phobos/Deimos Sample Return
- Asteroid redirect
- Plume Sample Return
- Io Plume Diver
- SEP Tug
- Trojan Mission
- Hilda Missions
- Centaur Missions

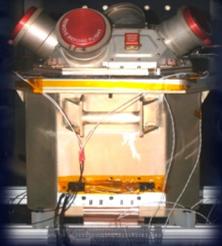
List was developed by Nathan Strange (formerly at JPL)



Graph from Damon Landau, JPL

ST7-DRS

SPACE TECHNOLOGY 7 DISTURBANCE REDUCTION SYSTEM



Busek ST7 CMNT
Electro spray
Propulsion System
on LPF



Busek Colloid
MicroNewton
Thruster (CMNT)

ELECTROSPRAY THRUSTERS DEMONSTRATED PRECISION SPACECRAFT CONTROL ON THE NASA/ESA LPF MISSION

When DRS was active, position noise was comparable to the diameter of a DNA Helix (2nm)

- Electro spray thrusters were flight qualified and successfully demonstrated ultra-stable spacecraft attitude and drag-free control on the ESA/NASA LISA Pathfinder/ST-7.
- The Busek CMNT were qualified with a 3458 - hour ground test before thrusters demonstrated precision spacecraft control for >2400 hours on the LPF Mission.
- Electro spray thrusters are highly scalable in thrust with number of emitters in a thruster head in macrofabricated and microfabricated technologies for ionic liquid and liquid metal propellants.
- Micro and macrofabricated electro spray thrusters are under development for smallsat missions and large observatories.



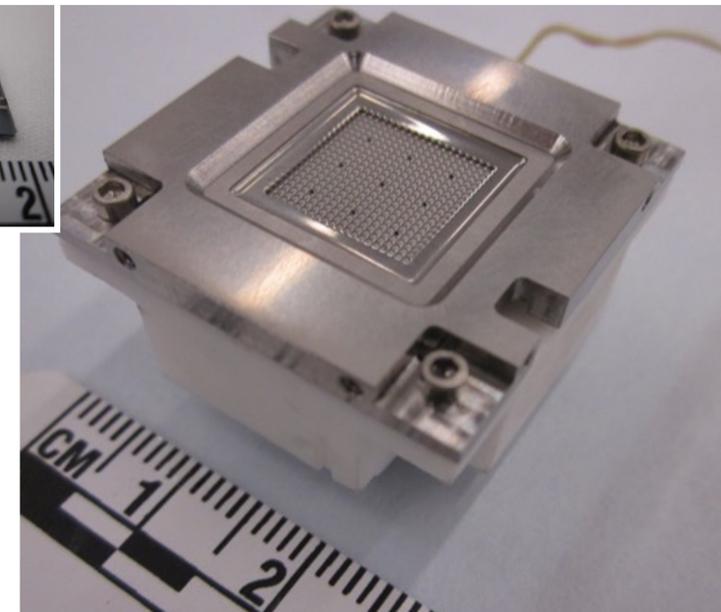
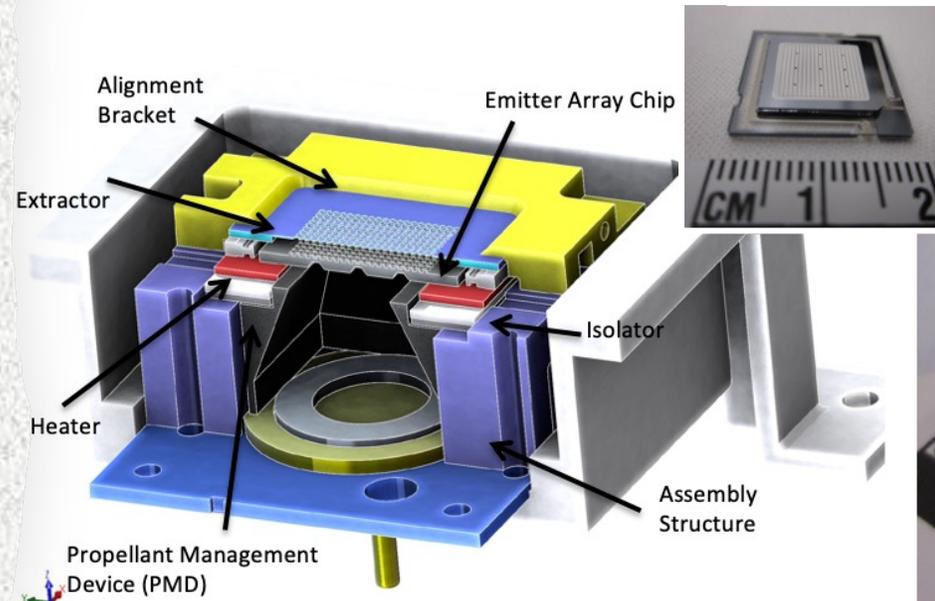
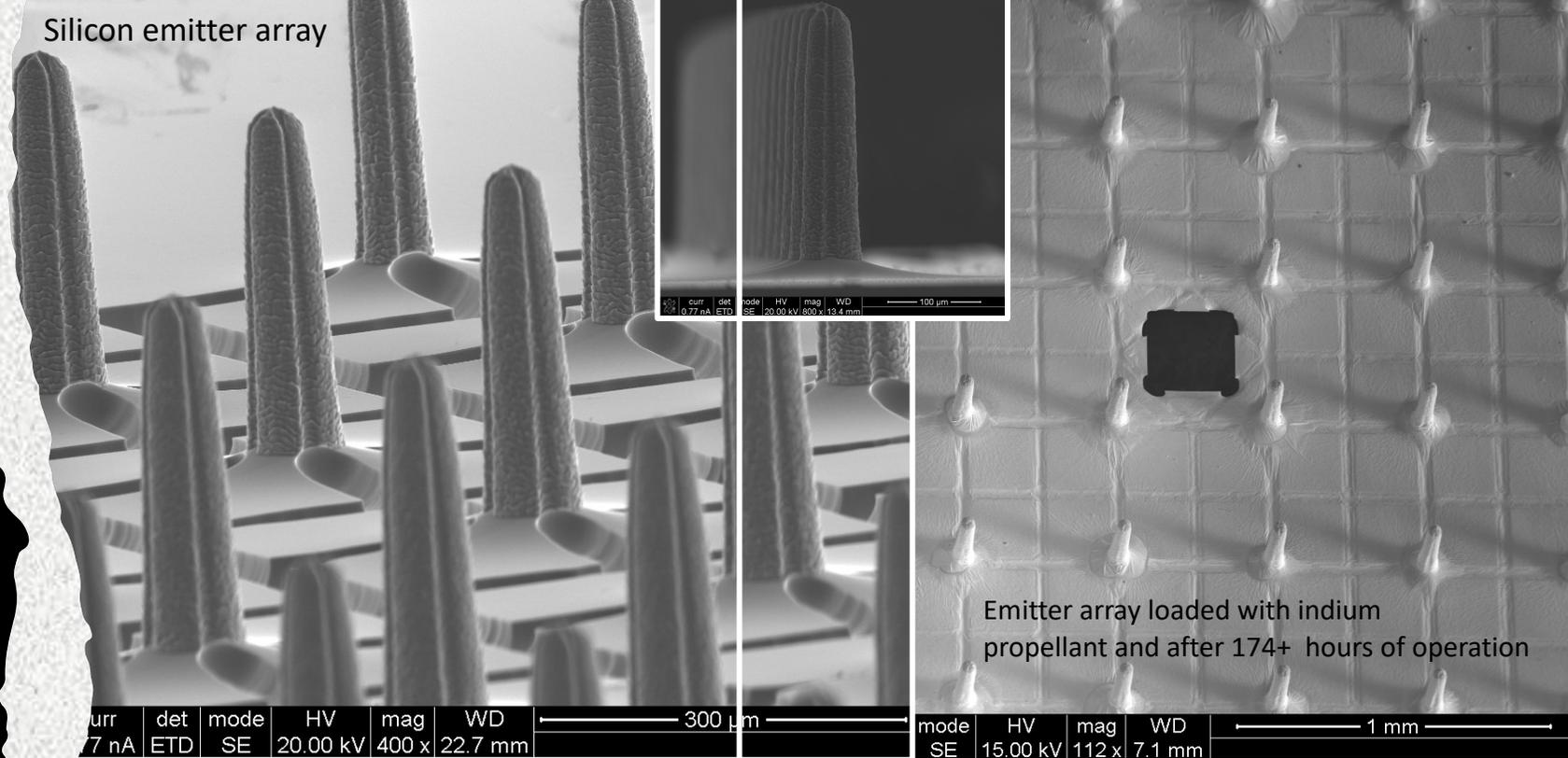
Electrospray thruster thrust is highly scalable with number of emitters.

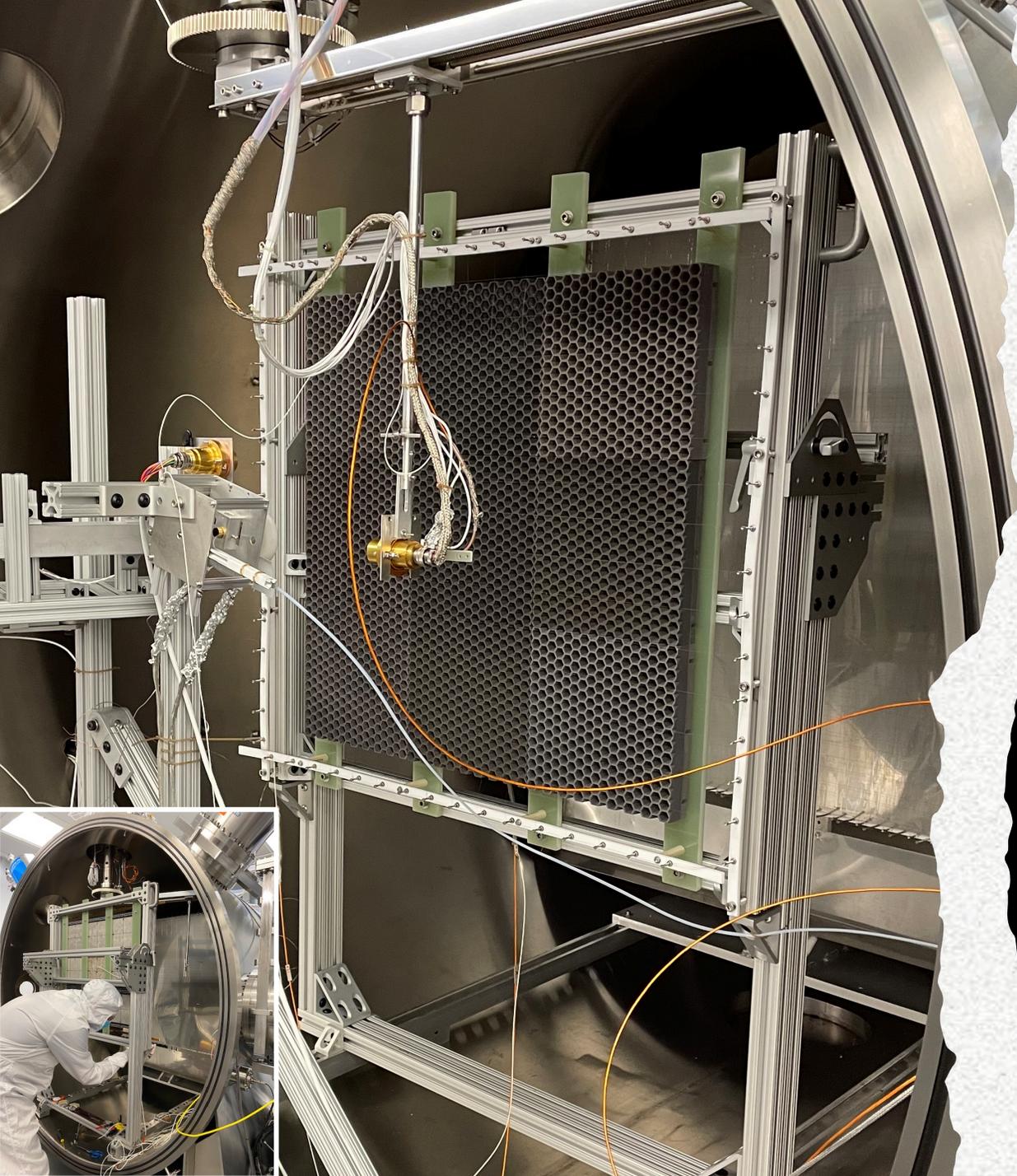
Electrospray thrusters can be microfabricated with compact arrays of emitters with any geometry.

Microfabricated thrusters have highly integrated and compact assemblies for highly distributable architectures and lower voltage operation.

JPL MEP is one microfabricated electro spray thruster technology under development for smallsats:

- 400 microfabricated silicon electro spray emitters in 1 cm^2
- Capillary force driven feed system etched into the emitter array chip
- Indium metal propellant
- Thrust/Isp: $100 \mu\text{N} / >3100 \text{ s}$ (2 kV)
- Power: 3.5 W
- Mass/Volume: $30 \text{ g} / 9 \text{ cm}^2$





NASA JPL MICRO PROPULSION LABORATORY (MPL)

Long Duration Electro spray Propulsion System Test Facility for Mission Qualification

- **Thruster qualification to mission requirements requires long duration performance evaluation in ground test facilities.**
 - Requires an understanding of thruster failure modes
 - Requires an understanding of facility effects and mitigation of them
- **MPL is a unique electro spray test facility**
 - 40 m² Class 100 cleanroom
 - One 2 m UHV chamber and 2 smaller chambers
 - Thruster cleaning, assembly, and inspection
 - 3D porous aluminum geometric black body beam target to absorb ionic liquids to minimize thruster, facility and spacecraft contamination
 - Linear and rotational probe or thruster positioning system
 - Thrust stand, Faraday Probe, TQCM
 - Computer controlled ionic liquid electro spray thruster testing demonstrated for hundreds of hours.
 - Triax (3 kV) and quadrax (6 kV) cables for high voltage low current (picoAmpere) measurements with very low noise levels
 - 3D measurement microscope & SEM
- **Lab personnel expertise in macro and microfabricated electro spray thruster design, fabrication, testing, and modeling for ionic liquids and indium.**
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