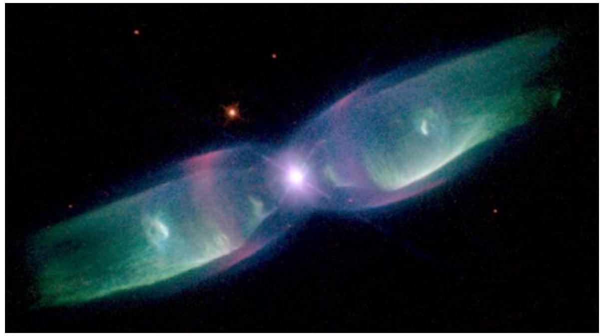
การประยุกต์ Plasma Thruster ทางเลือกการขับเคลื่อนดาวเทียมเยือนดวงจันทร์

ดร.อาหลี ตำหมัน

นักวิทยาศาสตร์นิวเคลียร์ชำนาญการ

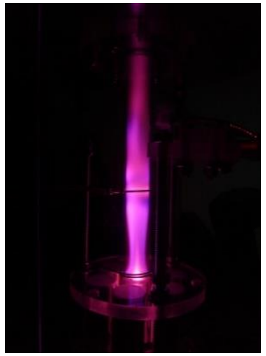
Plasmas as Energetic Particle Source

Natural plasmas

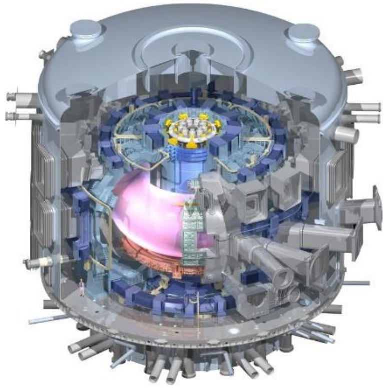


Space Plasmas

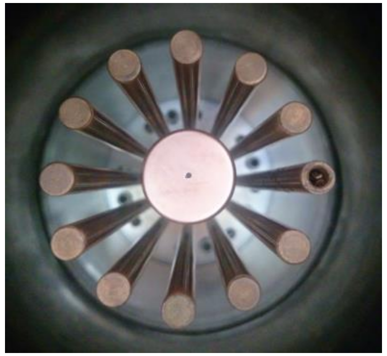
Laboratory Plasma



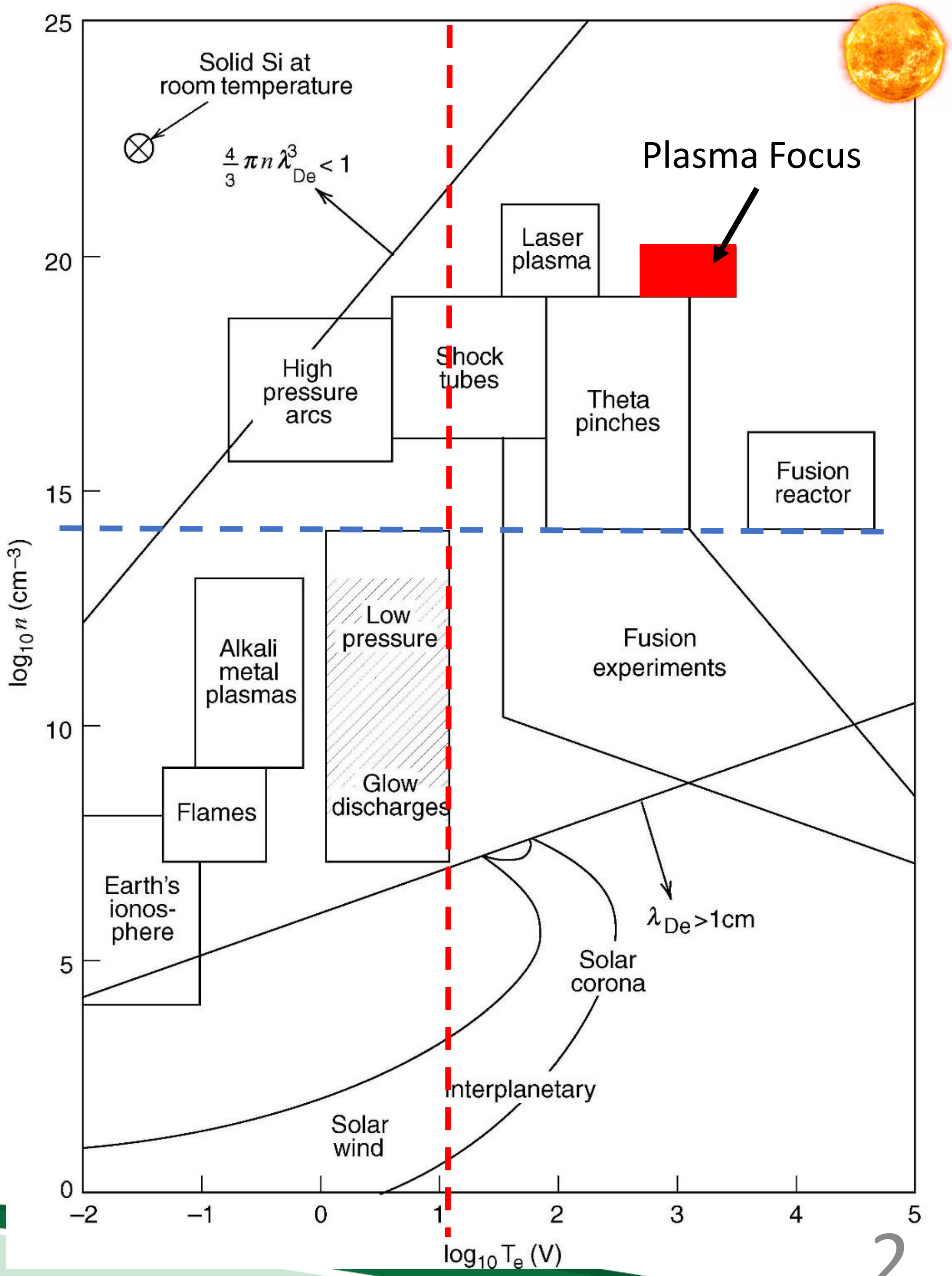
Low Pressure
(Processing Plasmas)



Fusion Reactor

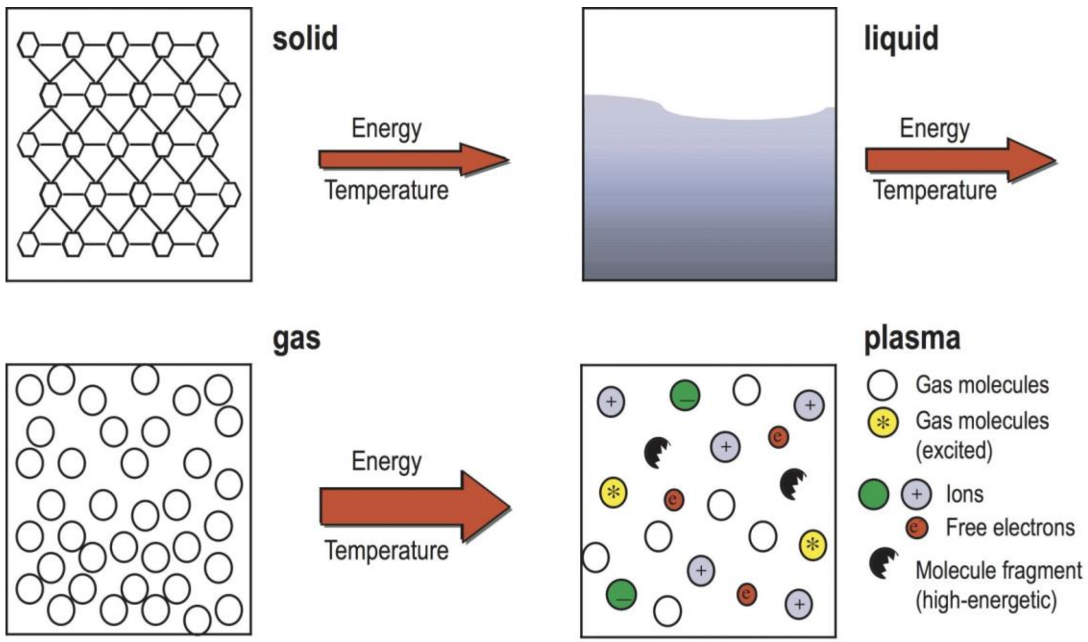


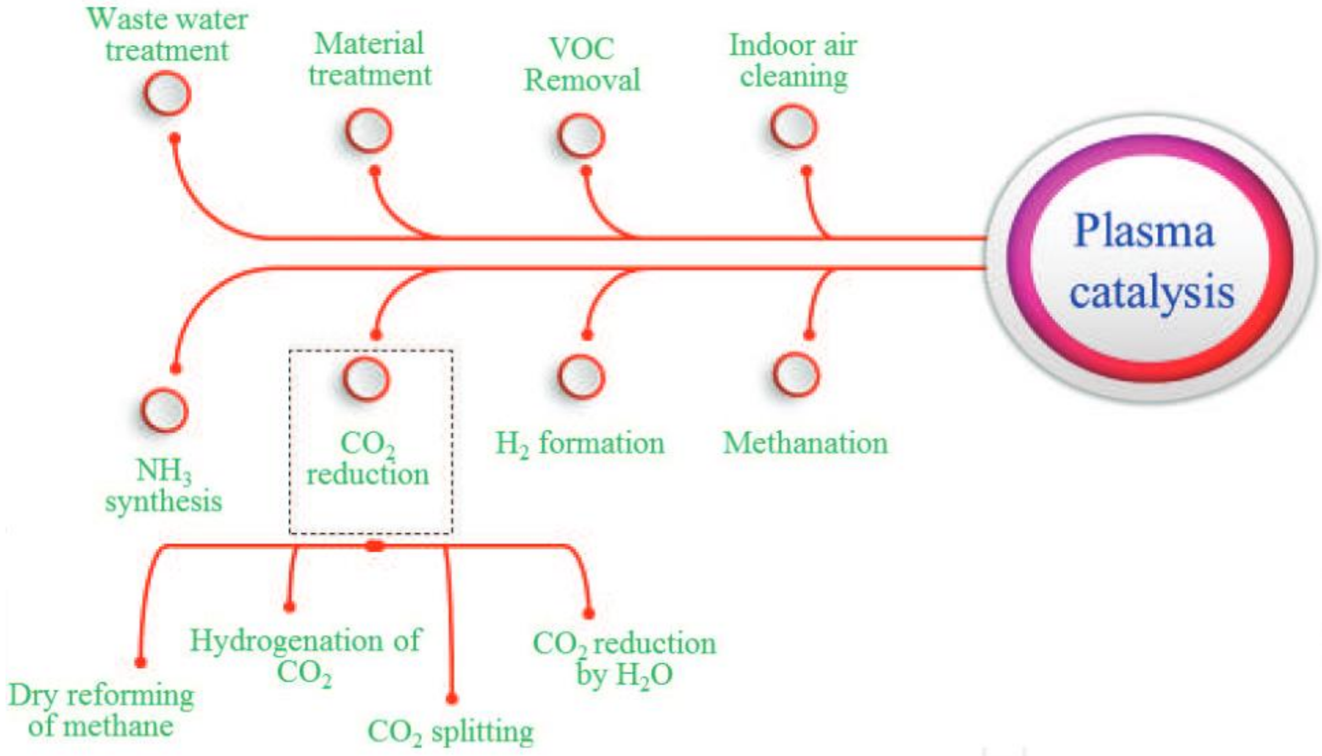
Plasma Focus



Plasma, 4th state of matter

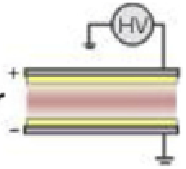
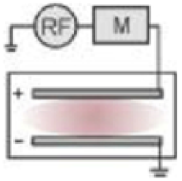
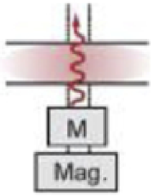
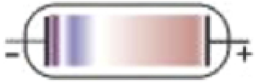
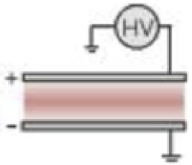
- https://www.plasmatreat.com/plasma-technology/what-is-plasma.html
- Chen G 2018



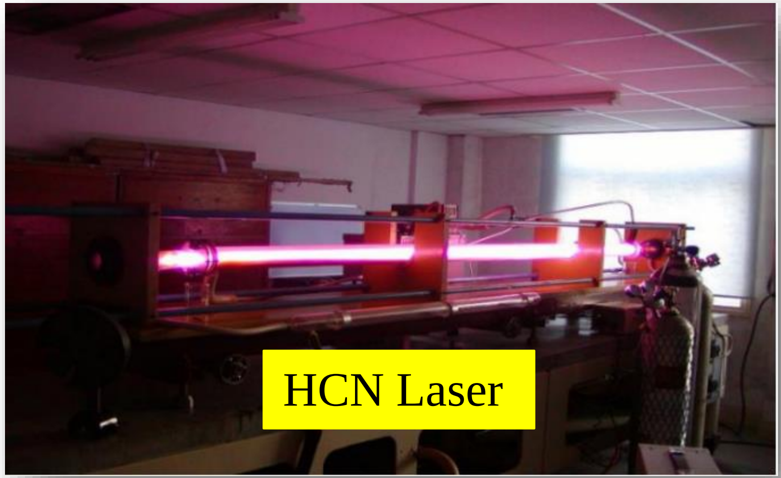


Plasma Source

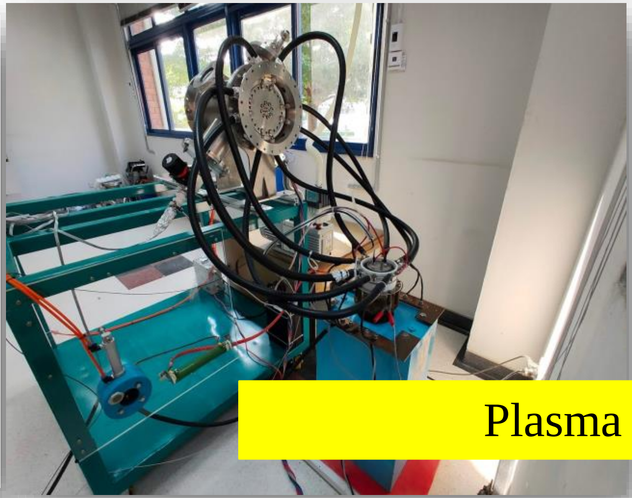
(Chen G 2021)

Discharge type		P (mbar)	N_e(cm^{-3})	T_e(eV)	T_{gas}(K)
Dielectric barrier		Atm.	10^{12} - 10^{15}	2-10	300-500
Radiofrequency		10^{-3} – atm.	10^{12} - 10^{15}	1-5	300-500
Gliding arc		atm.	10^{11} - 10^{15}	0.5-3	600-3500
Microwave		10^{-5} – atm.	10^{10} - 10^{15}	1-3	300-6000
Glow		10^{-5} – atm.	10^{9} - 10^{12}	0.5-11	300-1000
Corona		atm.	10^{8} - 10^{14}	2-10	300-800

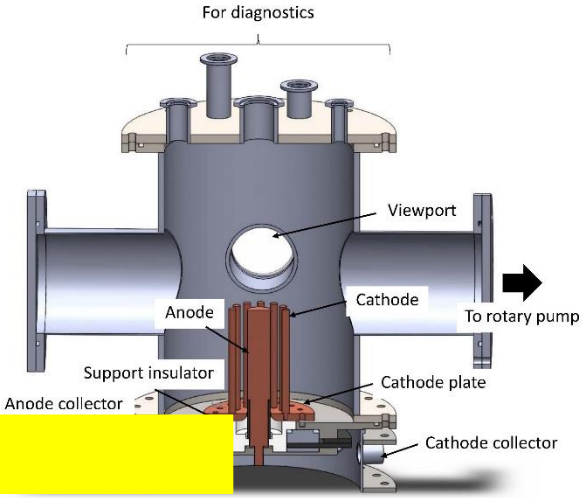
Plasma Source

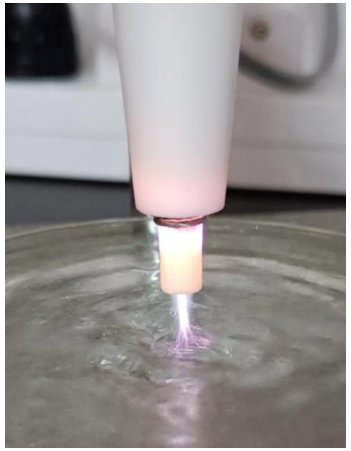


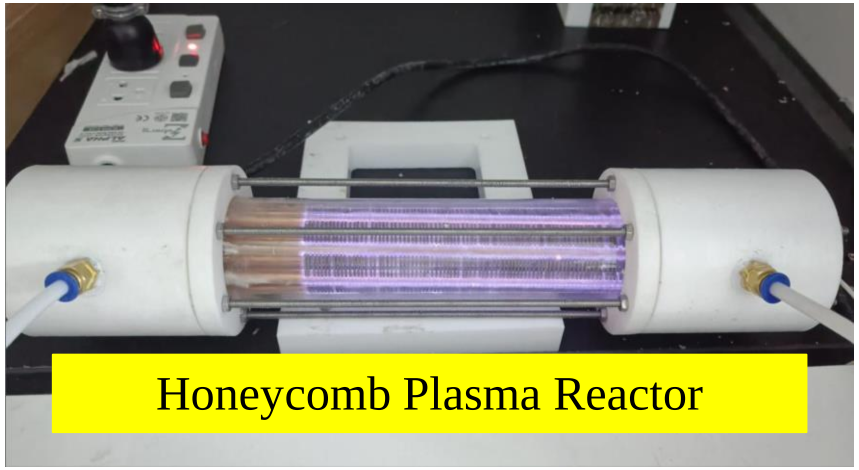
HCN Laser



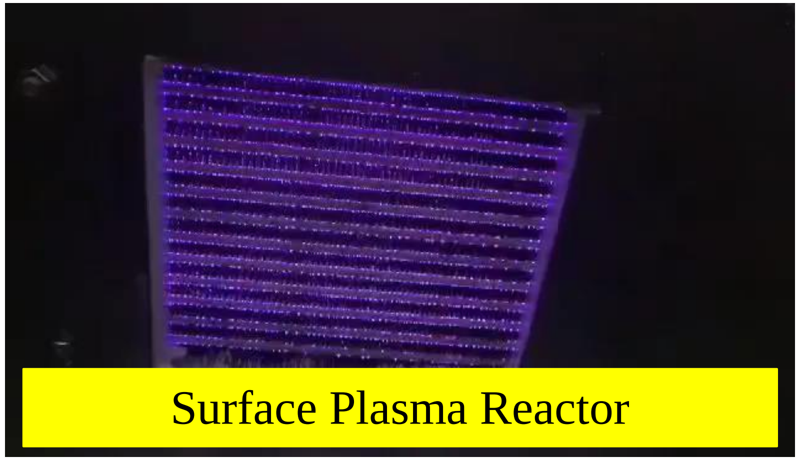
Plasma Focus



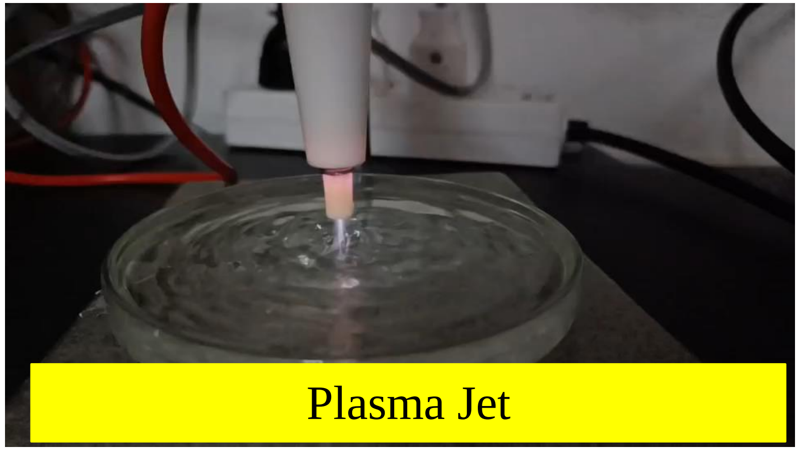




Honeycomb Plasma Reactor



Surface Plasma Reactor



Plasma Jet

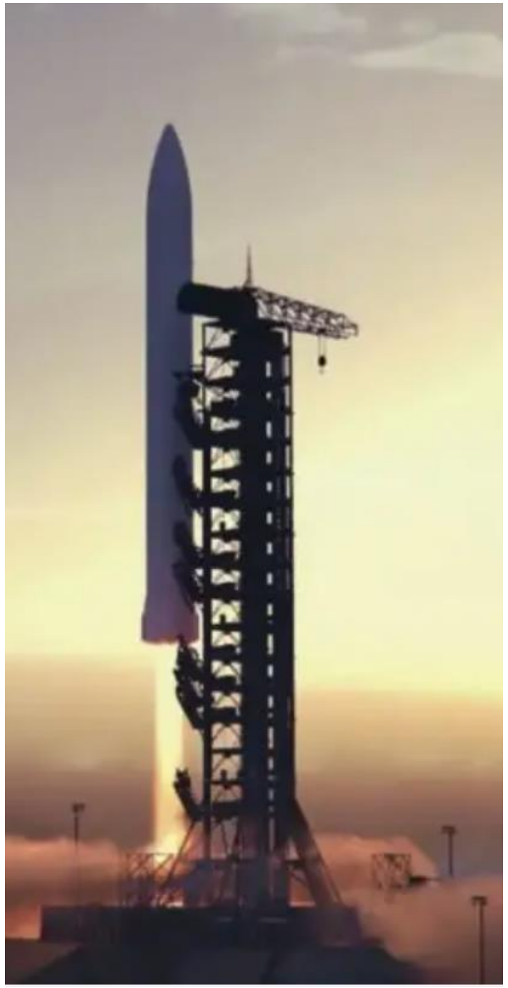
Thruster

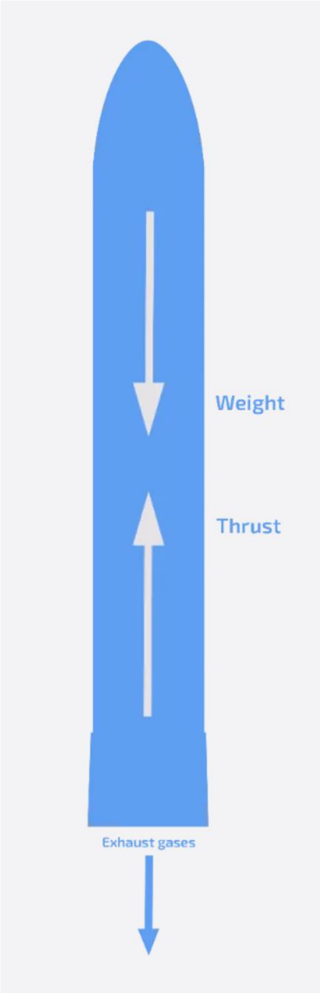
$$I = F * \Delta t$$

Impulse = Thrust * Total time of Firing

$$I_{sp} = \frac{F}{\dot{m} * g}$$

Specific Impulse = $\frac{\text{Total Impulse}}{\text{Weight}}$





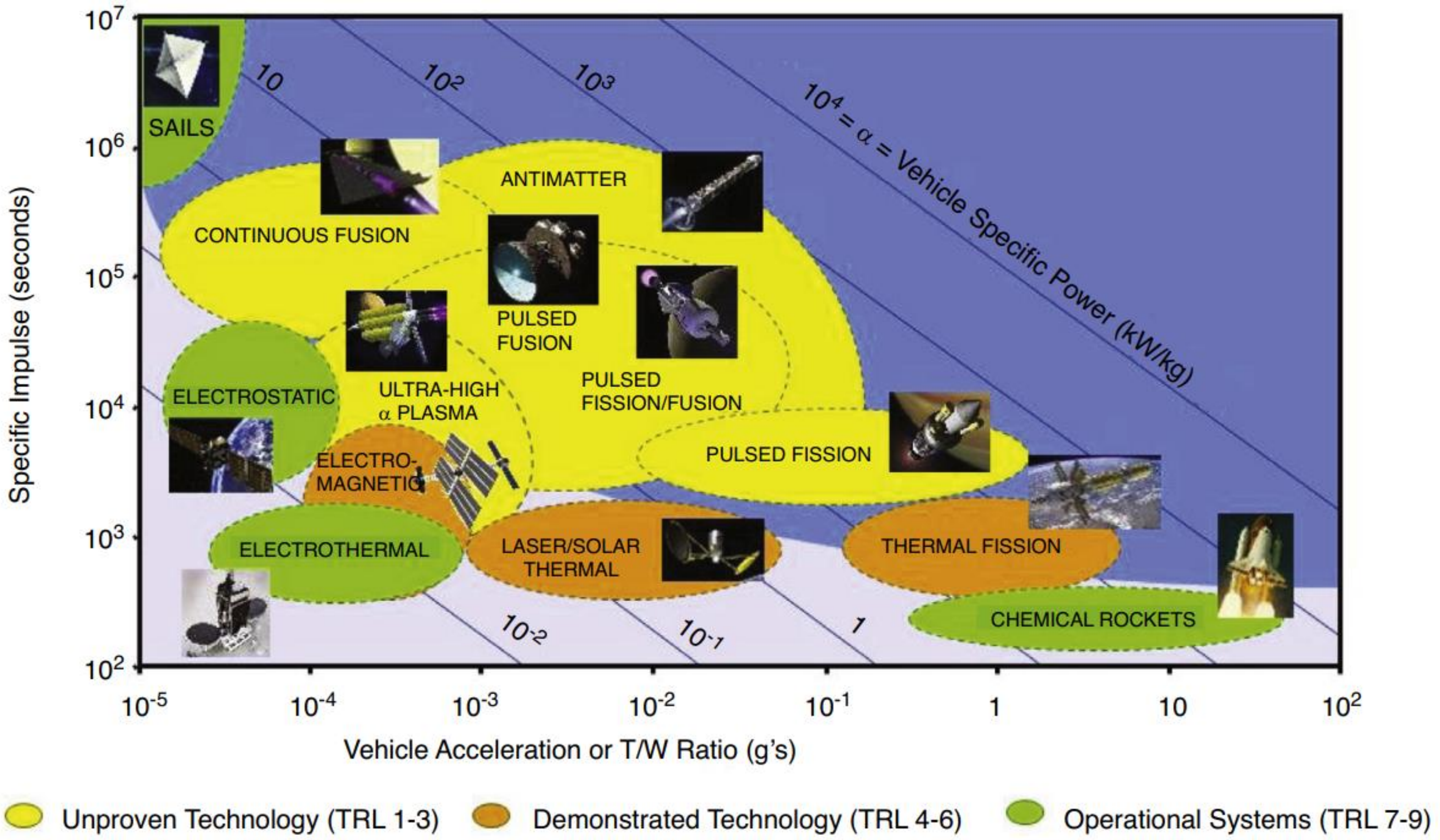


Fig. 3.4 ***Space propulsion system performance for a variety of concepts*** *(courtesy NASA).*

https://www.skyrora.com/rocket-fuel-is-it-rocket-science/, NEXT Ion Propulsion System Development Status and Capabilities, NASA/TM—2008-214988

Ion Thruster

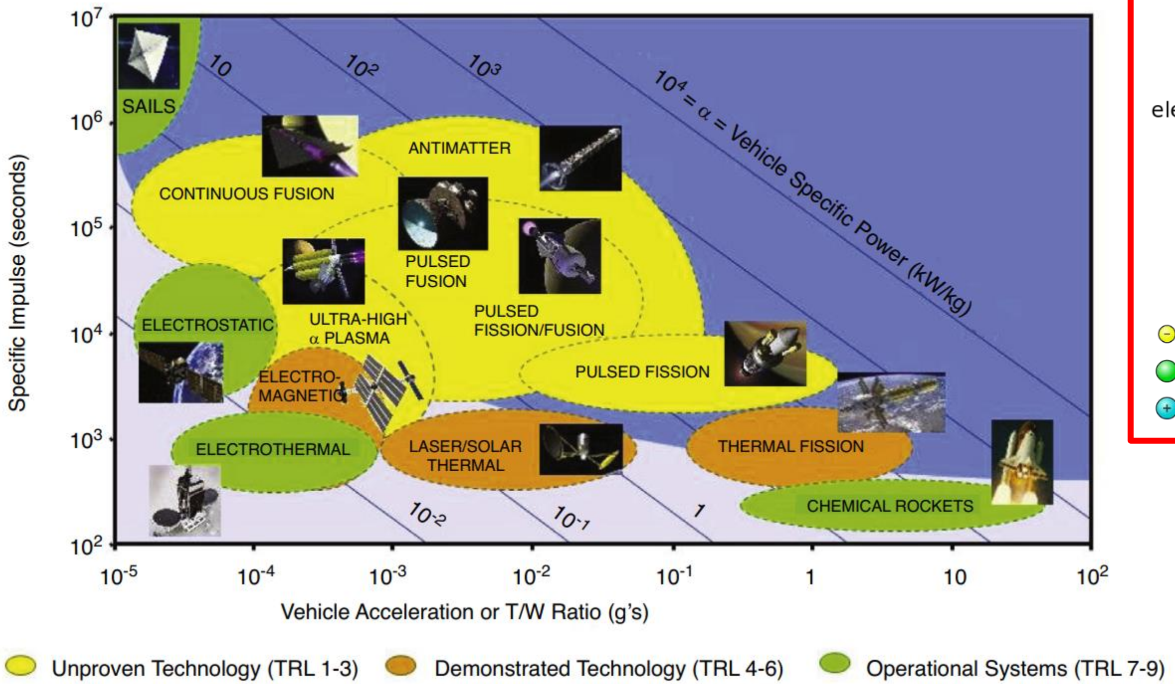
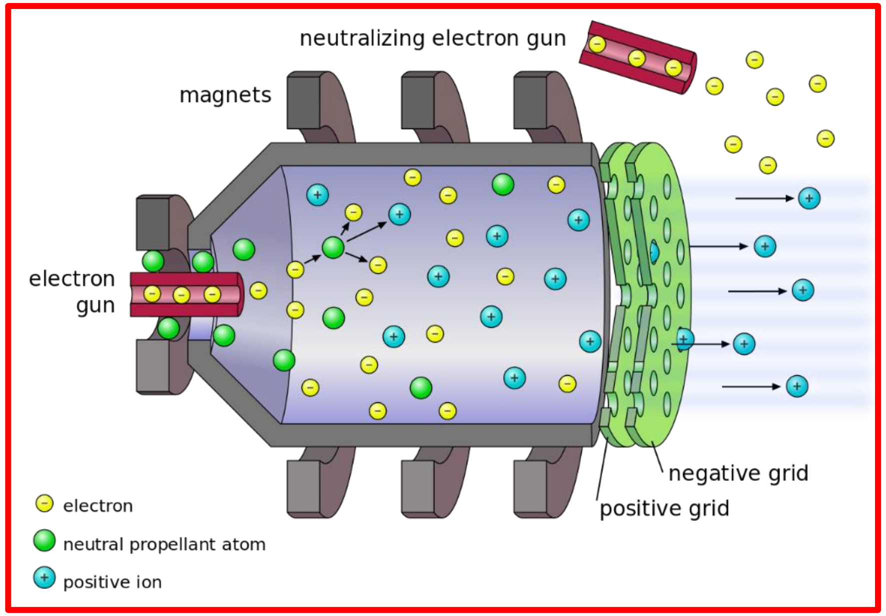


Fig. 3.4 ***Space propulsion system performance for a variety of concepts*** *(courtesy NASA).*



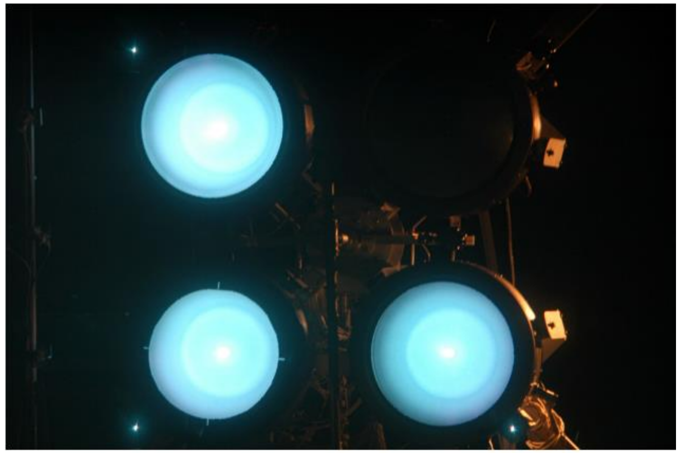
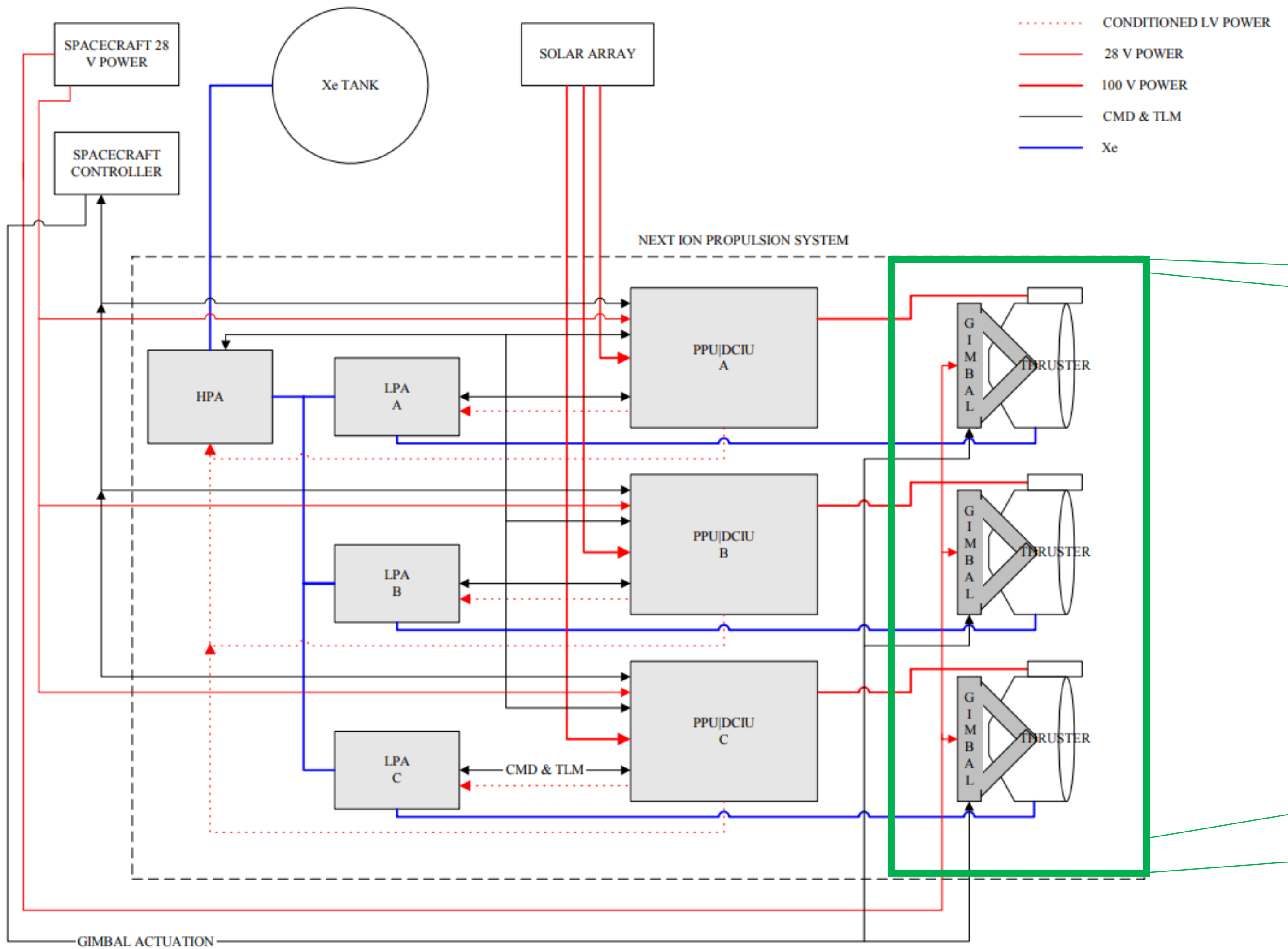


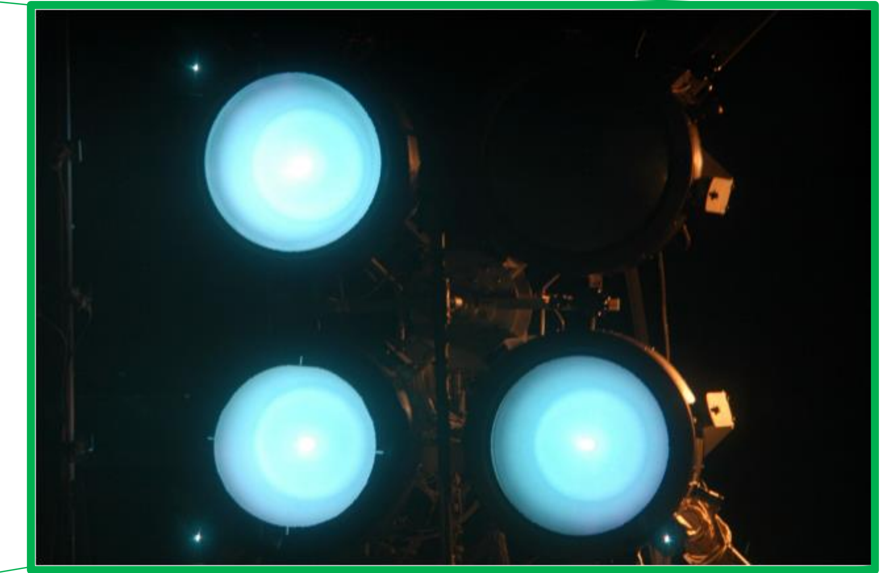
Figure 7.—Three NEXT EM Thrusters at full power in Multi-Thruster Array Test at NASA GRC.

System Input Power Range, kW	0.6 – 7.4
Thrust, mN	25-235
Maximum Specific Impulse, s	4220
Maximum Thruster Efficiency	70%
Maximum PPU Efficiency	94%
Maximum Beam Current, A	3.52
Maximum Beam Voltage, V	1800
Thruster Mass (with harness), kg	<14
PPU Mass, kg	<36

NEXT Ion Propulsion System Development Status and Capabilities, NASA/TM—2008-214988

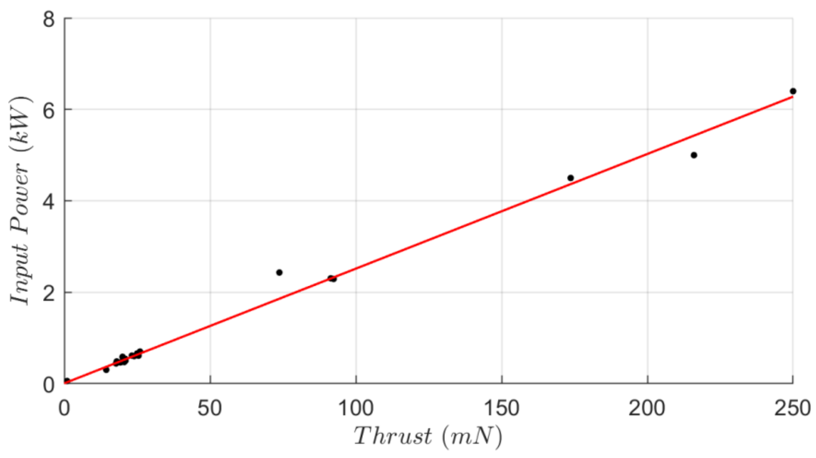
Ion Thruster: NEXT Ion Propulsion System





NEXT Ion Propulsion System Development Status and Capabilities, NASA/TM—2008-214988

Ion Thruster, Thrust : 2 mN at very low power(100 W)



	NSTAR (Throttle Level 15) [23]	XIPS-13 cm (Nominal Operating Condition) [24]	XIPS-25 cm (Mission Level 1) [25]	XIPS-25 cm (Mission Level 2) [25]	XIPS-25 cm (Mission Level 3) [25]	ETS-8 [33]
T (mN)	92.4	17.8	92.0	79.9	61.8	23.0
P_{in} (kW)	2.29	0.44	2.30	2.00	1.60	0.58
I_{sp} (s)	3120	2585	3383	3320	3242	2640
η_T	0.62	0.51	0.65	0.64	0.62	0.58
η_m	0.78					
η_e	0.84					
V_b (V)	1100	751	1215	1215	1215	1003
I_b (A)	1.76	0.40	1.66	1.44	1.11	0.47
V_T (V)	1280	1050	1495	1495	1495	1500
$\|V_{acc}\|$ (V)	180	299	280	280	280	473
$\dot{m}_p$ (mg/s)	3.02	0.70	2.78	2.46	1.95	0.89
$\|B_{cusp}\|$ (G)	Not available	Not available	Not available	Not available	Not available	Not available
$\|B_t\|$ (G)	Not available	Not available	Not available	Not available	Not available	Not available

Preliminary Design for 2 mN Thruster

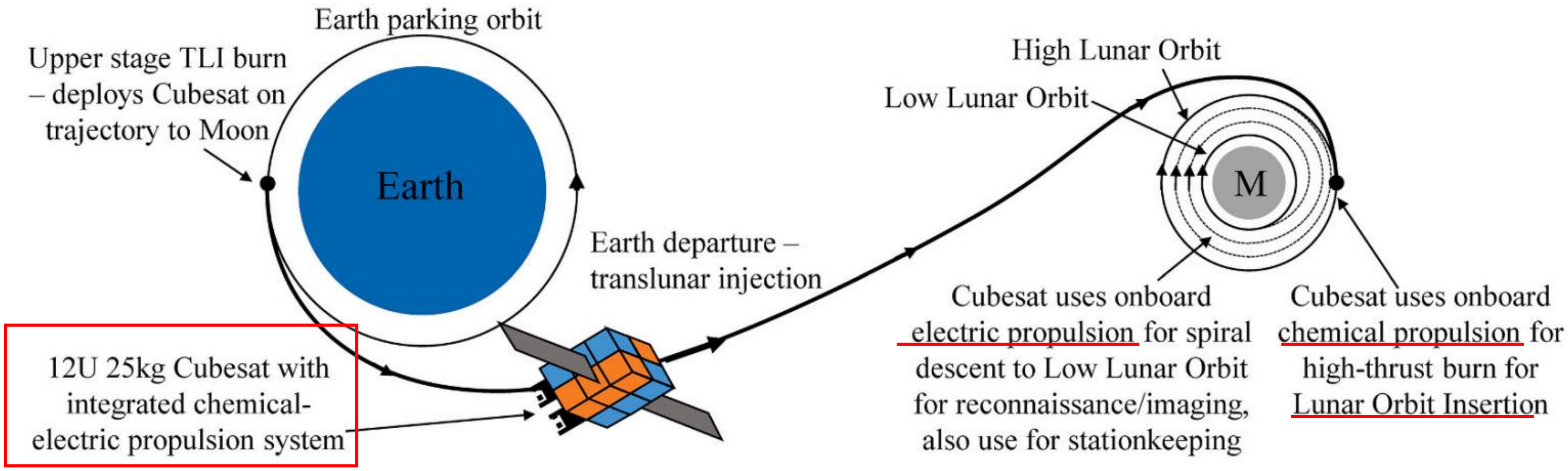
Fulfill the requirements of
- **LUMIO**: CubeSat mission orbiting in the Earth–Moon region
- **M-ARGO**: Deep-space CubeSat mission

Parameter	Value
Thrust (mN)	2
Input power (W)	54
Specific impulse (s)	1771
Total efficiency	0.32
Electrical efficiency	0.72
Mass utilization efficiency	0.50
Discharge voltage (V)	28
Discharge loss (W/A)	361
Total voltage between grids (V)	1159
Accel grid potential (V)	−232
Propellant mass flow rate (mg/s)	0.12

Parameter	Value
Discharge chamber diameter (mm)	50
Discharge chamber length (mm)	50
Grids material	Molybdenum
Screen-grid thickness (mm)	0.38
Screen-grid holes diameter (mm)	1.91
Accel-grid thickness (mm)	0.51
Accel-grid holes diameter (mm)	1.14
Distance between grids (mm)	0.66
Number of holes	433
Number of injectors	2
Injector internal diameter (mm)	0.83
Total weigth without cathodes (kg)	0.301

Preliminary Design Tool for Medium-Low-Power Gridded Ion Thrusters, Appl. Sci. 2023, 13, 5600.

Multimode space propulsion



Review of multimode space propulsion, Progress in Aerospace Sciences Volume 118, October 2020, 100627

Multimode space propulsion

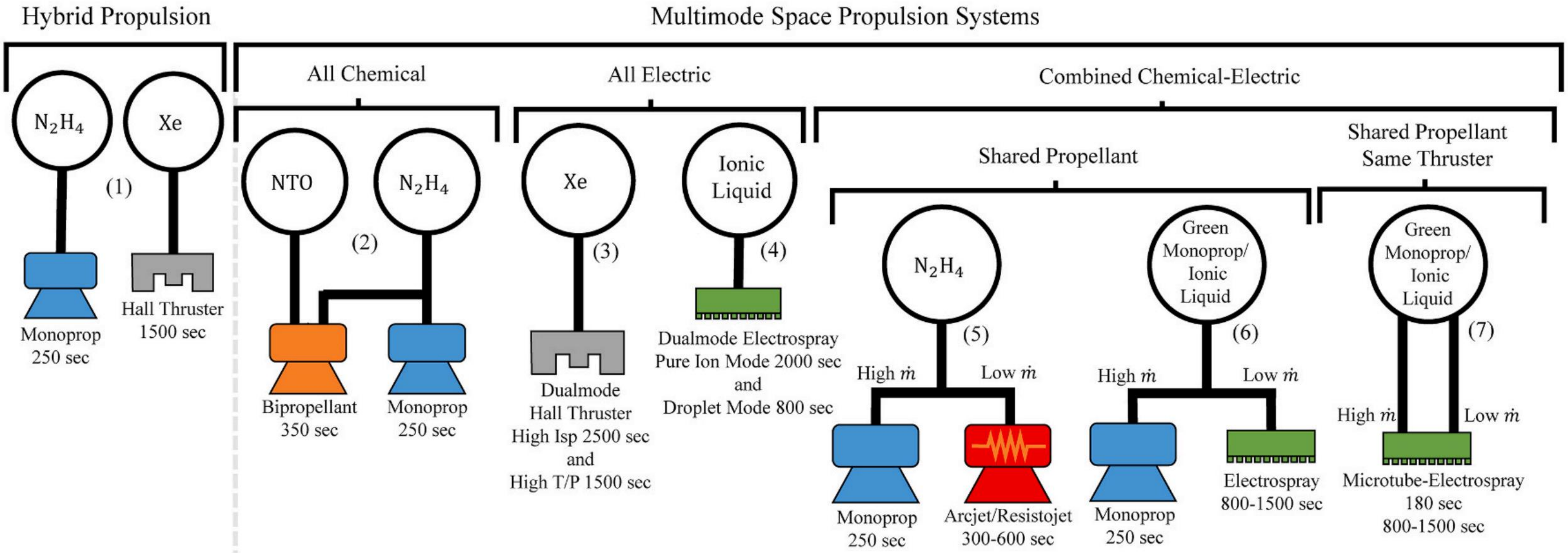


Fig. 1. Illustration of hybrid propulsion and multimode space propulsion.

Review of multimode space propulsion, October 2020Progress in Aerospace Sciences 118:100627

Multimode space propulsion

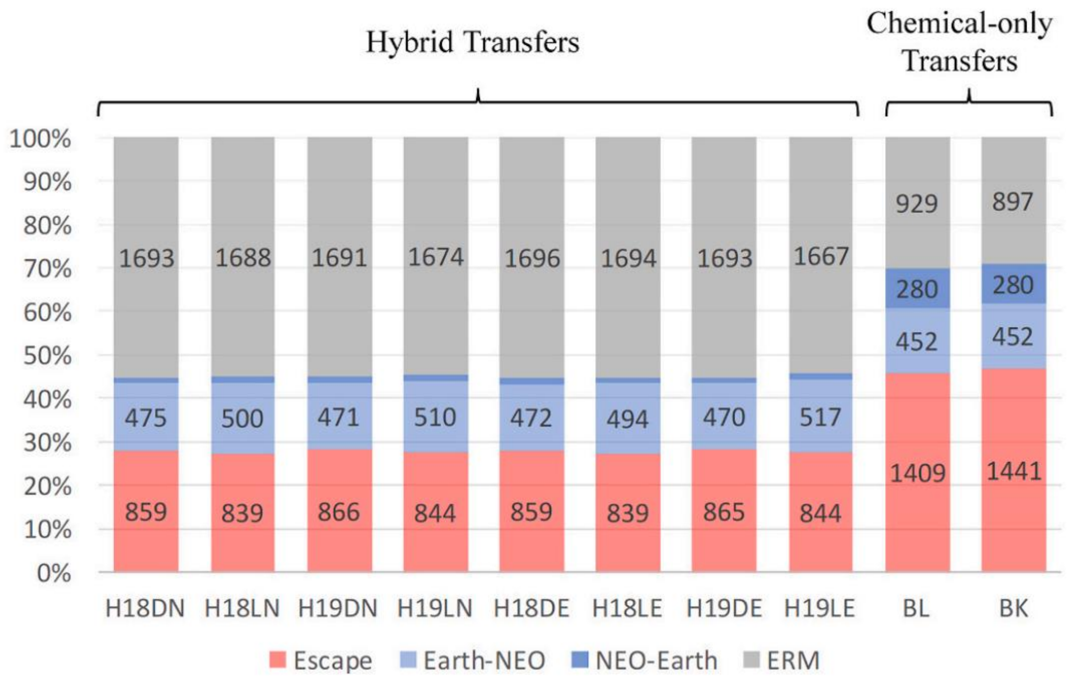


Fig. 4. Mass breakdown for hybrid and chemical-only transfers from Earth to a NEO asteroid [55]. Reproduced with permission.

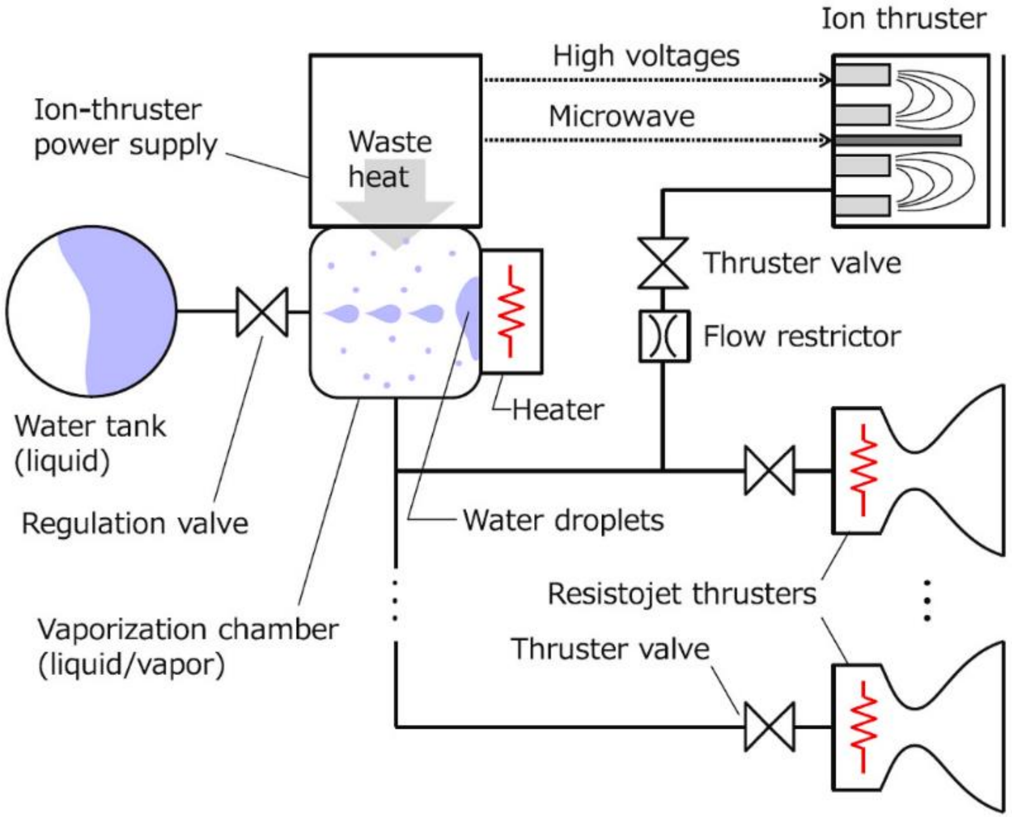
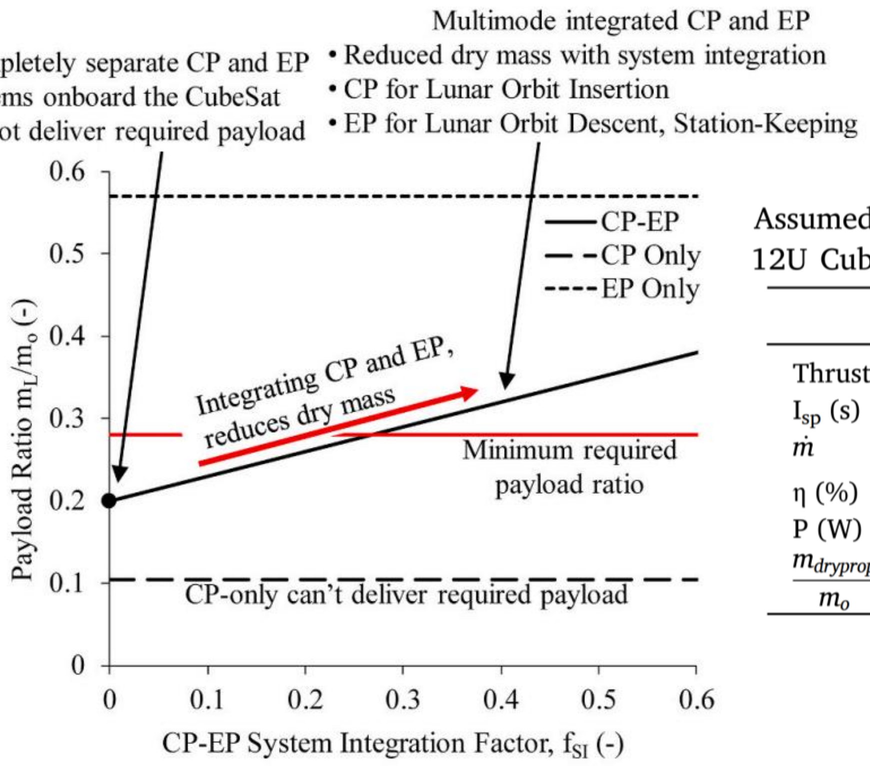


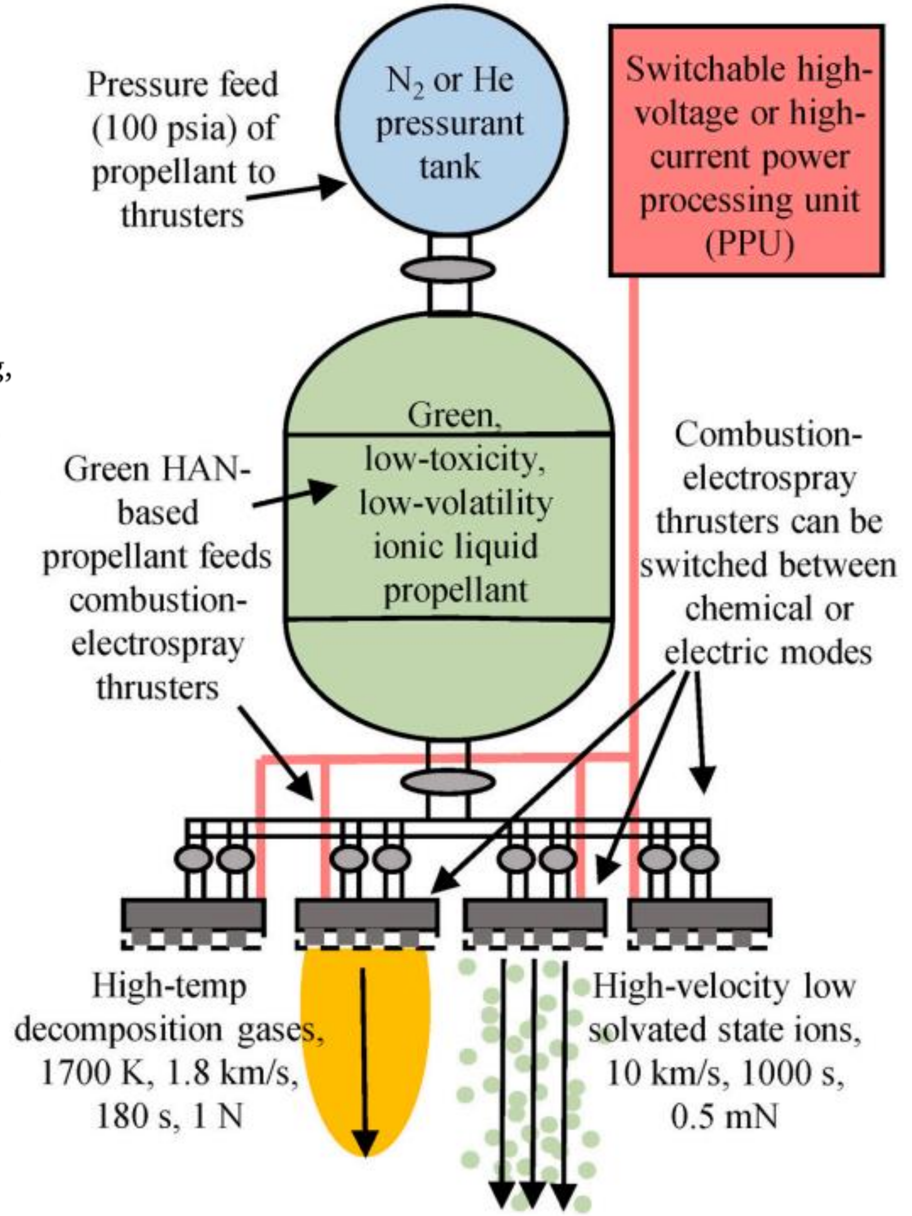
Fig. 2. Schematic of water-unified resistojet-ion thruster propulsion system [38]. Reproduced with permission.

Multimode space propulsion



Assumed performance of propulsion systems for a 25 kg, 12U CubeSat lunar mission.

	Chemical Propulsion	Electric Propulsion
Thrust	8 N (1.8 lbf)	4 mN
I_{sp} (s)	200	1000
$\dot{m}$	4.1 g/s	0.41 mg/s
η (%)	–	50
P (W)	20 (preheat)	40
$\frac{m_{dryprop}}{m_o}$	0.26	0.25



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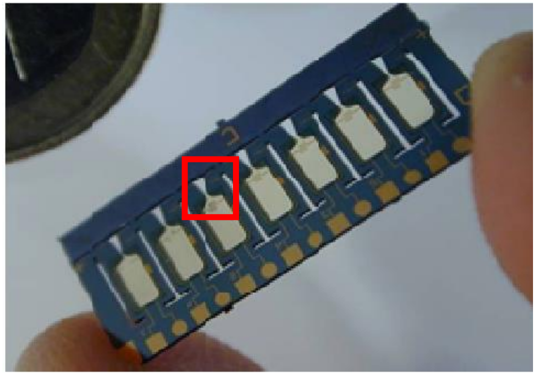
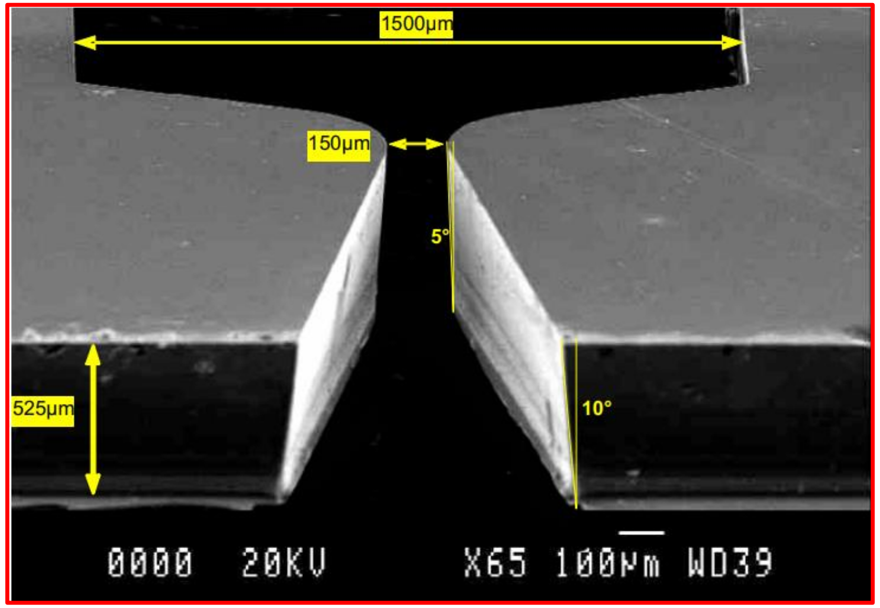
MEMS-based Propellant Technology





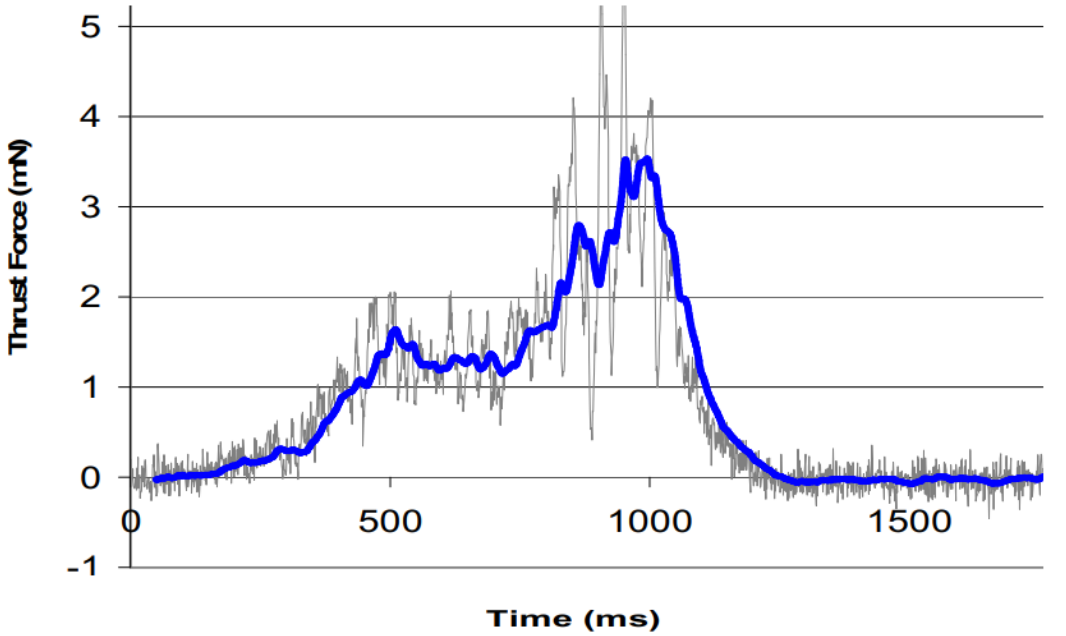
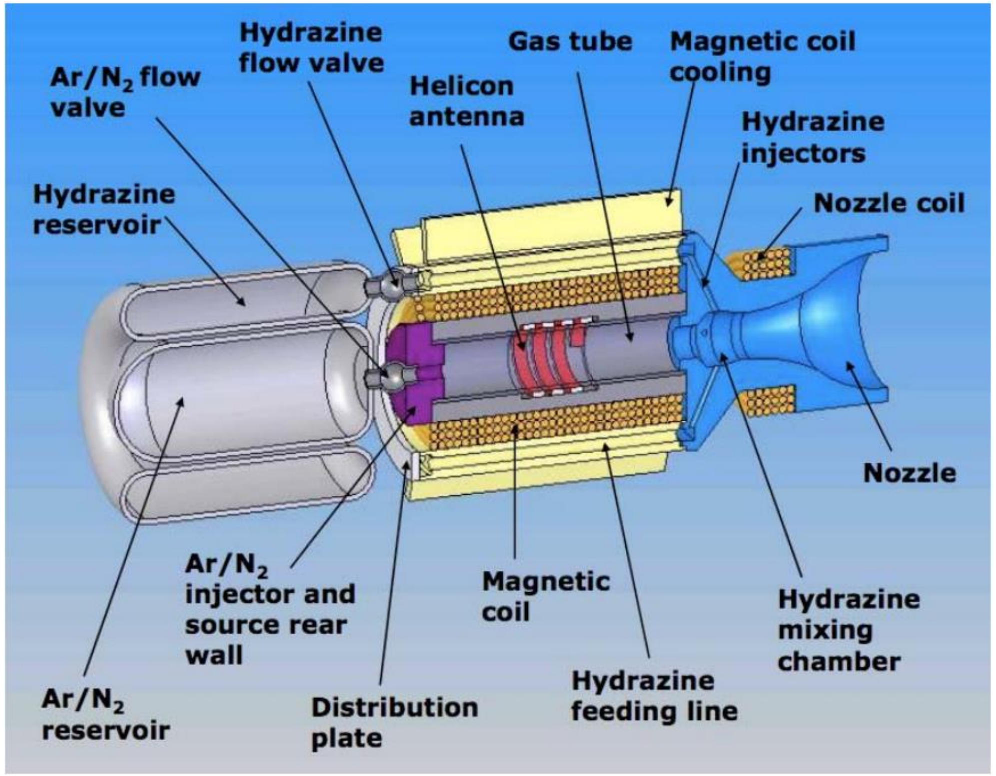
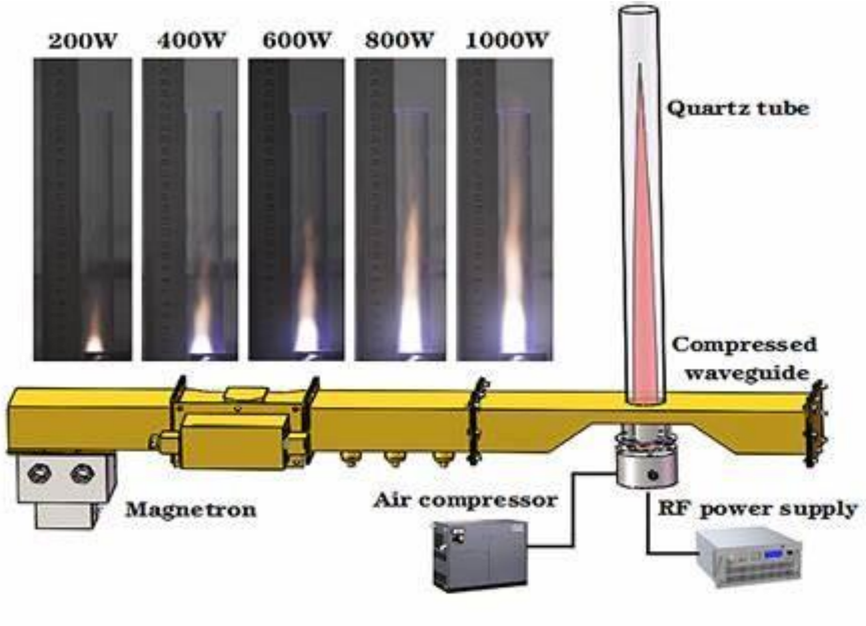
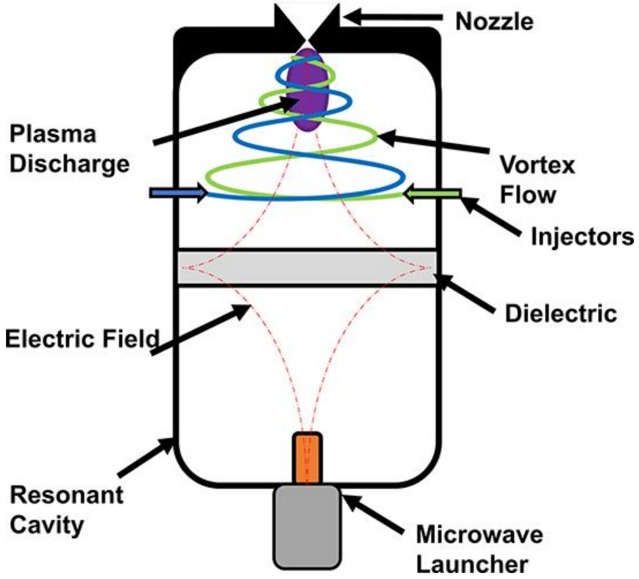


Figure 9. Thrust force vs. Time for thruster of Wt=100μm, loaded of (SD+30%PN) propellant.

Plasma Thruster







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Plasma Sources and Applications Centre/Space Propulsion Centre, National Institute of Education, **Nanyang Technological University, Singapore**

Vacuum facilities

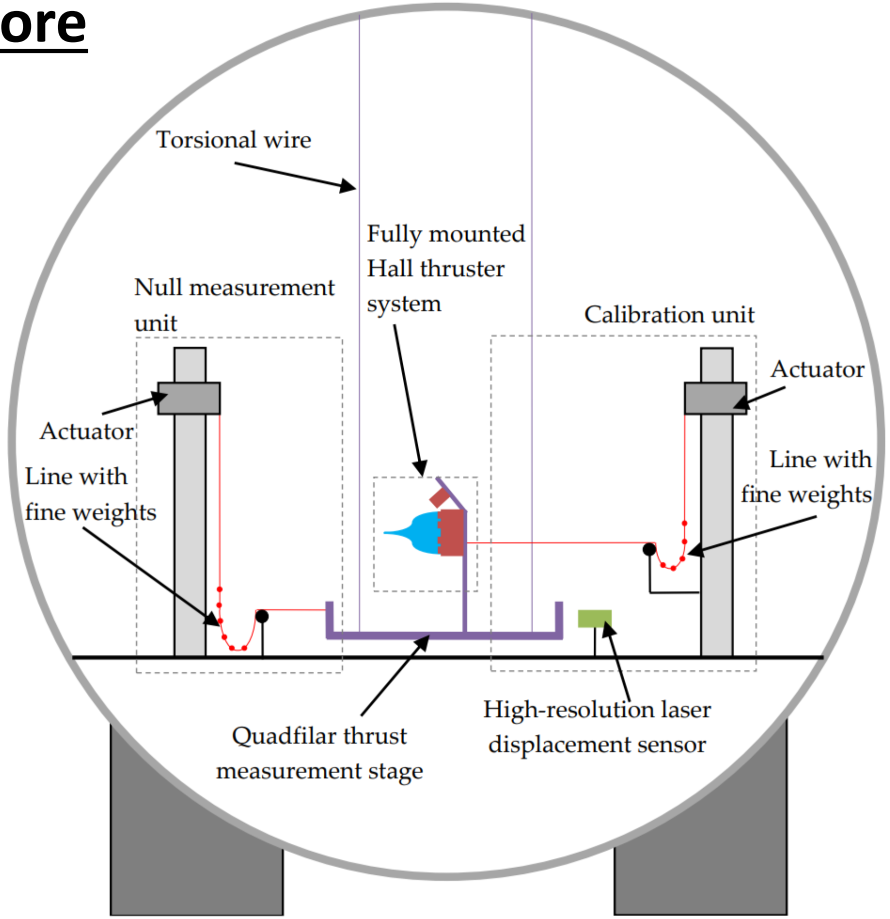
Space Environment Simulation Chamber

Cathode Experiments

Thruster Experiments

Plasma Sources and Applications Centre/Space Propulsion Centre, National Institute of Education, **Nanyang Technological University, Singapore**

Vacuum facilities



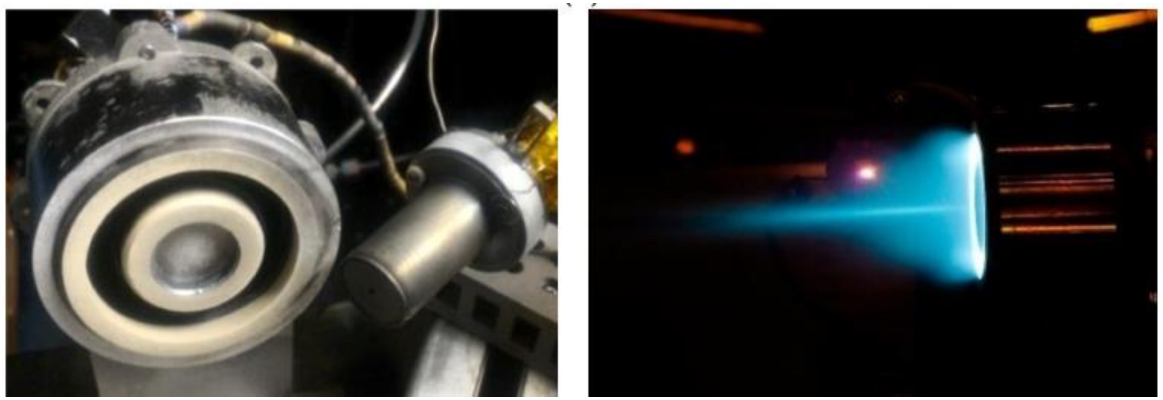
Quadfilar Measurement System

Facility for Propulsion Research and Development

Plasma Sources and Applications Centre/Space Propulsion Centre, National Institute of Education, **Nanyang Technological University, Singapore**

25 W

50 W



200 W

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Thank you