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# HEMP

## Innovative Electric Propulsion Technology for Commercial and Scientific Spacecraft

9th VDE ITG International Vacuum Electronics Workshop 2024

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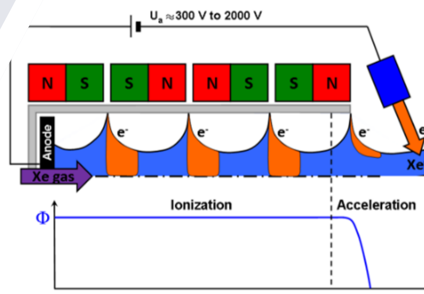
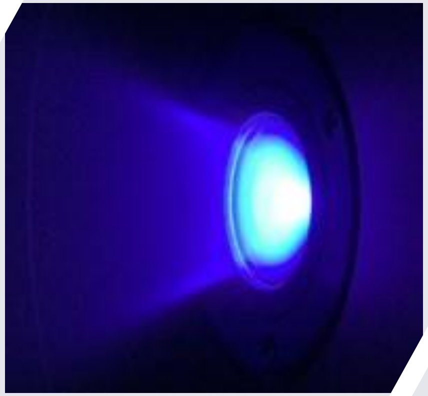
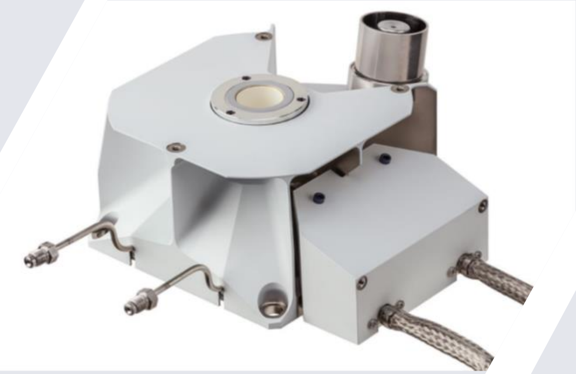
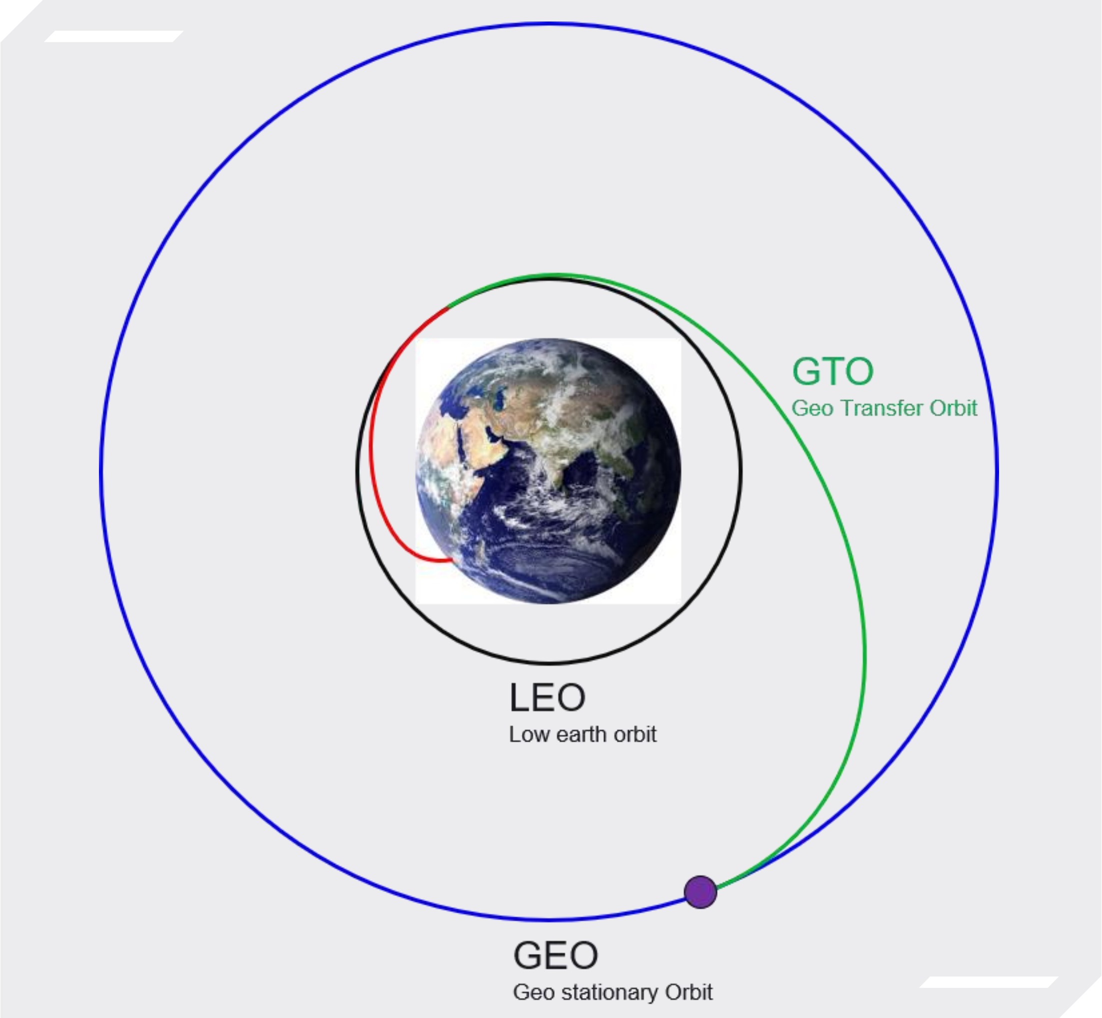
# Outline

- > Fundamentals of propulsion and electric propulsion
- > Principal of operation – HEMP
- > Performance of the HEMP Thruster Module EV0
- > Roadmap and Outlook: HEMP Thruster Module EV0+



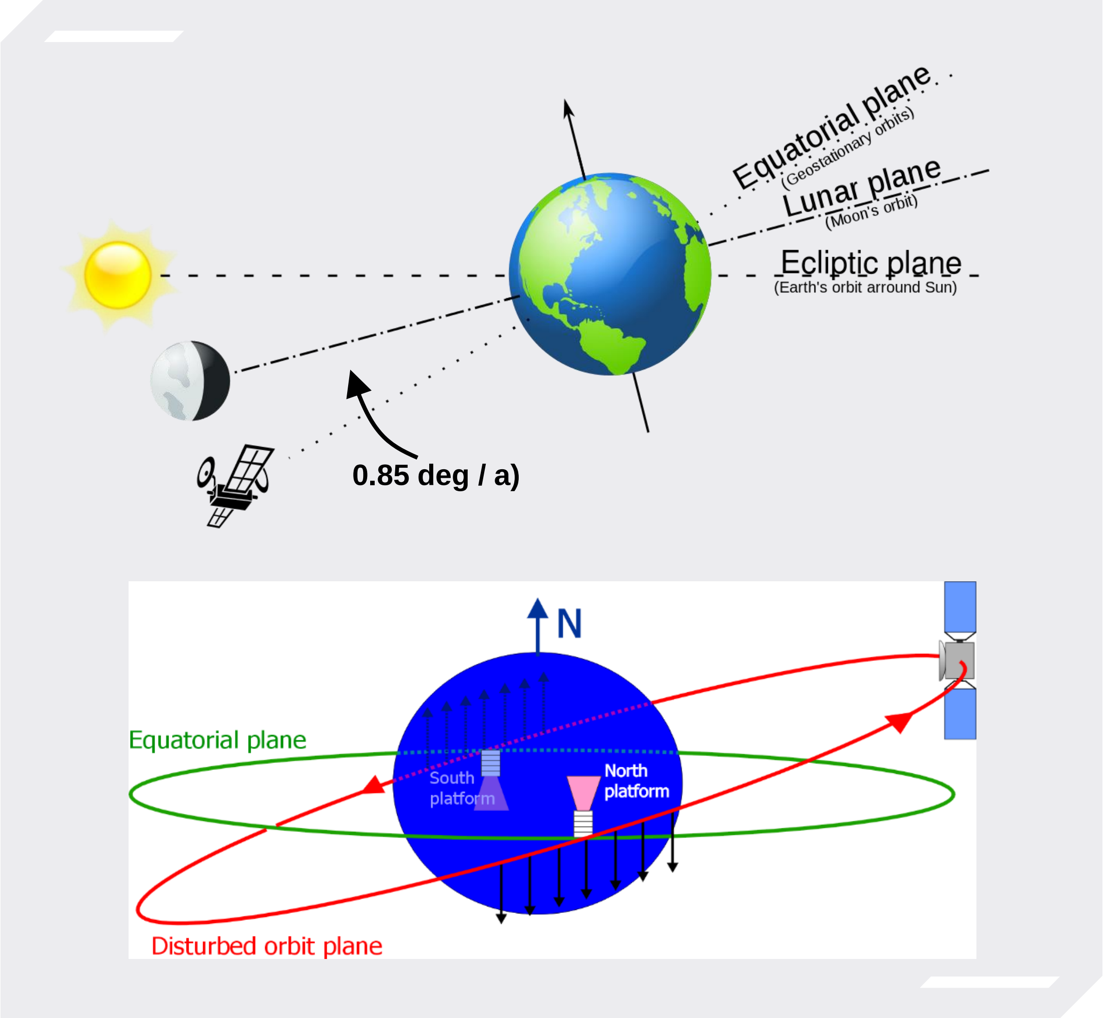



# Fundamentals of Propulsion: Moving in Space - Velocity demand – Δv – orbit transfer

> To move from one orbit to another orbit, the object has to gain velocity (Δv)

| | | Δv | v |
|---|---|---|---|
| Launch to | ⇩ | | 0 m/s |
| | LEO | | 7.802 m/s |
| Transfer to | ⇩ | +4.098 m/s | |
| | GEO | | 11.900 m/s |
| Operation: 15a NSSK | | +750-825 m/s | |

Typical values
figures may vary depending on launch site, trajectories, orbits




# Fundamentals of Propulsion: Moving in space – Example: North-South Station Keeping

## > NSSK-North South Station Keeping

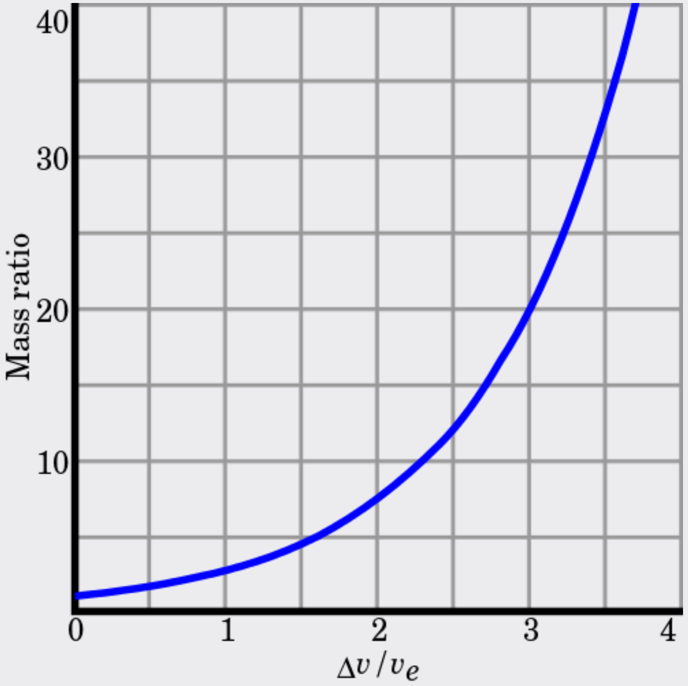
## > Gravitational forces push Geostationary satellites out of their Equatorial orbit finally into ecliptic plane

## > To compensate:

- Thrust maneuvers 2x per day
- Around the orbital nodes

# Fundamentals of Propulsion: Rocket equation – thrust through reaction

$$\Delta v = v_e \ln\left(\frac{m_0}{m_f}\right)$$

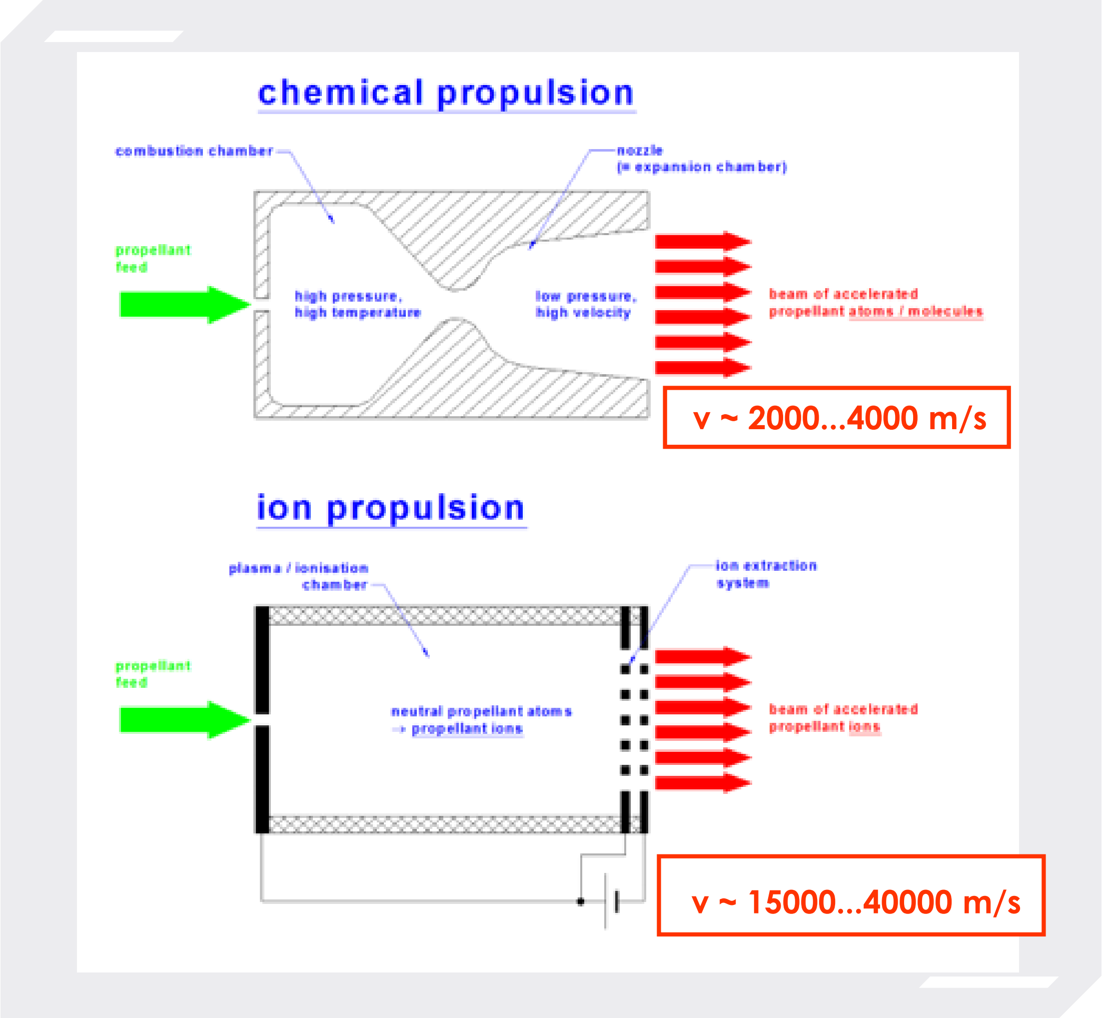



## > The rocket equation describes acceleration of vehicles by expelling parts of its mass with constant high speed

| | |
|---|---|
| $\Delta v$ | change of velocity of the vehicle |
| $v_e$ | effective exhaust velocity |
| $m_0$ | start mass (wet mass) |
| $m_f$ | final total mass (dry mass) |

$\Delta$ v increases with exhaust velocity and with relative amount of propellant ejected

Imperative:
➔ High exhaust velocity required to keep wet mass as low as possible (higher payloads possible)



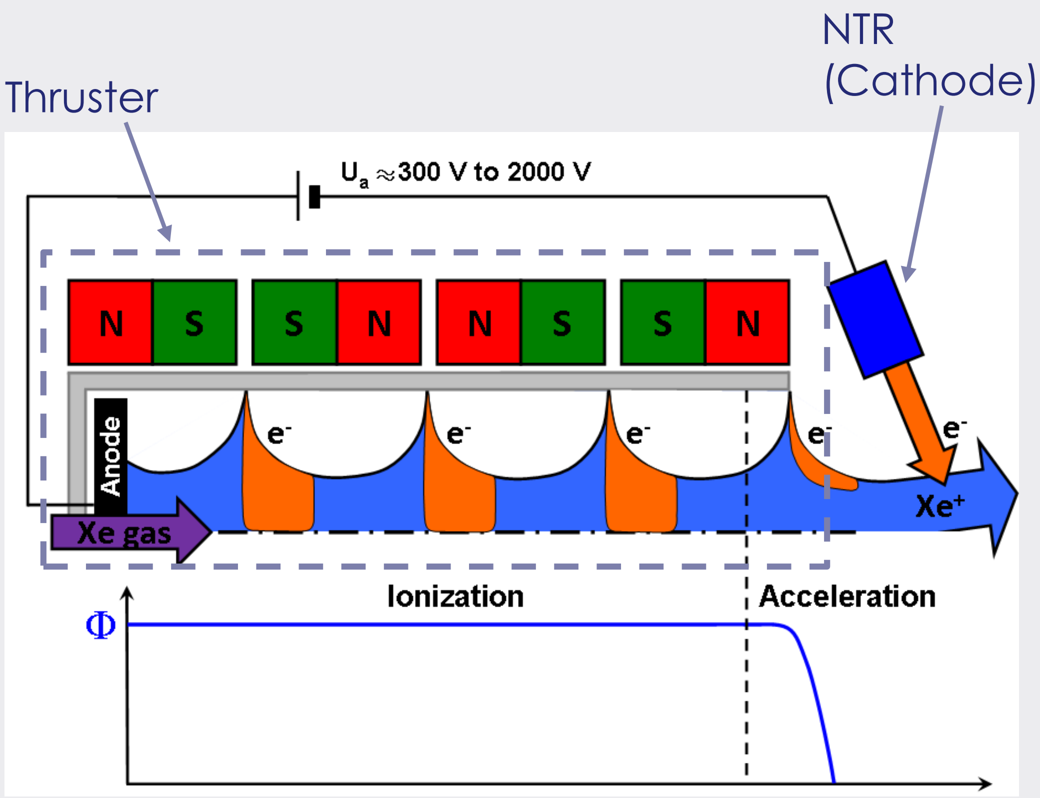

# Fundamentals of Propulsion: Chemical vs. Ion Propulsion

## > Chemical: Energy stored in Propellant

- specific energy limited
- mass acceleration through thermal expansion
- high thrust due to high propellant mass flow: $T = \dot{m}_p \, v_e$
- exhaust velocity limited by temperature at nozzle inlet: $v_e \propto \sqrt{T_1}$

## > Ion Propulsion: Energy not in propellant, provided from outside

- specific energy unlimited
- mass acceleration by electrical field
- typically low thrust
- exhaust velocity defined by supplied electrical power: $v_e \propto \sqrt{U}$




Section view of the HEMP Thruster and Potential

# Principal of operation – Thales High Efficiency Multistage Plasma Thruster HEMPT

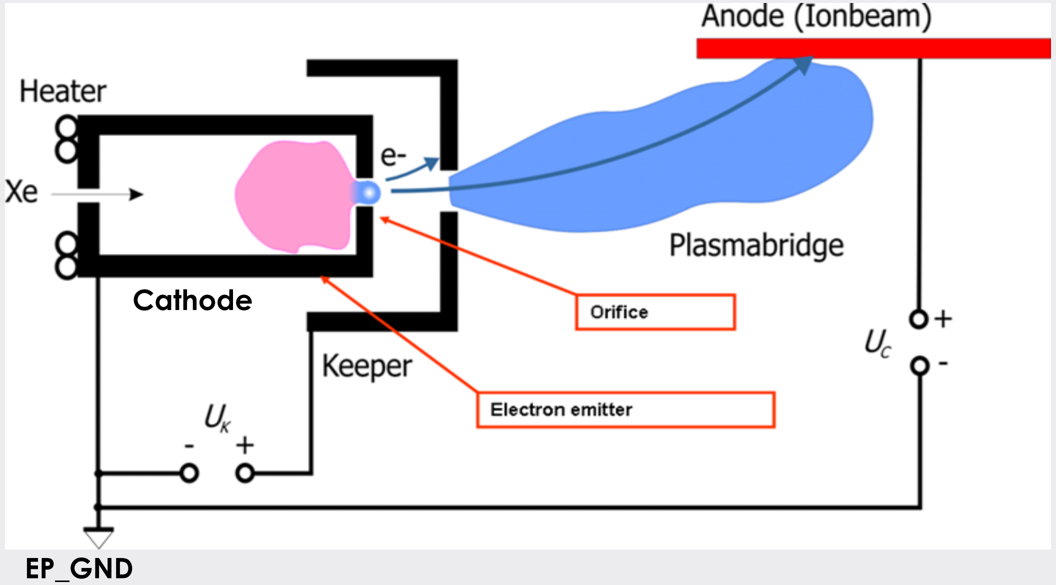
> thruster with permanent magnets and a cylindrical dielectric discharge channel

- Minimized plasma-wall contact:

  magnetic cells form strong confinement of electrons in cusp-mirror configuration → almost no channel erosion
- High ionization efficiency:

  due to efficient electron confinement
- Efficient ion acceleration by electric field
- Long life time and performance stability:

  due to negligible channel erosion
- Thruster and system architecture with minimum complexity: cost-efficient & reliable
- Concept allows wide operational range (voltage and current)




# Principal of operation – Hollow Cathode Neutralizer HCN

## > HCN Operational Principle:

- Low voltage high density Xenon/Krypton discharge serves as conductor for emitter electrons to form neutralizing plasma bridge
- Advantage: High current and current density possible
- Example: 3A of electron current is conducted through 1mm² !

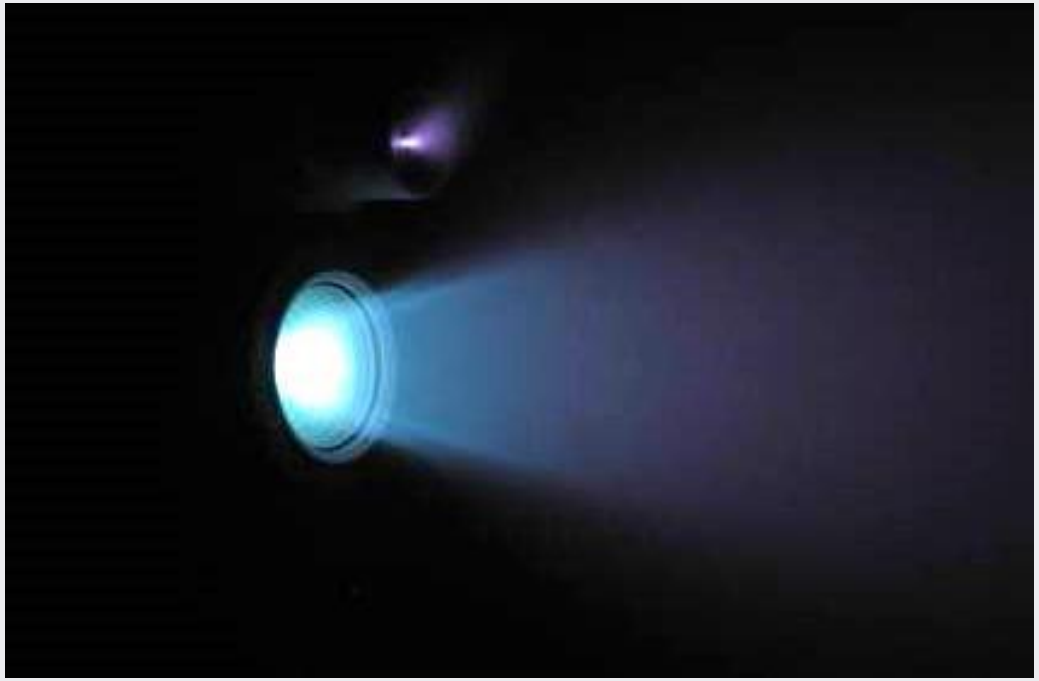
## > Properties:

- Ba impregnated Metal Matrix W/Os electron emitter

  high thermionic emission at moderate temperatures (low work function material)

  low ignition and sustaining voltage for keeper discharge and for plasma bridge
- Cathode technology with best flight heritage from TWTs

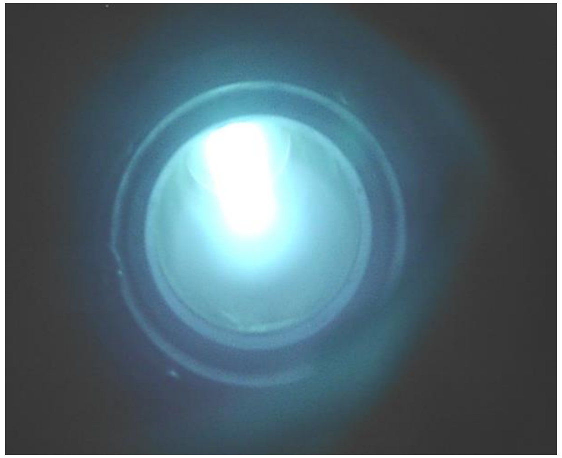
  minimized technological risk, high reliability and life time

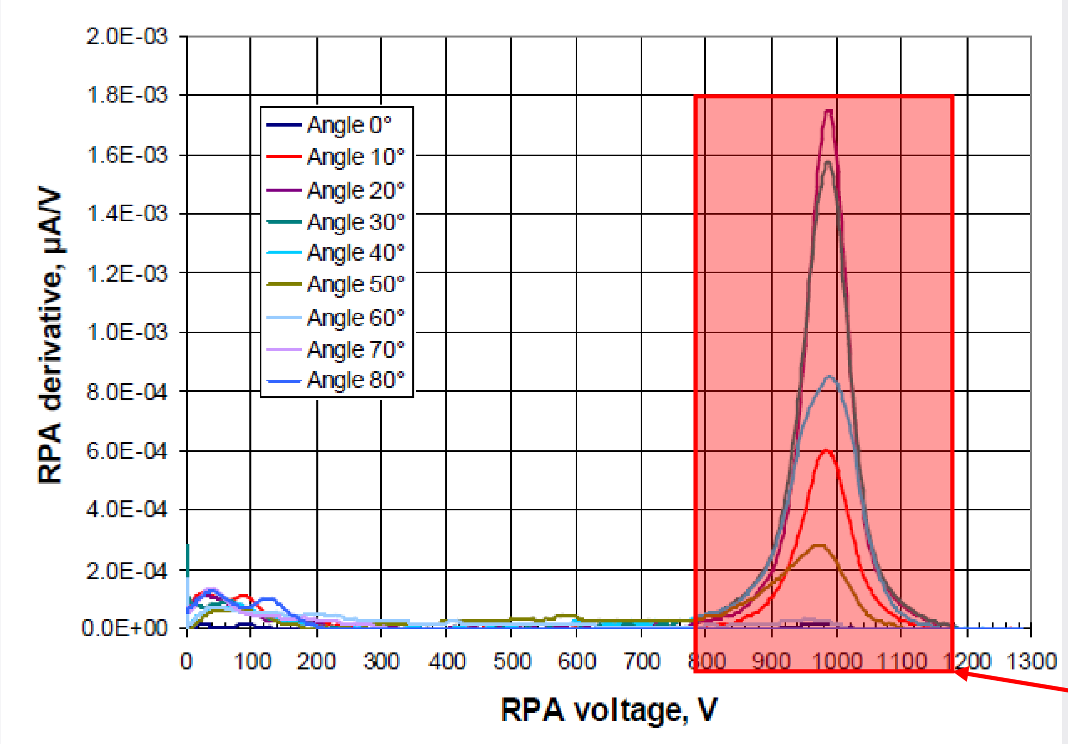


# Principal of operation – HEMPT Confinement

## > HEMPT Operational Principle:

- Electrons are efficiently trapped in a cusp-mirror configuration (magnetic cells)
- Plasma electrons are prevented from contacting the discharge channel walls

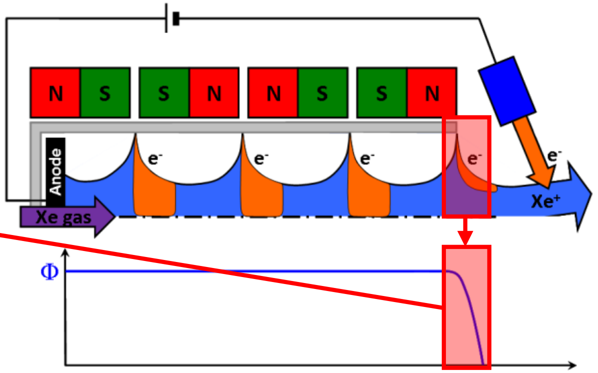





# Performance of the HEMP Thruster Module (HTM) EV0 – Plume Characteristics

> Separated ionization and acceleration zones cause most of the ions to be generated at anode potential

→ high ion acceleration efficiency

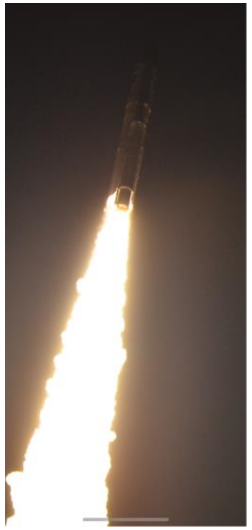


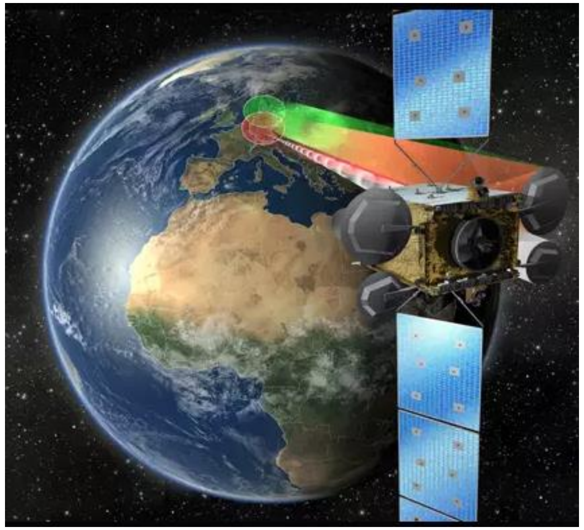
# Recent Success: Thales Thruster HEMPT 3050

**Fully qualified thruster**

**TRL 8**
**Life Test**

**Heinrich Hertz satellite:**
**Launch: 5th July 2023**
**In orbit since 21st July 2023**





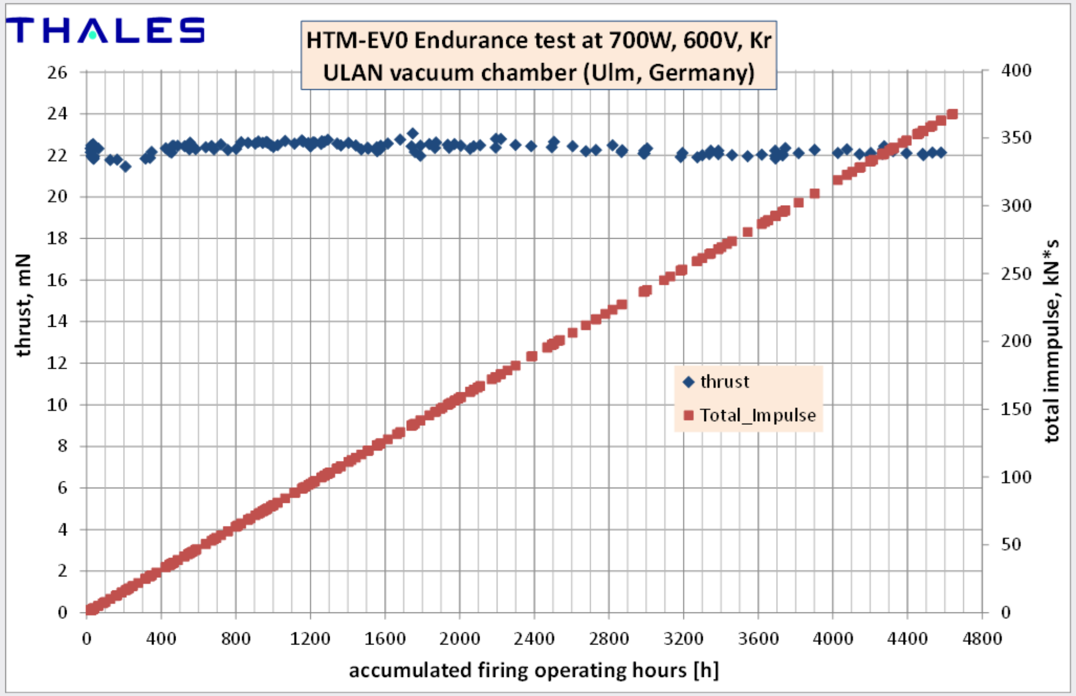
**KEY TECHNICAL ELEMENTS**

Thrust: 44 mN
ISP: 2400 s
Power: 1.4 kW
Operating Voltage: 1000V
Total Impulse: 1.47 MNs
Life time >9000 h operation qualified for space

# Performance of the HEMP Thruster Module EV0

- 200 W – 700 W flexible power rating
- Thrust: up to 32 mN
- Operating Voltage 300 V – 800 V
- Propellant: Xenon or Krypton
- ISP: up to 2100 s (ISP = $\frac{v_e}{g}$, with g = 9,81 m/s²)
- Total Impulse target: >1.0 MNs
- 1.5kg mass (depending on harness length)
- Dimensions: approx. 180x190x90 mm

# Performance of the HTM EV0 – Krypton Endurance Test with Engineering Model



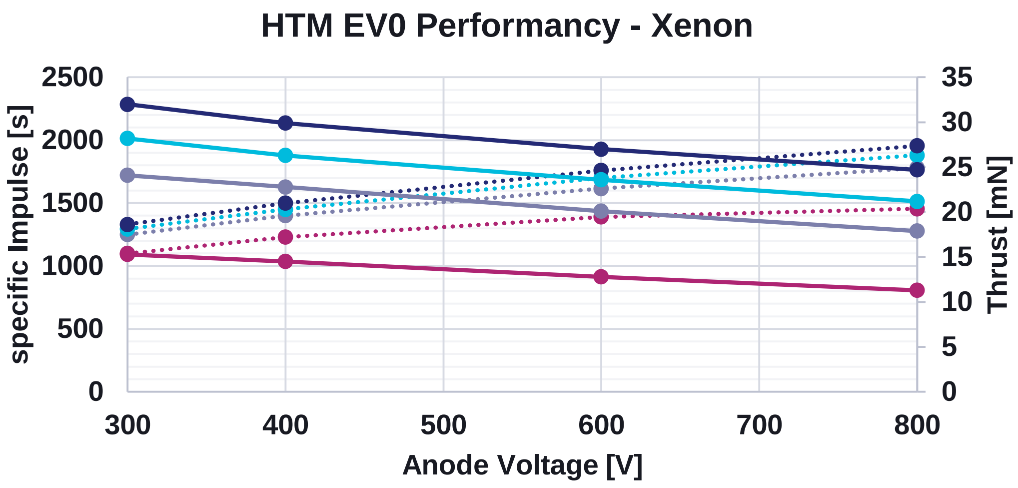

- 4650 firing hours, 600V-700W working point, ~360 kNs
- Test interrupted due to time schedule, thruster module still operational
- Thrust degradation ~ 2%, specific impulse degradation ~ 4%

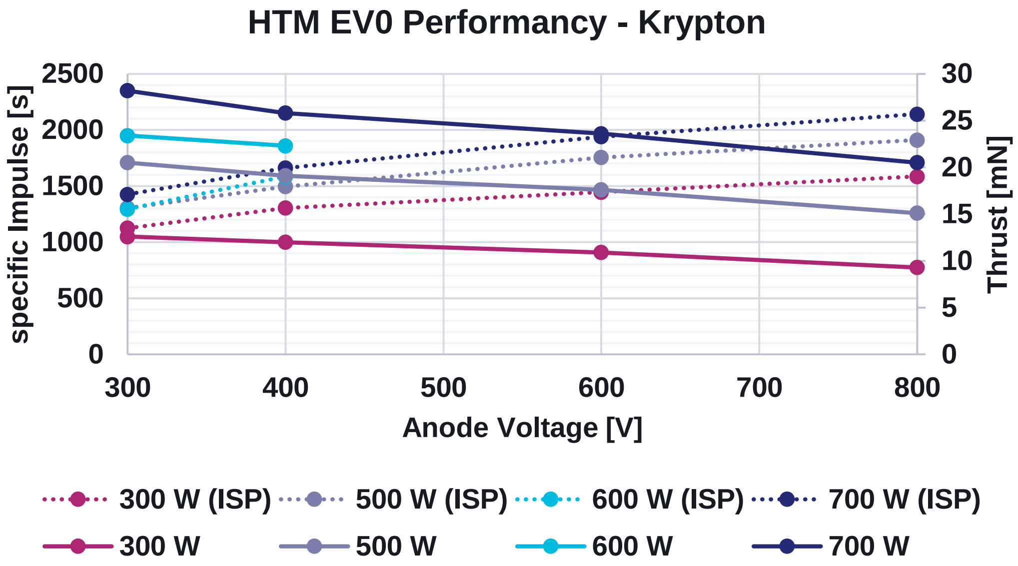
HTM-EV0 Engineering Model

# Performance of the HTM EV0 – Different Propellants and OPs

| 54 Xe Xenon 131.29 | 300 W | 500 W | 600 W | 700 W |
|---|---|---|---|---|
| 300 V | Thrust 15.3 mN<br>ISP 1100 s | Thrust 24.1 mN<br>ISP 1250 s | Thrust 28.2 mN<br>ISP 1295 s | Thrust 32.0 mN<br>ISP 1330 s |
| 400 V | Thrust 14.5 mN<br>ISP 1230 s | Thrust 22.8 mN<br>ISP 1400 s | Thrust 26.3 mN<br>ISP 1450 s | Thrust 29.9 mN<br>ISP 1500 s |
| 600 V | Thrust 12.8 mN<br>ISP 1390 s | Thrust 20.1 mN<br>ISP 1615 s | Thrust 23.6 mN<br>ISP 1700 s | Thrust 27.0 mN<br>ISP 1760 s |
| 800 V | Thrust 11.3 mN<br>ISP 1455 s | Thrust 17.9 mN<br>ISP 1780 s | Thrust 21.2 mN<br>ISP 1880 s | Thrust 24.7 mN<br>ISP 1955 s |

| 36 Kr Krypton 84.80 | 300 W | 500 W | 600 W | 700 W |
|---|---|---|---|---|
| 300 V | Thrust 12.6 mN<br>ISP 1125 s | Thrust 20.5 mN<br>ISP 1305 s | Thrust 23.4 mN<br>ISP 1295 s | Thrust 28.2 mN<br>ISP 1425 s |
| 400 V | Thrust 12.0 mN<br>ISP 1305 s | Thrust 19.1 mN<br>ISP 1495 s | Thrust 22.3 mN<br>ISP 1585 s | Thrust 25.8 mN<br>ISP 1660 s |
| 600 V | Thrust 10.9 mN<br>ISP 1445 s | Thrust 17.6 mN<br>ISP 1755 s | -- | Thrust 23.6 mN<br>ISP 1940 s |
| 800 V | Thrust 9.3 mN<br>ISP 1585 s | Thrust 15.1 mN<br>ISP 1910 s | -- | Thrust 20.5 mN<br>ISP 2140 s |



# Roadmap and Outlook: HEMP Thruster Module EV0+

| TRL 8 | Final qualification | Delta design | BB tested |
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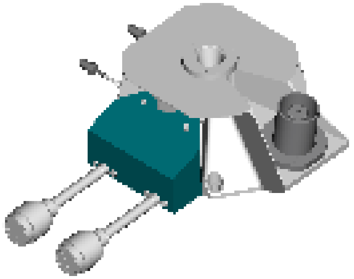
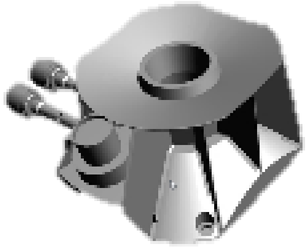
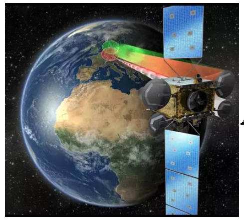
|  |  |  |  |
| **HEMPT 3050** | **HEMPT EV0** | **HEMPT EV0 +** | **HEMPT EV1** |
| Technology demonstrator | Low cost small engine for constellations | **Low cost medium engine for any orbits** | **Low cost medium engine for any orbits** |
| 1400 W<br>Thrust : 44 mN<br>ISP : 2400 s | 200 – 700 W<br>10 – 32 mN<br>Up to 2200 s | **500 – 1200 W<br>30 – 45 mN<br>Up to 2800 s** | **1000 – 3000 W<br>30 – 140 mN<br>Up to 3200 s** |
| Xenon<br>**In orbit** | Xenon & Krypton<br>**Qualified / in production** | **Xenon & Krypton<br>Ready to start dev.** | **Xenon & Krypton<br>BB tested – In standy** |

# Roadmap and Outlook: HEMPT recent commercial successes



DLR

**Thales thruster onboard Heinrich Hertz mission (Ariane 5 Launch on July 5th 2023)**

multiple

commercial

projects

# Conclusion

## > Fundamentals of propulsion and electric propulsion

- High exhaust velocity beneficial

## > Principal of operation – HEMP

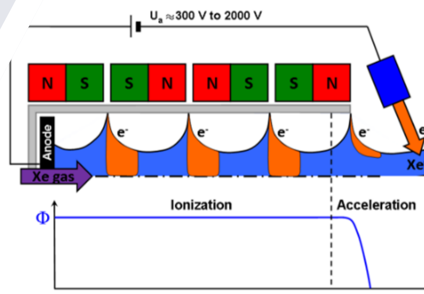
- Simple design with high exhaust velocity and no channel erosion

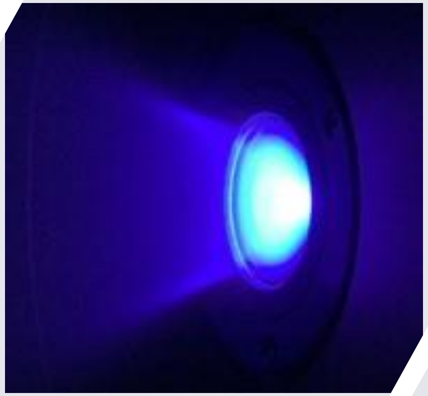
## > Performance of the HEMP Thruster Module EV0

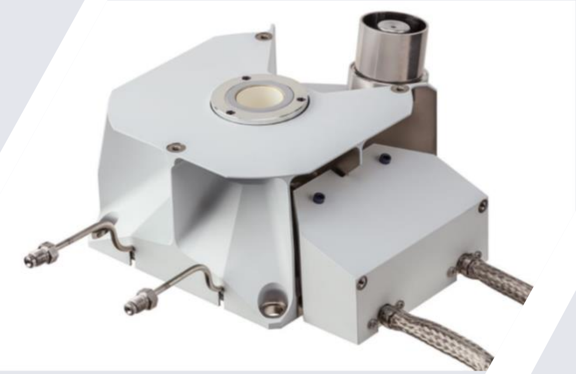
- High ion acceleration efficiency at different operating points with different propellants

## > Roadmap and Outlook: HEMP Thruster Module EV0+

- Commercial success HTM EV0 and HTM EV0+ ready for development



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# Thank you

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# Contact


## Gabriel SUSKE

Electric Propulsion System Engineer

+49 731 40729 314

Gabriel.suske@thalesgroup.com