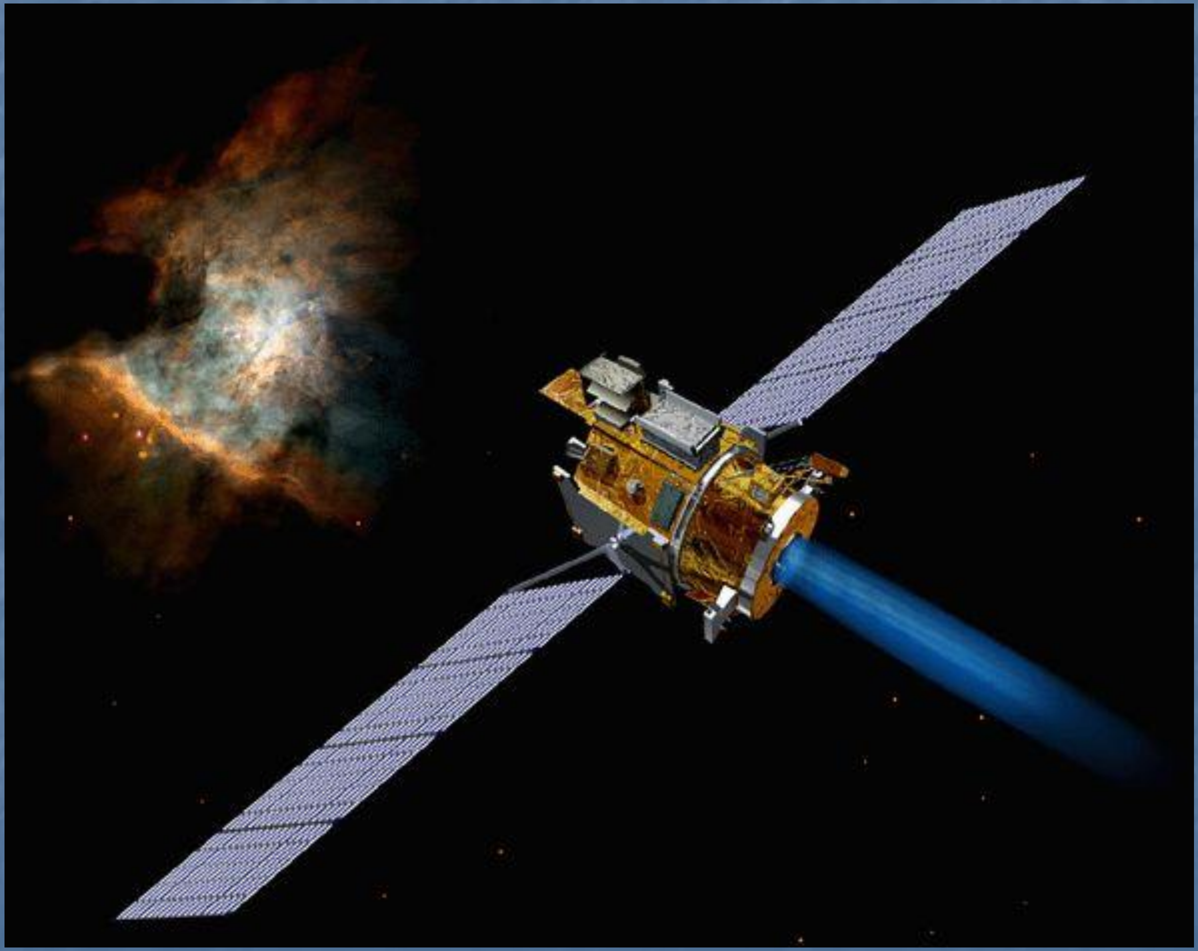
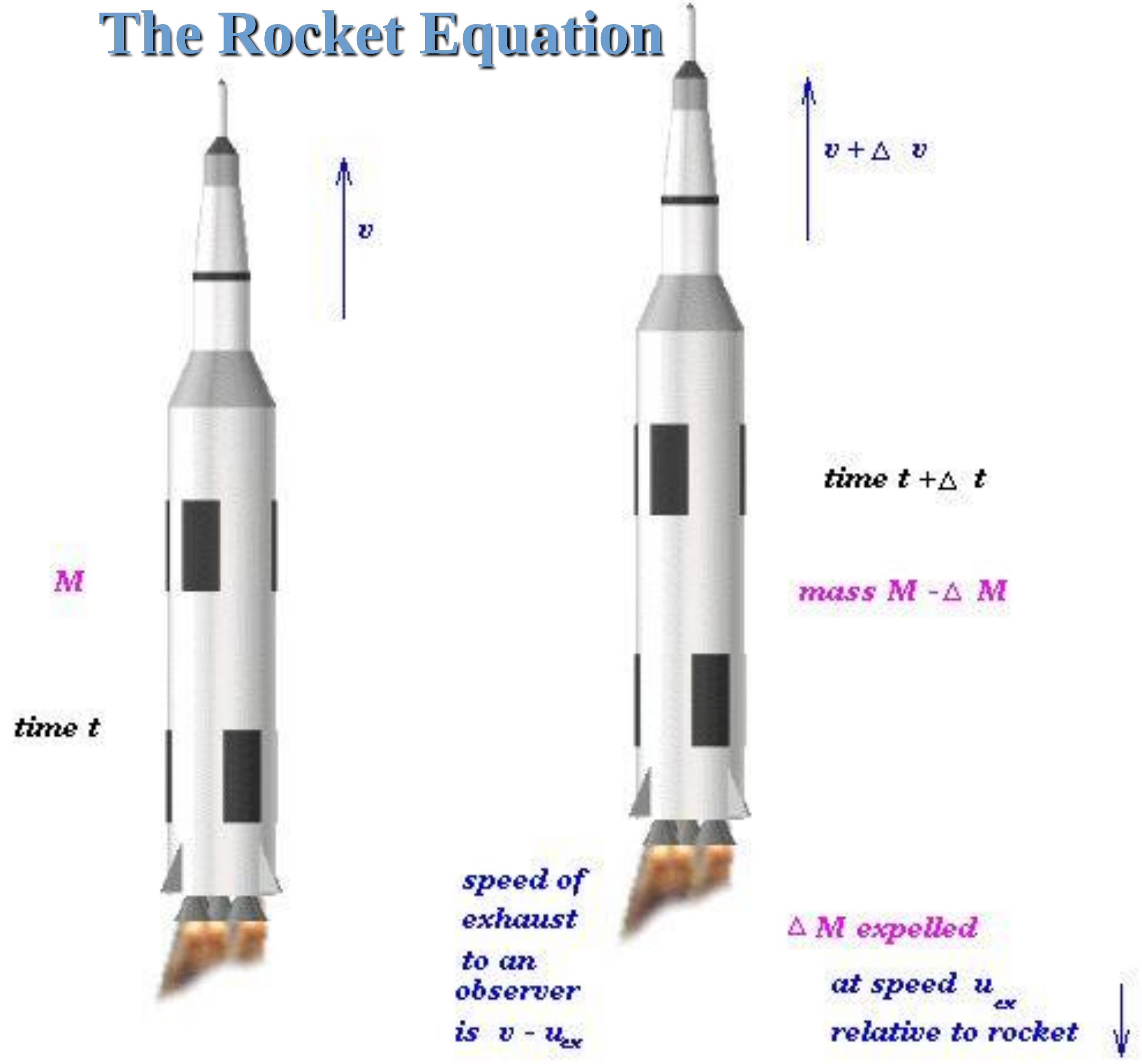
Electric Propulsion



Limitations of Chemical Rockets

- Chemical rocket: exhaust ejection velocity intrinsically limited by the propellant-oxidizer reaction
- Larger velocity increment of the spacecraft could be obtained only with a larger ejected mass flow.
- Mission practical limitation: exceedingly large amount of propellant that needs to be stored aboard

The Rocket Equation



Understanding the motion of a spacecraft

The Rocket Equation (II)

- The rocket equation links the mass of exhausted propellant ΔM, the relative exhaust velocity u_{ex} and the velocity increment of the spacecraft Δv:

$$\Delta m = M_0 \left[1 - \exp\left(-\frac{\Delta v}{u_{ex}} \right) \right]$$

- For a given Δv, the larger u_{ex}, the smaller ΔM, and viceversa
- A large ΔM requires the storage of a large amount of propellant on board, reducing the useful payload

Advanced (Electric) Propulsion

The Concept:

- Definition - Electric propulsion: A way to accelerate a propellant through electro(magnetic) fields
- There is no intrinsic limitation (other than the relativistic one) to the speed to which the propellant can be accelerated
- Energy available on board is the only practical limitation

Advanced (Electric) Propulsion *(II)*

Understanding what's behind it:

- Tradeoff 1: more energy available, less propellant, less mass required
- Tradeoff 2: more time allowed for a maneuver, less power needed

Advanced (Electric) Propulsion *(III)*

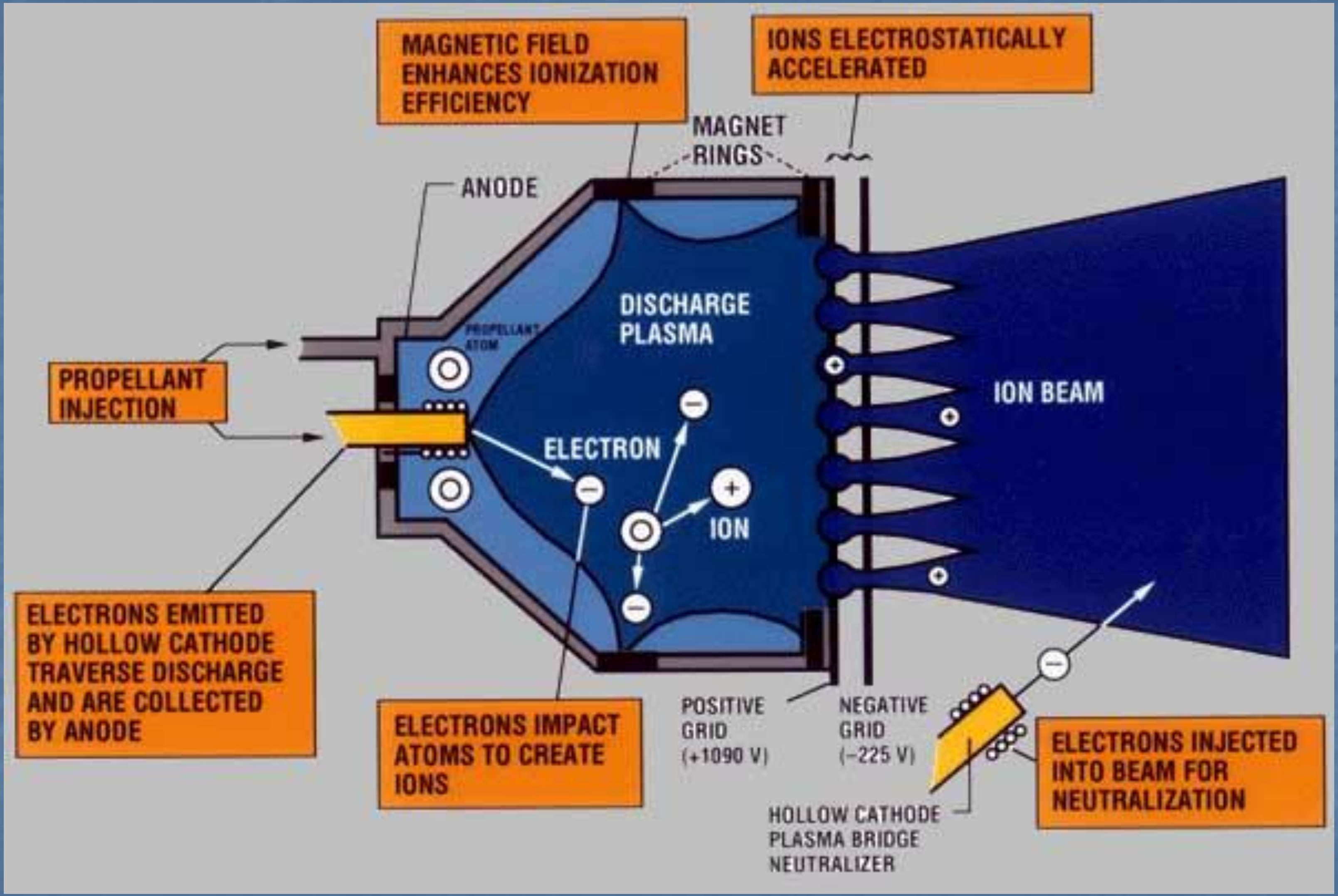
Features:

- High exhaust speed (*i.e.* high specific impulse), much greater than in conventional (chemical) rockets
- Much less propellant consumption (much higher efficiency in the fuel utilization)
- Continuous propulsion: apply a smaller thrust for a longer time
- Mission flexibility (Interplanetary travel, defense)
- Endurance (commercial satellites)

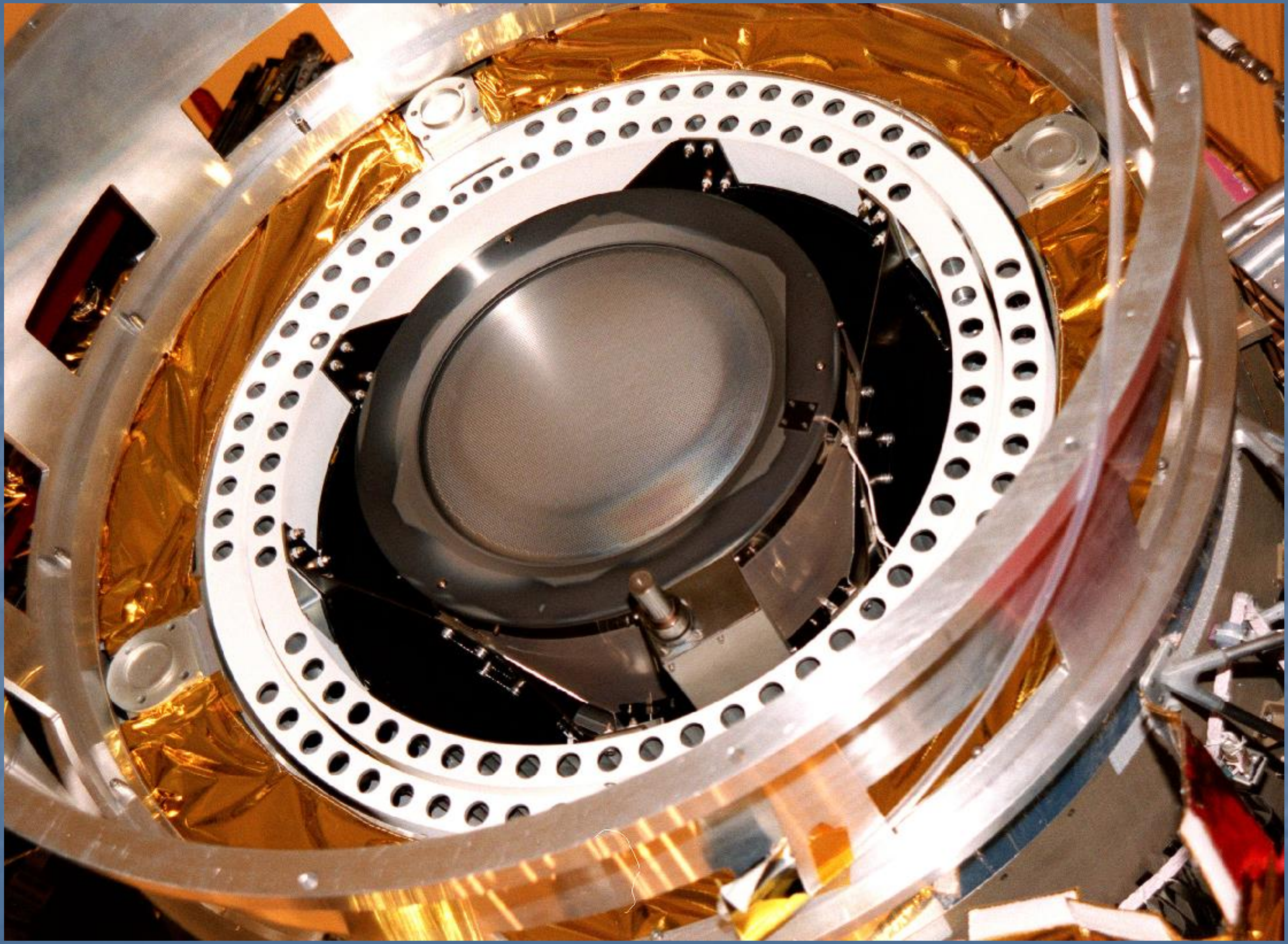
Electric Propulsion Concepts

- Variety of designs to accelerate ions or plasmas
- Most concepts utilize grids or electrodes: power and endurance limitations
- Ion Engine
- Hall Thruster
- RF Plasma Thrusters (ECR, VASIMR, Helicon Double Layer)
- Magnetoplasma Dynamic (MPD) Thrusters
- Plasmoid Accelerated Thrusters

Ion Engine

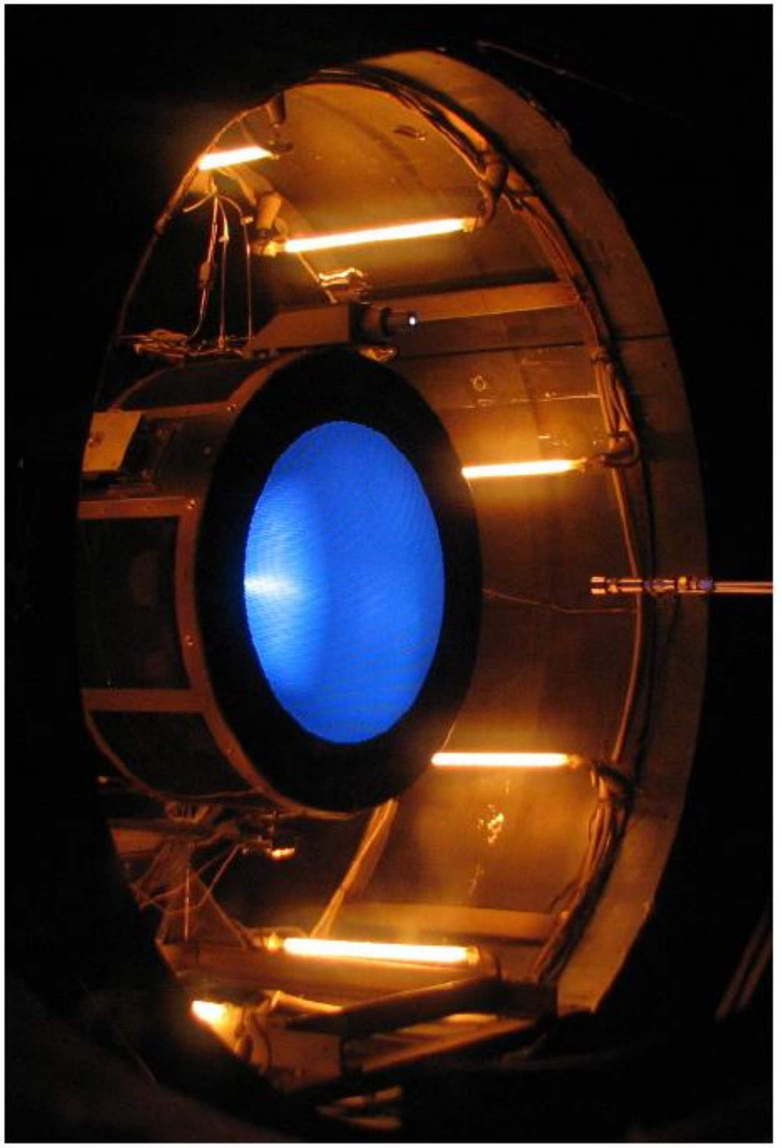


- Scheme of a gridded ion engine with neutralization



NASA's Deep Space One Ion Engine

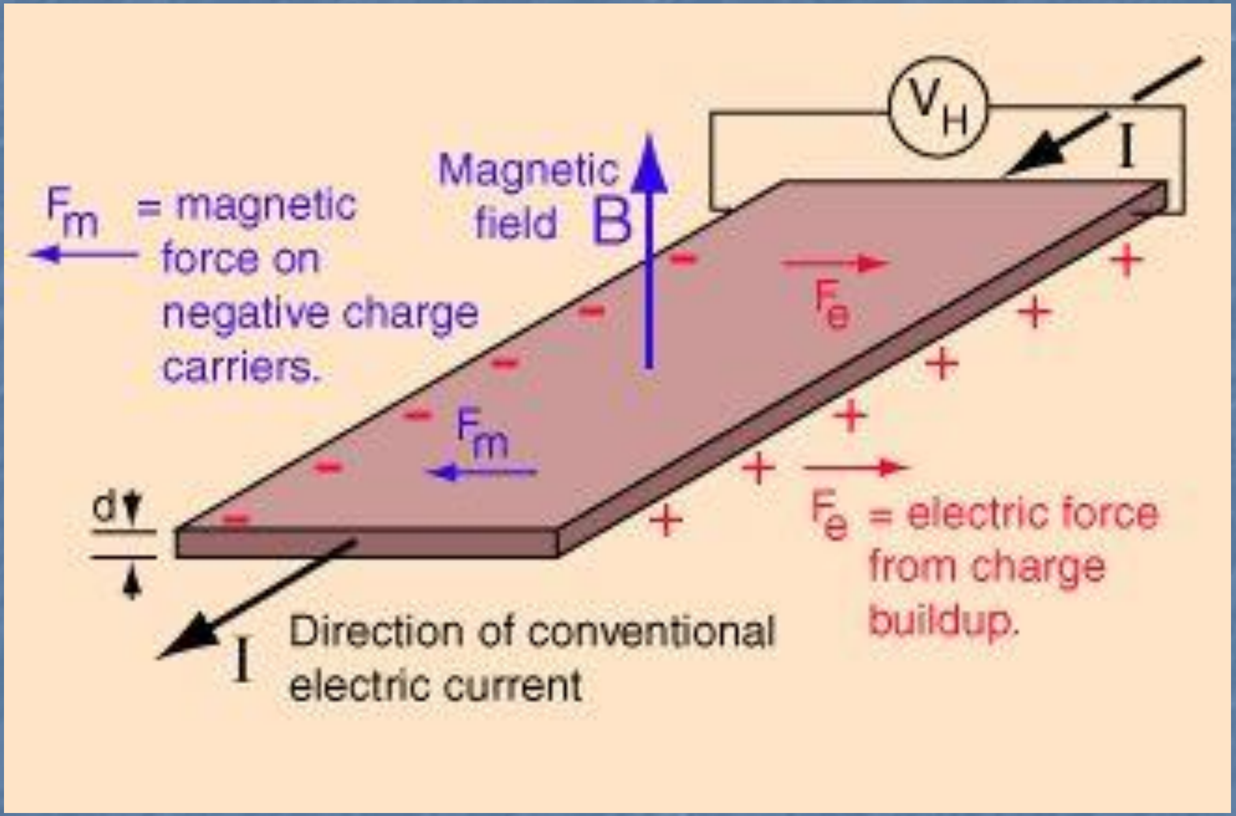
Ion Engine



Characteristic	NEXT
Thruster Power Range, kW	0.5-6.9
Throttle Ratio	> 12:1
Max. Specific Impulse, sec	>4100
Max. Thrust, mN	236
Max. Thruster Efficiency	>70%
Max. PPU Efficiency	94%
Propellant Throughput, kg	> 300
Specific Mass, kg/kW	1.8
PPU Specific Mass, kg/kW	4.8
PMS Single-String Mass, kg	5.0
PMS Unusable Propellant Residual	1.00%

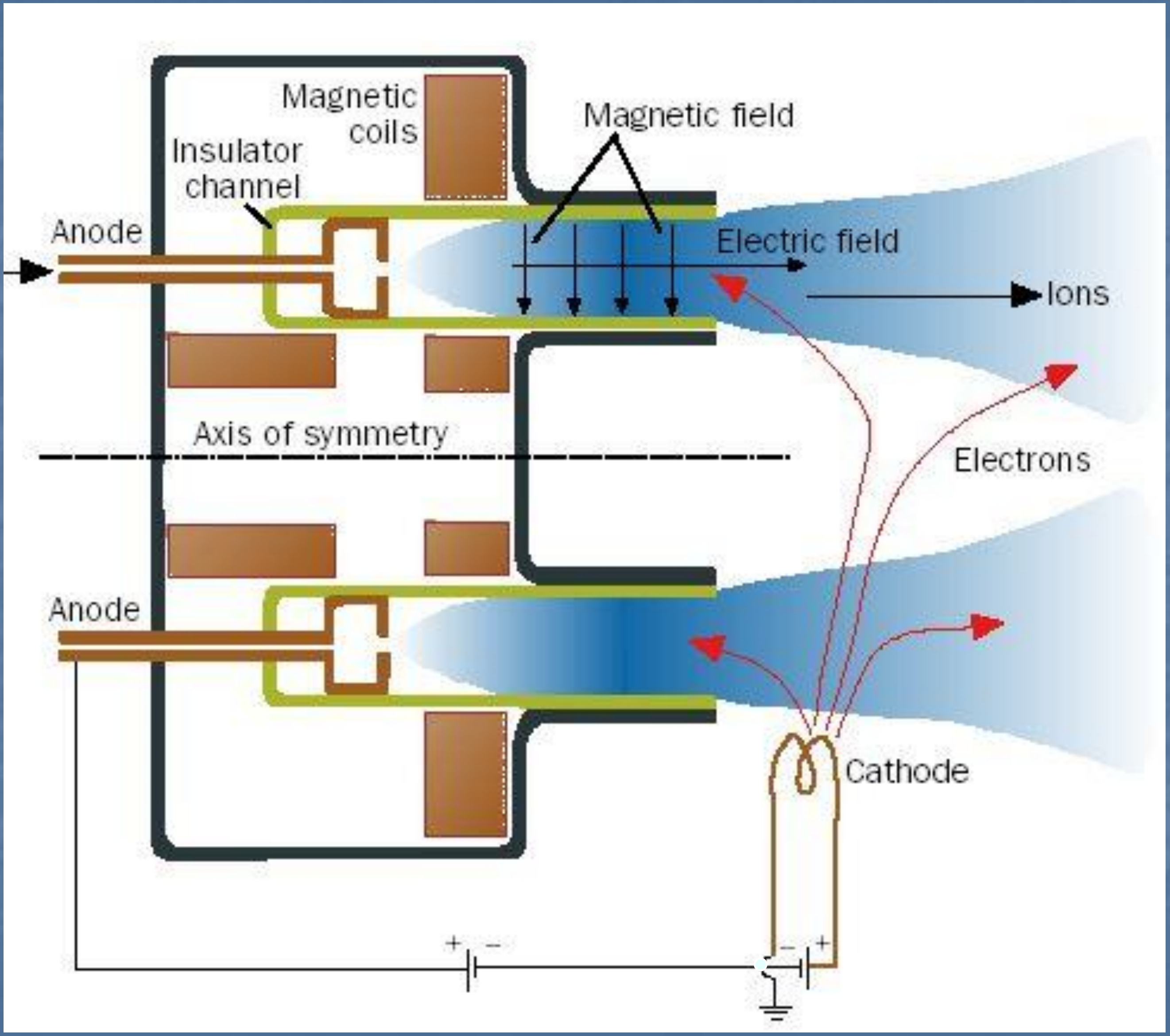
NASA's Evolutionary Xenon Thruster (NEXT) at NASA's JPL

Hall Thruster



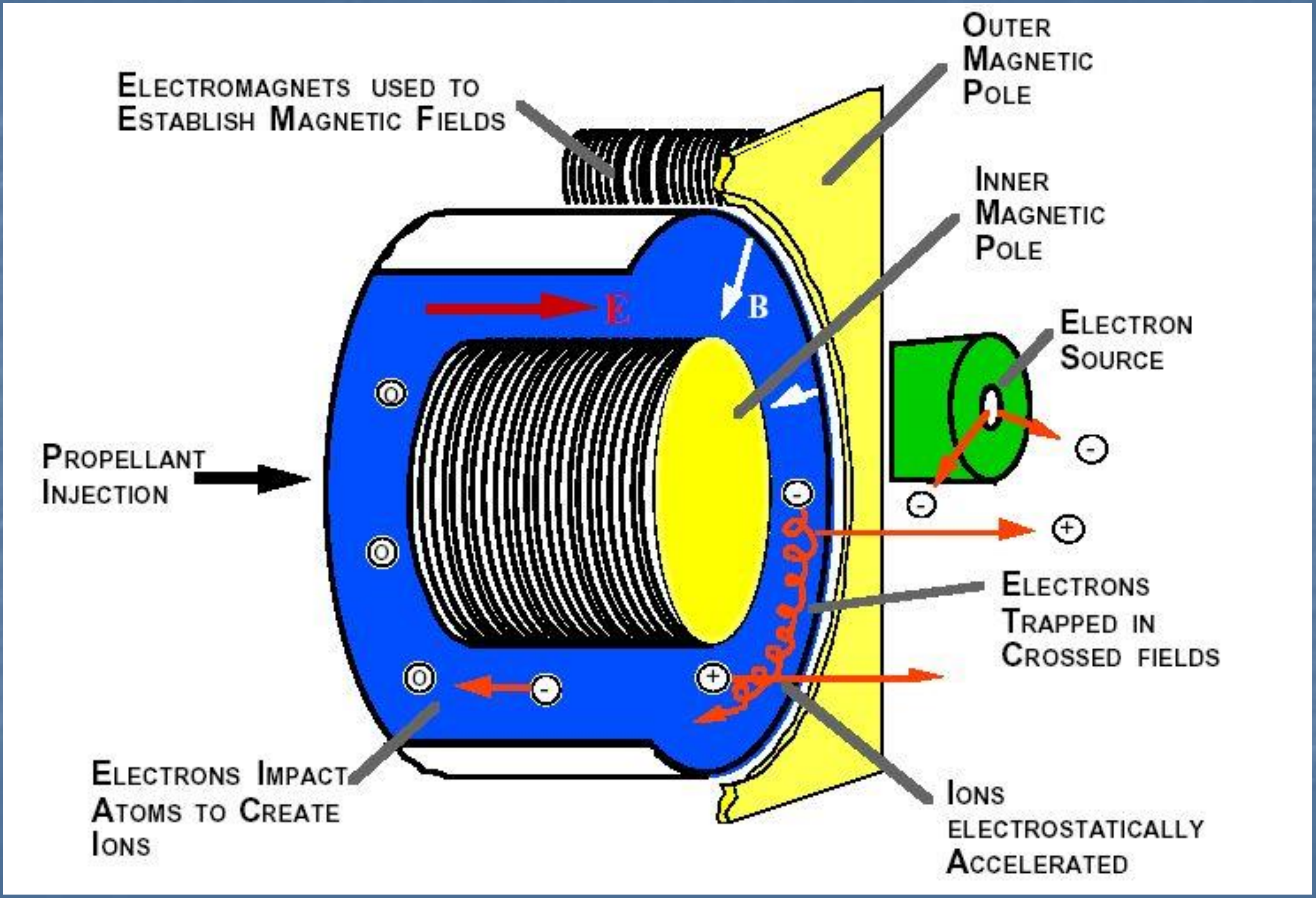
The Hall effect

Hall Thruster (II)



The Hall thruster scheme

Hall Thruster (III)



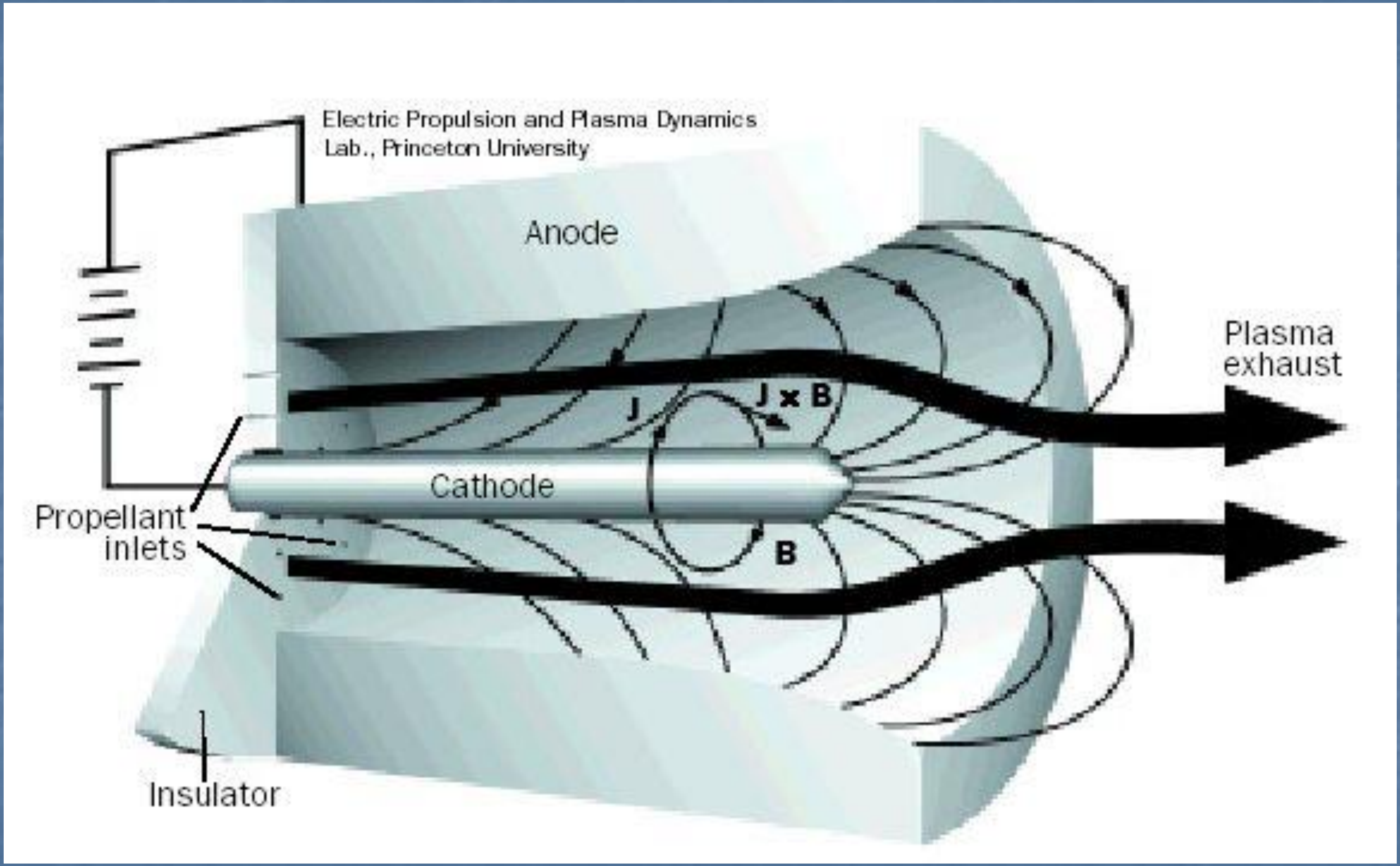
The Hall thruster: the Hall effect confines electrons

Hall Thruster (III)

Characteristic	HiVHAC
Thruster Power Range, kW	0.3 - 3.6
Throttle Ratio	12:1
Operating Voltage, V	200 – 700
Specific Impulse, s	1000 – 2800
Thrust, mN	24 – 150
Thruster Alpha, kg/kW	1.5
Propellant Throughput, kg	300

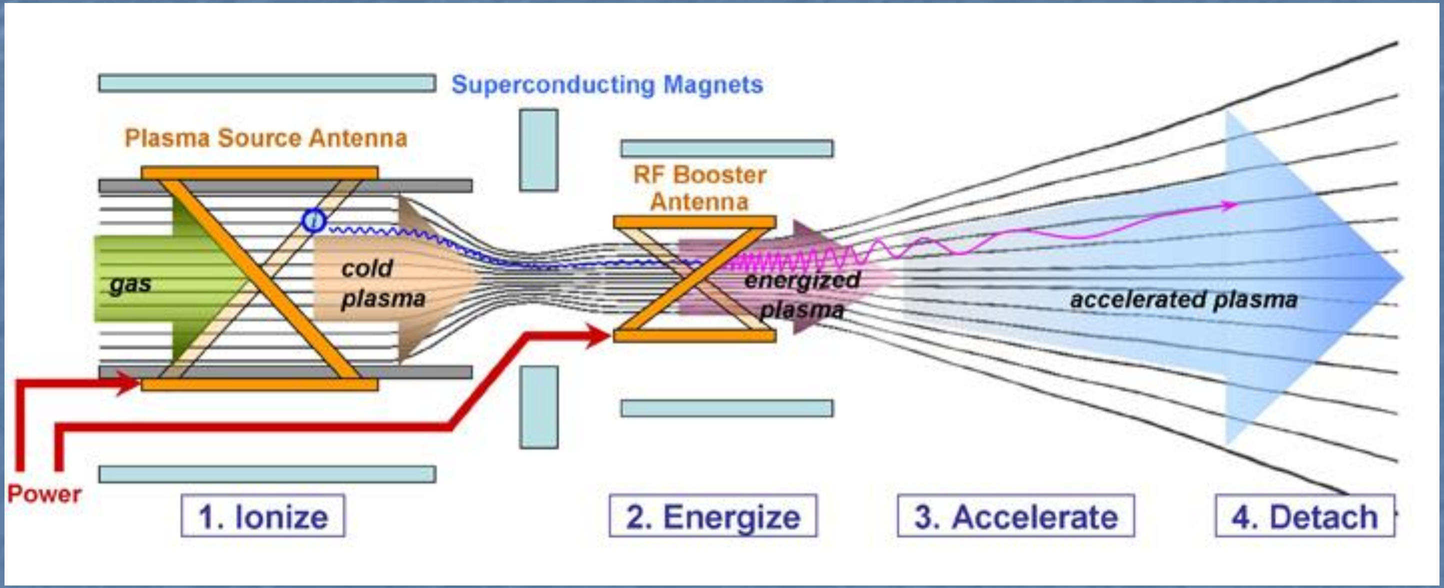
High Voltage Hall Accelerator (HiVHAC) Thruster - Hall Thruster (NASA Glenn R.C.)

MagnetoPlasma Dynamic Thruster



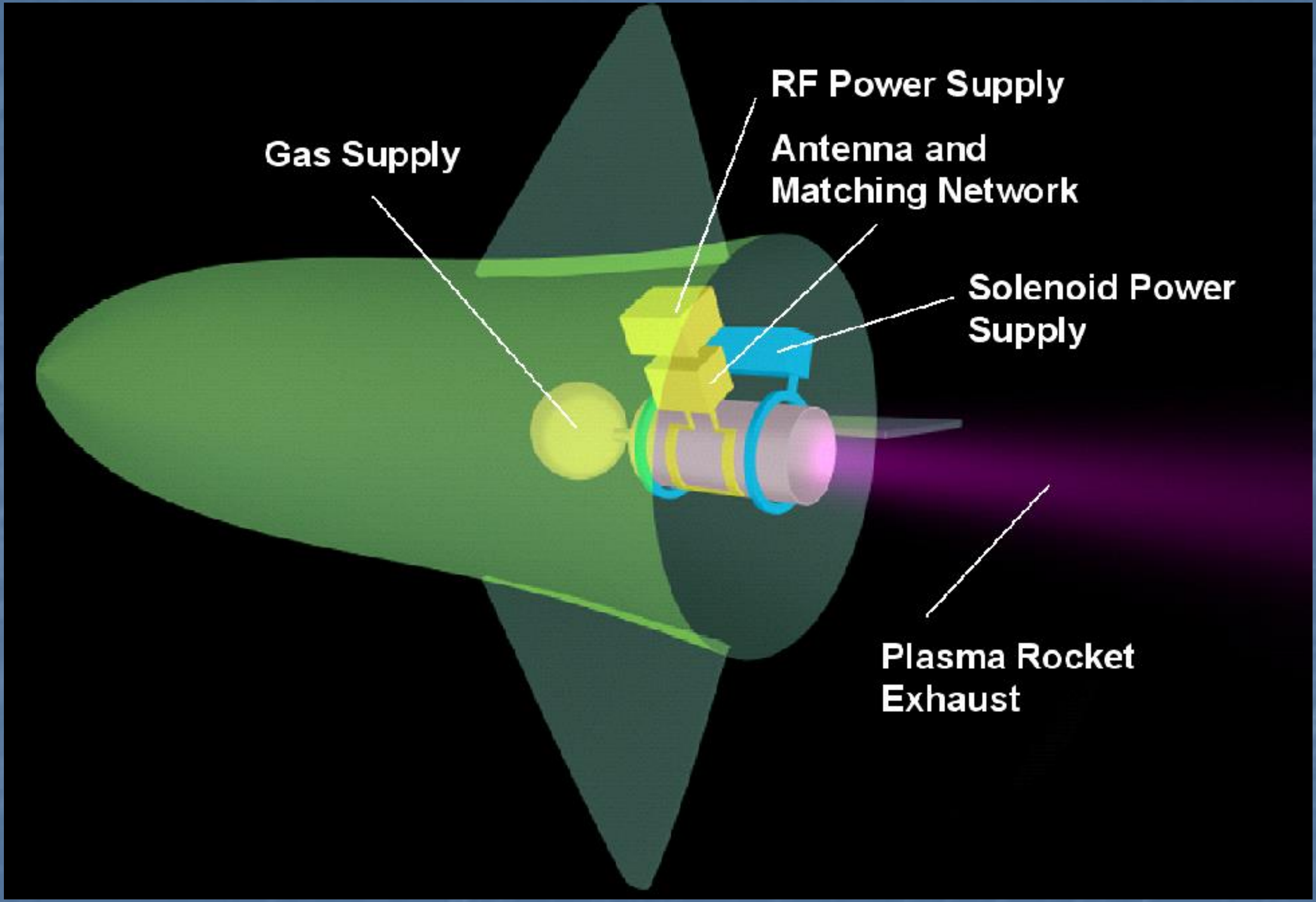
The MPD thruster

MagnetoPlasma Acceleration



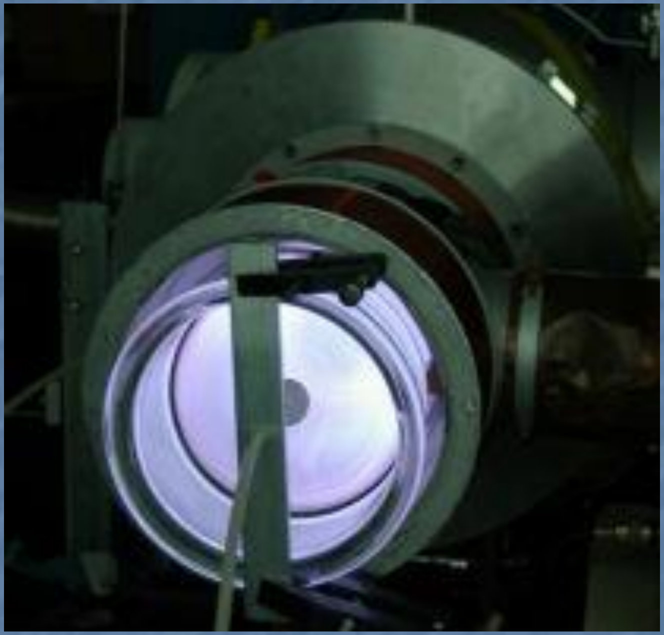
The VASIMR ® concept (Ad Astra Rocket Co.)

Helicon Double Layer Thruster Experiment



Artists rendering of a Helicon Double Layer Thruster concept (Australian National University)

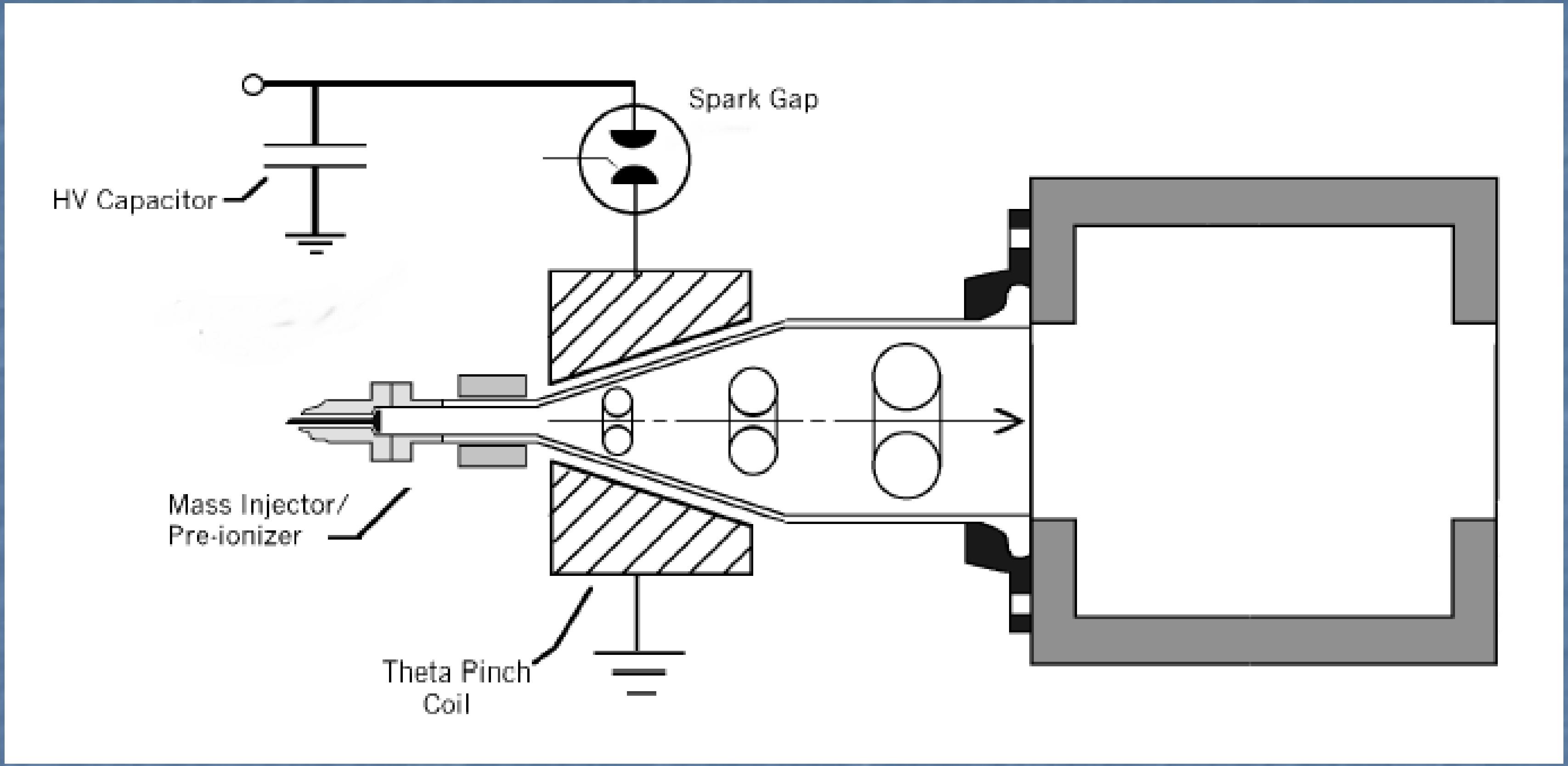
Helicon Double Layer Thruster Experiment



2003 Helicon Double Layer Thruster Experiment (Australian National University)

2005 Helicon Double Layer Thruster Experiment (European Space Agency, EPFL, Switzerland)

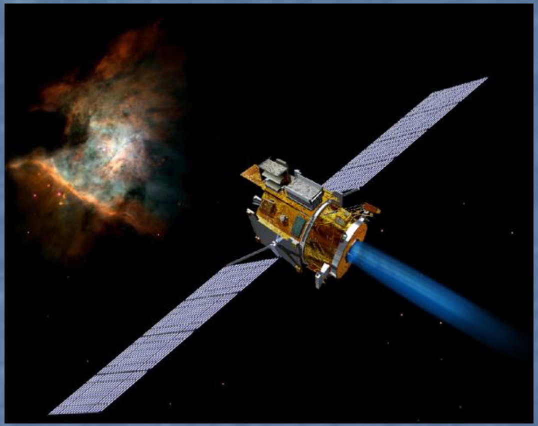
Plasmoid Thruster Experiment (PTX)



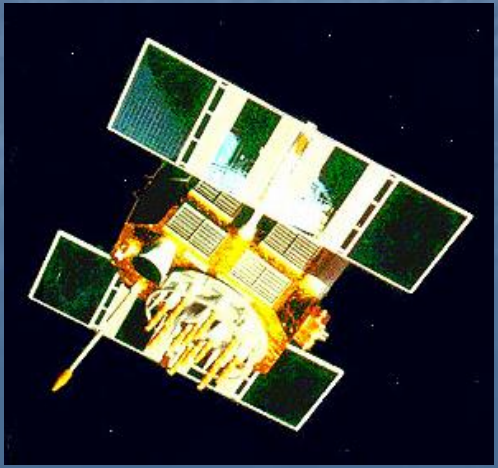
PTX Schematic (NASA MSFC/U. Alabama)

Electric Propulsion Applications

1. *ISS*



2. *Interplanetary Missions*



3. *Commercial/Defense*

Example: ISS Electric Propulsion Boosting

- ISS meeds drag compensation
- Currently ISS is "reboosted" periodically
- Presently Shuttle (or Soyuz) perform this operation
- Very high cost: 9000 lbs/yr propellant at $5,000/lbs = 45M$/yr!