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Title: A Microwave Thruster for Spacecraft Propulsion

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Intended for: This will be a presentation to high school students in the civil air patrol about spacecraft propuls

Abstract

This presentation describes how a microwave thruster can be used for spacecraft propulsion. A microwave thruster is part of a larger class of electric propulsion devices that have higher specific impulse and lower thrust than conventional chemical rocket engines. Examples of electric propulsion devices are given in this presentation and it is shown how these devices have been used to accomplish two recent space missions. The microwave thruster is then described and it is explained how the thrust and specific impulse of the thruster can be measured. Calculations of the gas temperature and plasma properties in the microwave thruster are discussed. In addition a potential mission for the microwave thruster involving the orbit raising of a space station is explored.

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A Microwave Thruster for Spacecraft Propulsion

Vincent Chiravalle

Los Alamos National Laboratory

Outline

- Chemical rocket engines in use today
- Characteristics and benefits of electric propulsion
- Recent space missions using electric propulsion
- The microwave thruster
- Experiments and computer models of the microwave thruster

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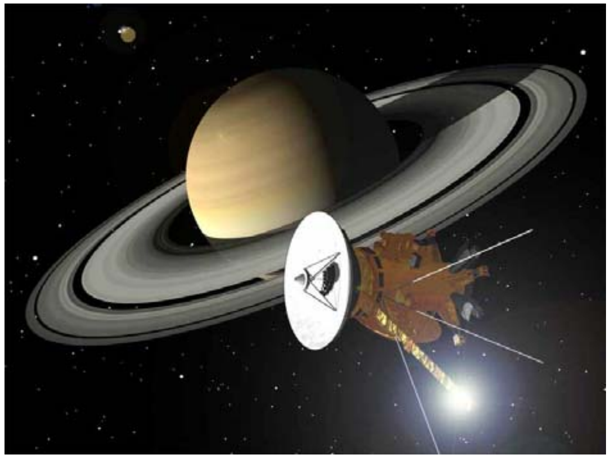
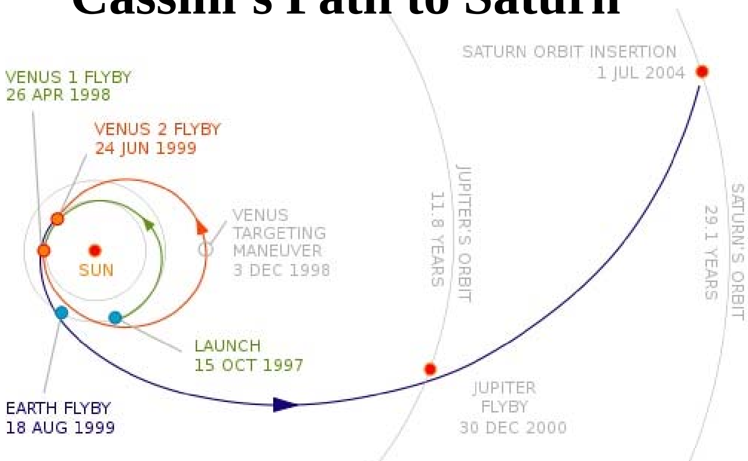
Cassini Spacecraft Entered Orbit around Saturn in 2004 using Chemical Rocket Engines



Cassini before Launch

Cassini has two engines which use about 3000 kg of fuel during the mission

Cassini's Path to Saturn



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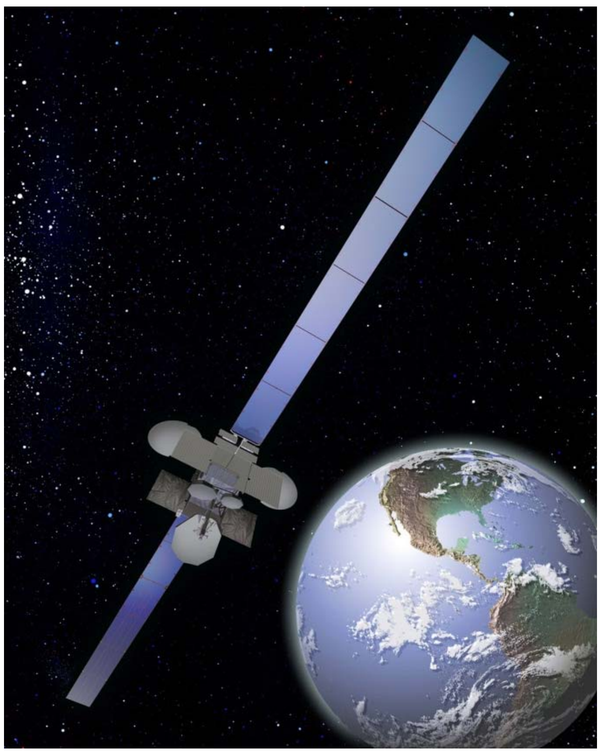
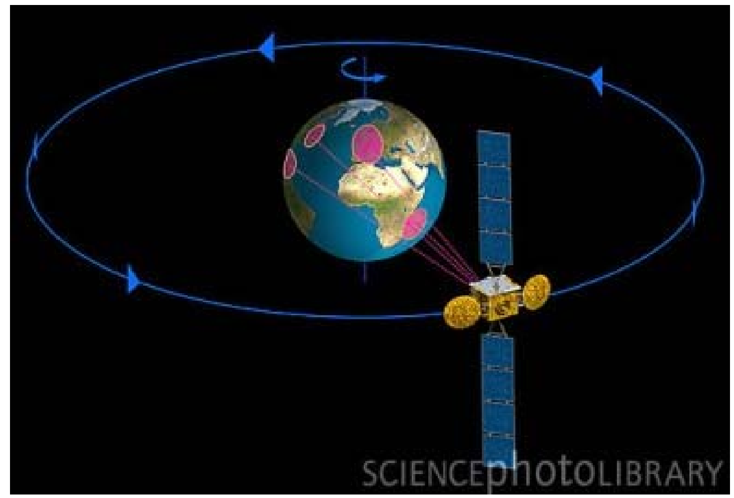
Communications Satellites use Chemical Rockets to Enter Orbit around the Earth

The Boeing 702 Satellite has 6 communications antennas and 2 large solar panels that generate 15 kW of electricity



Communication satellites orbit in a circle about 36,000 km above the Earth (GEO)



The Boeing 702 Satellite weighs about 3700 kg after entering orbit and it has a single chemical engine that burns about 2200 kg of fuel in order to place it in the correct circular orbit

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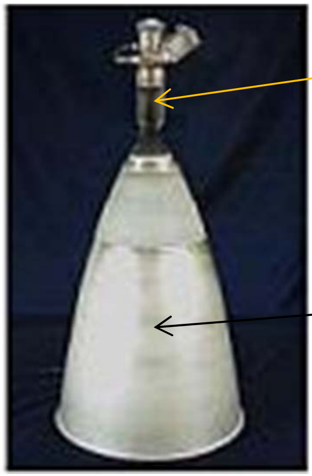
Both Cassini and the 702 Satellite use a Chemical Rocket Engine that generates about 100 lb of thrust

A Chemical Rocket Engine

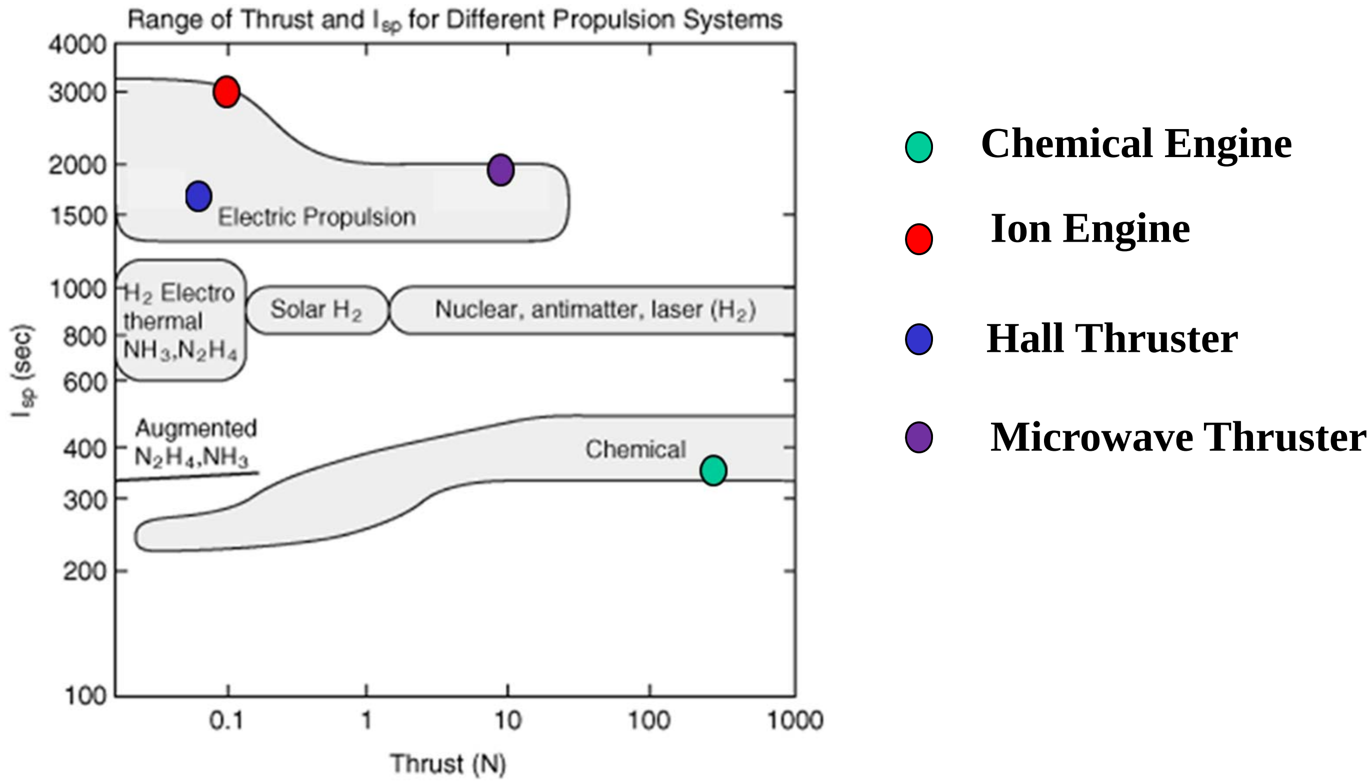
Characteristics

Unfuelled mass: **5.20 kg (11.40 lb)**
Height: **0.72 m (2.36 ft)**
Diameter: **0.36 m (1.19 ft)**
Thrust: **445 N (100 lb)**
Specific impulse: **323 s**



Specific impulse is a way of describing how fast the exhaust gas leaves the nozzle

Electric Propulsion Engines have a Higher Specific Impulse and a Lower Thrust than Chemical Engines



Spacecraft without electric engines have thrust levels of 100-500 N with a specific impulse that is less than 450 s

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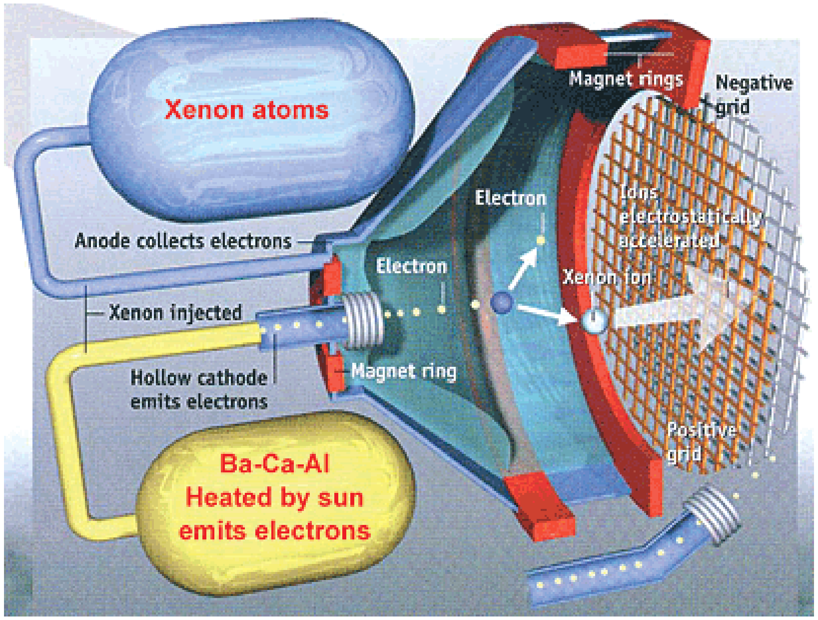
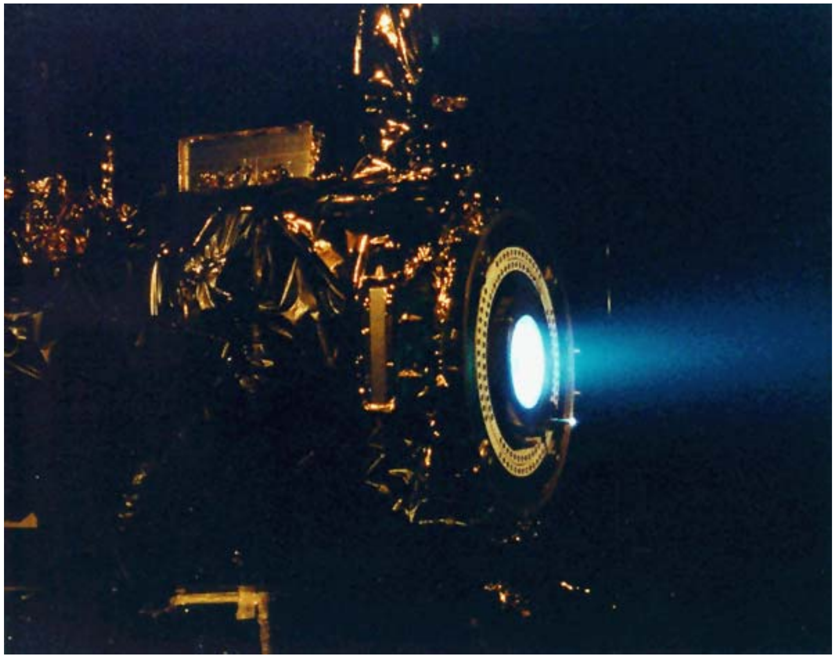
An Ion Engine Accelerates Xenon Ions using Two Electric Grids

Ion Engine Diagram showing the Acceleration Grids

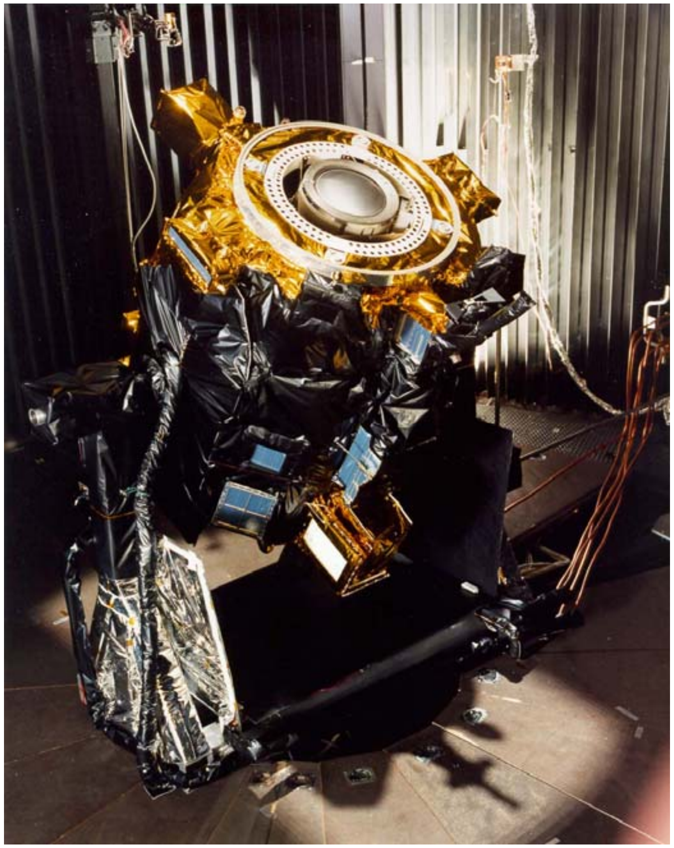


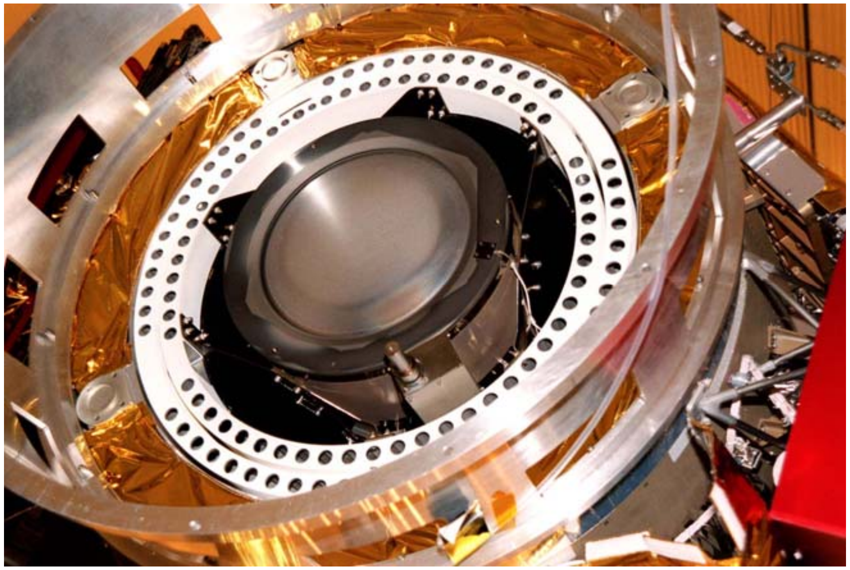
An Ion Engine firing with a Blue Exhaust Jet



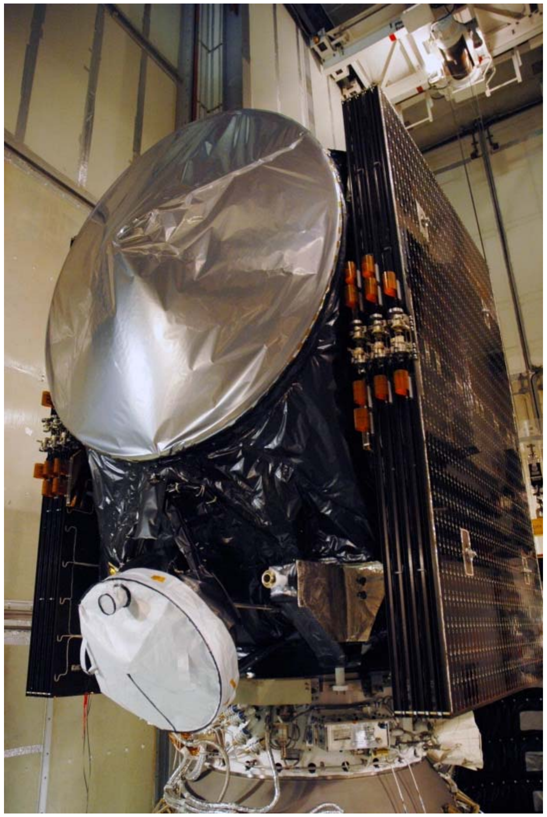
Pictures of the NSTAR Ion Engine setup for Ground Testing

The thin electric grids appear as the gray discs in the photos





The Dawn Spacecraft is using Ion Engines to explore Two Asteroids



Discharge Power: 2.3 kW
Specific Impulse: 3100 s
Thrust: 90 mN
Xenon: 385 kg

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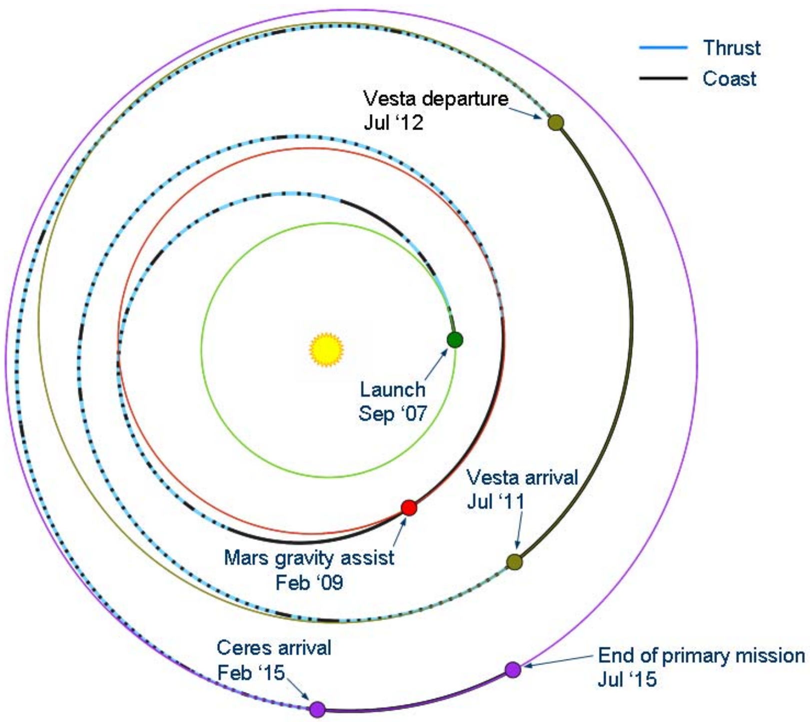
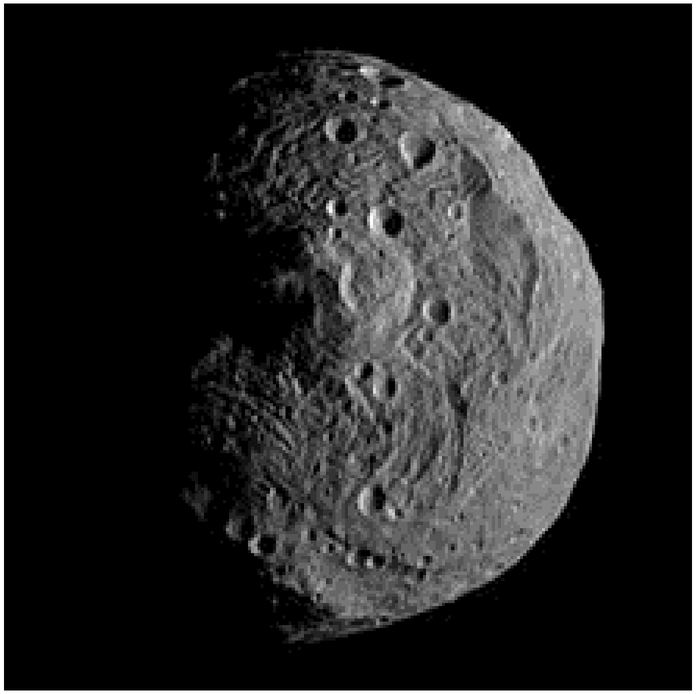
Dawn traveled to the Asteroid Vesta using a Long Spiral Path



Picture of Vesta taken from the Dawn Spacecraft



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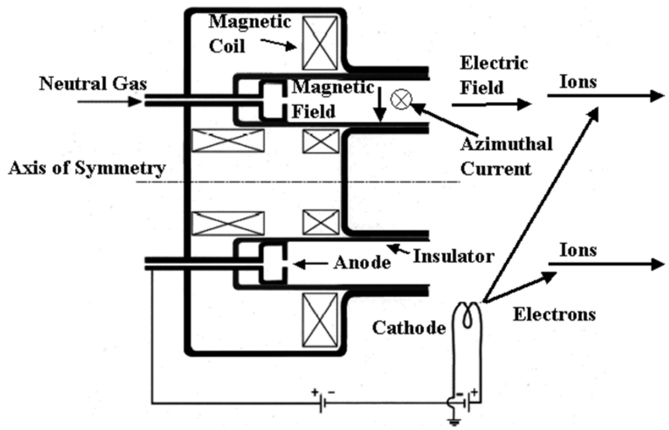
A Hall Thruster Accelerates Xenon Ions without Electric Grids



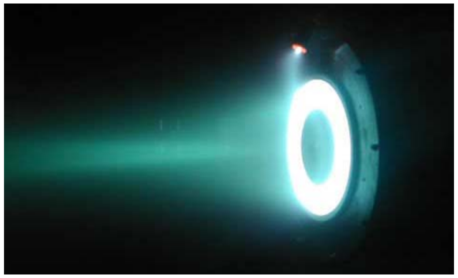
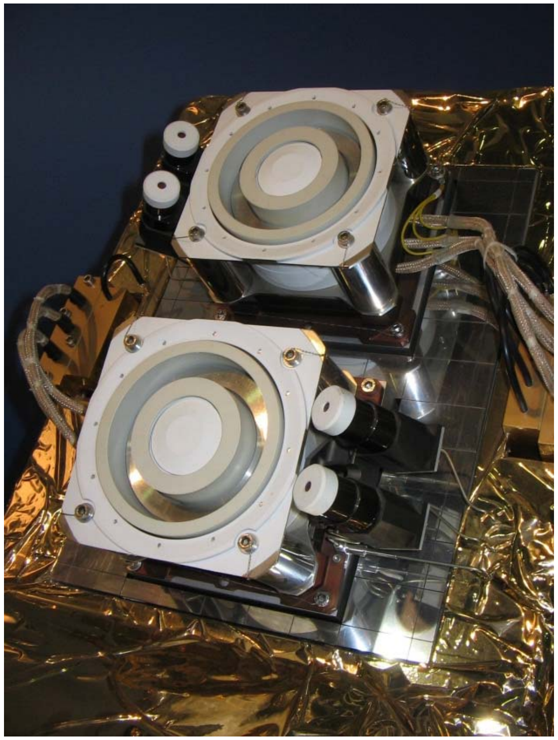
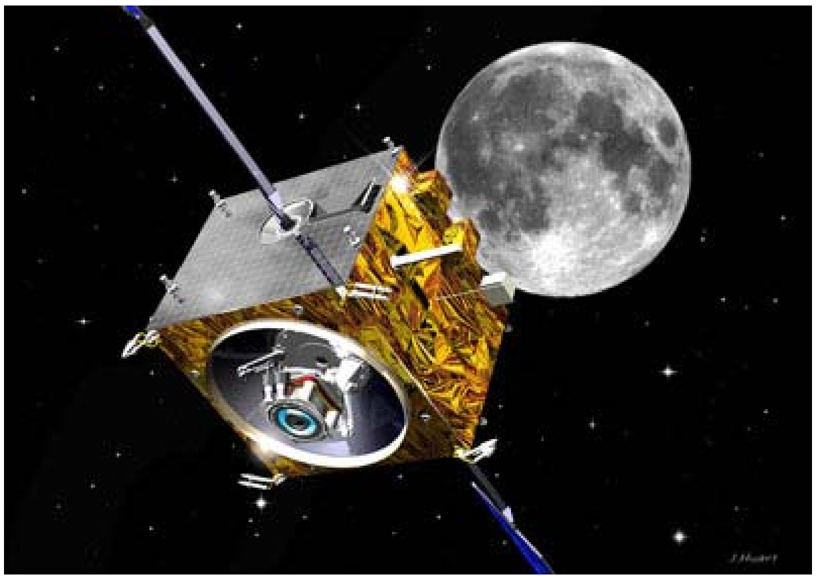


Photo of a Pair of Hall Thrusters

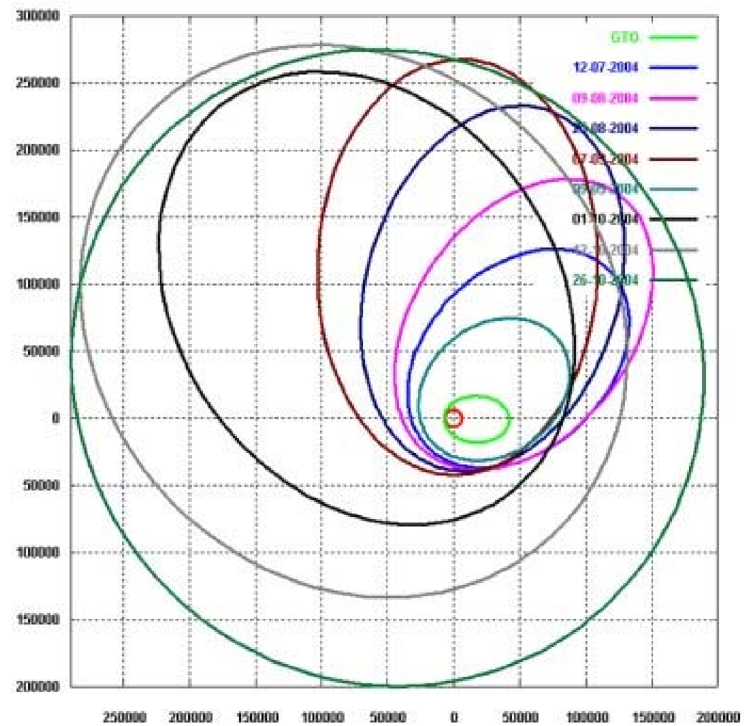


The SMART-1 Spacecraft used a Hall Thruster to travel to the Moon

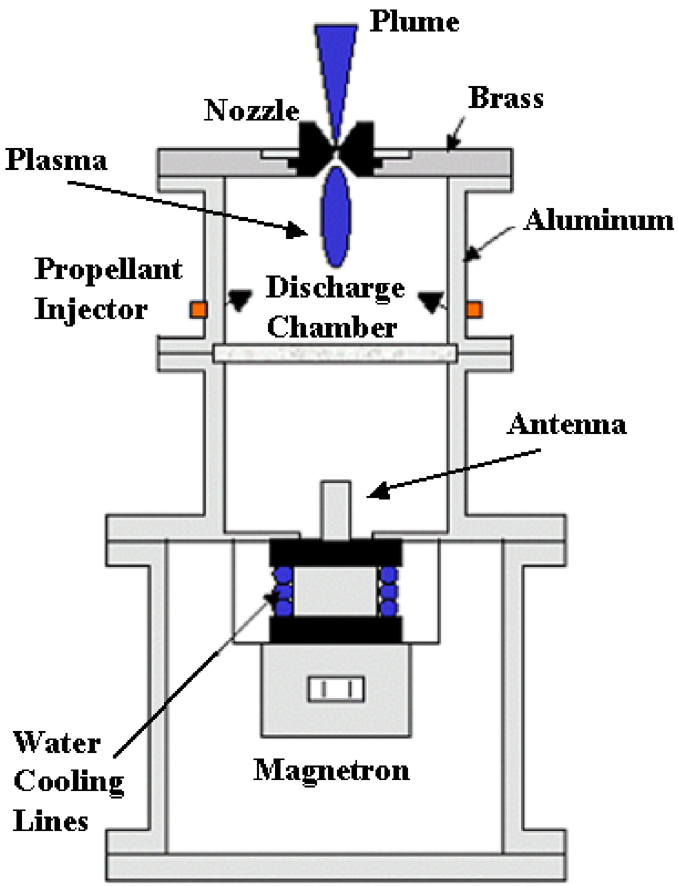


Discharge Power: 1.19 kW
Specific Impulse: 1600 s
Thrust: 70 mN
Xenon: 82 kg

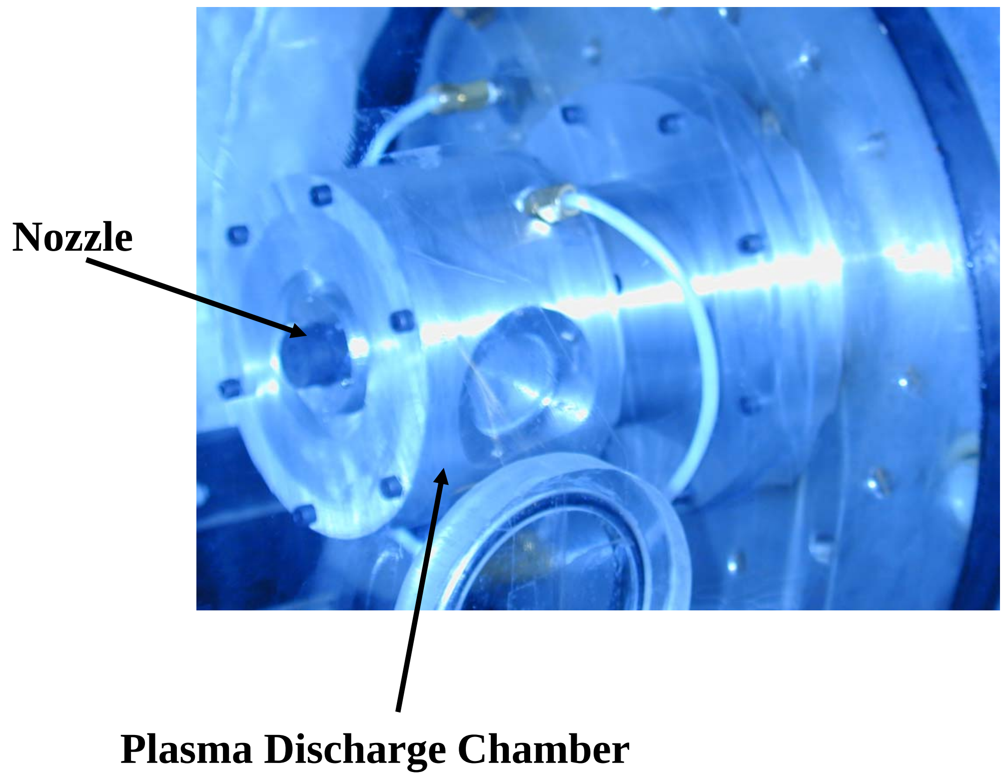
Complicated Path of the SMART-1



A Microwave Electrothermal Thruster (MET) uses Microwave Energy to Generate Thrust



Picture of a Microwave Thruster inside a Glass Vacuum Chamber



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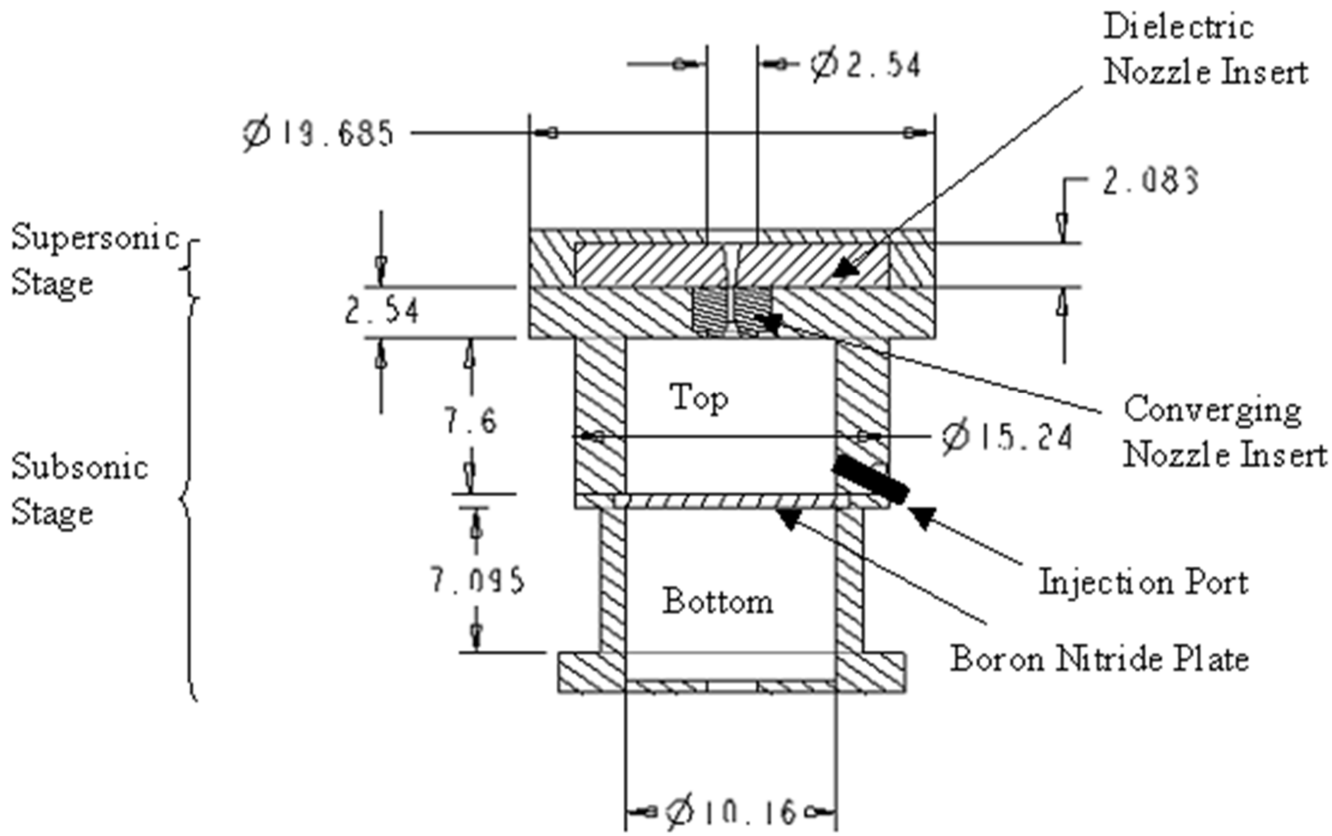
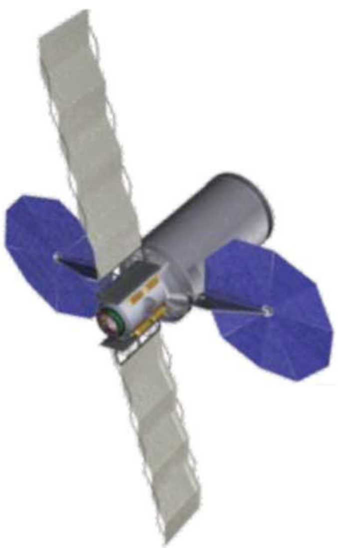
A Microwave Thruster has been developed with Two Plasma Discharge Cavities

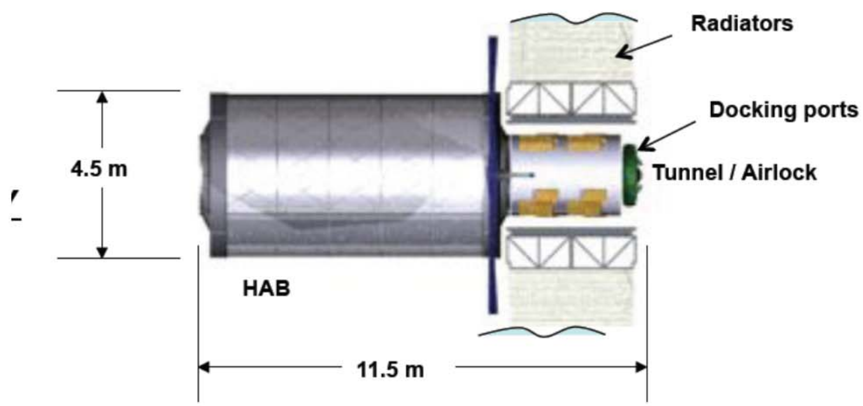


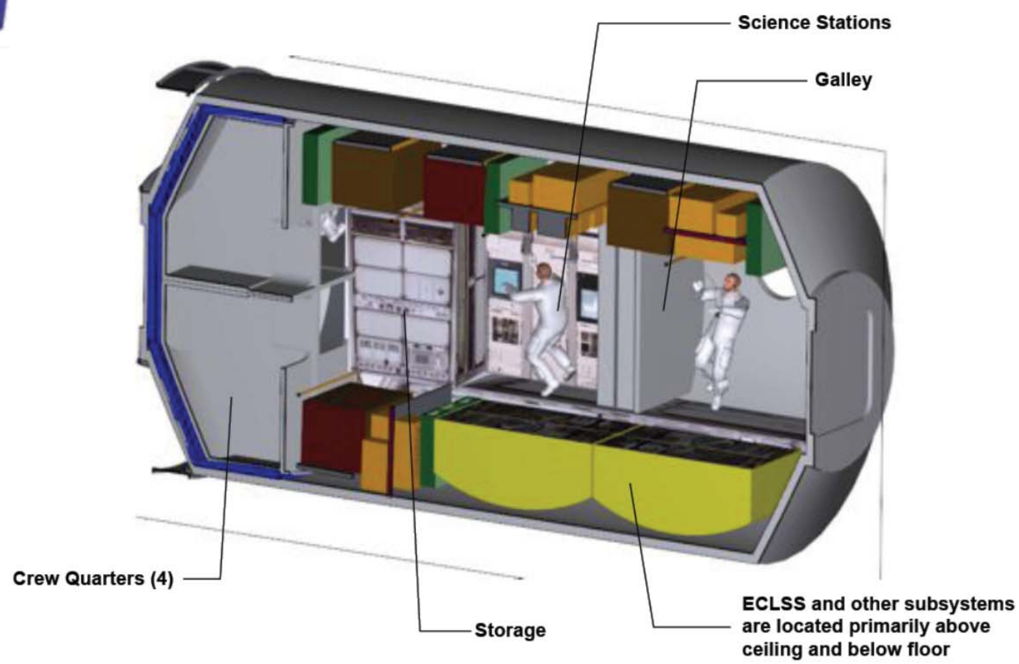
All dimensions are in centimeters

A Deep Space Habitat could house People for GEO Satellite Repair Missions lasting up to 60 Days

A Deep Space Mobile Home that weighs about 28 tons







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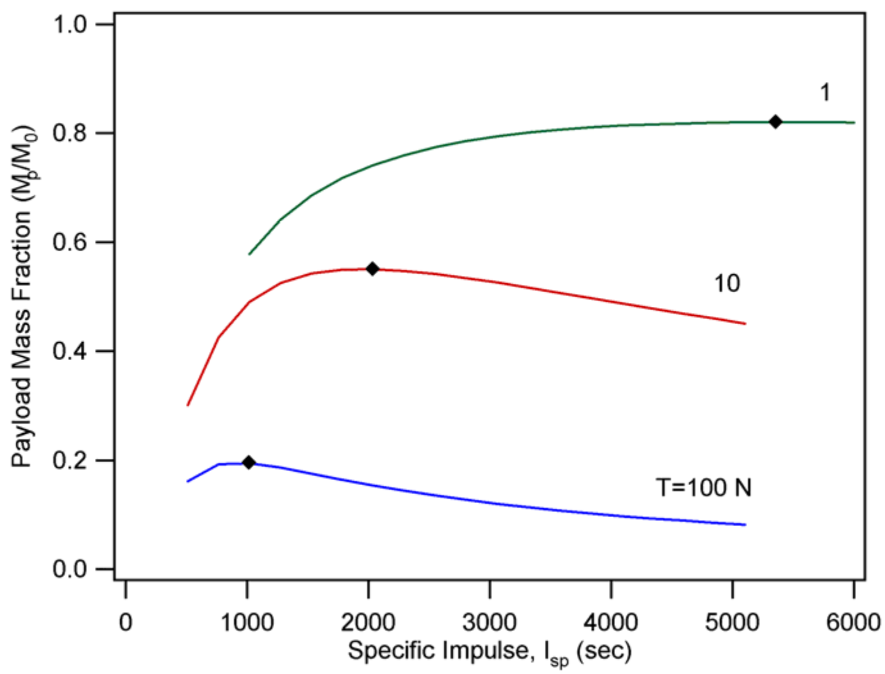
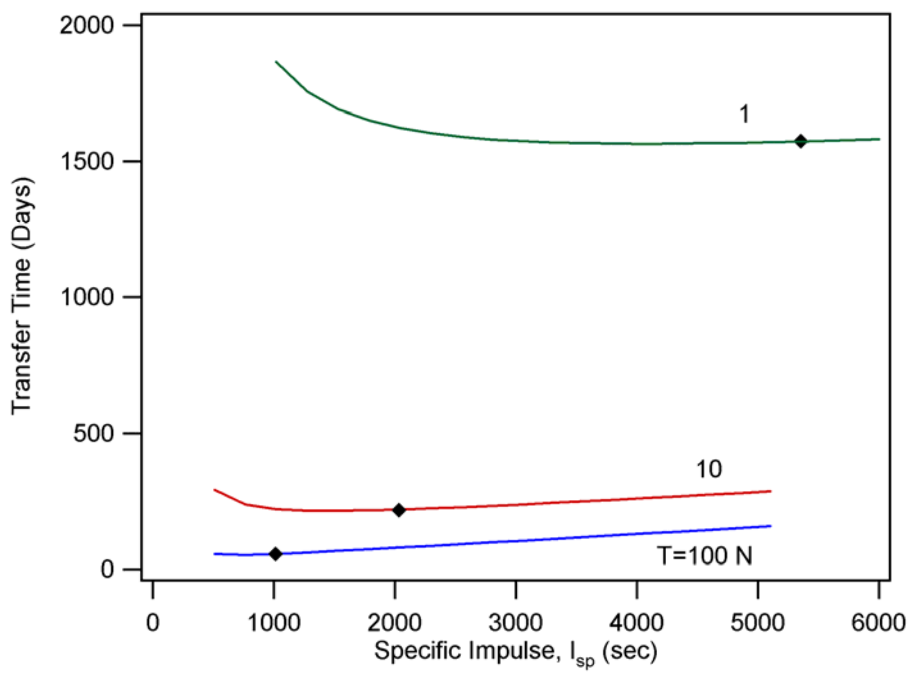
A Microwave Thruster operating at 100 kW and 10 N of thrust could move a Deep Space Habitat from LEO to GEO in about 215 days

Payload Amount vs. Specific Impulse for Different Engine Thrust Levels

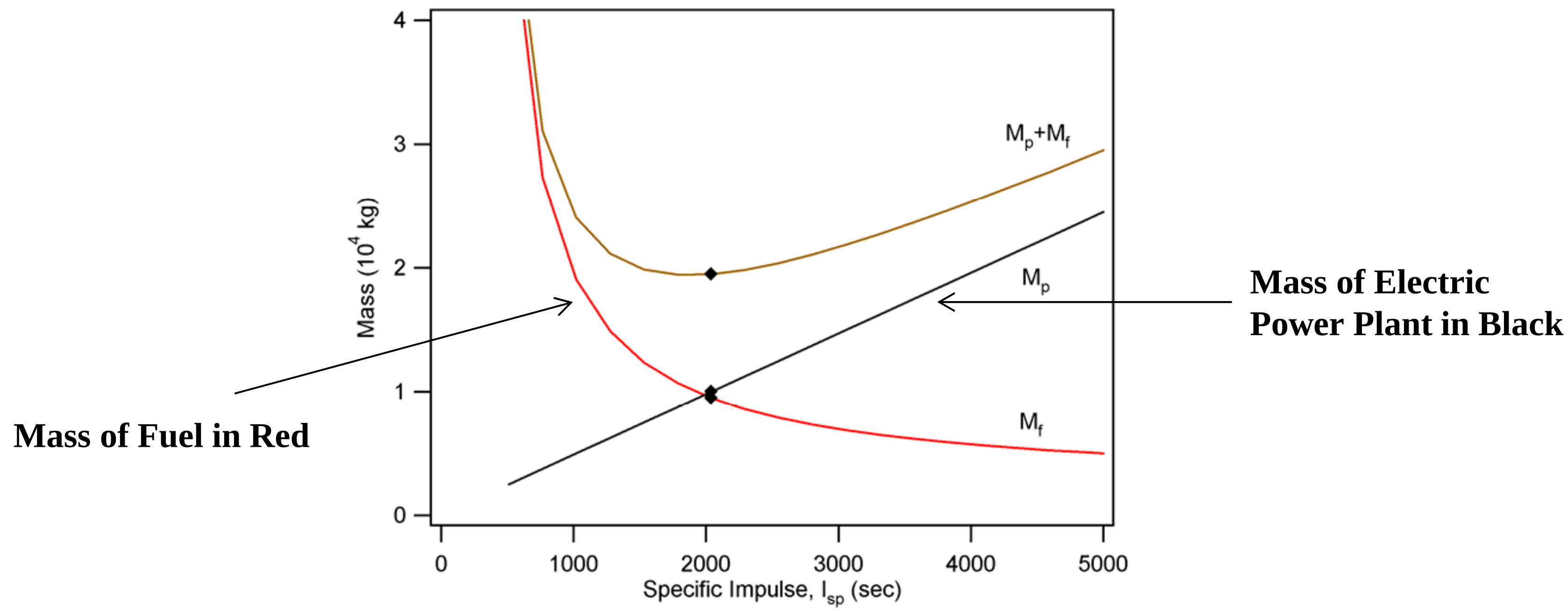


Transfer Time vs. Specific Impulse for Different Thrust Levels



Mass Breakdown for a 10 N Engine

Mass Variation of Power Supply and Fuel vs. Specific Impulse for 10 N



An Engine with 2000 s specific impulse is the best choice for moving between LEO and GEO

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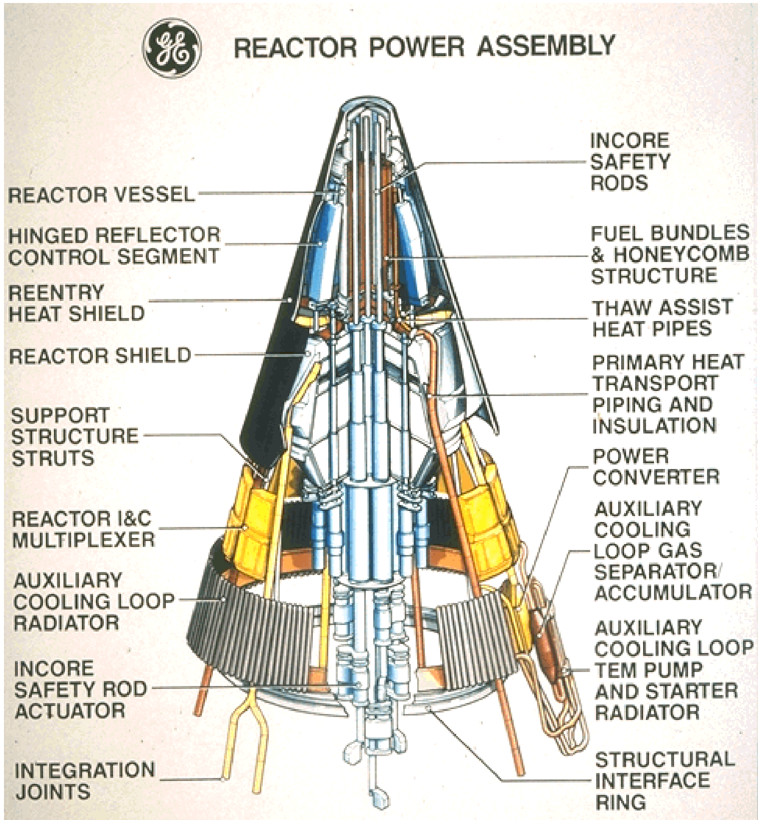
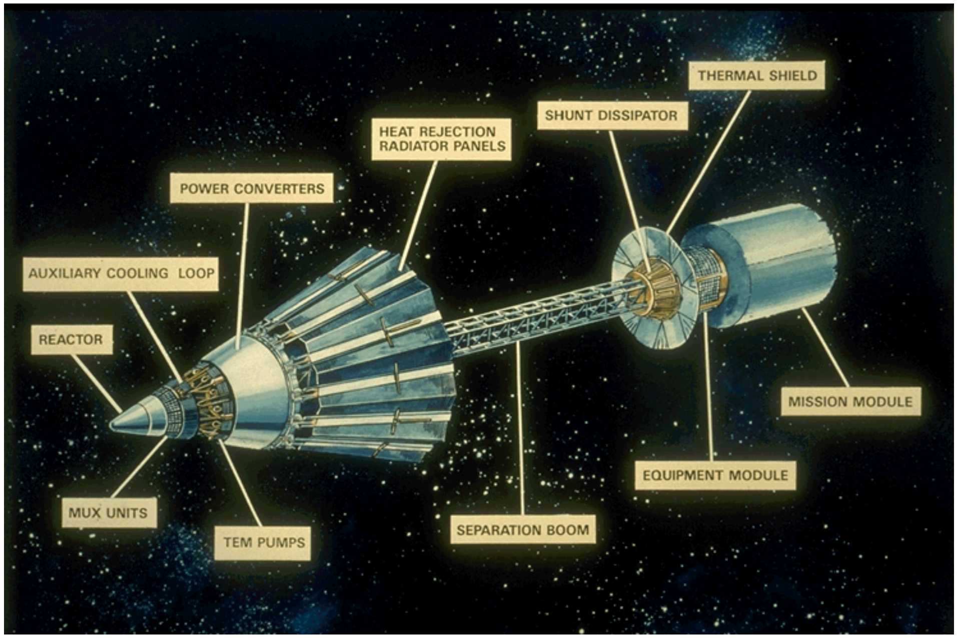
SP-100 Space Nuclear Reactor was designed to produce 100 kW for 7 Years

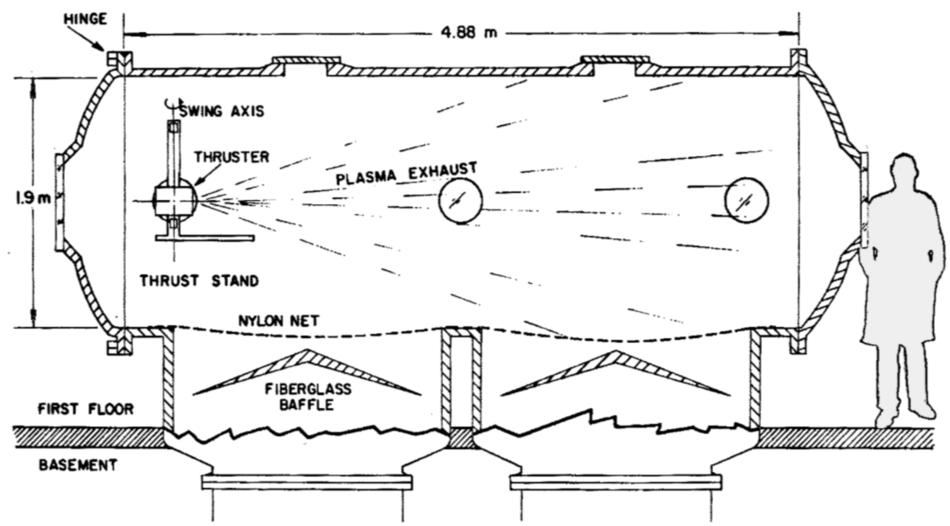


Nuclear powered spacecraft with the reactor separated from the payload with a long boom



A Large Vacuum Chamber is used to test Electric Thrusters on the Ground

Large Dielectric Vacuum Facility



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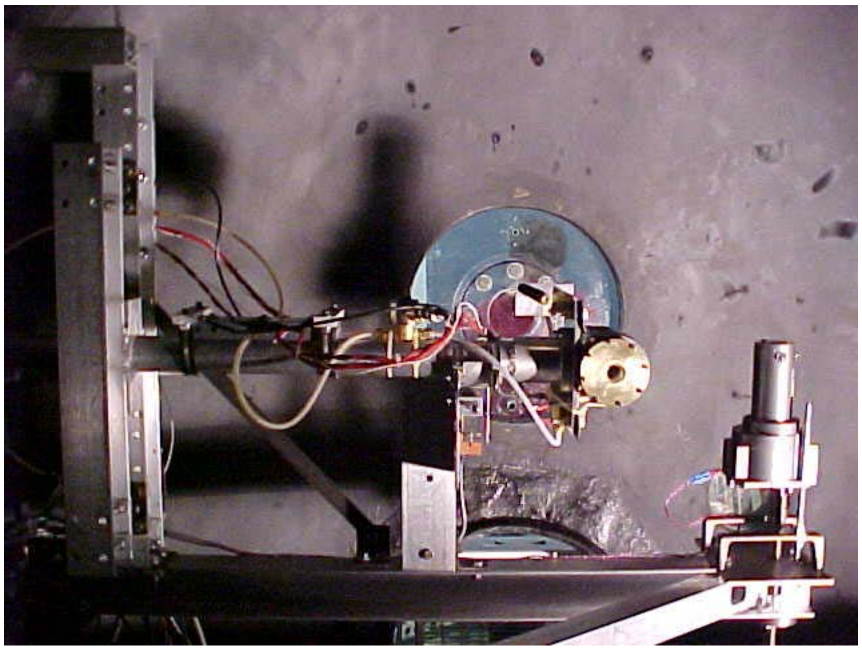
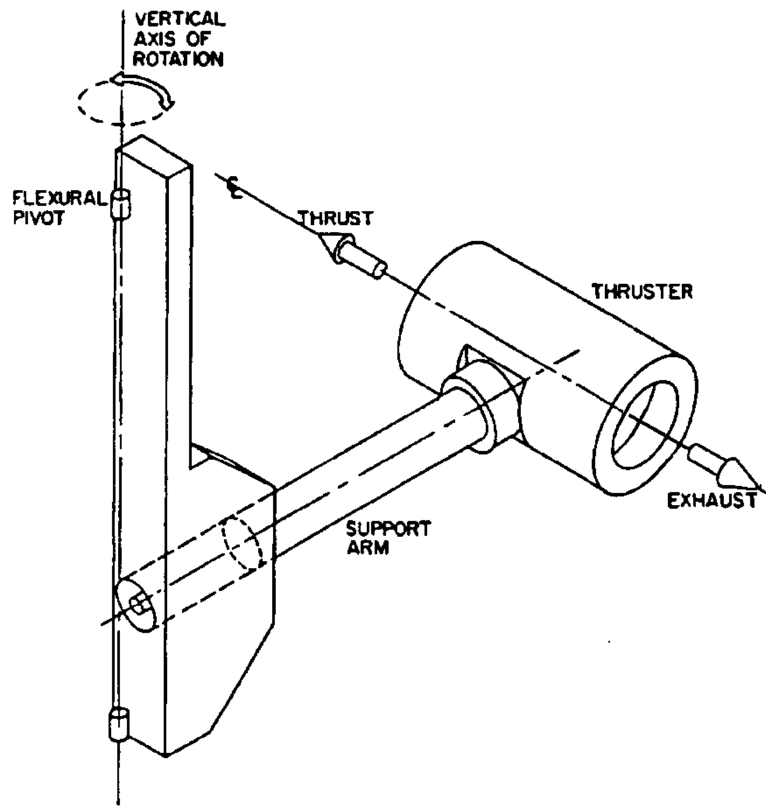
Thrust and Specific Impulse Measurements are performed with a Rotating Arm

Thrust Stand in a Large Dielectric Vacuum Tank



Schematic of Thrust Stand

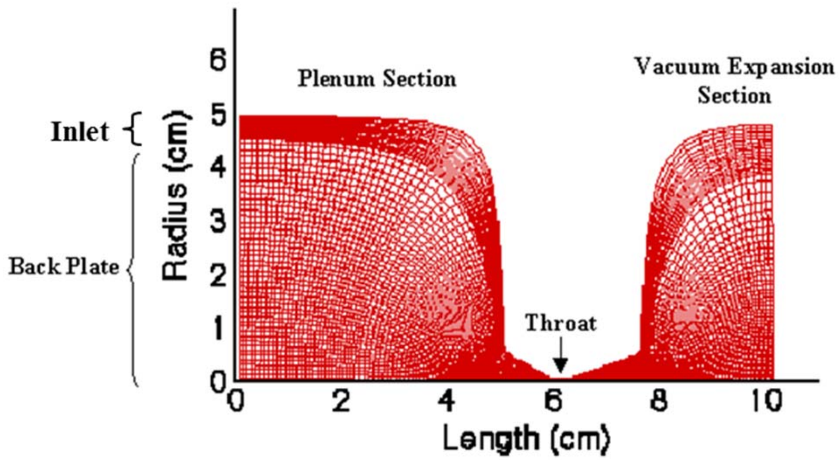


A Computer Model was developed to study how the Microwave Thruster Works

Conditions

- Propellant Gas: Helium
- Inlet Mass Flow is Fixed at 100 mg/sec
- Inlet Temperature in Plenum: 300 K
- Plenum Wall Temperature is Fixed at 900 K
- Plenum Microwave Energy Addition: 1kW
- Microwave Frequency: 2.45 GHz
- No Supersonic Energy Addition

61 radial cells by 190 axial cells



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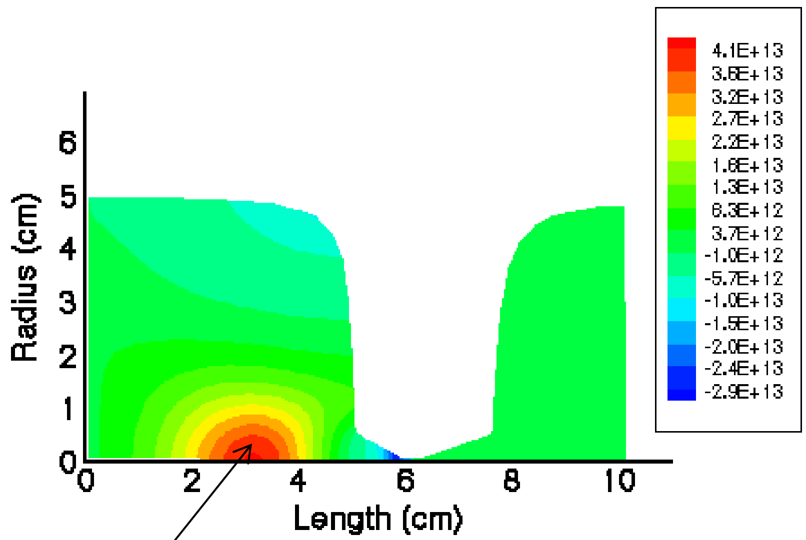
Plasma Location and Gas Velocity have been calculated for the Microwave Thruster

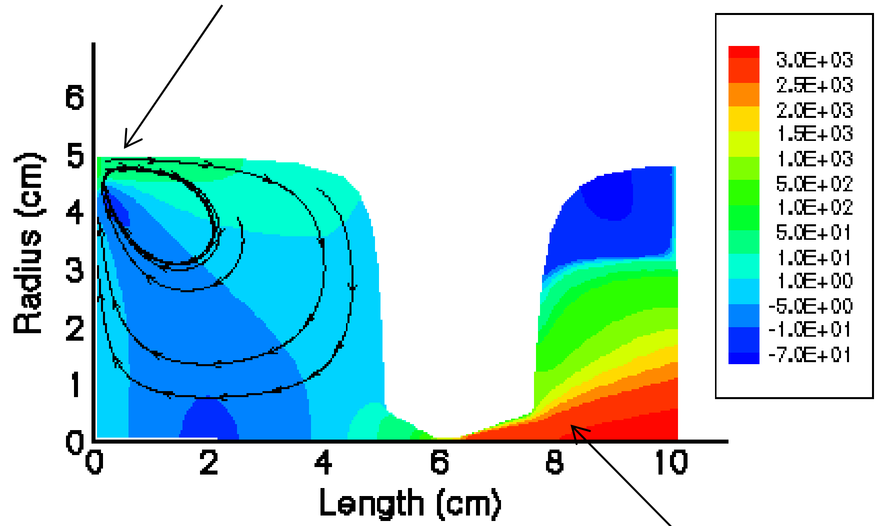
Net Electron Production Rate (cm^{-3} sec^{-1})



plasma

Axial Velocity (m/sec)

Gas Inlet



Exhaust Jet

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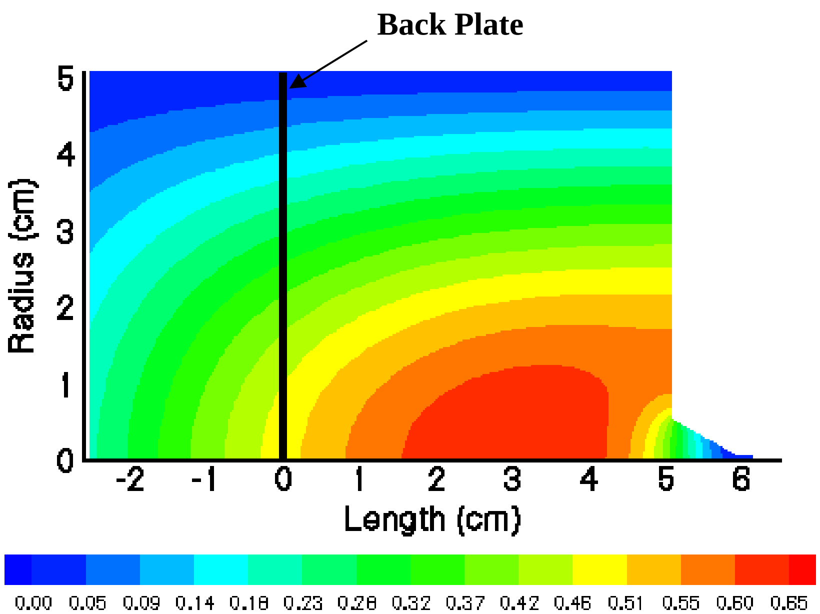
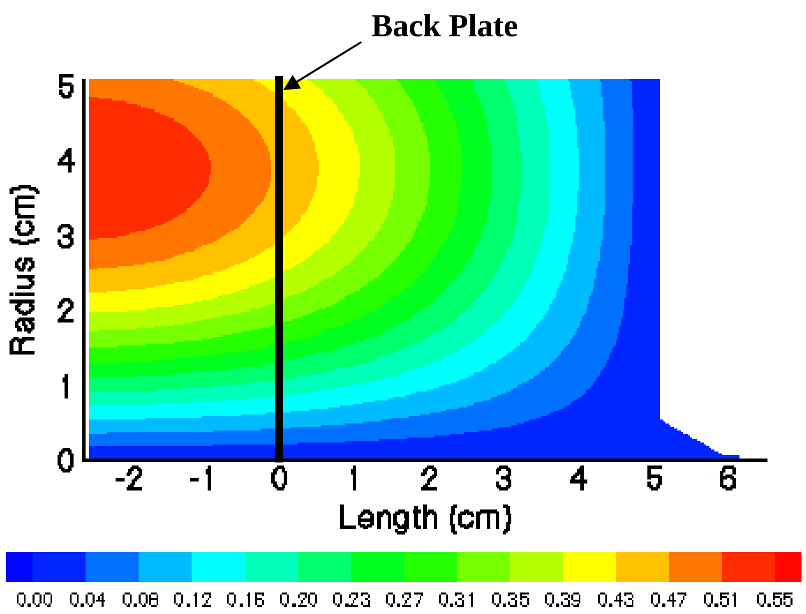
Electric Field Contours for the Microwave Thruster

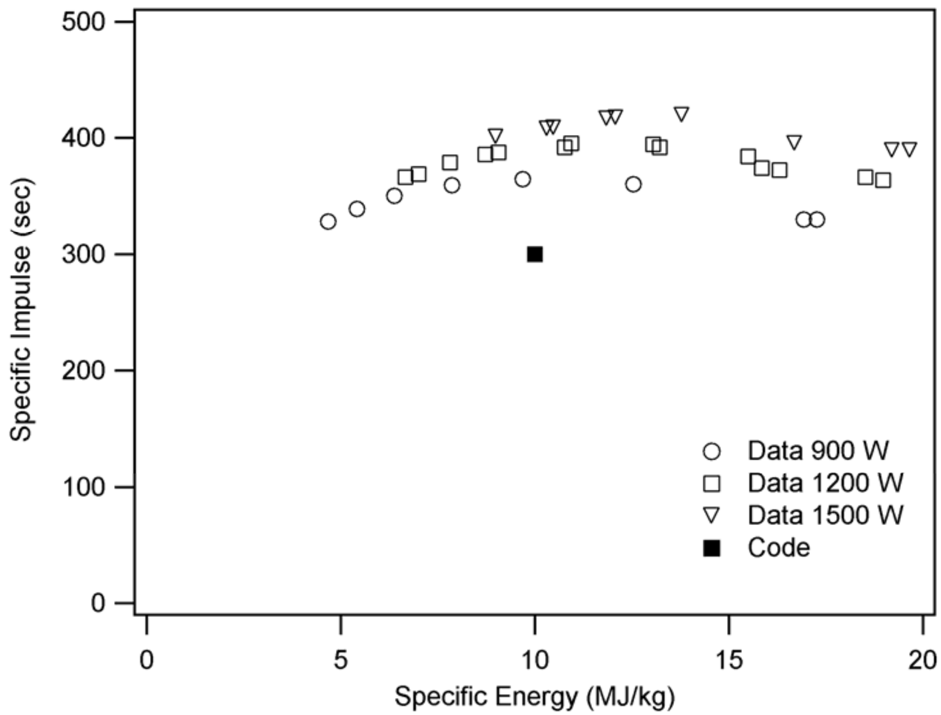
Axial Electric Field (kV/cm)



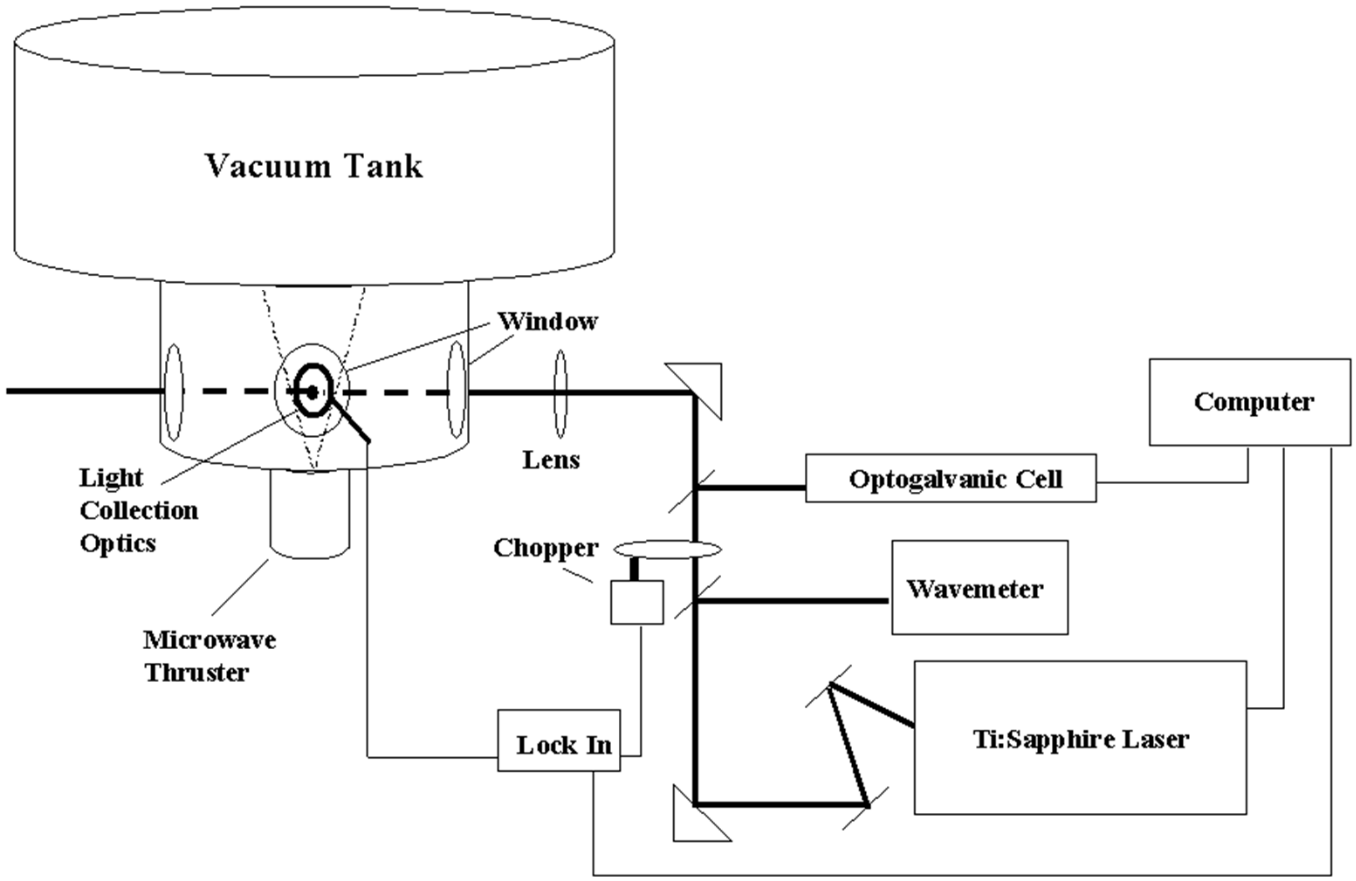
Radial Electric Field (kV/cm)



Comparison with Specific Impulse Measurements



The Velocity and Temperature of the Exhaust Jet in the Microwave Thruster can be measured using a Laser



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Laser Measurements were performed with the Microwave Thruster using Argon Gas

- Propellant Gas: Argon
- Mass Flow Rate: 570 mg/sec
- Pressure in the Plasma Chamber: 240 Torr
- Microwave Power: 900 W
- Exit Pressure in the Vacuum Tank: 2.5 Torr
- Laser focused on centerline, 7 mm from thruster exit

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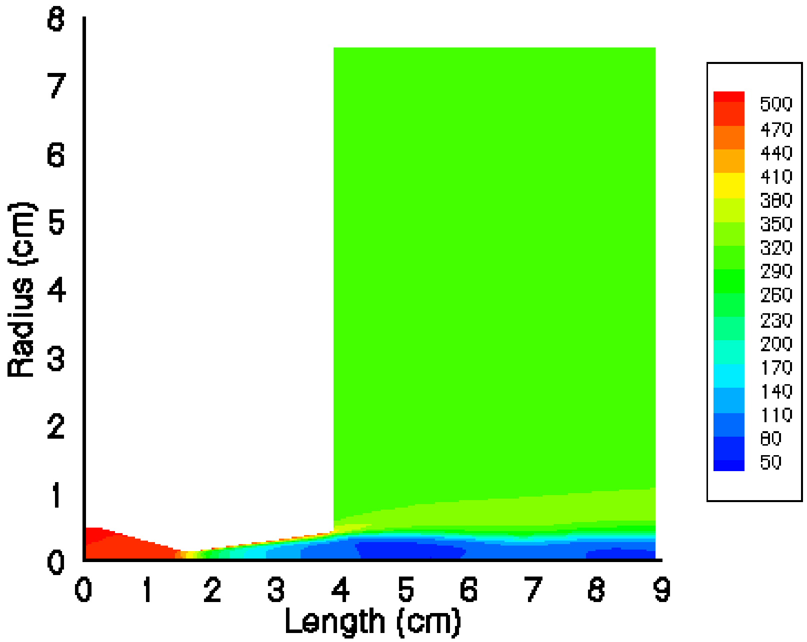
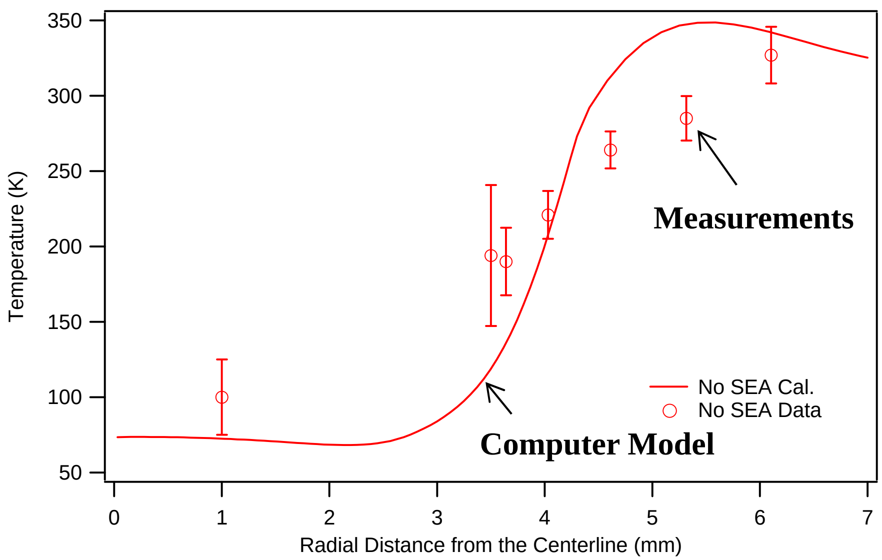
Temperature Profile in the Exhaust Jet

Calculated Temperature of the Exhaust Jet



Calculated and Measured Temperatures



Summary

- Chemical engines burn fuel and are used are to propel satellites and spacecraft
- Electric propulsion engines use electricity to make thrust and use less fuel than chemical engines
- Ion engines and Hall thrusters are two electric propulsion engines that have been used on recent space missions
- A microwave thruster uses microwave energy to create a plasma and produce a high speed exhaust jet
- The microwave thruster is suitable for raising the orbit of space station modules

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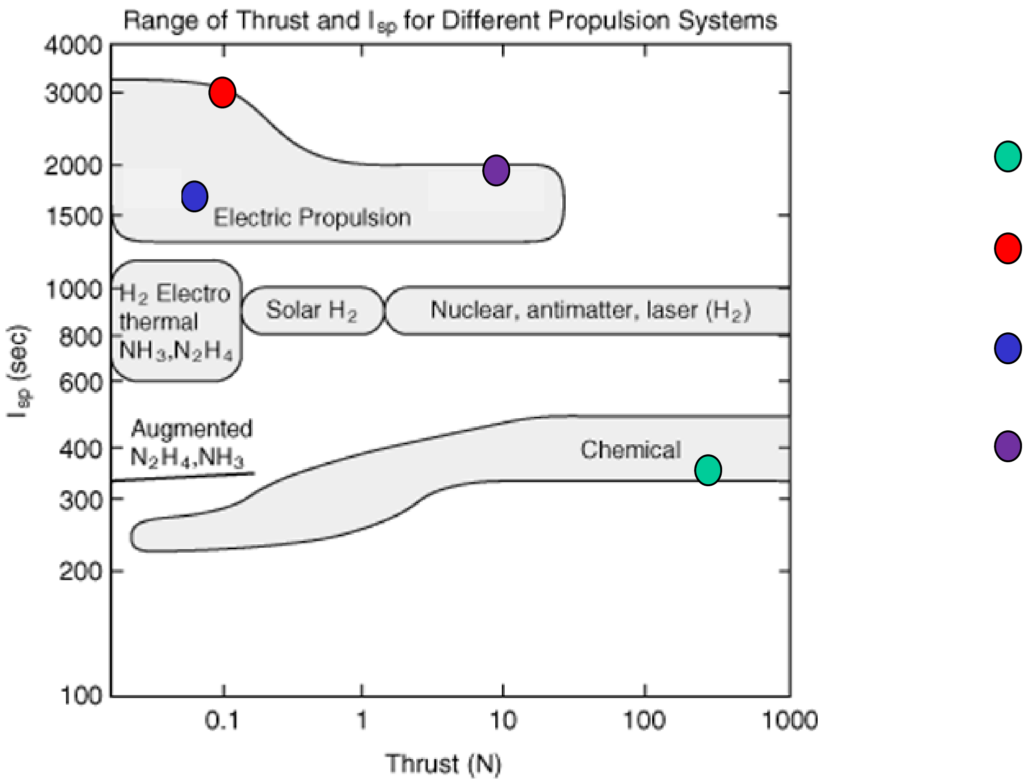
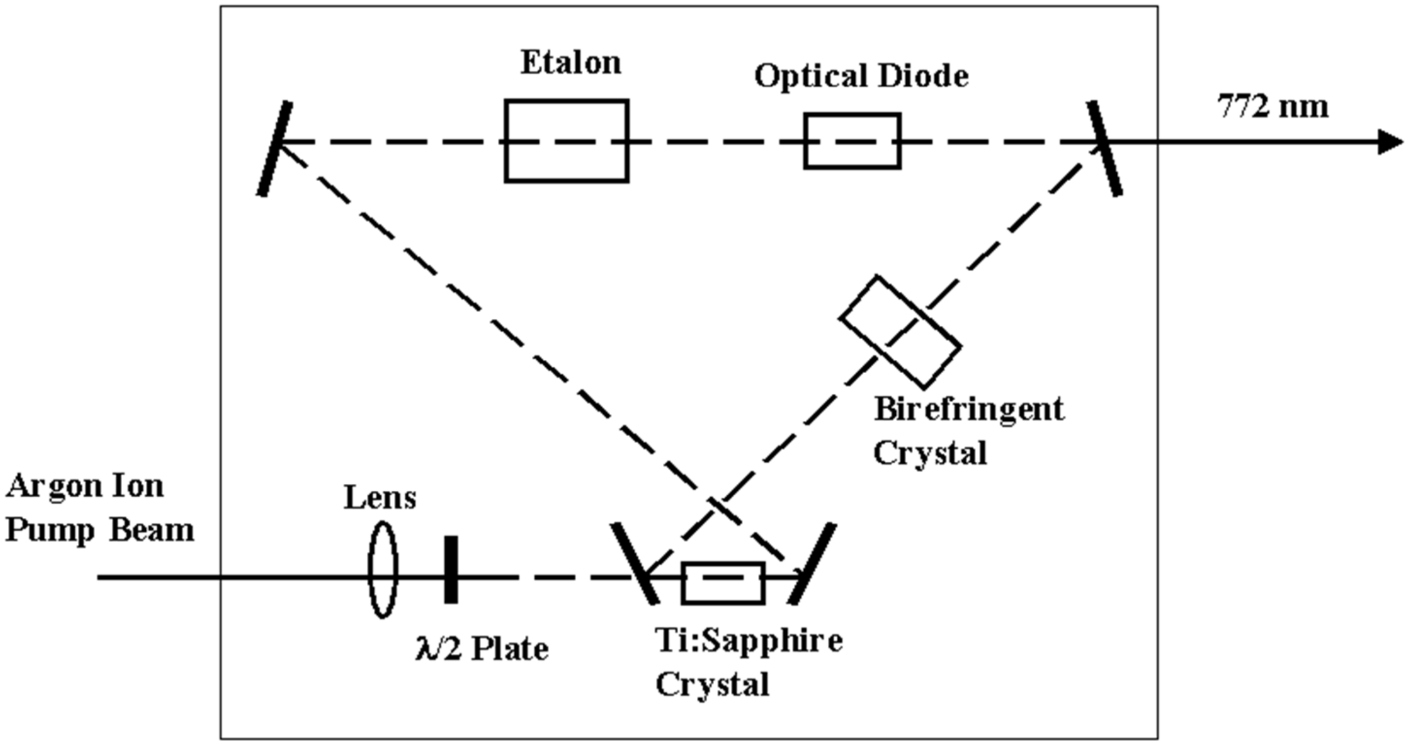
Electric Propulsion Engines have a Higher Specific Impulse and a Lower Thrust than Chemical Engines



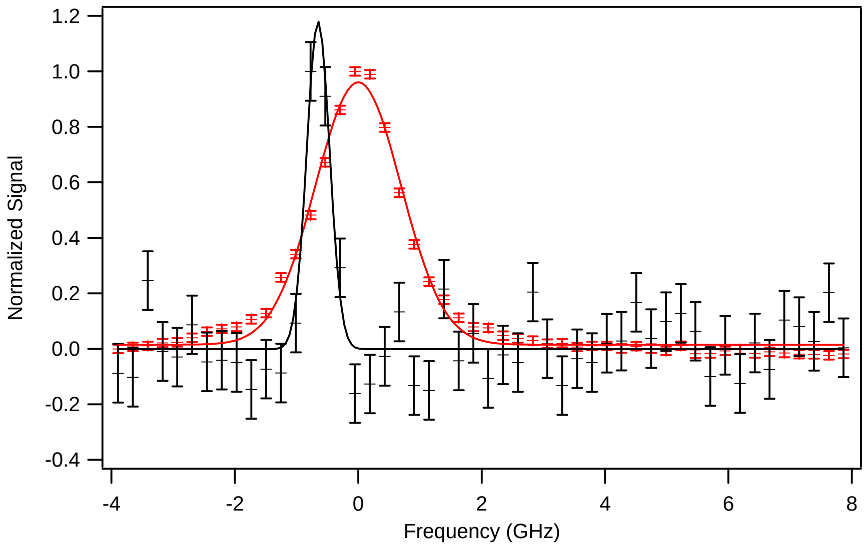
Spacecraft without electric engines have thrust levels of 100-500 N with a specific impulse that is less than 450 s

The Ti-Sapphire



Temperature and Velocity Measurement

LIF (Black) and Optogalvanic (Red) Signals



Results

- Measured Axial Velocity
  – 500 ±30 m/sec
- Measured Temperature
  – 100 ±30 K