VASIMR Plasma Rocket Technology

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OUTLINE

- Introduction
- Development Roadmap
- Flight Demonstration Concepts
- Mission Applications

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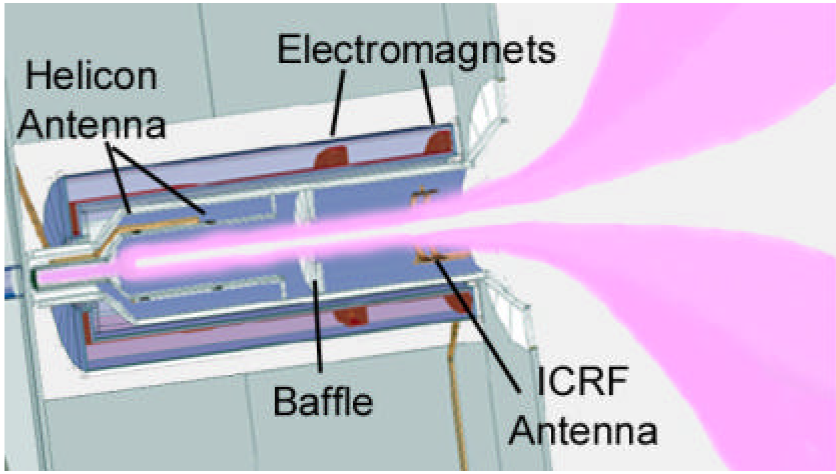
- Experimentation
    - Source, ICRF, Nozzle
- Theoretical Studies
    - Source, ICRF, Nozzle

Andrew Ilin

Benefits of VASIMR Propulsion

Variable Specific Impulse Magnetoplasma Rocket



- A high-Isp plasma rocket for space exploration and commercial applications
    - short trip times
    - high payload capacity
    - mission flexibility and abort capability
    - high-efficiency orbit transfer

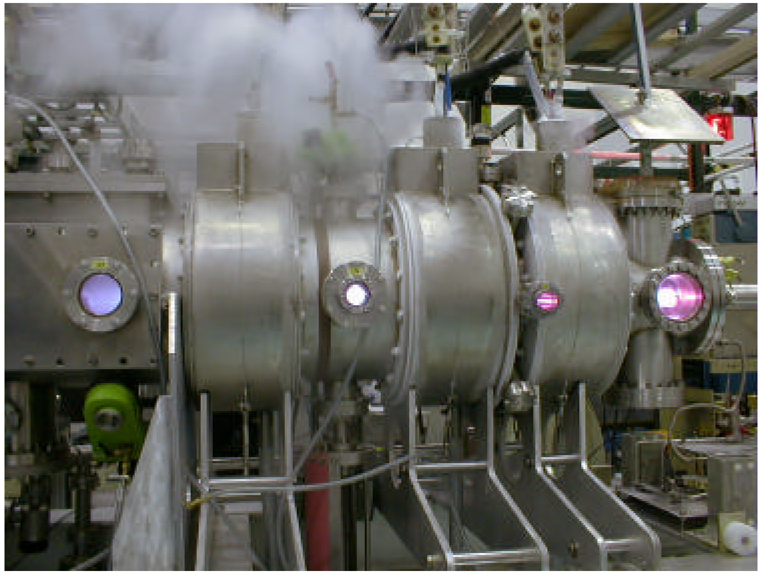
- Potential drag compensation for the ISS

- Variable specific impulse to improve trajectory optimization
    - higher thrust for escape from planetary orbits
    - higher efficiency for interplanetary cruise

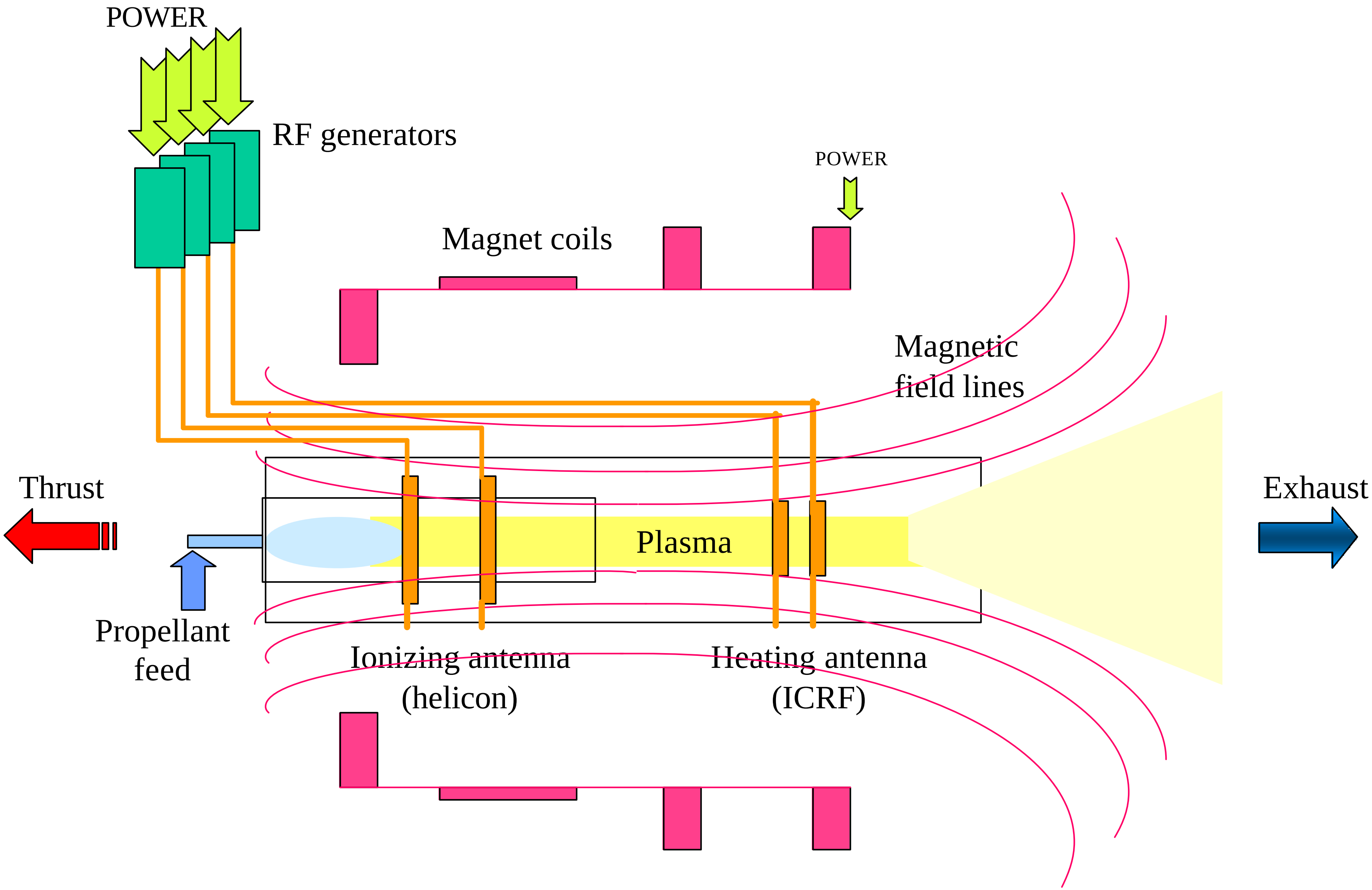
- Magnetoplasma technology is relevant to more advanced systems (including fusion)

- No moving parts, no combustion, no electrodes

- Hydrogen propellant: plentiful, inexpensive, and the best known radiation shield

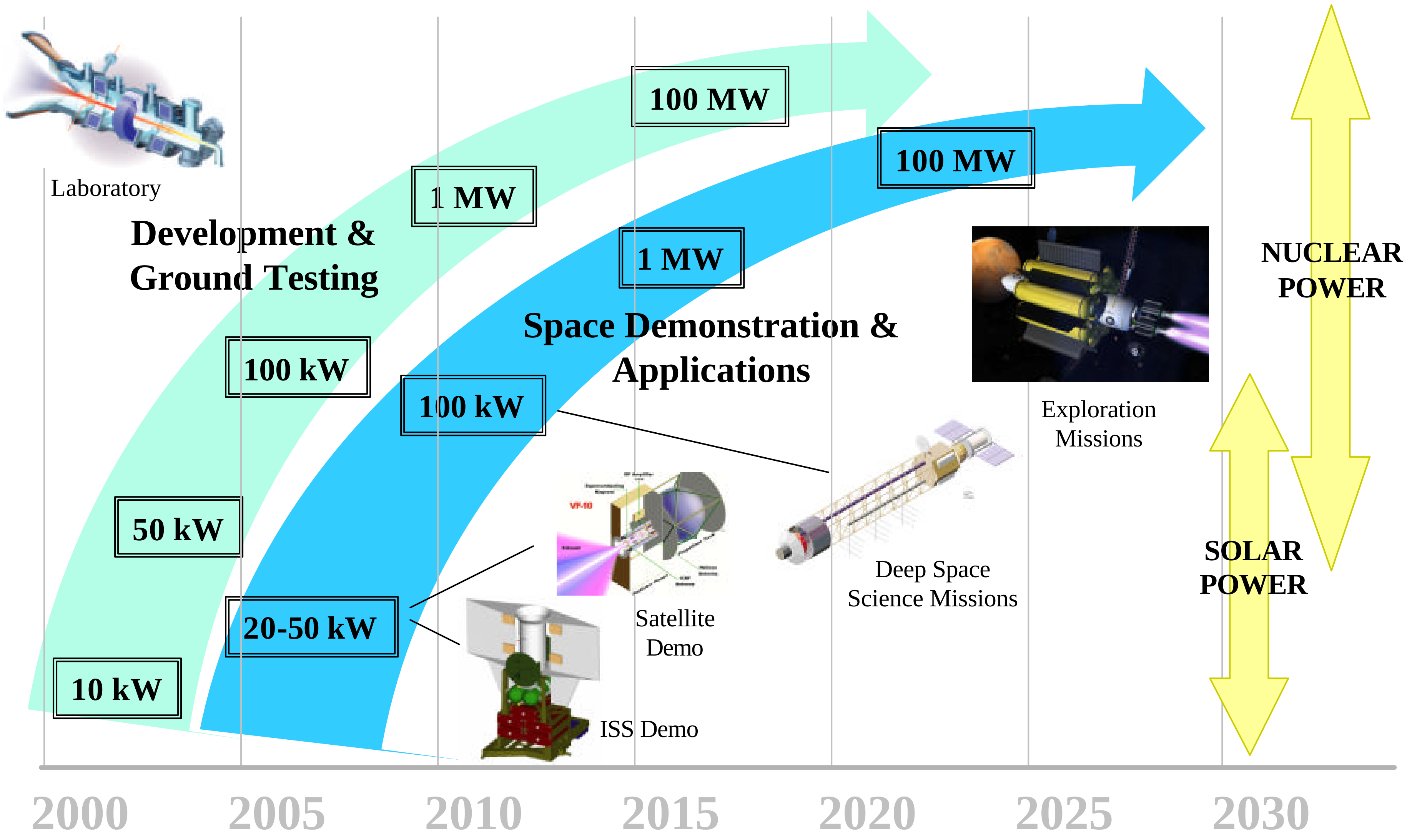


Simplified Diagram of VASIMR Thruster

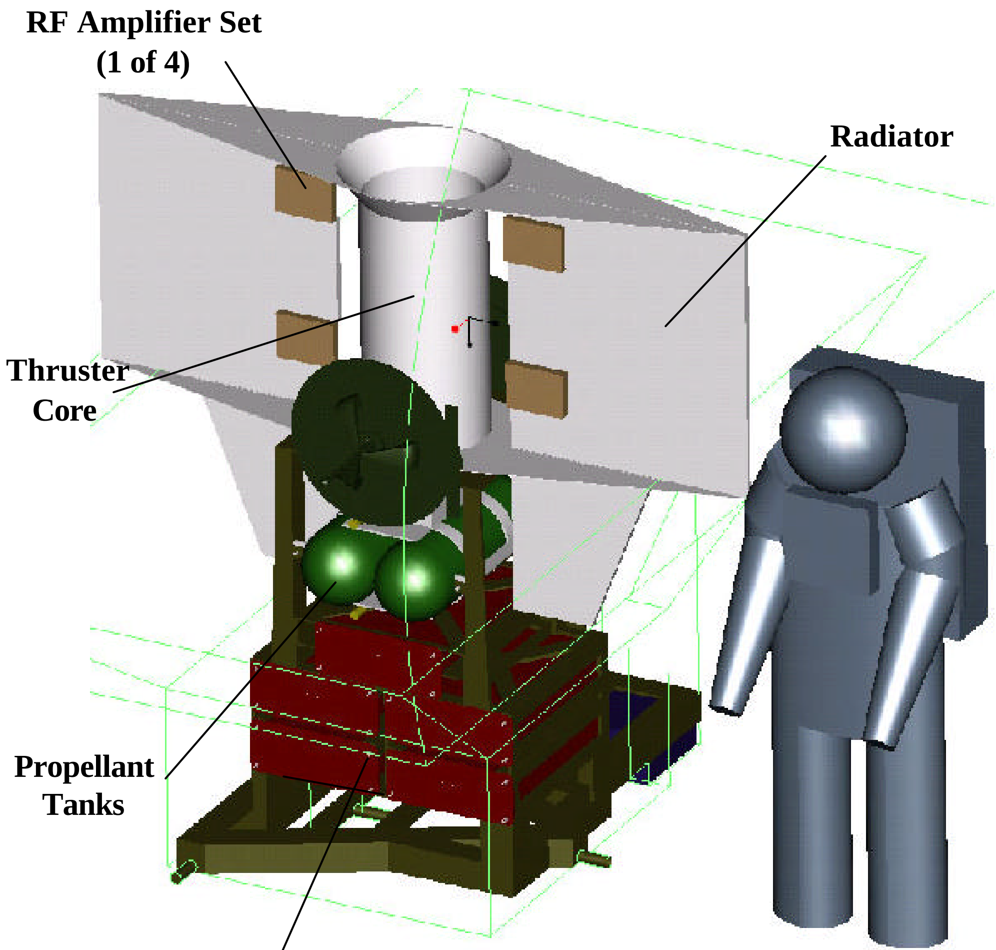


Development Roadmap

A variety of demonstrations and applications of increasing capability are envisioned



Proposed VASIMR Experiment on ISS



Approximate Dimensions
of Thruster Core:
Diameter < 0.5 m
Length < 1 m

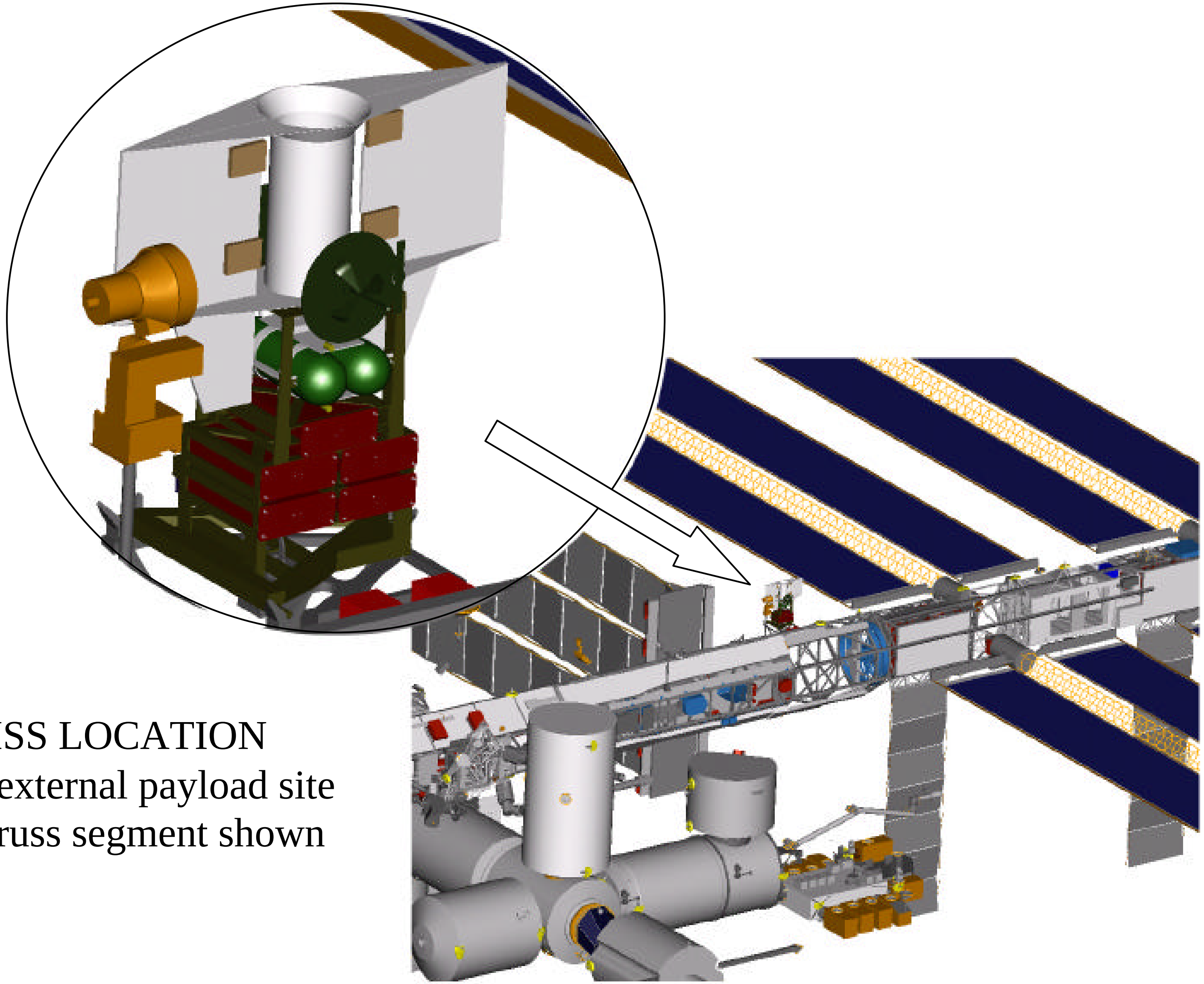
Initial Experiment

- Near-term, low-cost, minimum interfaces with ISS
- Periodic operation with stored power (25 kW)
  - 0.2 N thrust, 10,000 sec Isp
  - 0.5 N thrust, 5400 sec Isp
- Gaseous hydrogen propellant

Eventual Operations

- Continuous power
- Demonstrate VASIMR and other electric propulsion
- Reduce propellant for reboost
  - Extremely high Isp
  - Waste gas usage
- Improve ? g environment
- Serve as plasma contactor
- ISS becomes advanced technology test bed

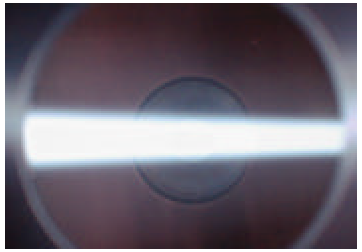
Proposed VASIMR Experiment on ISS

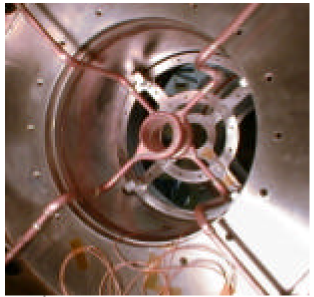


POTENTIAL ISS LOCATION
Attachment at external payload site on P3 (or S3) truss segment shown

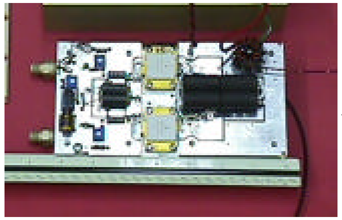
Flight-like Component Development and Testing

Plasma in lab experiment

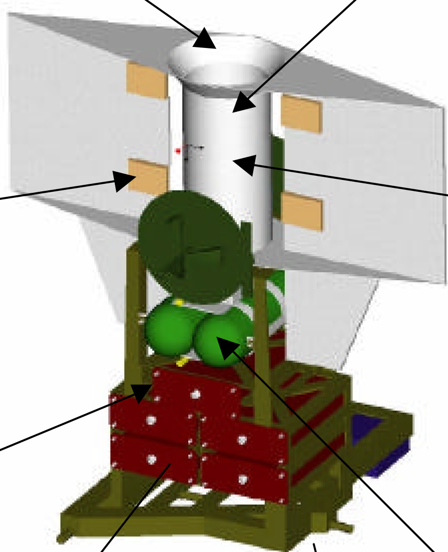


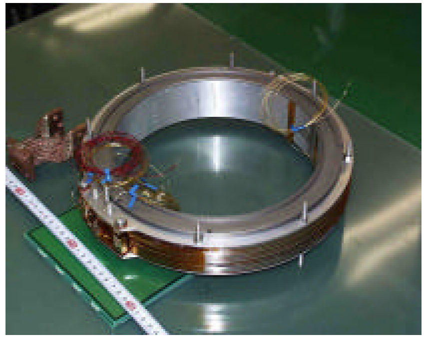


ICRF antenna



Prototype RF amplifier





Superconducting magnet

Universal Mini-Controller

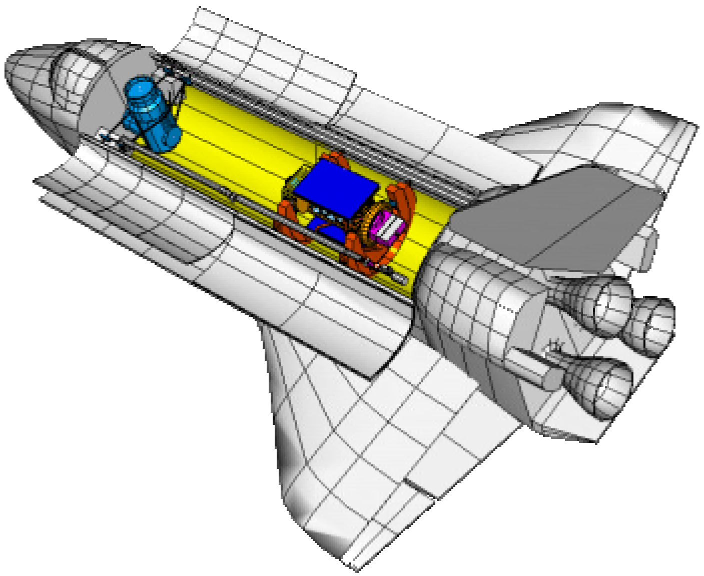
NiCd Batteries developed for X-38

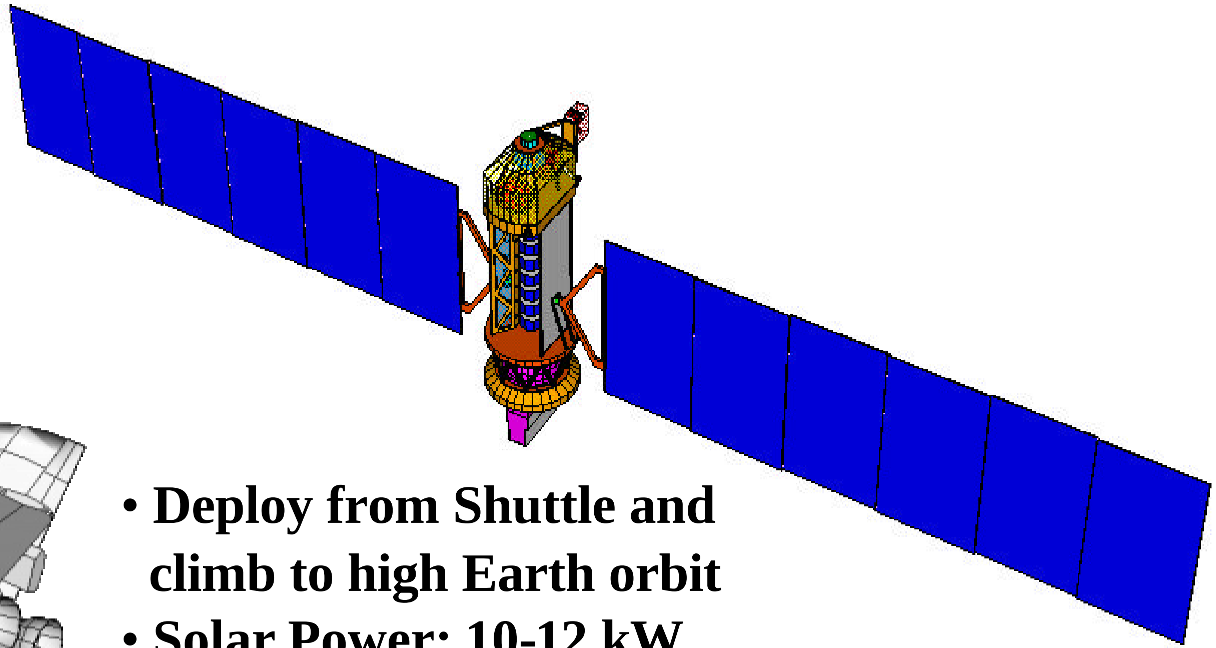
Standard payload interface

MMU propellant tank

Free-Flying Space Demonstration

- Demonstrate advanced space propulsion technology
- Measure natural radiation environment from low to high Earth orbit

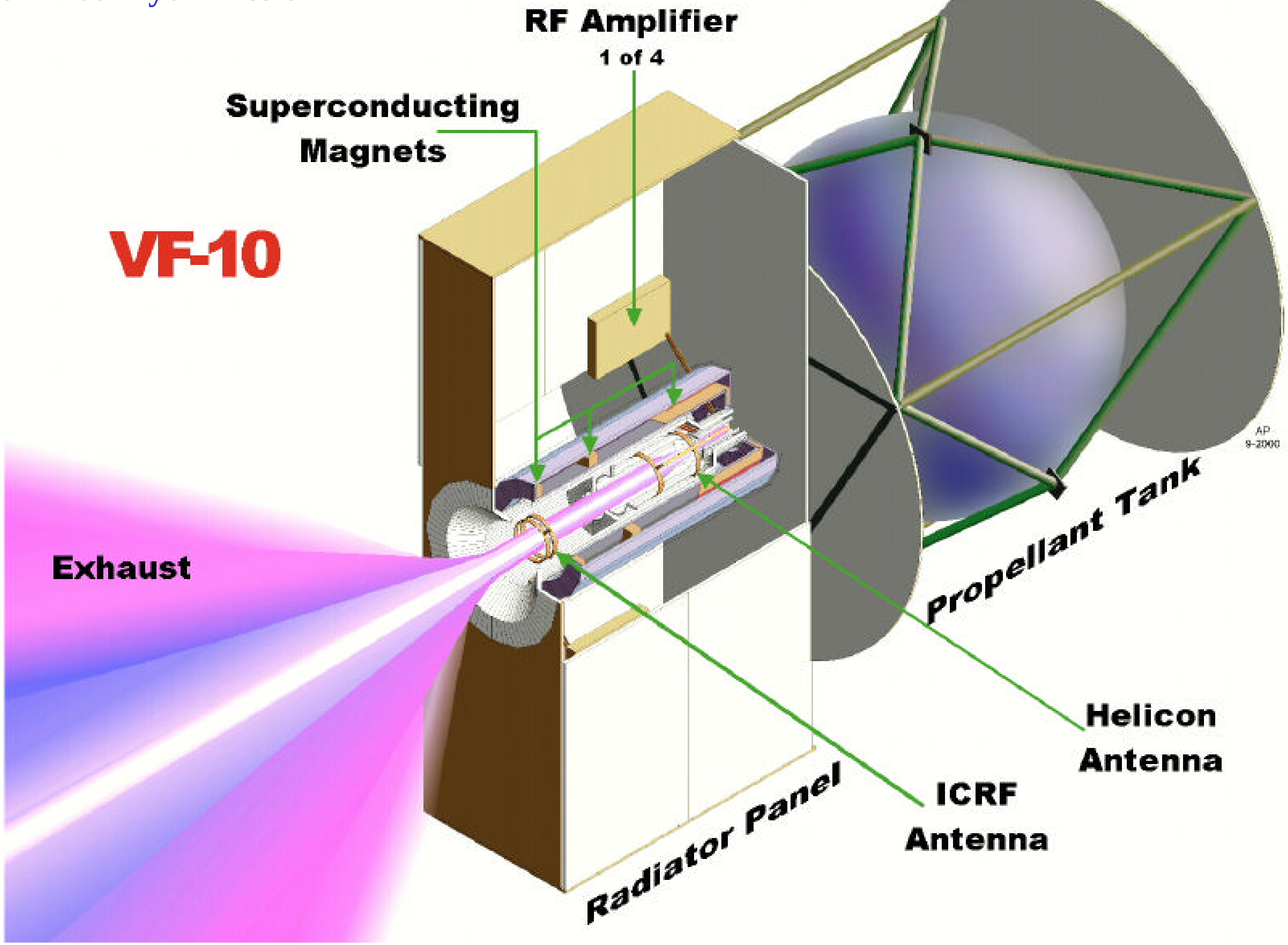




- Deploy from Shuttle and climb to high Earth orbit
- Solar Power: 10-12 kW
- Demonstrate two different propulsion systems
  - VASIMR
  - Hall thruster
- Operate scientific instruments on spacecraft and on deployed microsatellites

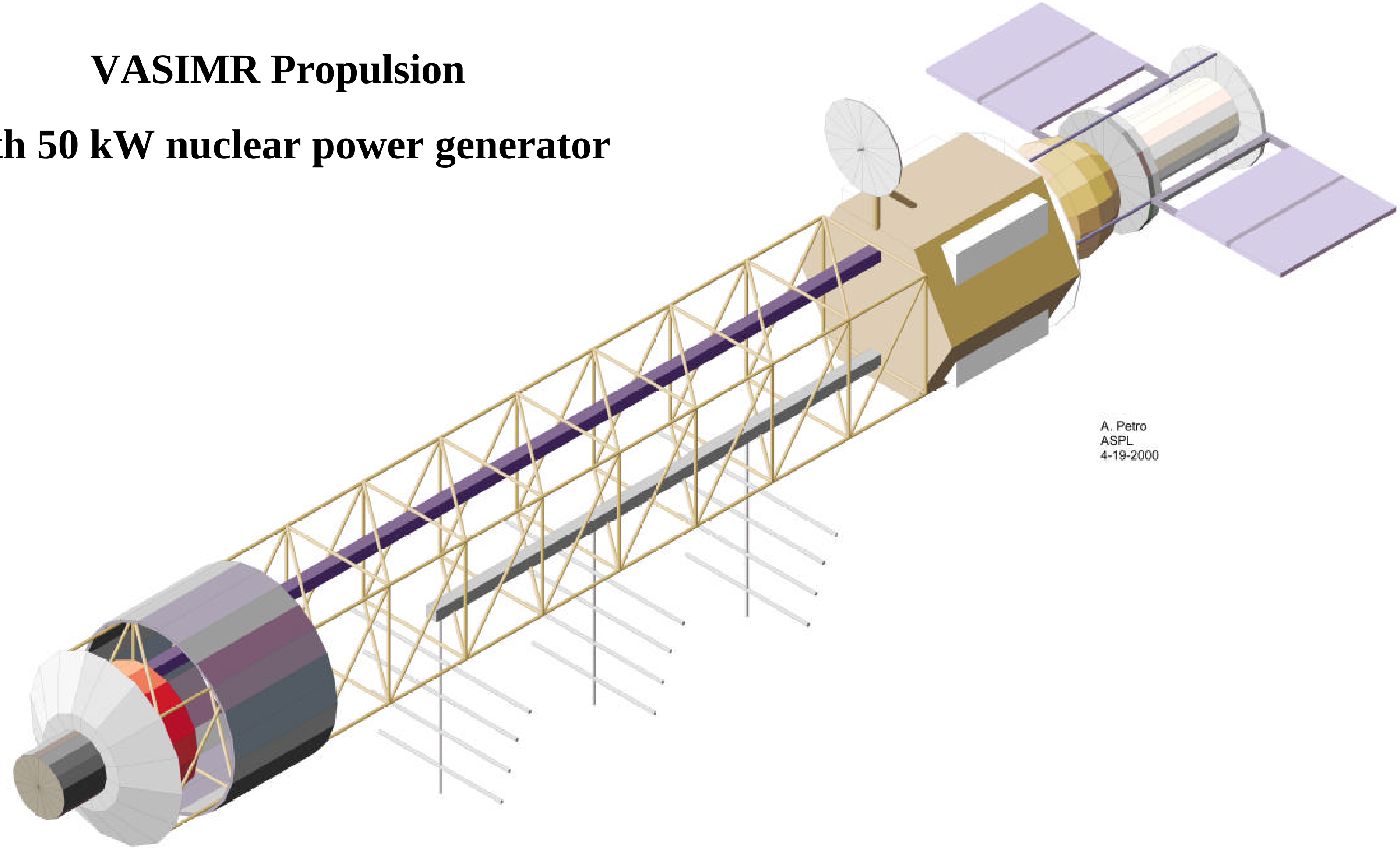
10 Kilowatt Thruster Design

For Free-Flyer Mission



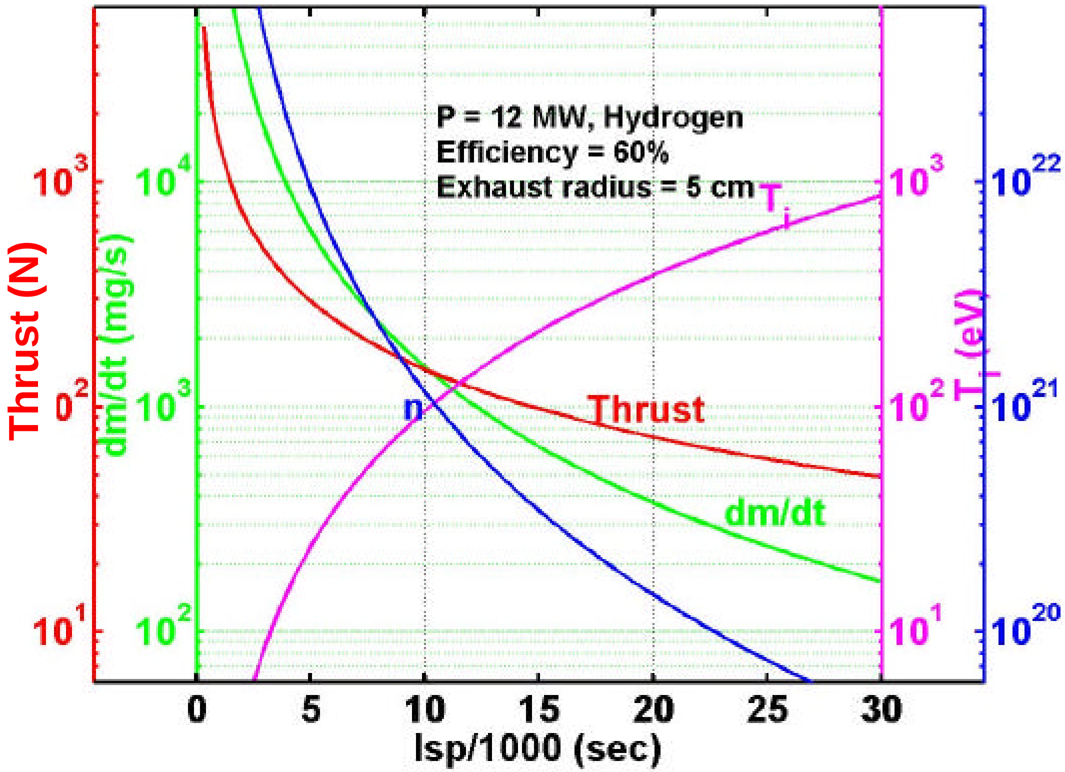
VASIMR Propulsion

with 50 kW nuclear power generator

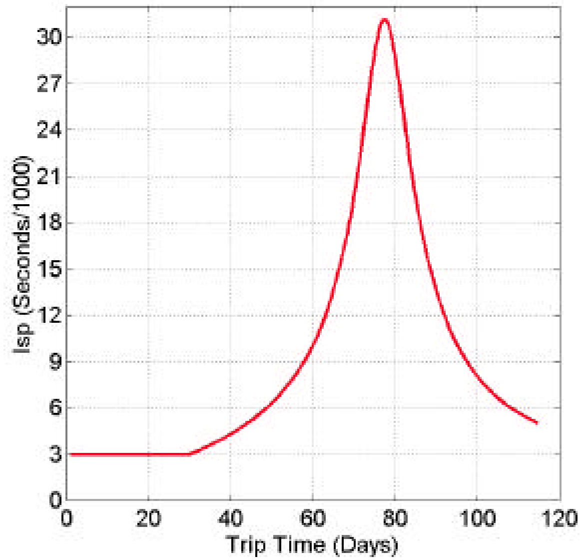


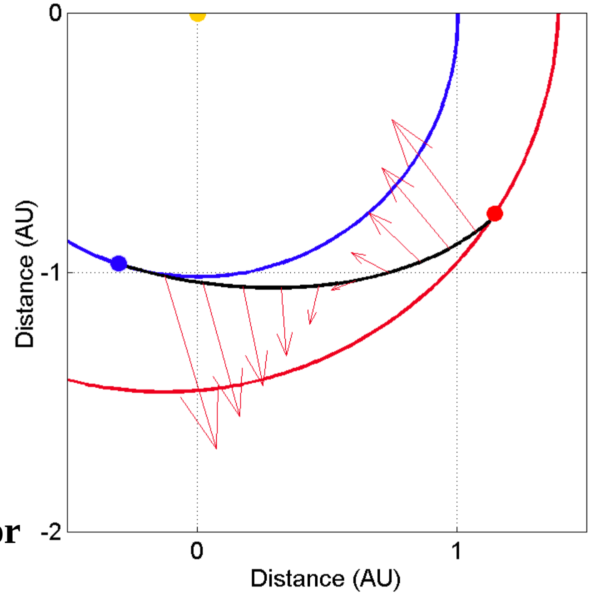
Piloted Mars Mission

VASIMR Performance



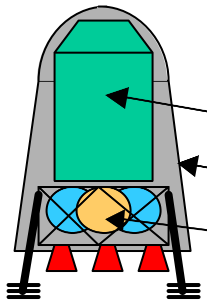
Isp Profile





Earth-to-Mars Thrust Vector

Piloted Mars Mission



Crew Lander (60.8 mt Payload)

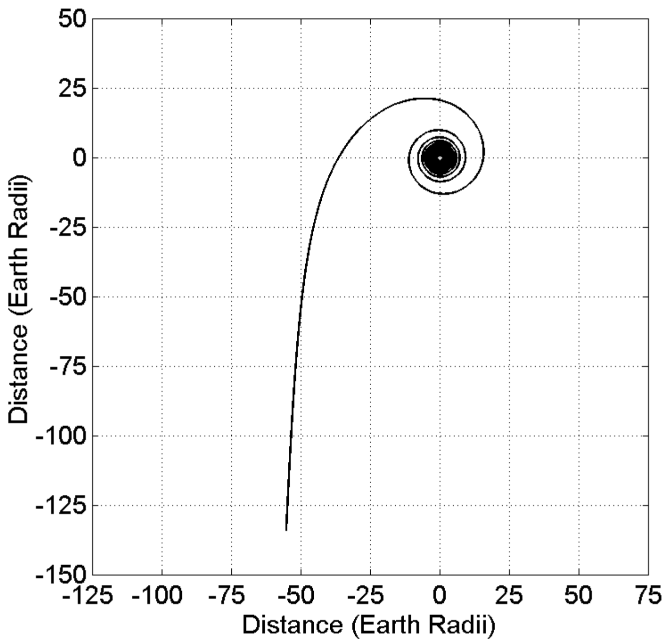
31.0 mt Habitat

13.5 mt Aeroshell

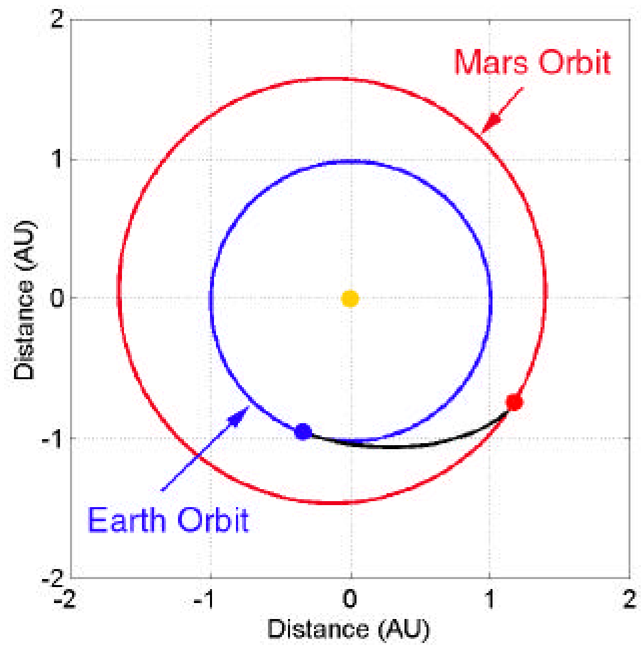
16.3 mt Descent System

Departing LEO May 6, 2018

188 mt IMLEO, 12 MW power plant, ? = 4 kg/kW



30 Day Spiral

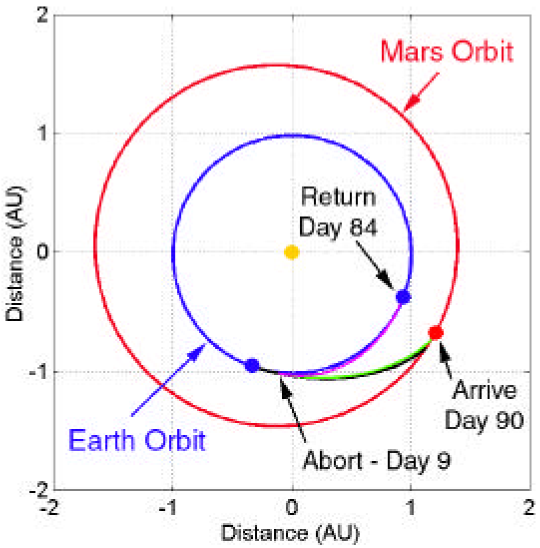


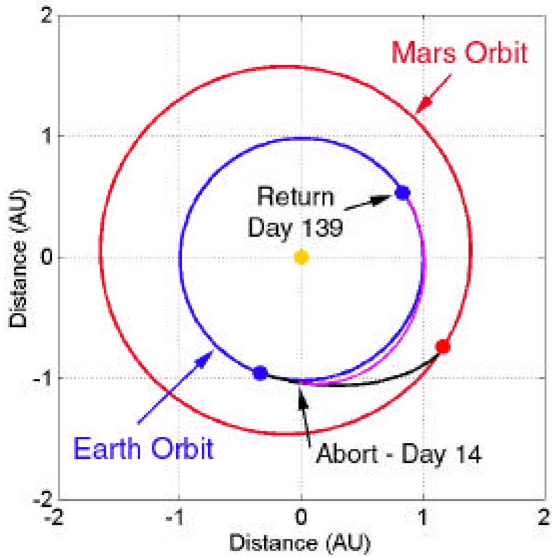
85 Day Heliocentric Transfer

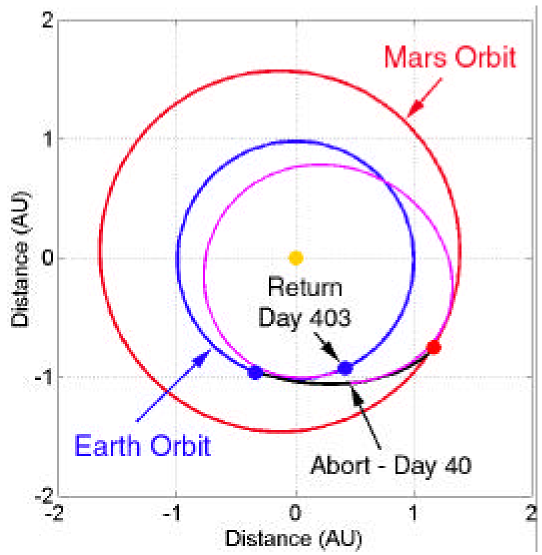
Mars Mission Abort Capability

Aborts due to loss of propellant

Aborts deep into the mission due to non propulsion system failures





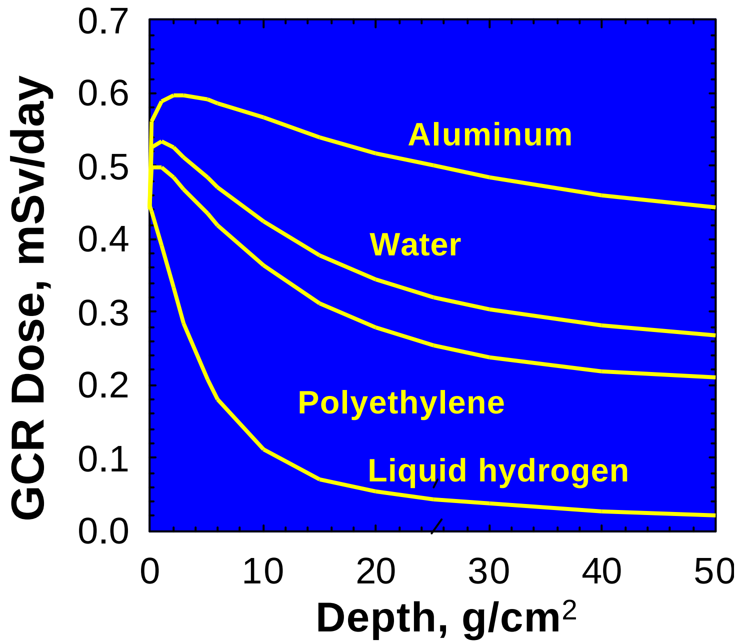


Radiation Shielding with Hydrogen Propellant

Hydrogen is the best material for shielding humans from radiation in space.

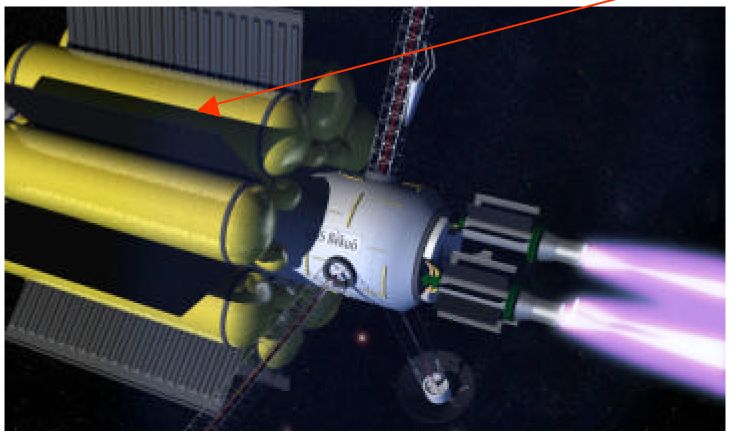
VASIMR propellant can provide effective radiation protection for the entire trip.

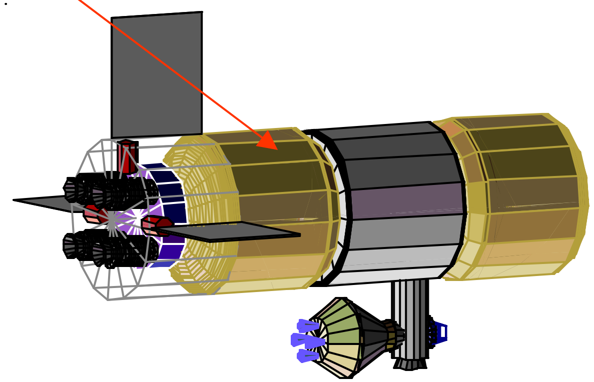
The graph shows radiation shielding capability for various materials.



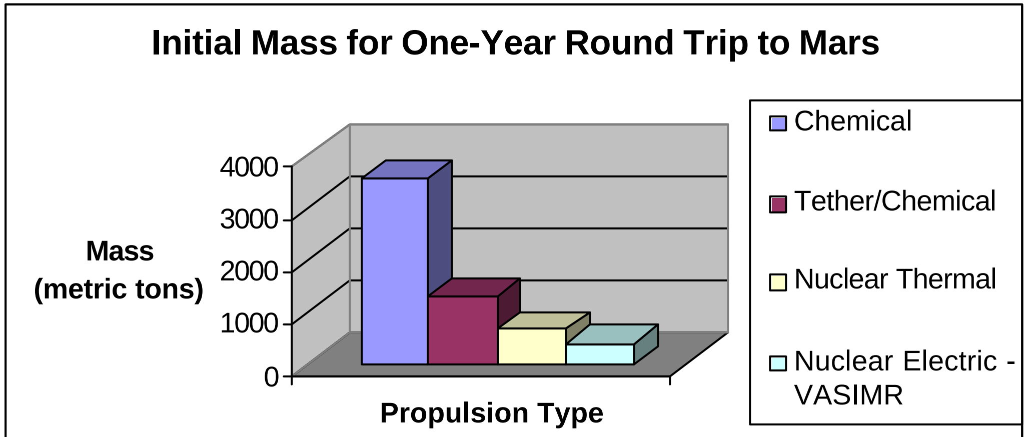
Two Mars Vehicle Concepts

LH_2 propellant provides crew shielding

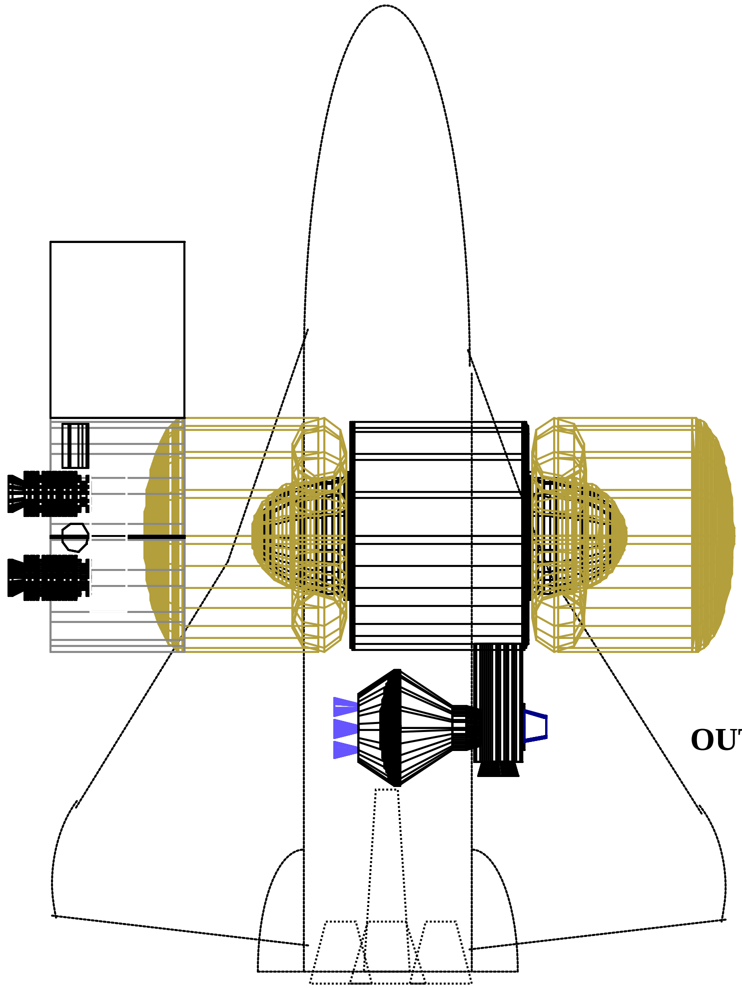




Comparative Study of One-Year Round-Trip Mission to Mars
Crew of Four



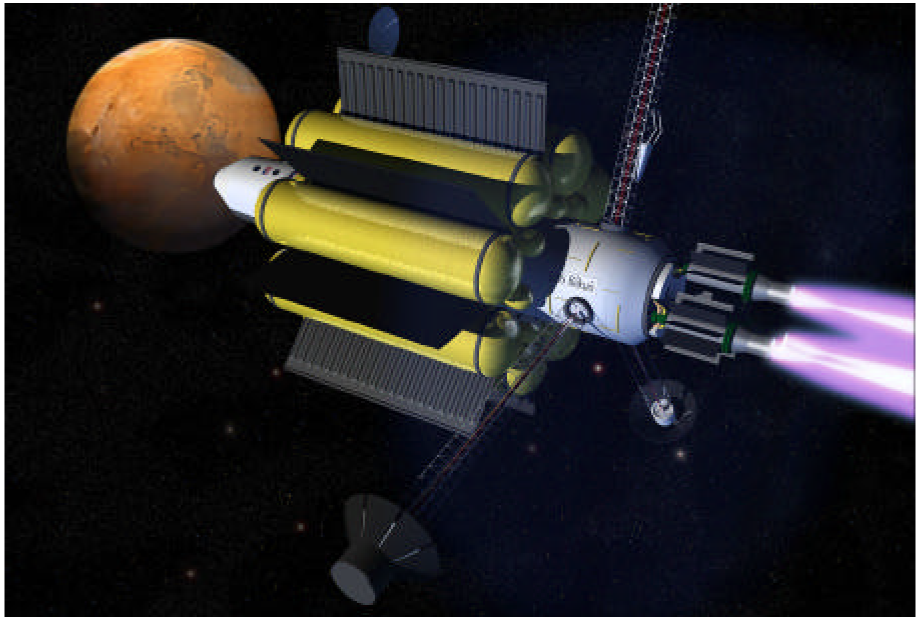
From MSFC/SAIC Study July 2000



OUTBOUND CREW SHIP FOR ONE-YEAR ROUND TRIP MISSION

SIZE COMPARISON TO SPACE SHUTTLE ORBITER

Higher Power Dramatically Reduces Trip Time



200MW Earth to Mars Missions

? = 0.5

Maximal I_{sp} = 30,000

Payload Mass = 22 mt

Total Initial	Spiraling around Earth		Heliocentric trajectory		Final relative	Total trip
Mass (mt)	fuel (mt)	time (days)	fuel (mt)	time (days)	velocity (km/s)	time (days)
600	180	7	298	34	0	41
350	117	5	111	42	0	47
250	88	4	40	49	0	53
600	152	8	324	31	6.8	39

Summary

- Power-rich architectures offer the most robust systems for space exploration

- High power electric propulsion with variable thrust and Isp reduces risk and provides mission flexibility

- High-Isp propulsion systems have potential in near-Earth applications

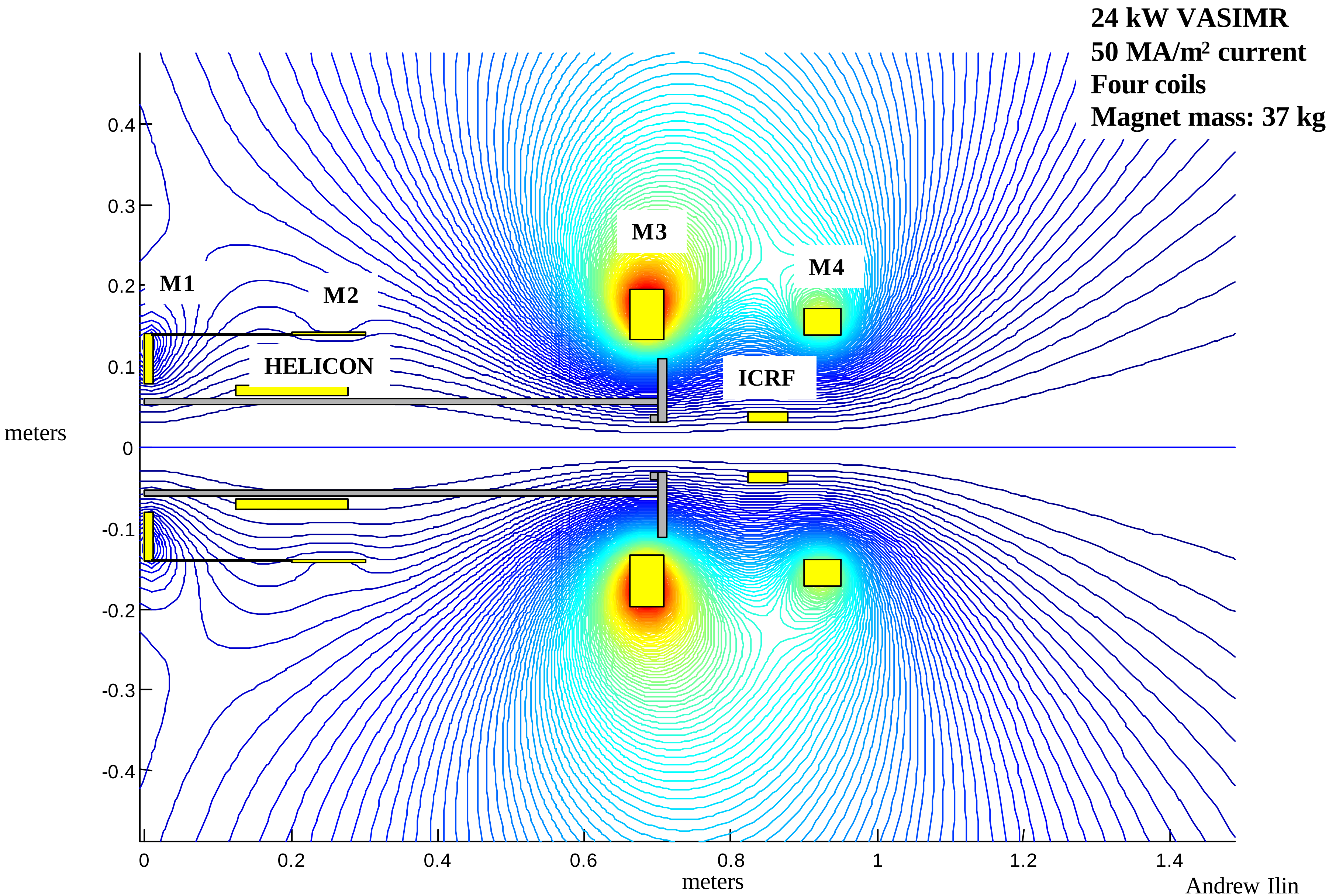
- The ISS can become an important facility for demonstrating advanced propulsion and power technology and those test operations can directly benefit the ISS.

Backup Charts

Main DOE and University Collaborators

- **Oak Ridge National Laboratory, Fusion Energy Division**: Dr. Stanley Milora, Director
  - Dr. Wally Baity, RF systems (team lead)
  - Dr. Mark Carter, RF systems, plasma theory, magnetic system design
  - Dr. Rick Goulding, experimental plasma generation and heating
  - Dr. William Schwenterly, superconducting magnet design
- **Los Alamos National Laboratory**:
  - Drs. Pat Colestock and Max Light, helicon physics and wave diagnostics
- **MSE Technology Inc.(former DOE facility:)** Mr. David Micheletti, Program Manager
  - Dr. Jean Luc Cambier, plasma fluid (MHD) simulation
- **University of Texas, Austin, Fusion Research Center**:
  - Dr. Roger Bengtson, experimental plasma physics and diagnostics (team lead)
  - Dr. Boris Breizman, plasma theory and system scaling
- **University of Maryland, Dept. of Physics/East West Space Science Center**: Dr. Roald Sagdeev, Director
  - Dr. Konstantinos Karavasilis, trajectory simulation and optimization
  - Dr. Sergei Novakovski, plasma fluid (MHD) simulation
- **Rice University, Dept. of Physics and Astronomy**: Dr. Patricia Reiff, Dept. Chair
  - Dr. Anthony Chan, plasma theory (team lead)
  - Dr. Carter Kittrell, experimental plasma spectroscopy
- **University of Houston, Dept. of Physics**:
  - Dr. Edgar Bering, experimental plasma physics and ion diagnostics
- **MIT, Dept. of Nuclear Engineering:** Dr. Jeffrey Fryberg, Dept. Chair
  - Dr. Oleg Batischev, plasma non-linear theory and simulation
- **MIT, Plasma Science and Fusion Center**: Dr. Miklos Porkolab, Director
  - Dr. Joseph Minervinni (team lead) superconducting magnet design
  - Dr. Joel Schultz, Superconducting magnet design
- **Princeton Plasma Physics Laboratory**:
  - Dr. Samuel Cohen, Magnetic nozzle and plasma diagnostics
- **University of Michigan**:
  - Dr. Brian Gilchrist, plasma interferometry

Magnetic Field Lines



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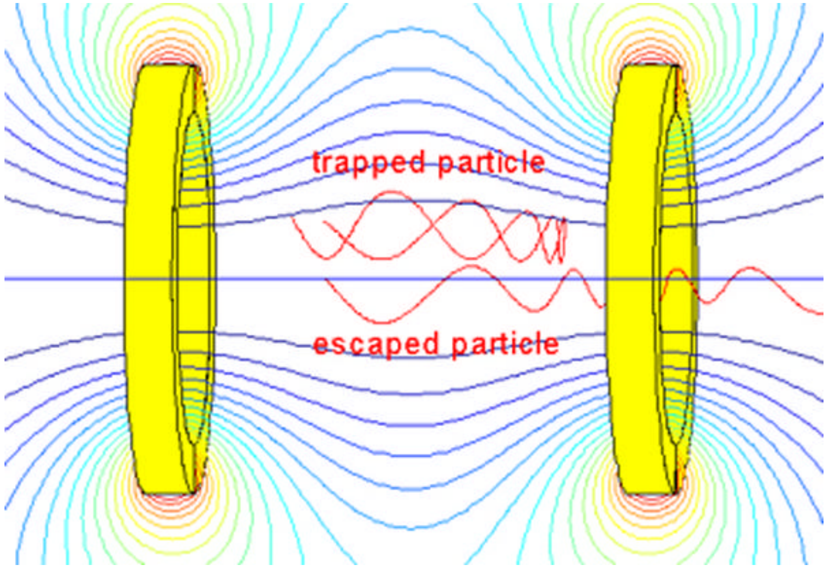
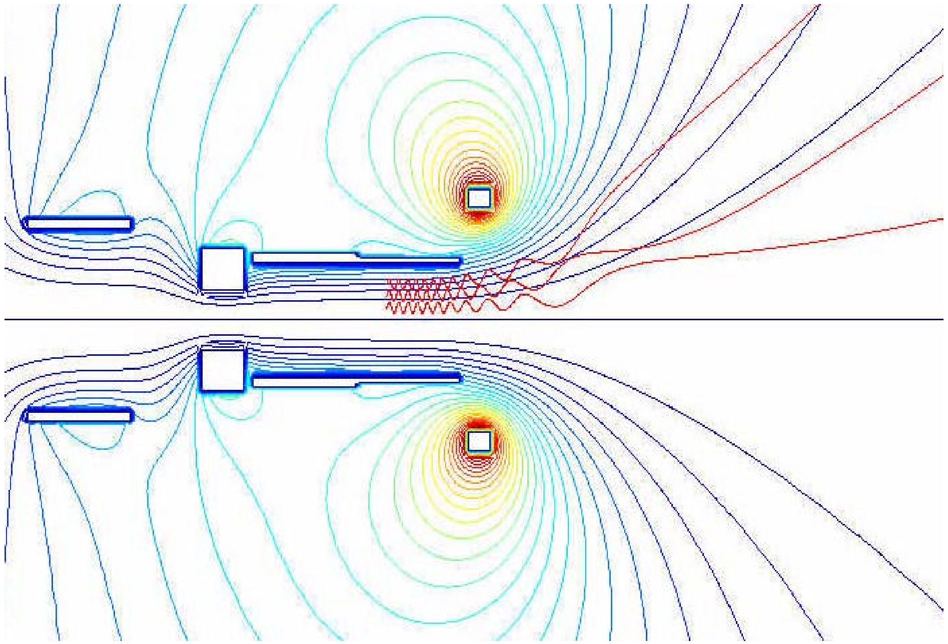


Magnetic Mirror

Charged particles (protons and electrons) move in helical orbits at their cyclotron frequency.



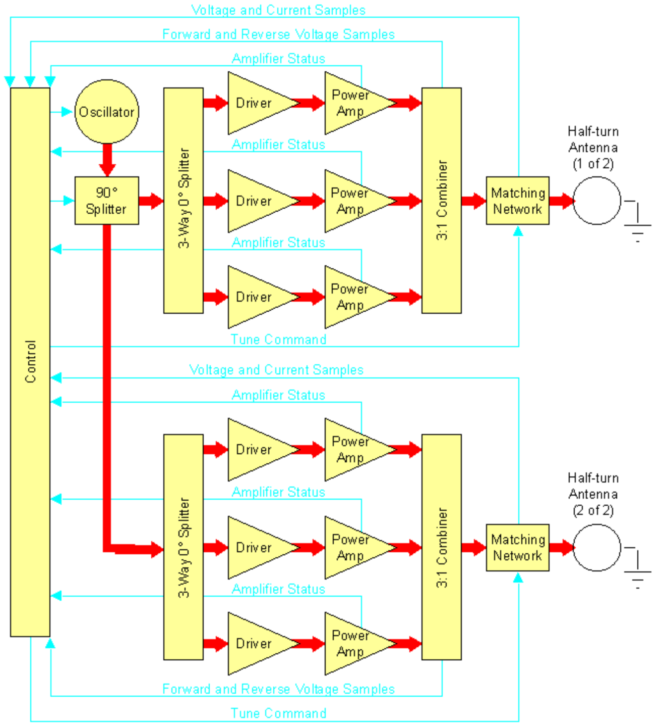
Magnetic Nozzle

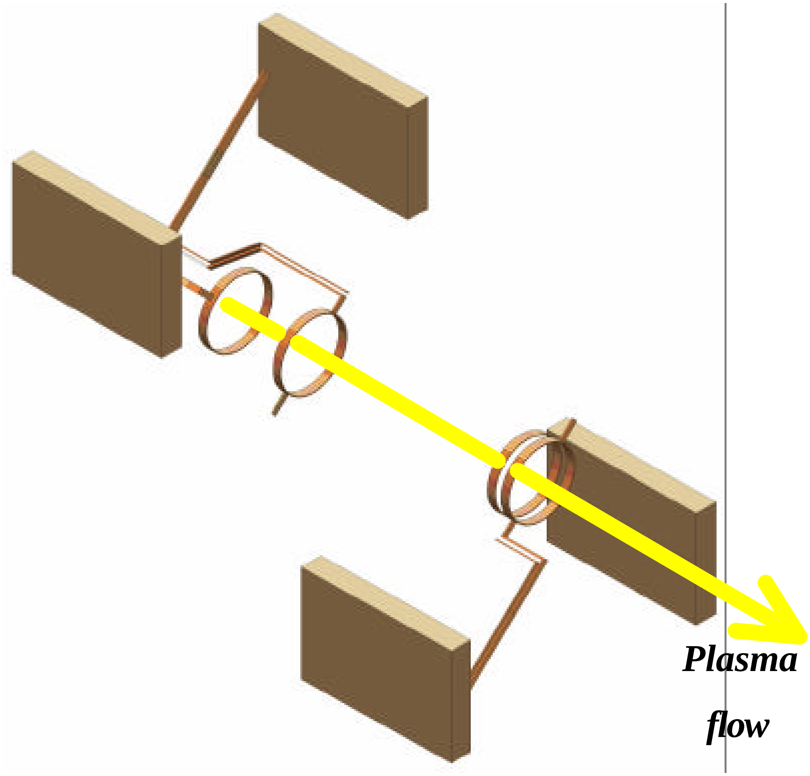
When particles see an expanding magnetic field, they are accelerated axially at the expense of their rotational motion.

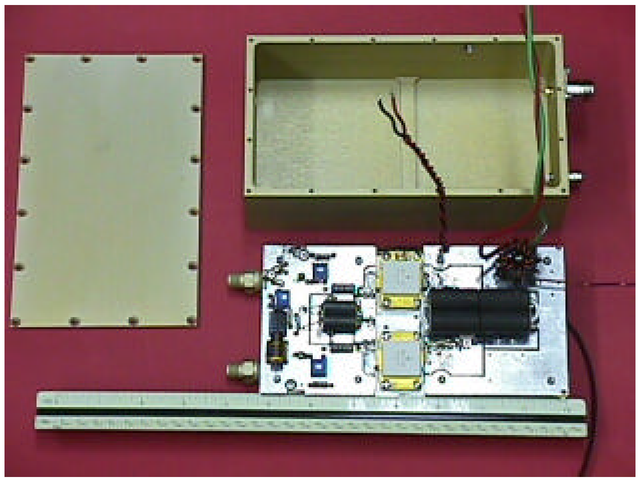
Both ions and electrons leave at the same rate!

Solid-State RF System Design

- ***Design draws from ORNL expertise in RF heating of fusion plasmas.***
- ***System architecture is robust and failure tolerant.***
- ***Prototype hardware has been built and is undergoing testing.***

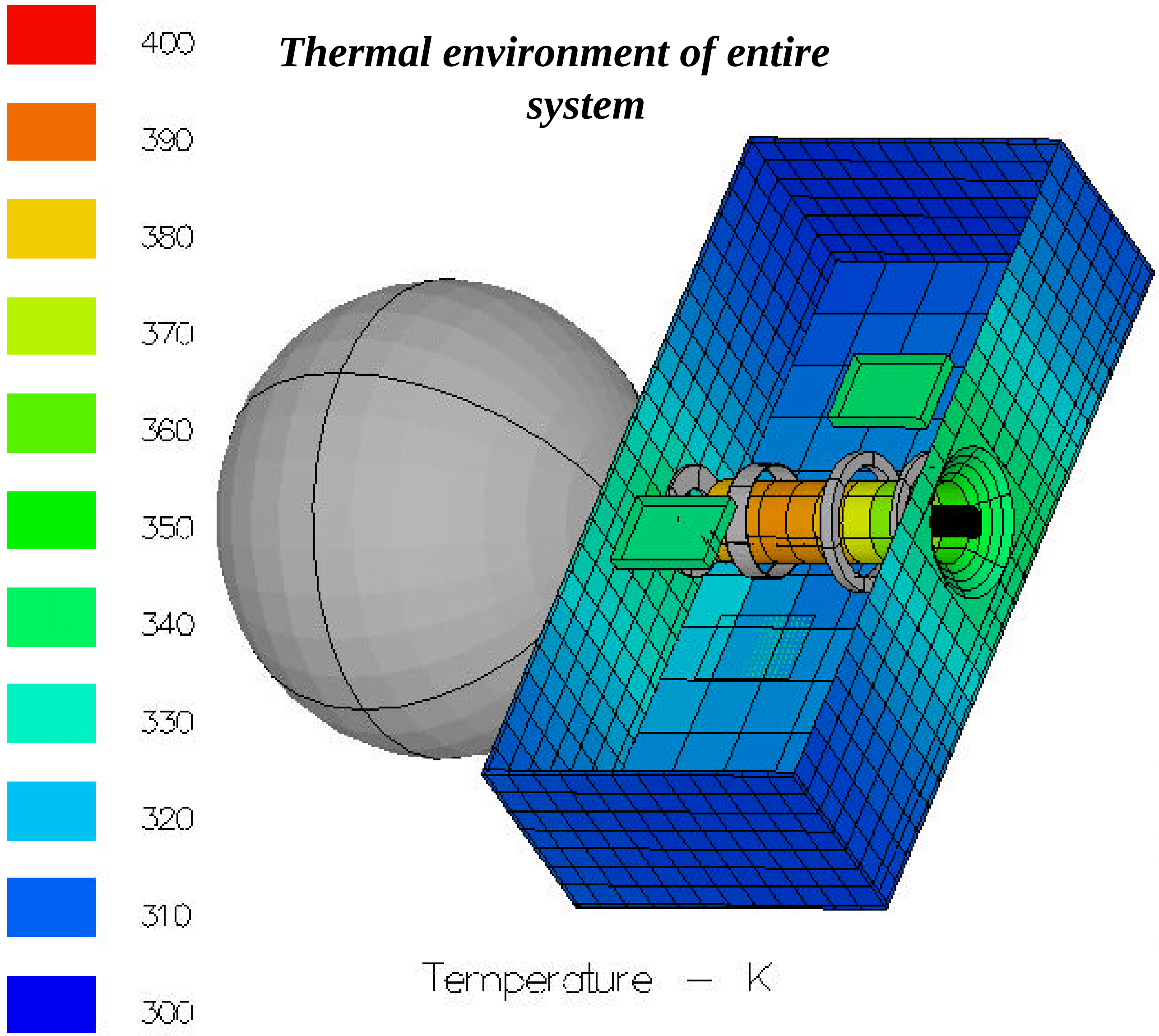


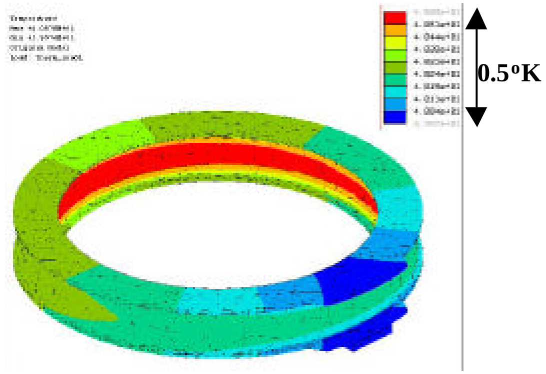




Thermal Studies

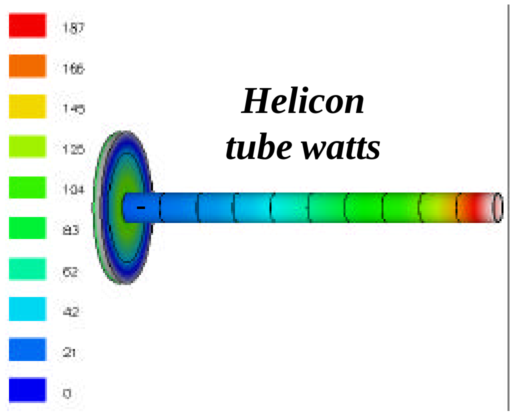
Thermal environment of entire system



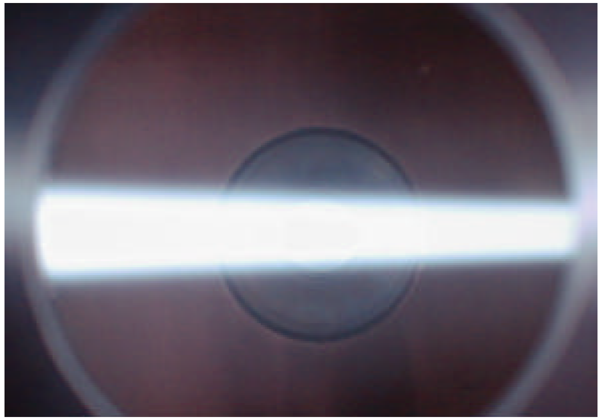


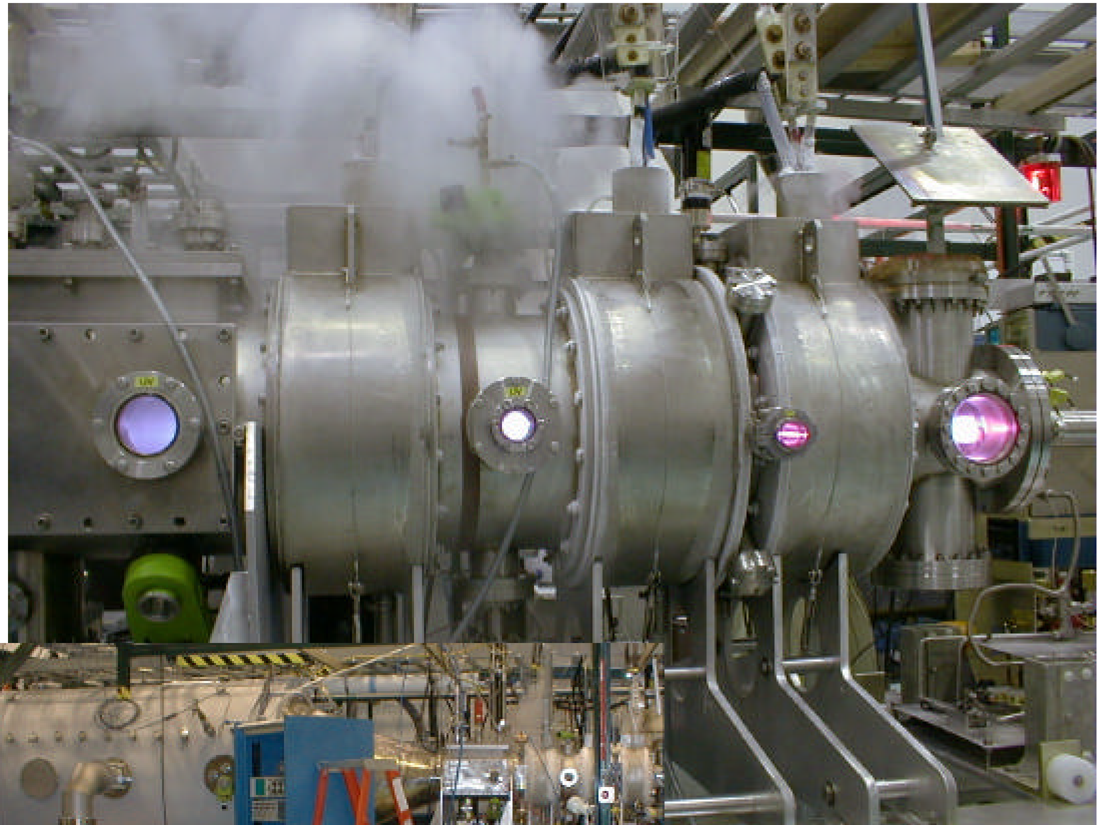
Thermal control of superconductor

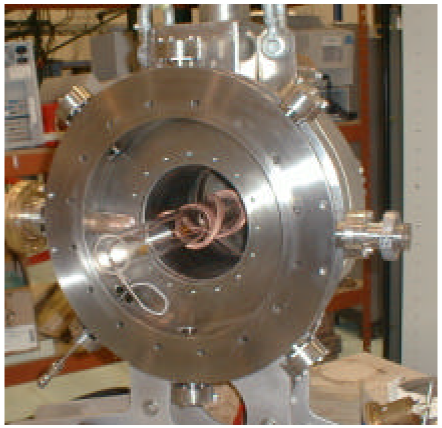
Thermal environment of helicon tube.

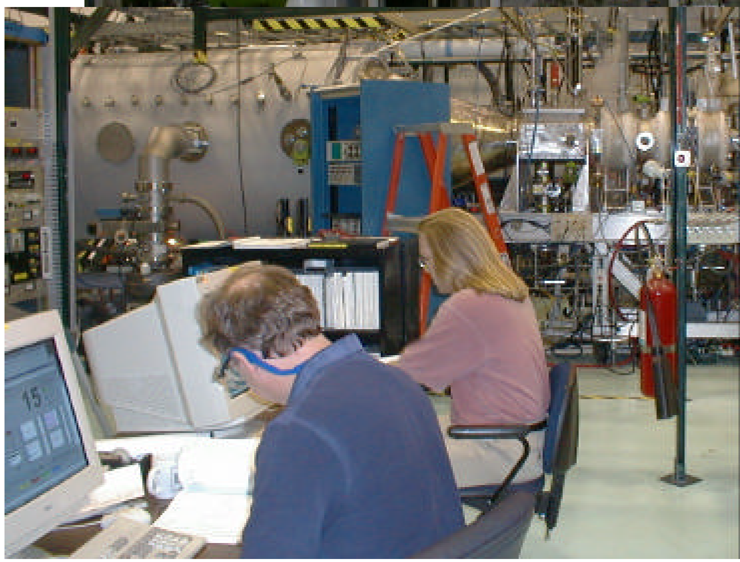


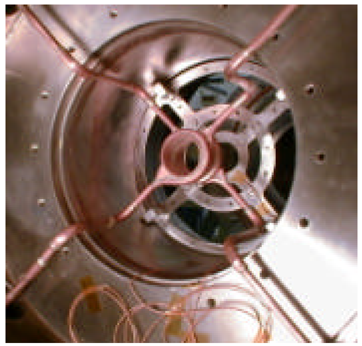
VX-10 Development &Testing







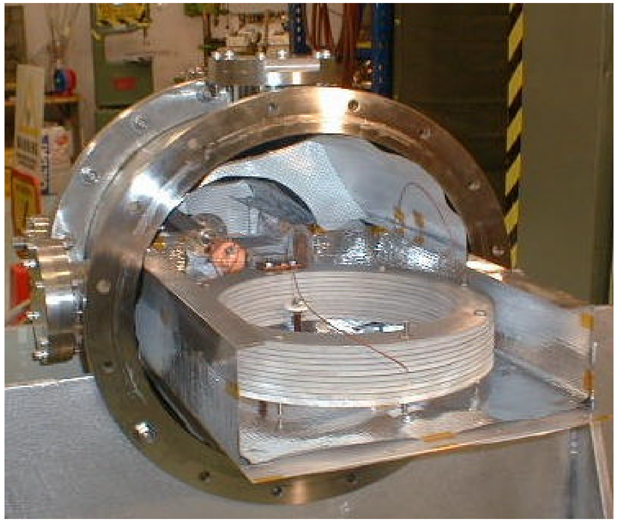


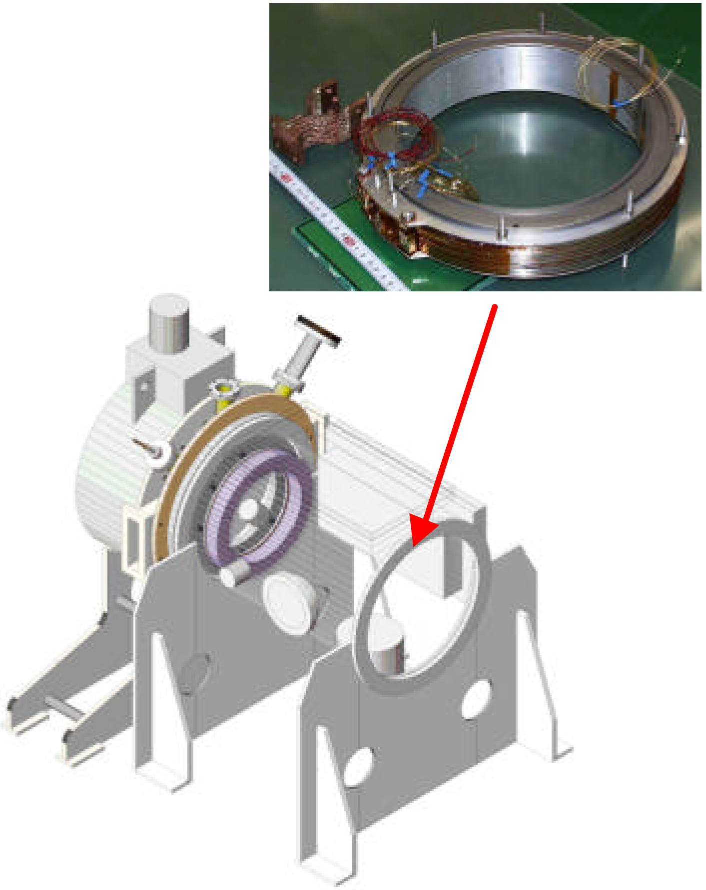


Superconducting Magnet Technology

A vacuum chamber has been assembled for thermal testing of the superconducting magnet and cryocooler prior to integration into the VASIMR experiment.

5 kg superconducting magnet will replace 150 kg conventional LN_2-cooled magnet





Definitions

- Plasma: A super heated gas of electrically charged particles at temperatures greater than 10,000 ^{o}K. A magnetic field is used to guide and control the plasma (magnetoplasma.)
- VASIMR:Variable Specific Impulse Magnetoplasma Rocket.
- RF: radio frequency power used to create and heat the plasma in the VASIMR.
- Helicon: 1st stage of VASIMR, is a high density plasma source, working with RF power to breakdown the propellant gas and produce the plasma.
- ICRH: ion cyclotron resonance heating, is the mechanism by which RF waves further heat the plasma in the VASIMR 2nd stage. They do so by resonating with the natural cyclotron motion of the ions in the magnetic field.
- Bekuo: means “Star or Shooting Star” in the language of the Bri-Bri Indians of Costa Rica, descendants of the Maya. The name honors the native American civilizations, our earliest scientists and astronomers.

VASIMR Primer

The VASIMR system is a high power, electrothermal plasma rocket featuring a very high specific impulse (I_{sp}) and a variable exhaust. Its unique architecture allows in-flight mission-optimization of thrust and I_{sp} to enhance performance and reduce trip time. VASIMR consists of three major magnetic stages where plasma is respectively injected, heated and expanded in a magnetic nozzle. The magnetic configuration is called an asymmetric mirror. The 1st stage handles the main injection of propellant gas and the ionization subsystem; the 2nd stage acts as an amplifier to further heat the plasma. The 3rd stage is a magnetic nozzle which converts the plasma energy into directed momentum. The magnetic field insulates nearby structures from the high plasma temperature (>1,000,000 ^{o}K.) It is produced by high temperature superconductors cooled mainly by radiation to deep space. Some supplemental cooling from the cryogenic propellants (hydrogen, deuterium, helium or mixtures of these) may also be used.

The system is capable of high power density, as the plasma energy is delivered by wave action, making it electrodeless and less susceptible to component erosion. Plasma production is done in the 1st stage by a helicon discharge, while additional plasma heating is accomplished in the 2nd stage by the process of ion cyclotron resonance.