Mini-Magnetospheric Plasma Propulsion (M2P2):

for

High Speed Interplanetary and Heliospheric Missions

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Mini-Magnetospheric Plasma Propulsion (M2P2)

- Facilitate High Speed Spacecraft

  For the Exploration of the Solar System and Beyond

- Use the Solar Wind as a Free Energy Source

  Greatly reduce the Energy and Fuel Requirements ->
  Cheaper, Faster and More Diverse Missions

- Enabling Technology Exists Today

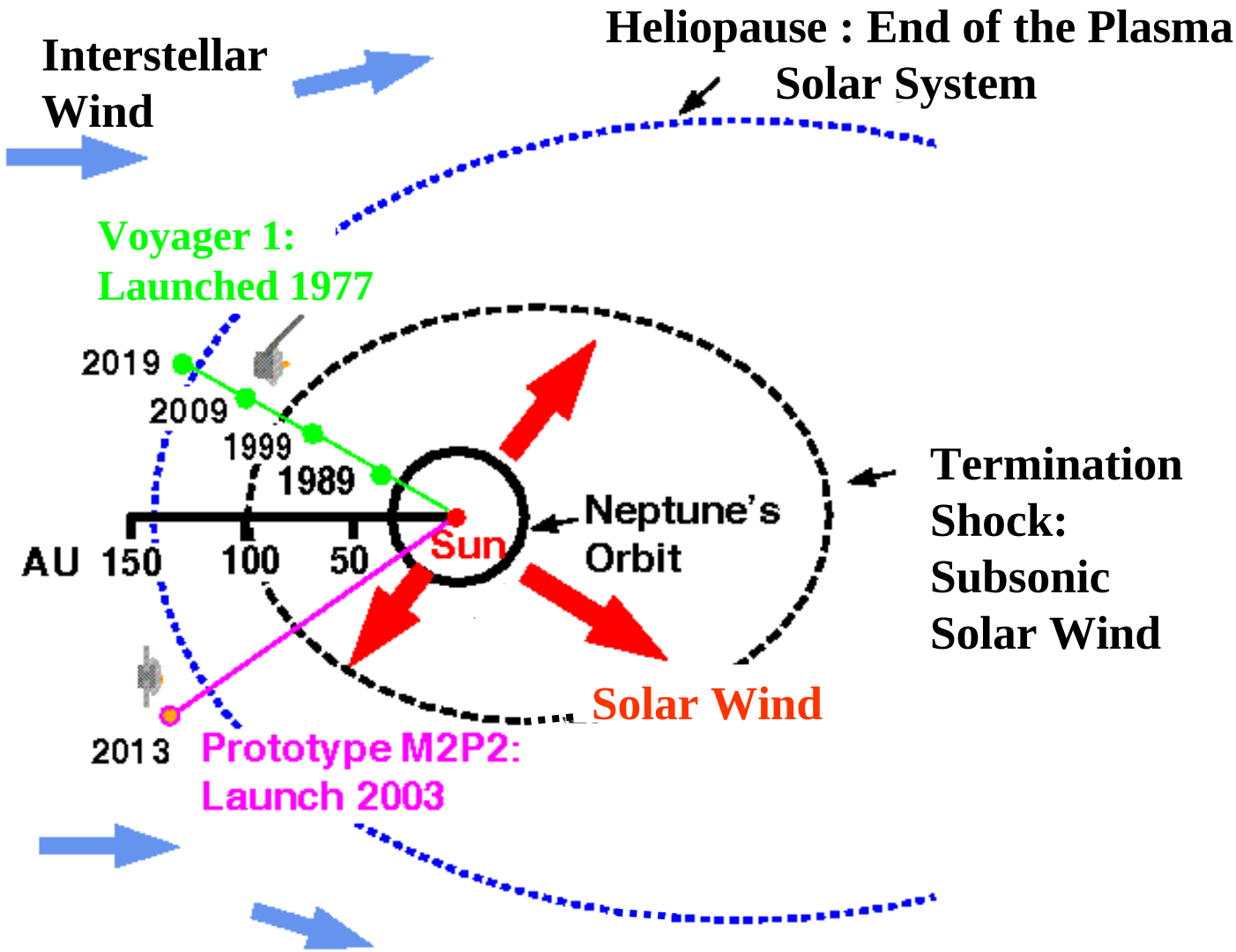
  to attain 50-80 km/s in 3 month accel. period

- Immediate Return to NASA Missions

  - Interstellar Probe Precusor

  race Voyager 1 out of the Solar System

  - Planetary Missions: Mars, Jupiter


Interstellar Wind
Heliopause : End of the Plasma Solar System
Voyager 1: Launched 1977
2019
2009
1999
1989
AU 150
100
50
Sun
Neptune's Orbit
Termination Shock: Subsonic Solar Wind
Solar Wind
2013
Prototype M2P2: Launch 2003

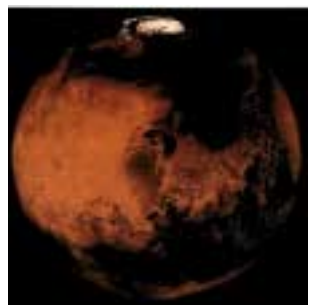
Proposed NASA Missions : Sample Return

Needed: Fast Propulsion

Radiation Shielding

Mars

(<1000 day)



The Moon

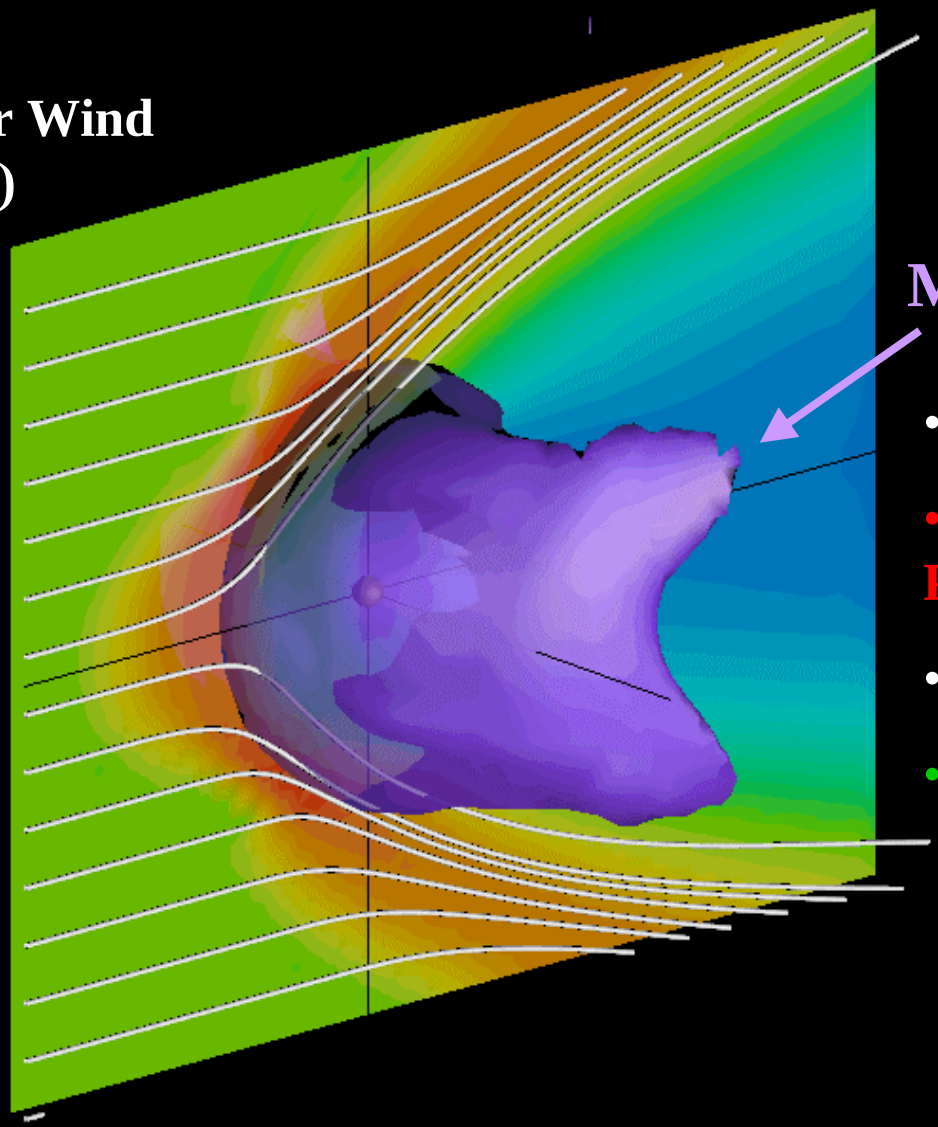
(<100 day)

Jupiter

(<5000 day)

Formation of a Magnetic Wall

Supersonic Solar Wind (400 - 1000 km/s)



Streamlines & Contours of density

Magnetic Wall

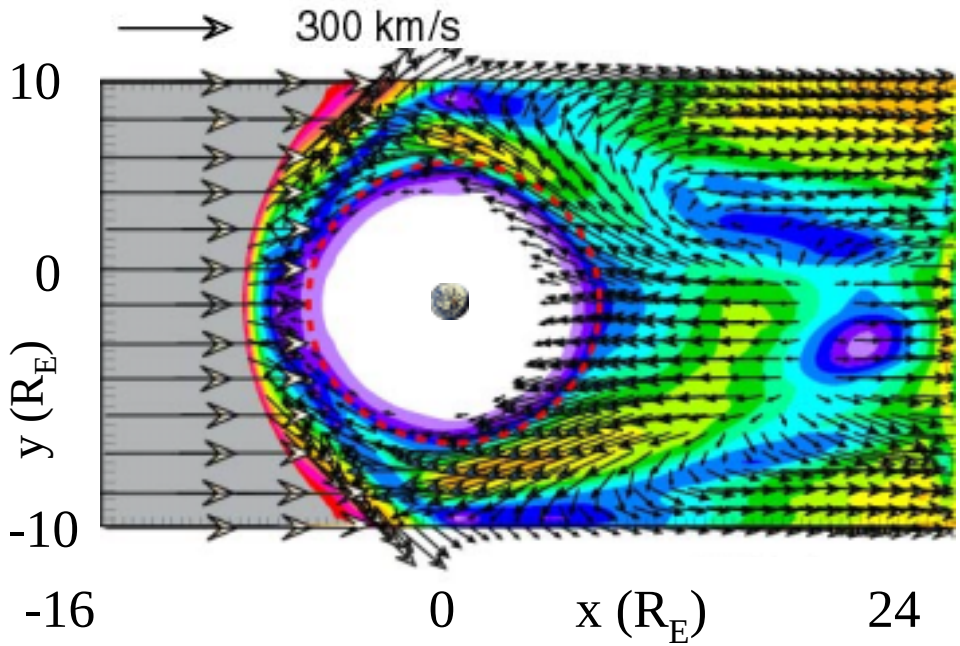
- **15 - 30 km radius**
- **Electromagnetic-Plasma Interaction**
- **Not Mechanical**
- **Constant Force Surface**

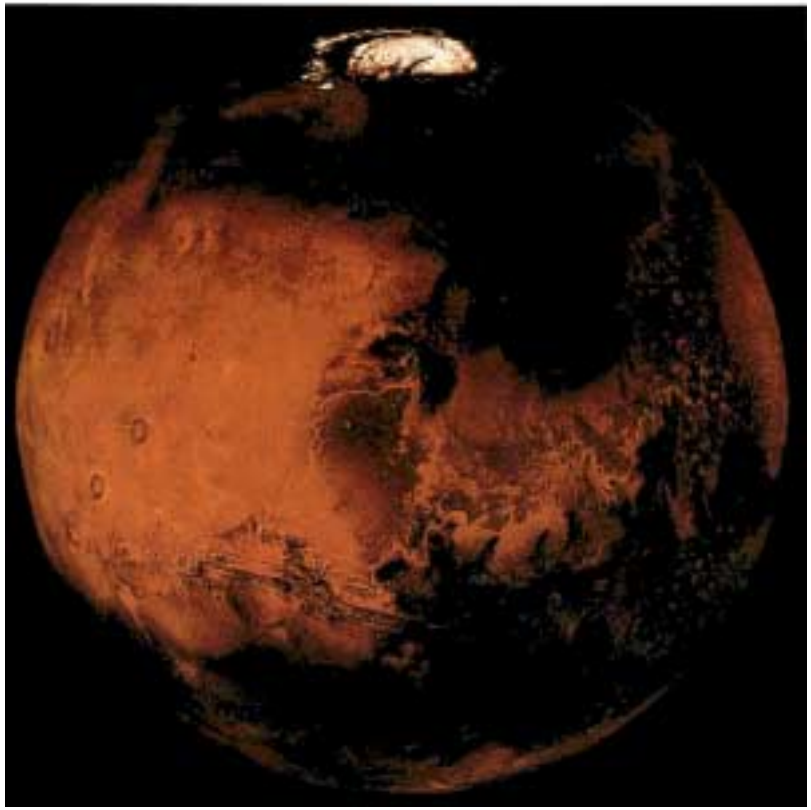
1 R_E = 6371 km

Earth

and its

Magnetosphere



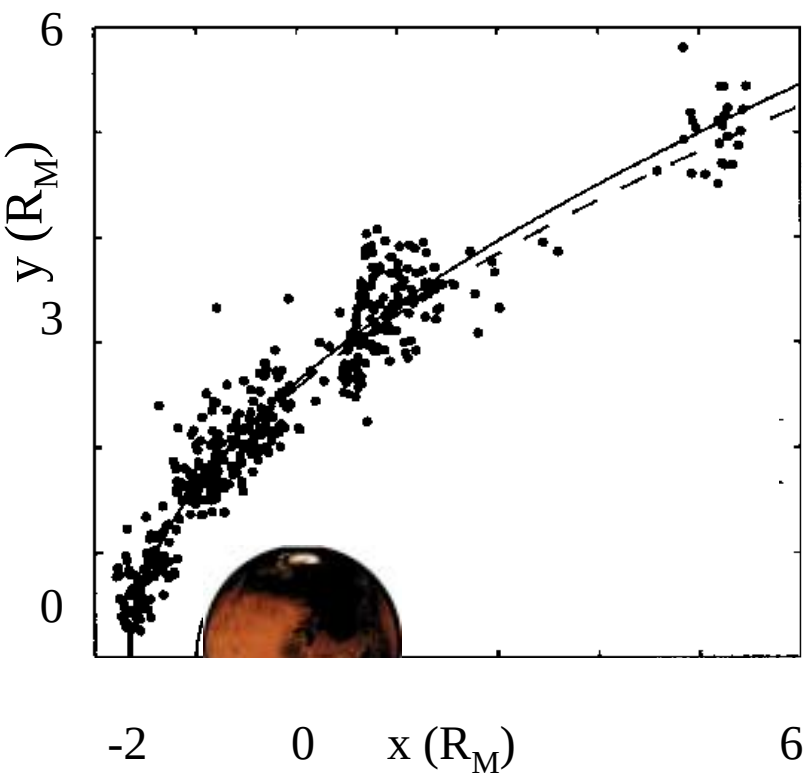


1 R_M = 3393 km

Mars

and its

Magnetosphere

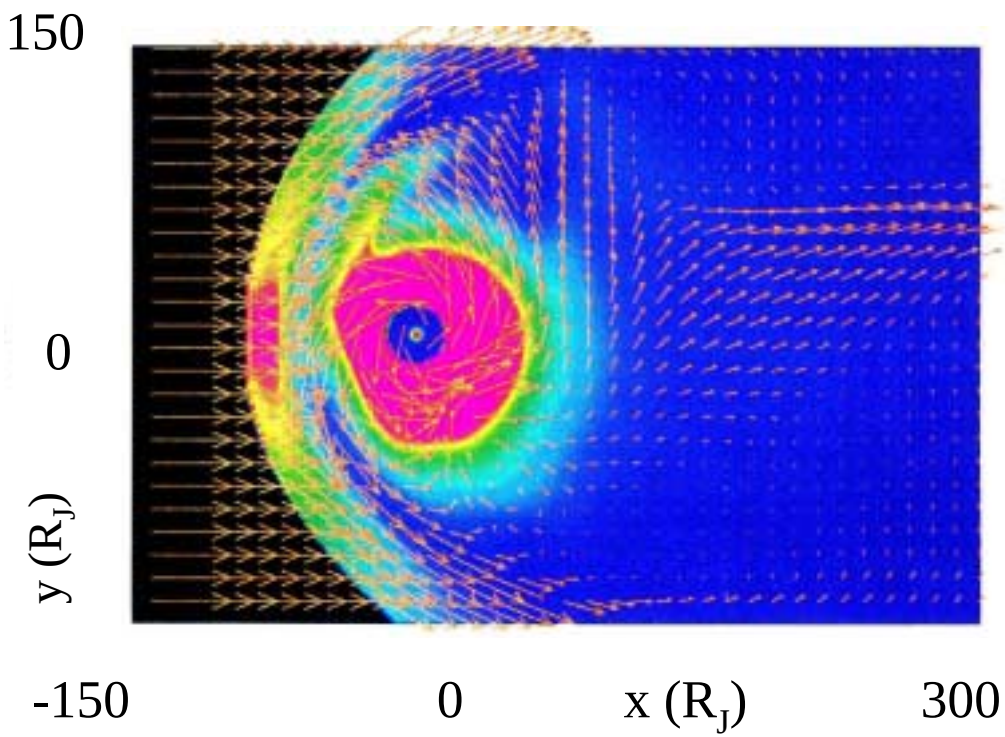


1 R_E = 71,600 km

Jupiter

and its

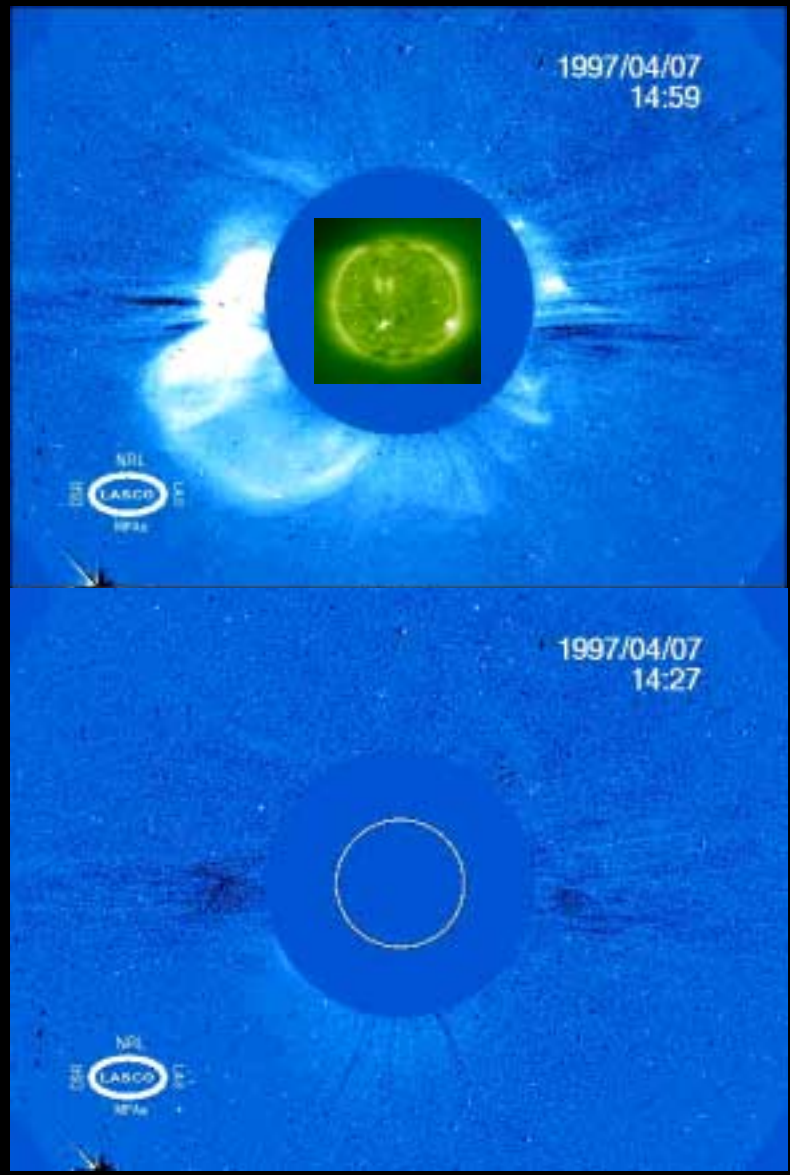
Magnetosphere



Solar Activity :

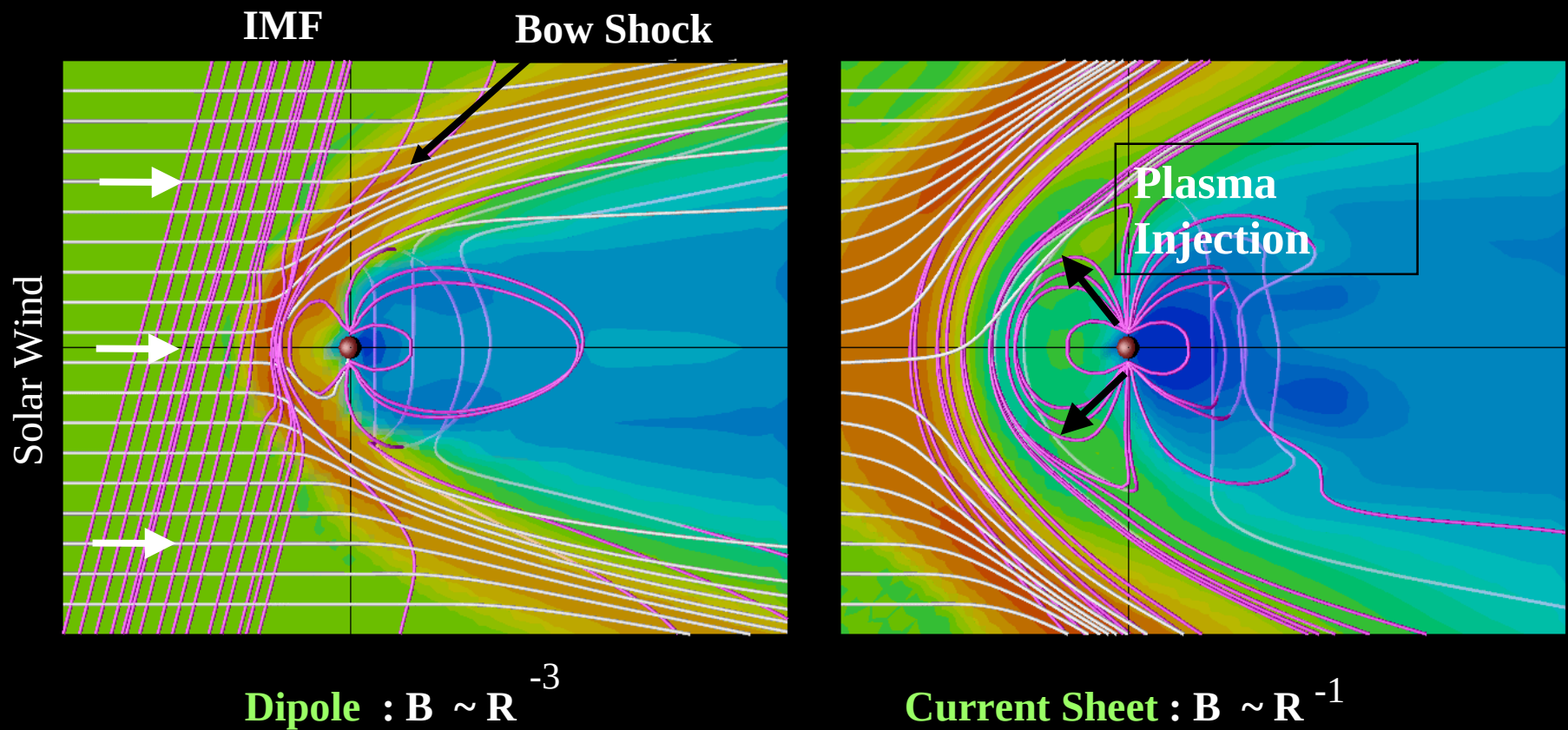
Corona Mass Ejections

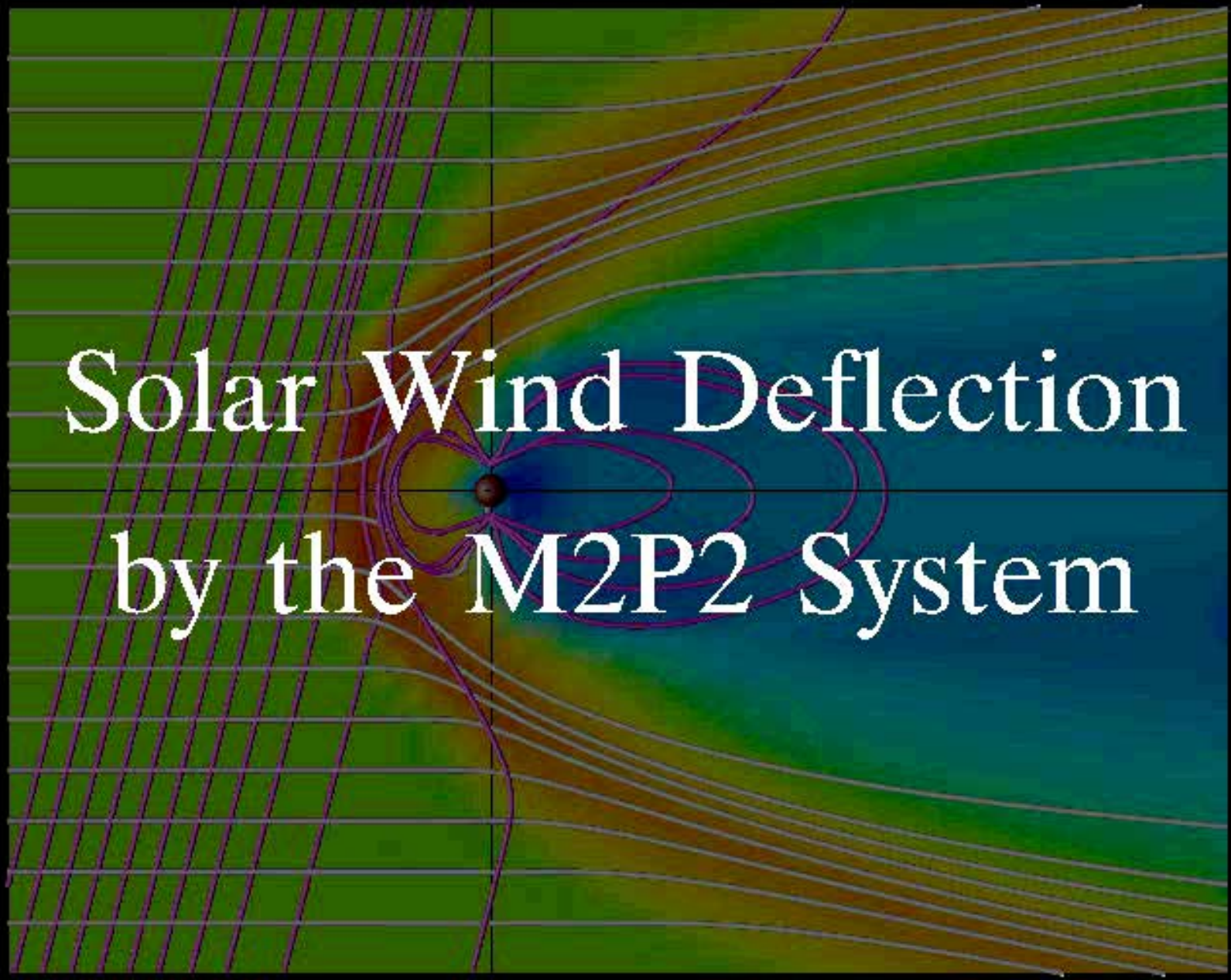
Example of Magnetic Inflation in Nature



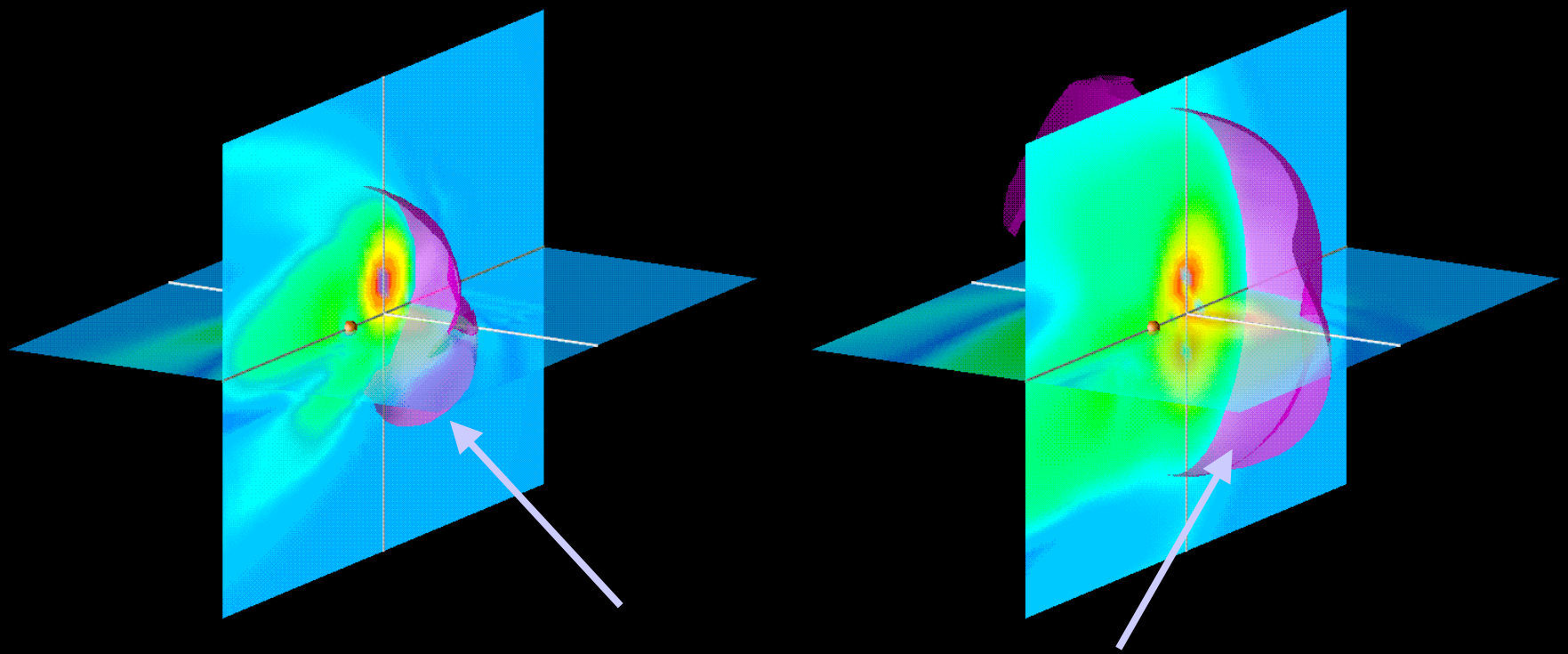
Creating A Mini-Magnetosphere

Magnetic Field + Plasma Injection = Strong Solar Wind Coupling




Solar Wind Deflection
by the M2P2 System

Magnetic Wall for Large Scale Radiation Shielding



Isosurface of Magnetic Field Intensity

M2P2 Milestones:

✓**Prove Feasibility through Computer Simulations (Phase 1)**

➢**Generation of *High Density, Strongly Magnetized Plasma***

$>10^{11}$ cm^{-3} plasma density

> 300 G magnetic field

< 1 kW of Power

~ 0.25 to 1 kg/day fuel consumption

➢**Demonstrate *Inflation* of Magnetic Field**

➢**Test Performance of *Different Propellants***

• **Demonstrate *Deflection* and *Thrust* from a Plasma Wind**

M2P2 Capabilities

- **Mini-Magnetosphere (Single Unit) : *20-30 km Radius***
  Inflation is *Purely Electromagnetic*
  ***No Large Mechanical Struts* have to be deployed**

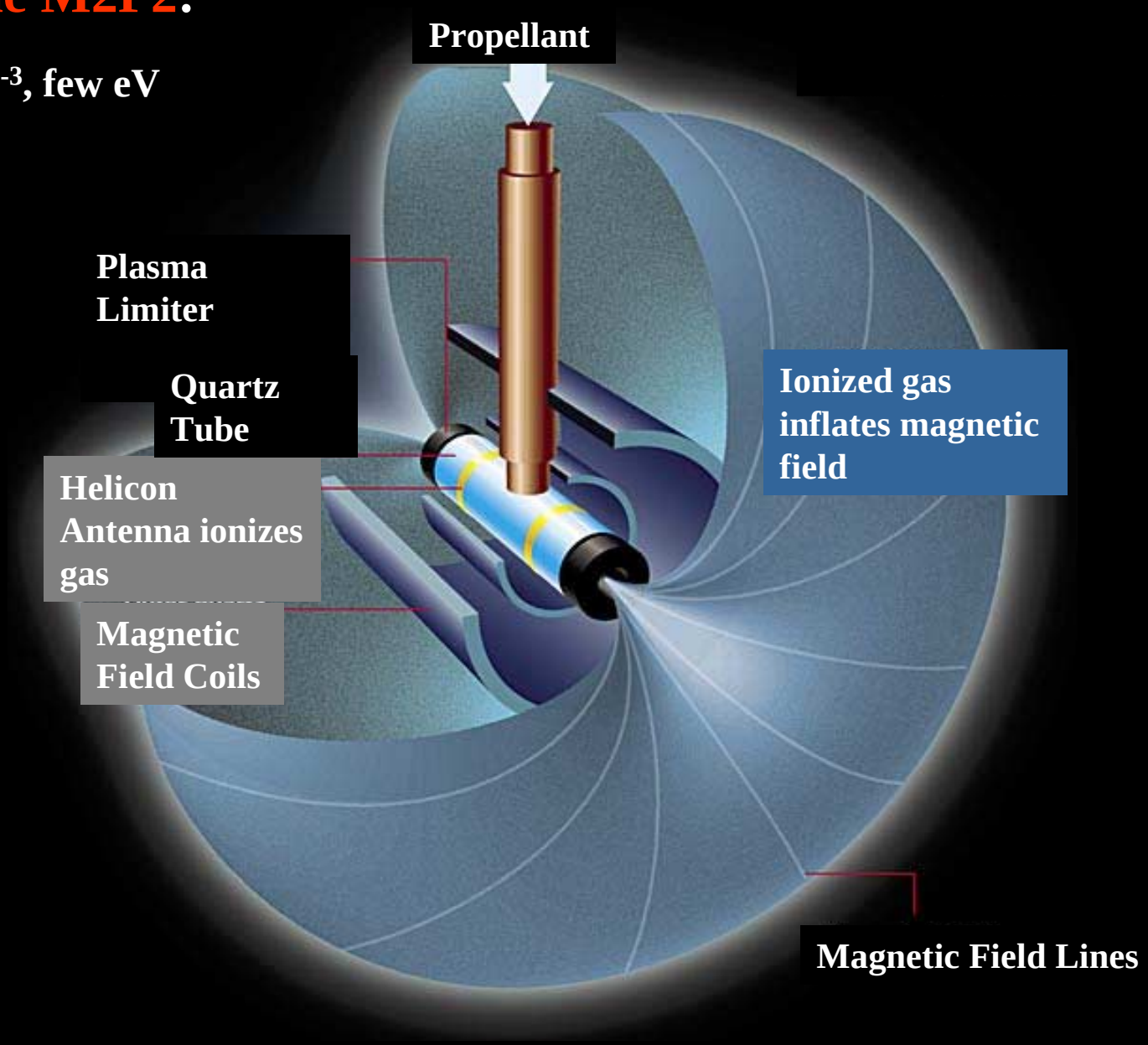
- **Intercept**
  ~ *1-3 N* of Solar Wind Force
  ~ 0.6 MW of Solar Wind Energy

- **Scientific Payload of 100 to 20 kg would attain**
  50- 80 km/s in 3 month acceleration period

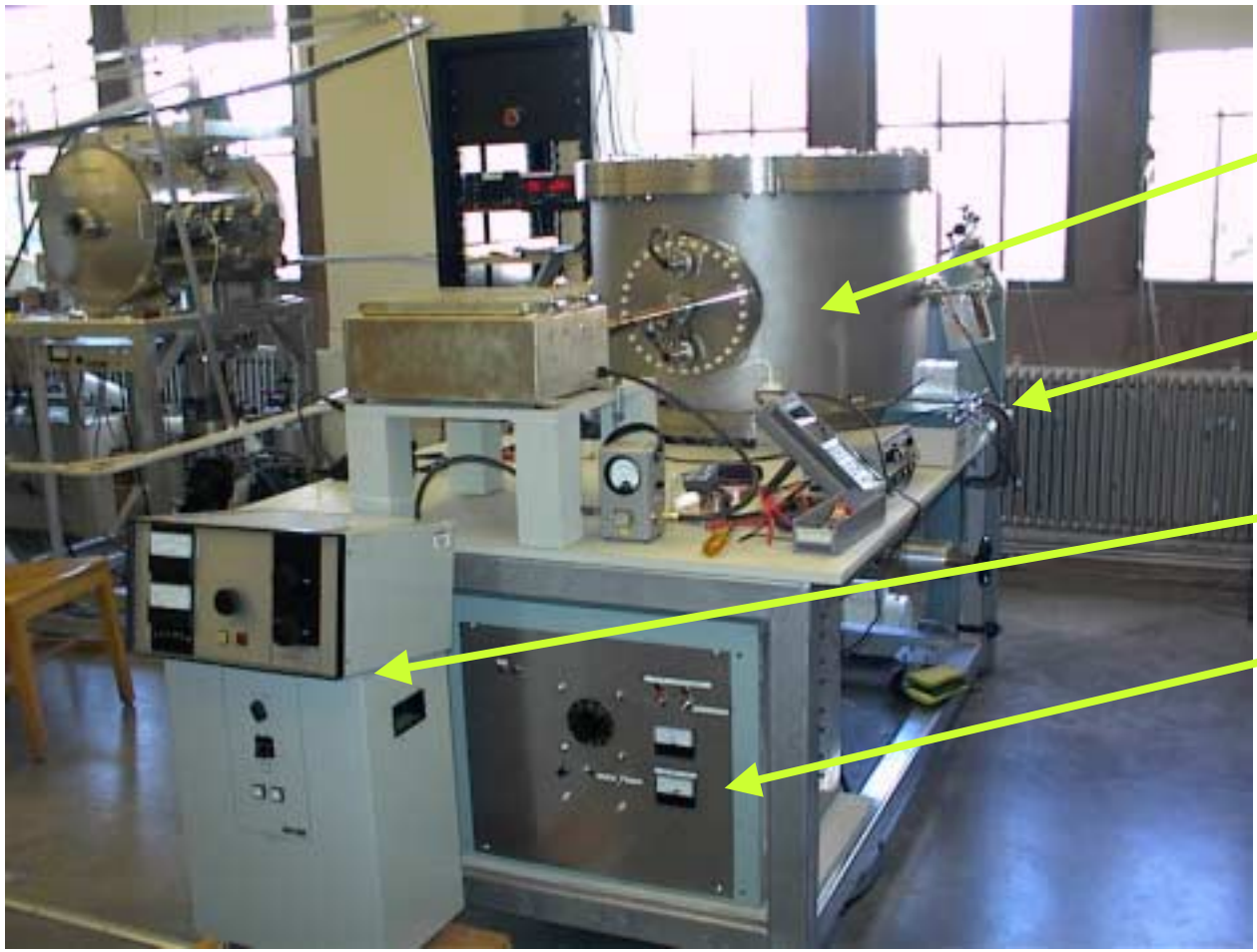
- **Economies of Scale for Multiple Units**

Inside the M2P2:

- ~ 10^{11} cm^{-3}, few eV
- ~ 400 G



Experimental Arrangement



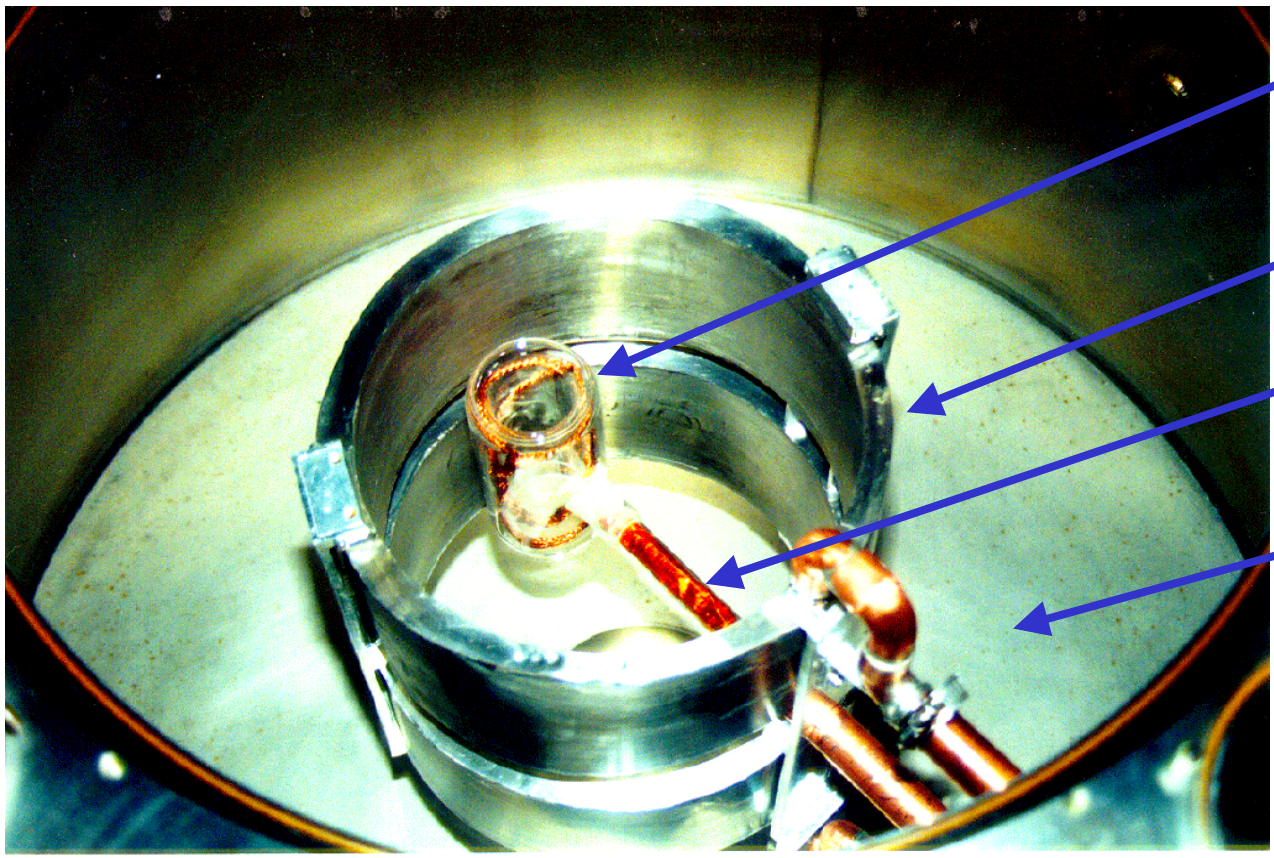
400 Liter Vacuum Chamber

Propellant Bottle

RF Amplifier

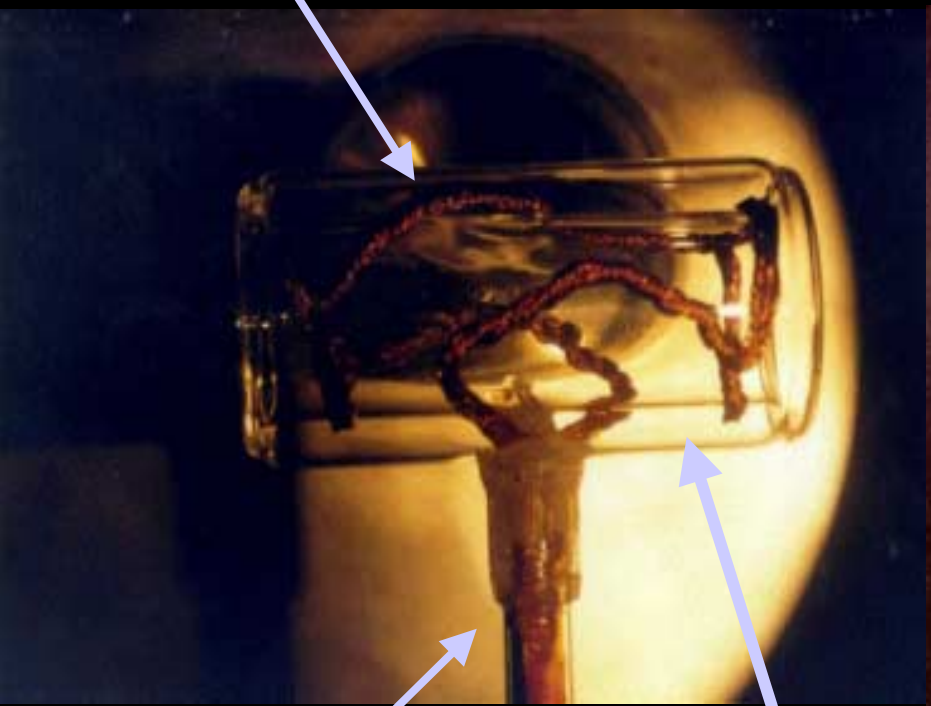
Power Supply

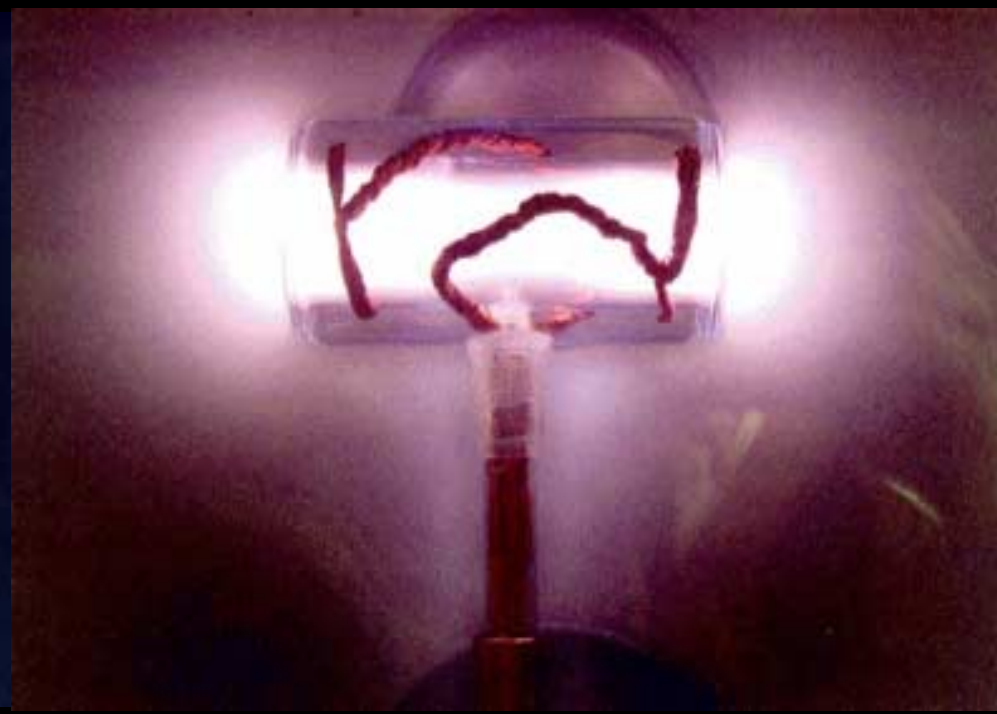
Experimental Arrangement
Top View



Helical single turn coil
5cm OD (Copper braid)

Helium: 40 mTorr, No magnetic Field



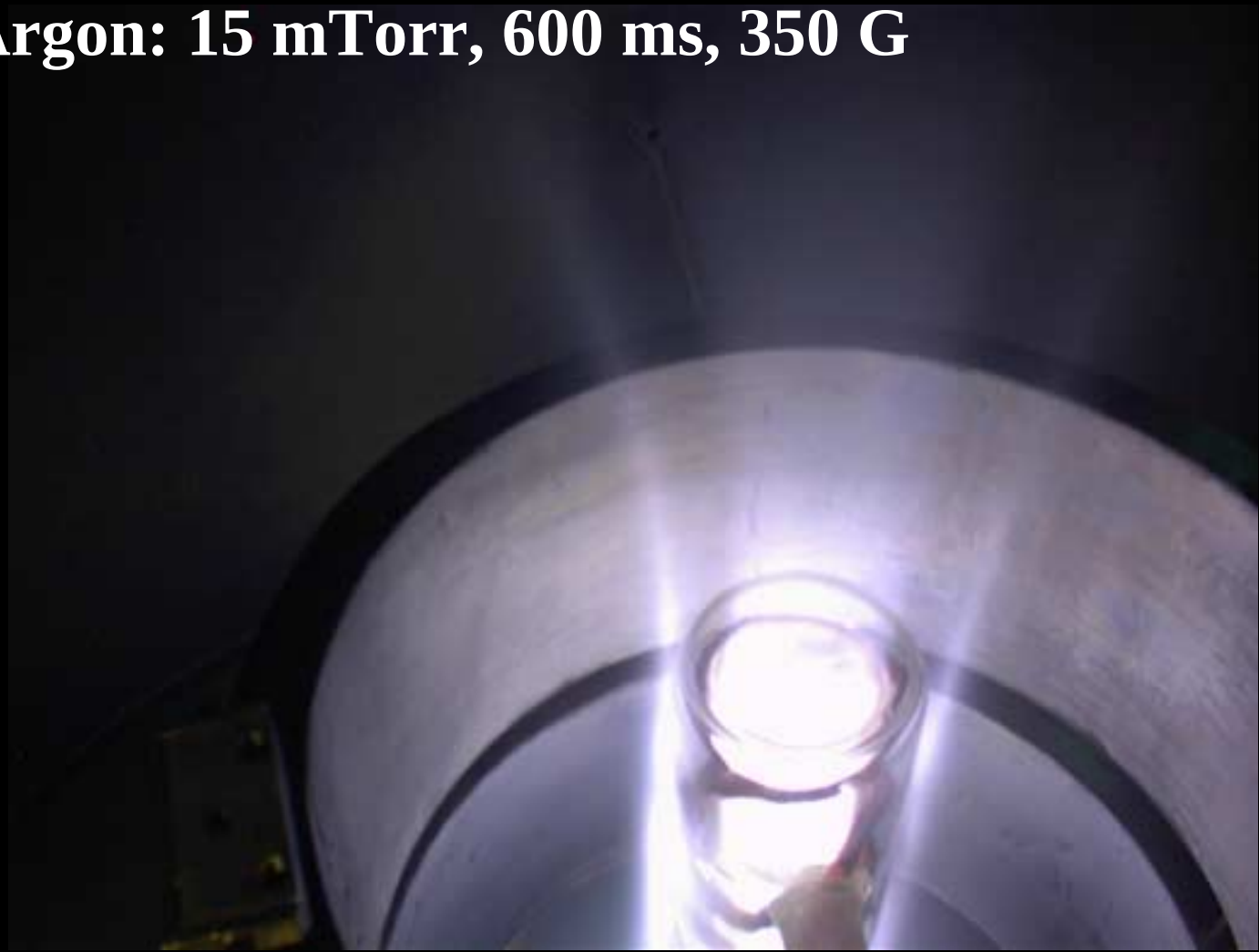


Center gas feed

Quartz encasement

Laboratory Helicon Antenna Design

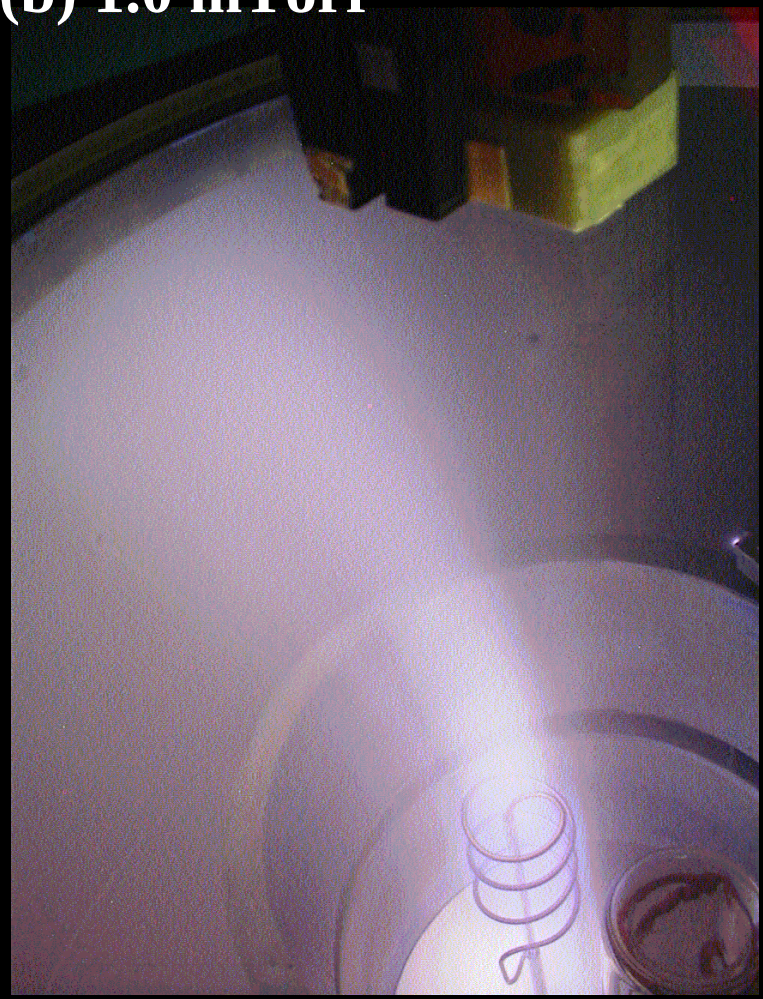
Argon: 15 mTorr, 600 ms, 350 G



Argon: 350 G, 250 msec exposure, 200 W input

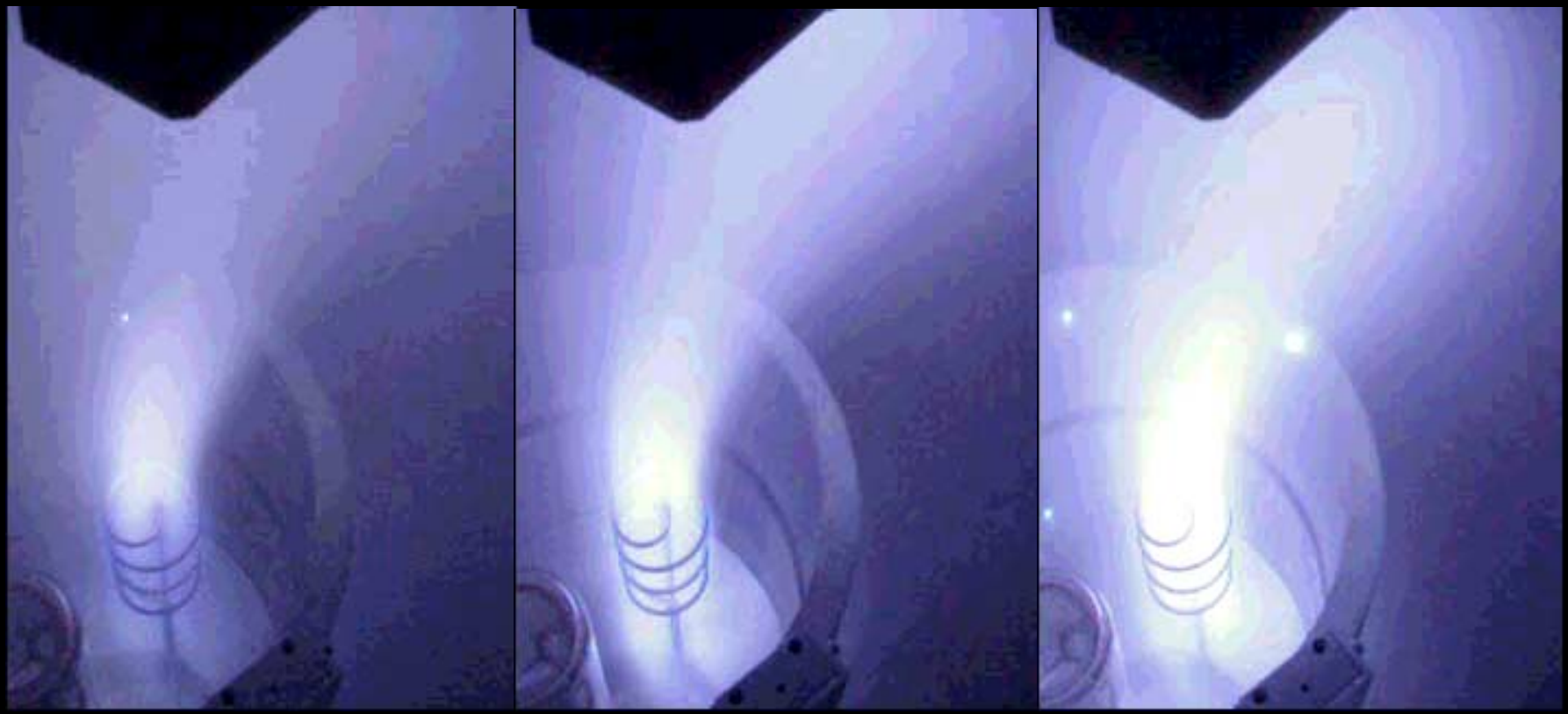
(a) 0.25 mTorr

(b) 1.0 mTorr



✓Plasma Production: ~ 10^{12} cm^{-3}

Argon: 500 G 2 mTorr, 280 W, 250 msec duration – frames from an mpeg movie



✓**Motion of Field Lines**

Nitrogen: 0.5 mTorr, 350 G,

1200 ms, 500 W

Helium: 4.0 mTorr, 350 G,

1200 ms, 500 W

✓ **M2P2 has flexibility in propellant to be used**

Mini-Magnetospheric Plasma Propulsion

New Approach for Rapid Exploration of the Solar System

- Description
  - Create a magnetic bubble around and attached to a spacecraft that will then be carried by the solar wind.
  - Low energy plasma is used to inflate the magnetic field to produce a large cross-section (15-30 km) requiring about 3-9 mN of force, 1 kilowatt of power and 0.25 – 1.0 kg/day

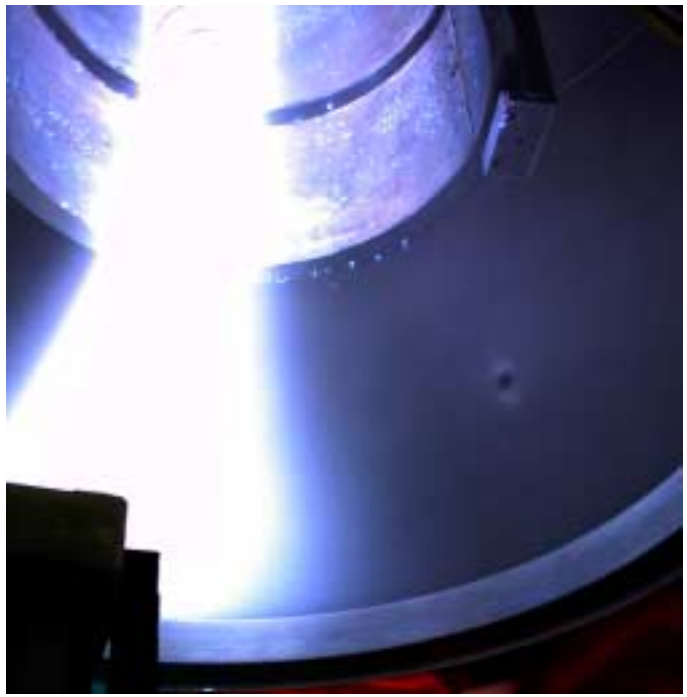
- M2P2 - Low-Cost Advanced Propulsion
  - Intercept 1-3 N of force
  - 0.6 MW of solar wind power
  - Accelerate a spacecraft of 100-200 kg to 50-80 km/s with an acceleration period of about 3 months using only about 15 to 30 kg of propellant.

- Economies of Scale with Multiple Units
  - Reduction of Surface to Volume Ratio
  - Lead to smaller losses of plasma from the mini-magnetosphere

- M2P2 - **Magnetic Radiation Shield**
  - At a radius of few 100 km reflect MeV and possibly GeV cosmic rays
  - Ideally suited for Human Exploration

Mini-Magnetospheric Plasma Propulsion

Technology Readiness Level and Potential Applications



- Working Lab. Prototype
  - Small Facility at Univ. of Washington
  - Preparing for a Large Tank Test at NASA-Marshall
- Potential Applications: Interstellar Precusor Mission
  - LEO De-orbiting
  - Geosynchronous Station Keeping
  - Geosynchronous to Escape Velocity
  - High Speed Planetary Orbit Transfers
  - Magnetospheric/Solar Wind Braking

- Variety of Propellants Possible
  - –Argon or Helium (for lab use)
  - –Liquid Hydrogen
  - –Water – refueling in space
  - –Waste Products : CO_2, NH_3