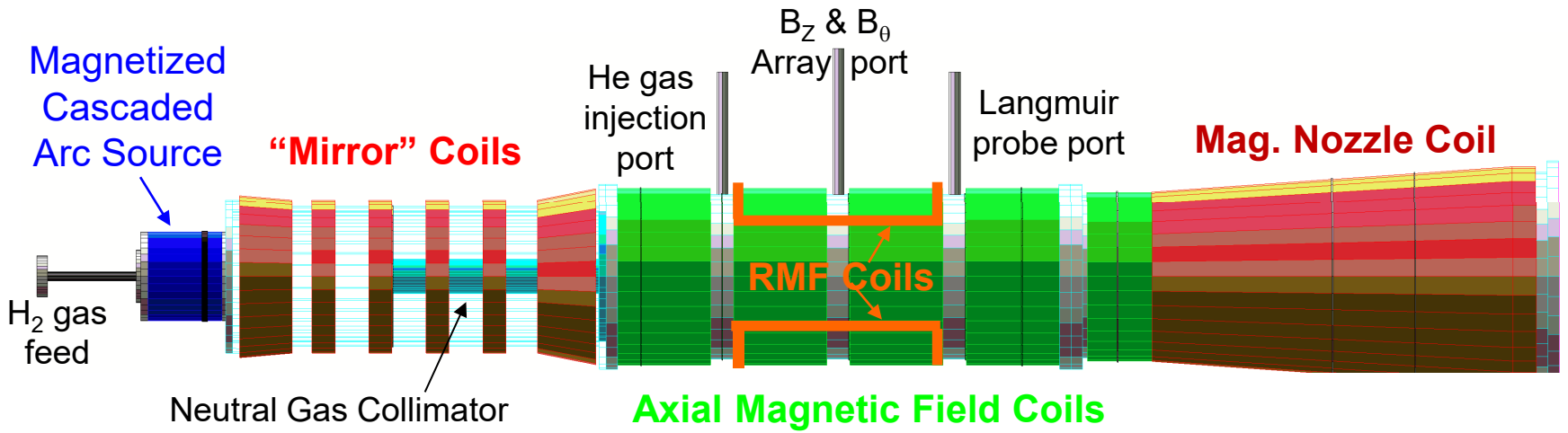
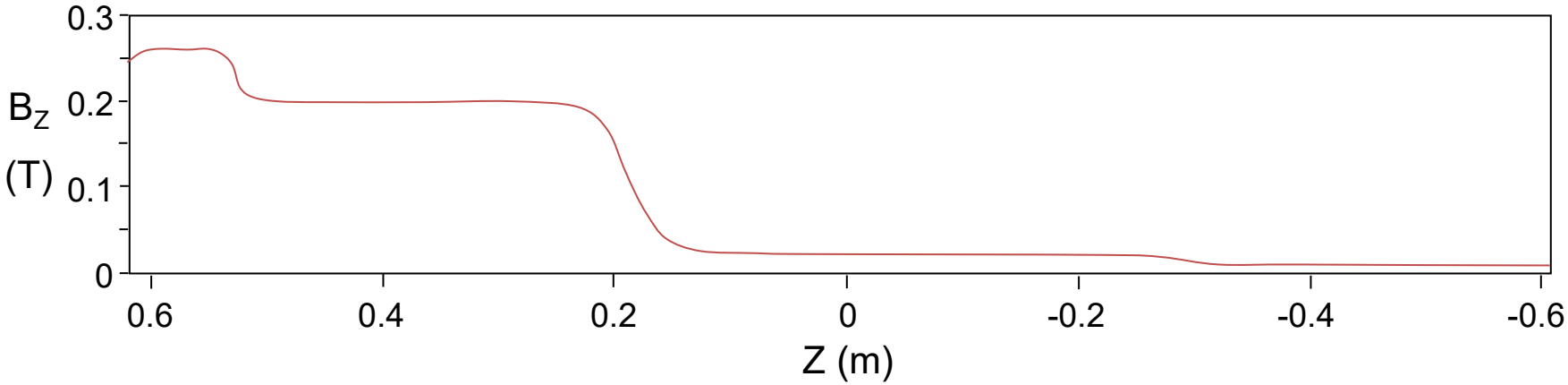
A Harvesting Planetary Orbiter to Enable Deep Space Missions to the Jovian Planets

John Slough
MSNW LLC
sloughj@msnwllc.com

2023 IEEE Aerospace Conference
Big Sky, Montana
March 4 - 11, 2023

STX-HF Experimental Layout

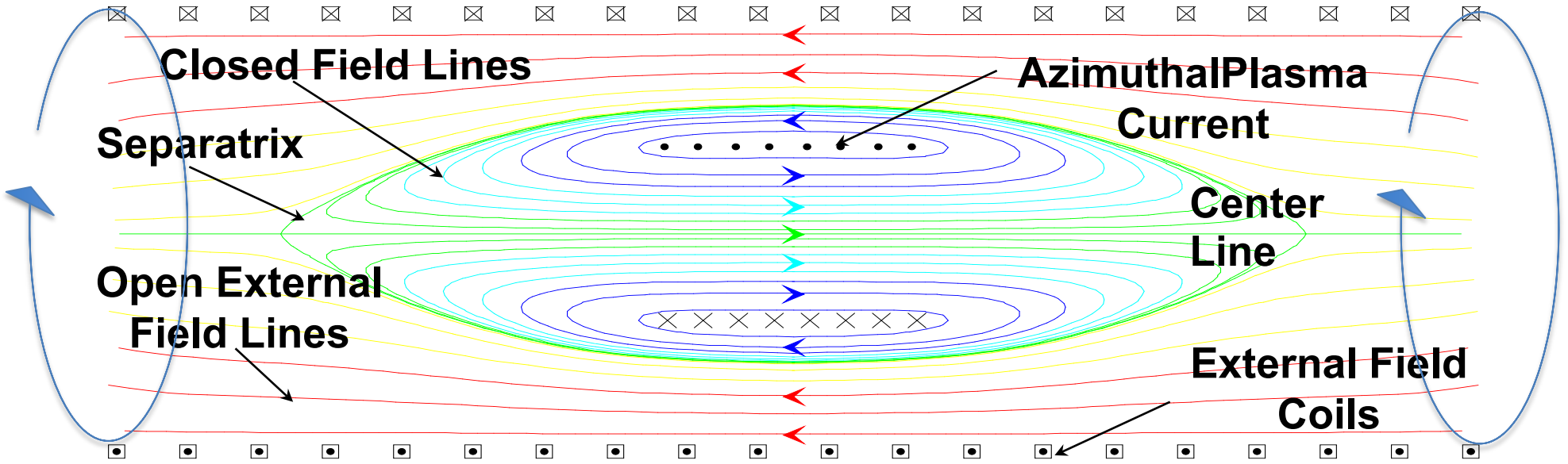




The Startup Experiment at High Flux (STX-HF) that demonstrated the essential physics to be employed in HarPO

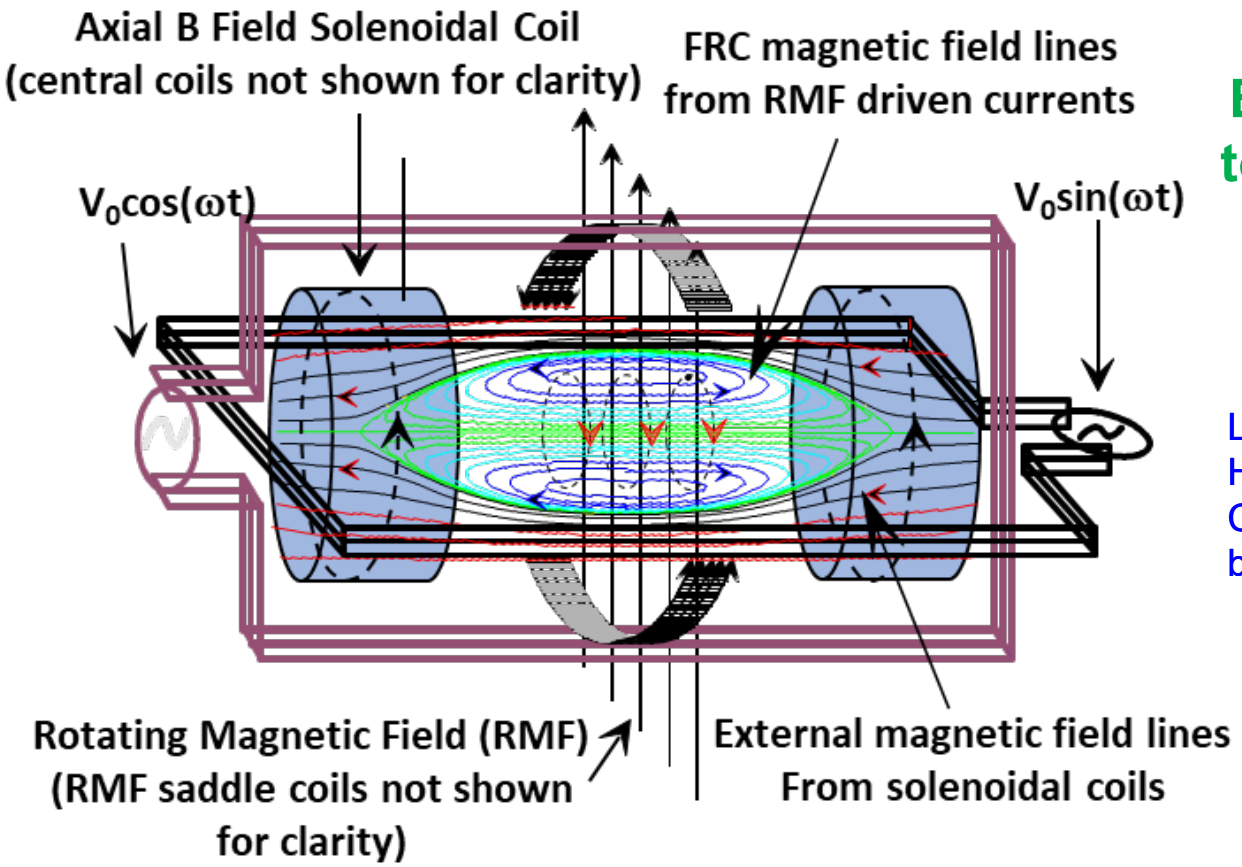
The Field-Reversed Configuration (FRC) Plasma

A self confined plasma current ring, held and confined by an external axial magnetic field



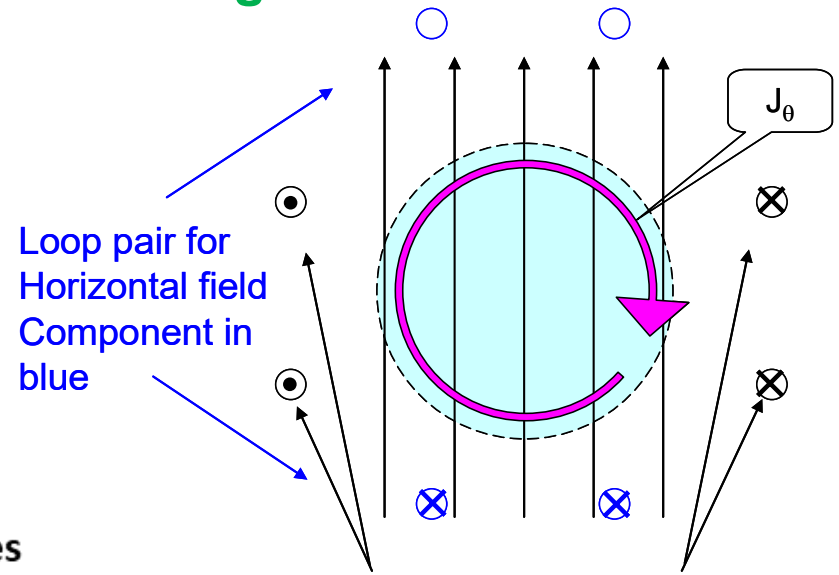
$$\beta \sim 1, \quad P_{interior(B=0)} \sim (B_{external})^2/2\mu_o$$

Rotating Magnetic Field (RMF) Generation of the FRC Plasma

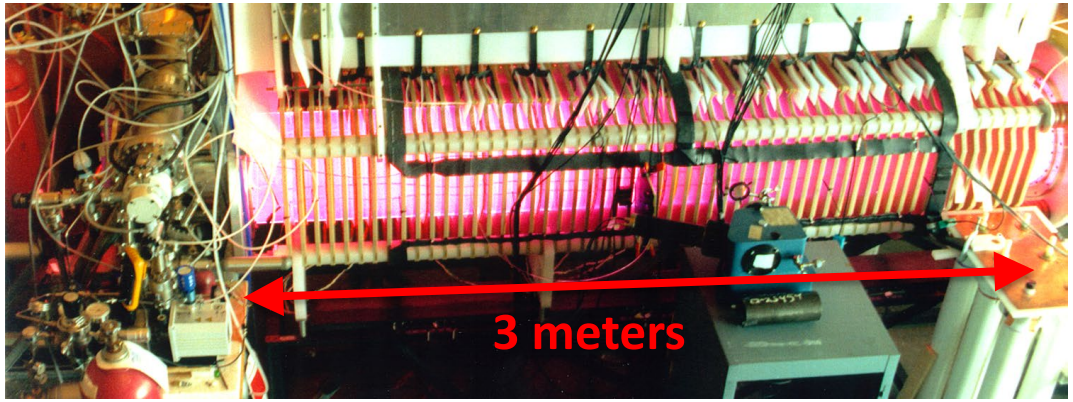


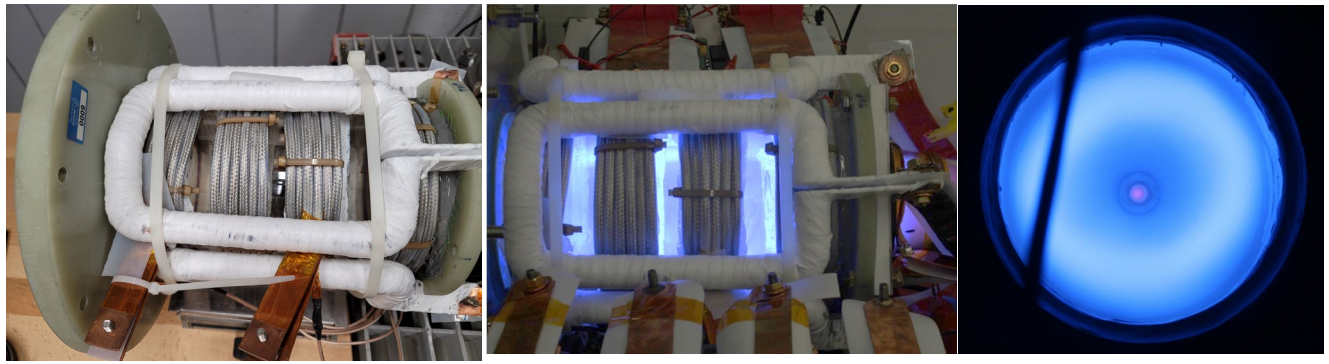
A simple Picture:

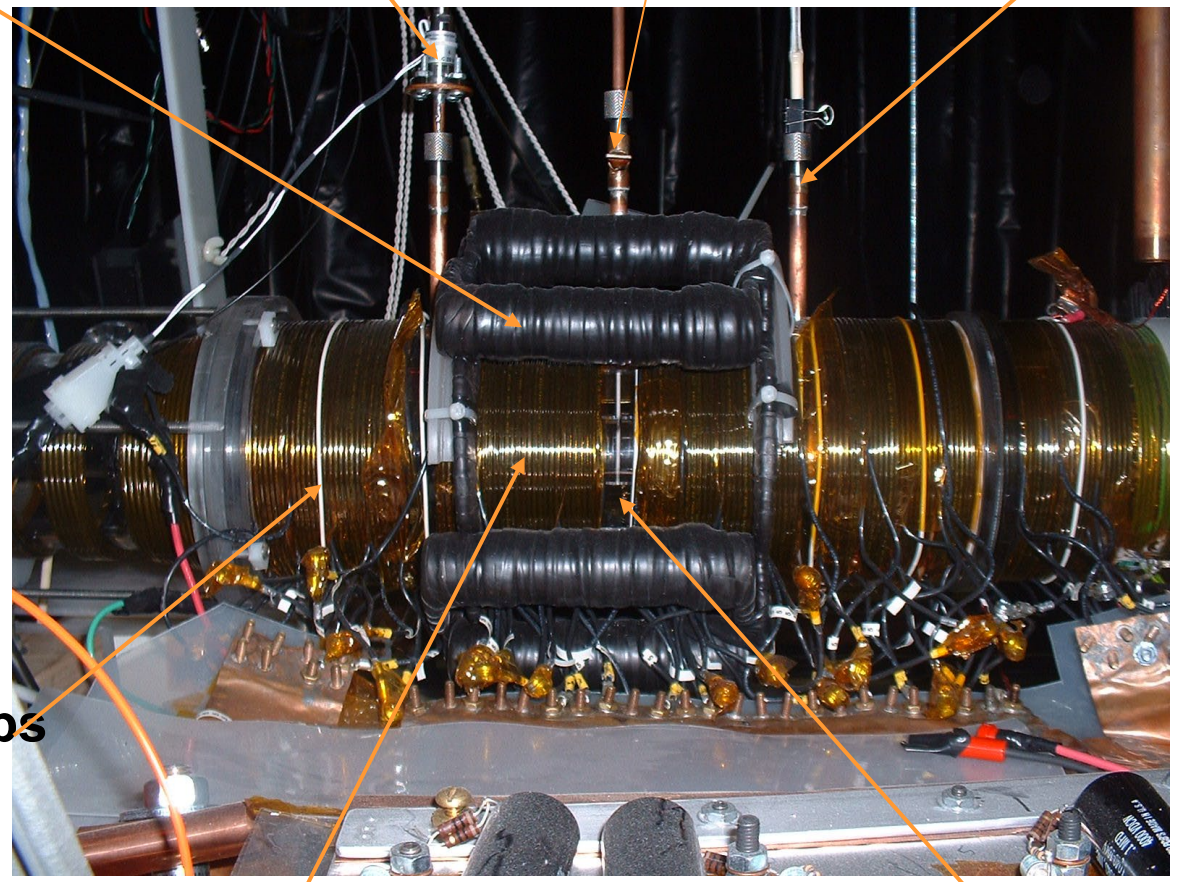
Electrons rotate with RMF, but ions do not due to much greater inertial mass ⇒ large θ current



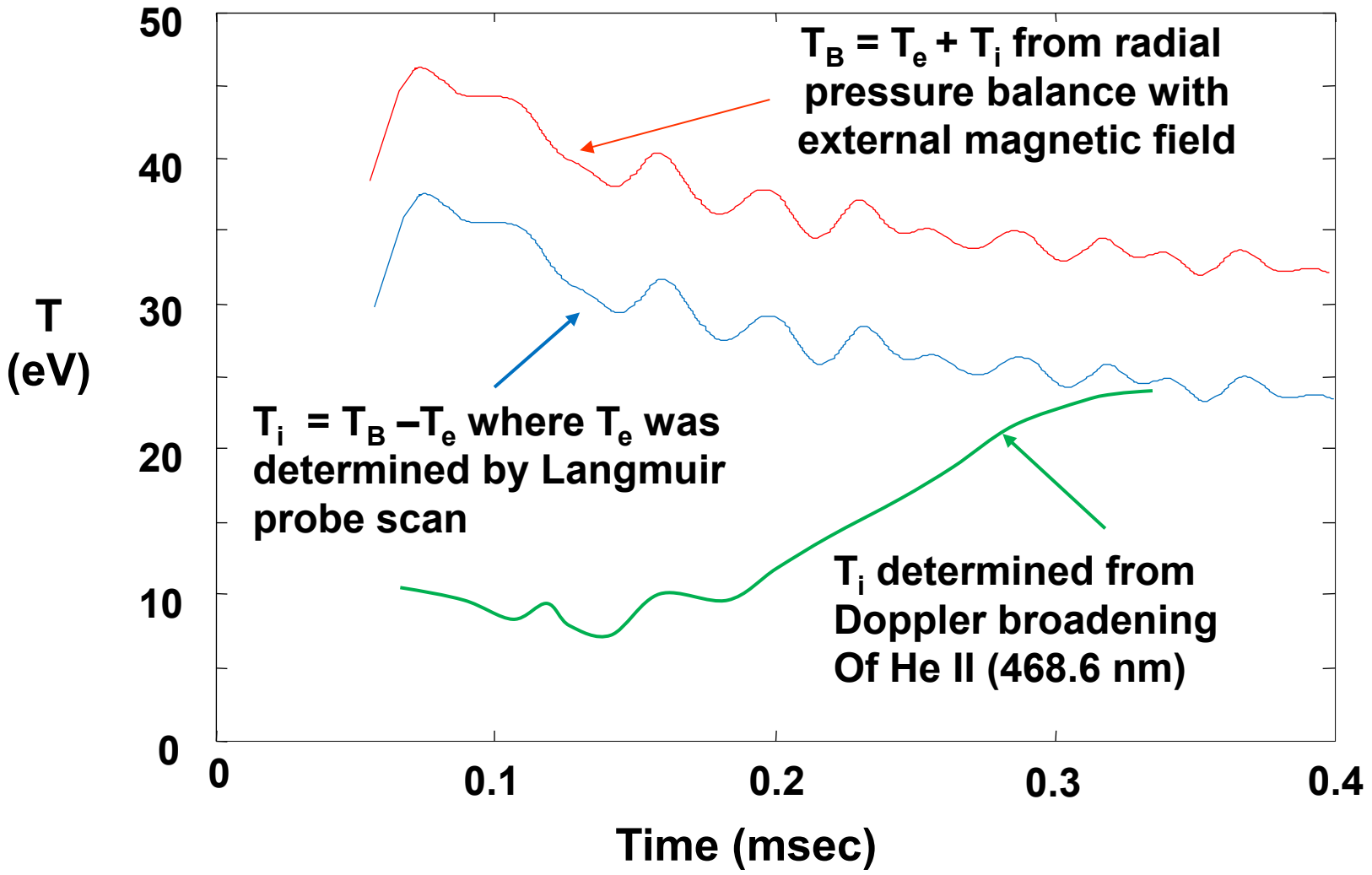
External loop antenna pair for vertical component of Rotating Magnetic Field



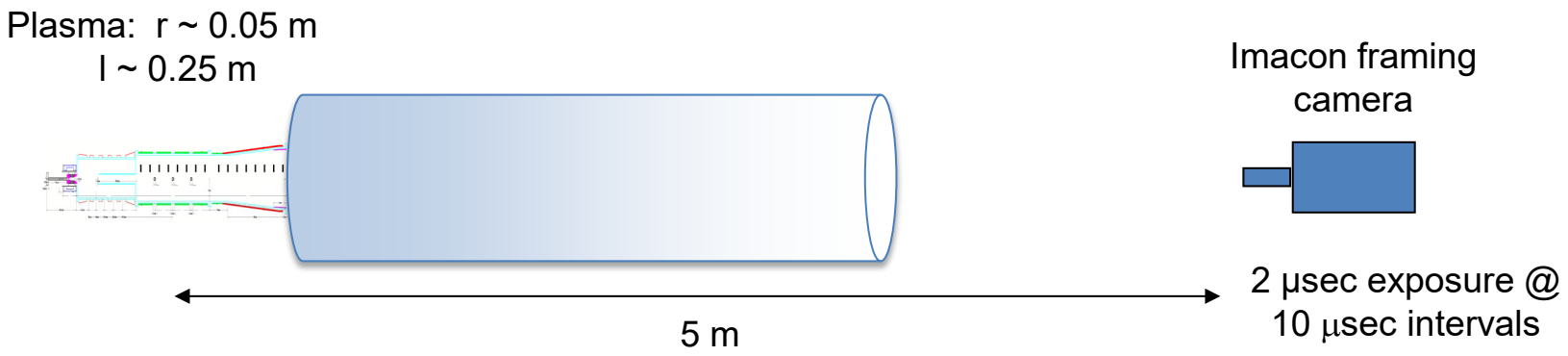


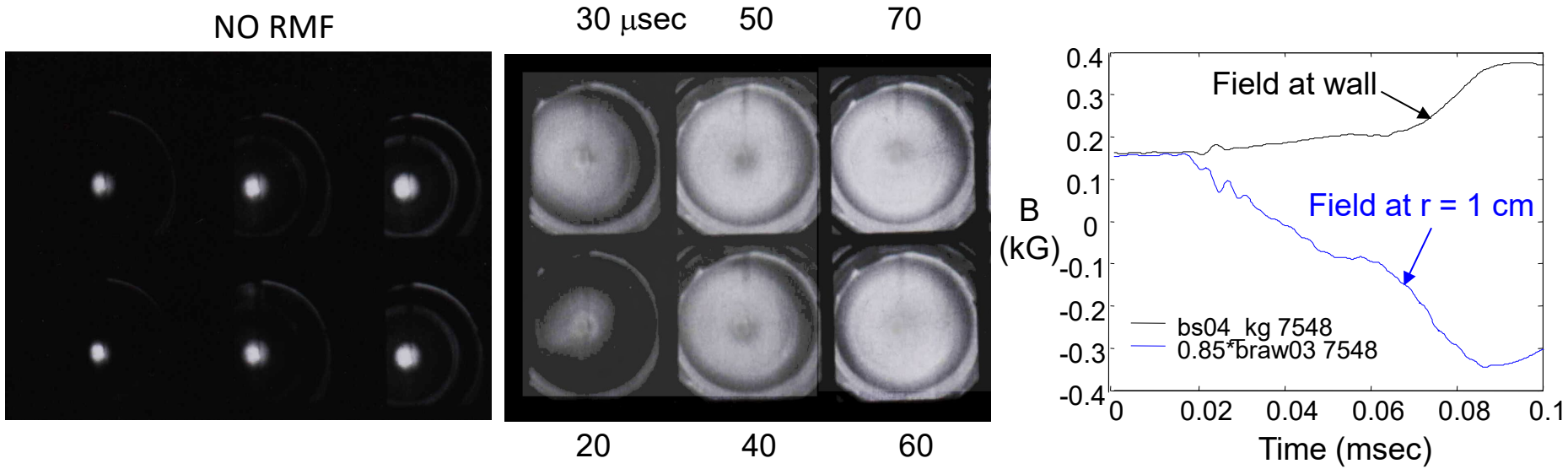

Helium needle injector
w fast puff valve
RMF coils
Internal B probe
Langmuir probe
Source
STX main
chamber
Flux loops
Parallel-fed, 14 turn
B field coil
Window access for Doppler
Spectroscopy

Ion Temperature Measurements with He Injection

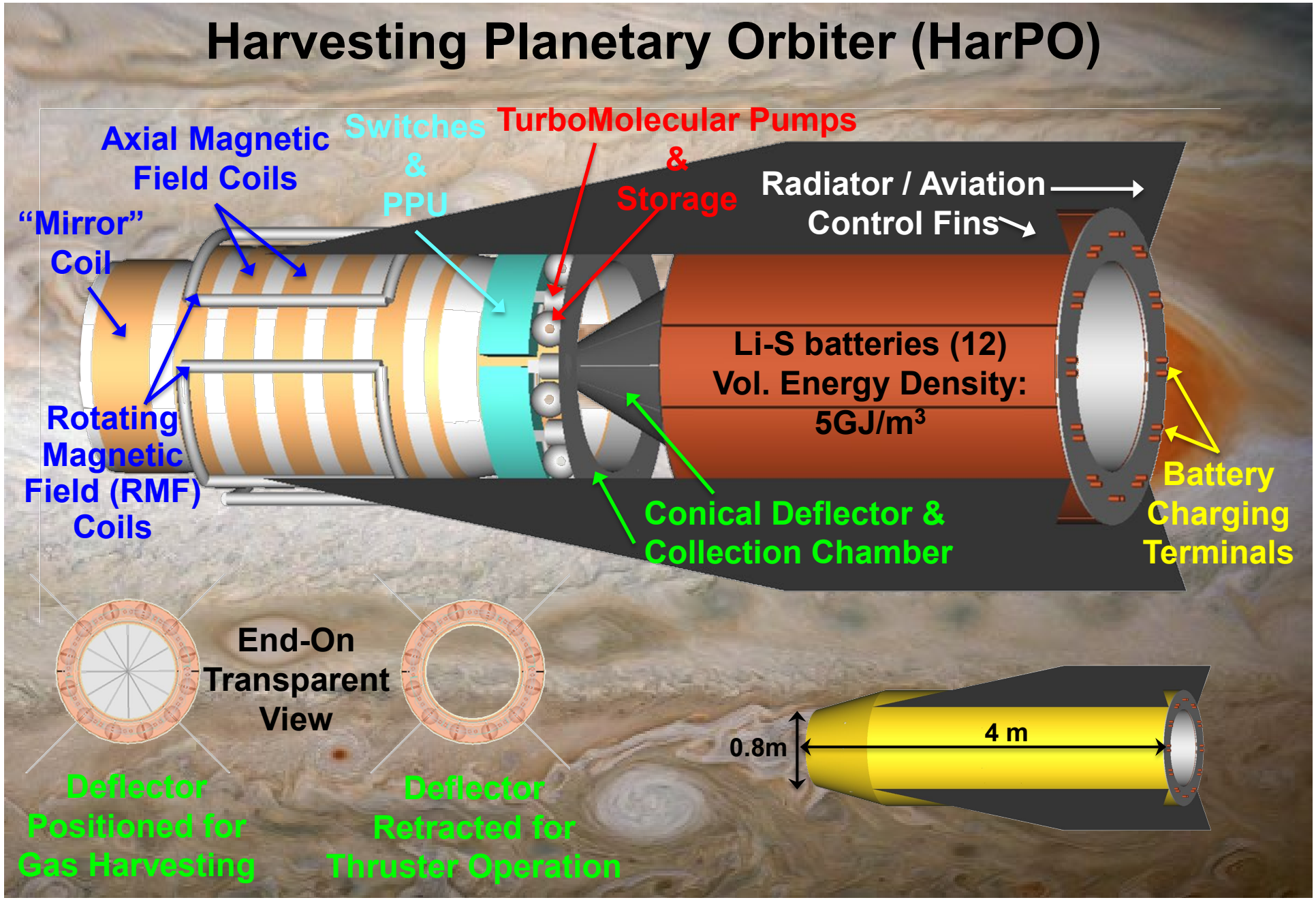


End-on Filtered (510-600 nm) Plasma Emission

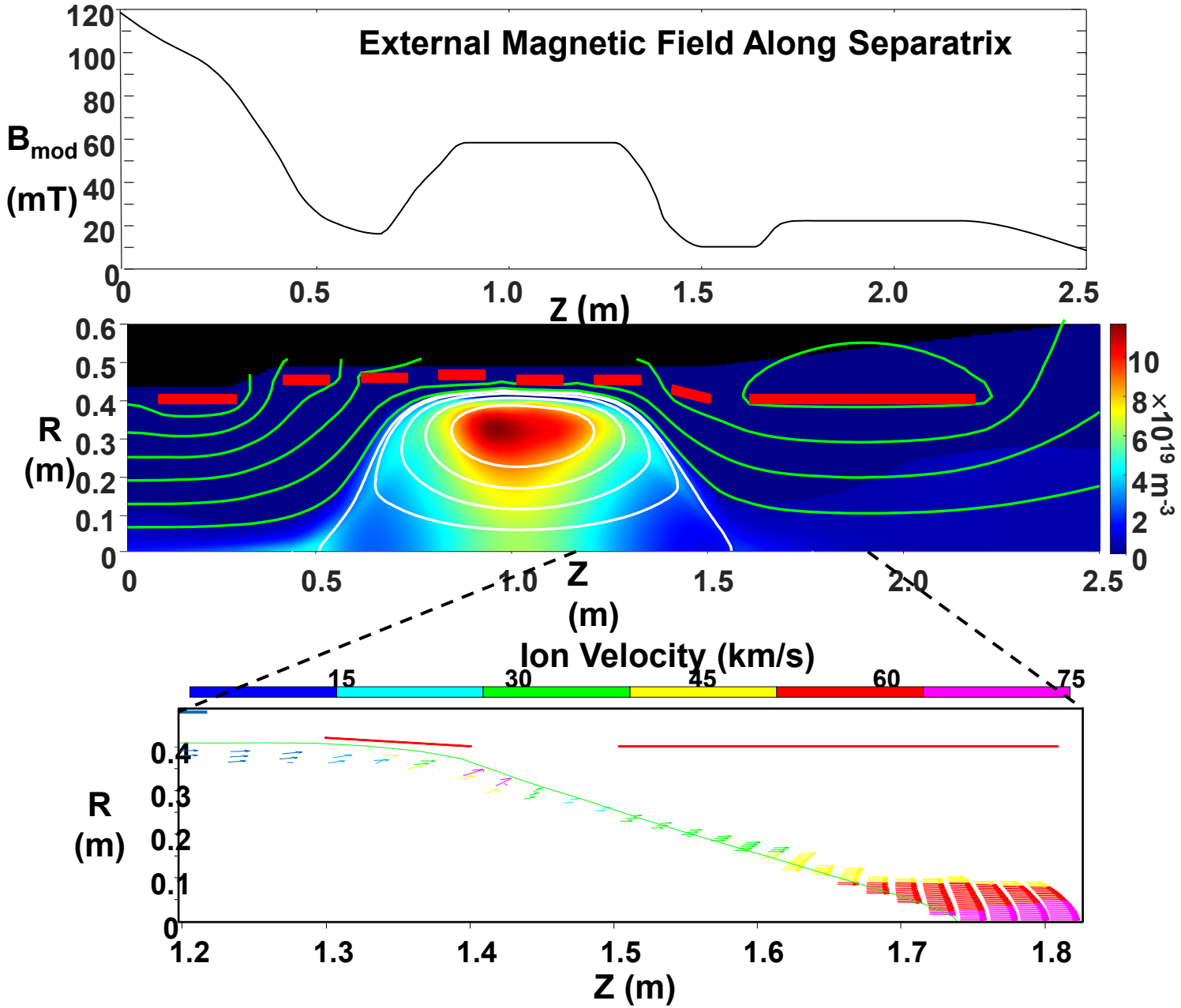




Filter eliminates Hα and Hβ line radiation. In "No RMF "case: emission is brighter primarily due to Hydrogen molecular band radiation which is greatly diminished by dissociation with the RMF


Harvesting Planetary Orbiter (HarPO)
Axial Magnetic Field Coils
Switches & PPU
TurboMolecular Pumps & Storage
Radiator / Aviation Control Fins
"Mirror" Coil
Li-S batteries (12)
Vol. Energy Density:
5GJ/m3
Rotating Magnetic Field (RMF) Coils
Conical Deflector & Collection Chamber
Battery Charging Terminals
End-On Transparent View
0.8m
4 m
Deflector Positioned for Gas Harvesting
Deflector Retracted for Thruster Operation

2D MHD Analysis of the Harvesting Planetary Orbiter



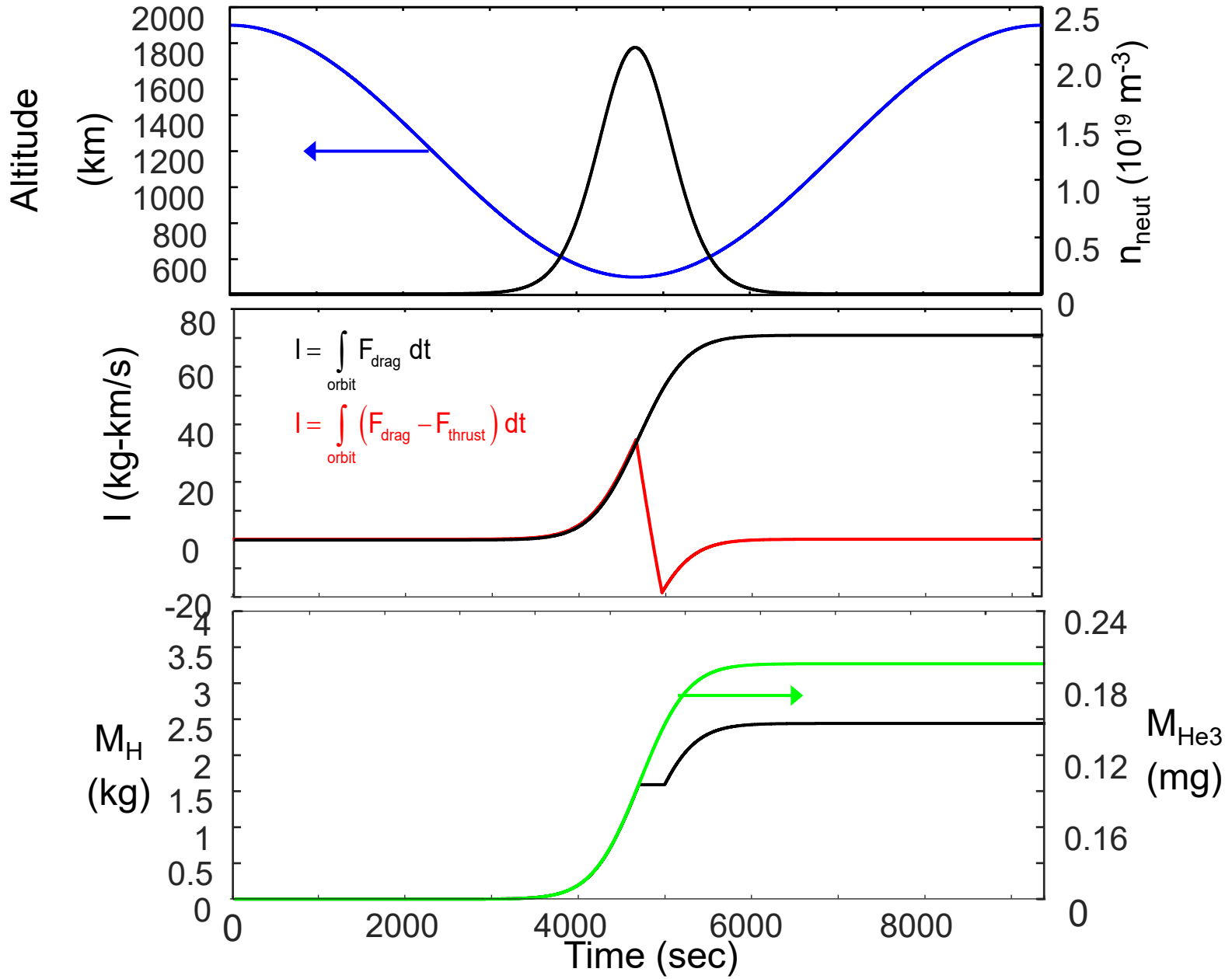
Magnetic field magnitude experienced by particle lost across the FRC plasma separatrix.

(Middle) Magnetic field lines and plasma density contours for HarPO RMF FRC equilibrium.

(Hydrogen plasma density scale is in units of 10^{19} m^{-3})

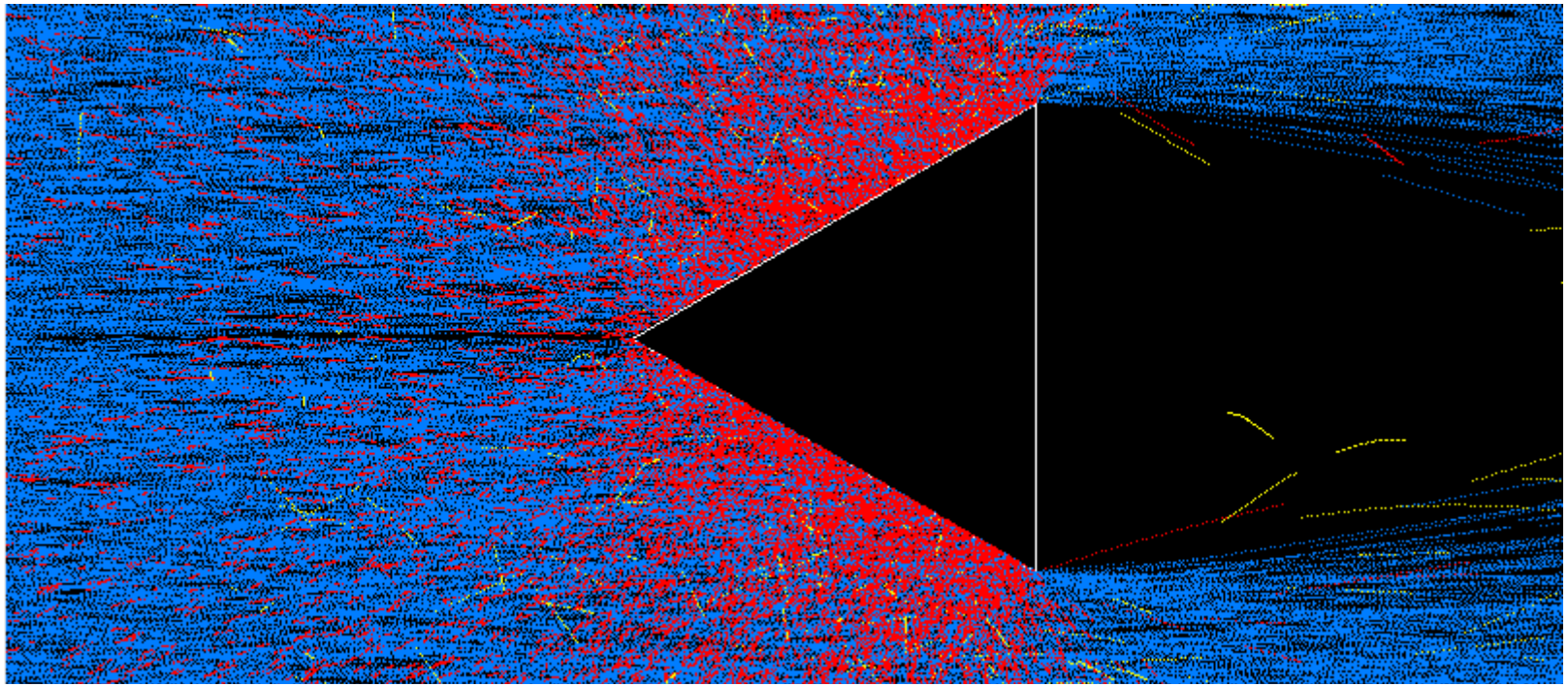
(Bottom) Velocity vectors of plasma near the separatrix. The vector length reflects local plasma density.

Key Parameters during HarPO elliptical orbit at Neptune



Physics of the Neutral Flow Dynamics and Capture Efficiency

Direct Simulation Monte Carlo (DSMC) calculation for supersonic (M = 10) molecular flow onto a conical surface with a diffusive reflection

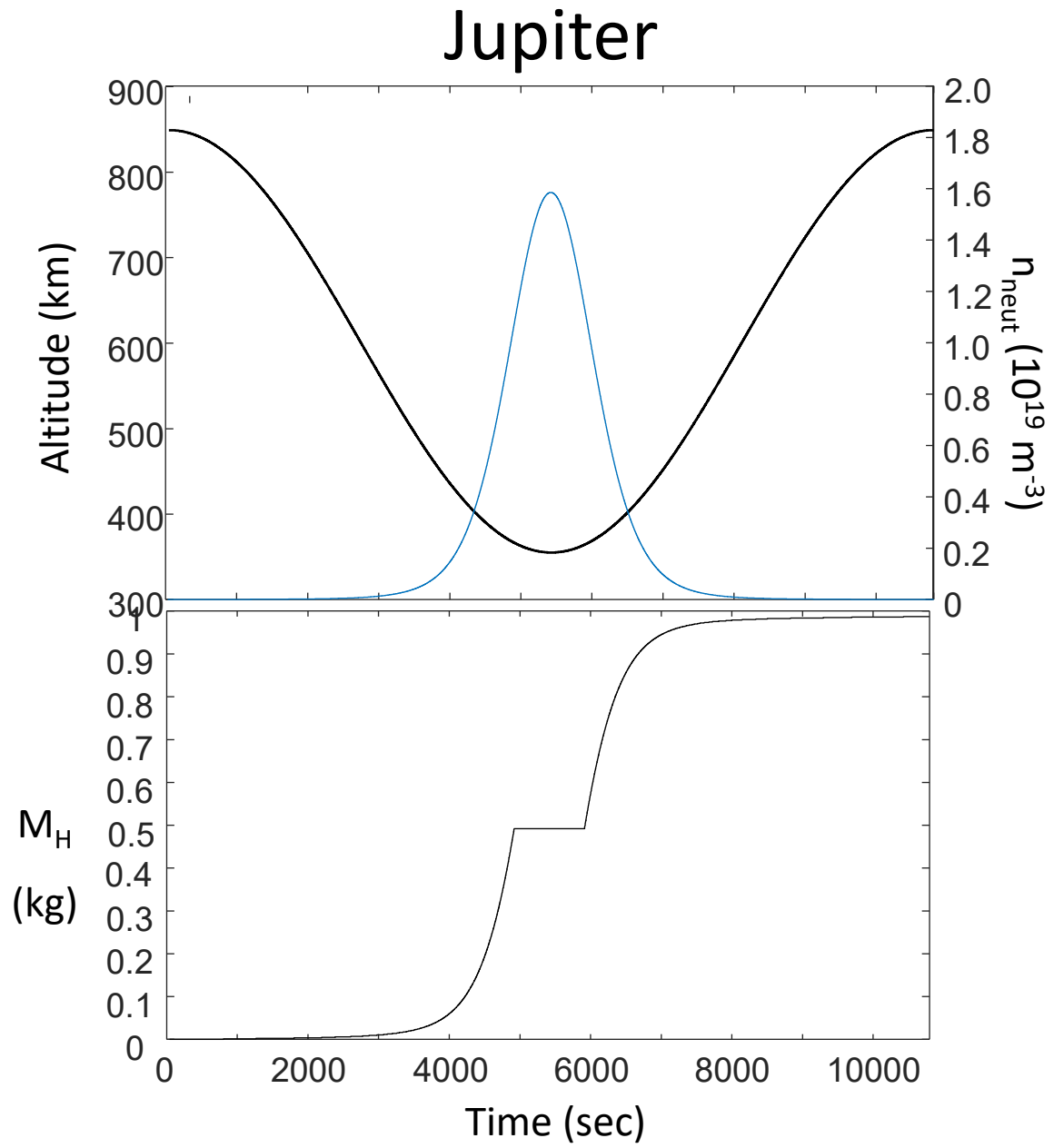


Red tracers represent particles that have struck the surface

Yellow tracers– particles suffering secondary collisions

Blue tracers– initial free streaming particles

Example mission employing HarPO



Destination	Orbital radius (AU)	Hohmann Δv from LEO (km/sec)	Transit time
Venus	0.72	3.5	4.8 months
Mars	1.52	3.6	8.5 months
Jupiter	5.2	6.3	2.7 years
Saturn	9.54	7.3	6.0 years
Uranus	19.19	8.0	16.0 years
Neptune	30.07	8.2	30.6 years

Jupiter Icy Moons Orbiter Mission (JIMO)

Transit Time from LEO: **6.1 years**

HarPO Transit from LEO: **2.7 years**

Total Dry Mass: **24 MT**

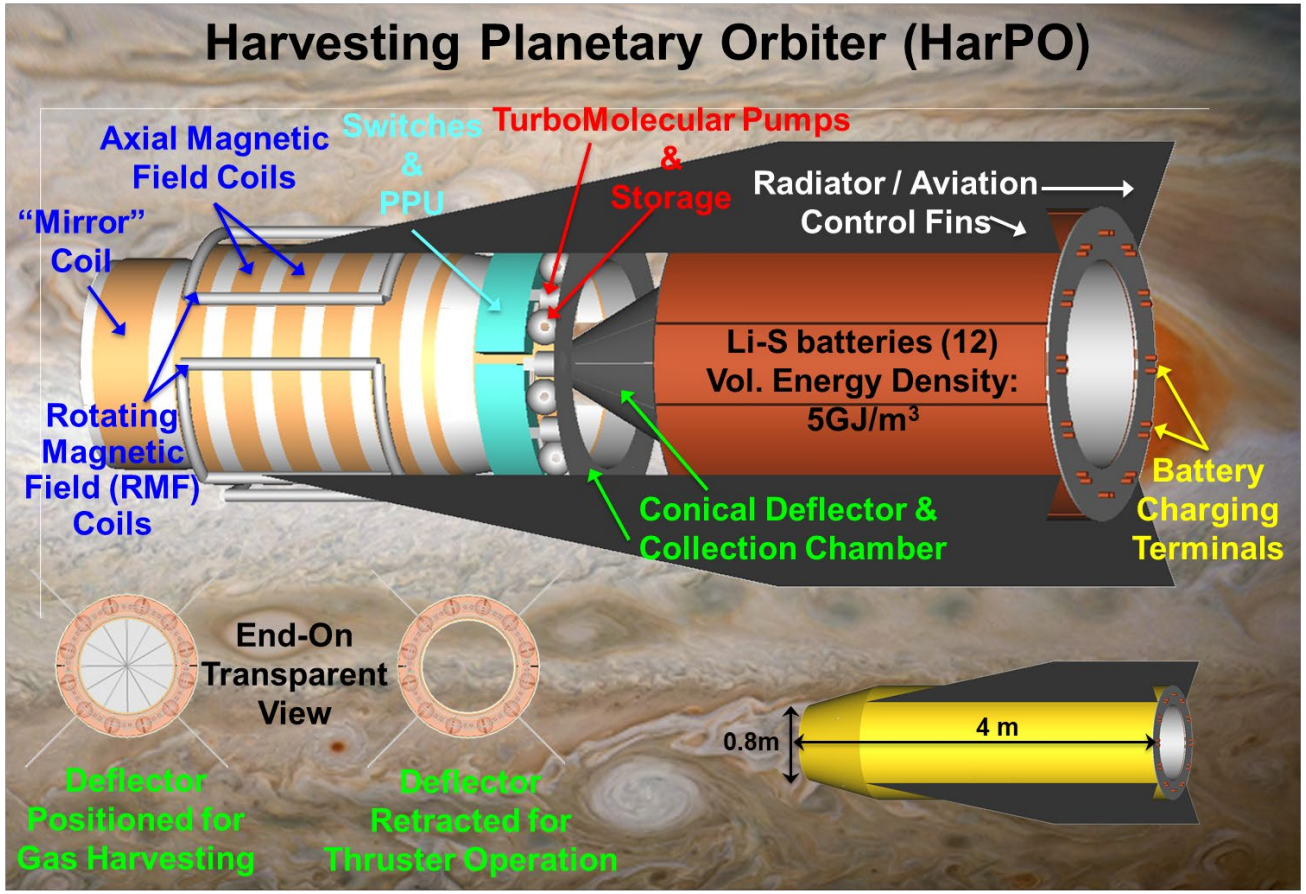
Reactor **6 MT**

JIMO Fuel Mass: **12 MT Xenon**

HarPO Fuel Mass: **1.4 MT Hydrogen**

The Harvesting Planetary Orbiter Summary

- The HarPO spacecraft would operate on essentially any gas from virtually all the planetary atmospheres including Earth
- Designed to harvest these atmospheres for additional exploration of other planets and moons as well as the transits to Earth
- Employs experimentally proven robust plasma creation and sustainment methodology in relevant conditions
- Uniquely capable as thruster physics works most efficiently on the Hydrogenic gases of the Jovian planets



- With the ability to refuel at virtually all planetary destinations, it would reduce the time and cost of cargo missions, sample and return missions, all the way to manned missions