Controlled Space Physics Experiments using Laboratory Magnetospheres

JOWOG 43

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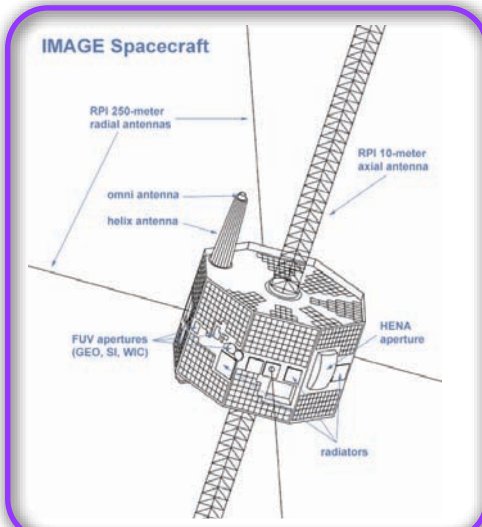
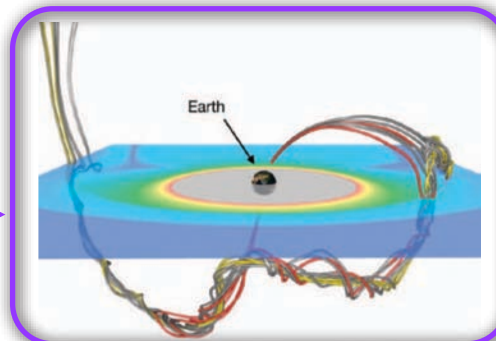
Test “whole plasma” magnetospheric models in relevant magnetic geometry and Explore phenomena by controlling injection of heat, particles, and perturbations

Four Elements of Achieving Predictive Understanding

Spacecraft Observations



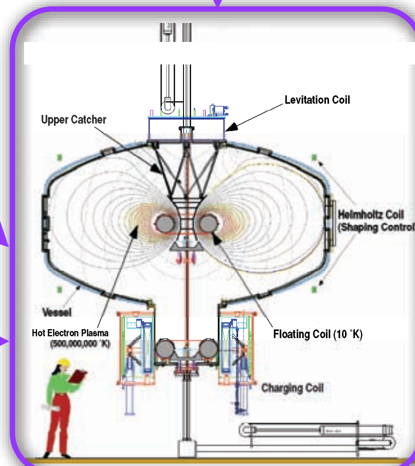
Scientific Simulations



Theory and Models

$$\frac{\partial f_s}{\partial t} + \langle \dot{\lambda}_i \rangle \frac{\partial f_s}{\partial \lambda_i} + \langle \dot{\phi}_i \rangle \frac{\partial f_s}{\partial \phi_i} = \frac{1}{(E+E_0)\sqrt{E(E-2E_0)}} \frac{\partial}{\partial E}\left((E+E_0)\sqrt{E(E-2E_0)} D_{EE} \frac{\partial f_s}{\partial E} \right) + \frac{1}{T(\alpha_0)\sin 2\alpha_0} \frac{\partial}{\partial \alpha_0}\left(T(\alpha_0) \sin 2\alpha_0 D_{\alpha_0 \alpha_0} \frac{\partial f_s}{\partial \alpha_0} \right) - \left(\frac{f_s}{0.5\tau_b} \right)_{Loss\ Cone}$$

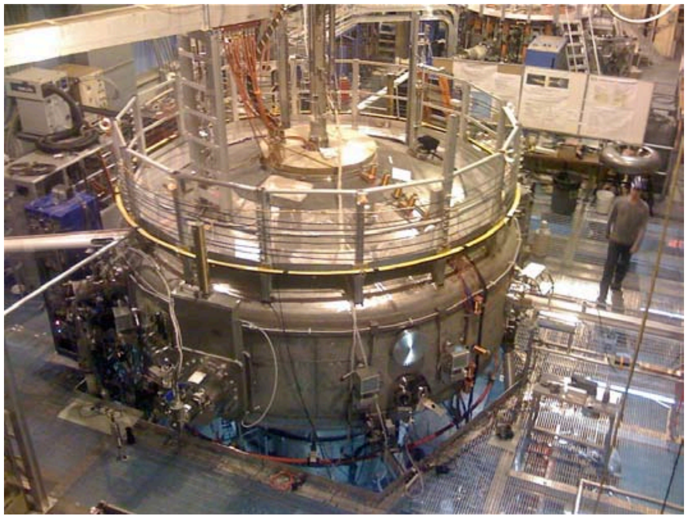
Controlled Experiments

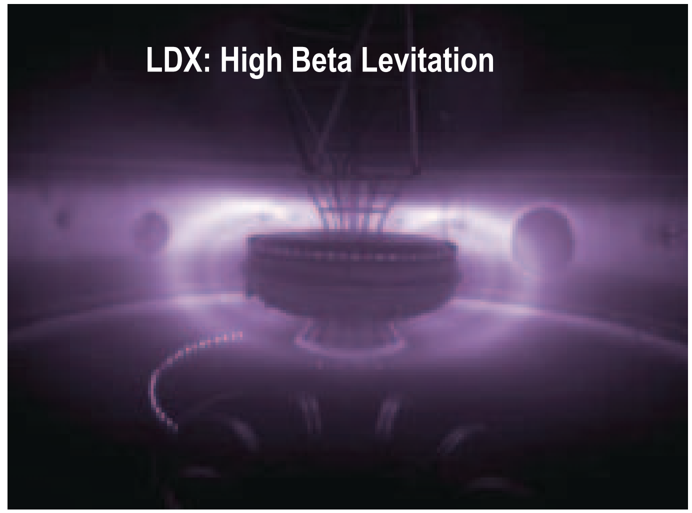


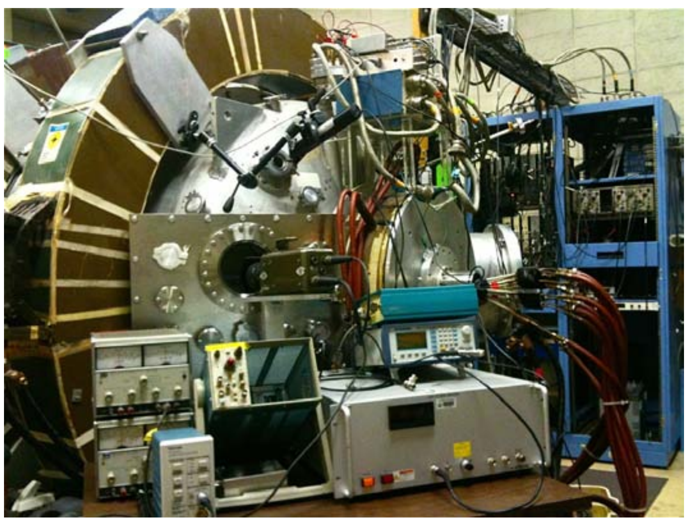
Outline

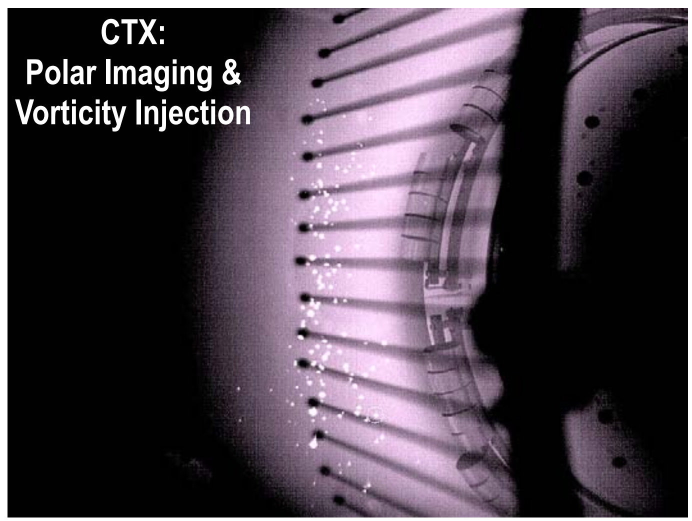
- Laboratory magnetospheres are facilities for conducting controlled tests of space-weather models
- How does a laboratory magnetosphere work?
- Production and study of “artificial radiation belts”
- Recent tests of radiation belt remediation
- Outlook: the largest magnetosphere on Earth

Laboratory Magnetospheres







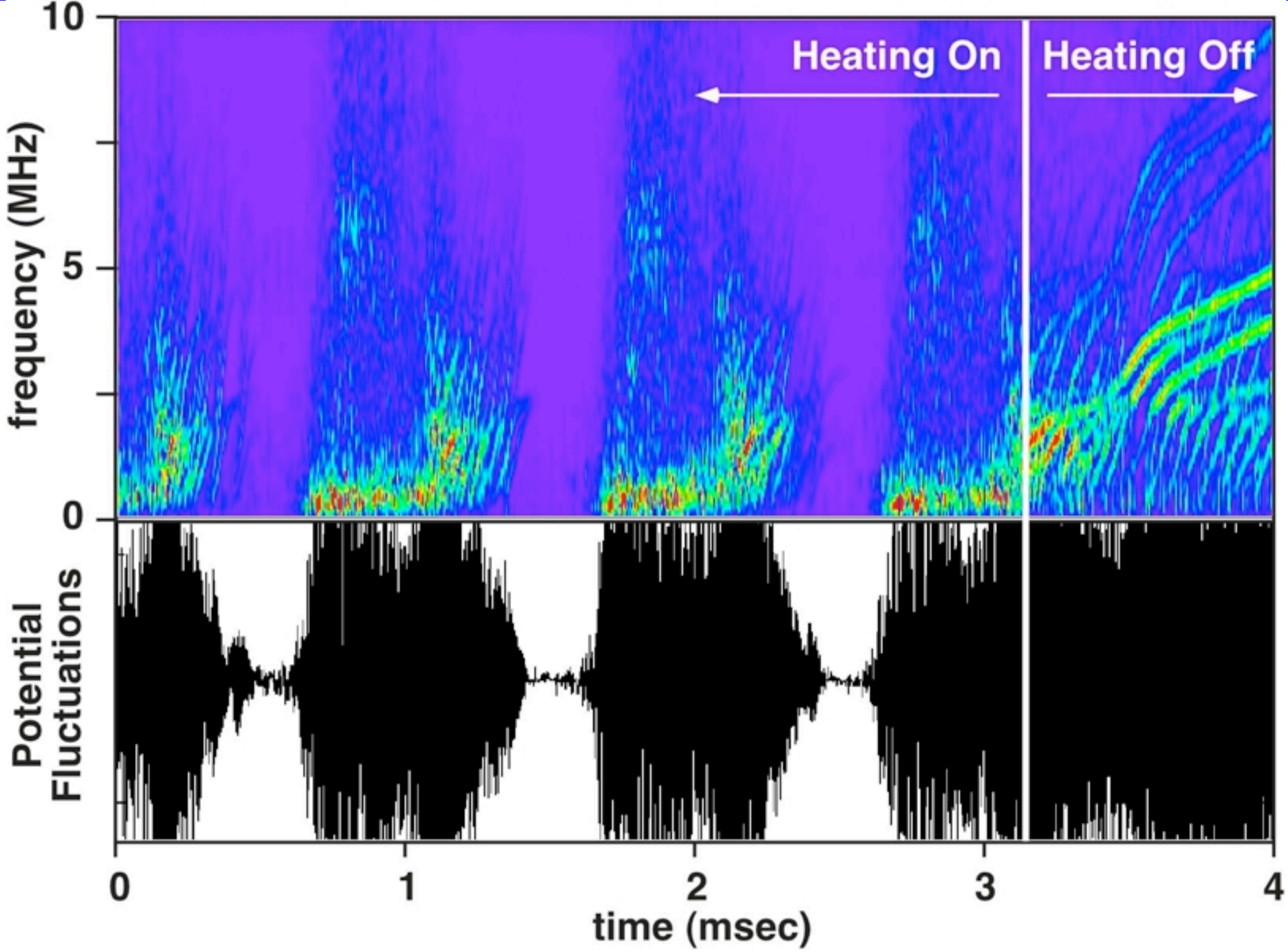


What has been discovered…

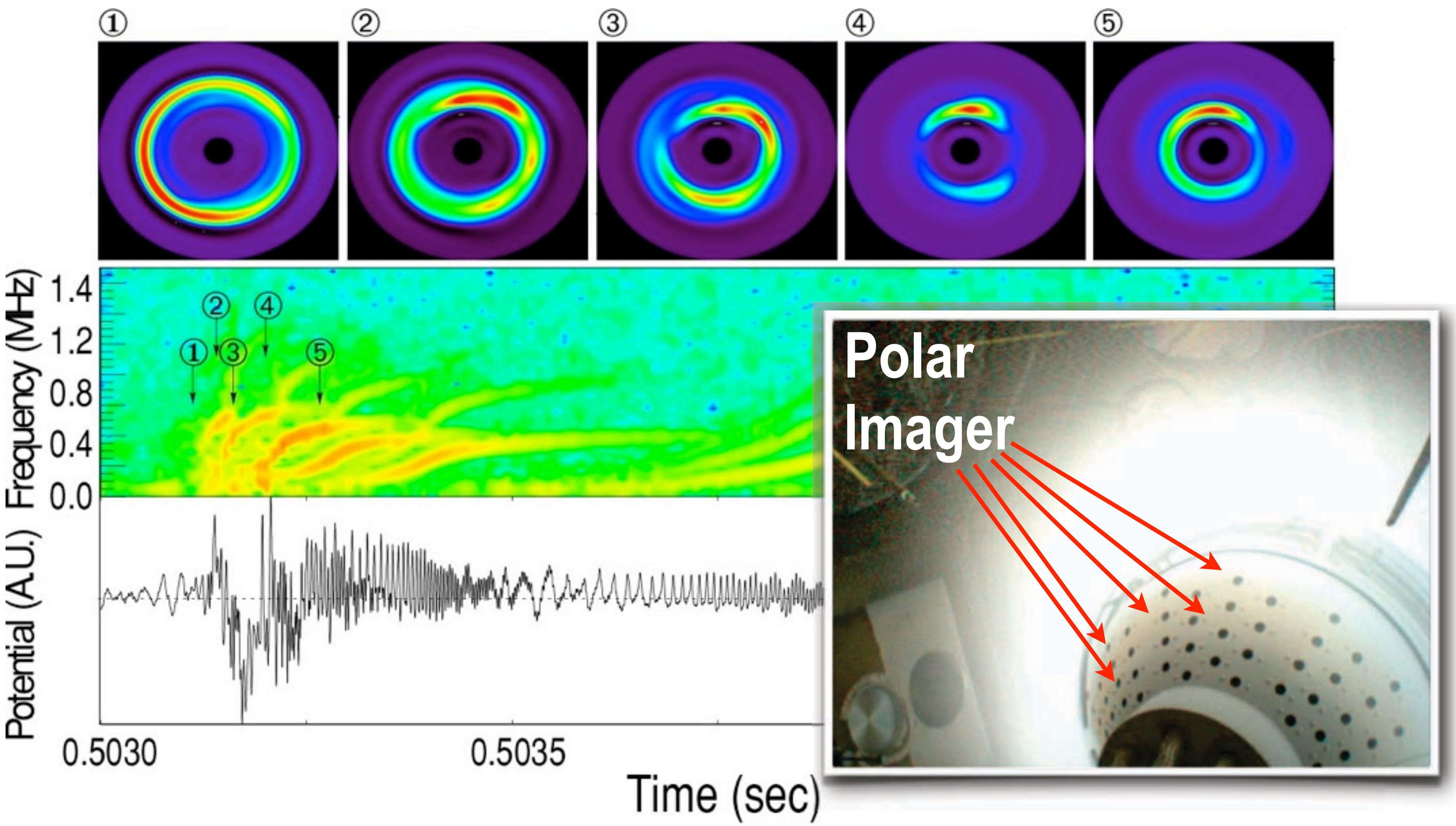
- High-pressure “artificial radiation belt” can be created (easily) in the laboratory, but “size” matters.
- Low-frequency, interchange dynamics dominate (2D physics in magnetized plasma). Radial particle transport models verified.
- Structure and dynamics of internally-driven motion are well-represented by flux-tube averaged gyrokinetic simulations
- Turbulent convection creates inward pinch and sustains plasma profiles comparable to planetary magnetospheres

➡ Many controlled experiments are possible…
Example: radiation belt “remediation” with mass injection

Internally-Driven Drift-Resonant Transport

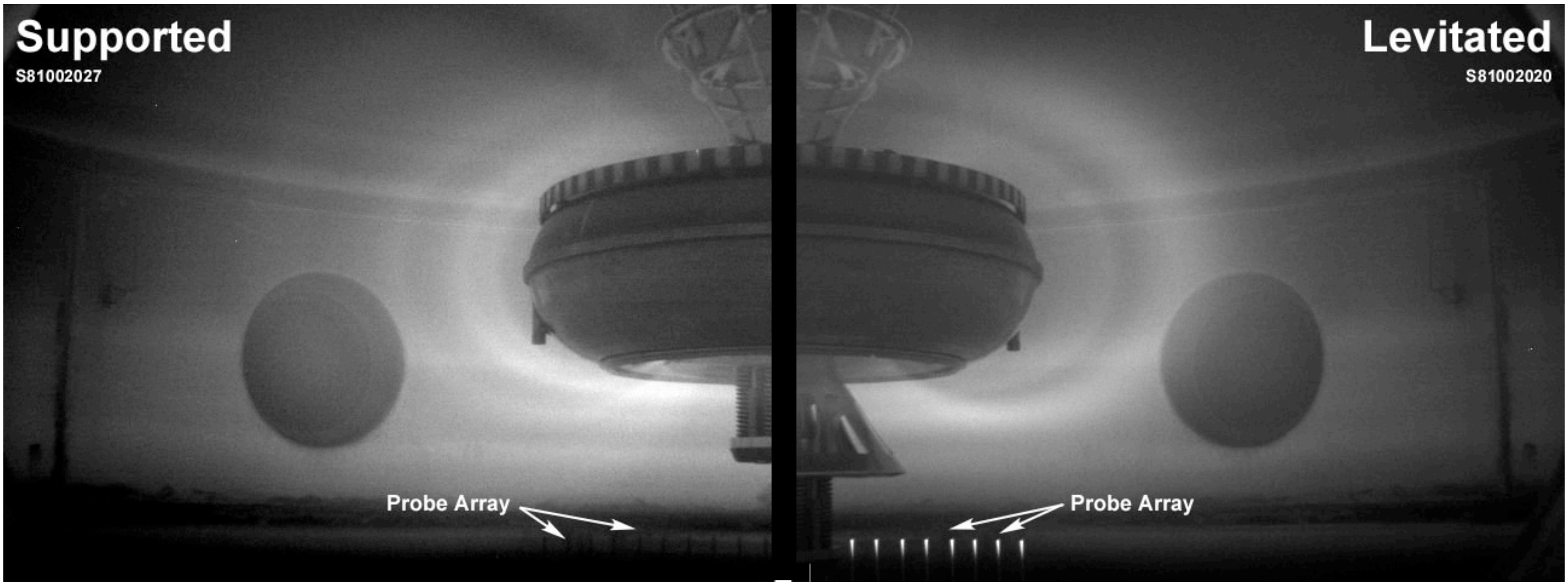


Polar Precipitation with Inward Transport



World’s Largest Lab Magnetosphere

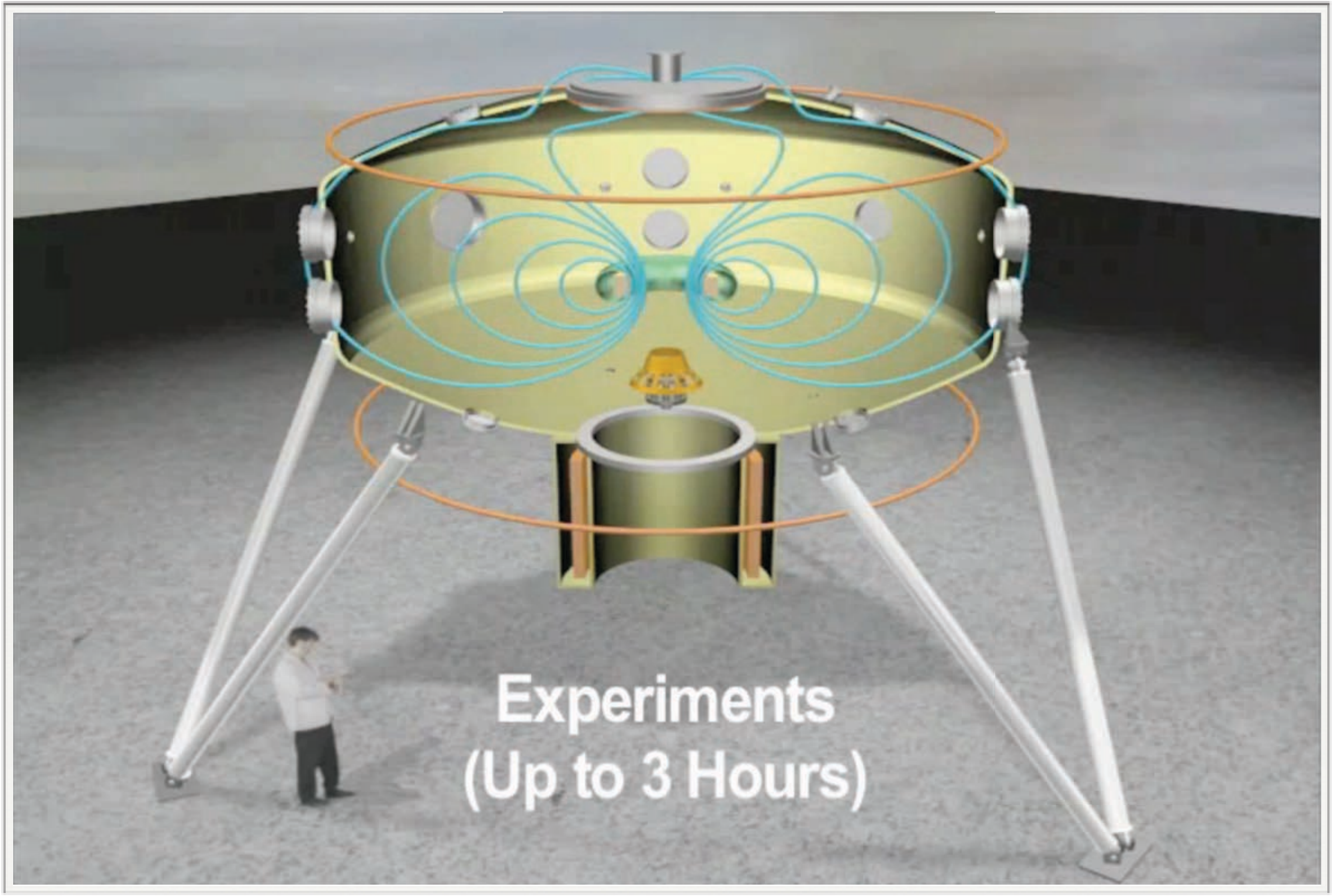
5 m



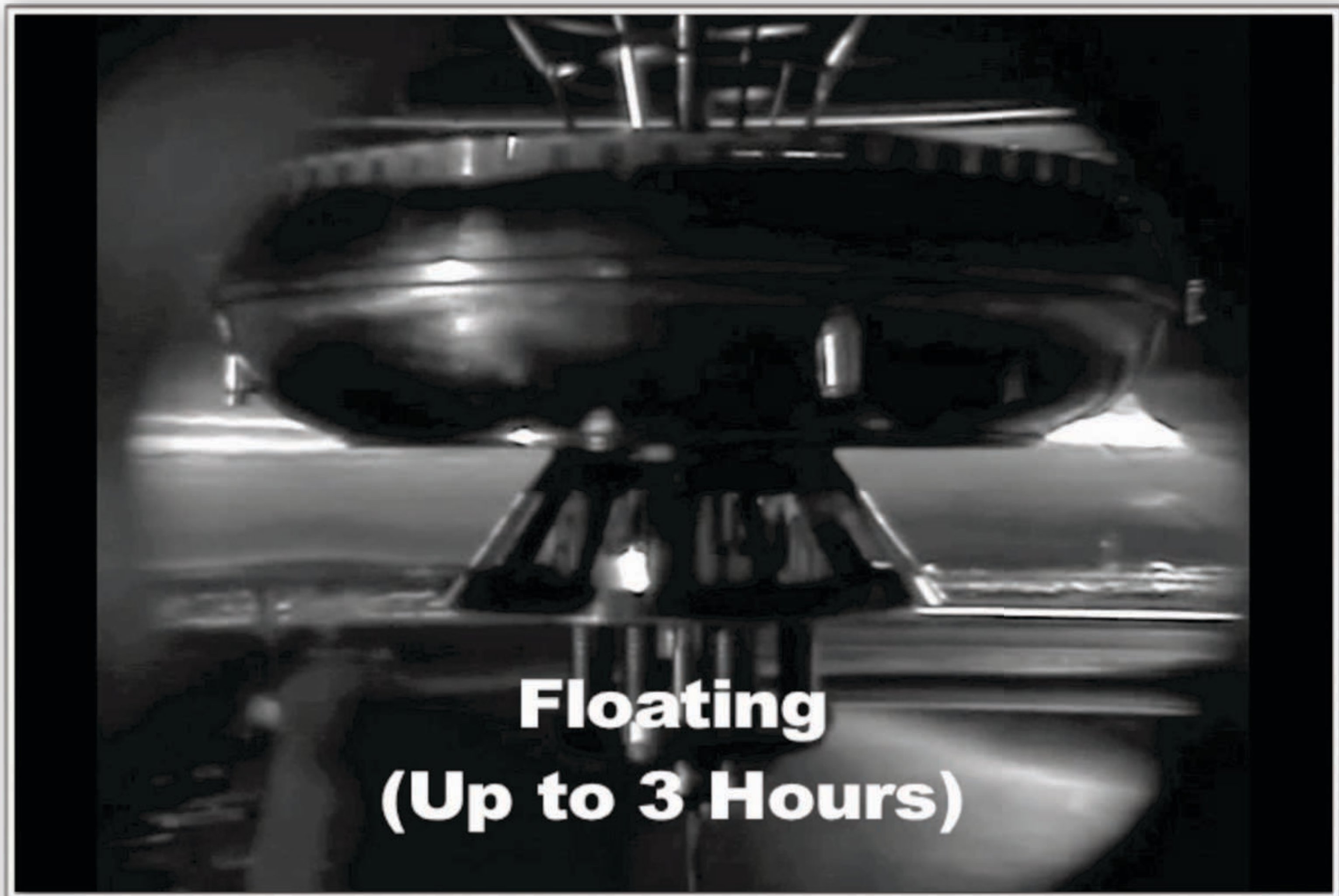
Size matters:

At larger size, trapped particle energy, intensity of “artificial radiation belt”, and plasma density *significantly* increase.

Magnetic Levitation Expands Scientific Capability

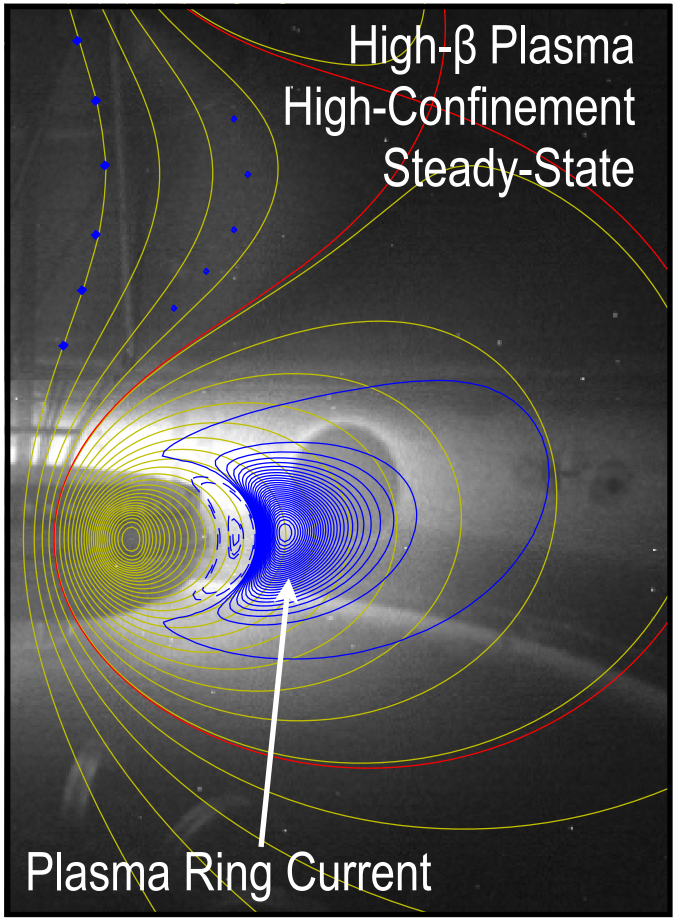


Levitation for Higher Density Plasma Studies

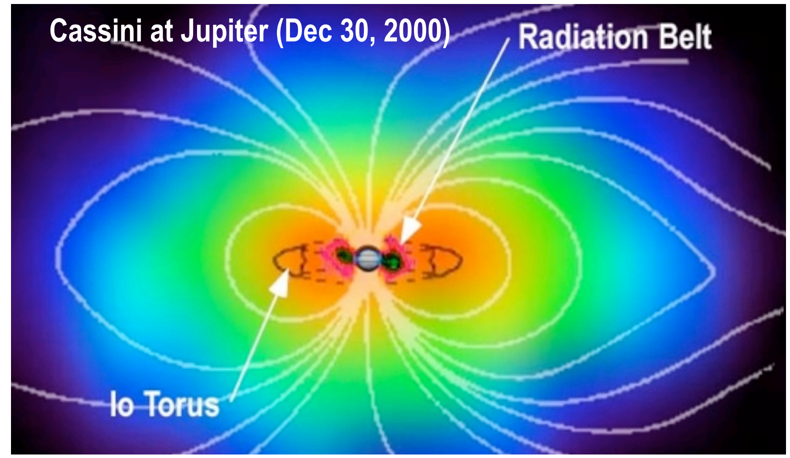


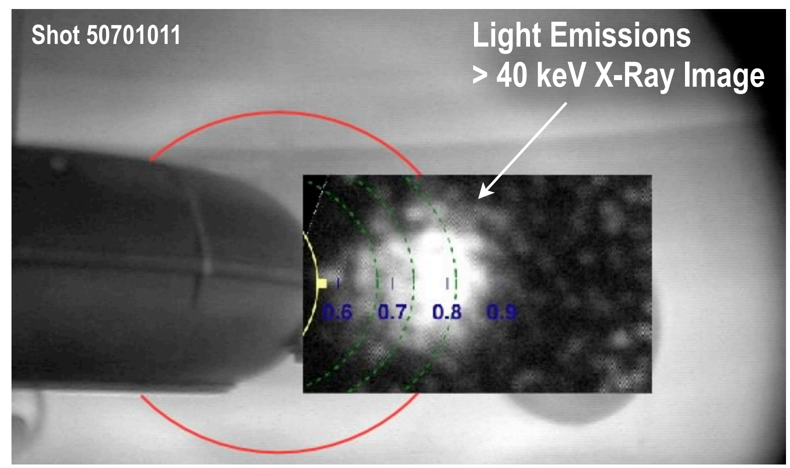
Levitated Dipole Achieves Extreme Plasma Beta and Magnetospheric Profiles

High Accuracy Equilibrium Measurements



Combining Whole-Plasma Imaging



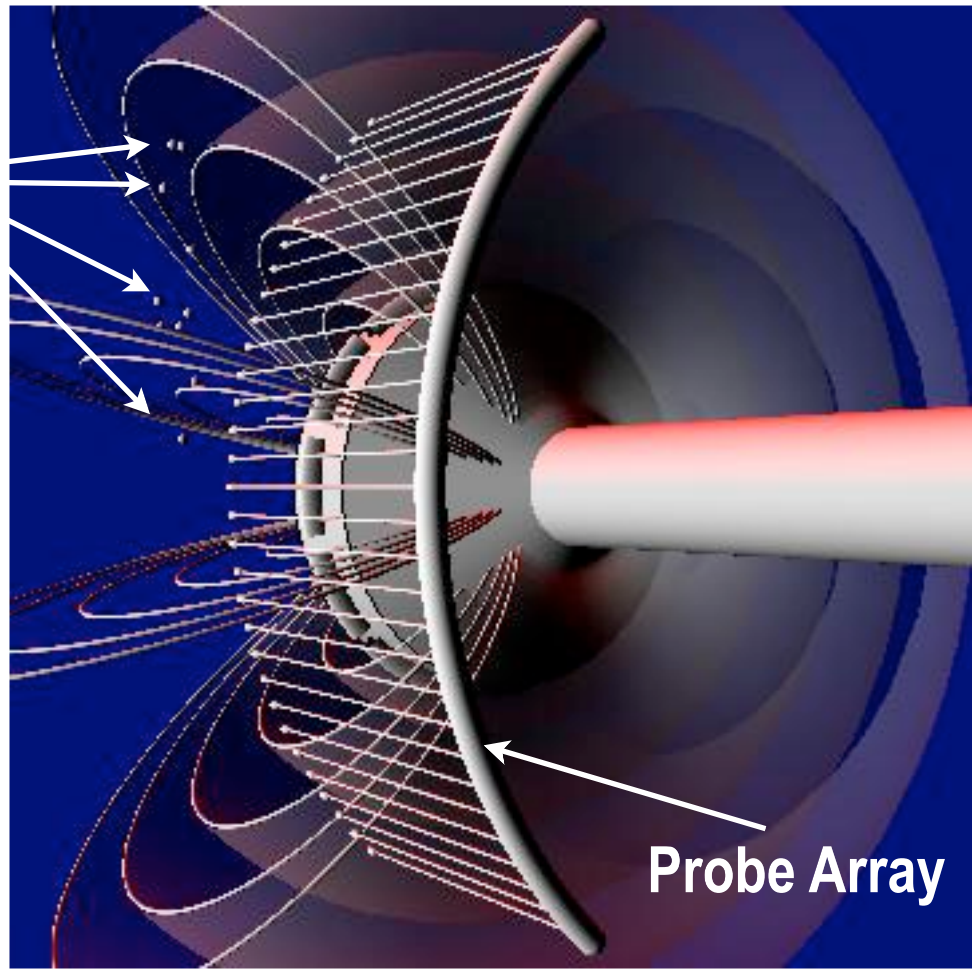


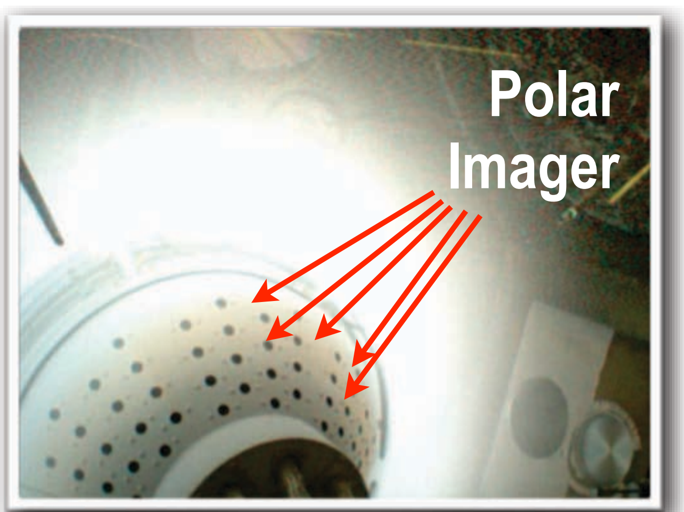
Example Experiments…

- Radial transport of trapped radiation belt particles
- Destruction of drift-echoes with applied “whistler chorus”
- Observation of turbulent inverse energy cascade by breaking rotational symmetry of plasma flow
- Creation of outward “planetary wind” (like Jupiter) by driving supersonic plasma rotation and centrifugal interchange
- Active feedback control of turbulent mixing

➡ Most recent example:
Radiation belt “remediation” with mass injection

First "Exploding Pellet" Experiments

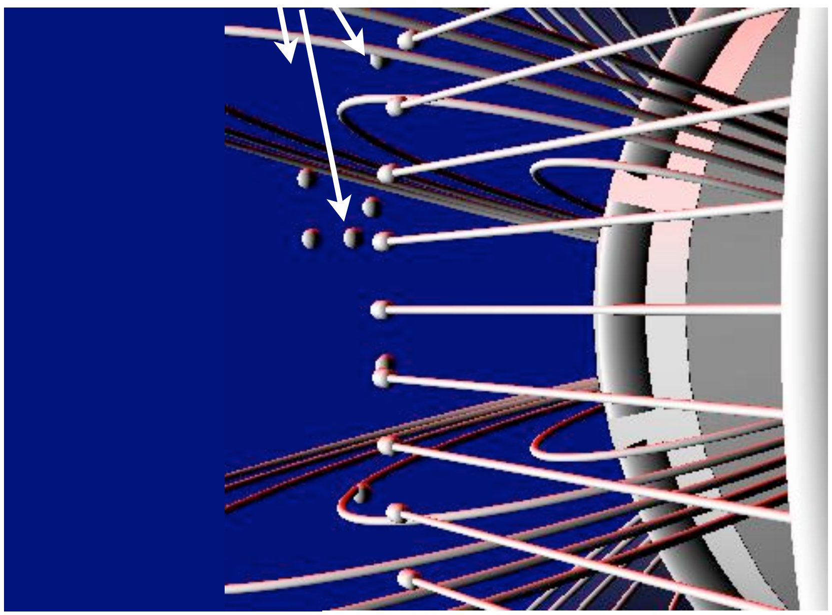




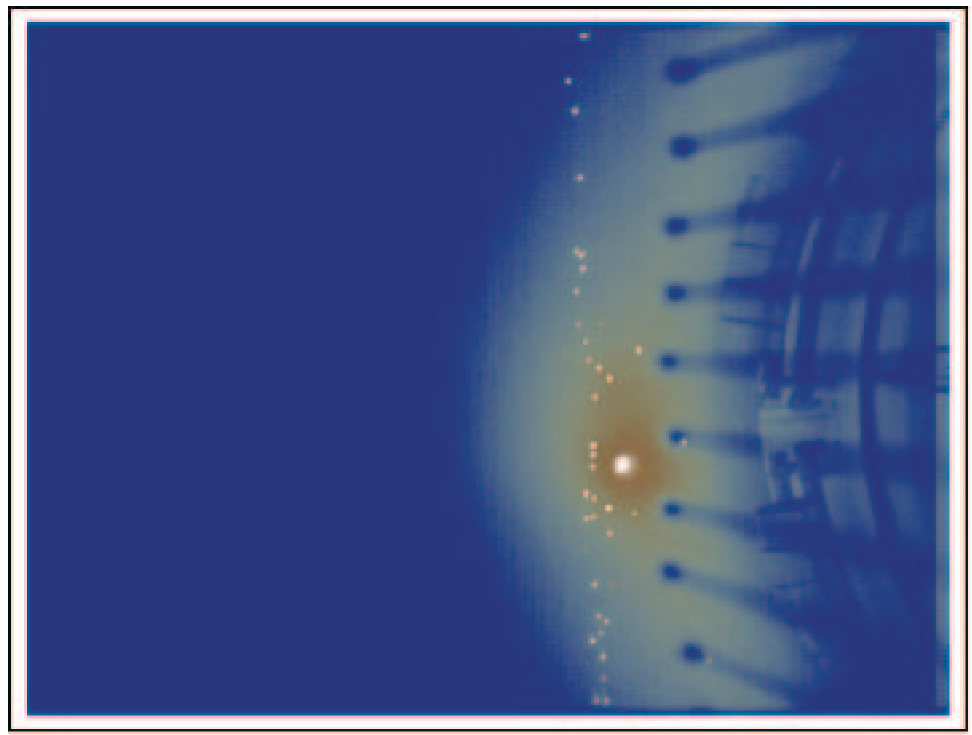
First "Exploding Pellet" Experiments

Next-step: "Exploding Pellet" Experiments scheduled August in larger MIT device with **×100 more energy** with faster dynamics expected

200 micron Polystyrene



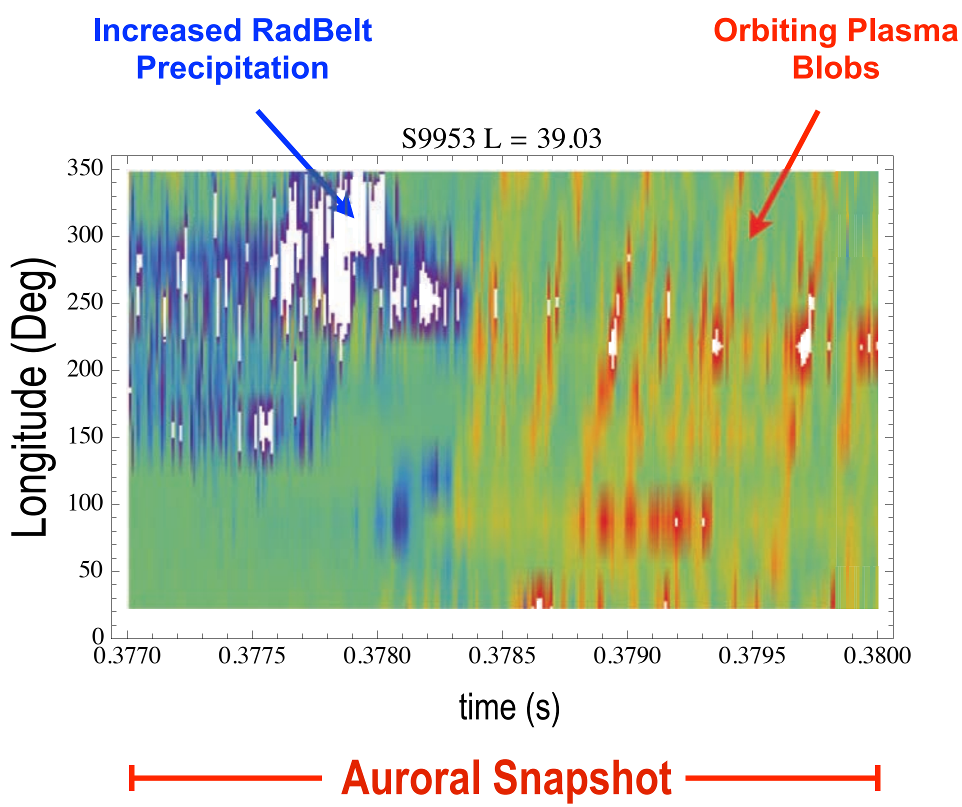
Fast Camera View

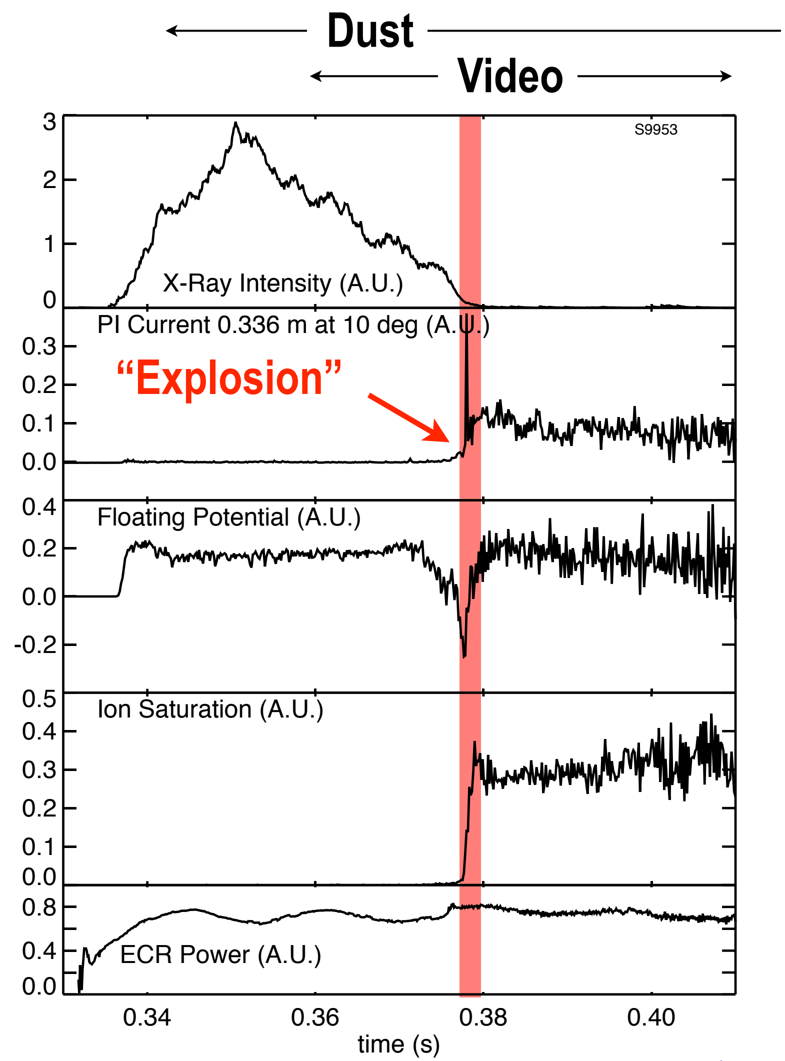


250 μsec/frame

First "Exploding Pellet" Experiments

High-Speed record of "Auroral Current" at the moment of "Explosion"





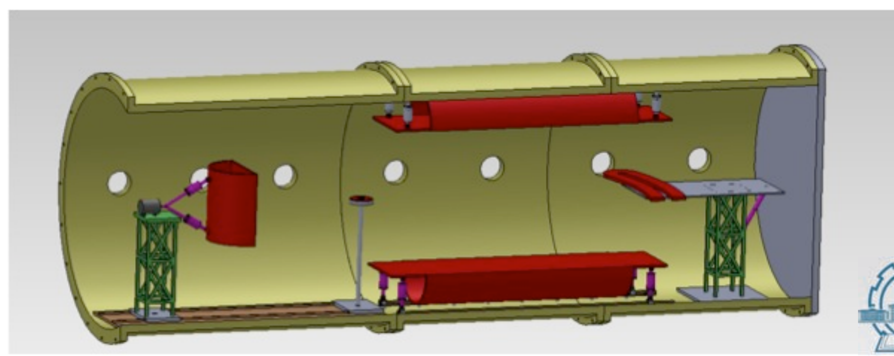
Laboratory Magnetospheres: Very Large Plasma Experiments World-Wide

- **Columbia University**: 1.7 m dia; 1.5 kW heating power
  Turbulence studies, radiation belt dynamics and transport

- **MIT**: 5.0 m dia; 25 kW heating power; ***Levitated***
  World's largest, highest energy, most capability (1 MW available)

- **Univ. Tokyo**: 2.0 m dia; 40 kW heating power; ***Levitated***
  e^-/e^+ plasmas, supersonic flow, highest power and near "perfect" confinement

- **HIT (Harbin, China)**: 3.5 m x 10 m (***under construction***)
  Solar wind, magnetotail distortion, space weather



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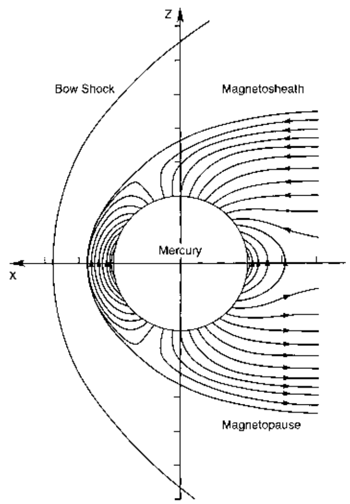
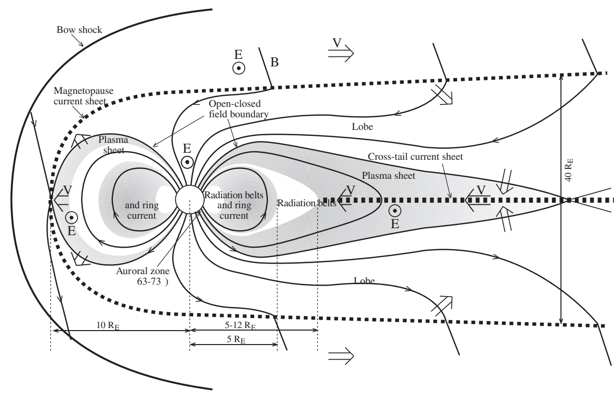
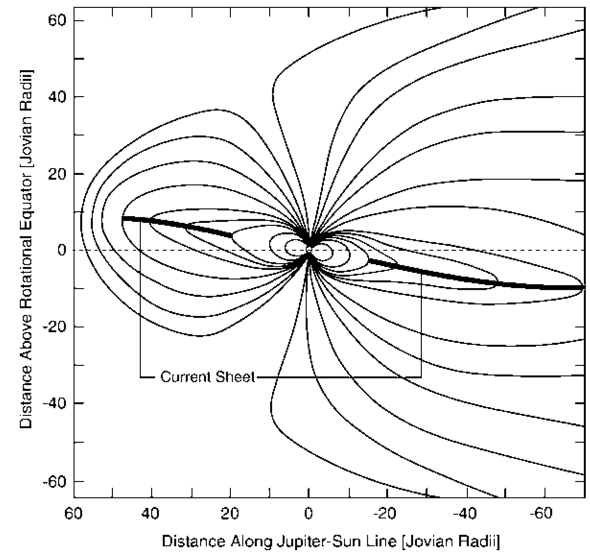
High Density and Large Size are required for Controlled Investigations of Alfvén Wave Dynamics



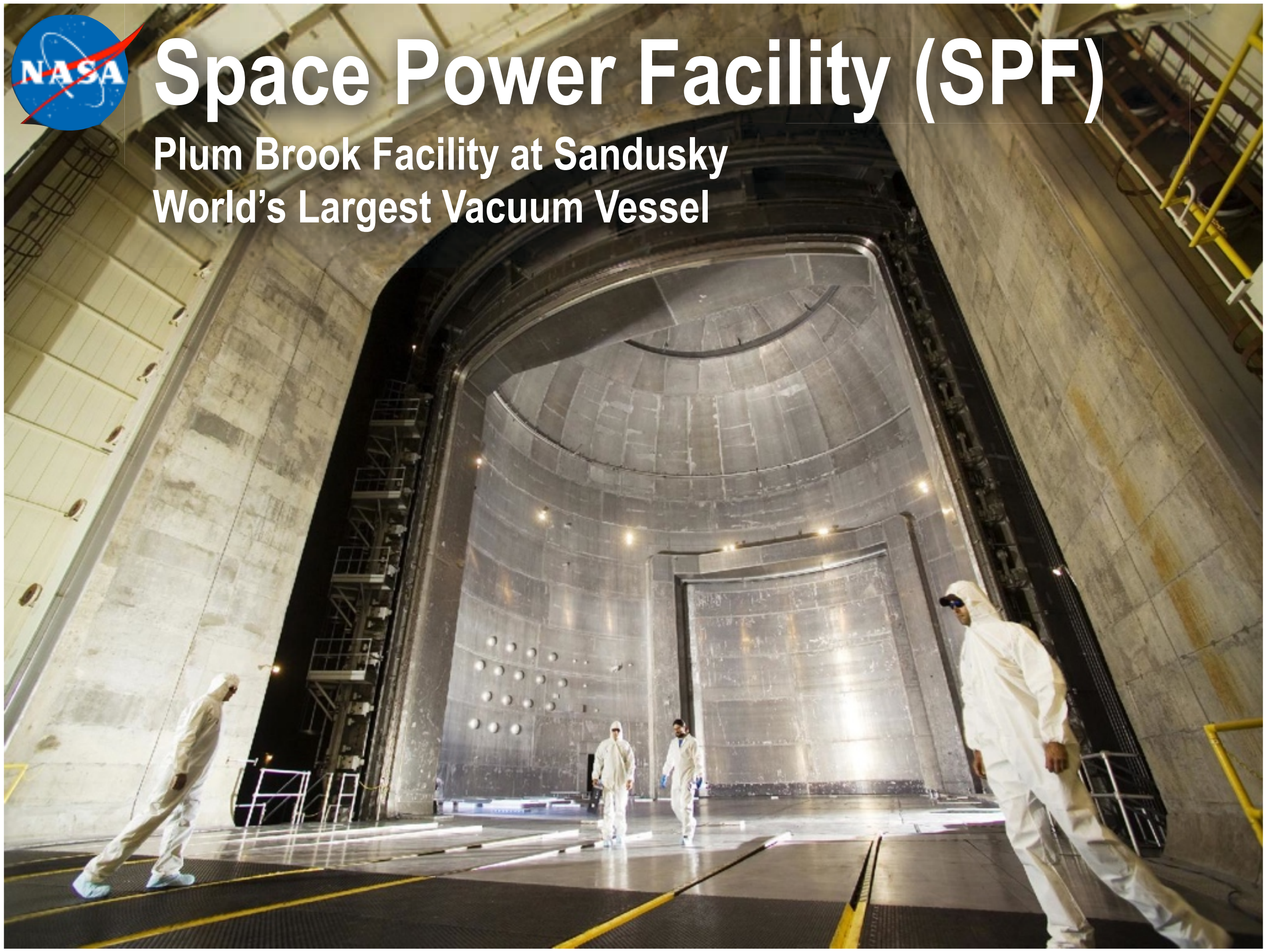




$$\frac{V_A}{L} \sim f_A \ll f_{ci} \rightarrow \frac{c/\omega_{pi}}{L} \ll 1$$

	Mercury	**Earth**	**Jupiter**
Size	2 R_H	10 R_E	100 R_J
Density ($c / \omega_{pi} L$)	0.1	0.003	0.00001
Comments	$V_a/L \sim f_{ci}$	Alfvén Resonances	Propagating Alfvén

Laboratory Magnetospheres at Any Scale



- Laboratory magnetospheres are facilities for conducting controlled tests of space-weather models
- Very large plasmas can be produced in the laboratory, continuously, with low power
- "Artificial radiation belt" dynamics and transport can be studied.
- "Artificial radiation belt" with large energy, belt intensity, and density are produced using larger laboratory magnetospheres
- Preliminary tests of radiation belt "remediation"
- Outlook: We can build/operate the largest magnetosphere on Earth

Acknowledgements