Driving Interchange Flow in a Dipole-Confined Plasma

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Collisionless Terella Experiment

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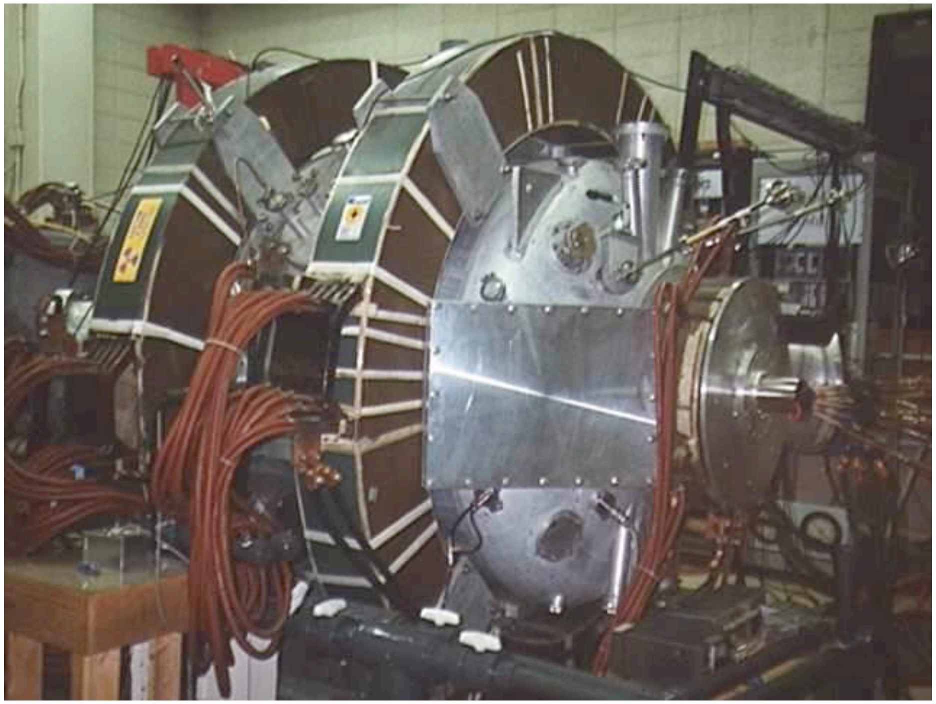
Abstract

The Collisionless Terrella Experiment (CTX) is a device utilizing a dipole field to study interchange and flow. Instabilities excited by hot electrons and centrifugal forces have been observed. This poster investigates several techniques to excite interchange motion and to modify the geometry of the resulting flow patterns. One method utilizes six meshes inserted at the inner edge of the plasma around the magnetic equator. Application of a non-axisymmetric bias to these meshes can cause the plasma at different radii to mix. A second approach uses a large voltage applied to an oversized probe in order to localize the convective motion of the plasma. First results from these investigations will be presented.

An Introduction to CTX



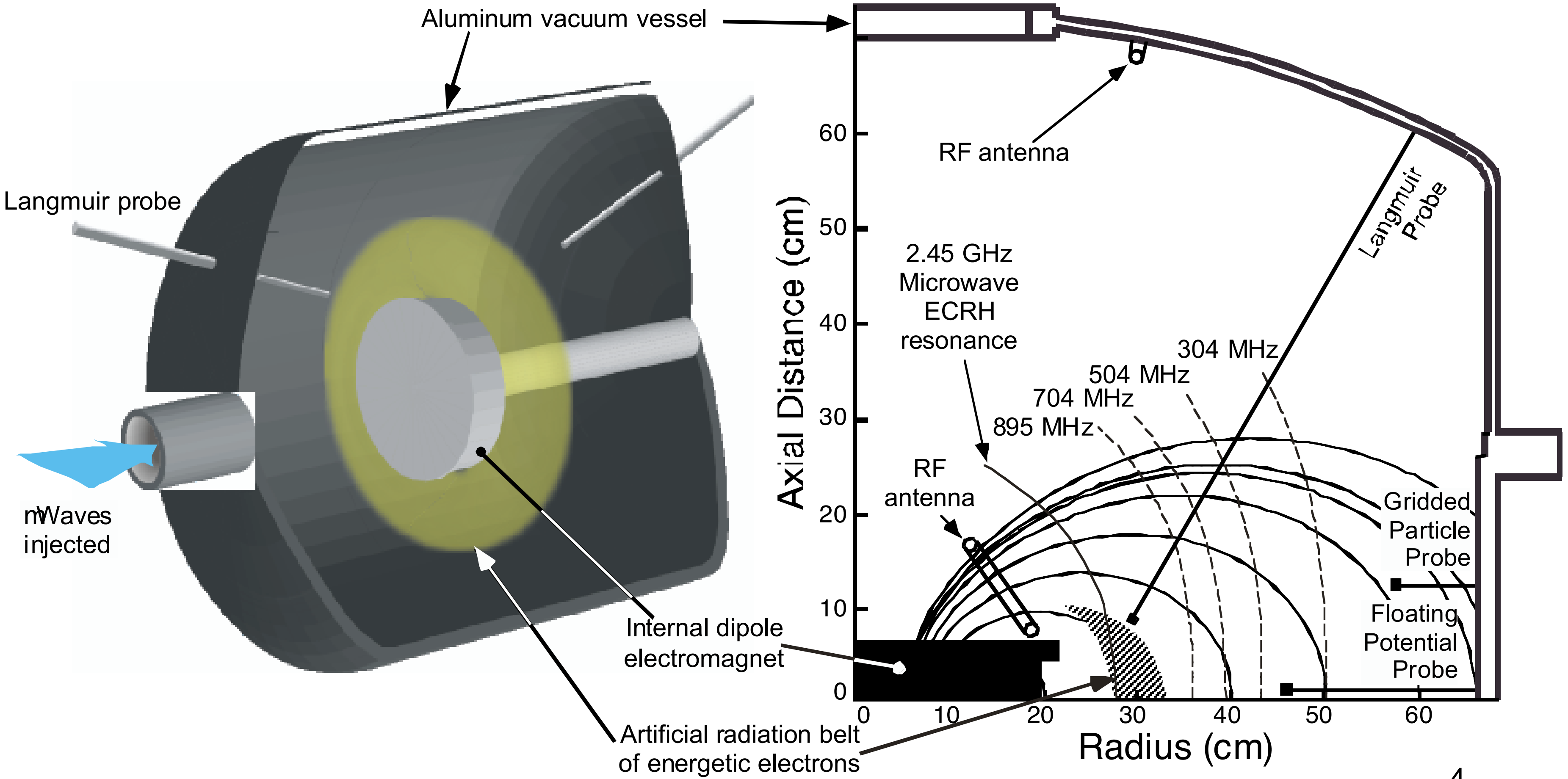
Basic parameters:

Magnetic field at equator, B_T	2 kG
Terrella radius, R_T	20 cm
Energetic electron energy, E_h	1-20 keV
Radius of peak intensity, L_h	1.5
Energetic electron density, n_h	$0.5 - 1 \times 10^{10}$ cm^{-3}
Total plasma density, n	$1 - 2 \times 10^{10}$ cm^{-3}

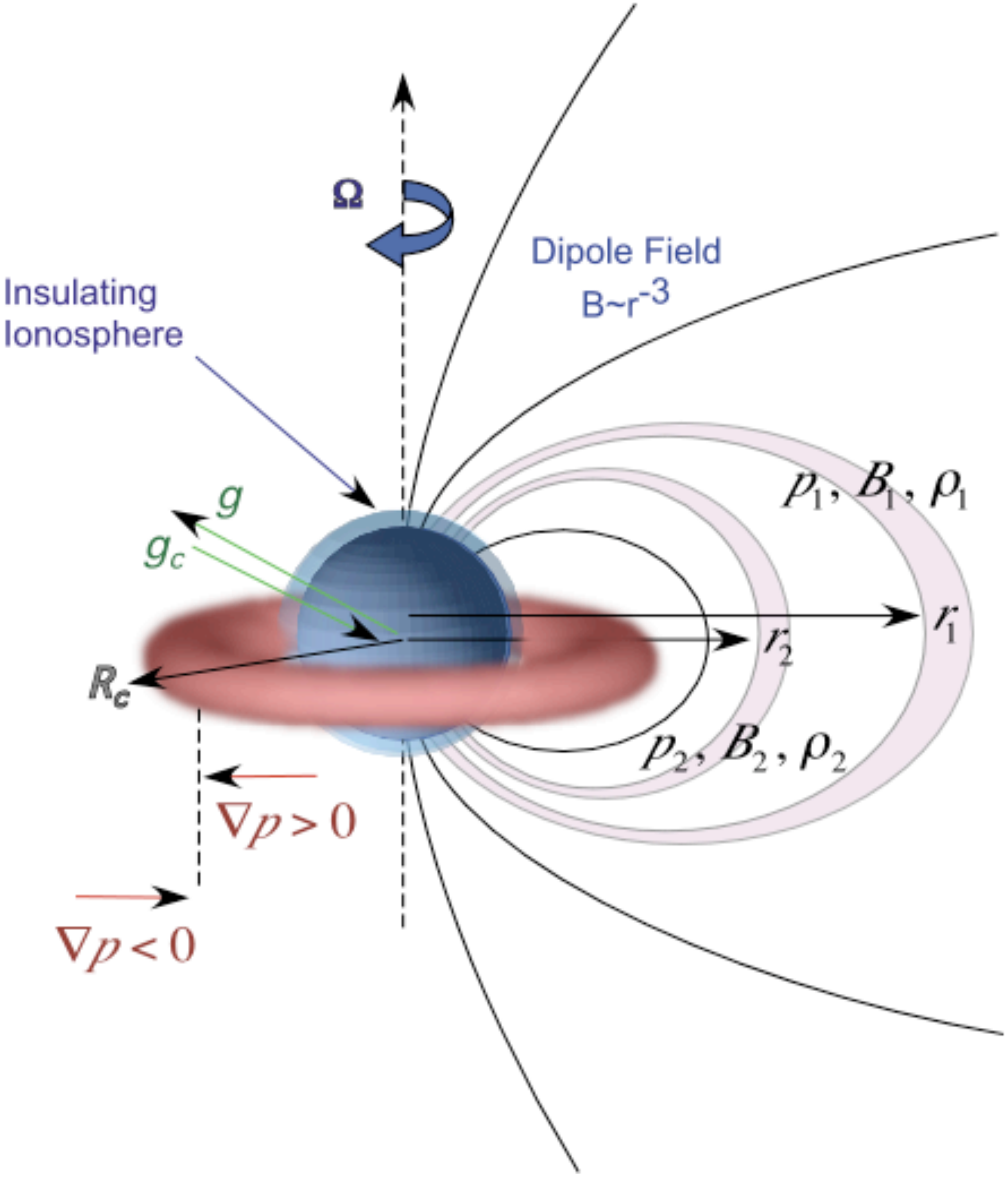
Dynamical parameters:

Cyclotron frequency, $\omega_c/2\pi$	2 GHz
Bounce frequency, $\omega_b/2\pi$	150 MHz
Drift frequency, $\omega_d/2\pi$	0.4 MHz
Normalized energy, $(\rho/L)^2$	5×10^{-5}

Magnetic Geometry and ECRH



Interchange In a Dipole



Charged particles in a Dipole Magnetic Field have three primary motions: Gyro, Bounce and Drift, each with their own frequency $\omega_c >> \omega_b >> \omega_d$. The Drift frequency arises from the magnetic gradient and curvature. The Gyro motion conserves μ and the bounce motion conserves J.

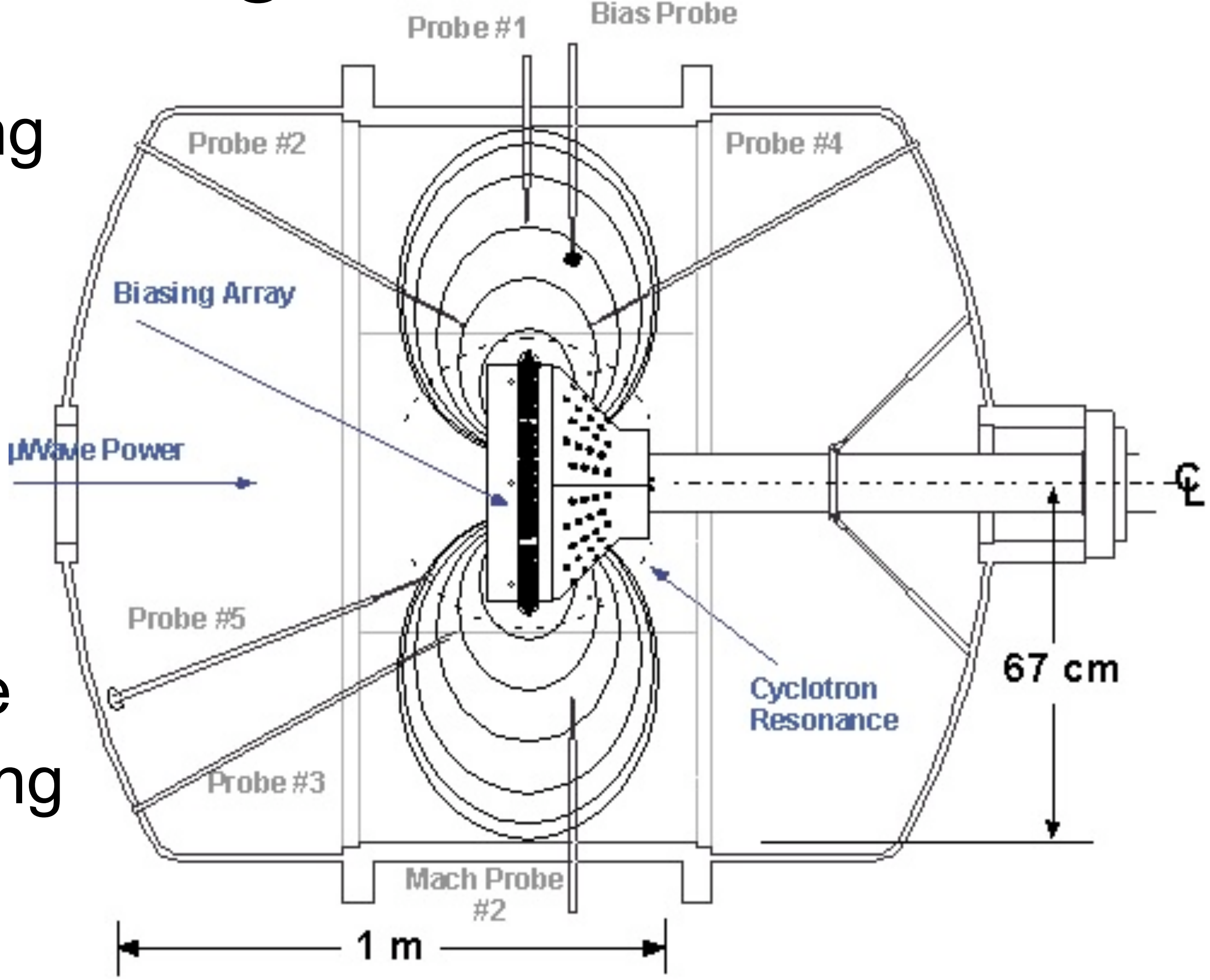
Interchange of flux tubes in a dipole is driven by gravity, pressure forces, magnetic gradients, curvature, and centrifugal forces.

Invariants

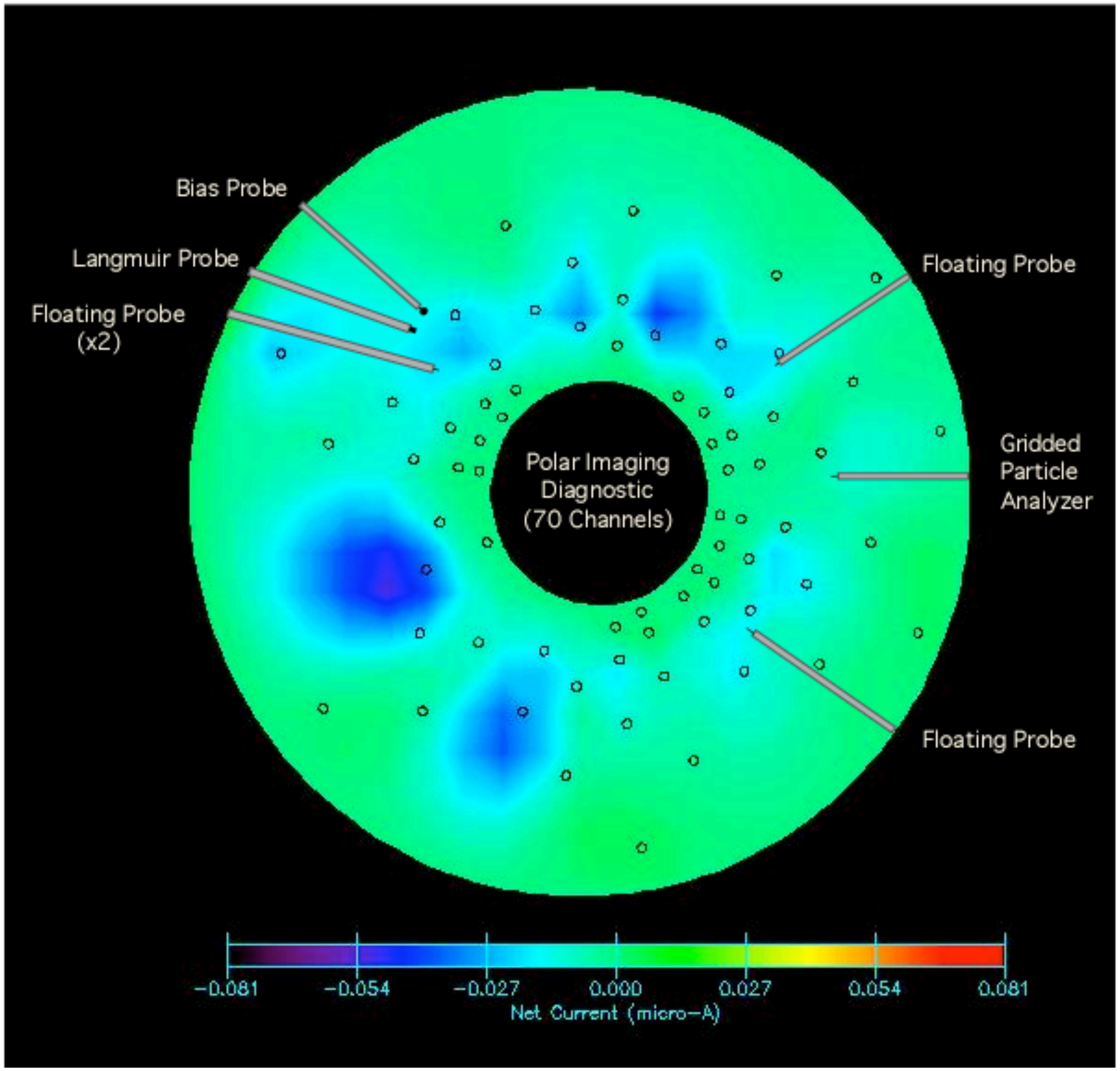
$$\mu = \frac{\mathrm{mv}_\perp^2}{2\mathrm{B}} \text{ and } J = \int \mathrm{v}_{II} ds$$

Diagnostics

- Four Floating Probes
- Gridded Particle Analyzer
- Langmuir Probe
- Mach Probe
- Polar Imaging Diagnostic



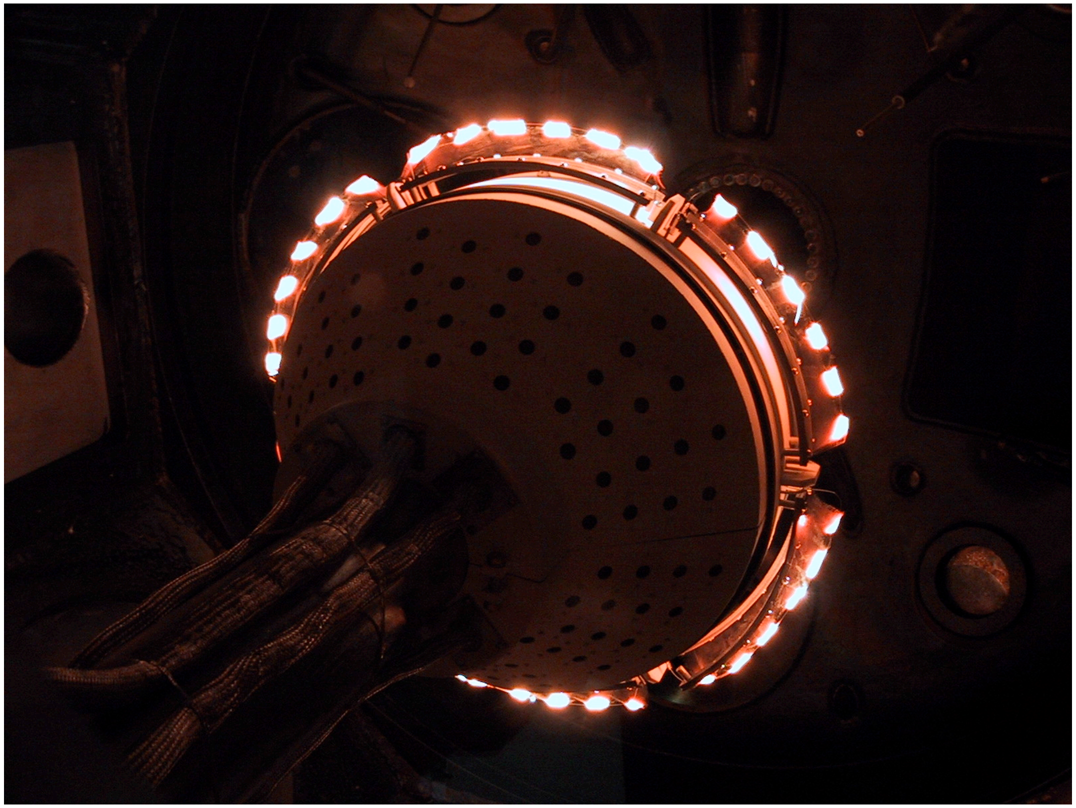
Placement of Movable Probes



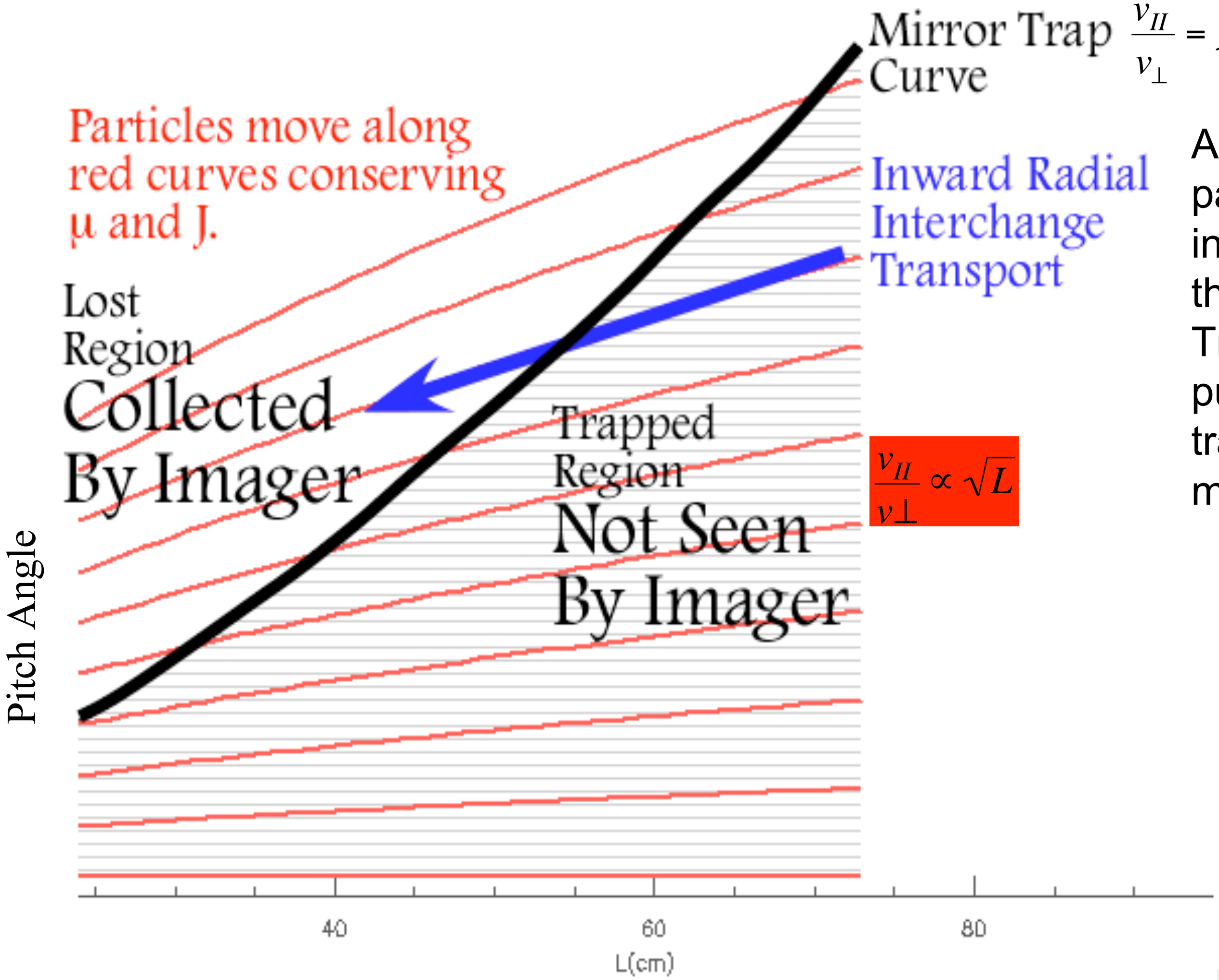
- Polar View
- Polar Imaging Diagnostic is an array of ~70 Retarding-Grid Particle Analyzers

Mesh Bias Setup

- Six tungsten meshes attached to high voltage power supply
- Equatorially located on innermost flux surface
- Insulated to ~4000 V with 20 mils alumina plasma spray coating



Polar Imager & The Loss Cone



$$\frac{v_{II}}{v_\perp} = \sqrt{\frac{B_{\max}}{B_{eq}} - 1} = \sqrt{\frac{B_{\max}}{B_0} L^3 - 1}$$

As deeply trapped particles are transported inward they move into the loss cone.
Trapped particles are pushed deeper into the trapped region when moving outward.

$$J \propto v_{II} L \qquad B_{eq} = B_0 / L^3$$

$$\mu = \frac{m_e v_\perp^2}{2 B_{eq}}$$

$$\frac{v_{II}}{v_\perp} = J \sqrt{\frac{m_e L}{2 \mu B_0}} \propto \sqrt{L}$$

Theoretical Motivation/Justification

- Parallel terms drop out due to insulating magnet cap
- Biasing Meshes forces current to flow cross-field,creating electric field
- Hall terms important, included
- Constants determined by Flux Tube Integration

$$\vec{J} = \overleftrightarrow{\sigma} \cdot \vec{E}$$

$$\vec{J} = \sigma_p E_\perp + \sigma_H (E_\perp \times \hat{b}) + \sigma_o E_\ell$$

$$\nabla \cdot \vec{J} = 0$$

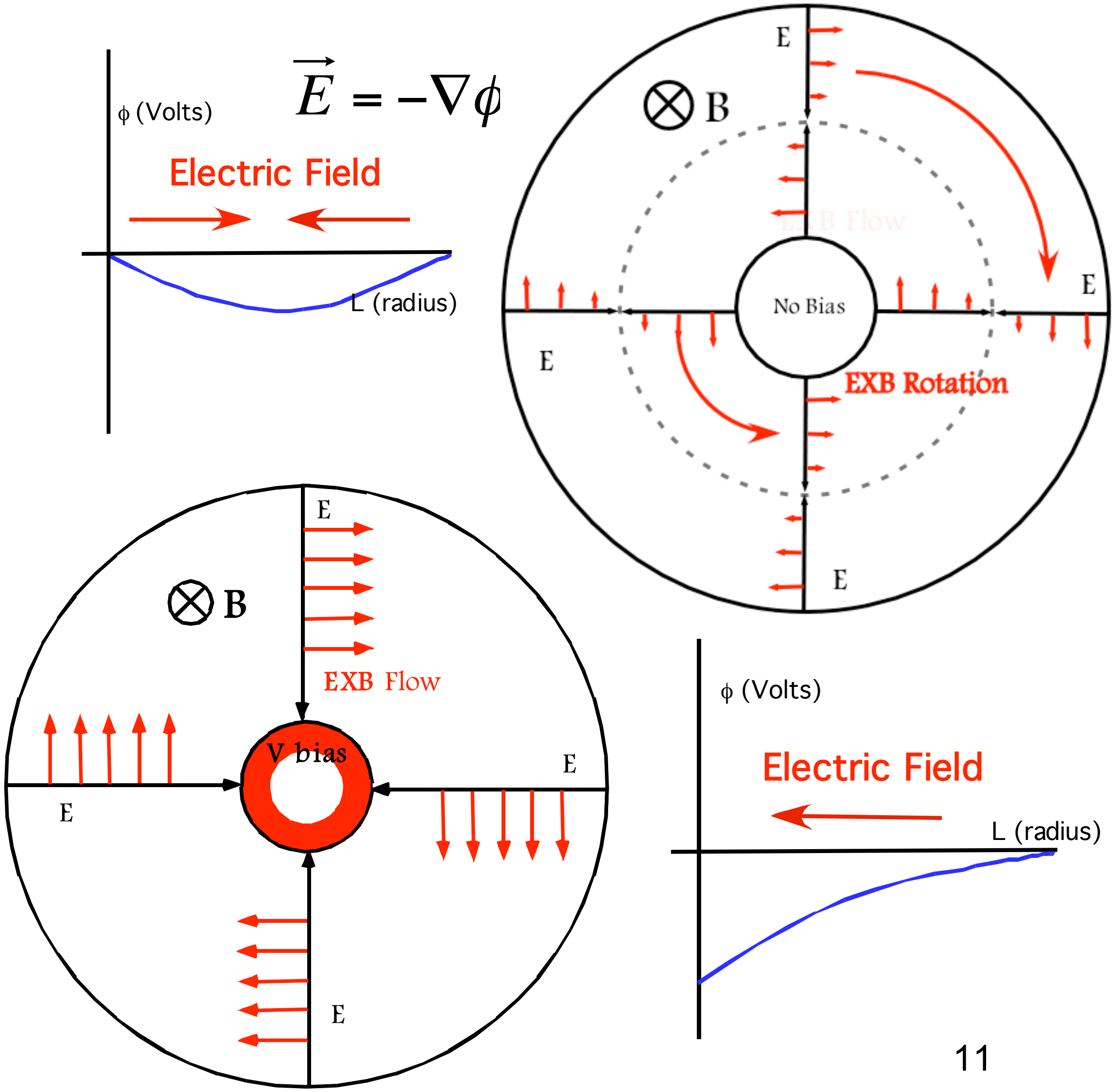
$$\nabla \cdot \vec{J} = (\nabla \sigma_p) \cdot E_\perp + \sigma_p (\nabla \cdot E_\perp) -$$

$$(\nabla \sigma_H) \cdot (E_\perp \times \hat{b}) - \sigma_H \nabla \cdot (E_\perp \times \hat{b}) = 0$$

$$c_1 \frac{\partial^2 \Phi^*}{\partial \psi^2} + \tfrac{c_2}{\psi} \frac{\partial \Phi^*}{\partial \psi} + \Phi^* \left[im \tfrac{c_3}{\psi} - m^2 \tfrac{c_4}{\psi^2} \right] = 0$$

Unbiased and Axisymmetric Cases

- Natural Plasma Potential Profile
- Witness shear in ExB flows
- Biased meshes negatively, create rigid rotation

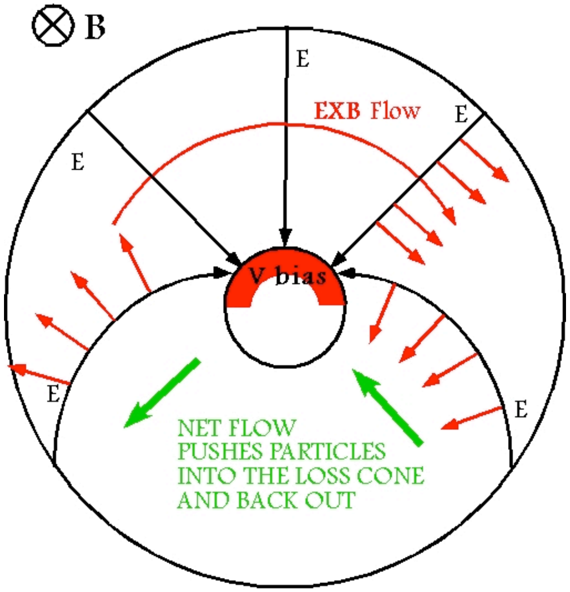


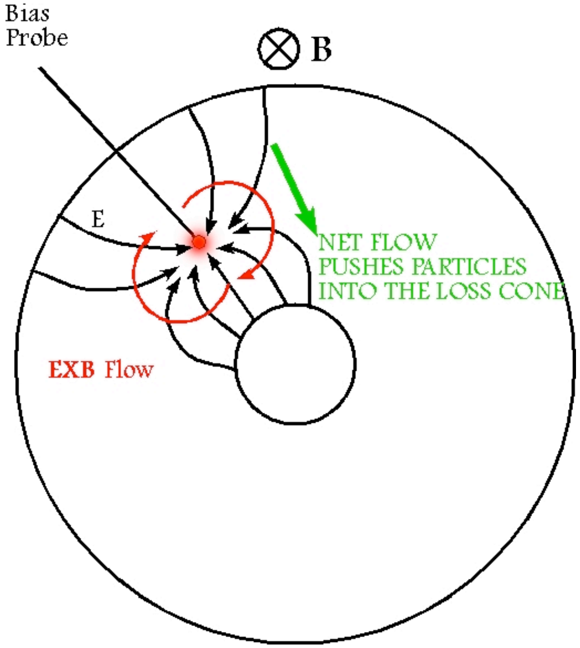
$$\vec{E} = -\nabla\phi$$

Expected Electric Fields

- If we apply a nonuniform potential or a point potential
- Nonaxisymmetric

Bias Probe





Axisymmetric Bias

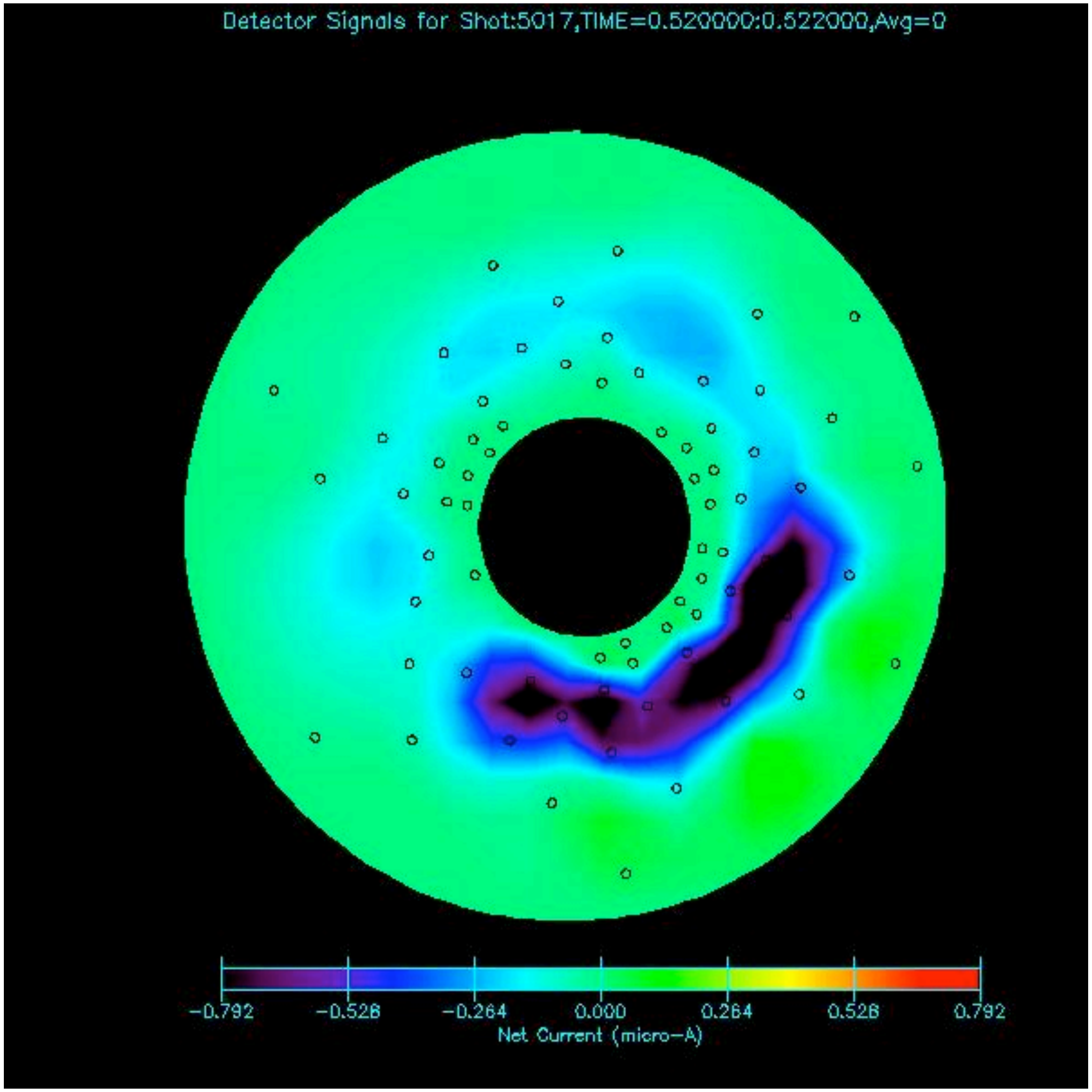
- Creates radial E-field
- Drives azimuthal ExB drift and significantly increases plasma rotation!
- Observe centrifugally driven flows: See Levitt, *et al*., PRL **94**, 175002 (2005).
- Excites low-frequency centrifugal interchange instability with very small real frequency in rotating ion frame.

Non-Axisymmetric Bias

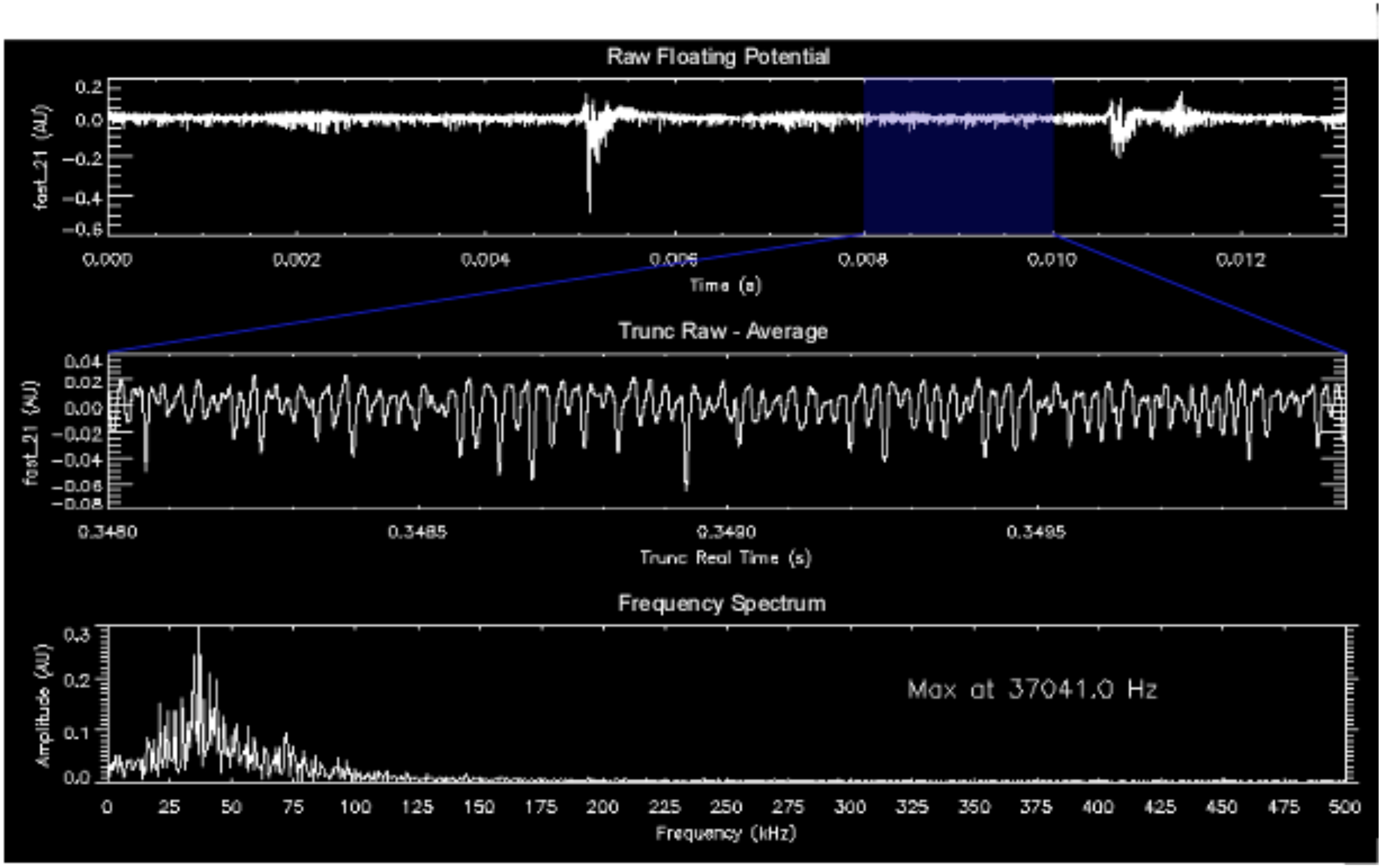
- Three lower meshes are grounded
- Convective Cell Formed (?)
- Electric Field and driven ExB flow geometry more interesting: drives both radial and azimuthal flows
- Dominant mode at floating probe experiences frequency doubling

Results Match Expectations

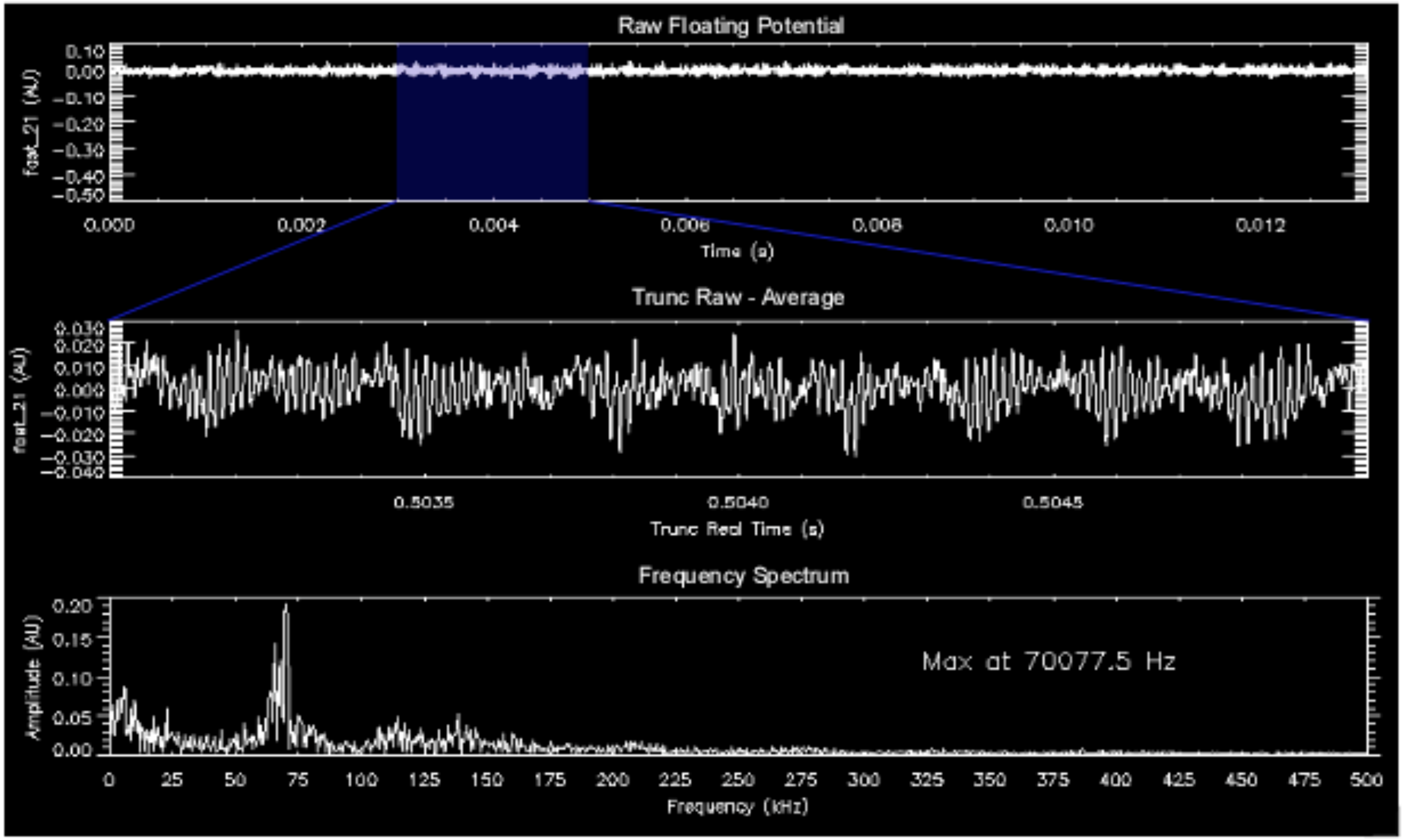
- Current collected is quasi-steady state
- Pronounced in area where inward radial transport shifts electrons in to the loss cone



No applied Bias

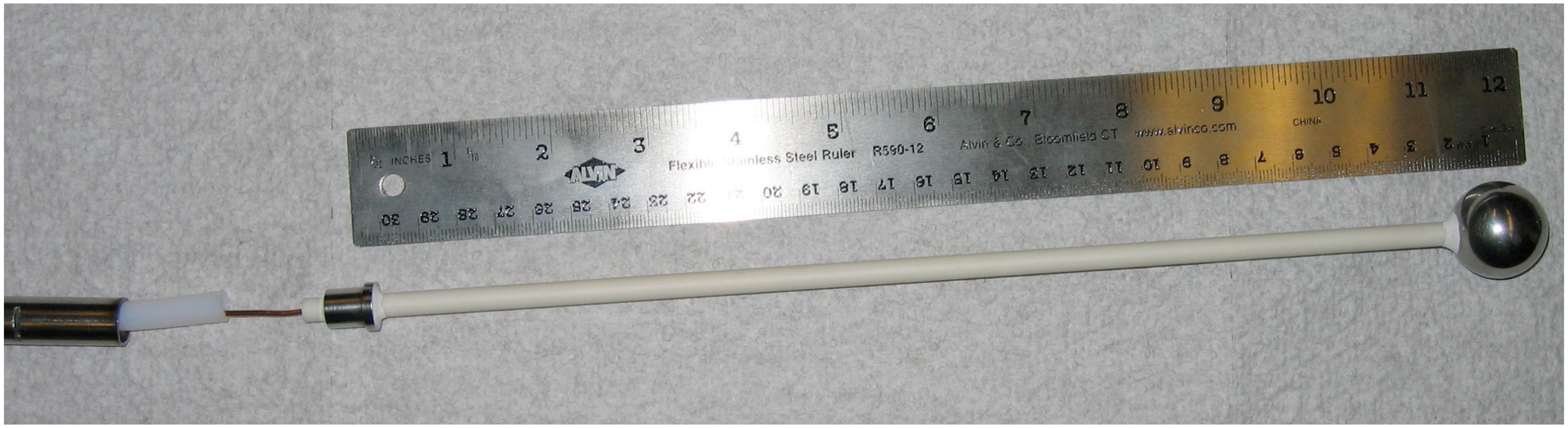


Upper Meshes V=-450 Volts

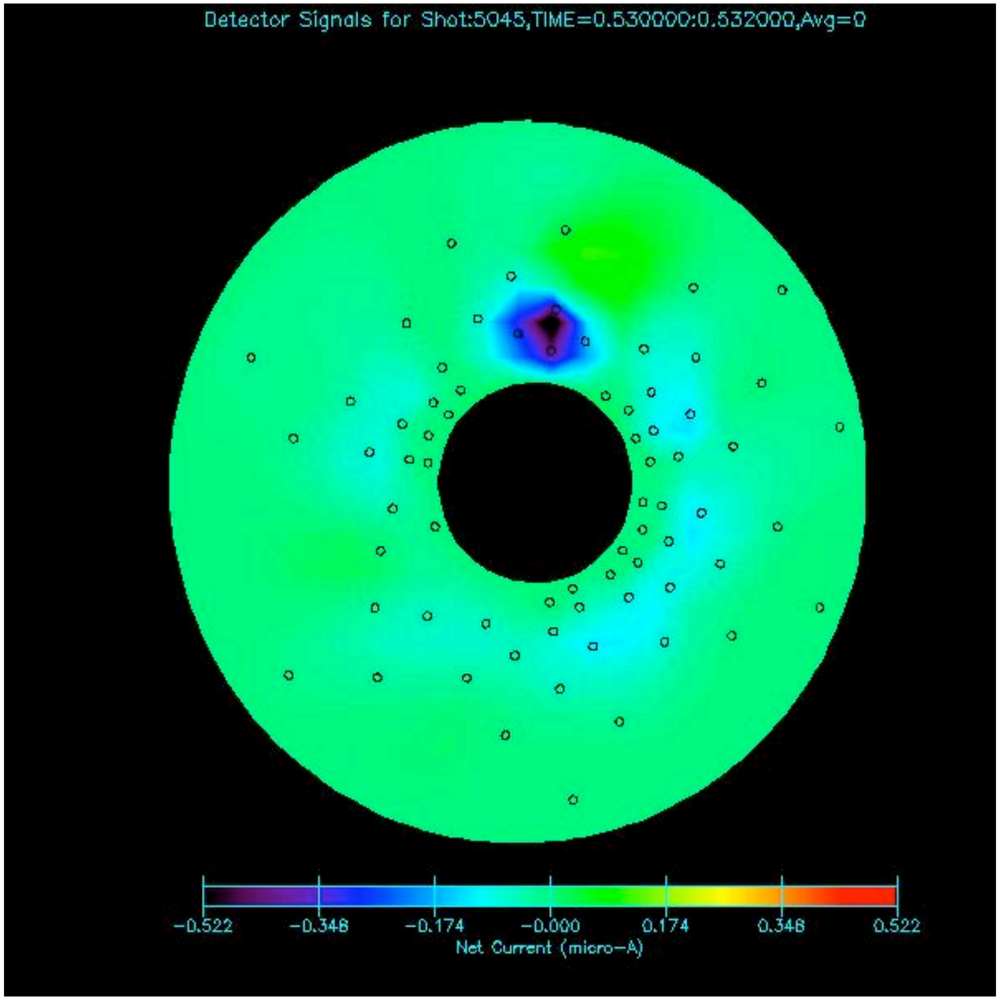


Second Approach: Movable Bias Probe

- Apply high voltage to 1” dia. stainless ball
- Placed along dipole equator
- Just Installed
- Applied voltage varied from 0 to -2000 V



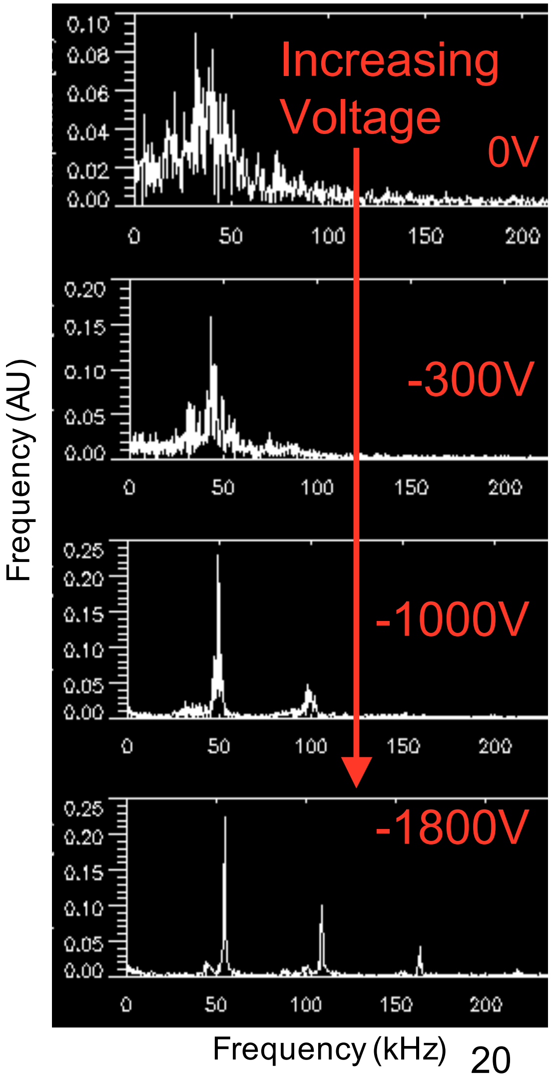
Probe Bias Alters Polar Currents



- As bias voltage is increased standard rotating mode weakens, while static spot grows.
- This is evidence of plasma flow in the radial direction, into the loss cone

Frequency Spectrum Shifts with High Probe Bias

- During voltage scan frequency spectrum changes and a coherent 50 kHz mode (and harmonics) appears
- Detected in both high-speed floating probes
- Mechanism still not understood



Future Work

- Apply positive bias
- Install second bias probe
- Apply dynamic (time-varying!) fields to equatorial meshes, rotating with plasma oscillation
- Investigate “electrostatic feedback”: mesh/probe potentials are applied to stabilize/amplify plasma convection