Reduction of Turbulence via Feedback in a Dipole Confined Plasma

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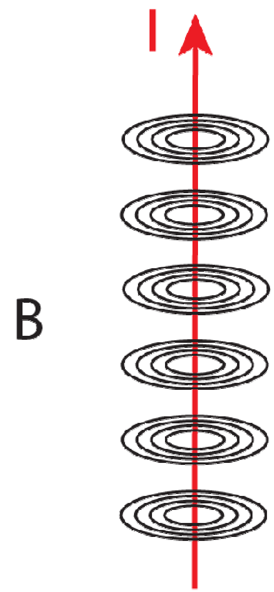
Outline

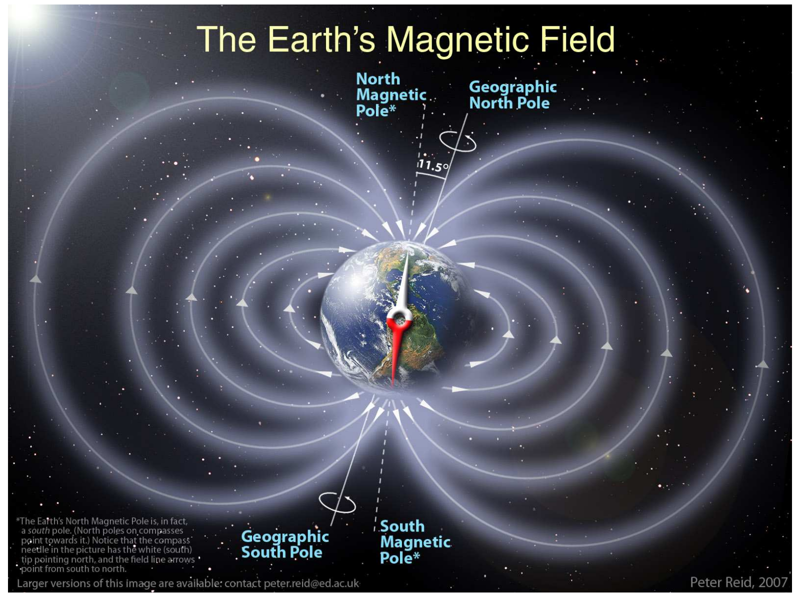
- Dipole Confinement Physics
- The Collisionless Terrella eXperiment
- Turbulence
- Feedback
- Preliminary Experiments with Feedback
- Future Experiments

Dipole Fields

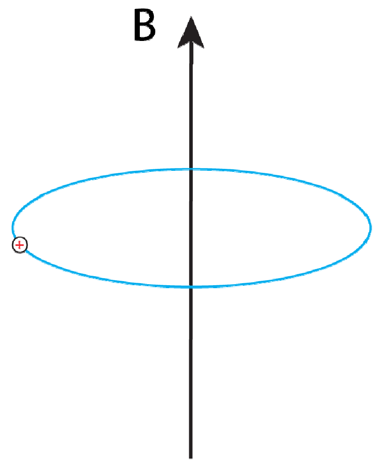
- Created in the laboratory by winding wire carrying an electric current.

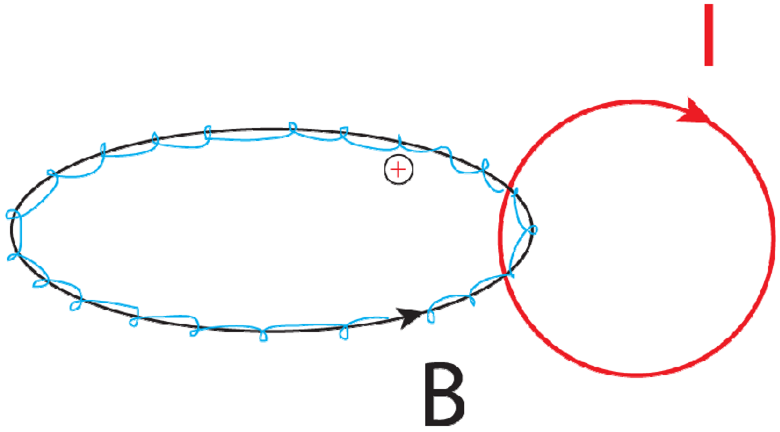


- Occur in nature in astro-physical bodies like planets and stars.
- Simplest form of magnetic confinement.



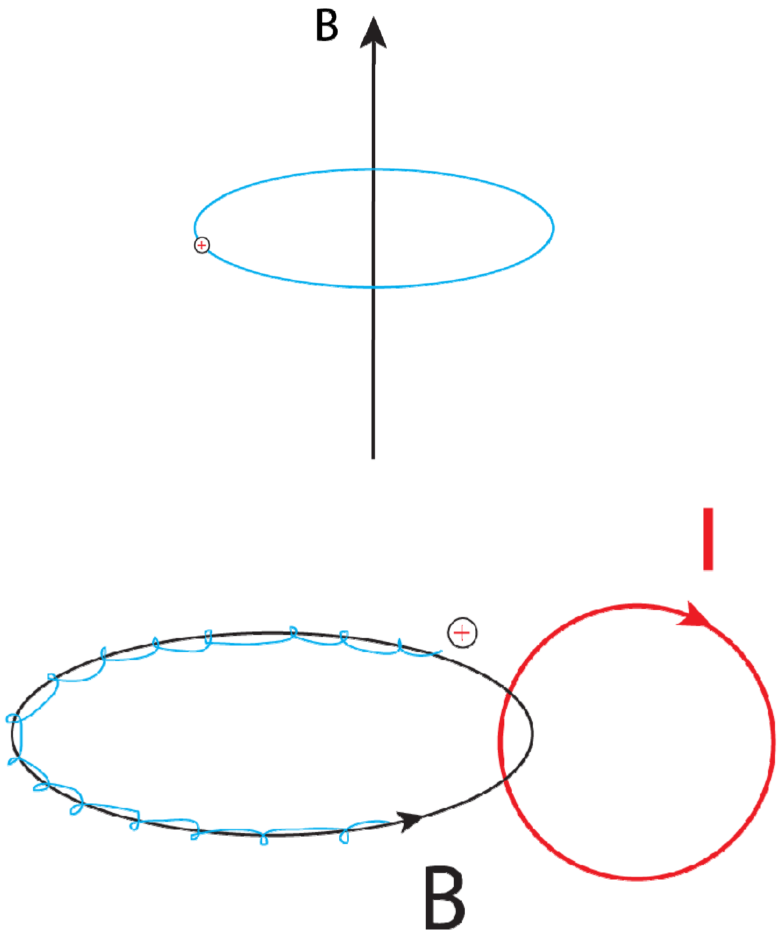
How Does a Dipole Confine Plasma?





- Charged particles trapped in 2D by Lorentz force, spin around the field lines.
- Wire loop traps particles along the field line!

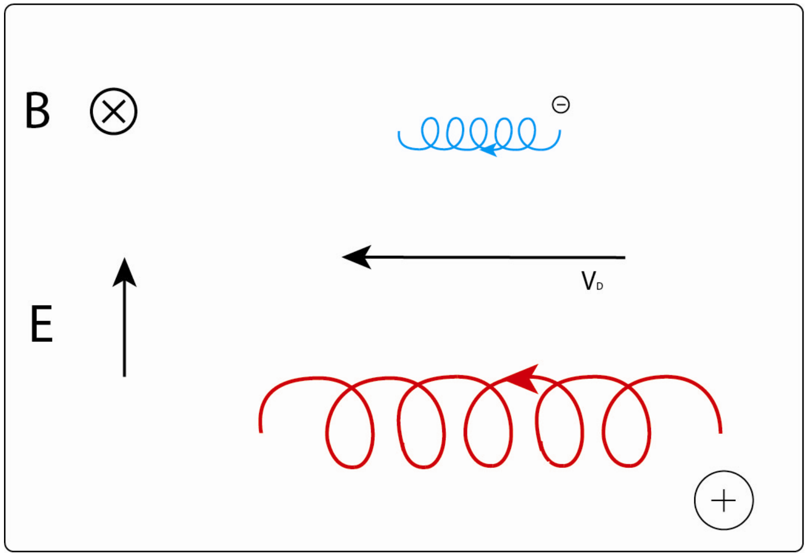
How Does a Dipole Confine Plasma?

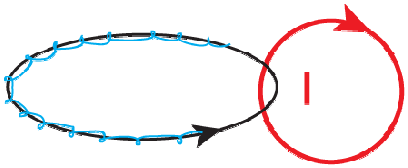


- Charged particles trapped in 2D by Lorentz force, spin around the field lines.
- Wire loop traps particles along the field line!
- Particle bounces between high field regions due to force from bent magnetic field.

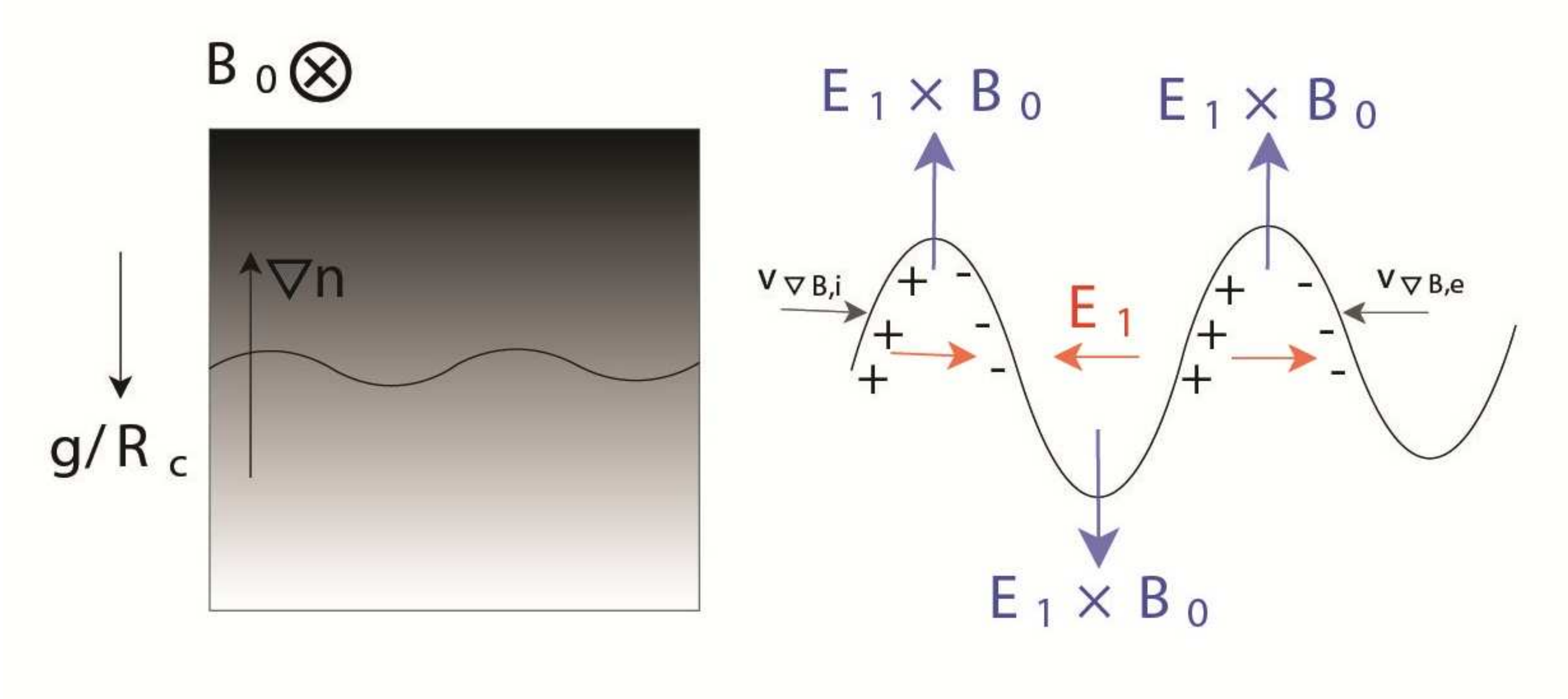
How does Plasma Behave in a Dipole?

- Fundamental drift in plasmas known as ExB
- Radial electric fields form in any real dipole plasma.
- ExB drift give us third main motion of plasma:
  - Gyro
  - Bounce
  - Precession



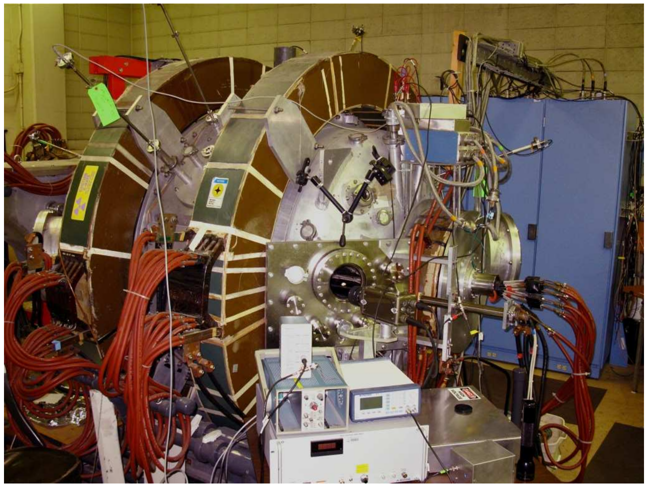


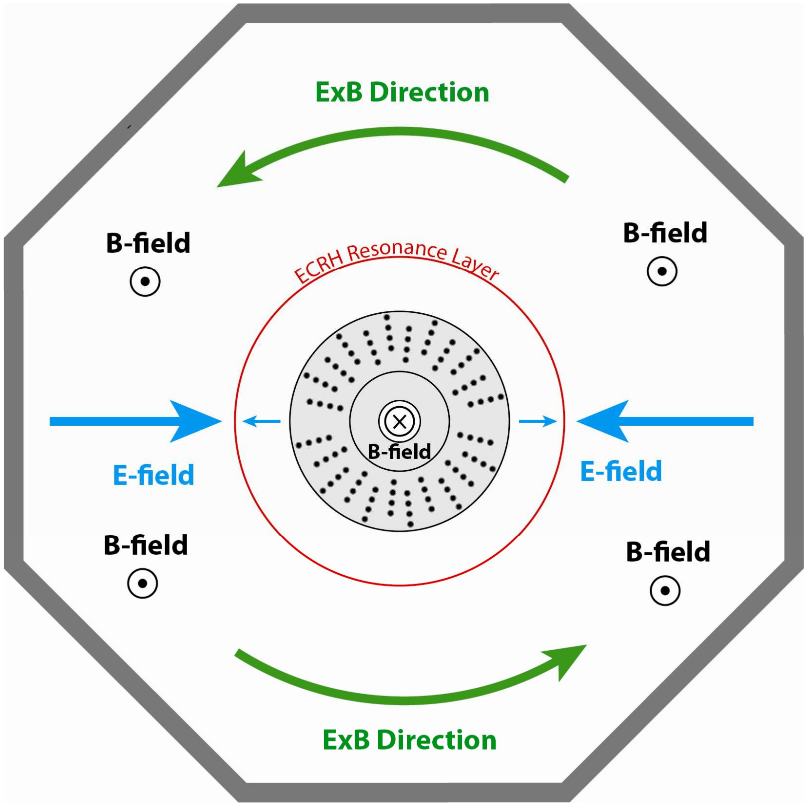
Instabilities in a Dipole Plasma

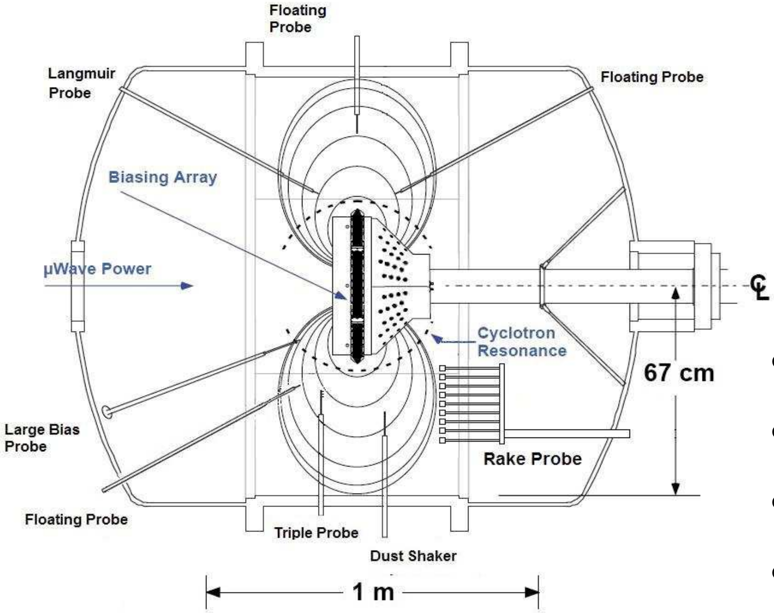


- Dominant instability due to the pressure gradient and the artificial gravity due to rotation.
- Rayleigh-Taylor analog to flux tube interchange.

A Real Dipole, CTX!

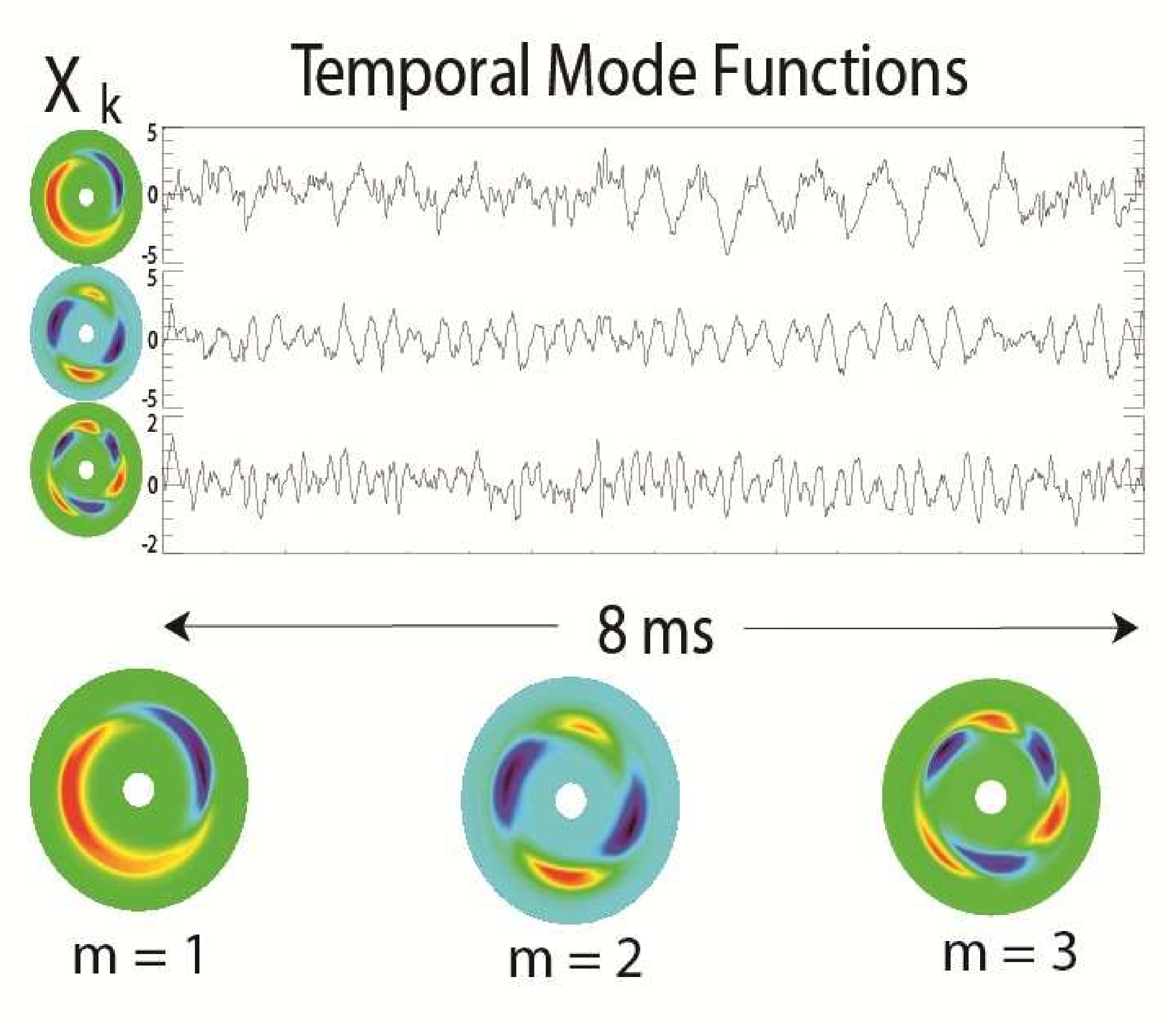






- Magnet in vacuum chamber (~10^{-7} Torr).
- Microwave resonance creates plasma.
- ExB results from radial E-field.
- Various diagnostic located in chamber.

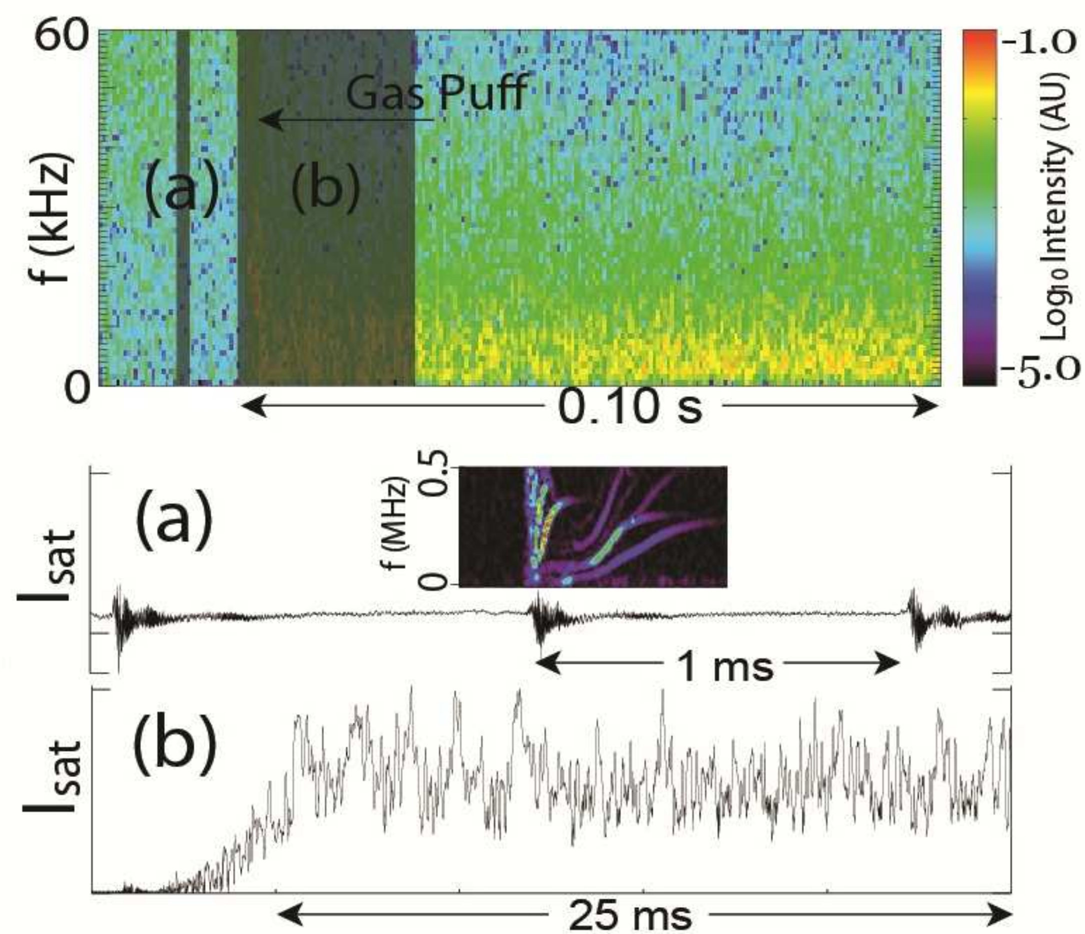
Mode Structures in CTX



- Imaging array gives us picture of the rotating density profile.
- Forms coherent spatial and temporal modes.

Regimes of Plasma Density in CTX

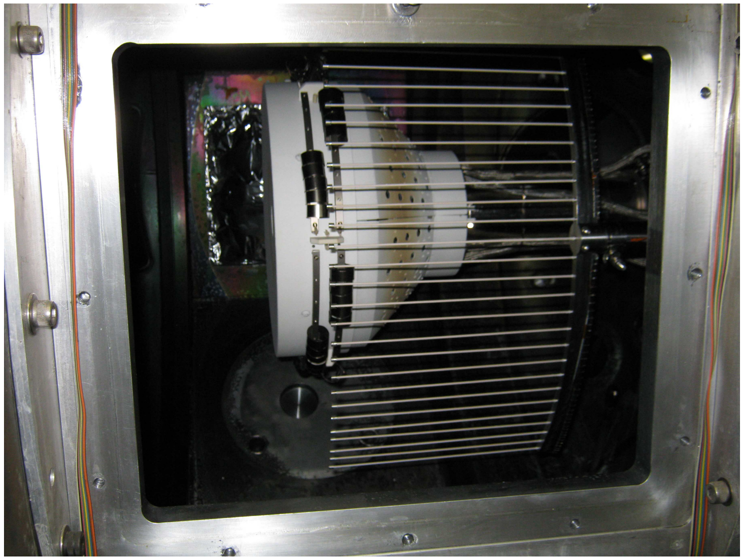
- Two operating regimes, "low" (~10^{-14} m^{-3}) and "high" (~10^{-16} m^{-3}) density.
- High density plasma created by increasing neutral pressure.
- Plasma density is calculated from ion current to conducting probe in plasma.
- High density also has new spectrum of turbulent fluctuations in potential and density.

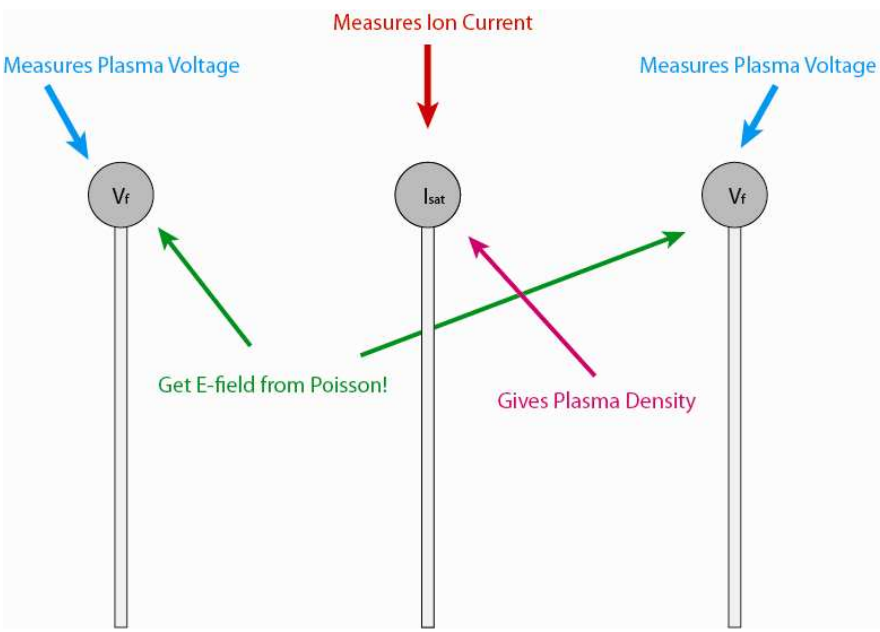


What is Turbulence?

- As you can see, turbulence is common!
- Highly interdisciplinary problem
- Chaotic and characterized by irregularity and high diffusivity.

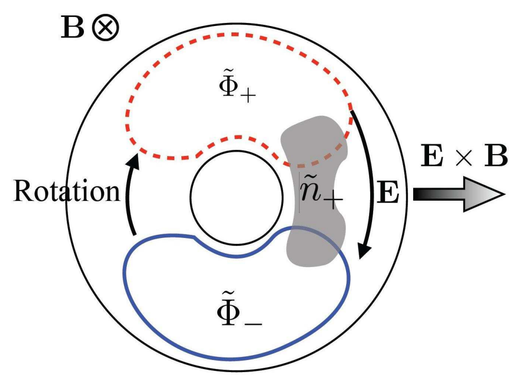
Turbulence in Plasmas





- Quantified by looking at RMS of fluctuations, correlation length, etc from probe measurements.
- Turbulence has large effects on particle/energy transport.
- Rake array measures electric fields and density, can calculate turbulent radial transport!

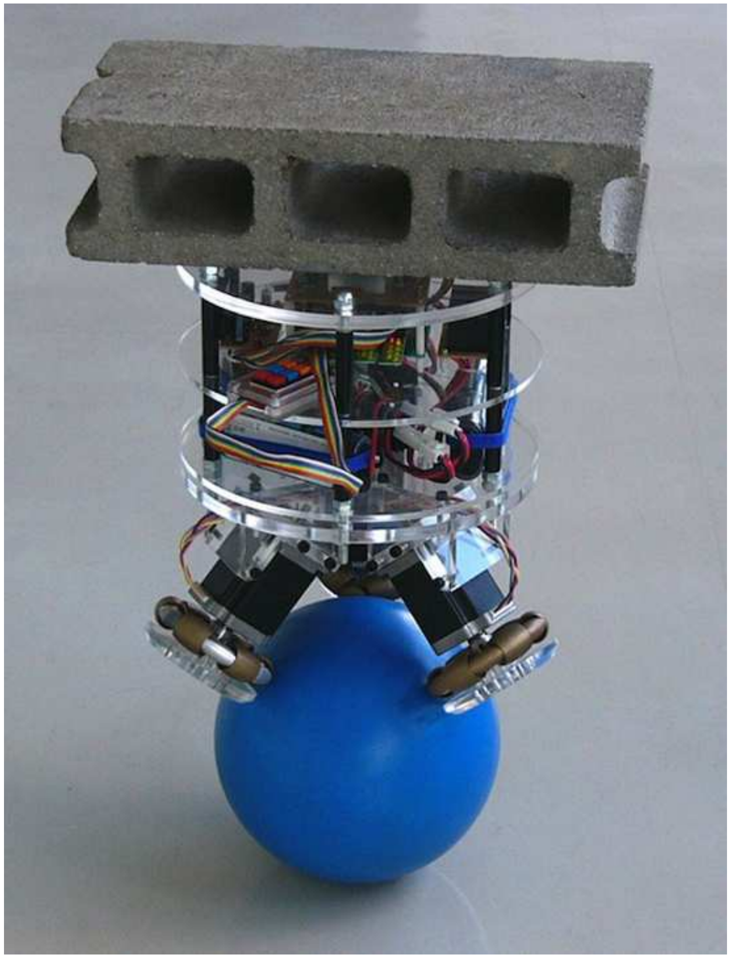
$$\Gamma_r = \tilde{n}\tilde{v}_r = \tilde{n}\frac{\tilde{E}_\varphi}{B}$$



B. A. Grierson Phys. Rev. Lett. 105, 205004 (2010)

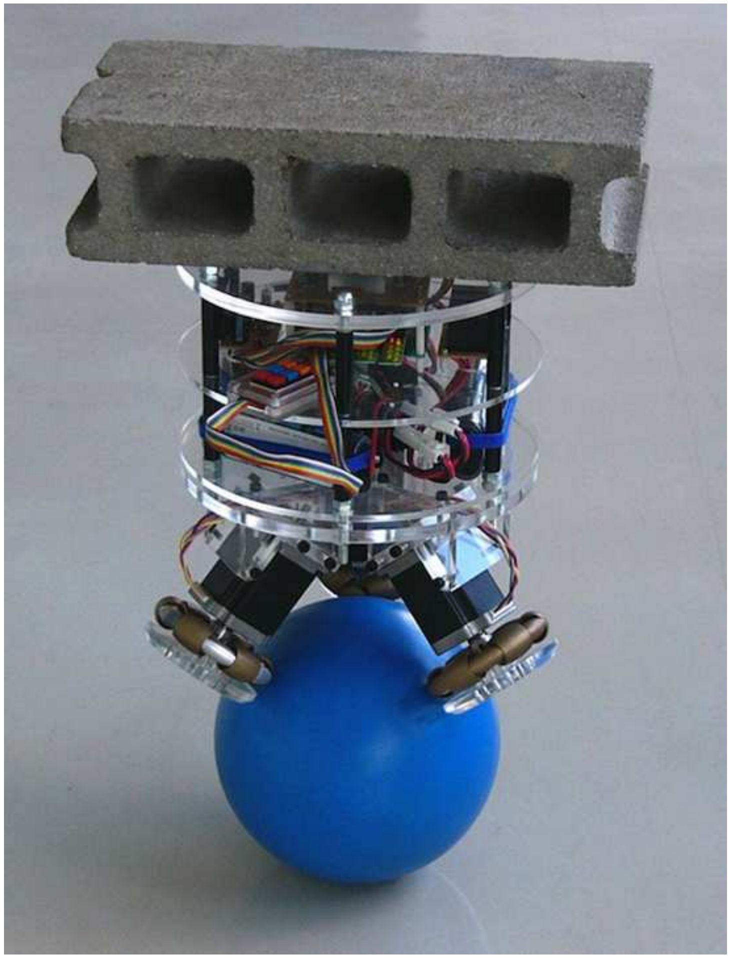
Feedback

- Feedback is the process of using the current and past information of a system to control the future state of the same system.



What does a Feedback System Need?

- **Sensor**
- **Actuator**
- **Phase Control**



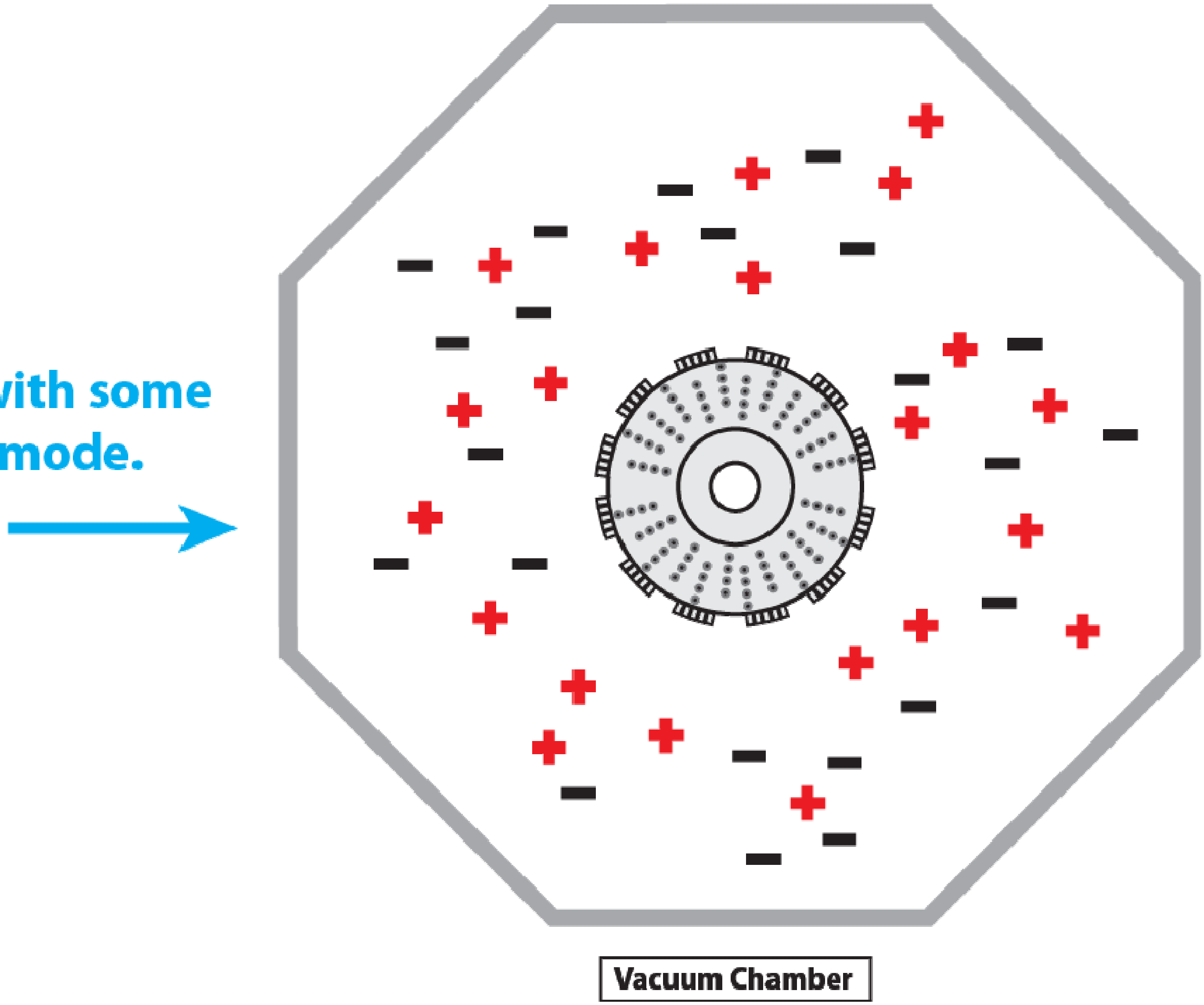
What does Phase Control change?

- **Positive feedback** **amplifies** a feature of the system, such as the typical example of a microphone close to a speaker.

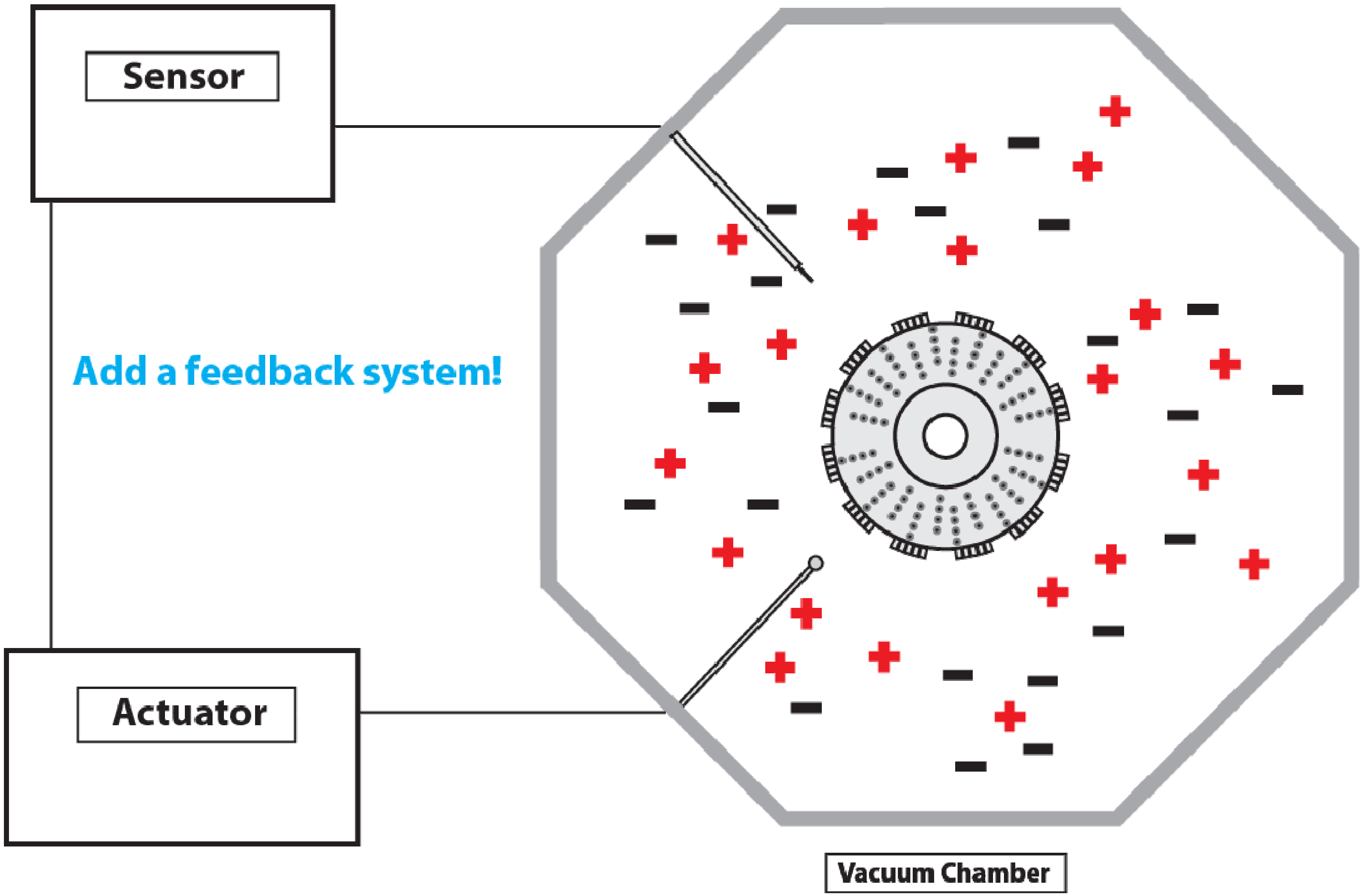
- **Negative feedback** implements a 180 degree phase shift from the above to **reduce** the measured levels. An example how be the thermostat in a car cools the engine.

Feedback with Plasma

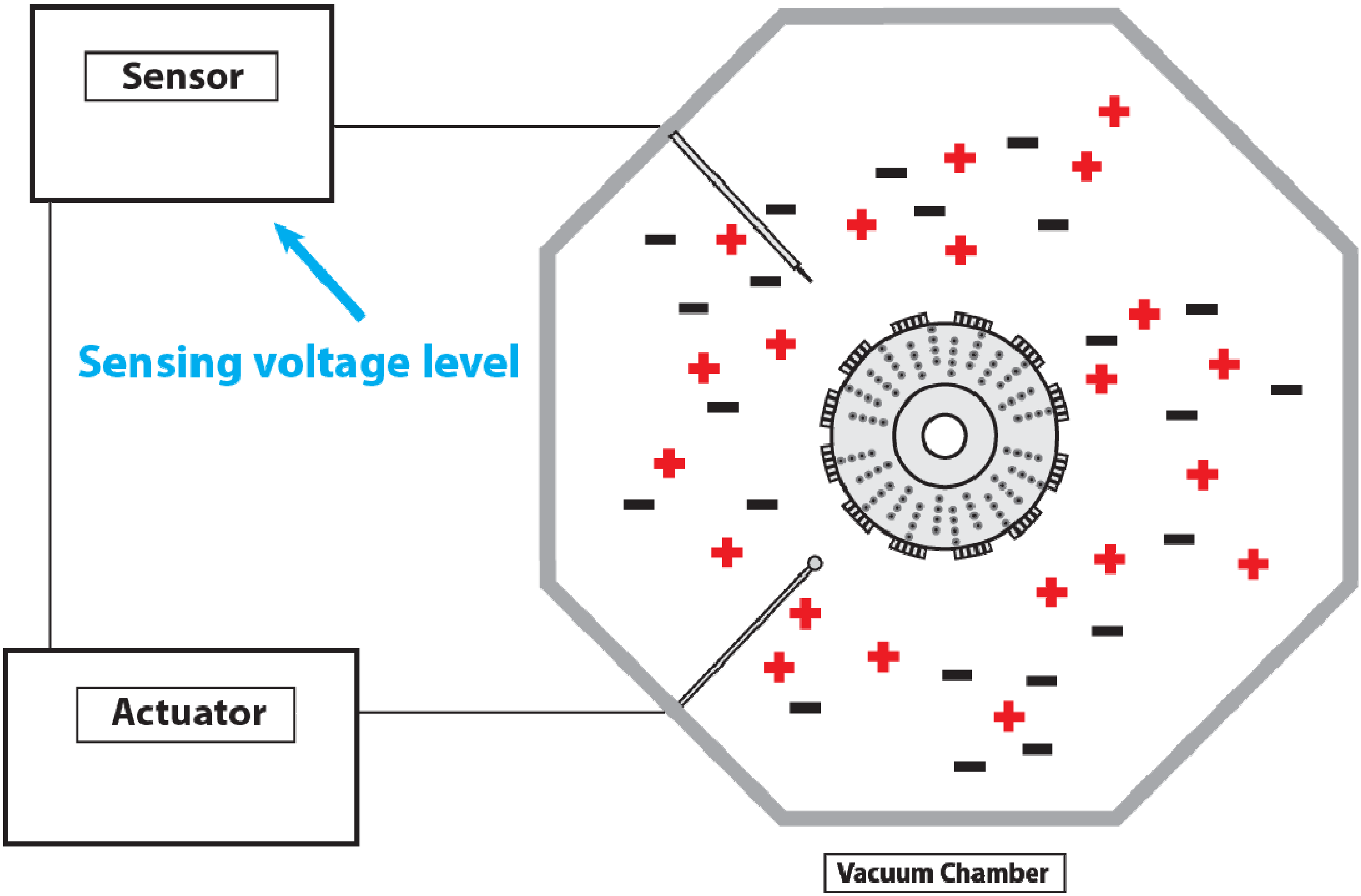
Plasma with some rotating mode.



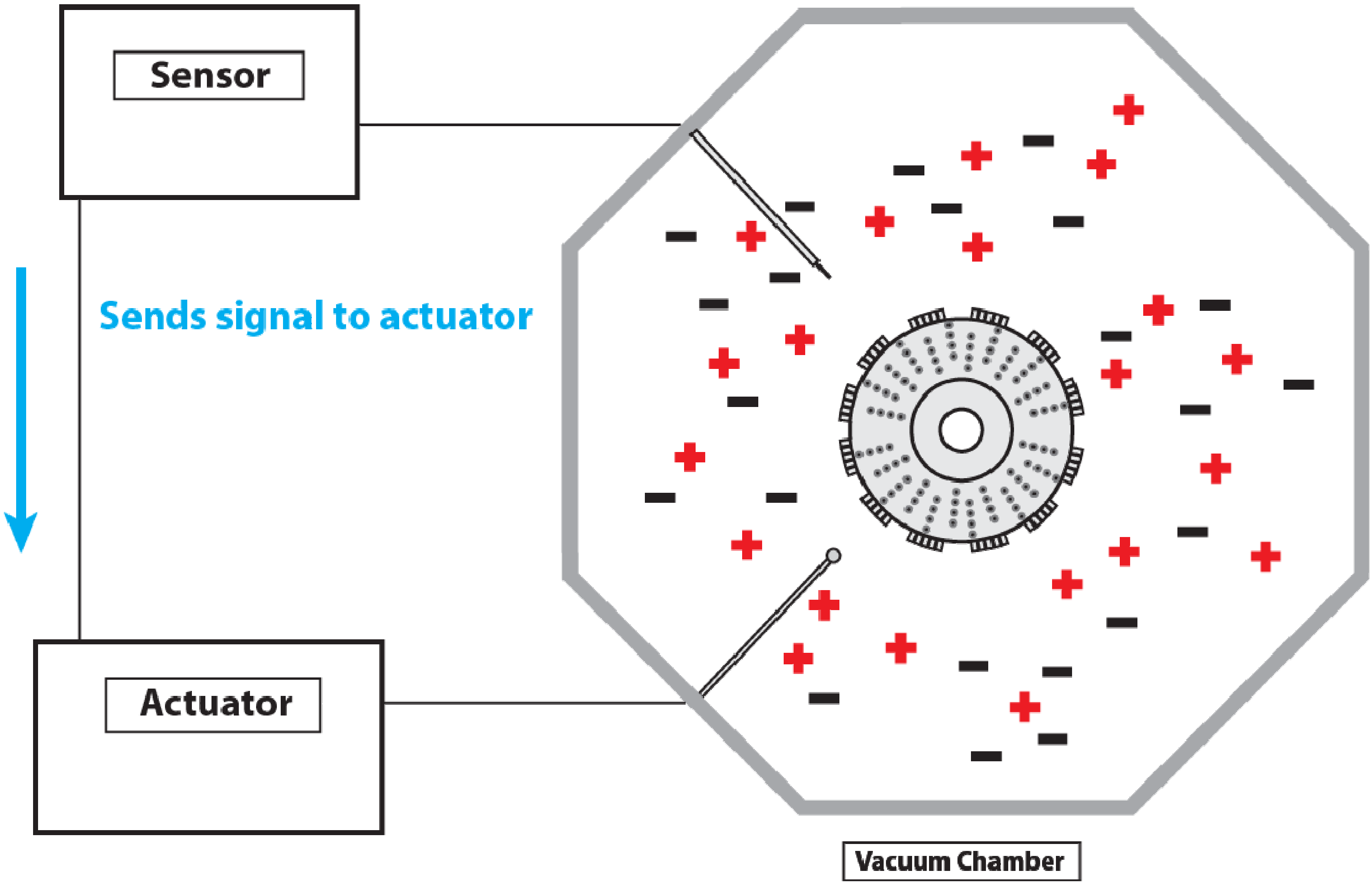
Feedback with Plasma



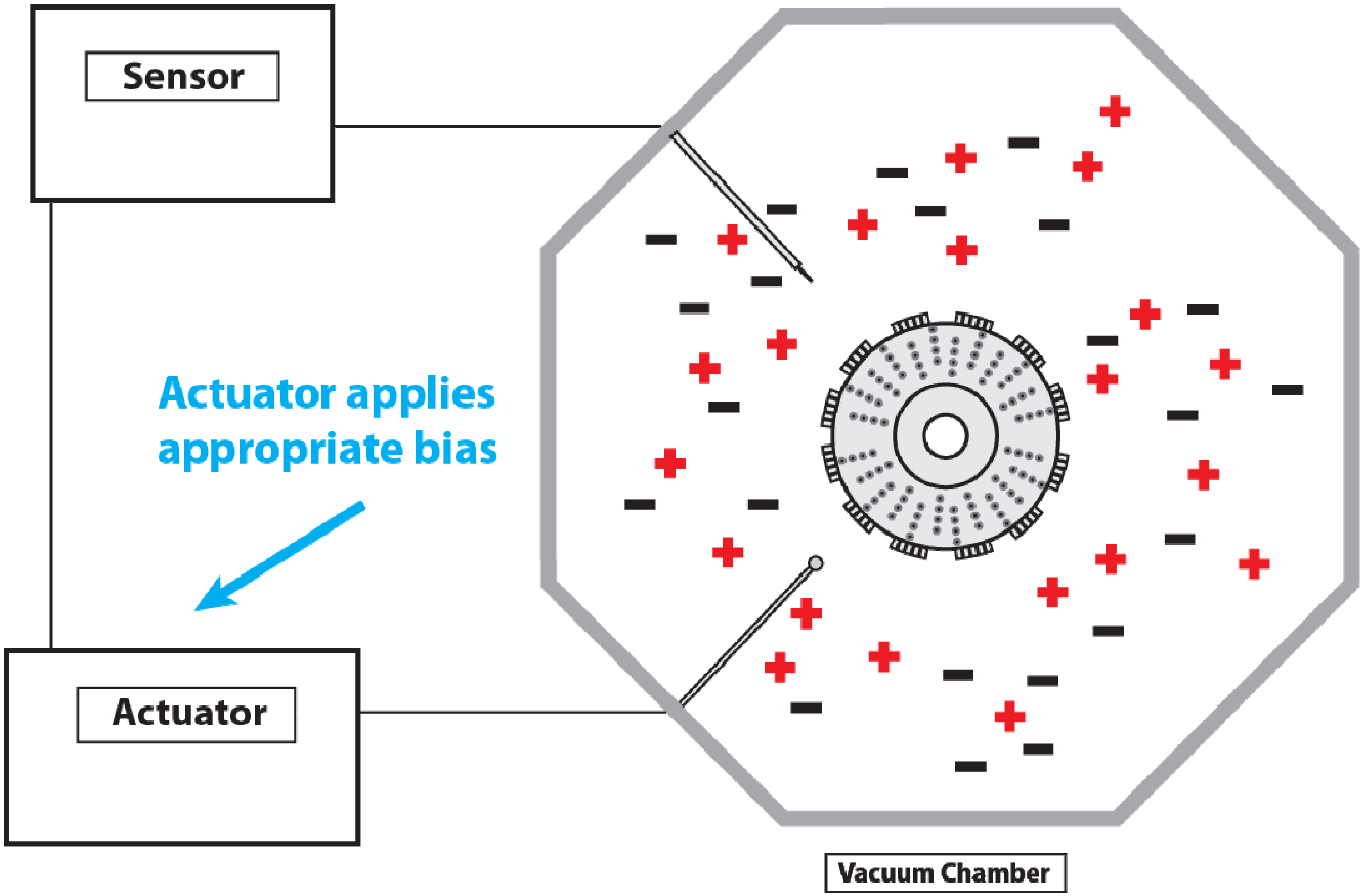
Feedback with Plasma



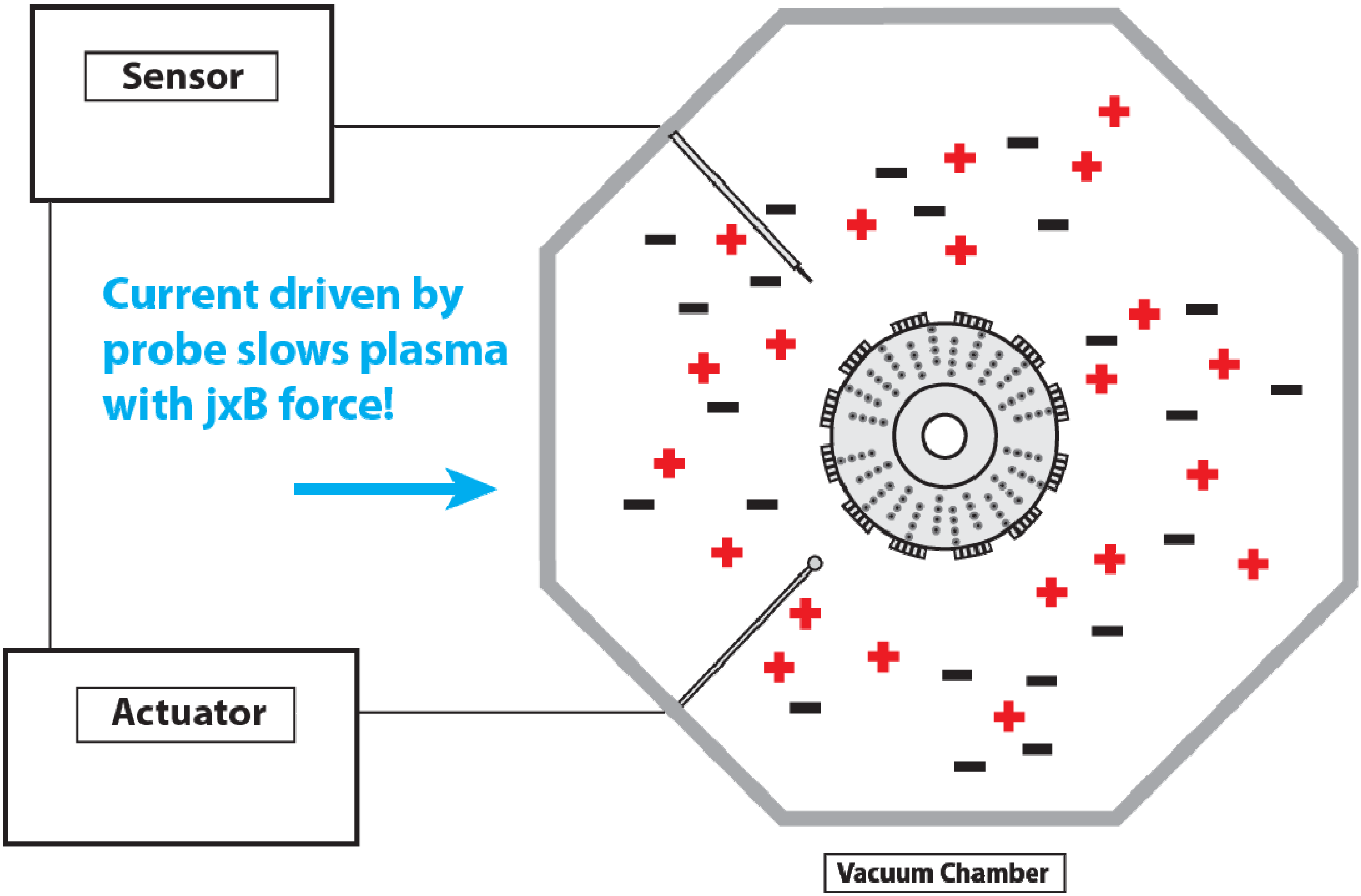
Feedback with Plasma



Feedback with Plasma

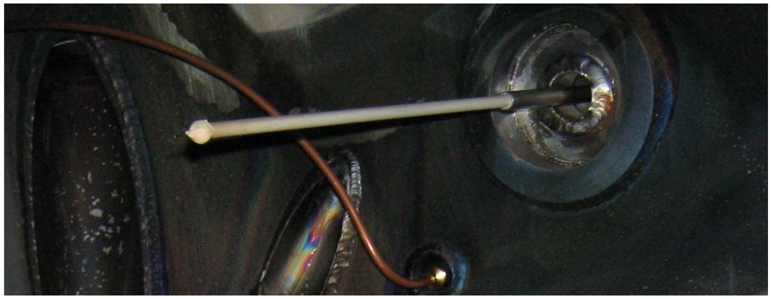


Feedback with Plasma

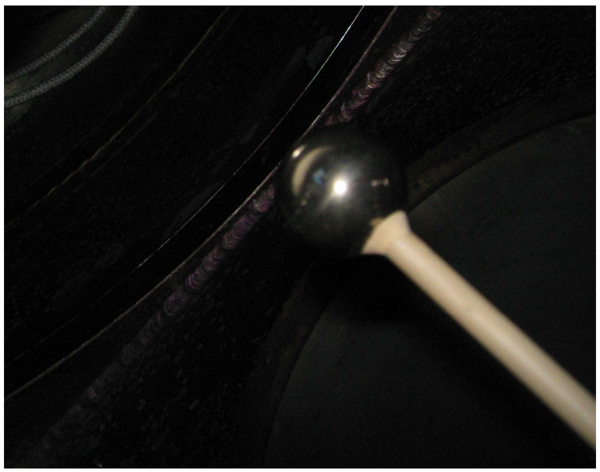


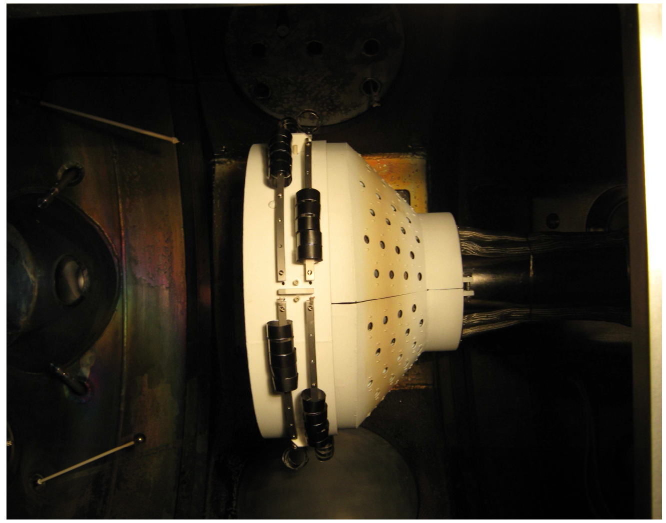
The Actual Components

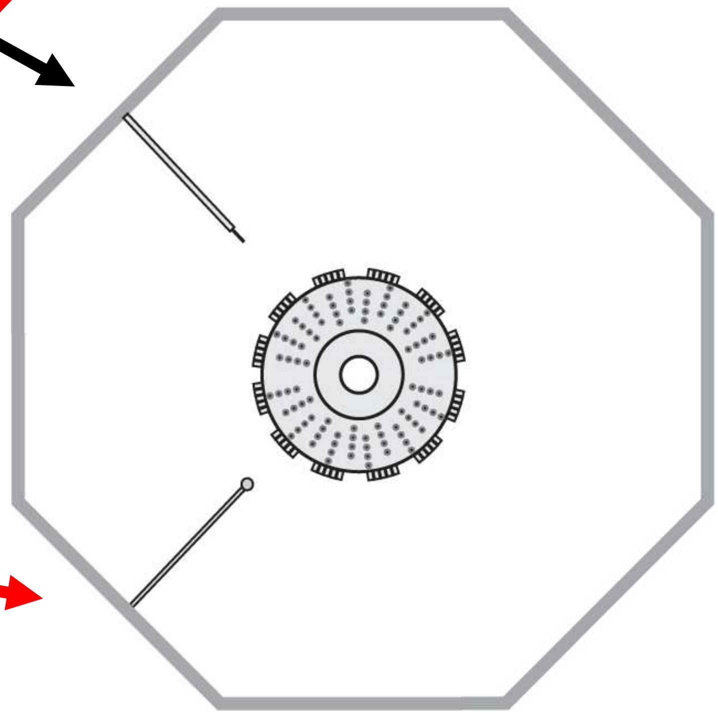
The Sensor



The Actuator

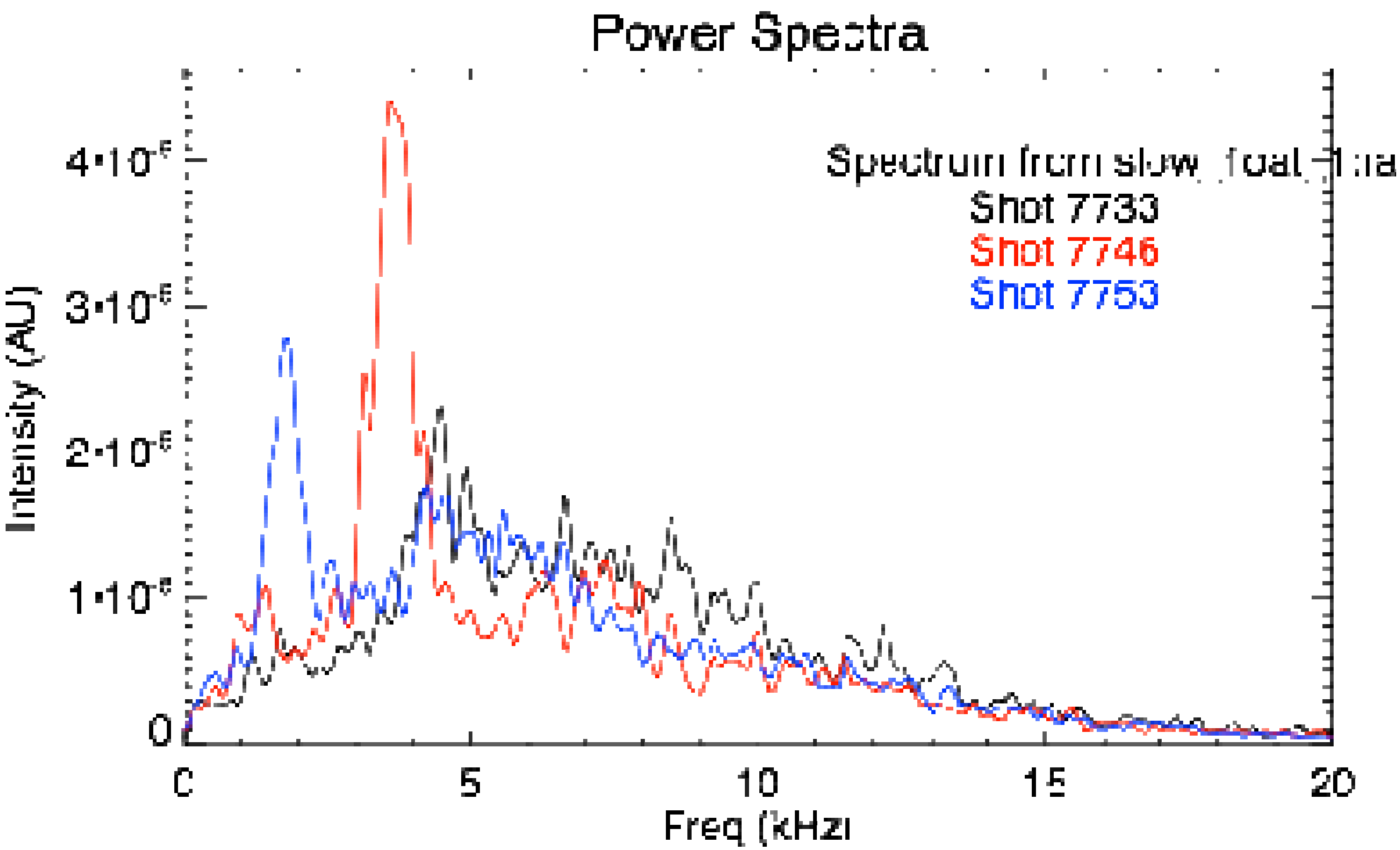




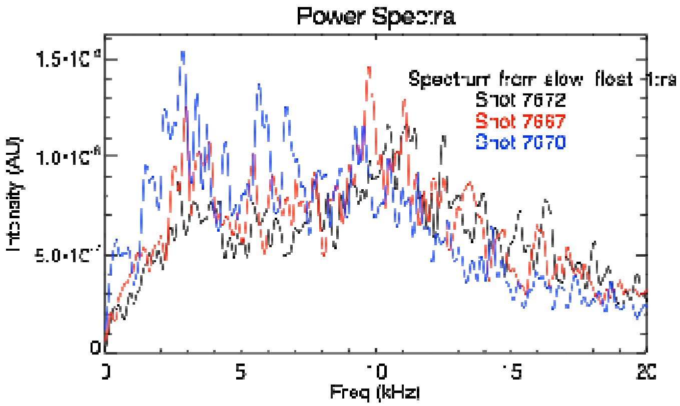


Results of Preliminary Experiment

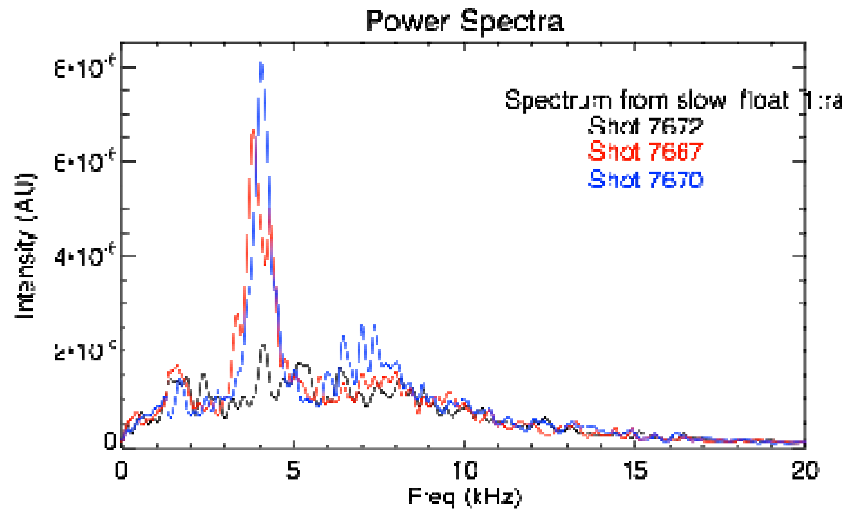
Feedback Off, "Positive", "Negative"



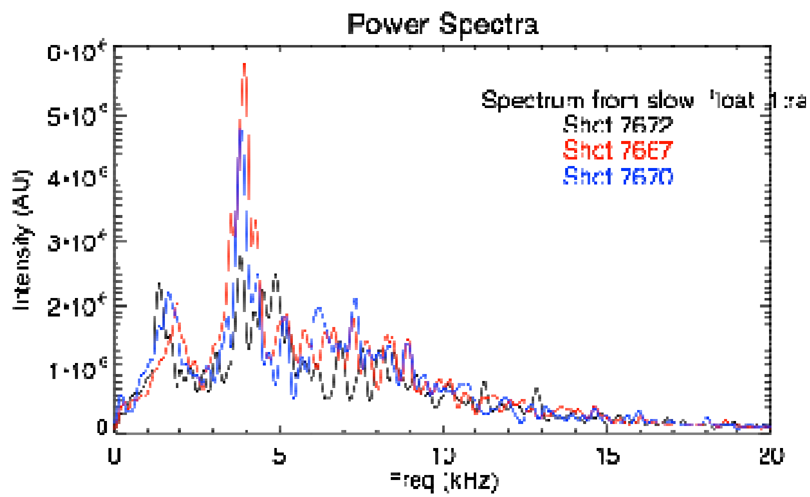
Results of Preliminary Experiment



Feedback on, 0.45s-0.55s

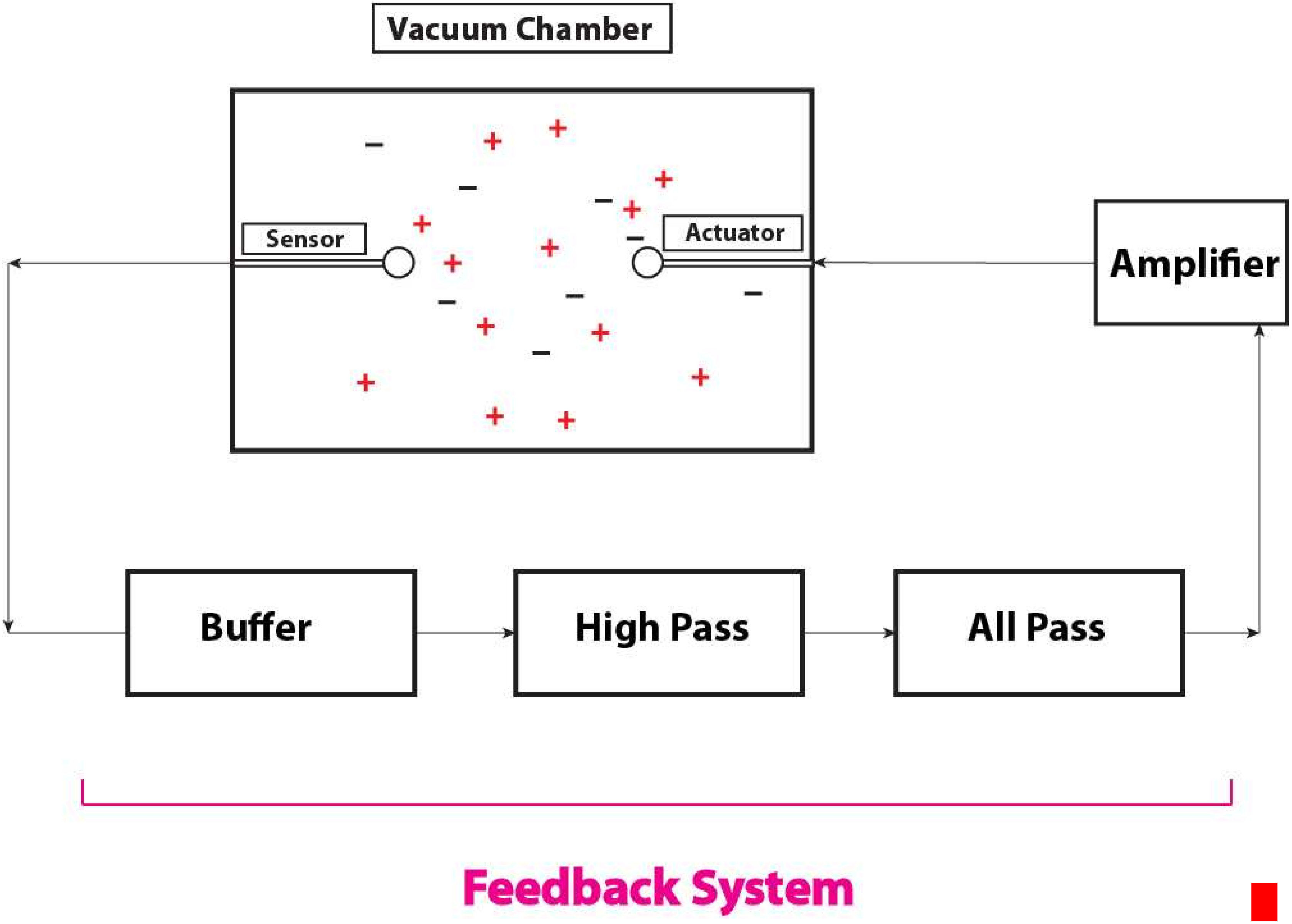


Feedback off, 0.25s-0.35s

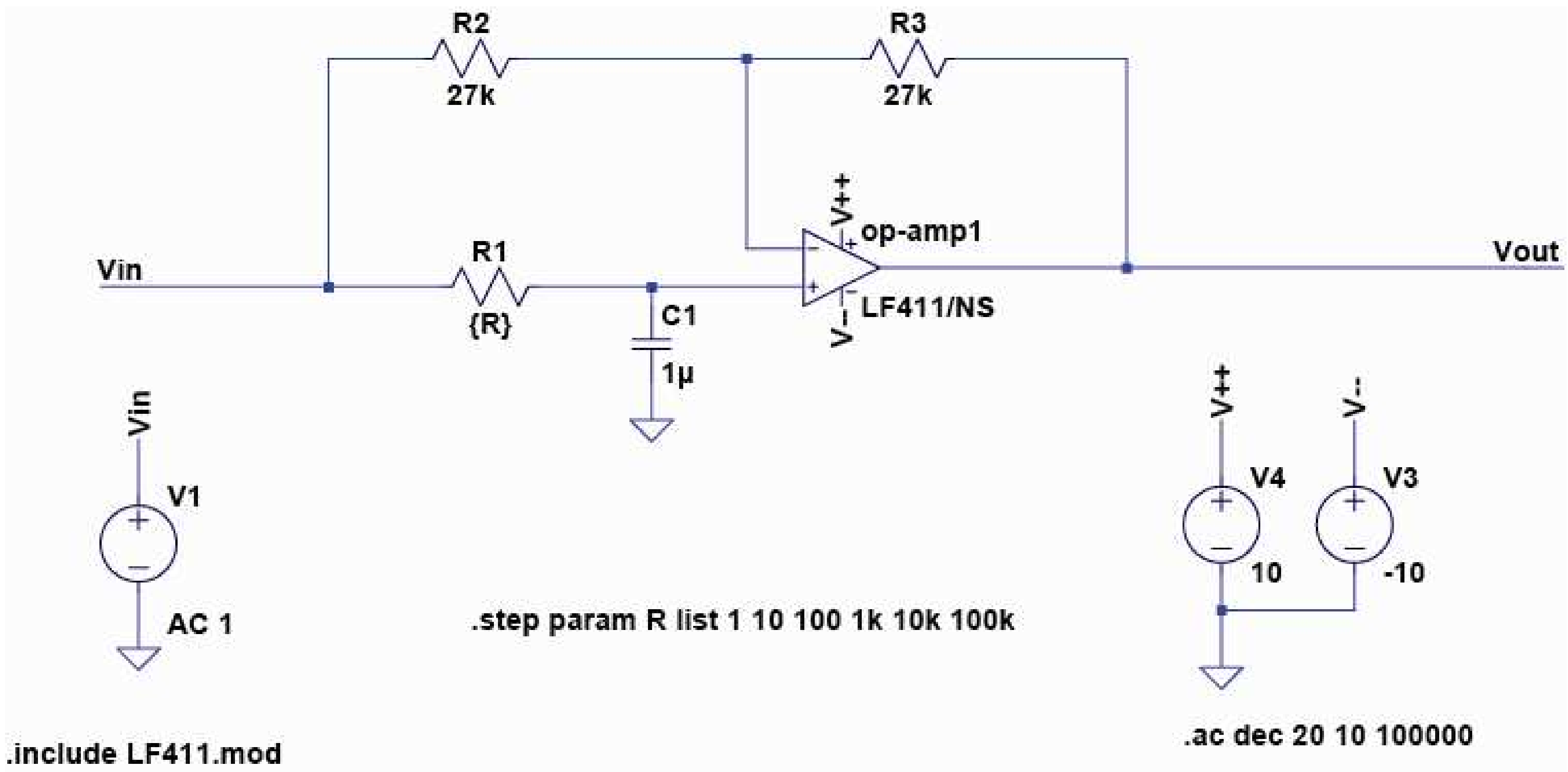


Feedback off, 0.55s-0.60s

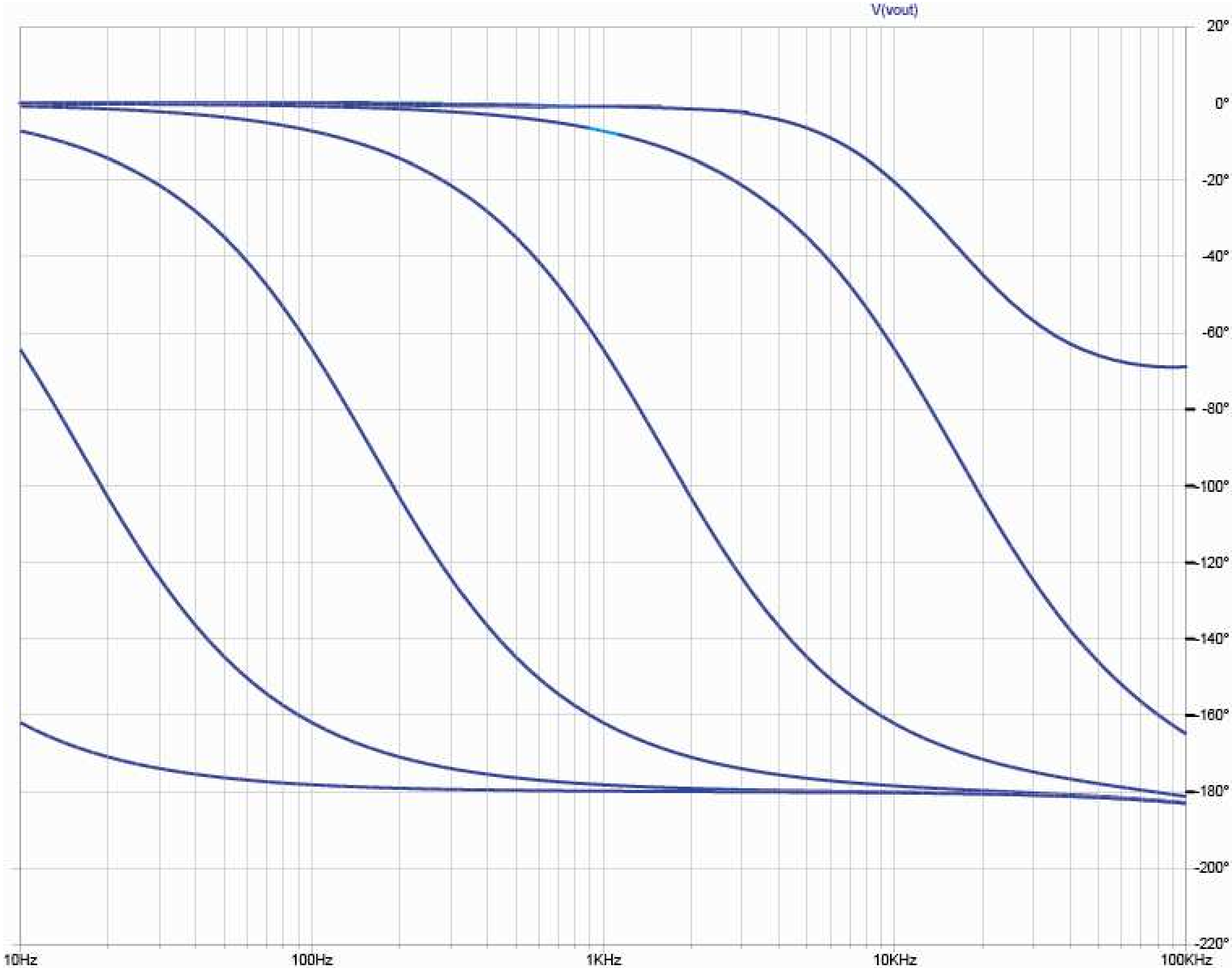
New Feedback System Detail



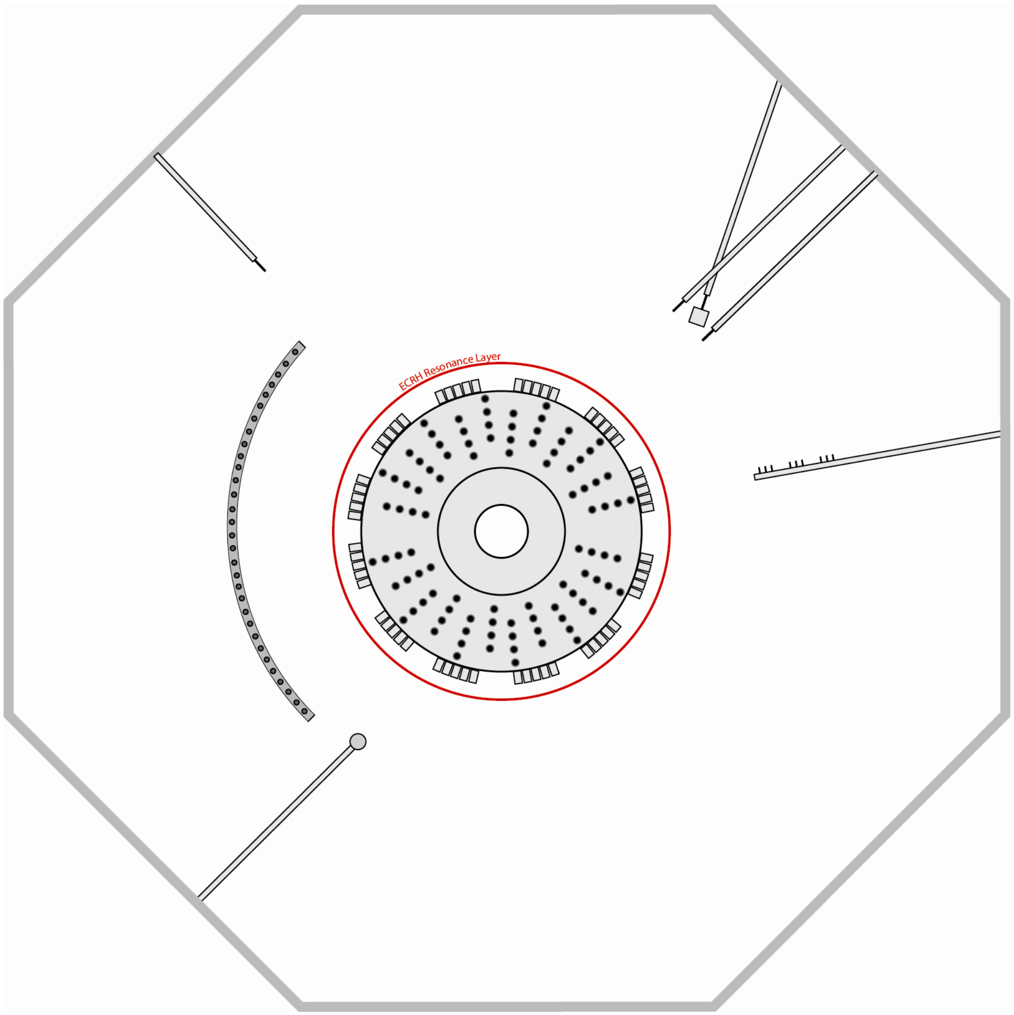
All Pass Filter (Phase Shifter)



All Pass Filter Phase Response



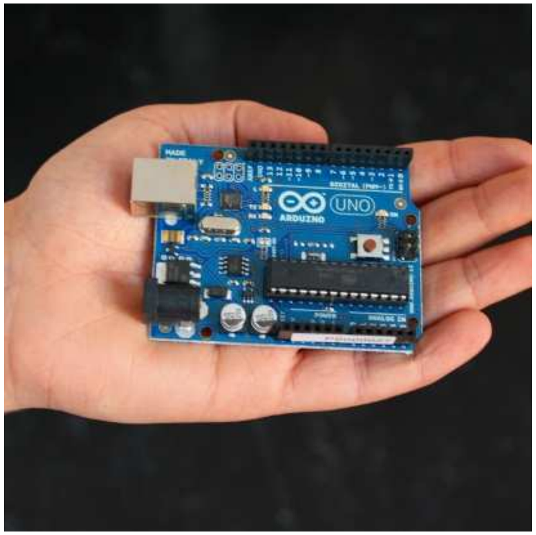
Planned Experiments

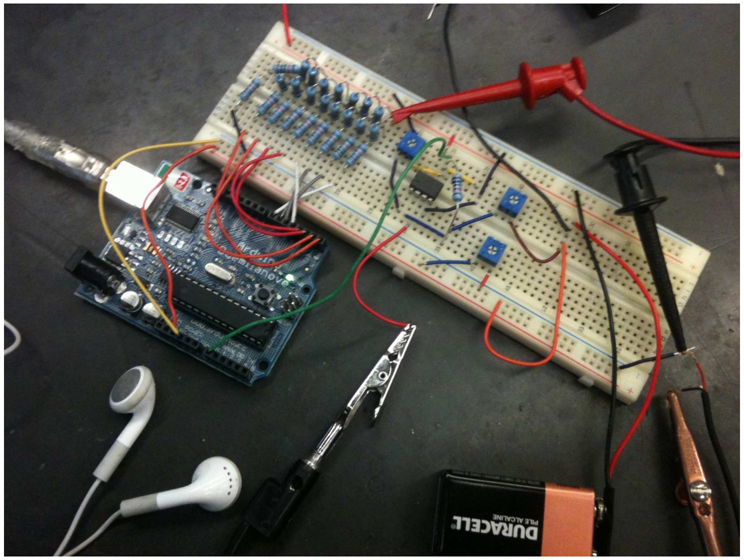


- First the phase shift sweep, followed by a filtering to target specific modes if the first is a success.
- Adjustment of probe location in the plasma to see if the relative or global position of the sensor/actuator pair has an effect.
- New sensor/actuator pairs, such as the Rake and equatorial array. This could have interesting effects due to the spatial resolution and phase shifts.

Digital Signal Processing

- Arduino microprocessors are an incredibly inexpensive means of DPS. With built-in ADC and simple adaptations to DAC, these could prove a fantastic way to approach feedback in our plasma.



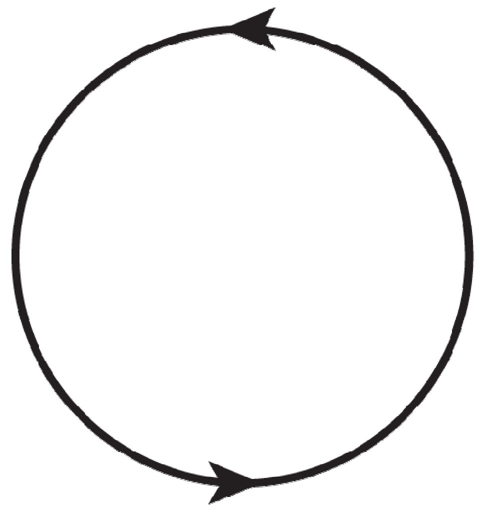


Thanks!

- Prof. Mike Mauel
- Matt Worstell
- Abed Balbaky

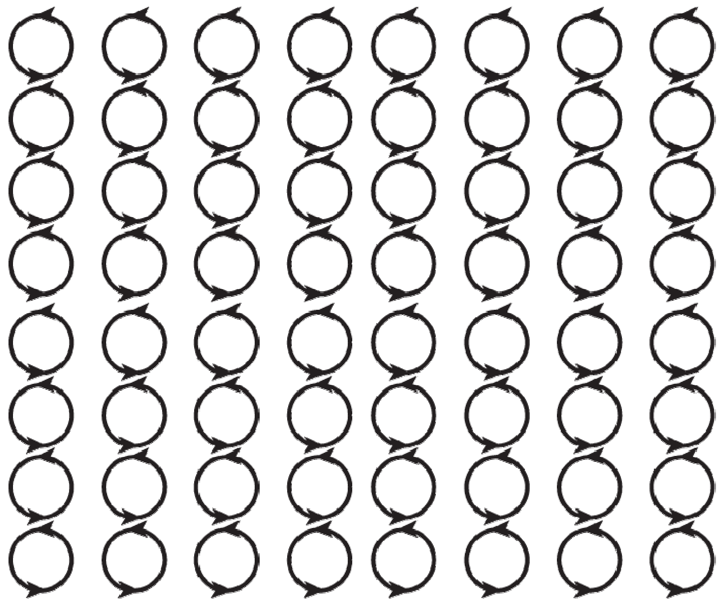
Extra Slides

Forward Energy Cascade



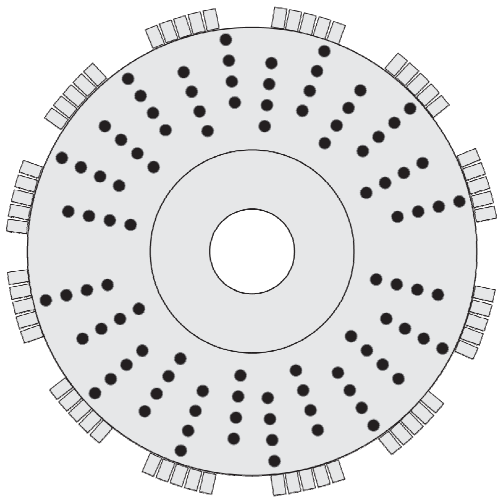
- In most 3D turbulent systems, we see a forward energy cascade.
- Energy at large scales is transferred to smaller scales as eddies break off of large structures.

Inverse Energy Cascade



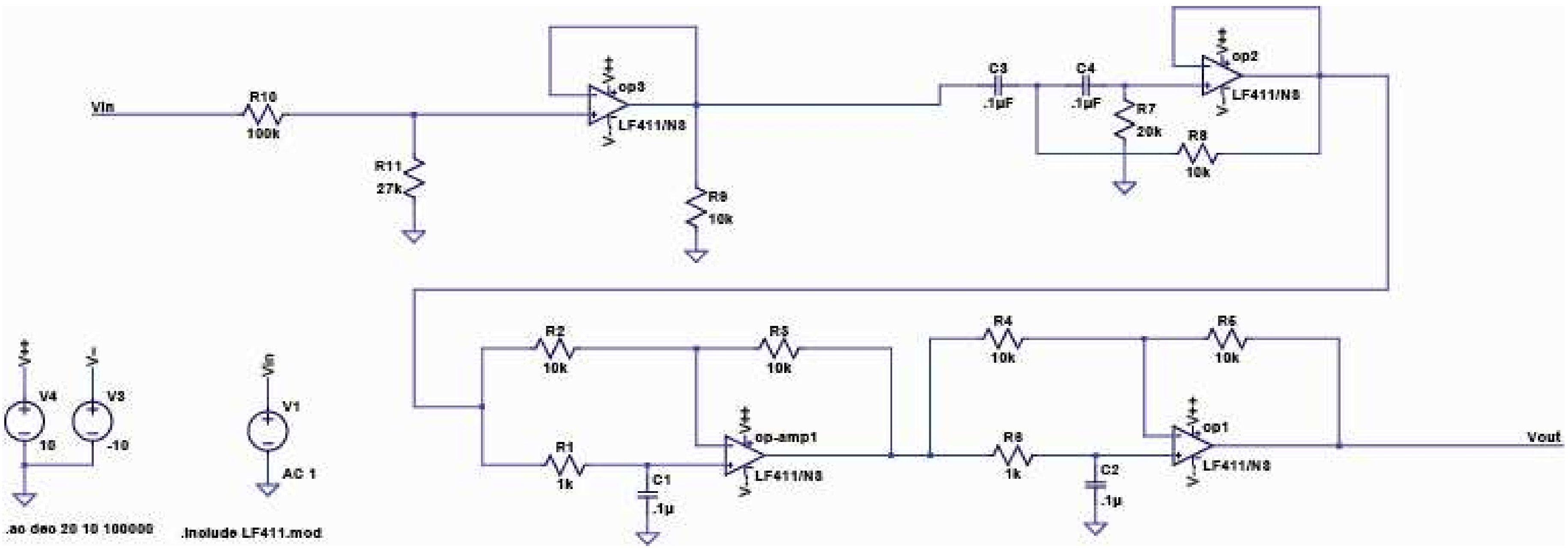
- In most 3D turbulent systems, we see forward energy cascade.
- Matt Worstell's work on observation of the inverse energy cascade resulting from the 2D nature of the system.

Injecting Energy at Small Scales



- In most 3D turbulent systems, we see forward energy cascade.
- Matt Worstell's work on observation of the inverse energy cascade resulting from the 2D nature of the system.
- Applied bias injects energy at length scales smaller than dominant fluctuations. Observe energy transfer to larger scale.

Feedback Circuit



Complete Circuit Response