INVESTIGATION OF ACTIVE FEEDBACK CONTROL OF TURBULENT TRANSPORT IN A MAGNETIZED LABORATORY PLASMA

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UNM

The University of Montana

Abstract

Many toroidal fusion devices now routinely generate edge and/or core transport barriers, where heat and particle transport are reduced far below Bohm diffusion levels. However, minimal particle transport is not necessarily desirable, since it can lead to such negative effects as core impurity accumulation, or alpha particle buildup in a reactor. Ideally, active, stable control over the transport, rather than simple minimization, could be obtained. To this effect, research is now underway to investigate active control of particle transport. Turbulence and transport dynamics are, of course, strongly nonlinear, and apparently not deterministic. However, modern nonlinear control methods now exist which do not rely on a model of the system dynamics to affect stable control. Experiments are being conducted in the new HELCAT (HELicon-CAThode) linear device at UNM. HELCAT is a 4 m long device, with B < 0.22 T, and cathode-produced densities, n ~ 1-5x10^12 cm^-3. Sheared ExB flows, generated via biased concentric rings, will be utilized to modify the transport. Fluctuations and flux will be monitored with probe arrays. Open loop experiments have demonstrated that drift fluctuations can be fully suppressed by simple biasing, though the physical mechanism remains unclear. Additionally, a 1D transport code is being utilized to model the system in order to investigate possible control methods numerically. Initial experimental and modeling results will be presented.

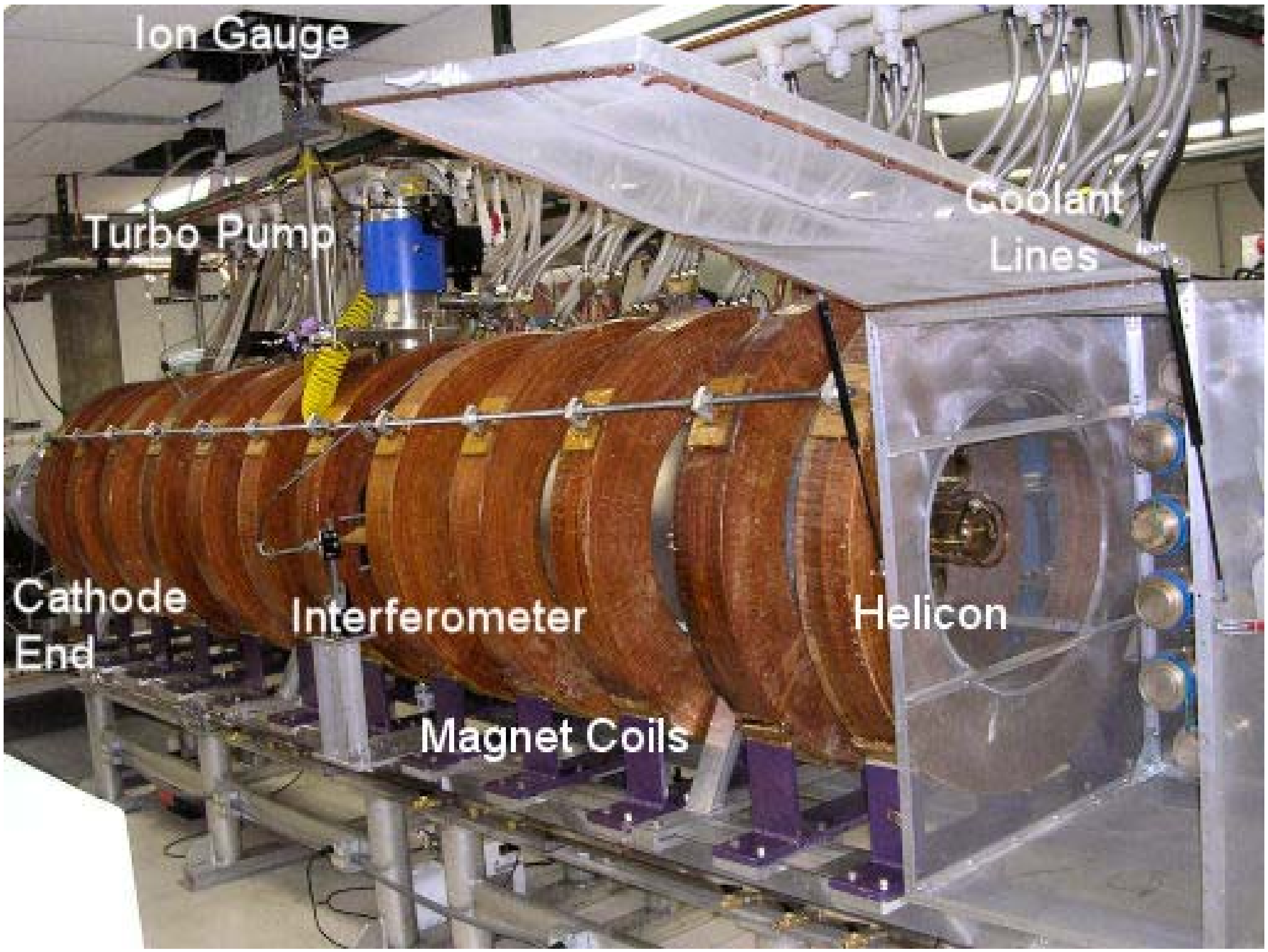
Motivation

- ***Transport barriers (internal and H-mode) are now routinely created in toroidal fusion devices. Radial diffusion levels far below Bohm diffusion are achieved.***
- ***However, while minimal heat transport is desirable, very low particle transport is not, since it can lead to such undesirable effects as core impurity accumulation, or buildup of alpha particle ash in a reactor.***
- ***Ideally, the turbulence-driven particle transport could be actively controlled to a desired stable operating point***
- ***It is well known that changes in plasma flow profiles (e.g. flow shear) can result in significant reductions or enhancements in turbulence and turbulence-driven transport, e.g. H-mode.***
- ***Although turbulence-transport-flow shear physics remain poorly understood, manipulation of flow profiles clearly provides a "control knob" for manipulating the transport.***

Experimental Setup: the HELCAT Device

HELCAT: (HELicon-CAThode)

- **Length: 4 m**
- **Diameter: 50 cm**
- **B_z: ≤ 2 kG**
- **Plasma Sources: Cathode & RF Helicon**



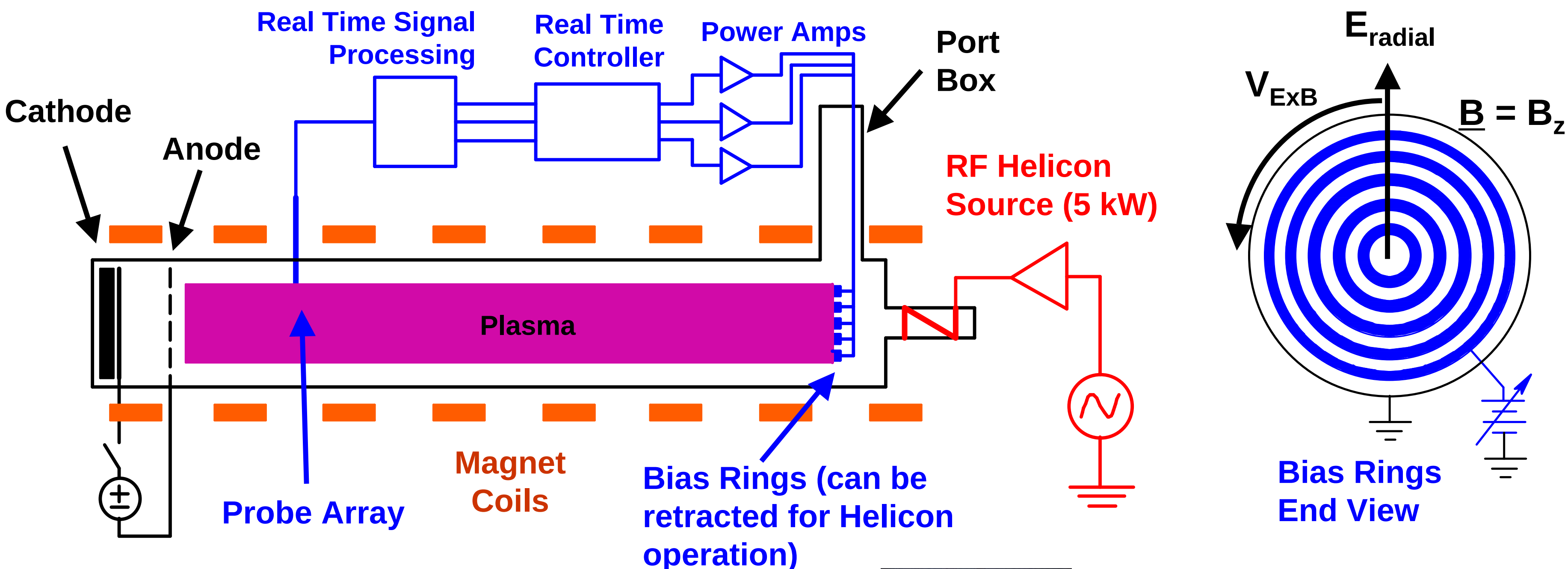
RF helicon plasma

- **$n \sim 1\text{-}5 \times 10^{19}\ m^{-3}$**
- **Te ~ 5 – 10 eV**
- **Ti ~ 0.1 eV**
- **D = 10 – 20 cm (FWHM)**

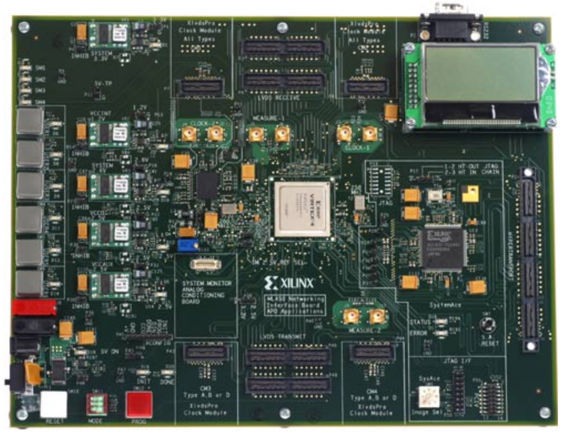
Cathode plasma

- **$n \sim 1\text{-}5 \times 10^{18}\ m^{-3}$**
- **Te ~ 5 – 10 eV**
- **Ti ~ 1 eV**
- **D (Plasma Diameter) = 10 – 20 cm (FWHM)**

Real Time Control System *(under construction)*



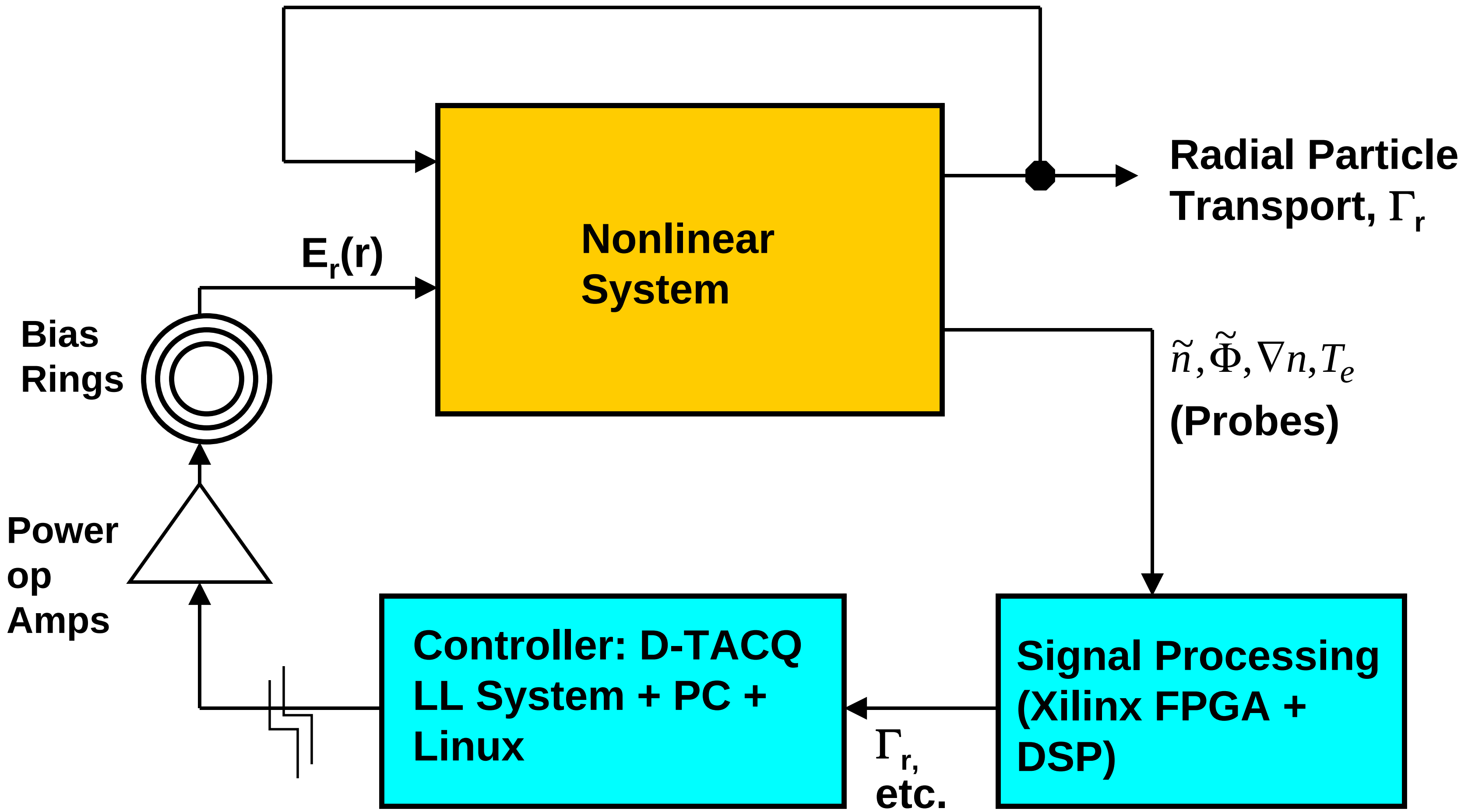
***Real Time Signal Processing*: Xilinx FPGA**



***Real Time Linux-based Control System*: I/O via a D-TACQ ACQ196CPCI data acquisition card operating in "Low Latency" mode.**

***Power Amps:* Kepco BOP**

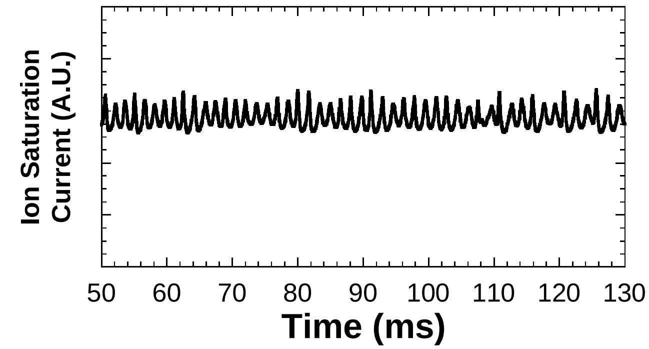
Control Block Diagram



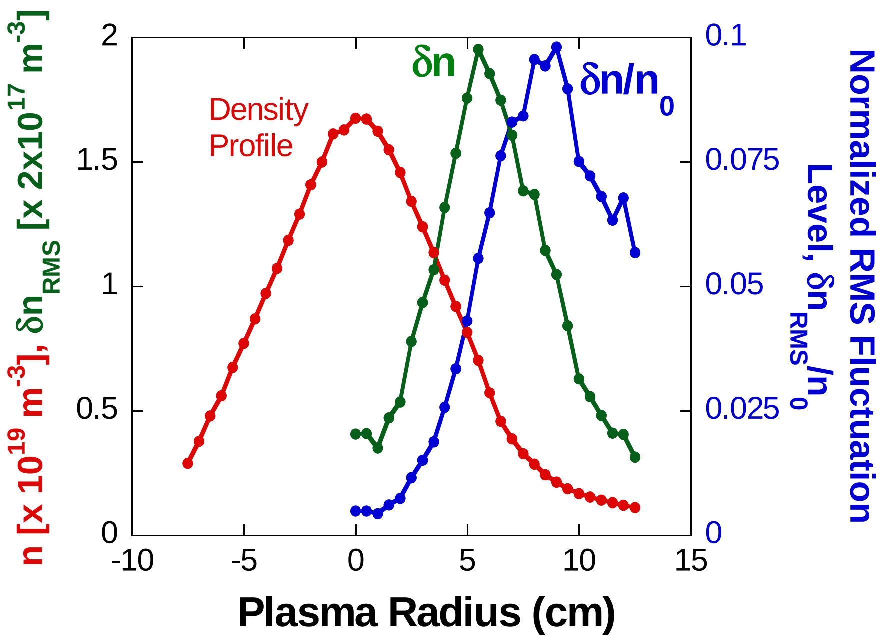
Edge Fluctuations are Consistent with Drift Waves

- Fluctuations peak in the center of the density gradient region
- $f \sim \frac{\omega^*}{2\pi} \approx$ 700 Hz at B_0 = 350 G, Ar
- Small potential fluctuations: $\frac{\delta n}{n} \sim \frac{e}{kT_e}\delta\phi$
- Transition from coherent mode at low B_0 (350 G) to turbulent at higher B_0 (1 kG)

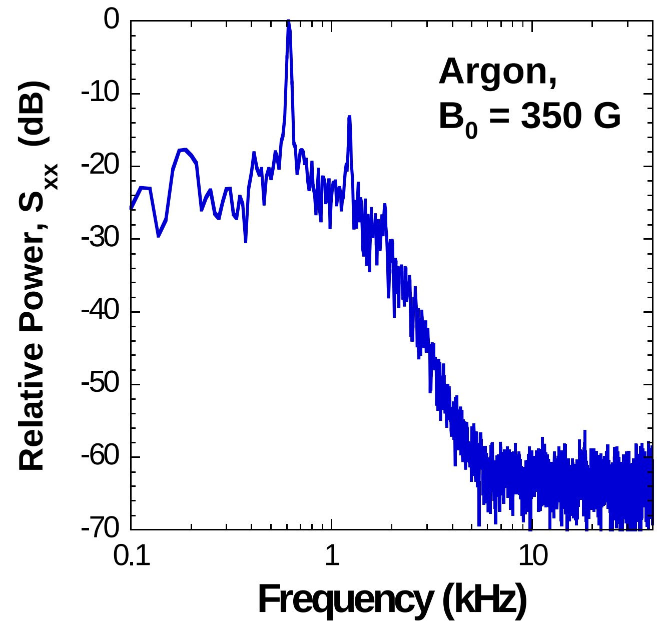
Ion sat. current vs. time,
Argon, 350 G



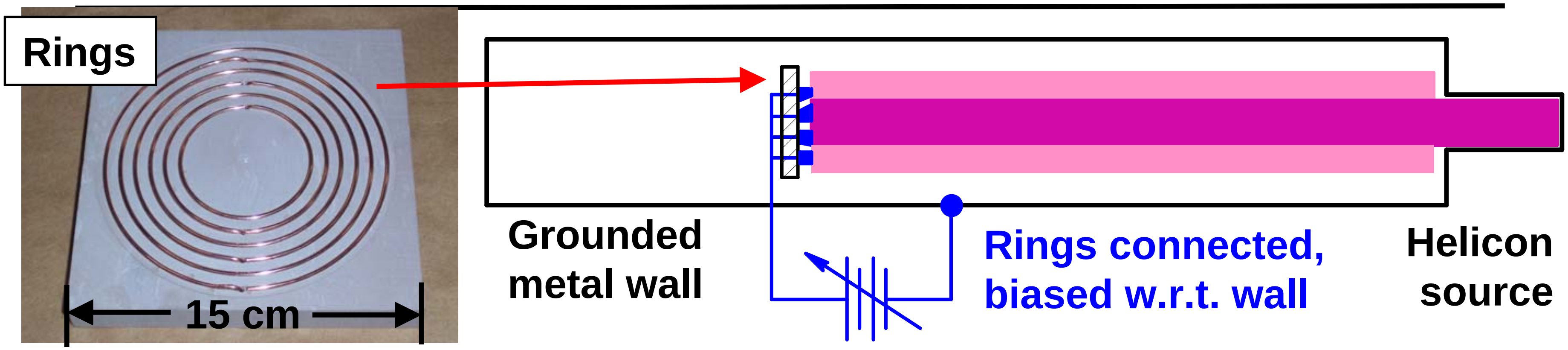
Spatial Profiles, **Argon, B_0 = 350 G**

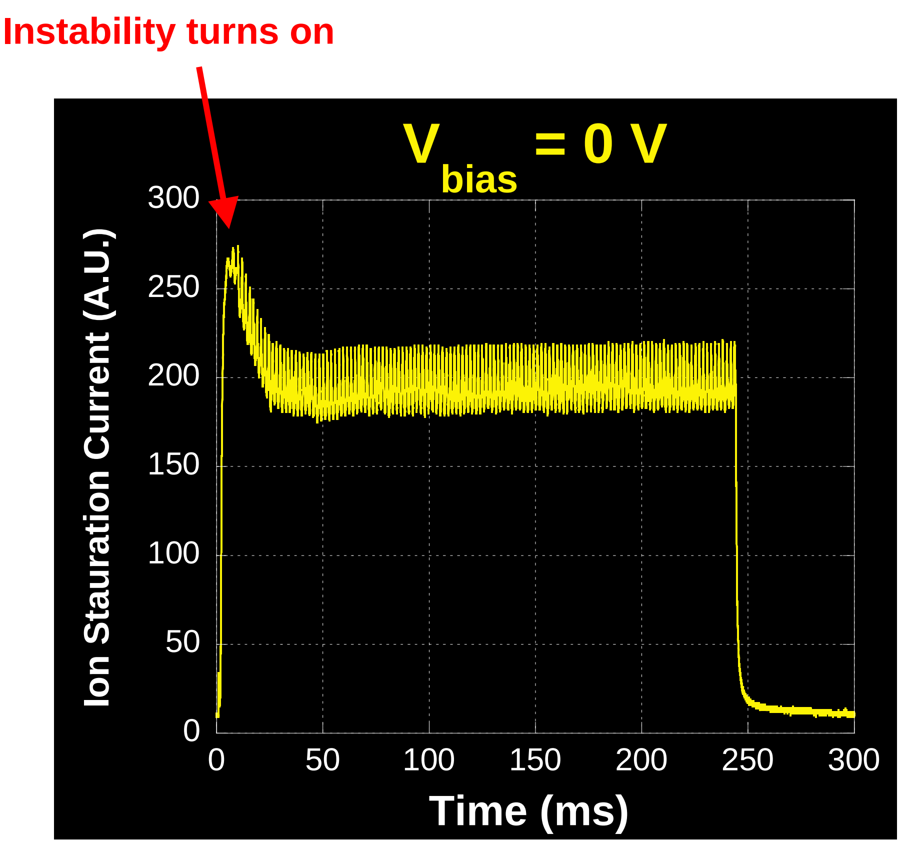


Ion sat. Power Spectrum

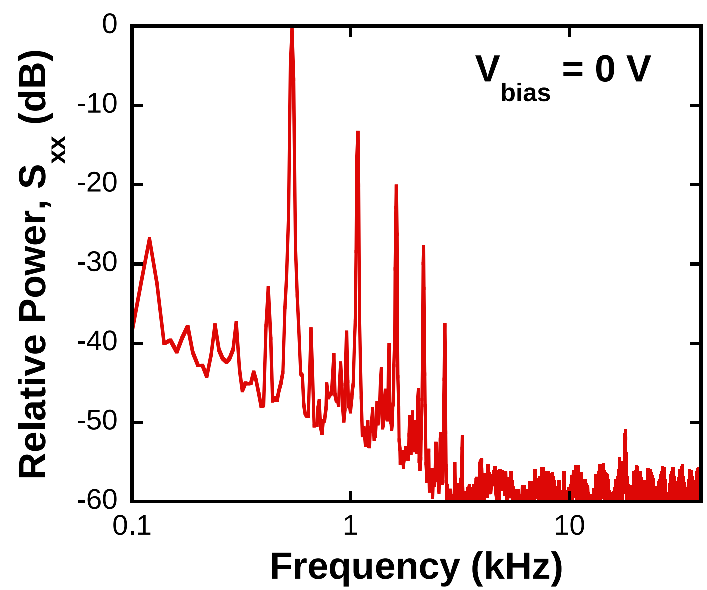


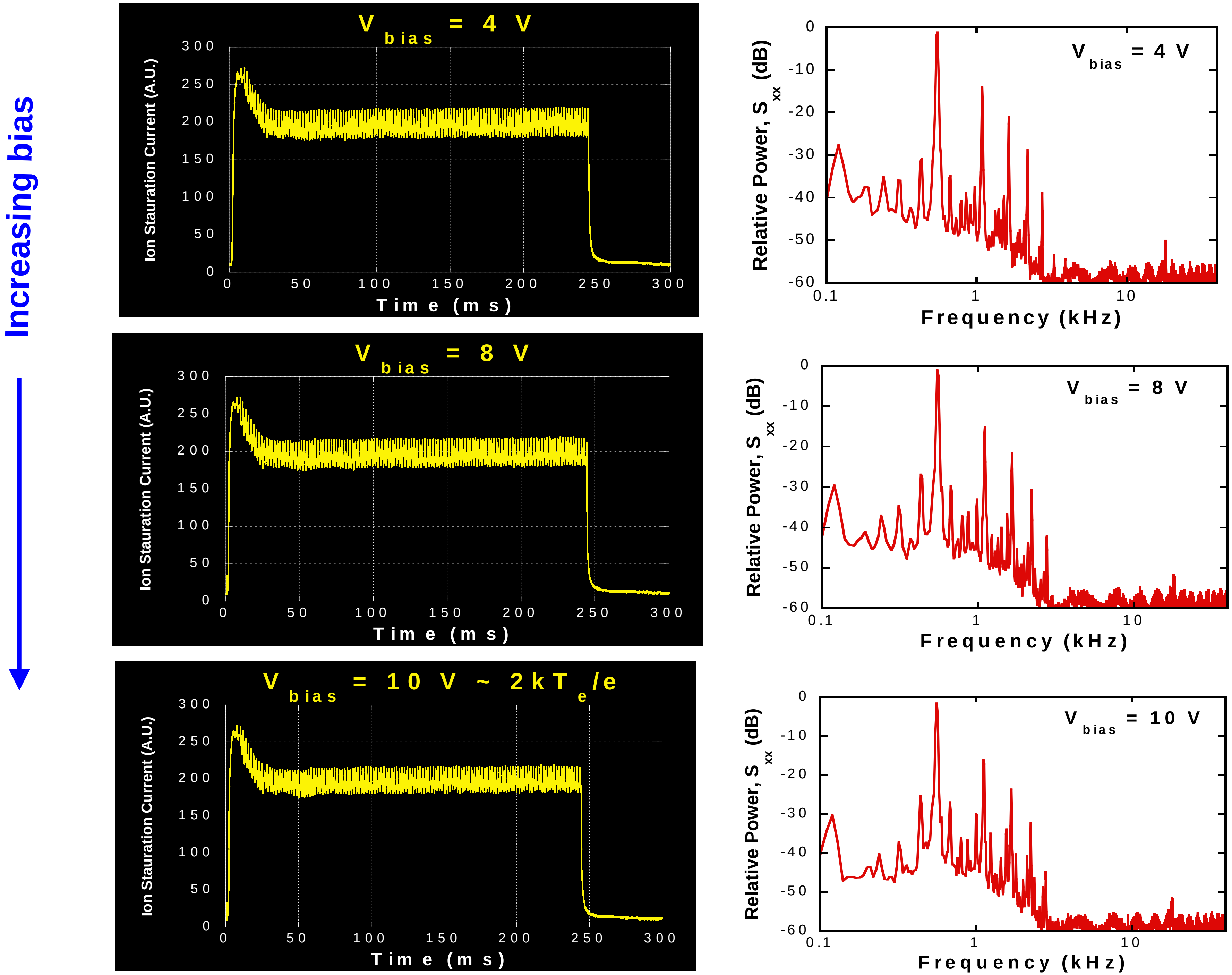
Simple Biasing Can Suppress Fluctuations at Low Magnetic Field



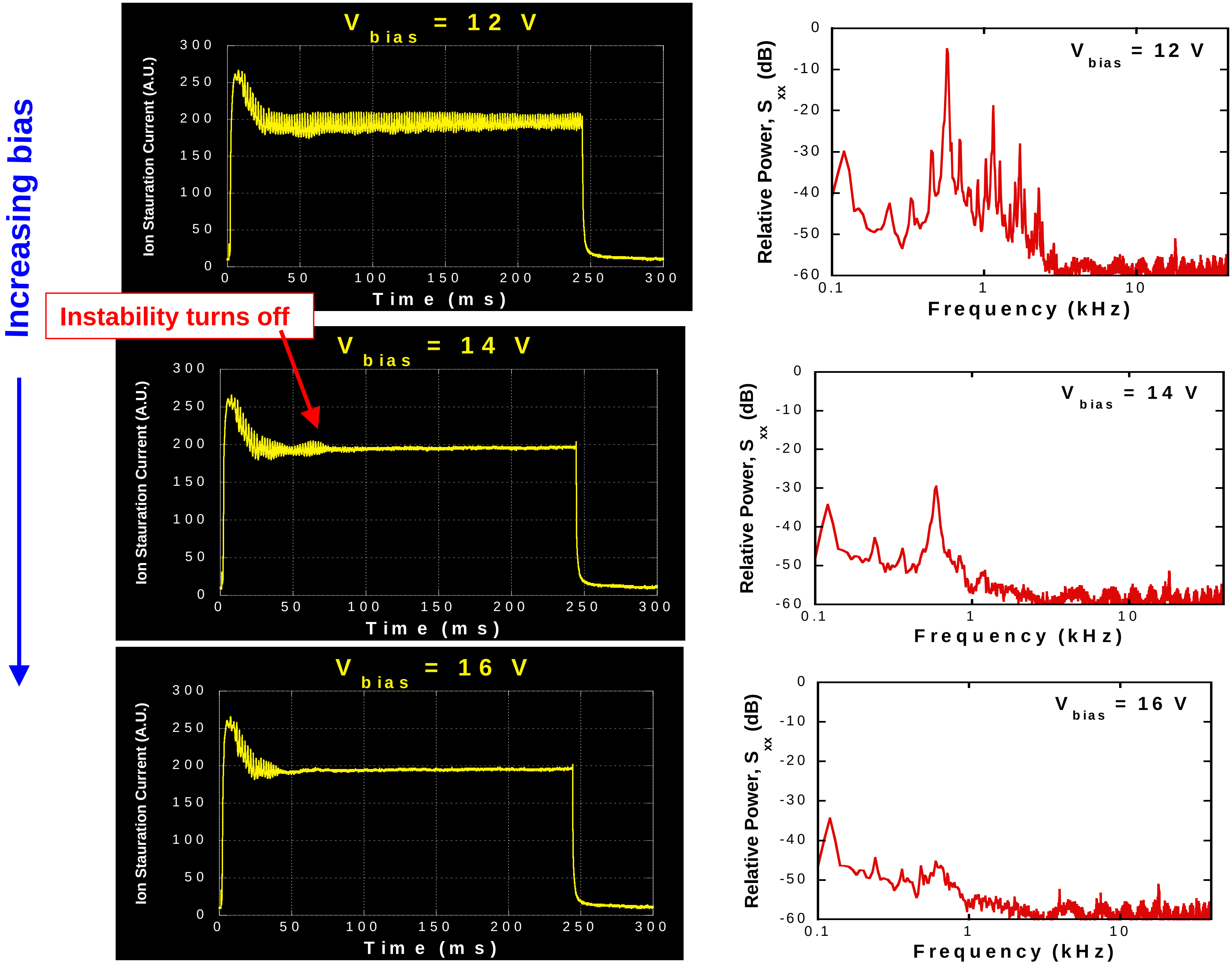


Ion saturation current, probe @ R = 5.5 cm, Ar, B_0 = 350 G, ρ_s ~ 4cm

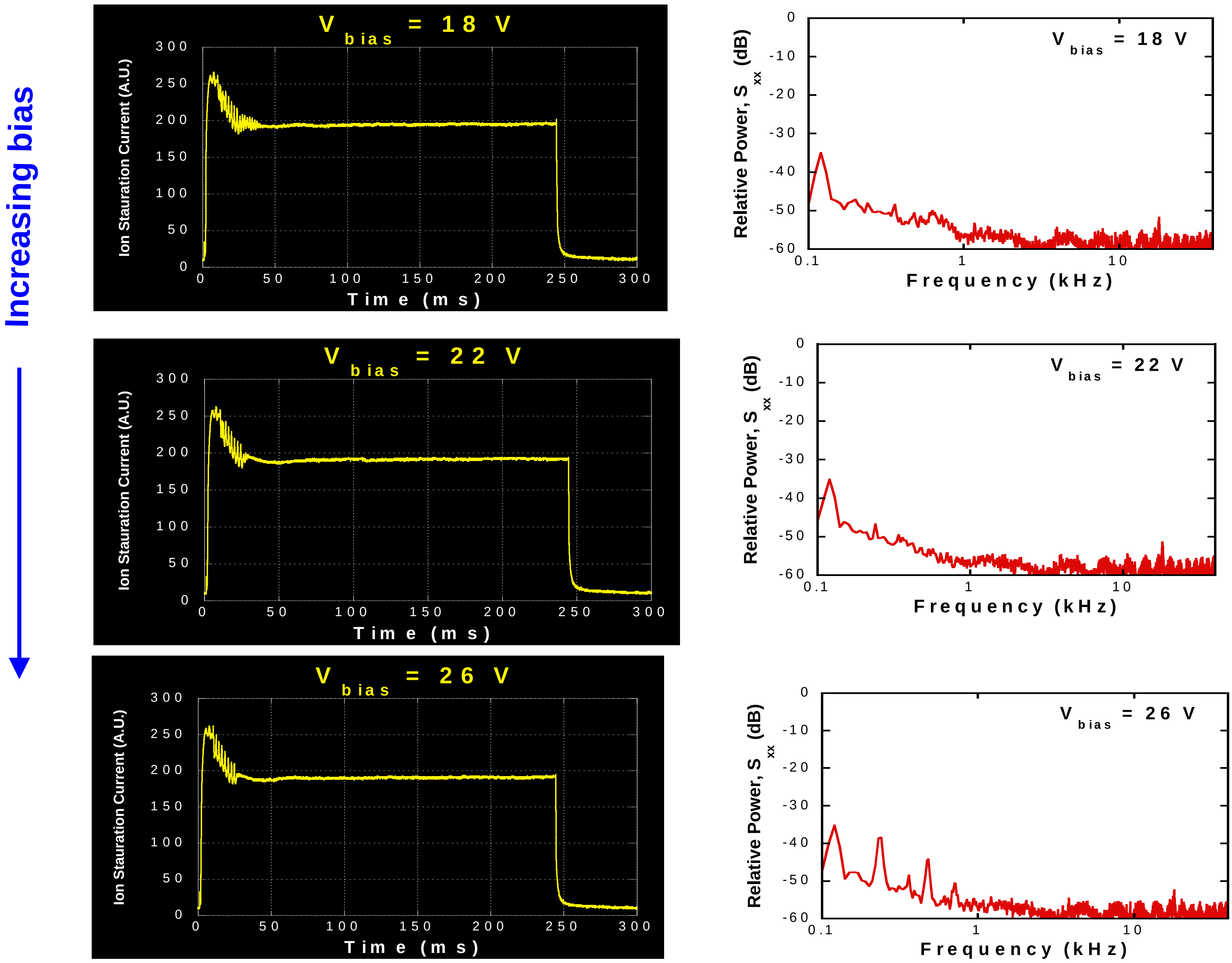


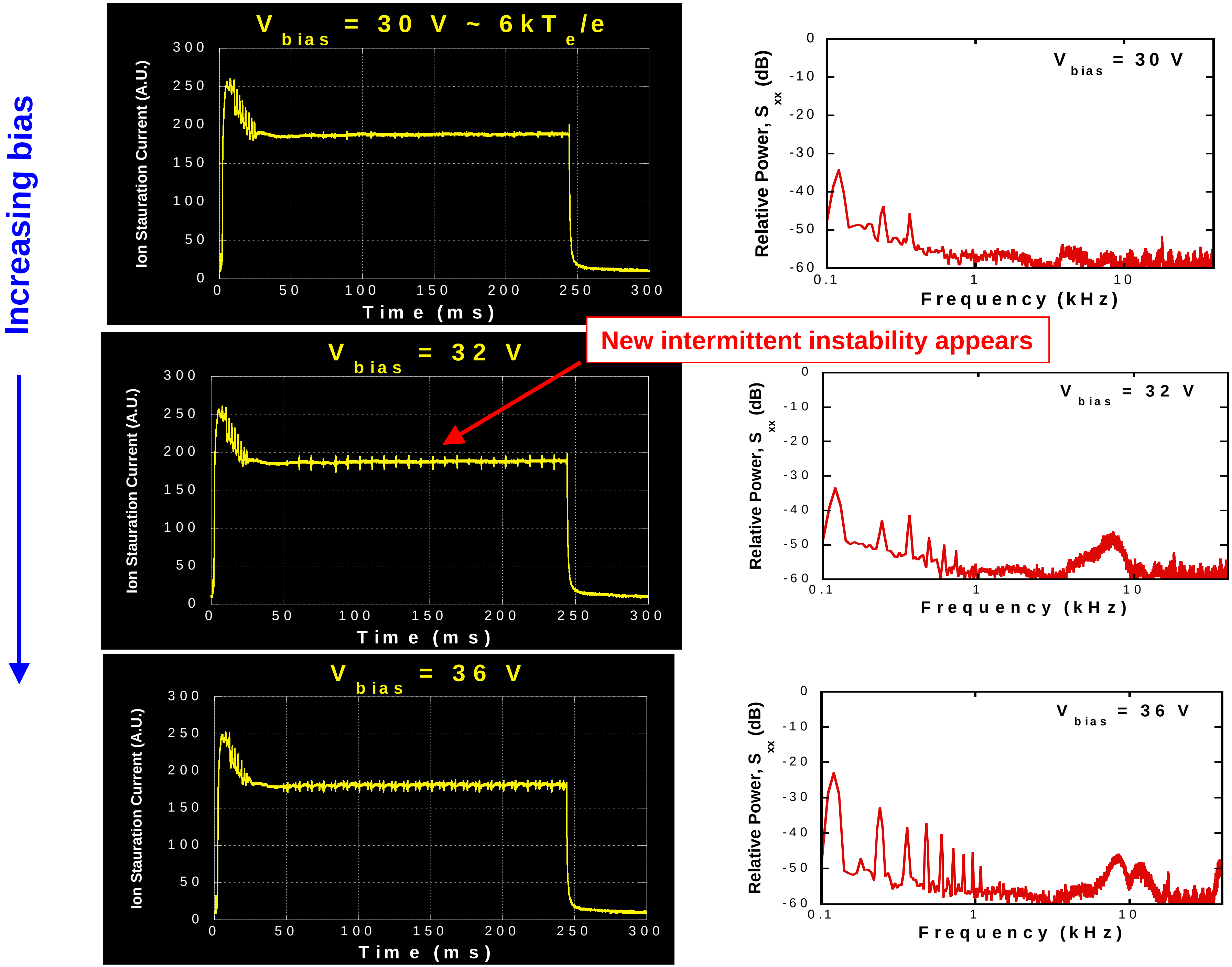


Increasing bias
V bias = 4 V
Ion Stauration Current (A.U.)
Time (ms)
V bias = 8 V
Ion Stauration Current (A.U.)
Time (ms)
V bias = 10 V ~ 2kT e /e
Ion Stauration Current (A.U.)
Time (ms)
V bias = 4 V
Relative Power, S xx (dB)
Frequency (kHz)
V bias = 8 V
Relative Power, S xx (dB)
Frequency (kHz)
V bias = 10 V
Relative Power, S xx (dB)
Frequency (kHz)

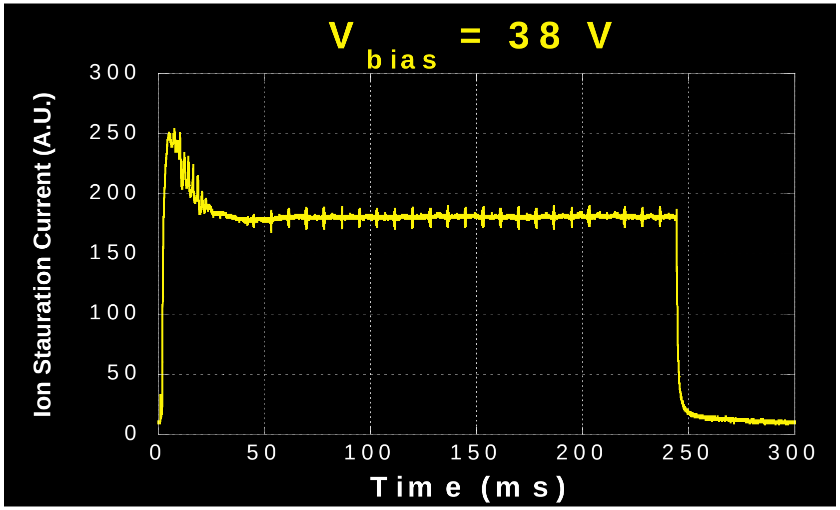


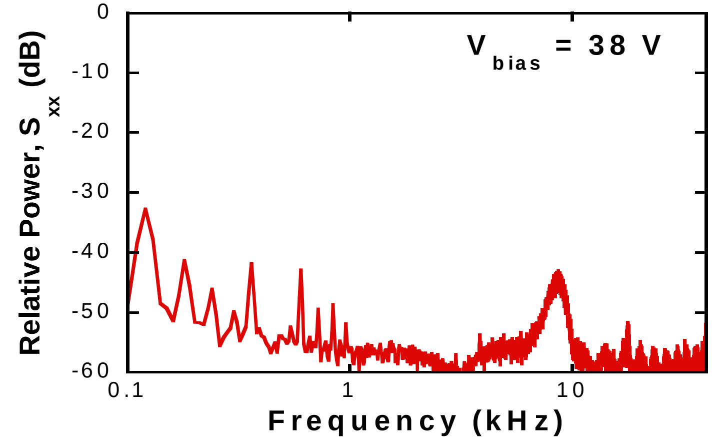
Increasing bias
Instability turns off
V bias = 12 V
V bias = 14 V
V bias = 16 V
Ion Stauration Current (A.U.)
Time (ms)
0
50
100
150
200
250
300
Relative Power, S xx (dB)
Frequency (kHz)
0
-10
-20
-30
-40
-50
-60
0.1
1
10


Increasing bias
V bias = 18 V
V bias = 22 V
V bias = 26 V
Ion Stauration Current (A.U.)
Time (ms)
Relative Power, S xx (dB)
Frequency (kHz)

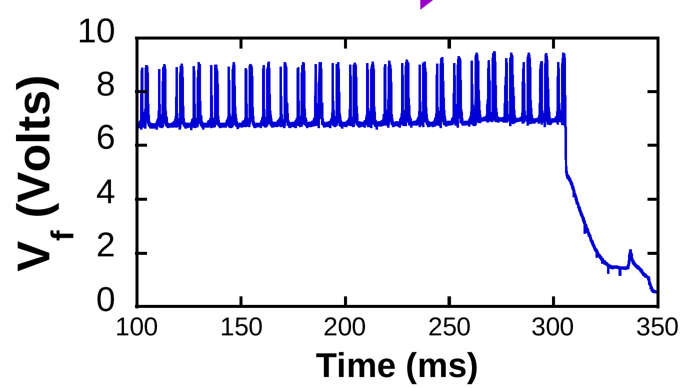


Increasing bias
V bias = 30 V ~ 6kT e /e
Ion Stauration Current (A.U.)
Time (ms)
V bias = 30 V
Relative Power, S xx (dB)
Frequency (kHz)
New intermittent instability appears
V bias = 32 V
Ion Stauration Current (A.U.)
Time (ms)
V bias = 32 V
Relative Power, S xx (dB)
Frequency (kHz)
V bias = 36 V
Ion Stauration Current (A.U.)
Time (ms)
V bias = 36 V
Relative Power, S xx (dB)
Frequency (kHz)





New mode. Has large potential fluctuations, $\delta\phi/\phi$
=> Kelvin-Helmholtz?



Ion saturation current, probe @ R = 5.5 cm, Ar, B_0 = 350 G , ρ_s ~ 4cm

Potential and Derived E_r Profiles under Simple Biasing

Argon, B_0 = 350 G

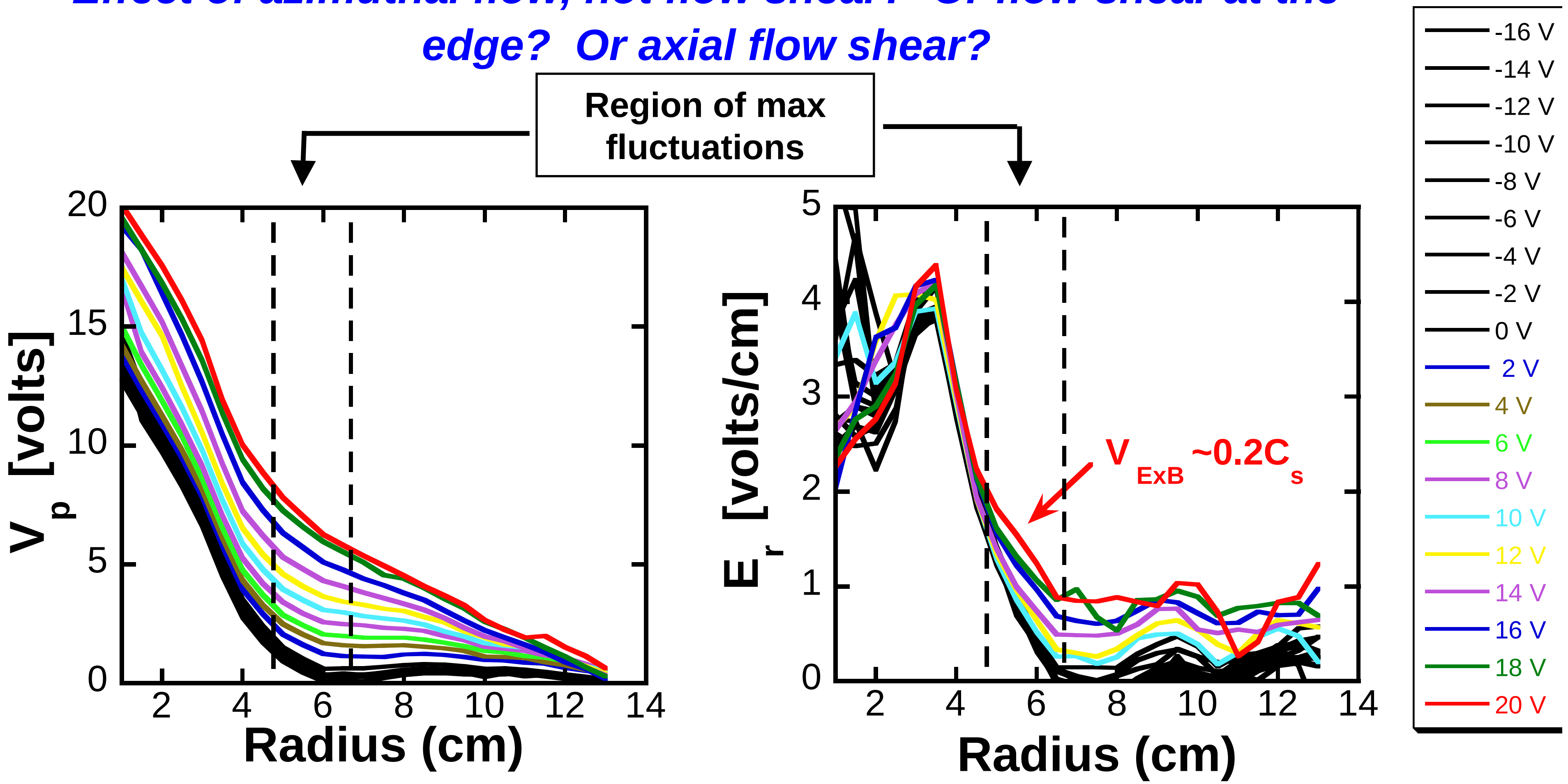
Plasma Potential Profile with Varying Ring Bias

(Derived from V_f and T_e measurements)

Radial E-field Profile with Varying Ring Bias

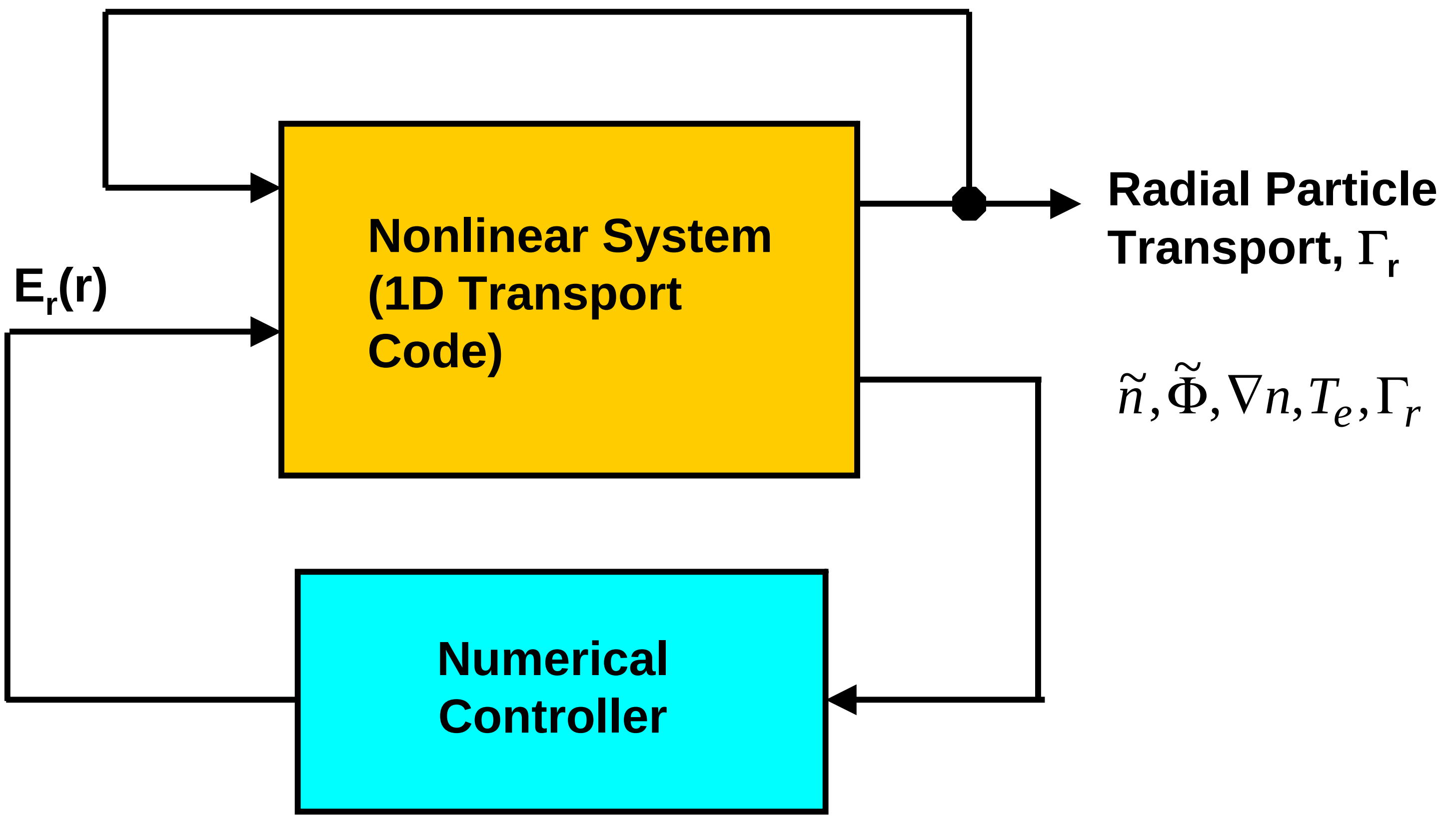
(Derived from V_p derivative)

Effect of azimuthal flow, not flow shear? Or flow shear at the edge? Or axial flow shear?



Investigating Feedback Control Numerically

- **In addition to experiments, work is underway to investigate turbulent transport control numerically**
- **A 1D transport code will be used together with MATLAB control engineering tools (SIMULINK) to investigate possible control algorithms numerically**

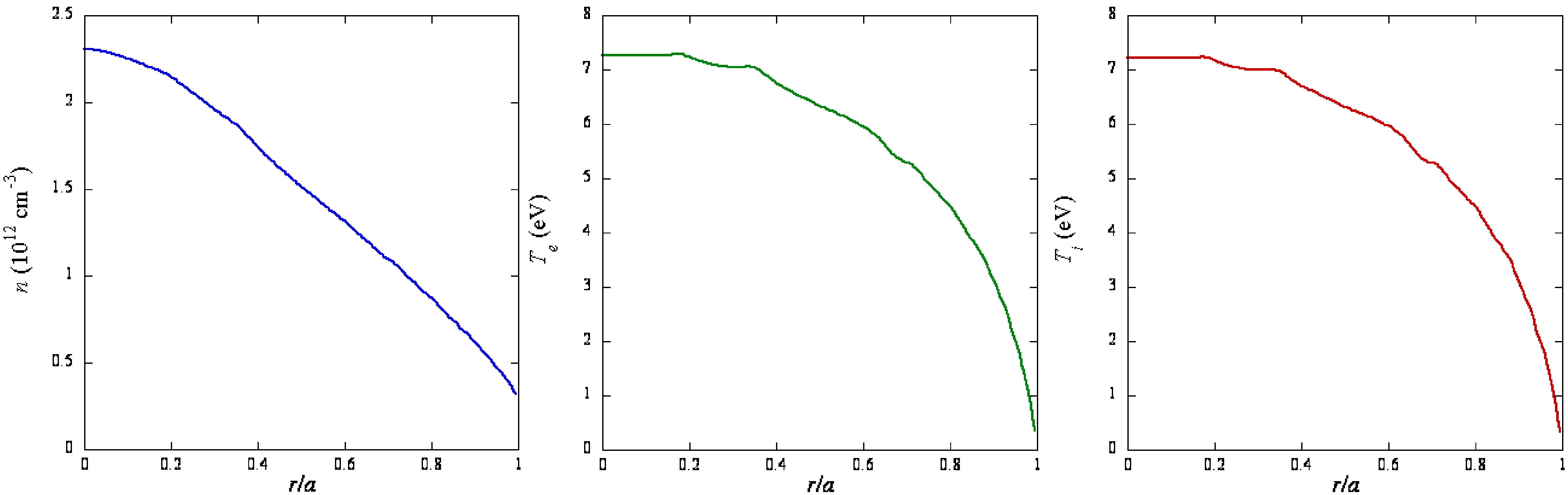


System Modeling with a 1D Transport Model

- ***A one-dimensional transport code is being used to model HELCAT plasmas***
  - ***The transport code includes collisional and anomalous transport with an envelope equation for the fluctuations***
  - ***The code includes evolution of density, ion & electron temperature, poloidal velocity, rms fluctuations, and the radial electric field (see D. E. Newman, et al., Phys. Plasmas, 1997)***
  - ***The Helicon/Cathode source is modeled as a flat-top input of energy and particles***
  - ***Biased rings are modeled as radially-localized sources of poloidal momentum***

System Modeling with a 1D Transport Model (cont)

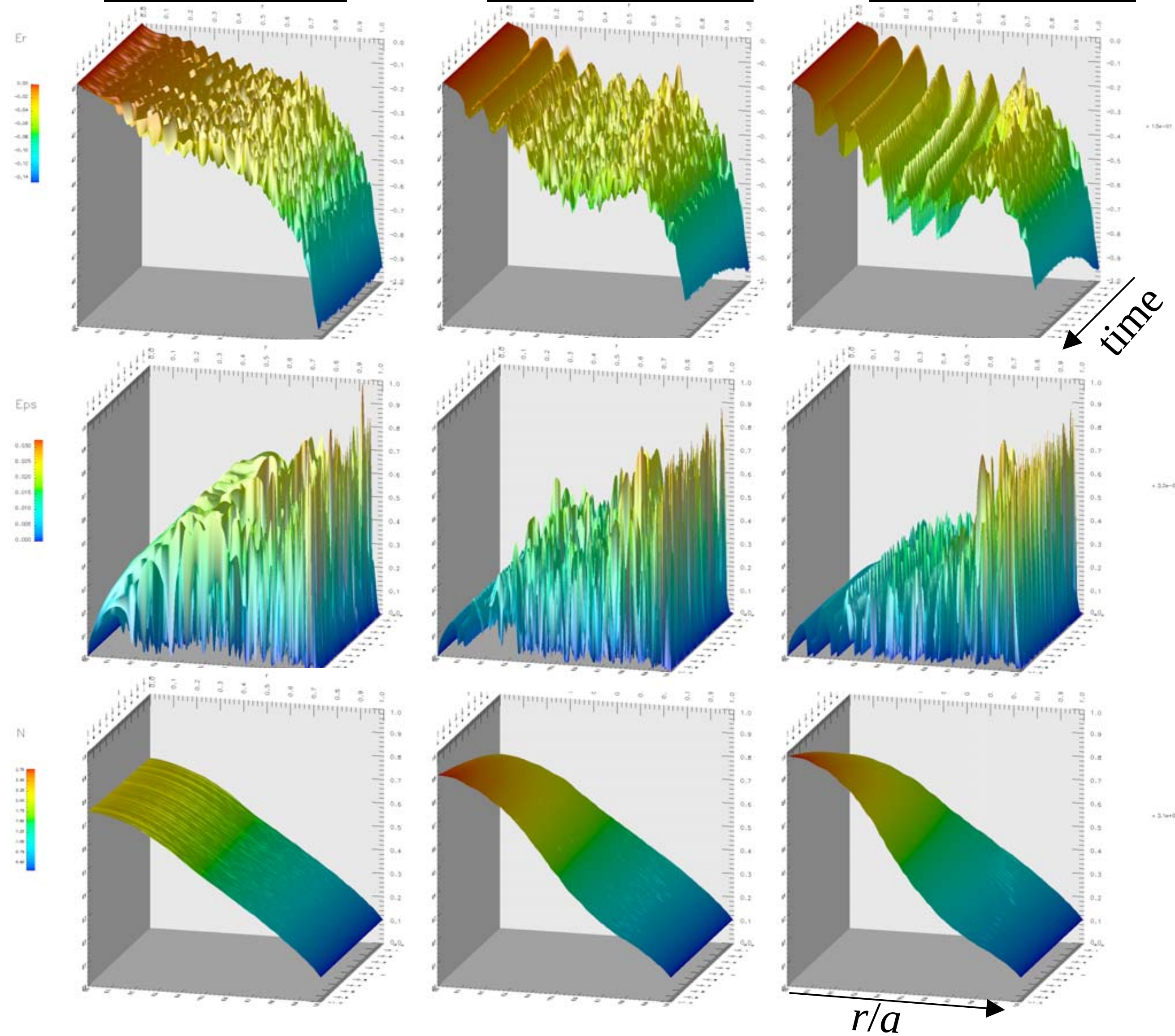
- ***The transport code finds equilibria similar to those in the experiment with the exception that the ion temperature is too high***



  – ***The code does not include charge-exchange collisions with neutrals as an energy sink for the ions and this may be the cause of the higher ion temperatures in the code***

Increasing all 6 of the poloidal momentum sources simultaneously decreases the fluctuations

Sources = 0 | **Sources = 20** | **Sources = 50**



- ***Radial electric field develops structure***
- ***Fluctuation amplitude decreases***
- ***Density profile peaks with decreasing fluctuations***

Summary and Near Term Plans

- **A set of concentric metal rings is used to control $E_r \times B_z$ flow profiles**
- **<u>Simple biasing</u> of all rings connected together w.r.t. the vacuum wall <u>can suppress drift fluctuations</u> easily at low B_0. Higher bias voltage is required at higher B_0. At higher B_0, there is a range of bias voltages where suppression is intermittent, before full suppression is observed.**
- **At large bias values (> 5-6 $\times$ kT_e/e at 350 G) a second, intermittent instability - possibly Kelvin-Helmholtz - appears.**
- **Research in the near term will focus on:**
  - **understanding in detail the effect of biasing on the overall plasma potential and flow profiles, and turbulent transport**
  - **closing the real-time control loop and exploring active feedback control of transport**
- **Work is also underway to model the system with a 1D Transport Code (*the "plant"*), and utilize control engineering tools, such as SIMULINK, to investigate control algorithms numerically.**

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