Initial Results from Biased Electrode Experiments in HSX.

S. Gerhardt , A.F. Almagri, D. T. Anderson, J.N. Talmadge
HSX Plasma Lab, University of Wisconsin

Abstract

Initial experiments using a biased electrode in HSX have been performed. A radial current is drawn from the plasma, causing plasma rotation. This rotation is measured by a "Gundestrup" probe[1]. It is found that without bias, the QHS mode rotates only very slowly, but that the Mirror mode rotates more quickly. When bias is applied, a density rise occurs, implying an improvement in the particle confinement. There is evidence for a small reduction in the radial conductivity in the QHS mode compared to the Mirror mode. It is found that the change in rotation per unit current drawn is larger in the QHS mode than the Mirror mode, implying reduced radial conductivity in this mode. The flow rise times in the QHS mode are longer than the Mirror mode, implying smaller damping rates. Simple comparisons with the Coronado and Talmadge model of flow damping are shown, supporting the hypothesis that in the Mirror mode, parallel viscosity contributes to the damping, but that the damping in the QHS mode is neutral dominated.

Outline of this Poster

* Description of the biased electrode and "Gundestrup" probe..

* Flow velocity and direction in unbiased plasmas.

* Demonstration of confinement improvement with plasma biasing.

* Experimental evidence for reduced radial conductivity in the QHS mode.

*Estimation of radial conductivity and damping rates, based on the model of Coronado and Talmadge.

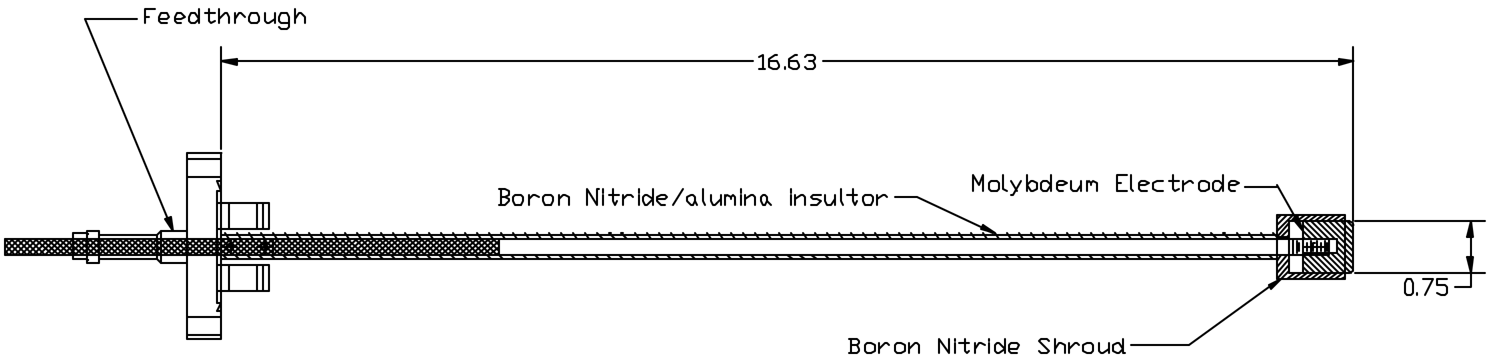
* Future Work

The Plasma Biasing System

* The Power supply is a 10mF capacitor bank, capable of charging to 600V. It has been tested at 600 V and 300A into a dummy load.

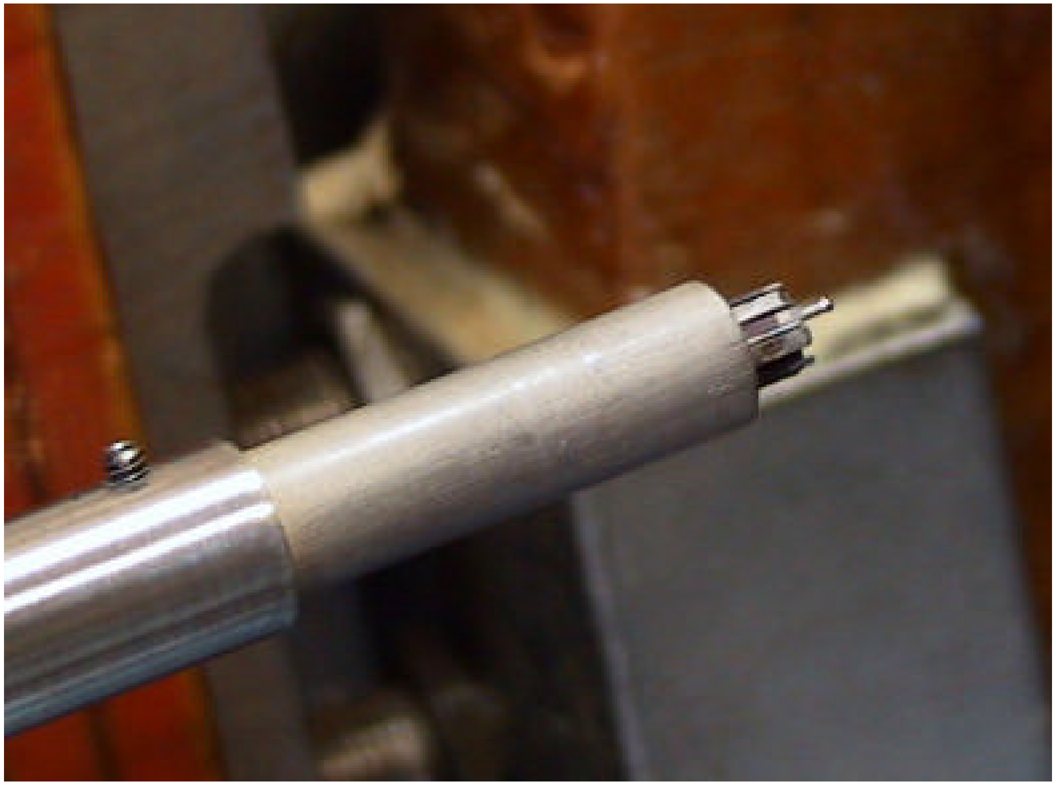
* The bias can be turned on and off in ≈20μs

* The bias electrode is shown below.



The Flow Measurement Probe

* To measure edge plasma flows in HSX, we have constructed a "Gundestrup"[1] probe.
* This probe consists of 6 tips, facing radially outward. The probe head shields the tips, so they are sensitive to plasma from only one direction.



* Modeling is required to relate the measured I_{sat} to the plasma flow velocity and angle[2].

* We use the "unmagnetized" model of Hudis & Lidsky[3].

* In this model, the measured I_{sat} signal can be related to the flow velocity and angle as[3]:

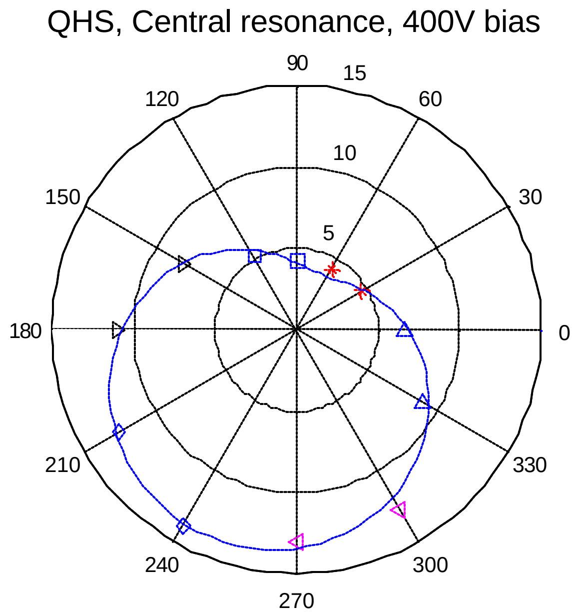
$$I_{sat} = I_{is0}\left(1 + X\cos\left(\theta_p - \theta_f\right)\right)$$

where θ_p is that angle of the normal to the probe tip, θ_f is the angle of the flow, and

$$X = M\,\frac{\sqrt{2T_i\left(T_e + T_i\right)}}{T_e}$$

Here, M is the Mach number, given by $M = V_f/c_s$.

* An example of the fit is given below, for a 400 V Bias, QHS discharge, during the period of bias.

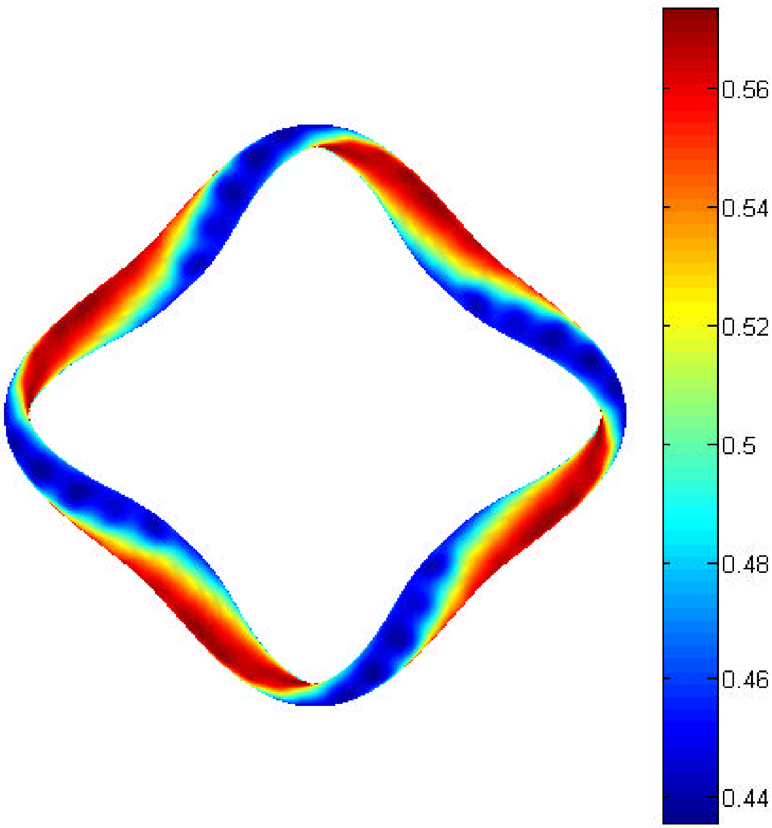


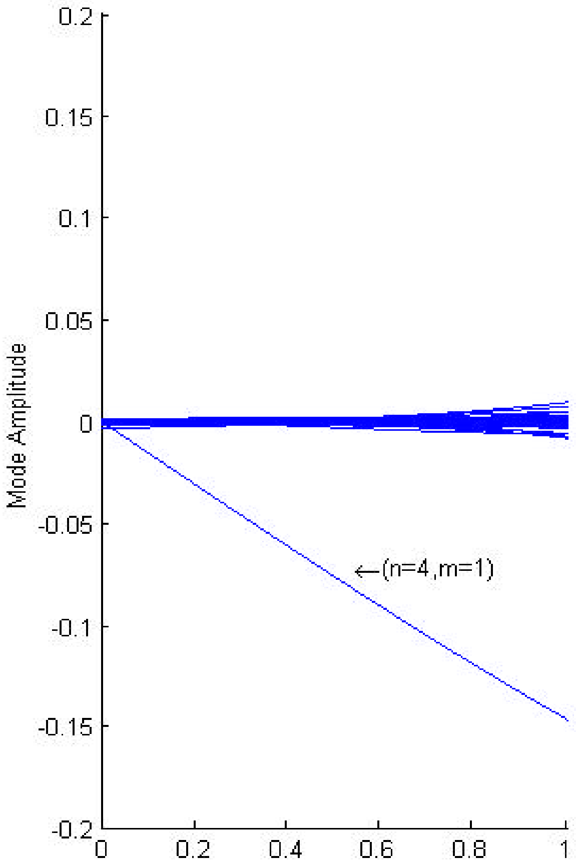
* This fit predicts I_{is0}=8.7, X=.567, θ_f=247°. Using T_e=20eV, T_i=8eV, the Mach number of the flow is .643.

* Repeating this procedure many times during the shot provides a time history of the flow speed and angle.

The QHS and Mirror Modes

*HSX is the first stellarator in the world to posses a direction of Quasi-Symmetry. Shown below are an outer flux surface and the Boozer Spectrum





* This quasi-symmetry leads to the virtual elimination of superbanana orbits and a factor of 3 reduction in banana transport over a comparable tokamak.

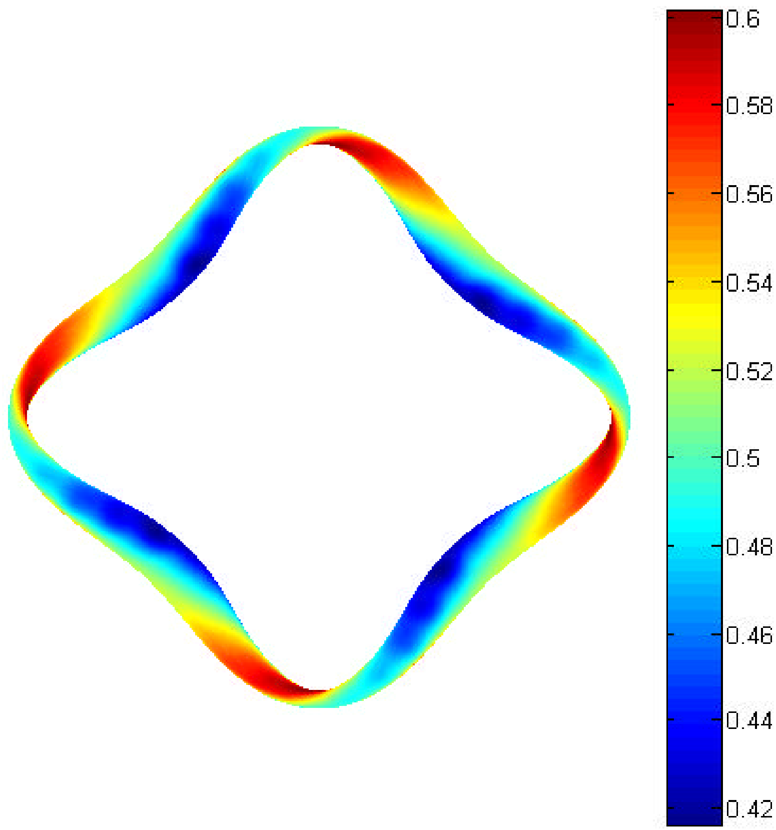
* In this symmetry direction, there is very small parallel viscosity, determined by symmetry breaking terms like modular coil ripple. The plasma should be free to rotate in this direction.

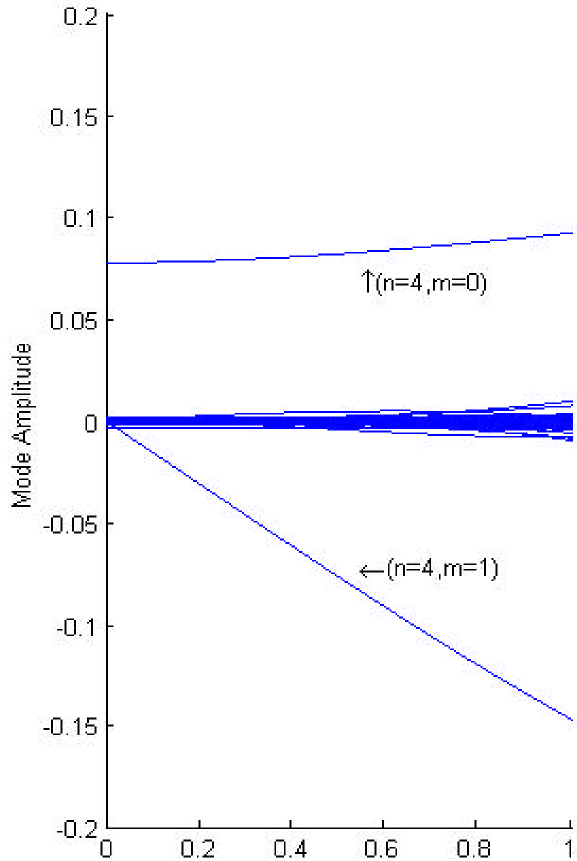
* This symmetry can be broken by the introduction of a large mirror term, reintroducing superbanana transport and large parallel viscous damping in all directions on a flux surface.

* Theoretical predictions described below predict that the viscous damping rates are up to 2 orders of magnitude larger in the Mirror mode.

*A Mirror mode surface and the Boozer spectrum are shown below.

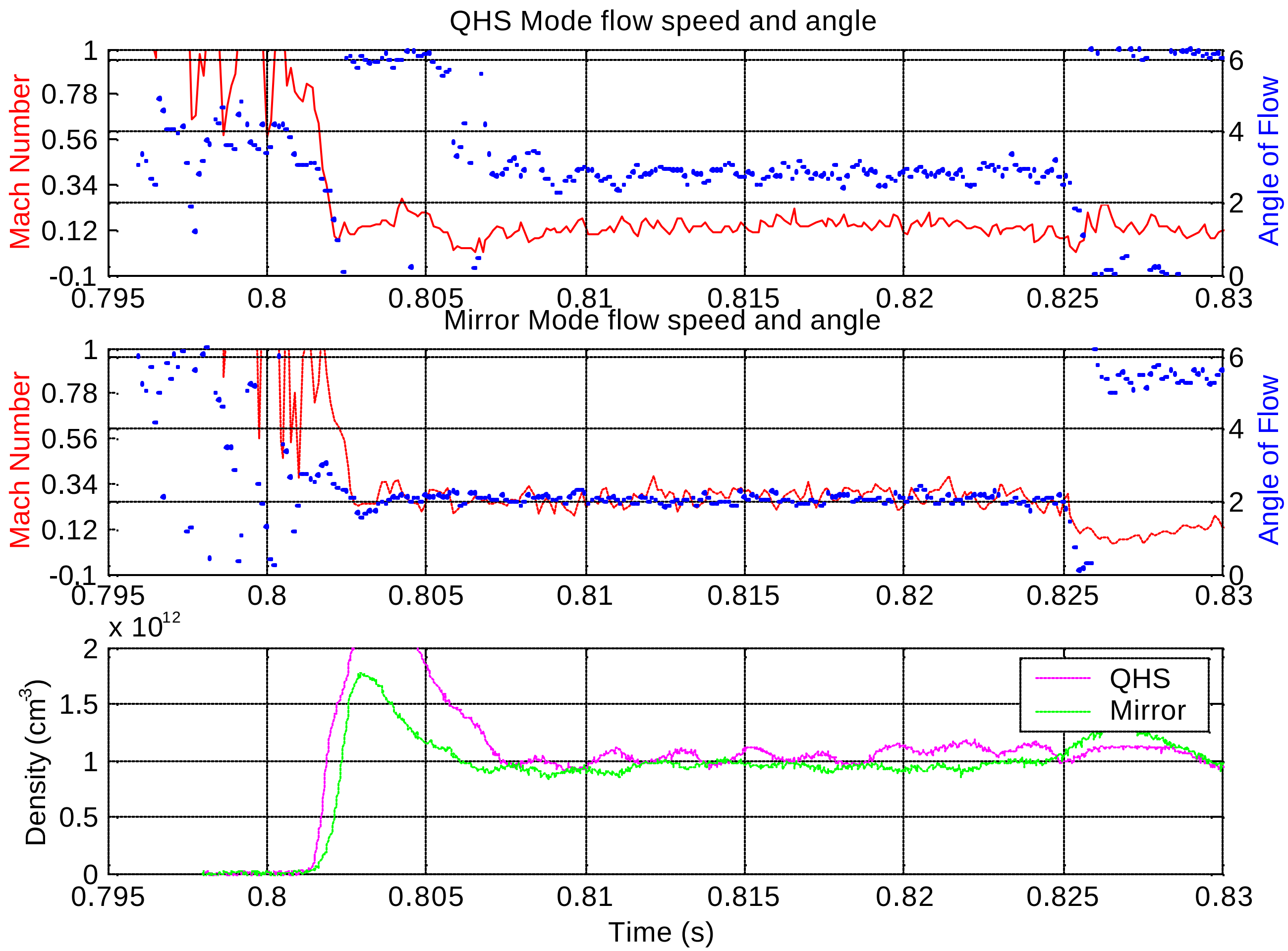
* In this poster, we have begun to study the physics of E_r formation and flow damping in HSX.





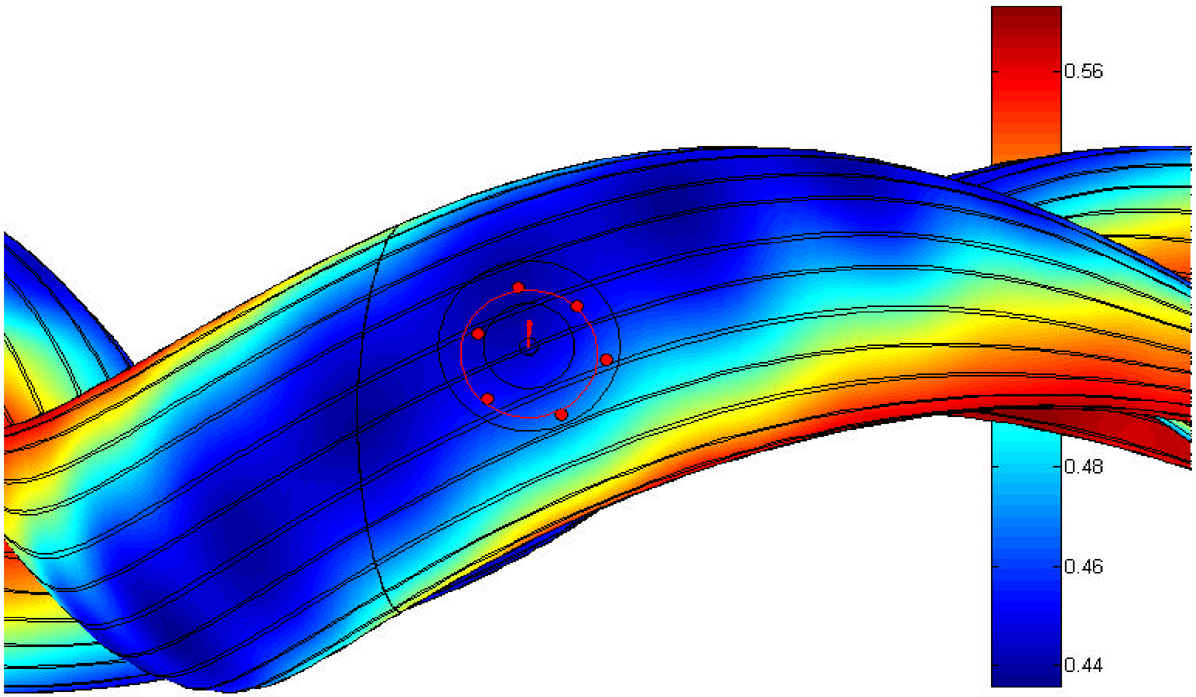
Plasma Flows in Unbiased Plasmas

* The charts below show the flow angle and speed of QHS and Mirror shots, with the same line averaged density ($1 x 10^{12}$ cm^{-3}).



* Note that the QHS flow speed is smaller than the Mirror Flow Speed, so that there is large error in the QHS flow angle.

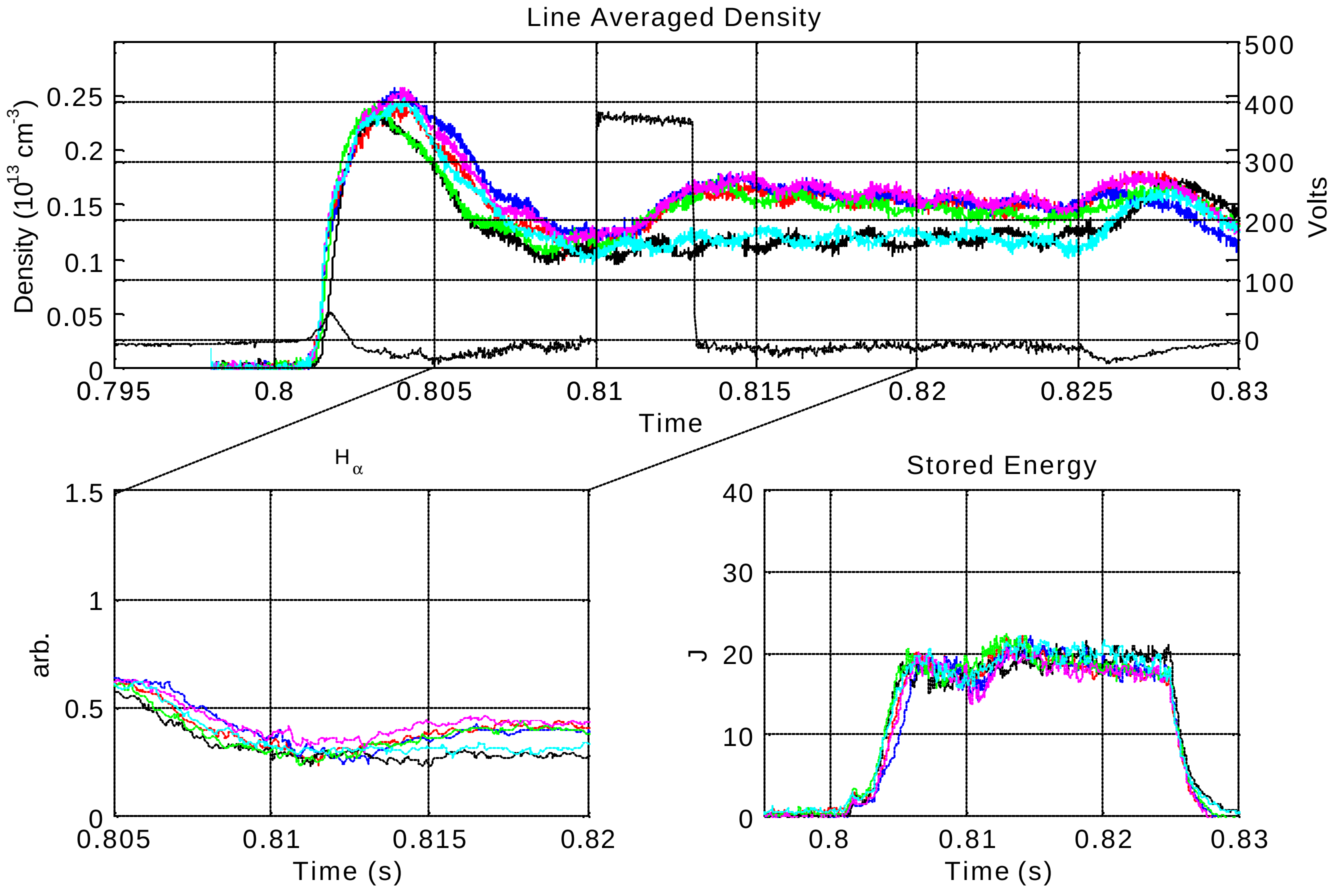
* Estimates of the radial electric field based on Triple Probe measurements show outward directed electric fields in both cases, with the Mirror E_r approximately twice as large as the QHS.



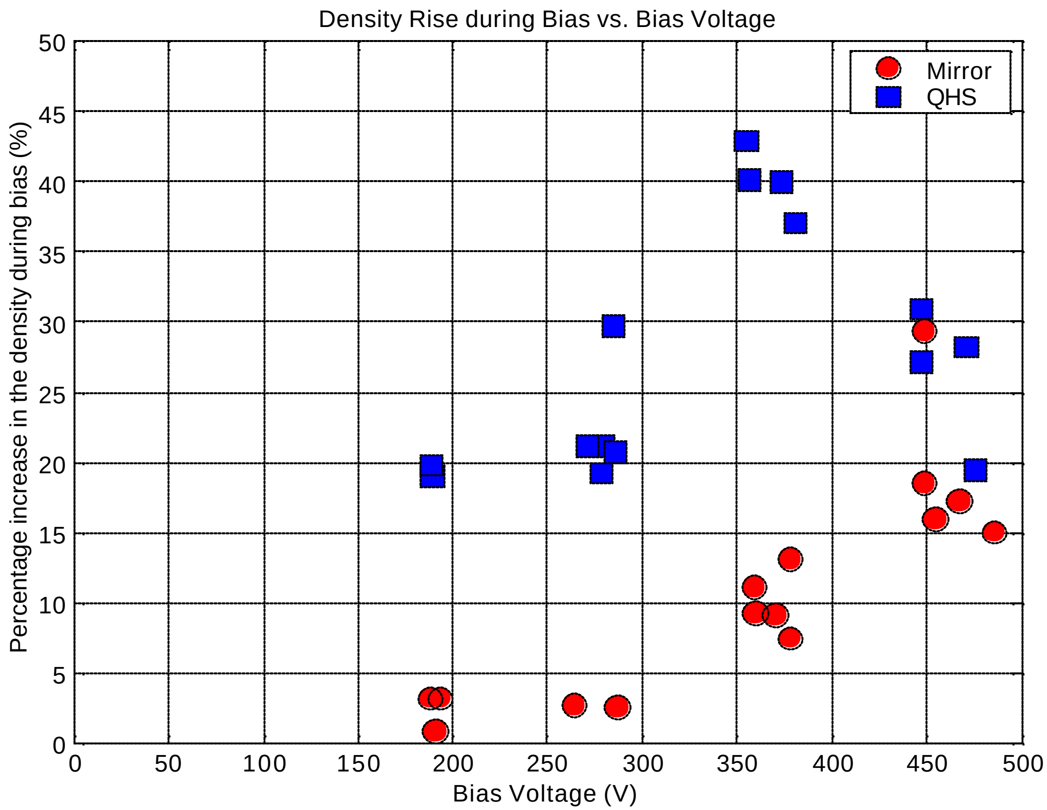
*The plot at right shows the flow direction of the unbiased QHS plasma superimposed on the QHS surfaces.

Evidence of Improved Confinement with Biasing

*Below, the density evolution of 6 QHS discharges are shown. Four of the discharges have 400 V bias applied at the plasma edge, two do not. The gas fueling is set to provide constant density without bias.



* As can be seen, the density increases during the bias pulse, without a significant increase in the H_α radiation. The Stored Energy remains constant



* This result is consistent with an improvement in particle confinement without a large improvement in energy confinement.

* As shown at right, this density rise seems to be smaller in the Mirror Mode than the QHS mode, for equivalent line density and bias probe location.

Evidence of Reduced Radial Conductivity in QHS mode.

* The radial conductivity is defined as:

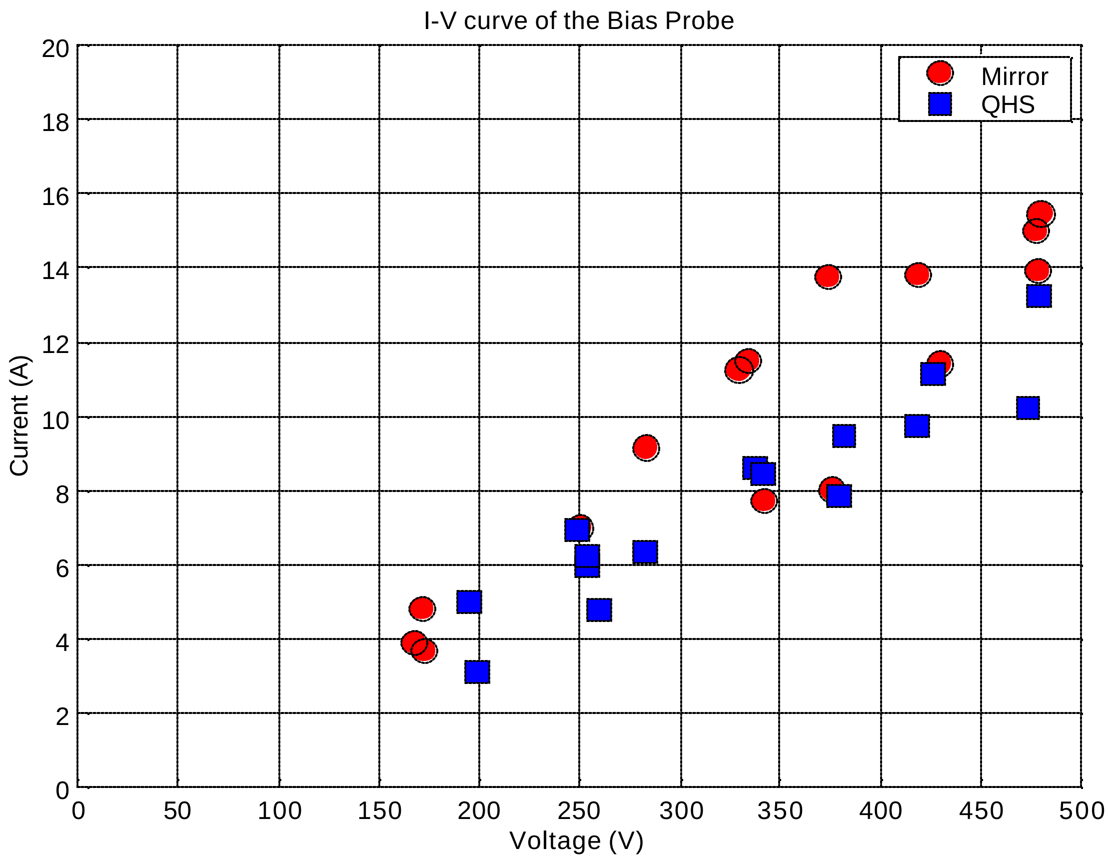
$$\left\langle \vec{J}^{(1)} \cdot \vec{\nabla} V \right\rangle = s_{r} \left(\vec{E} \cdot \vec{\nabla} V - \frac{1}{eN_i} \vec{\nabla} p \cdot \vec{\nabla} V \right)$$

V is the flux surface volume, J is the current, p the pressure gradient, and E the electric field.

* It can be interpreted as indicating how much radial current is required to sustain a given level of plasma rotation, i.e. the “efficiency” with which a radial current can drive rotation.

* Large flow damping leads to large radial conductivity; in axisymmetric tokamaks without neutrals, the radial conductivity is automatically zero.

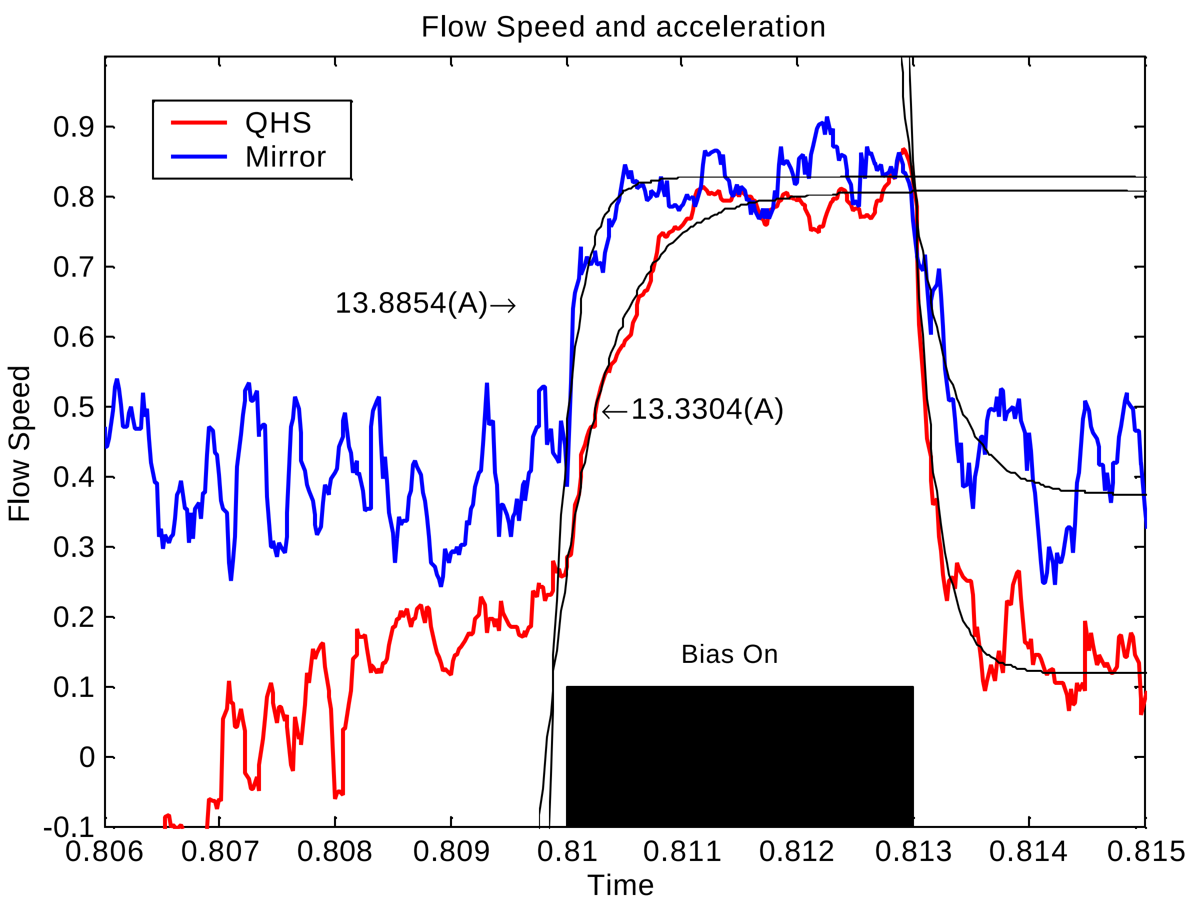
* We have preliminary data indicating that the radial conductivity is smaller in the QHS mode than the Mirror mode.



* The first evidence is in the bias probe I-V curve. The set of discharges below were taken with similar line density and with the probe in the same position relative to the separatrix.

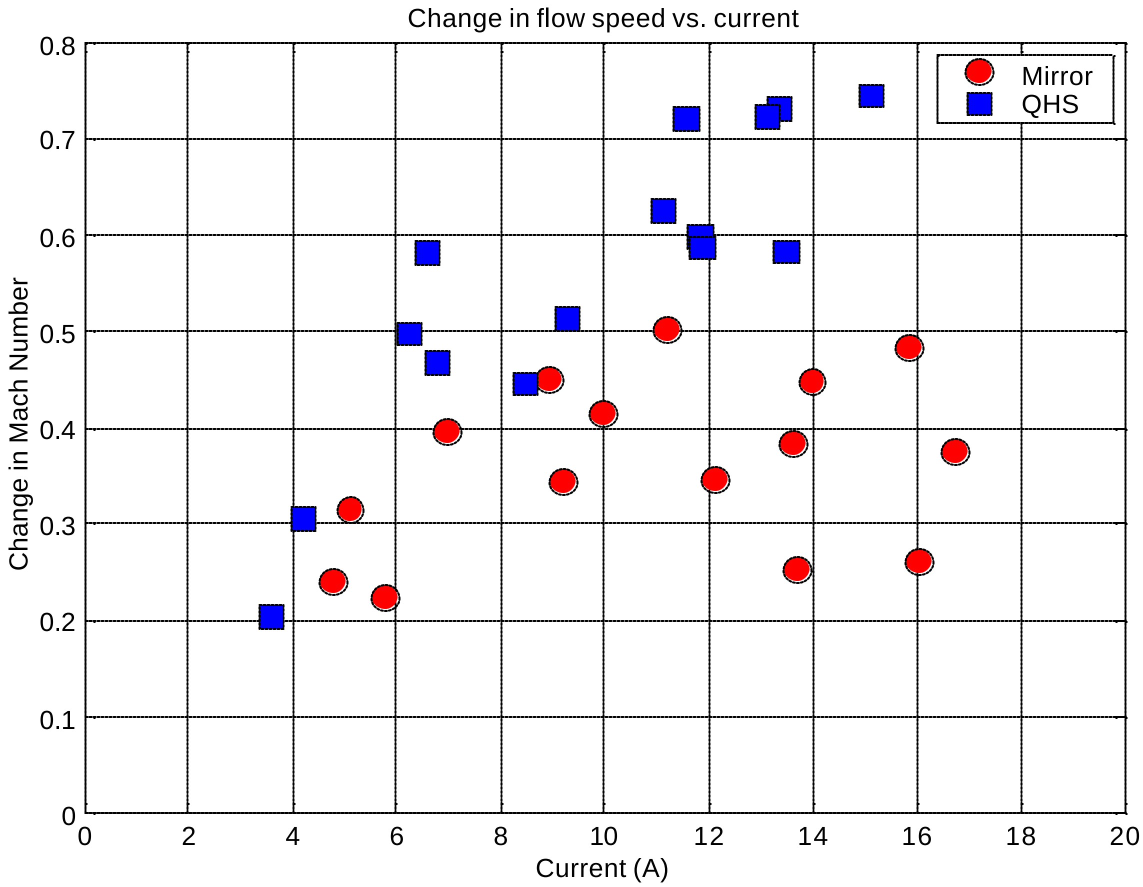
* Note the larger current drawn in the Mirror Mode.

* The speed waveform for biased Mirror and QHS shots is shown at below.



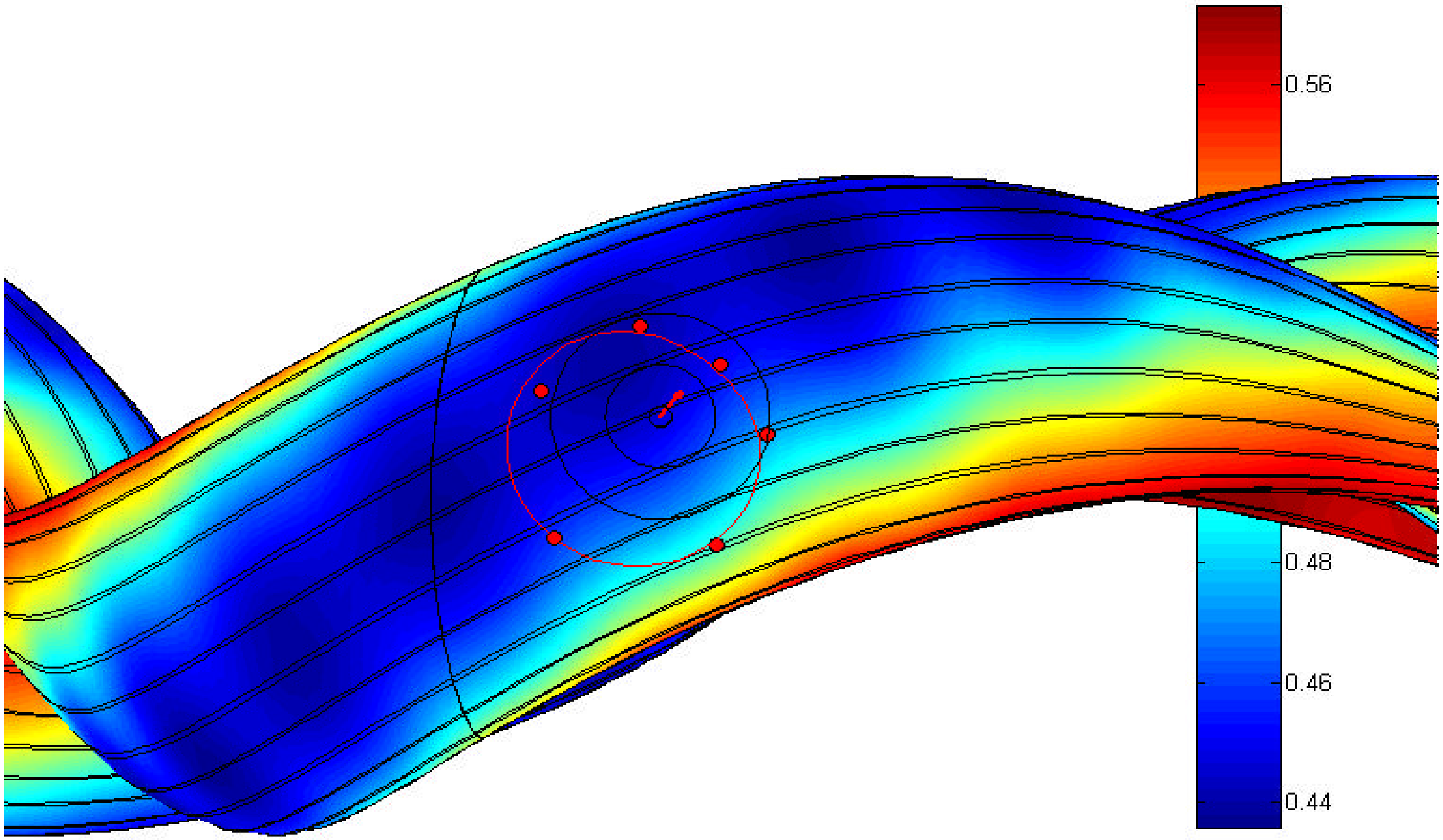
* The Mirror mode has a smaller increment of speed at the time of the bias, and a shorter rise time.

* To resolve how easily the rotation can be driven in the two different modes, plot the change in rotation speed as a function of the current drawn.

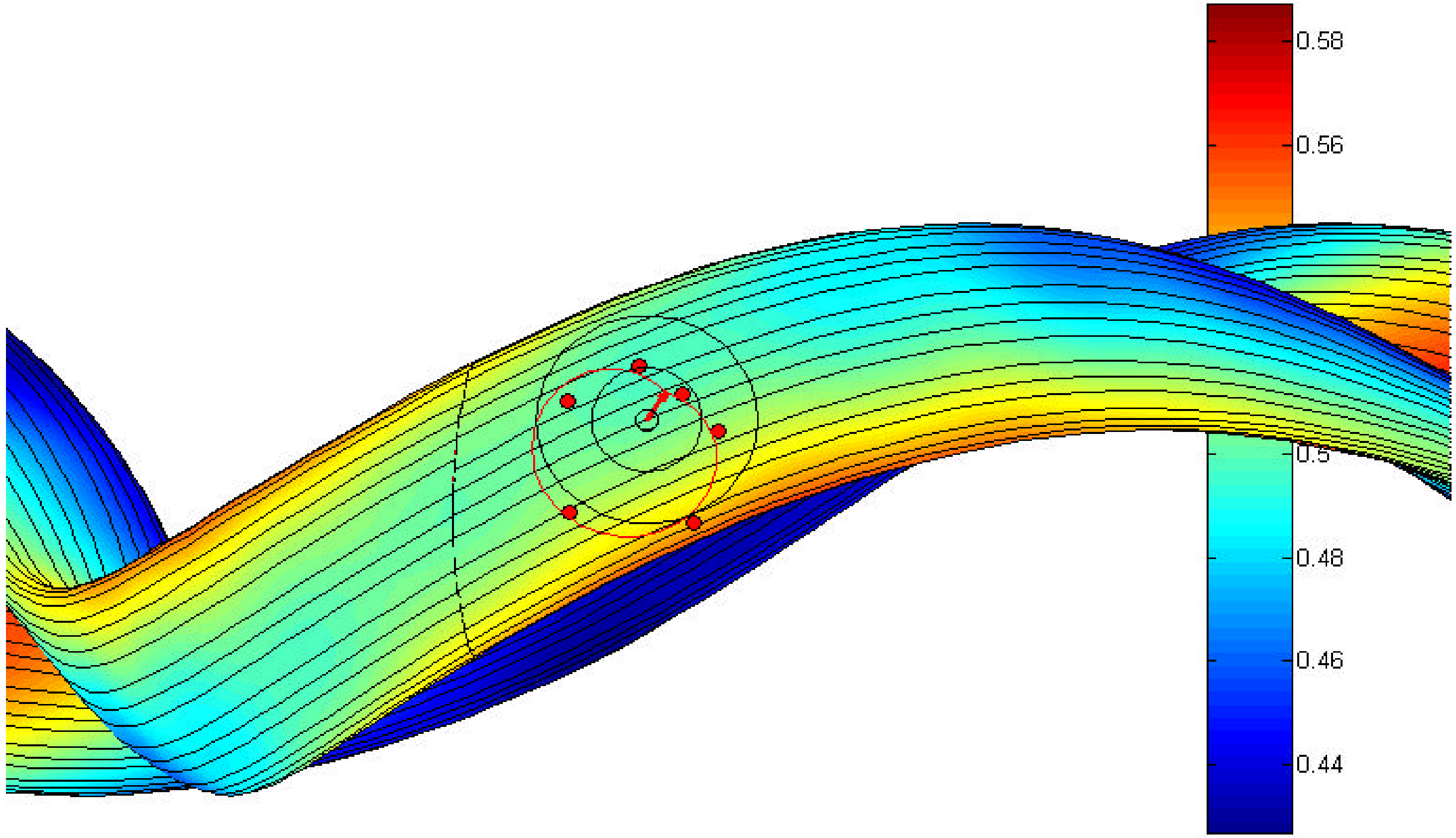


* For a given current (**j**x**B** force), the QHS mode is accelerated more, consistent with it having a lower radial conductivity!

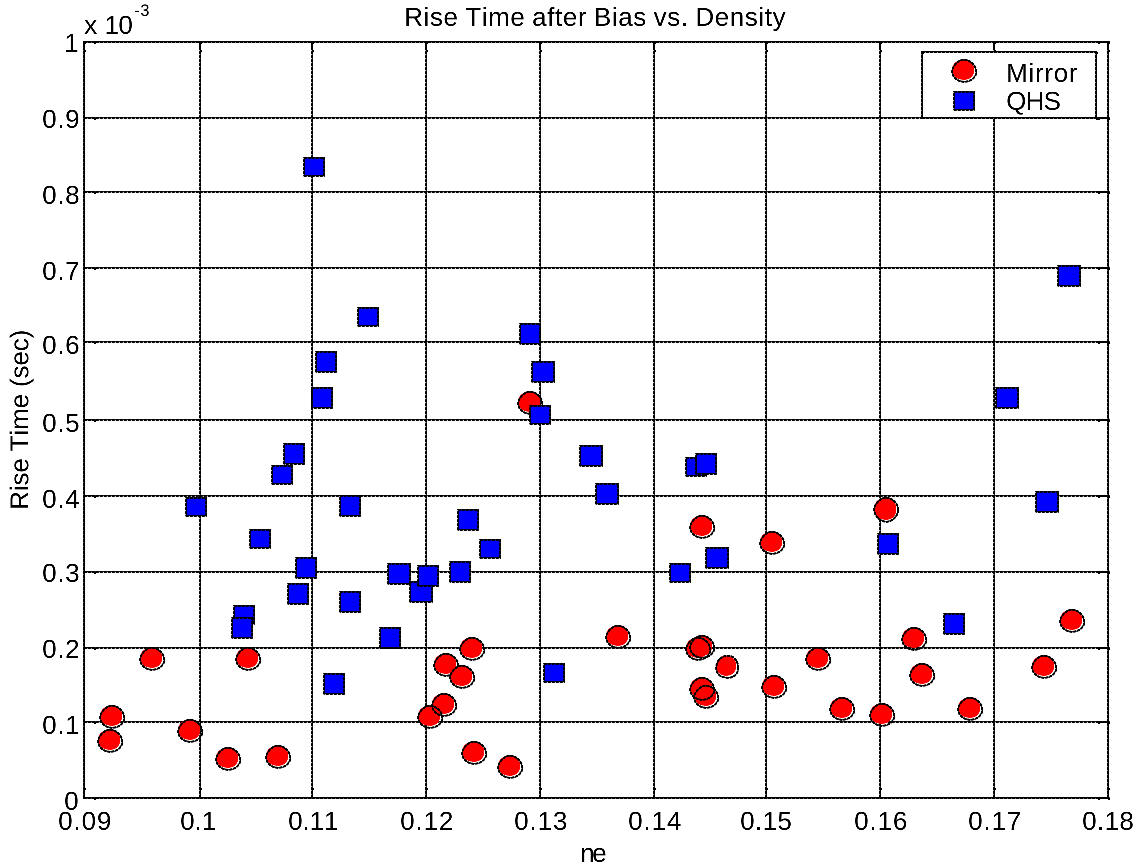
* As shown above, the mirror mode flow doesn't change direction when biased, but the QHS flow angle does change. Shown below is the QHS mode flow direction for the shot shown above.



* Shown below is the direction of the Mirror mode biased flow, superimposed on the Mirror Surfaces.



* The rise time at bias turn on has also been measured, and a small difference has been found. Note that this experiment is more susceptible to noise than the previous shown data.



* As is shown below, this small difference and fast rise time can be explained by a large neutral density in HSX.

Modeling the Radial Conductivity and Damping Rates

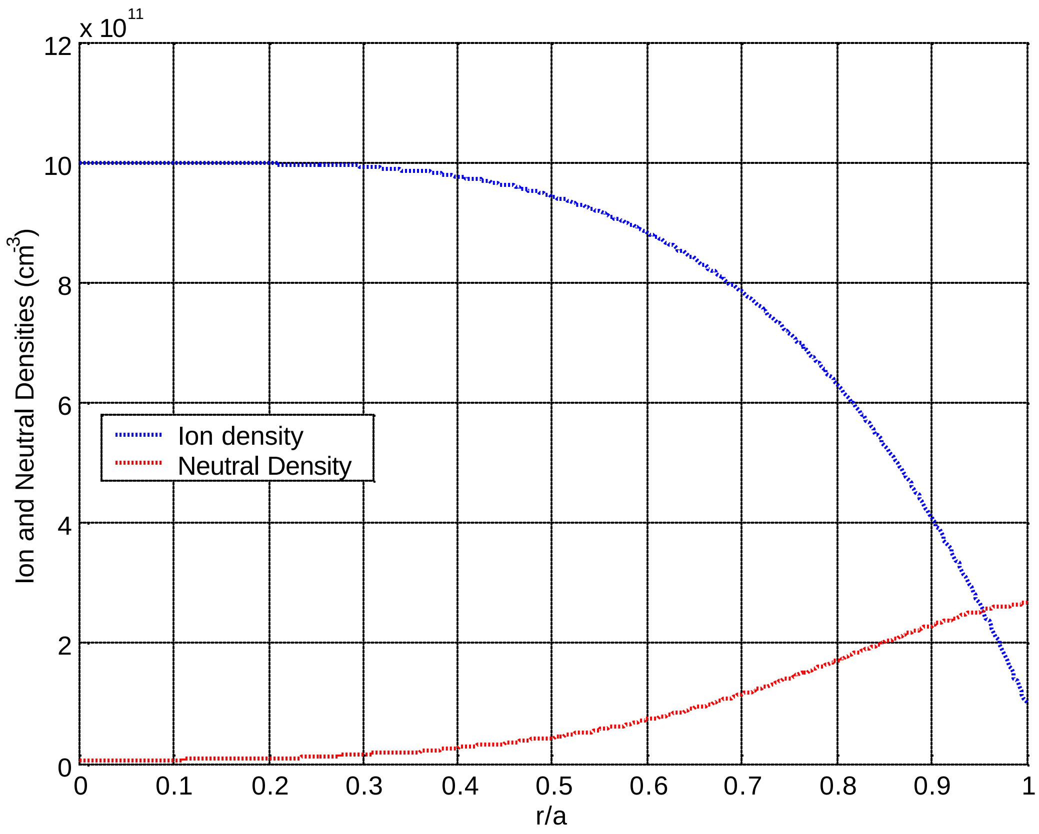
* In this model[4], the momentum balance and continuity equations are solved in Hamada Coordinates. It is assumed that flow damping is composed of parallel viscosity that is linear in flow speed and drag due to ion-neutral collisions.

* In the following calculations, the Boozer Spectrum is used, not the more appropriate Hamada Spectrum. Further, the Hamada basis vectors for a large aspect ratio Tokamak are used[5]. It is not known what errors these approximations in the magnetics introduces into the calculation.

* The model leads to expressions for the radial conductivity and an expression for two damping rates on a surface:

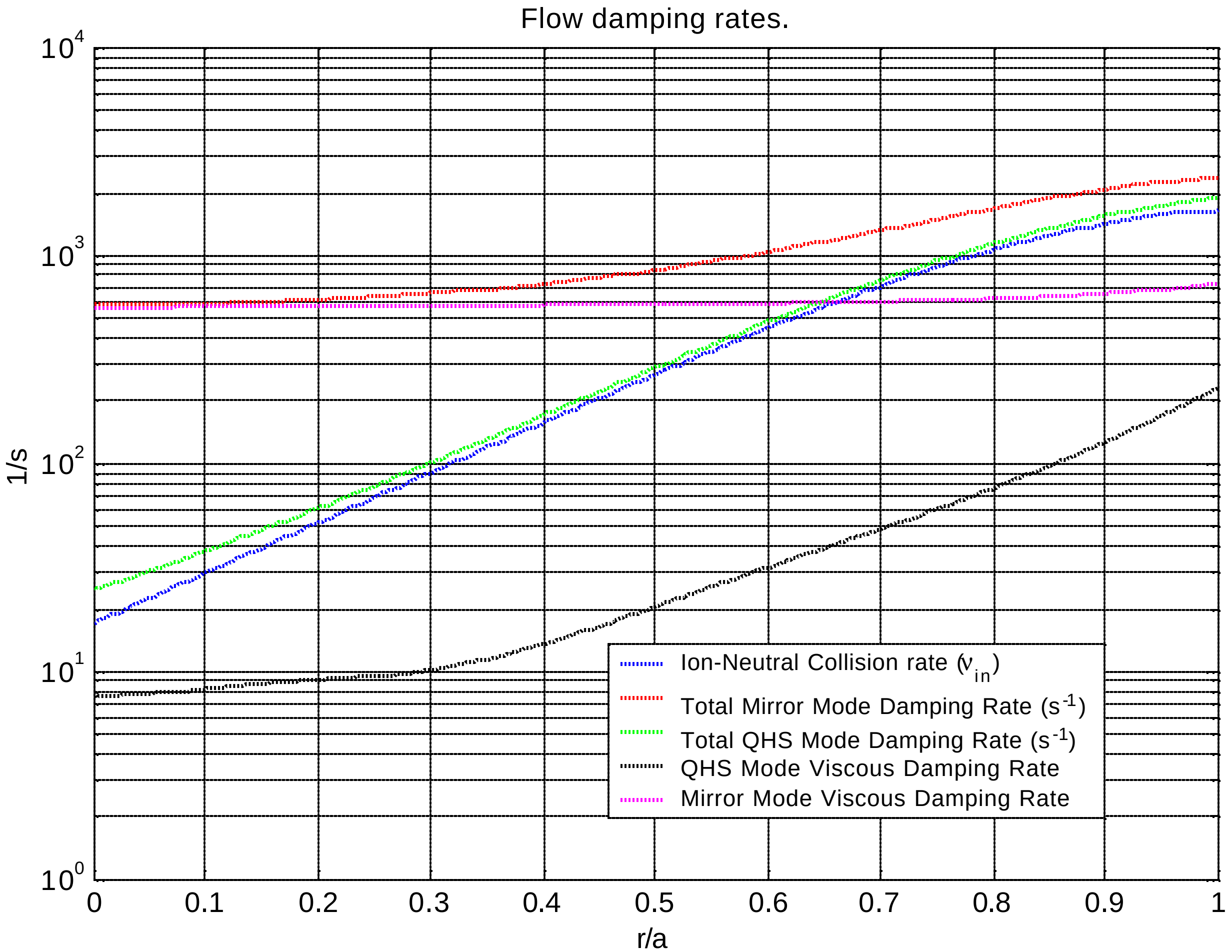
$$u^{\pm} = u_{in} + u^{\pm}_{visc}$$

- Here, $\nu^{\pm}_{visc}$ represent the damping rates due to parallel viscosity, and are dependent on the magnetic geometry and collisionality regime. The expressions used in the calculation are appropriate for the plateau regime.



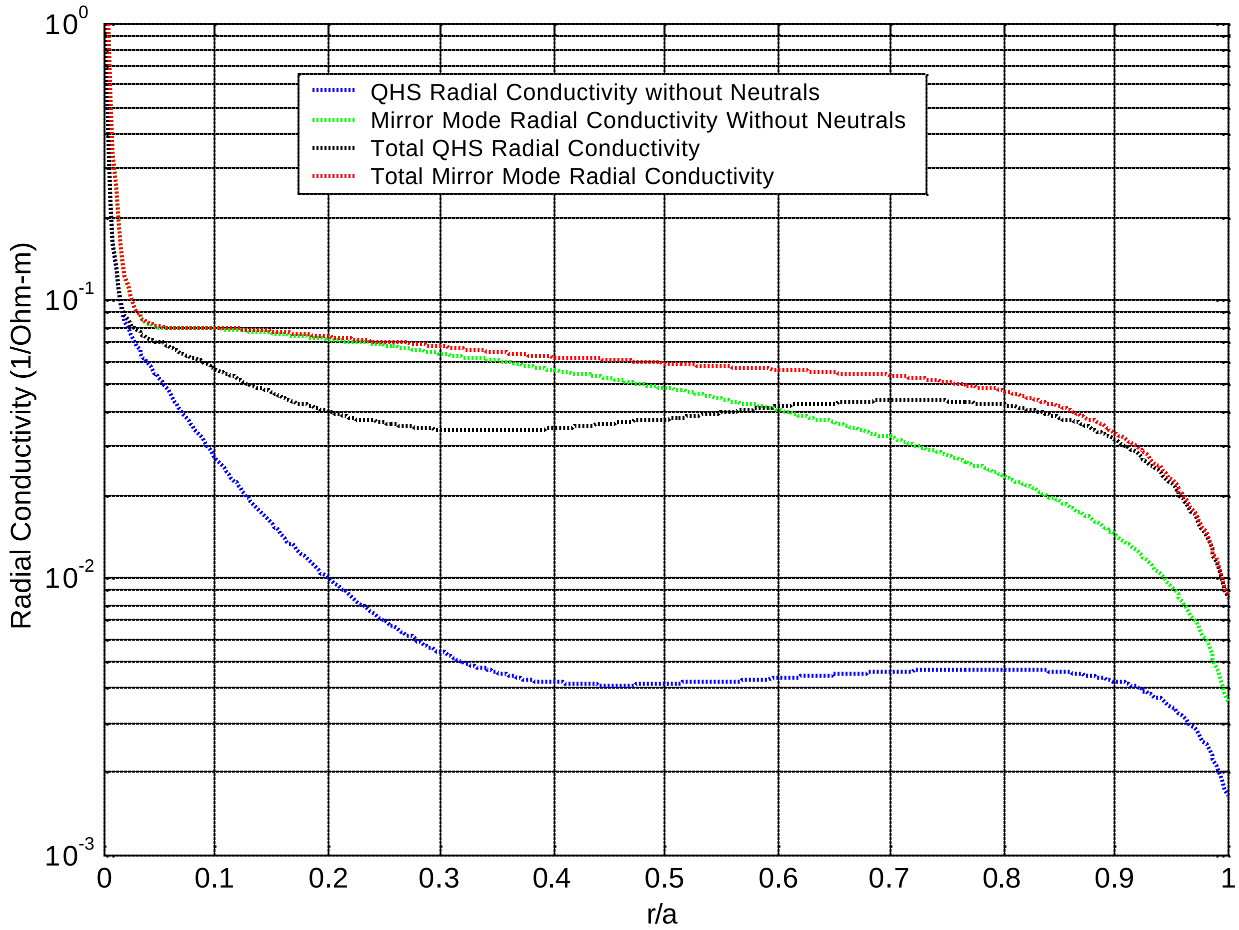
* The figure to the left shows the ion density and neutral density profiles assumed in the calculation.

* The graph below shows the calculated damping rates. Not that in the absence of neutrals, there is a strong difference between the QHS and Mirror mode.



* The neutral density assumed in this calculation brings the damping rates up to the measured values, but also obscures the damping due to parallel viscosity.

* In the next plot, the radial conductivity for each of the two modes is plotted, using the same density profiles.



* Again, although there is a strong difference between the two modes in the absence of neutrals, the neutral density serves to bring the QHS mode up to nearly the same level as the Mirror mode.

Future Work

* Use H_α emission to estimate the neutral density. Determine the contribution of neutrals to flow damping in HSX. Try to find ways to run HSX with lower neutral density.

* Make detailed measurements of the decay rates as a function of density and bias voltage.

* Use triple probes to measure $V_p=V_f+3.3T_e$. Use the profile of V_p to determine the edge structure of the electric field.

* Construct a Gridded Energy Analyzer to determine the Ion temperature. Use this coupled with the triple probe to measure the radial conductivity.

* Use Doppler spectroscopy to verify the probe measurements.

References

[1]Cryus S. Maclatchy, Claude Boucher, Deborah A. Poirier, and James Gunn, Rev. Sci. Instrum. **63**, 3923 (1992)

[2]B.J. Peterson, J.N. Talmadge, D.T. Anderson, F.S.B. Anderson and J.L. Shohet, Rev. Sci. Instrum. **65**, 2599 (1994)

[3]M. Hudis and L.M. Lidsky, J. Appl. Phys. **41**, 5011 (1970)

[4]M. Coronado and J.N. Talmadge, Phys. Fluids B **5**, 1200 (1993)

[5]M. Coronado and J. Galindo Trejo, Phys. Fluids B **2**, 530 (1990)

Copies

1) 2)

3) 4)

5) 6)

7) 8)

9) 10)

11) 12)