Reduced Turbulent Particle Flux and Plasma Rotation Control in Biased MST Plasmas

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ABSTRACT

Two topics associated with edge biased plasmas in MST are presented. The first relates to understanding an increase in the particle confinement with biasing. New Langmuir probe edge measurements reveal a large reduction in the turbulent particle flux, despite an increase in density fluctuations. A transport-reducing phase shift between the density and potential fluctuations plus a decrease in the mean wave number are responsible. These turbulence decorrelation features suggest that biasing induces flow-shear in the edge, but the change in the flow is large throughout the plasma, not concentrated in the edge. This global perturbation to the flow profile proves a useful tool in understanding momentum transport in MST, this poster's second topic. For example, the momentum profile rapidly flattens in a sawtooth crash. In biased plasmas, instead of slowing down at the crash, the core speeds up to match the bias-induced edge flow, evidencing robust profile flattening and supporting the explanation of nonlinear torques as the cause of the fast momentum transport.

Biasing in MST: turbulent transport reduction & momentum transport probe.

Past work has shown:

– increased radial electric field and $\mathbf{E} \times \mathbf{B}$ flow with edge biasing
– reduced potential fluctuations
– global flow profile changes (including larger flow-shear)
– ~50% increase in particle confinement time

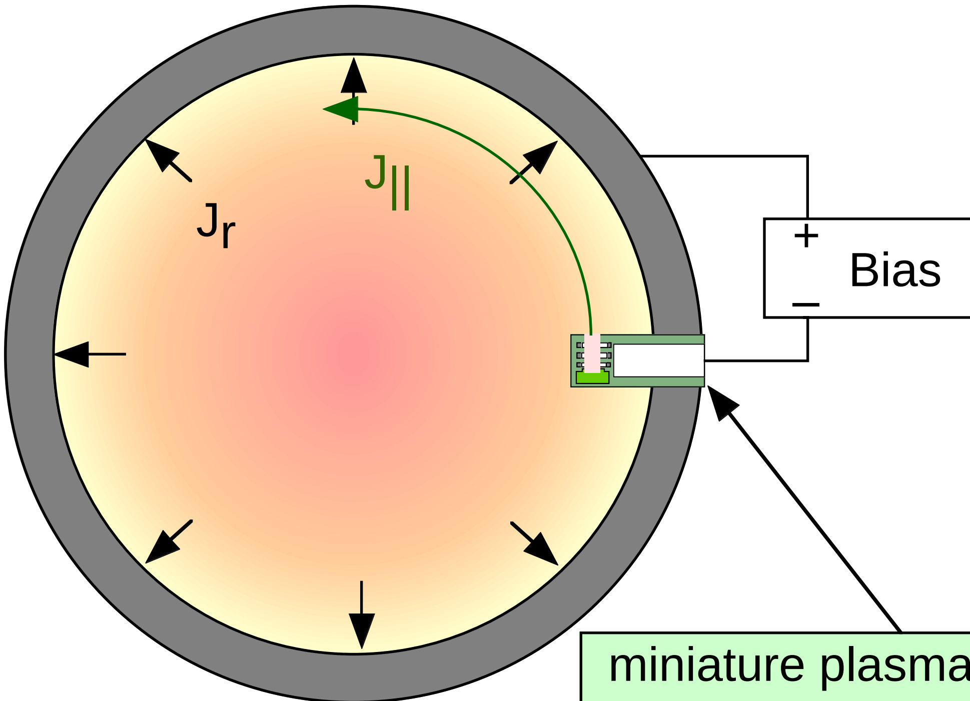
This poster:

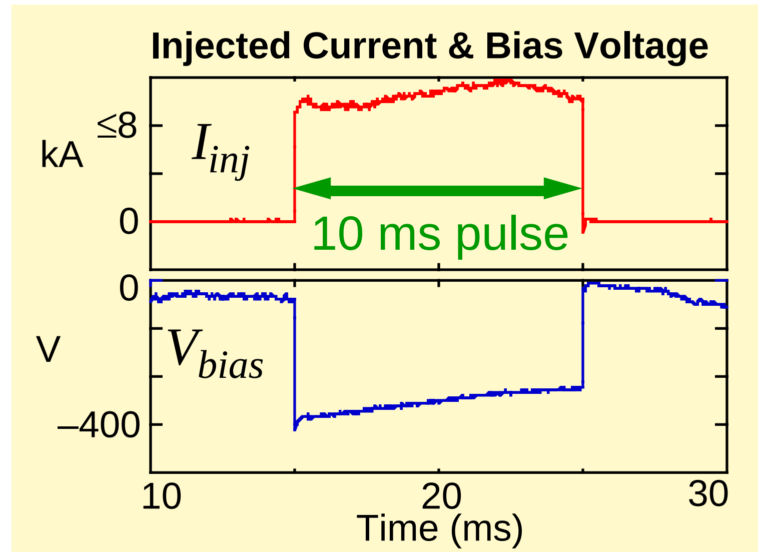
☞ New Langmuir probe measurements find:
– reduction in transverse electric field fluctuations (both $\tilde{\varphi}$ & $k_\perp$ reduced)
– density and potential fluctuations become nearly anti-correlated
– decrease in fluctuation induced particle flux throughout edge region

☞ Biasing (and other experiments) reveal momentum transport features:
– (anomalous) viscosity same order as heat & particle diffusivities
– fast edge-core momentum transport from bursty nonlinear $\tilde{\mathbf{J}} \times \tilde{\mathbf{B}}$ torques

Bias-induced plasma rotation using electrodes.

- Two types of bias electrodes used in MST:
  1. miniature plasma source (proved improvement of particle confinement with biasing)
  2. metal electrodes, molybdenum or carbon (used for turbulence studies in this poster)





miniature plasma source generates parallel-to-B current locally, which returns as cross-field current

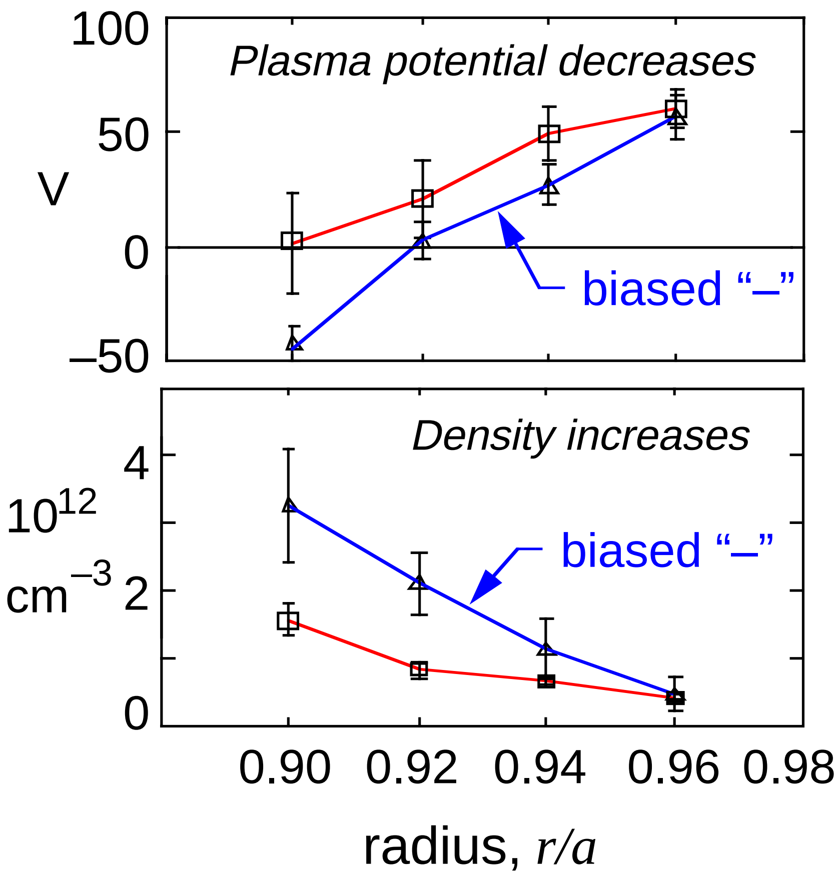
metal electrodes produce same radial return current, but not uniformly directed parallel current

bias effects for both types of electrodes the same

1. Particle Transport

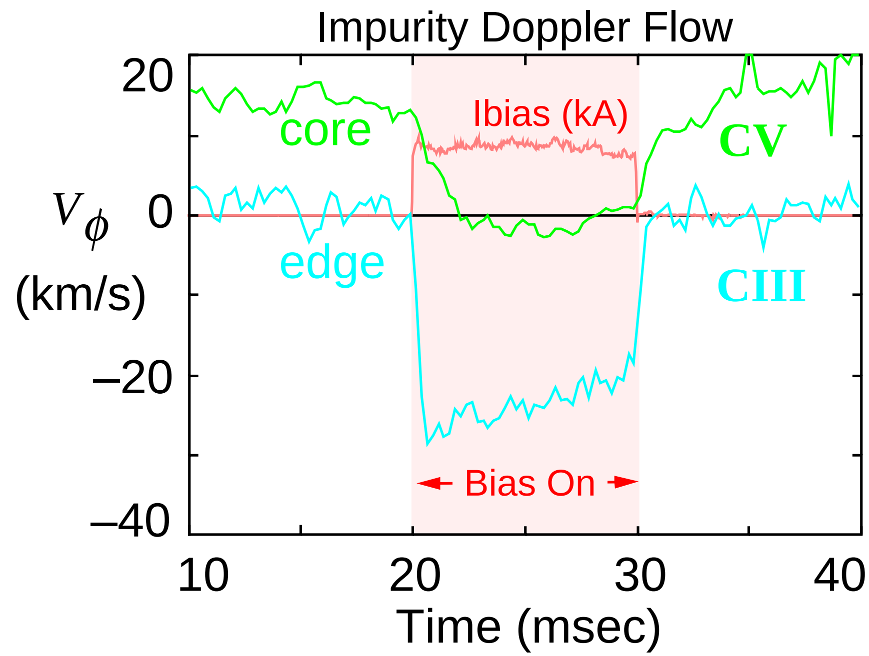
Biasing increases edge $\mathbf{E} \times \mathbf{B}$ flow velocity.

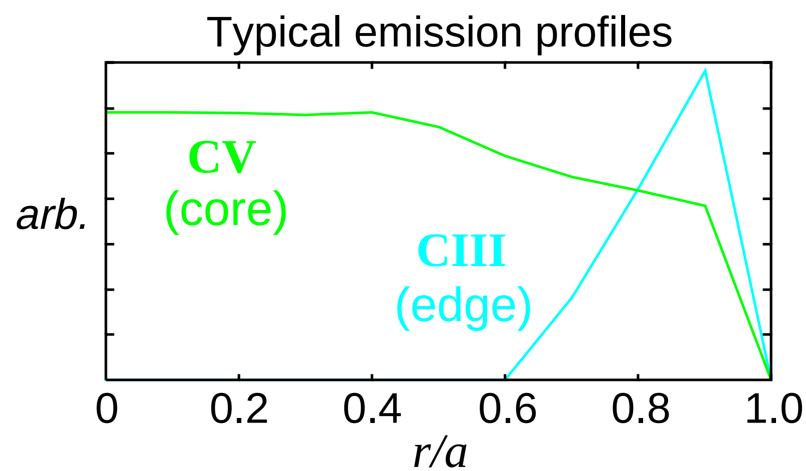
- **Edge probe potential & density profiles**



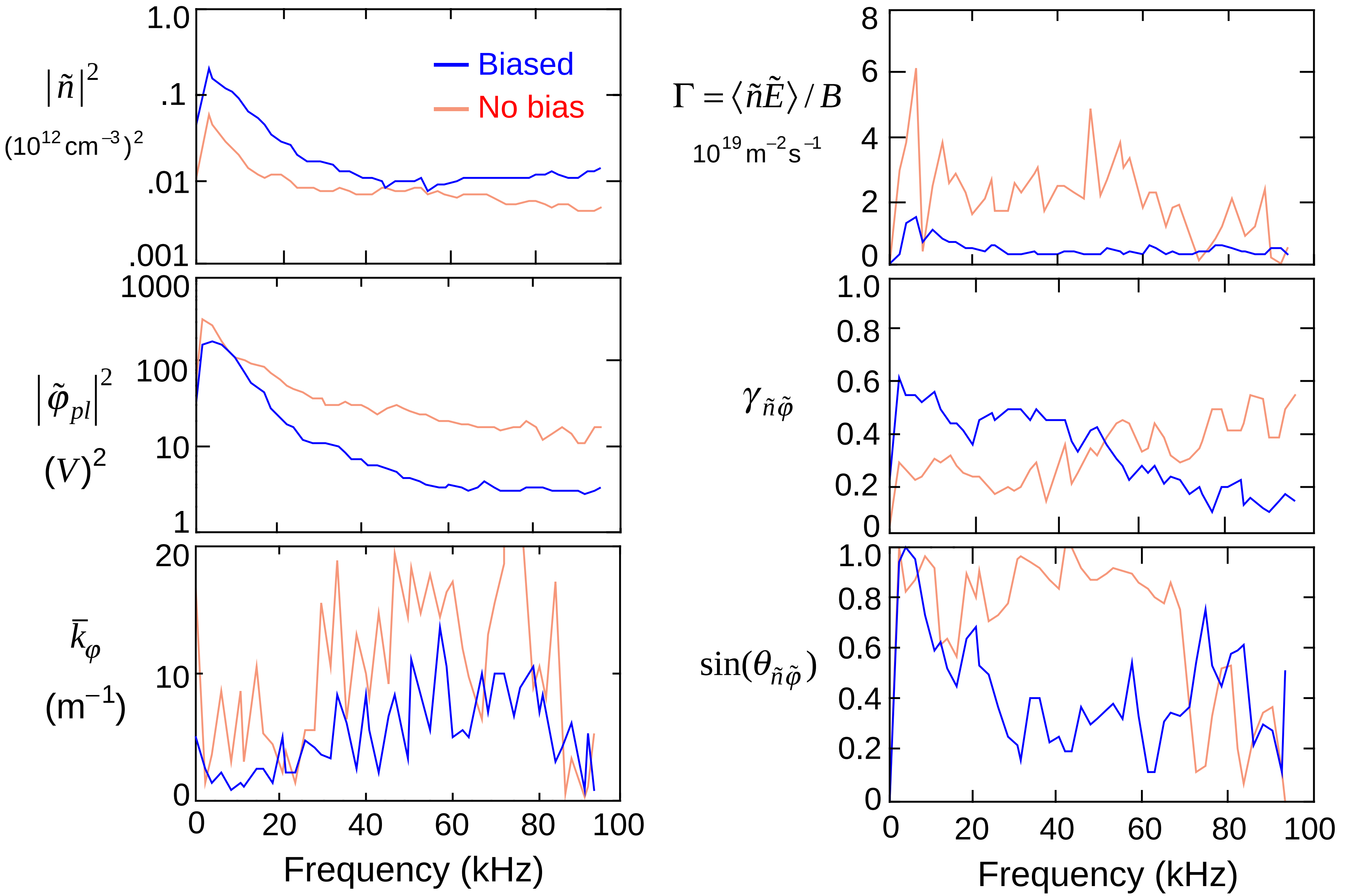
C.-S. Chiang Ph.D. thesis

- **Large change in flow, modest increase in flow shear**

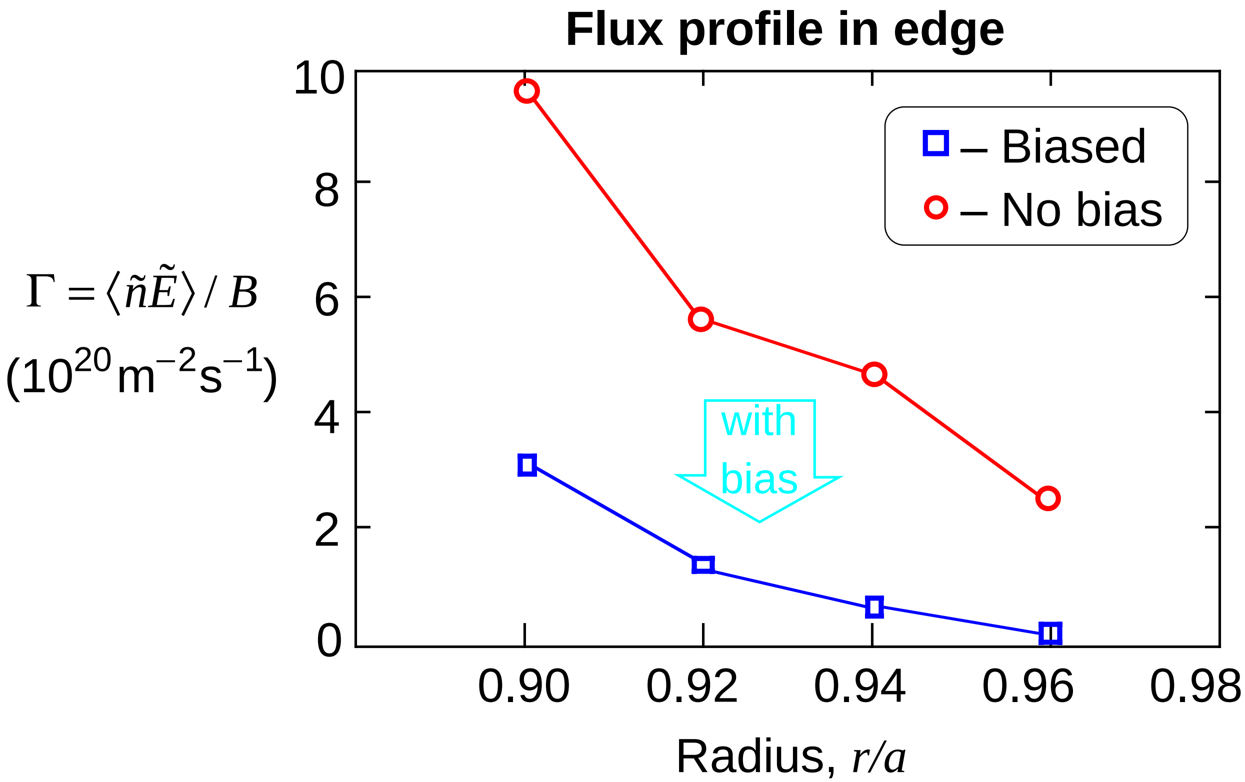




Reduced electric field fluctuations and weaker $\langle \widetilde{n}\widetilde{\varphi} \rangle$ cross-correlation lead to smaller turbulent particle transport.



Turbulent particle flux decreased throughout edge region.



Global particle balance confinement time increases ~50% with bias. (normally $\tau_p \sim 1.5$ ms)

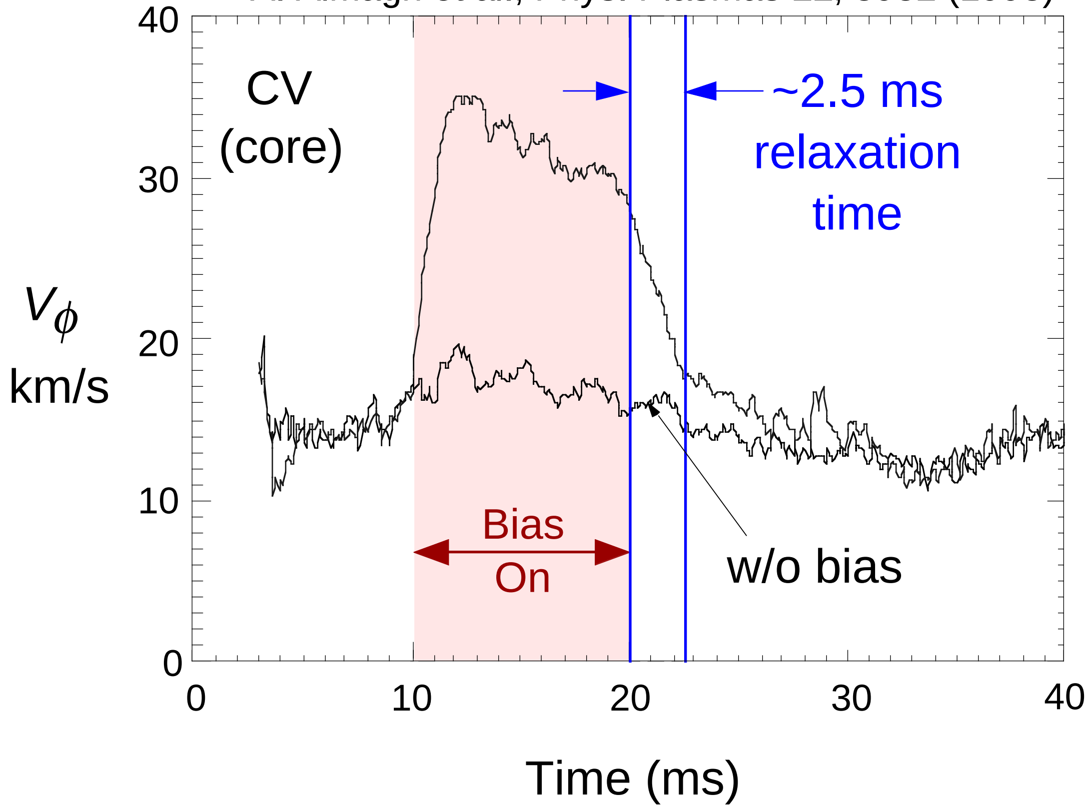
New dominant loss mechanism with bias? (turbulent flux decreased >50%)

2. Momentum Transport

Viscosity much greater than classical, estimated from flow damping following bias turn-off.

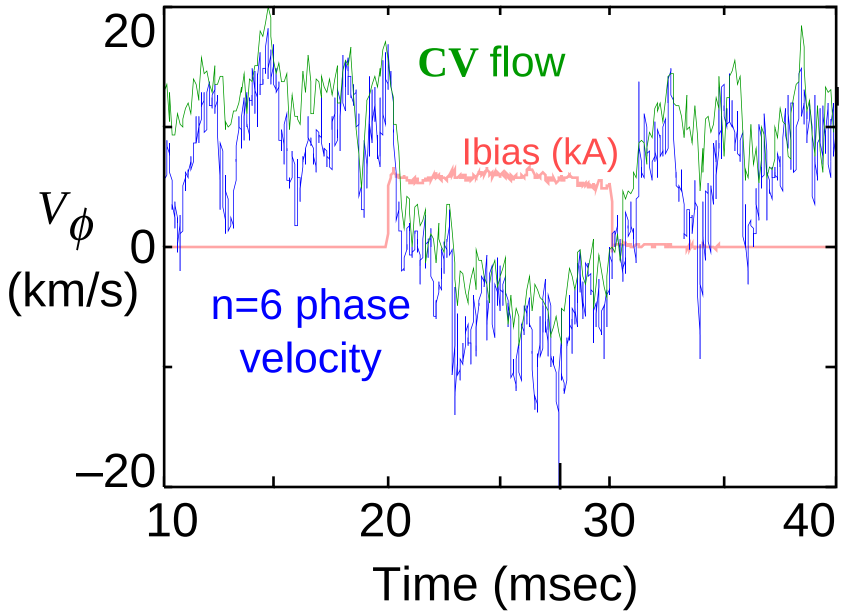
- $\nu_{\perp}$~50 m^2/s (about the same as particle & energy diffusivities)
- Longer damping time in high confinement, low magnetic fluctuation plasmas
- Independent of density (not shown here).

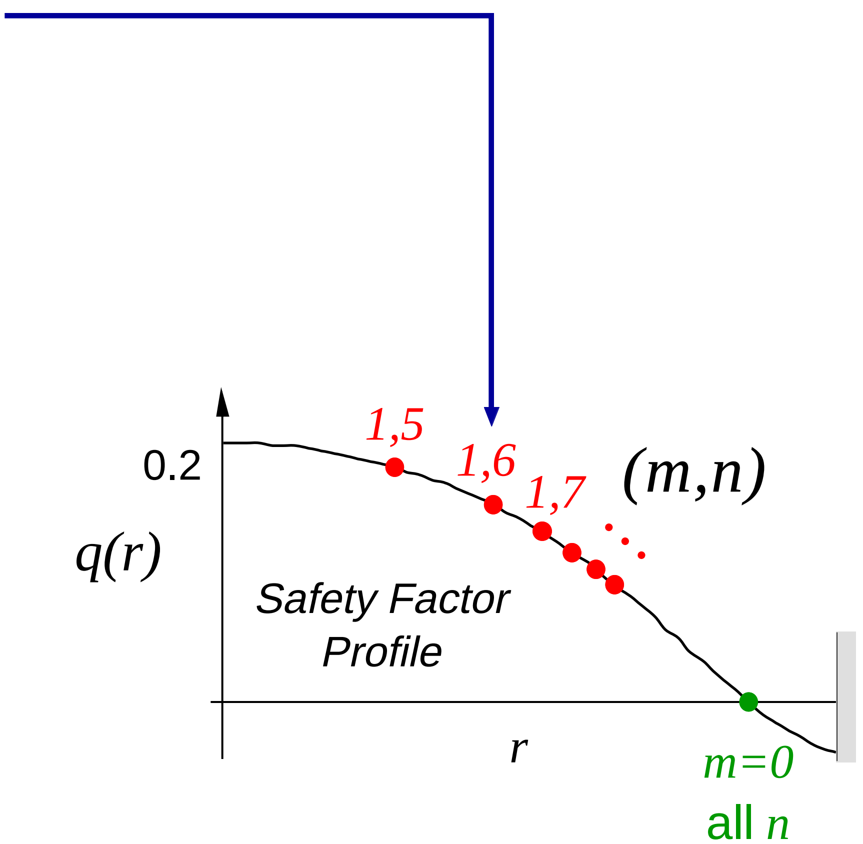
A. Almagri et al., Phys. Plasmas **11**, 3982 (1998)



Plasma flow strongly coupled to tearing mode dynamics.

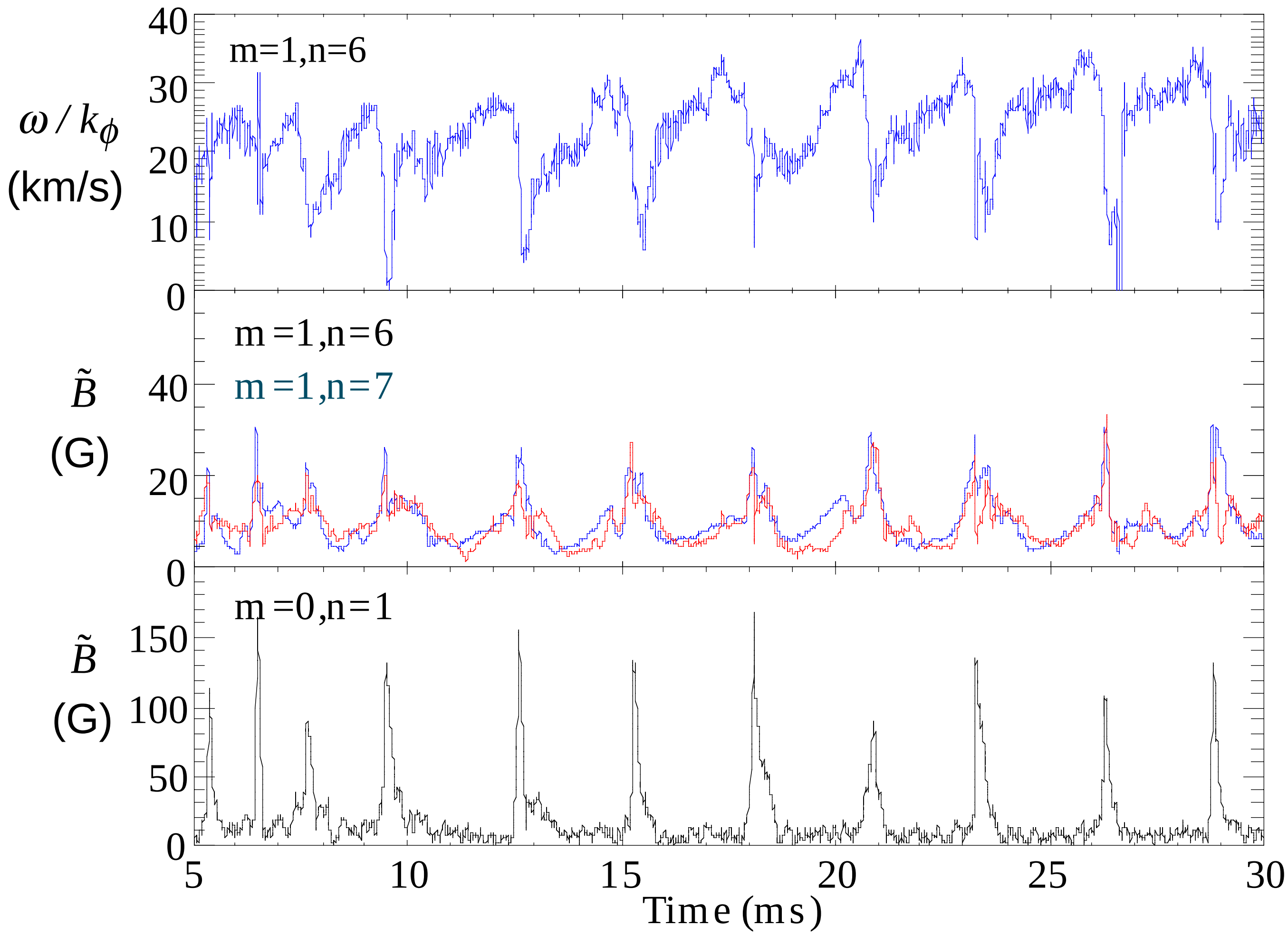
- Modes co-rotate with plasma near resonant surface





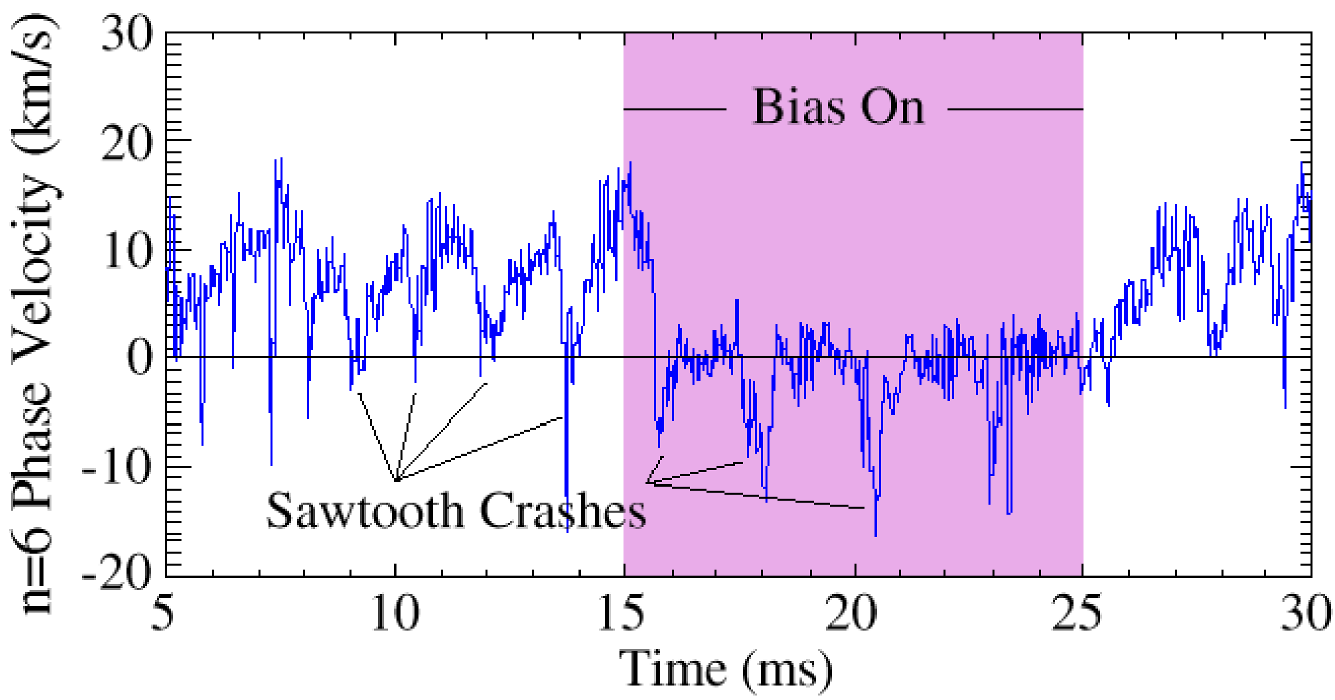
Core momentum quickly lost in sawtooth crash events

- Mode amplitudes burst at crash, core flow slows to near zero velocity



Core *accelerates* with bias, evidencing sawtooth crash is really momentum profile flattening.

- With bias, core modes speed up in the direction of edge flow



Fast momentum loss consequence of nonlinear torques.

- Mode evolution determined by resonant $\mathbf{J}\times\mathbf{B}$ torque balanced with viscous torque (i.e., local mode-plasma differential rotation)

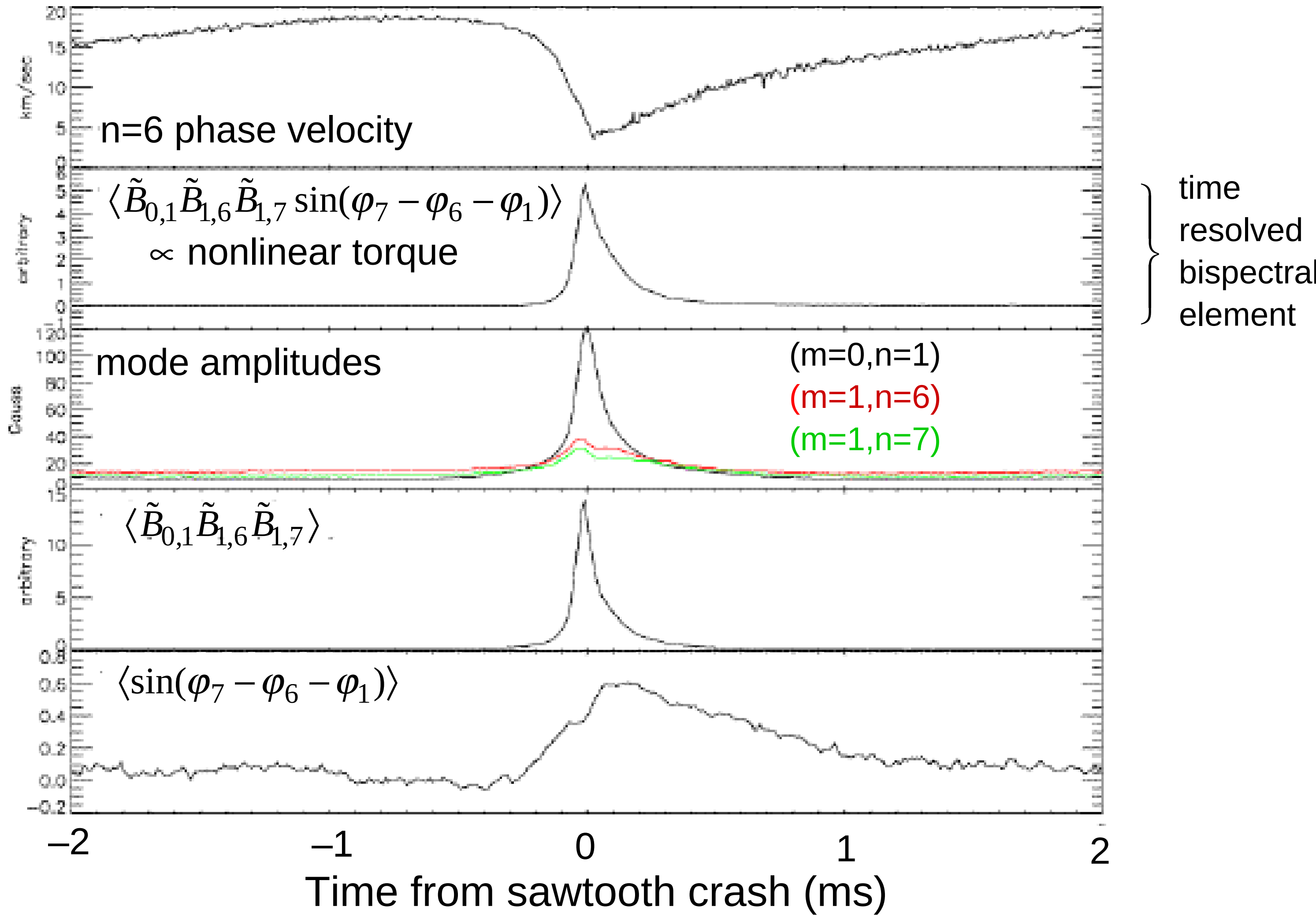
$$I\frac{d\Omega_{\mathbf{k}}}{dt} = \mathbf{R}\times(\tilde{\mathbf{J}}_{\mathbf{k}}\times\tilde{\mathbf{B}}_{\mathbf{k}}) + \mathbf{T}_{\nu}$$

- **Linear torque**, e.g., field error : $\tilde{\mathbf{J}}_{\mathbf{k}}^{fe} \sim \tilde{\mathbf{B}}_{\mathbf{k}}^{fe}$
  - Typically an added external torque on plasma

- **Nonlinear torque**: $\tilde{\mathbf{J}}_{\mathbf{k}}^{nl} \sim \sum_{\mathbf{k}'} C_{\mathbf{k},\mathbf{k}',\mathbf{k}-\mathbf{k}'}\tilde{B}_{\mathbf{k}'}\tilde{B}_{\mathbf{k}-\mathbf{k}'}$
  - $\left\langle \tilde{\mathbf{J}}_{\mathbf{k}}^{nl}\times\tilde{\mathbf{B}}_{\mathbf{k}}\right\rangle \sim \sum_{\mathbf{k}'} C_{\mathbf{k},\mathbf{k}',\mathbf{k}-\mathbf{k}'}\underbrace{\left\langle \tilde{B}_{\mathbf{k}}\tilde{B}_{\mathbf{k}'}\tilde{B}_{\mathbf{k}-\mathbf{k}'}\sin(\varphi_{\mathbf{k}'}-\varphi_{\mathbf{k}}+\varphi_{\mathbf{k}-\mathbf{k}'})\right\rangle}_{\text{magnetic bispectrum}}$
  - internal torques, redistribute momentum

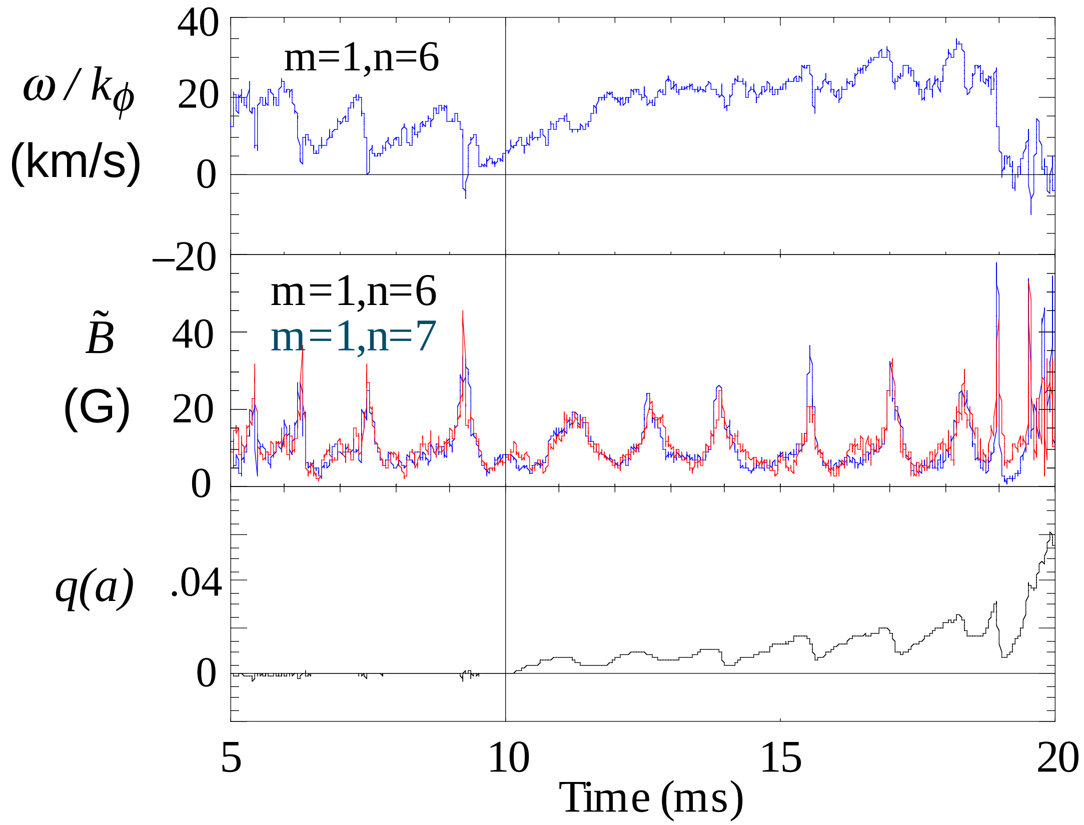
Nonlinear torques peak at sawtooth crash.

- Expected dominant NL torque: two adjacent core modes (m=1,n) and (m=1,n±1) coupled to edge (m=0,n=1) mode



Removing m=0 resonance eliminates nonlinear torque and momentum profile flattening at crash.

• Operate with $q(a)>0$ (ULQ) $\Rightarrow$ no resonant $m=0 \Rightarrow$ no nonlinear torque



Summary

- Biasing reduces electric field fluctuations and turbulent particle flux in edge
- Reduced $k_\perp$ and $\langle \tilde{n}\tilde{\varphi} \rangle$ anti-correlation suggest shear-flow mechanism, despite modest change in E_r-shear (***magnitude*** of flow more important?)
- Bias has been essential tool in understanding momentum transport
- Magnitude and character of viscosity clearly non-classical, strongly linked to magnetic turbulence
- Fast momentum transport from coupled tearing modes evident in nonlinear torque bursts at sawtooth crashes
  - measured large, transient bi-coherence of m=1 and m m=0 modes
  - fast core momentum loss eliminated by removing m=0 resonance