Observation of improved and degraded confinement through driven flow on the LAPD

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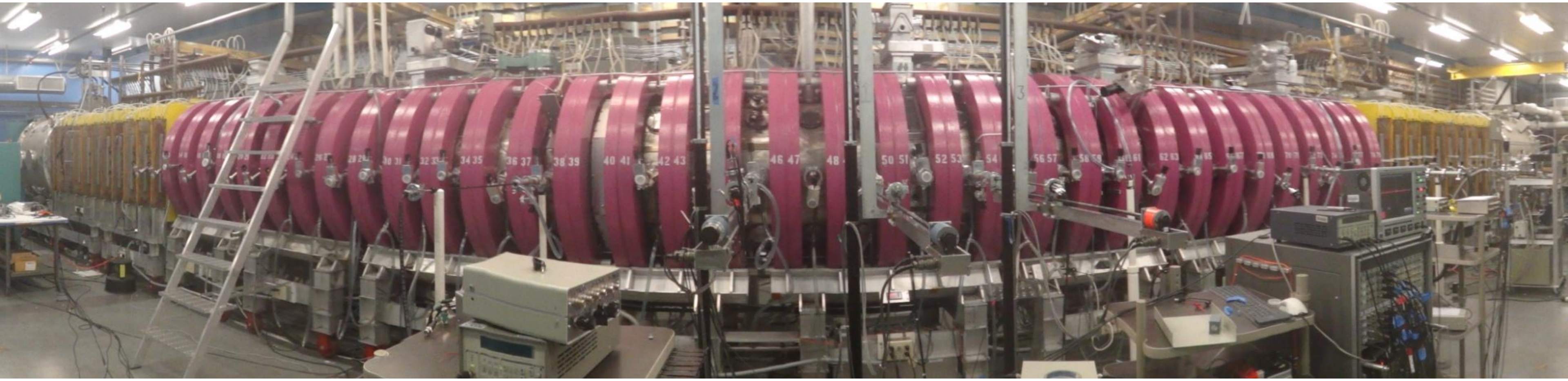
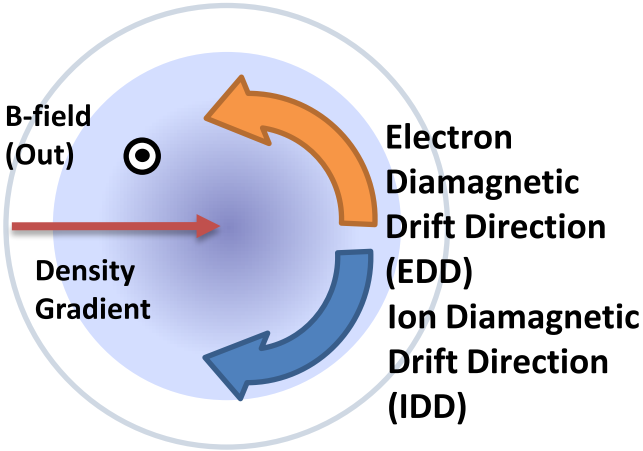
Overview

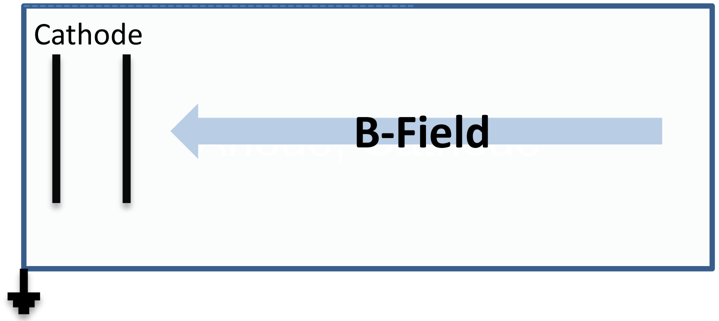
- Through limiter biasing, continuous control over flow in the LAPD edge is achieved, including a nearly zero flow and flow shear state achieved by nulling-out spontaneous edge flow
- Confinement improvement observed with increasing shearing for flow in *both IDD and EDD* directions, confinement degradation with low flow shear
- Particle flux and radial correlation length decrease with shear
  - Continuous reduction with increasing shear
  - Near total suppression of flux observed for shearing rates comparable to or below **the no-shear turbulent autocorrelation rate**
- Turbulent amplitude reduction explains majority of flux decrease
- Coherent modes appear at high shearing rates

The Large Plasma Device at UCLA

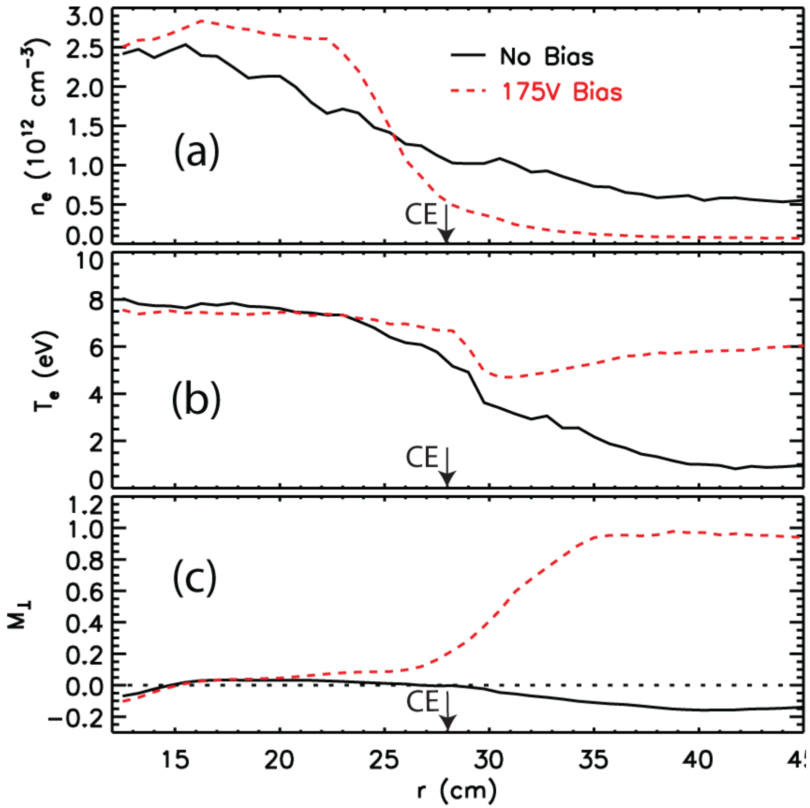


- 17 m long, 1 meter diameter, ~60 cm wide Helium gas plasma
- Magnetic Field: 1000G
- Density: Core ~ 5.0×10^{12} cm^{-3}
- Pulse Duration ~ 10ms
- Pulse rate – 1Hz
- plasma radius to ion gyroradius (a/ρ_i), is on the order of 100

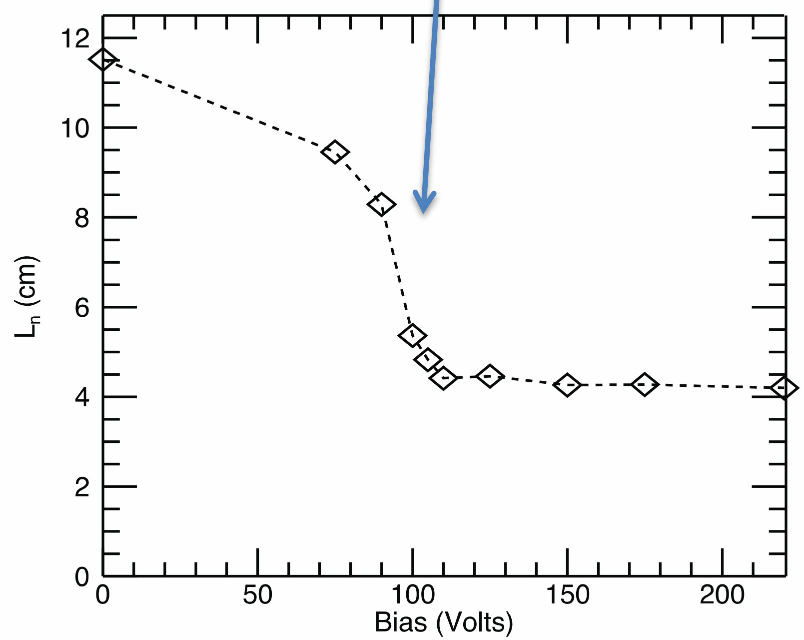




Previous work*: flow driven by chamber wall biasing revealed confinement transition



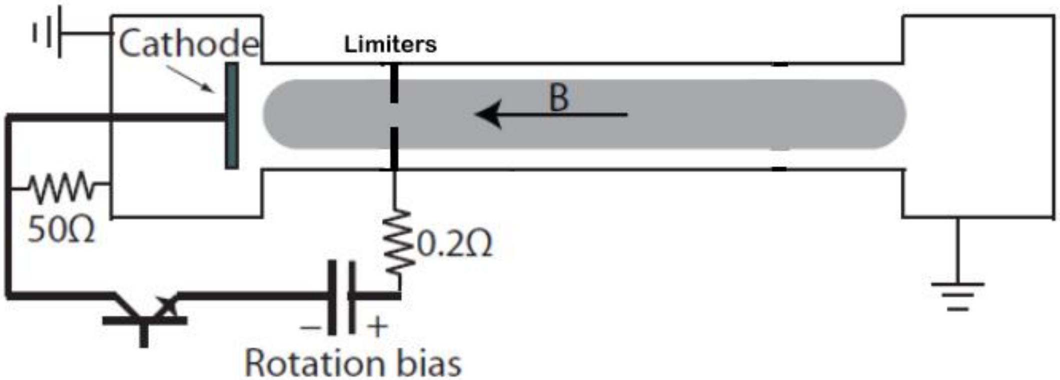
When bias exceeds threshold, **confinement improvement observed**



Threshold due to **flow penetration**, not a continuous variation in edge flow: below transition, no change in flow except in a narrow layer by the chamber wall

Carter, Maggs PoP 2009

New limiters installed, provide continuous control of edge flow through biasing



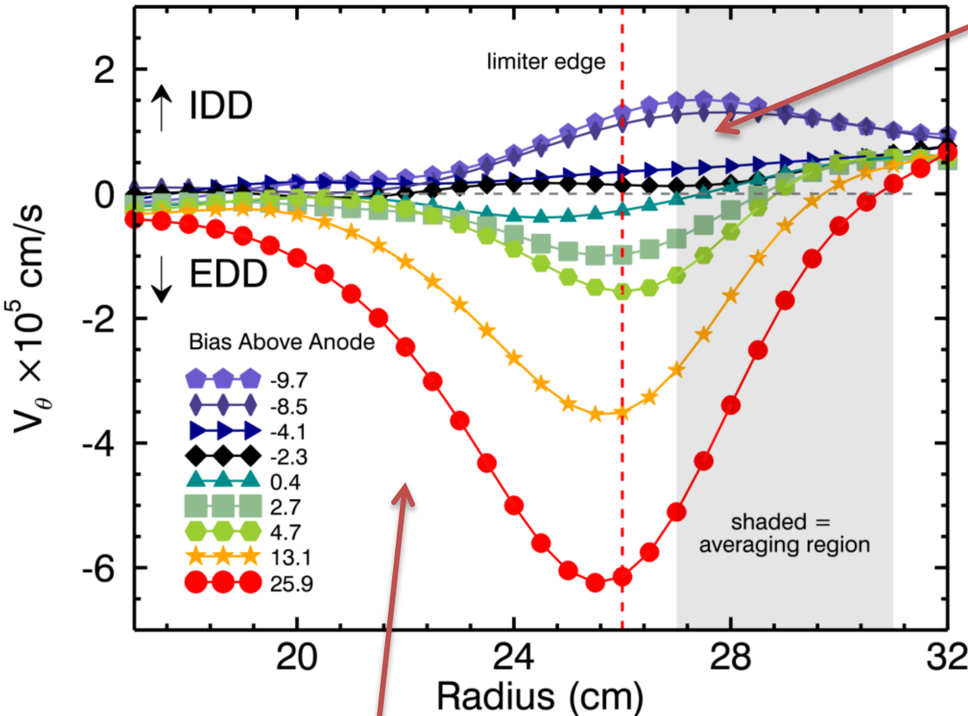
Limiters viewed from within plasma chamber

Biasable, moveable limiters (iris); 52cm aperture for these experiments

Biasing relative to cathode; anode potential typically comparable to plasma potential in core plasma

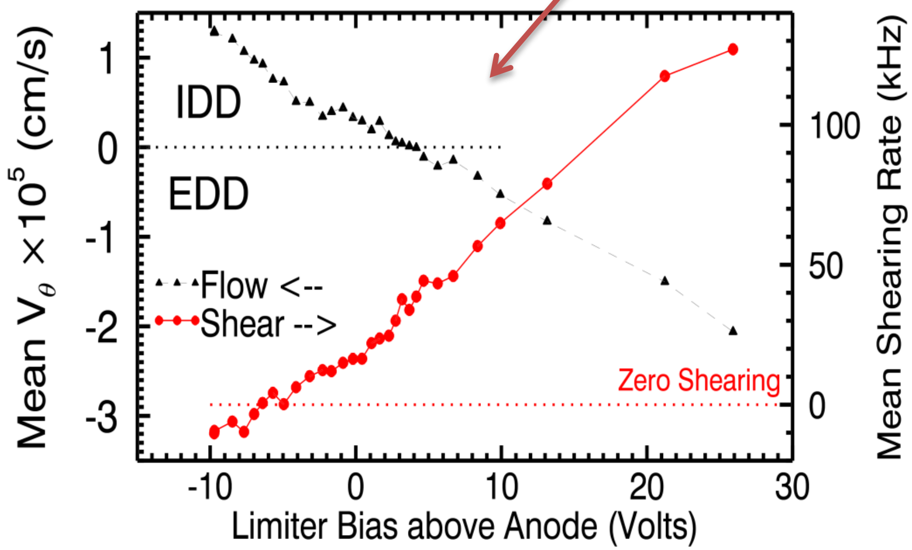
Potential in limiter shadow varies linearly, continuously with applied bias voltage

EDD and IDD flow achieved, scales linearly with bias voltage



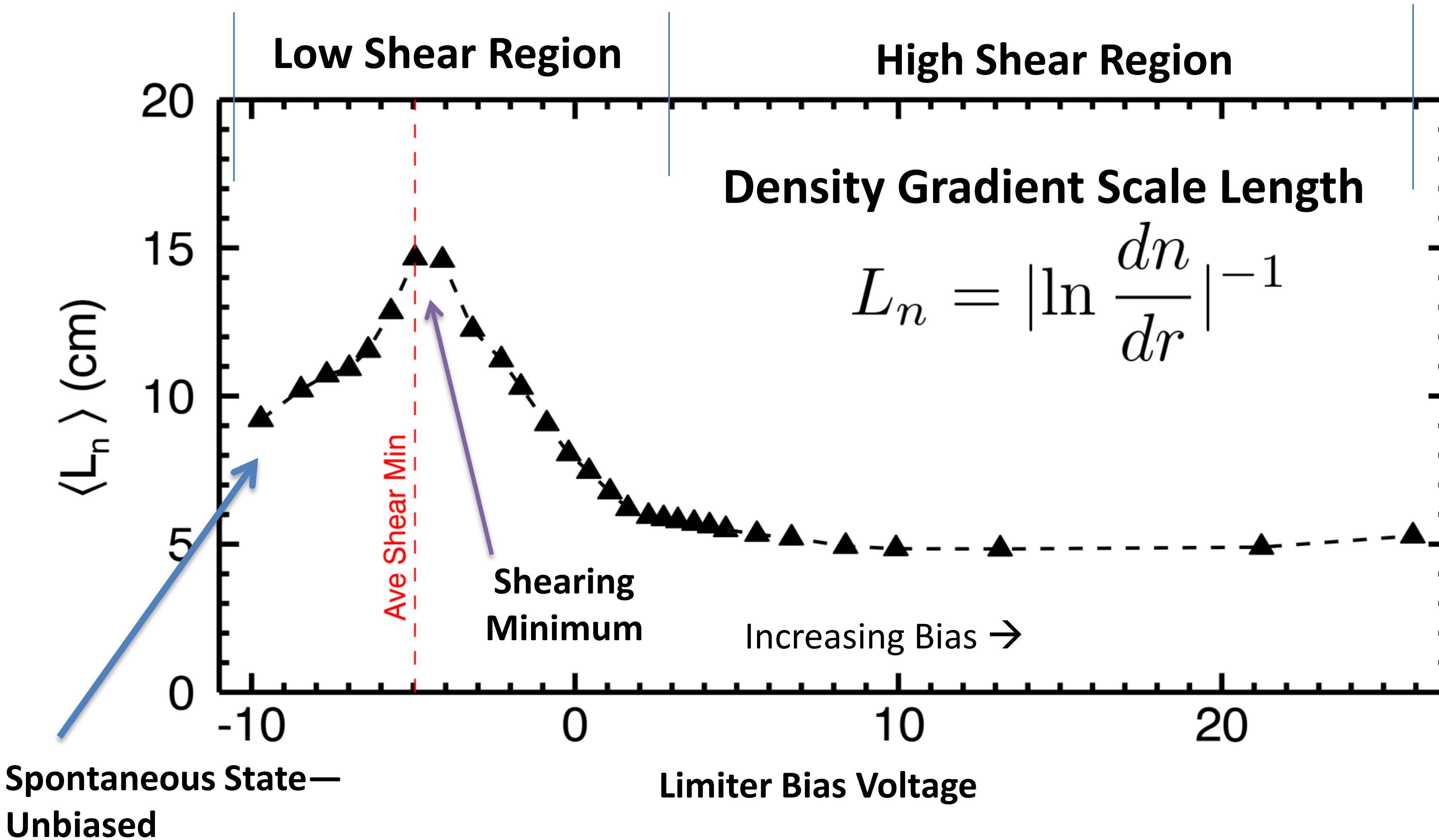
Spontaneous (unbiased) flow in IDD

Average edge flow velocity and shearing rate scale linearly with limiter bias

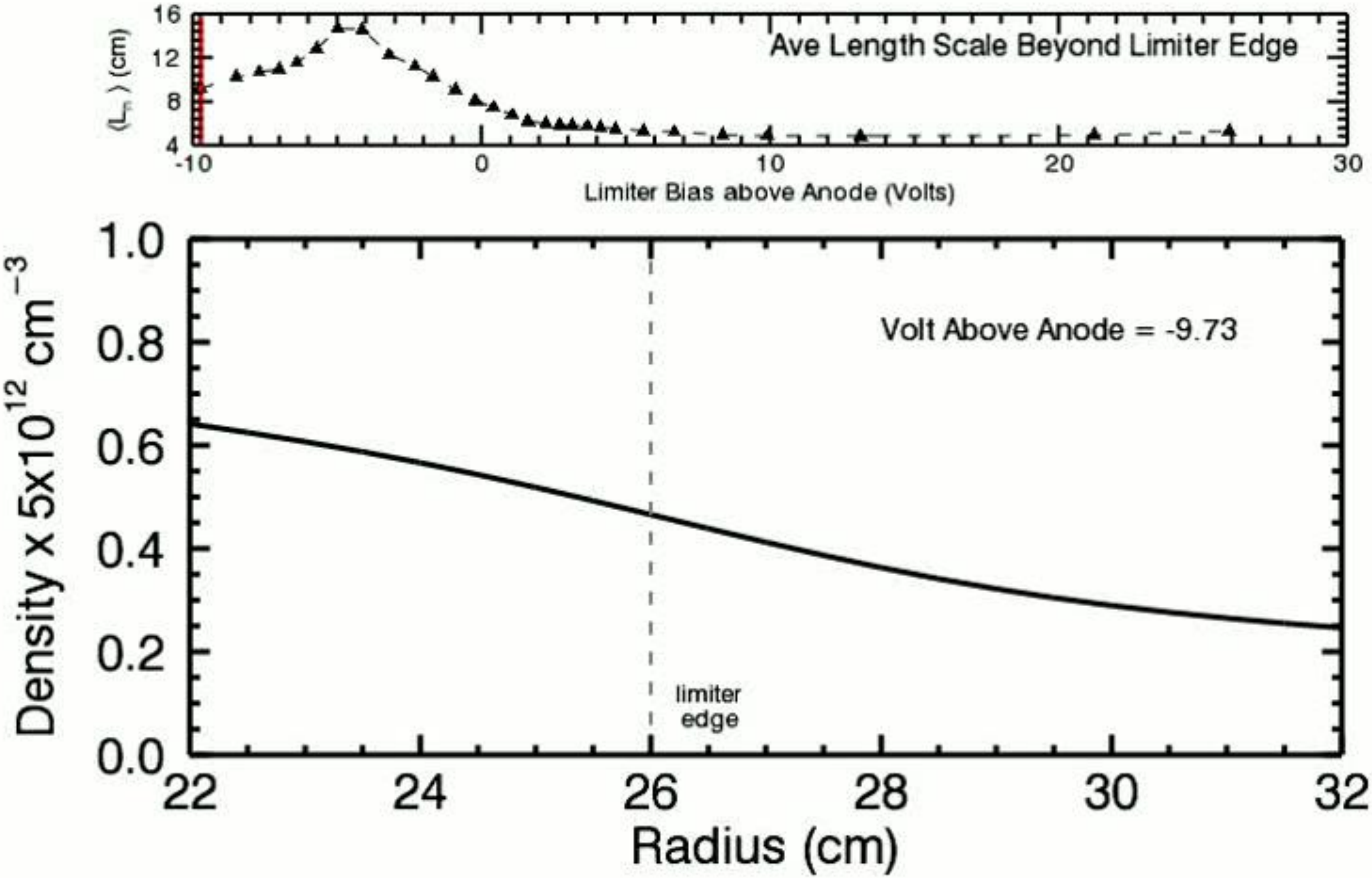


Biasing drives flow in EDD, opposing spontaneously induced flow

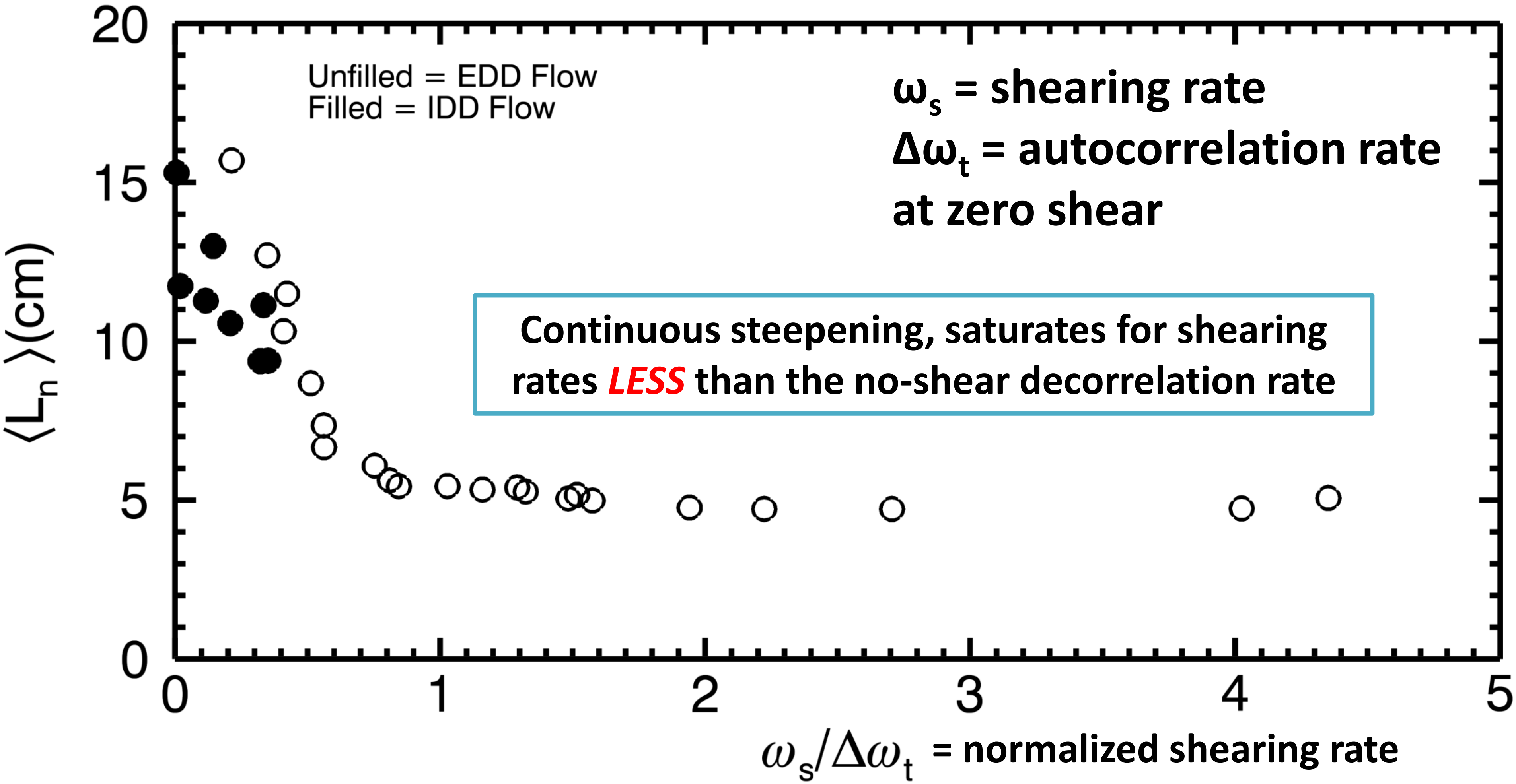
Confinement enhanced in both flow directions; degraded at low shear



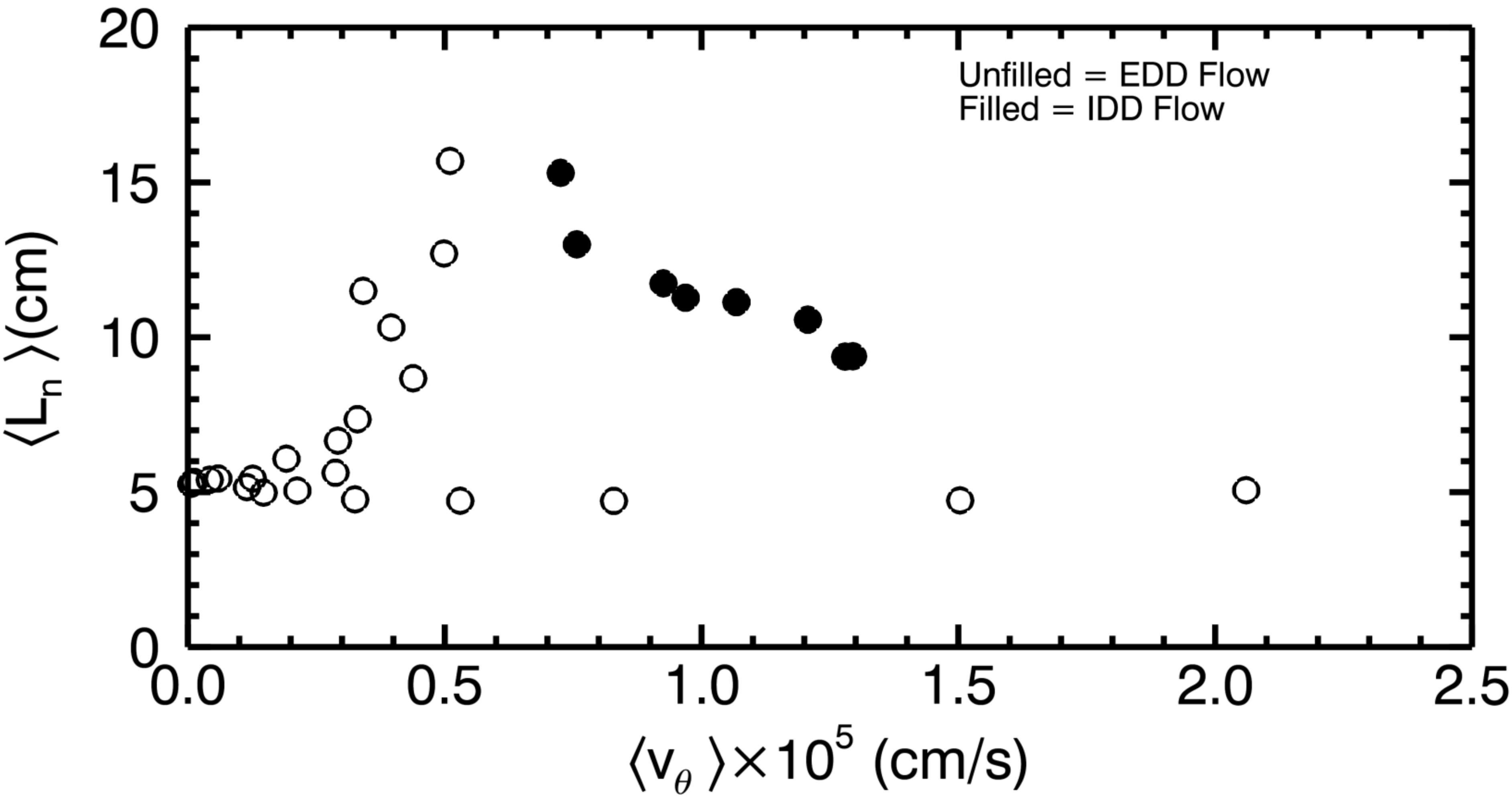
Density profile degrades, steepens with bias



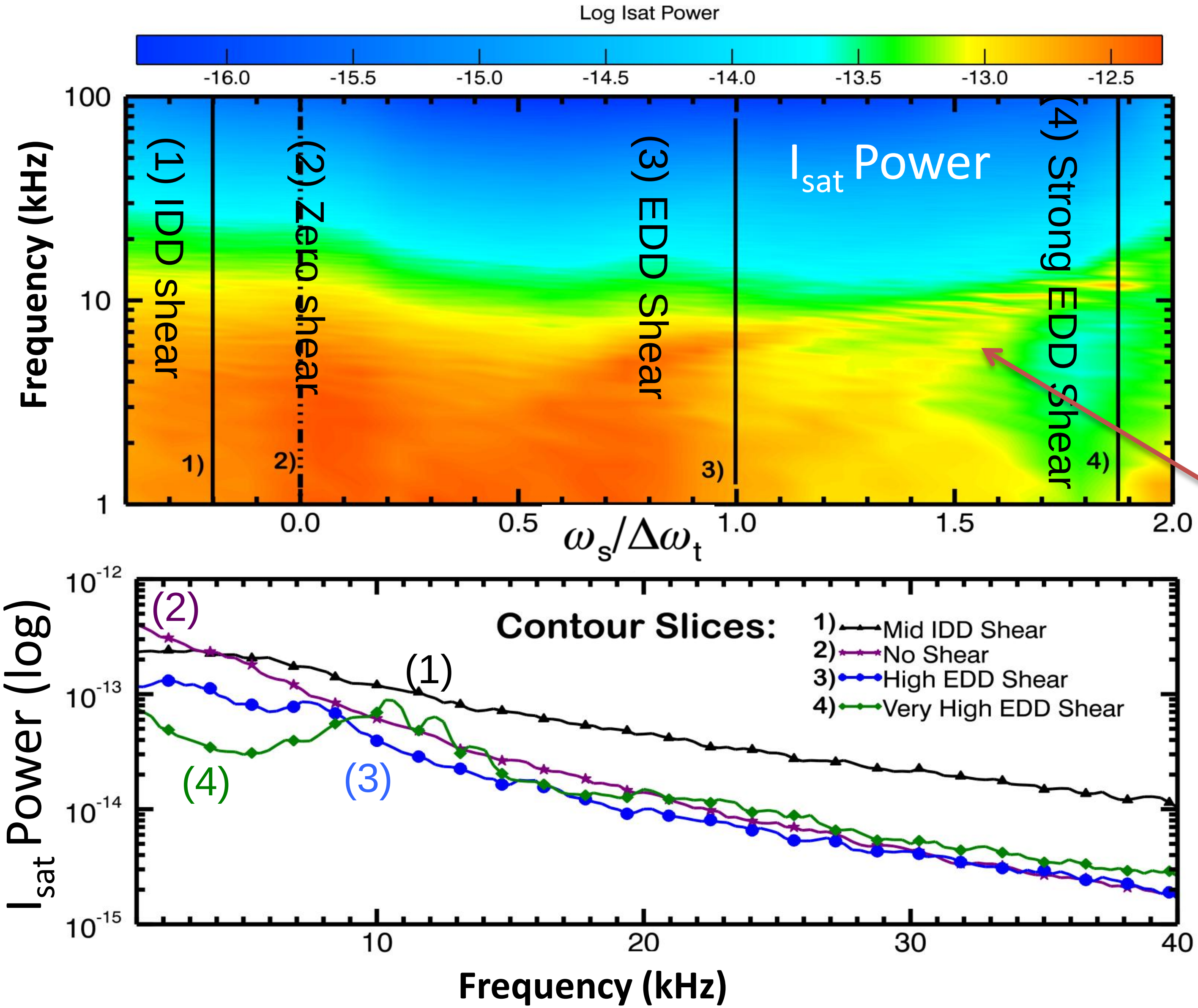
Profile steepening correlates with shearing rate



Profile steepening DOES NOT correlate with azimuthal flow



Fluctuation power is reduced with increased shearing and enhanced at low shear



Coherent mode appears at/above 10kHz at high shear

Transport measured locally through flux

Turbulent Particle Flux (Local):

E-Field Power

Crossphase

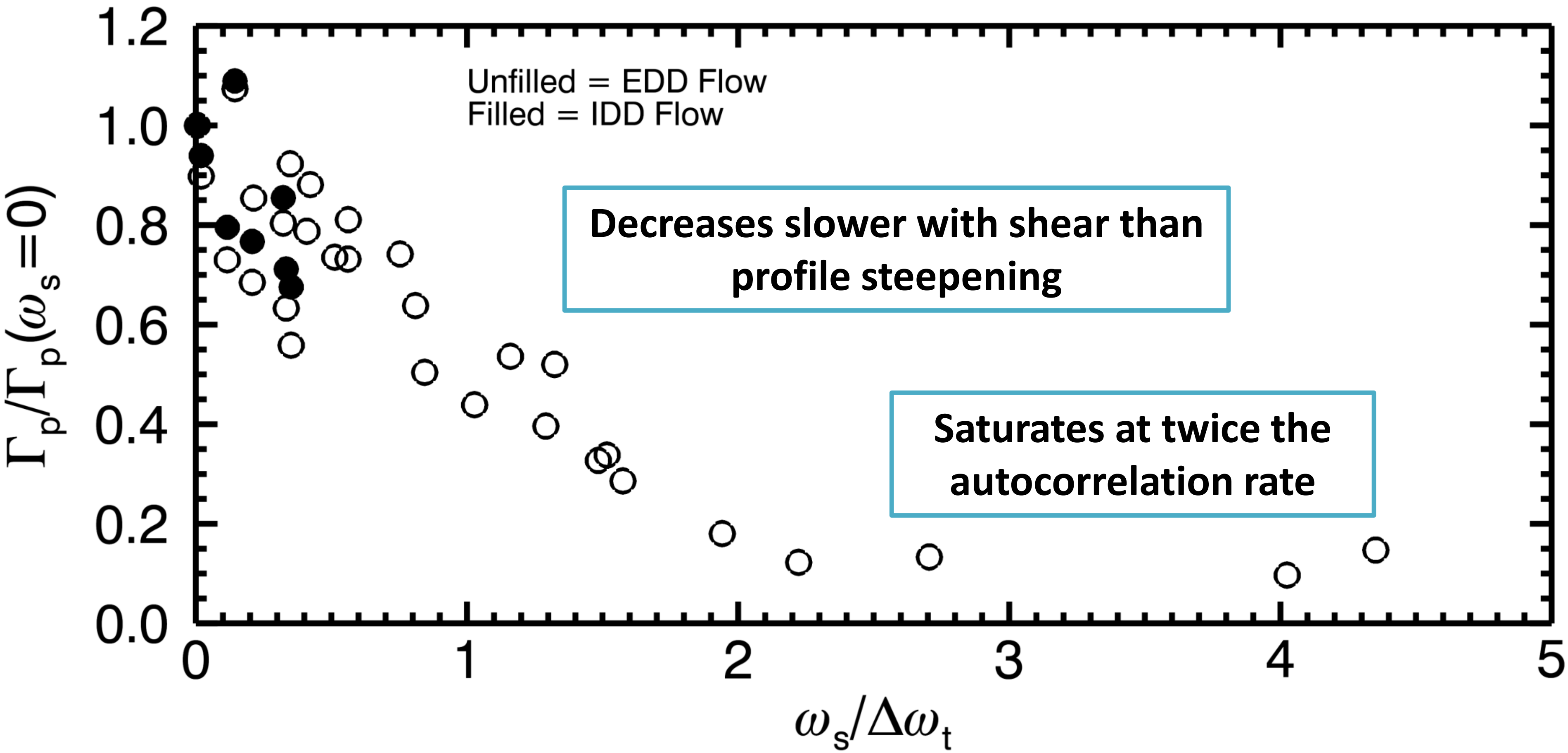
$$\Gamma_p = \langle \tilde{n}\tilde{v_r} \rangle = \frac{\langle \tilde{n}\tilde{E_\theta} \rangle}{B} = \frac{2}{B}\int_0^\infty |n(\omega)||E_\theta(\omega)|\gamma_{n,E_\theta}(\omega)\cos[\phi_{n,E_\theta}(\omega)]d\omega$$

Density Power

Coherency

Taken using simultaneous measurements of density and azimuthal electric field using Langmuir probes

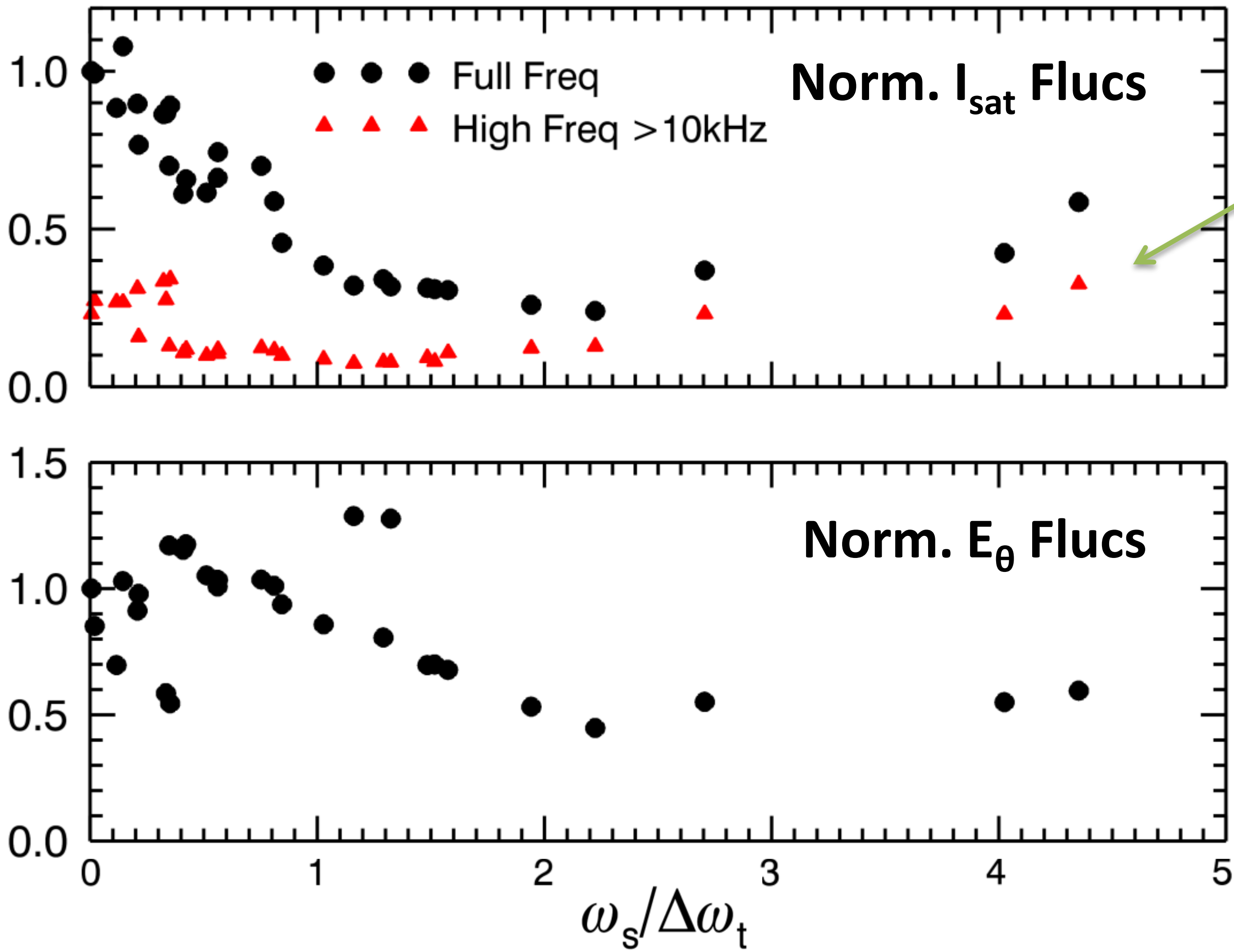
Flux decreases with shearing rate



Decreases slower with shear than profile steepening

Saturates at twice the autocorrelation rate

I_{sat} Fluctuations decrease with shear, E_θ Fluctuations much less affected

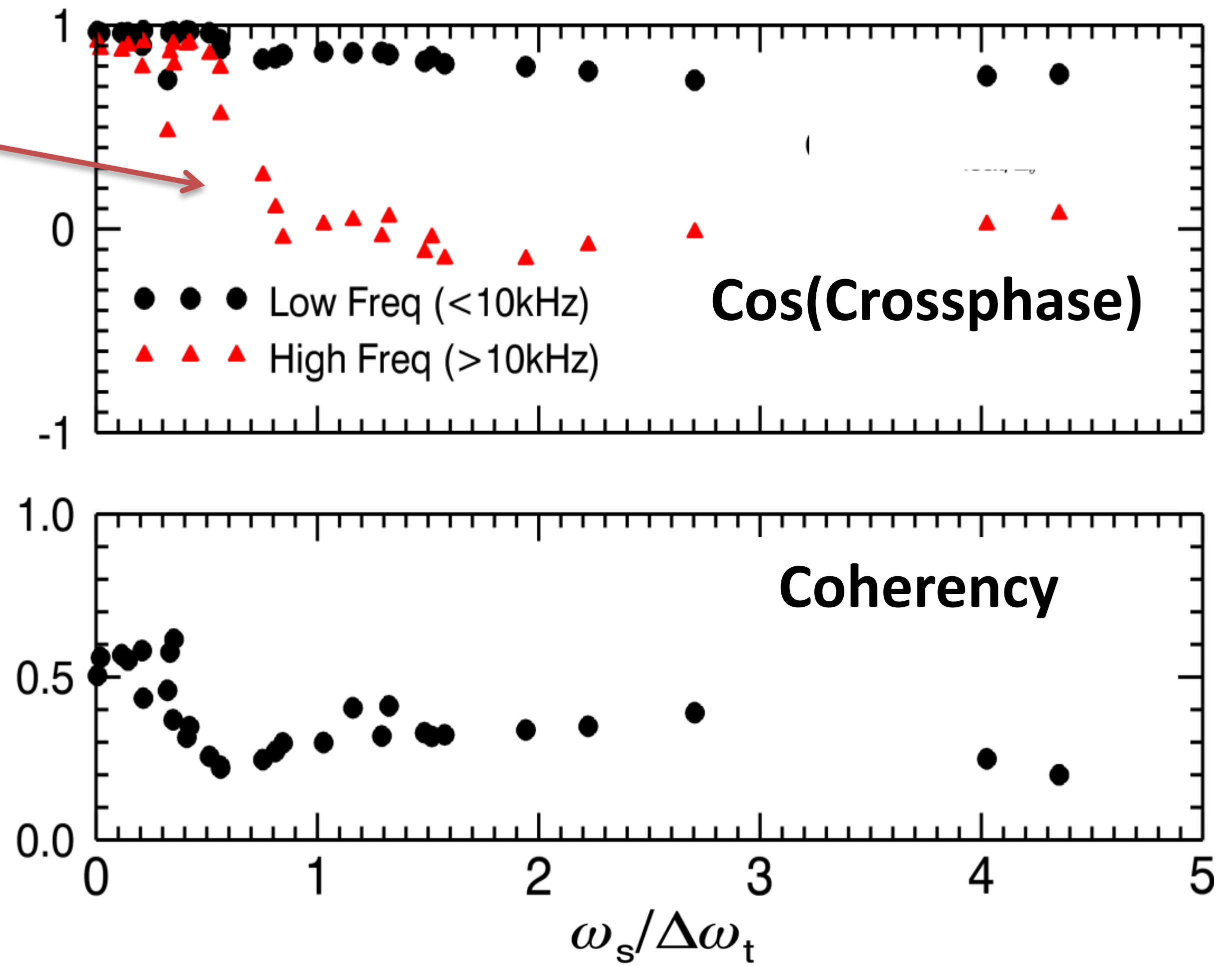


Isat fluctuation power increases in high shearing

Occurs for >10KHz where coherent mode is found

Crossphase steady in low-*f*, decreases in high-*f*

High frequency crossphase near zero when isat fluctuations from coherent mode are increased



Low frequency transport suppression ***dominated by decrease in fluctuations***

High frequency transport suppression ***dominated by decrease in crossphase***

--***even with appearance of coherent mode***

Results distinct from previous LAPD rotation results—crossphase dominated across all *f*

Predicted effects of shear on turbulence

Simplest model on effects of shearing on turbulence and transport made by Biglari, Diamond and Terry in 1990:

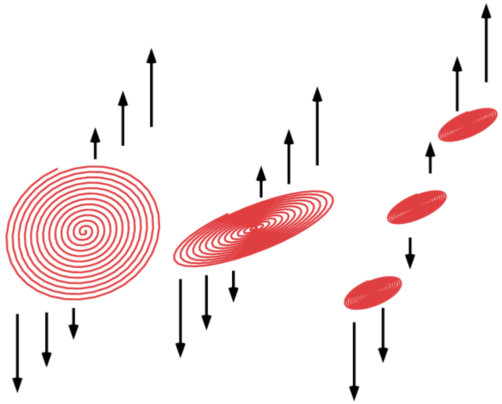
Starting with a non-mode specific fluid model, they predict radial correlation length to scale approximately as,

Shearing Rate

$$\Delta r_c \simeq \left(\frac{\omega_s}{\Delta\omega_t}\right)^{-1/3} \Delta r_t$$

No-Shear Radial Corr Ln

No-Shear Decorrelation Rate



Combining with a mixing length argument for turbulent fluctuations of a quantity such as density (assuming no shearing and constant gradient),

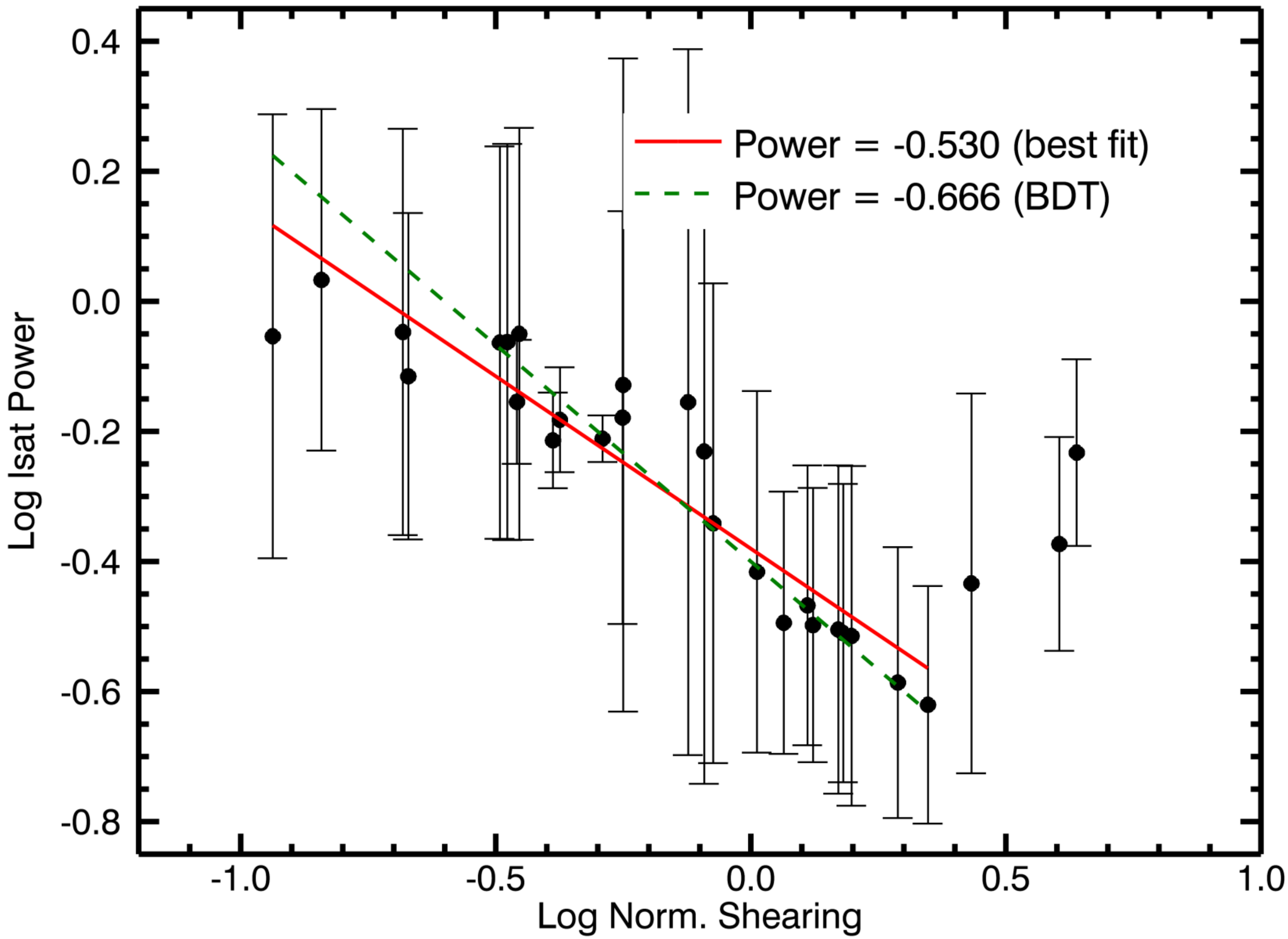
they get

$$\langle|\tilde{n}/n_0|^2\rangle_{\omega_s} / \langle|\tilde{n}/n_0|^2\rangle_{\omega_s=0} \sim (\omega_s/\Delta\omega_t)^{-2/3}$$

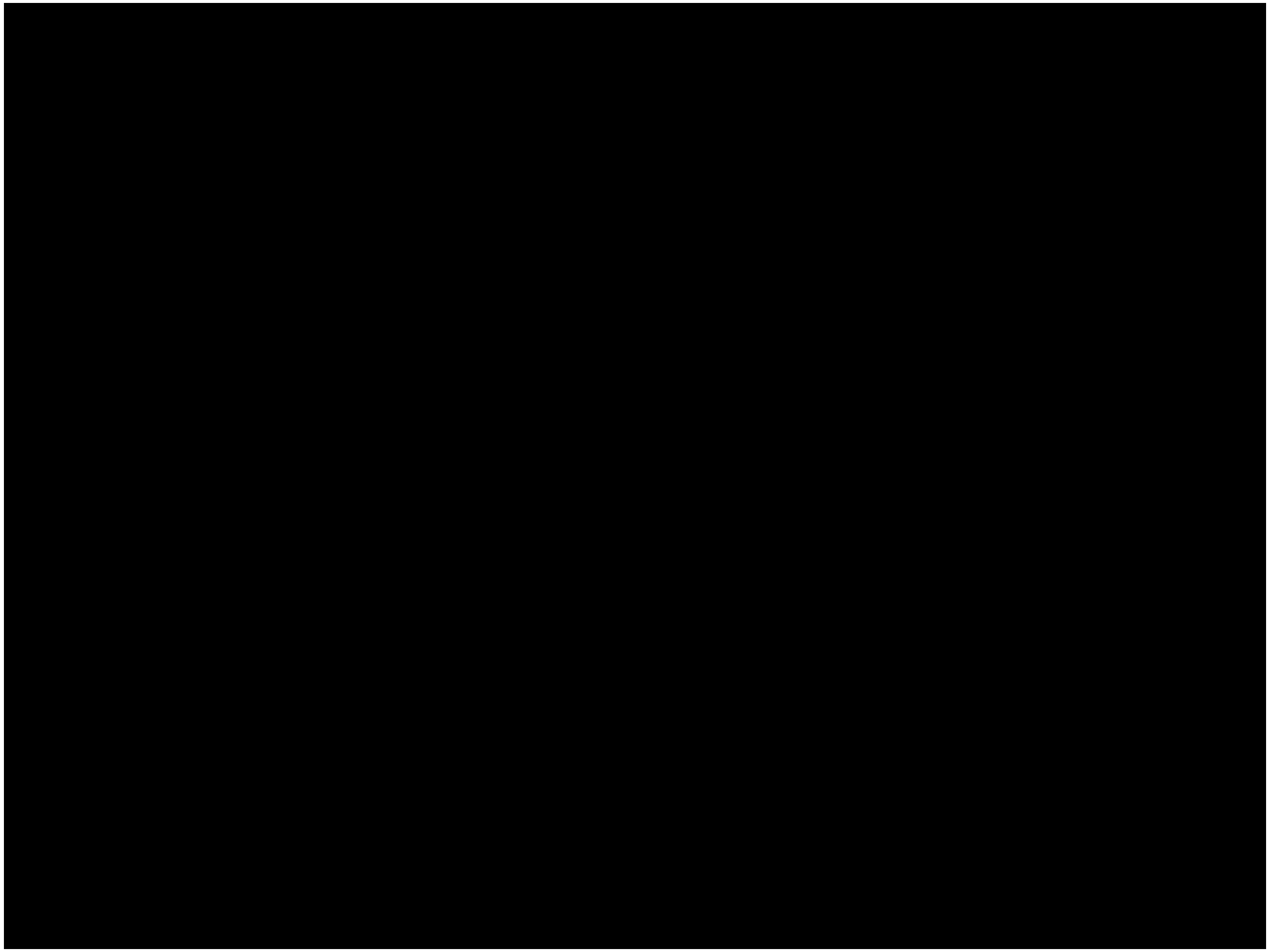
i.e. fluctuations scale with shear by a -2/3 power,

Heuristically, shear breaks up eddy size, diffusion step size

Isat fluctuations shows some correlation to BDT prediction



Change in turbulent structures: high speed visible imaging of LAPD turbulence



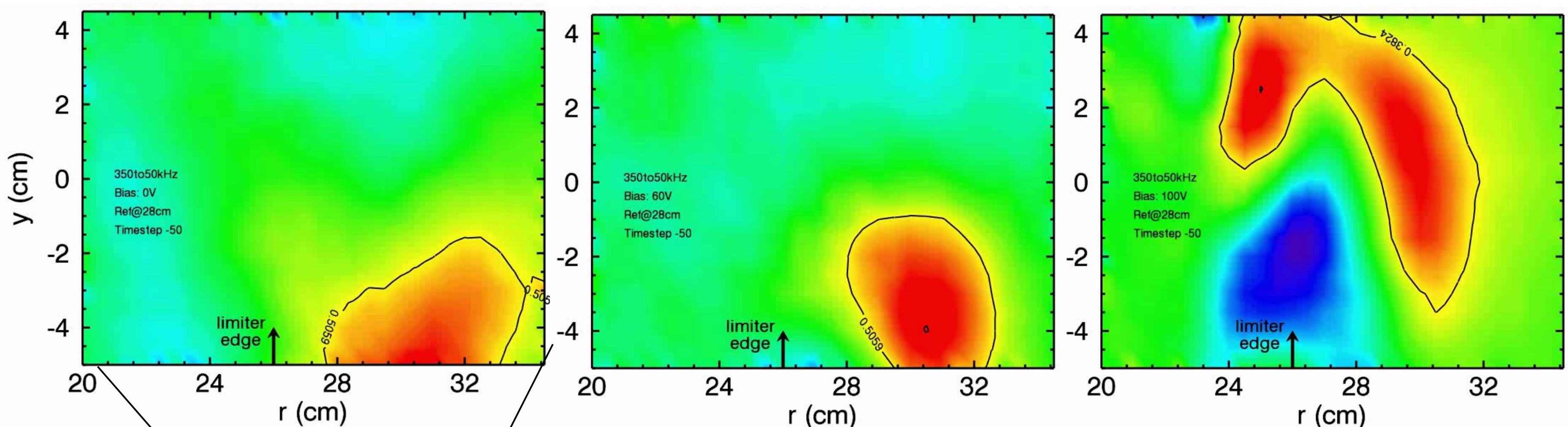
Mean Subtracted

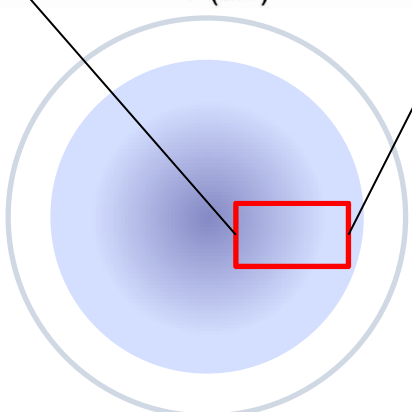
Correlation functions: radial correlation decreases, azimuthal increases with shearing

Low Bias, Low Shear, Flow in IDD

No Shear, Low Flow

High Bias, High Flow in EDD, High Shear





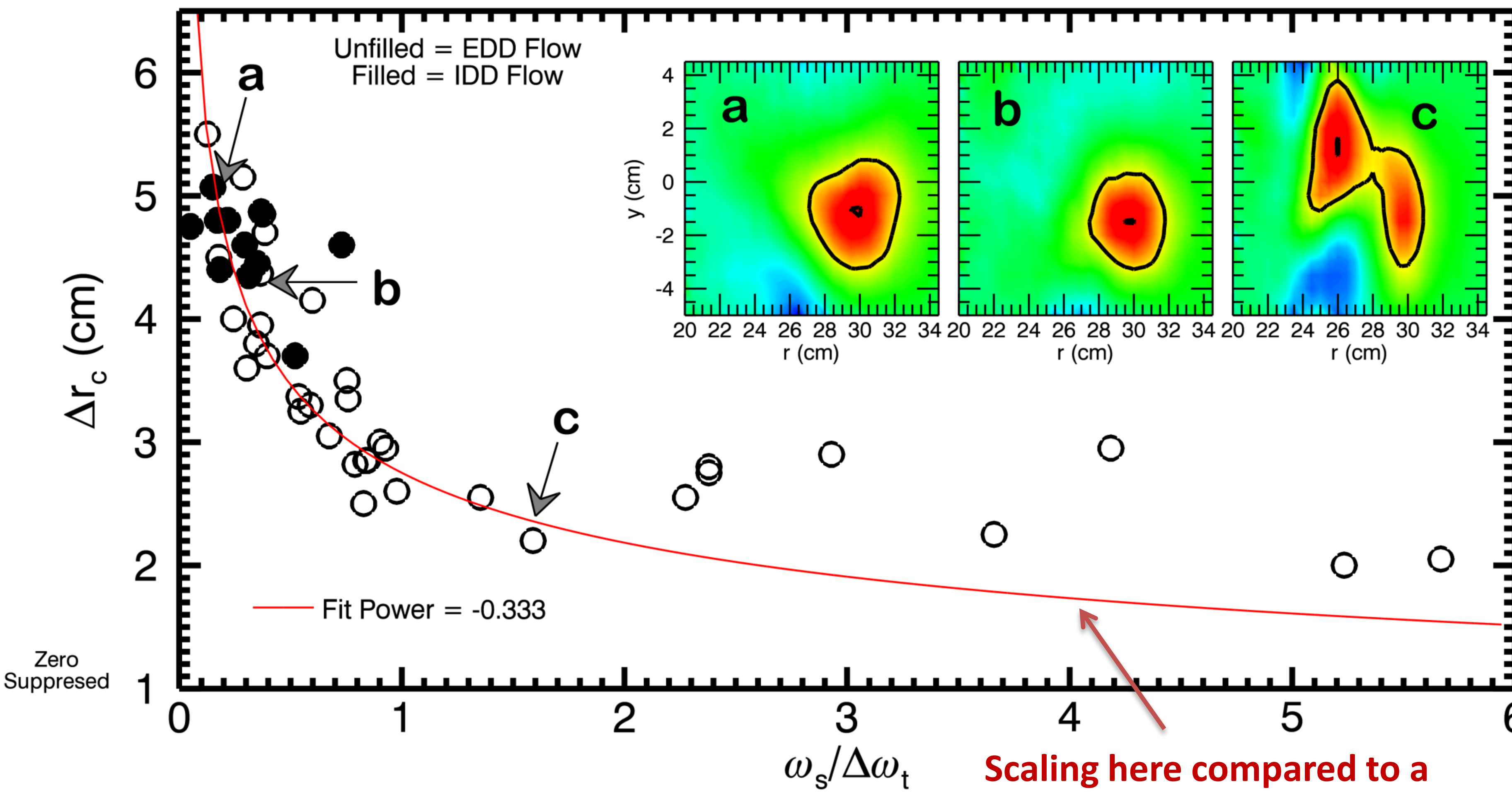
LAPD Cross-Section

Observations:

-Tilting corresponds to shear differential

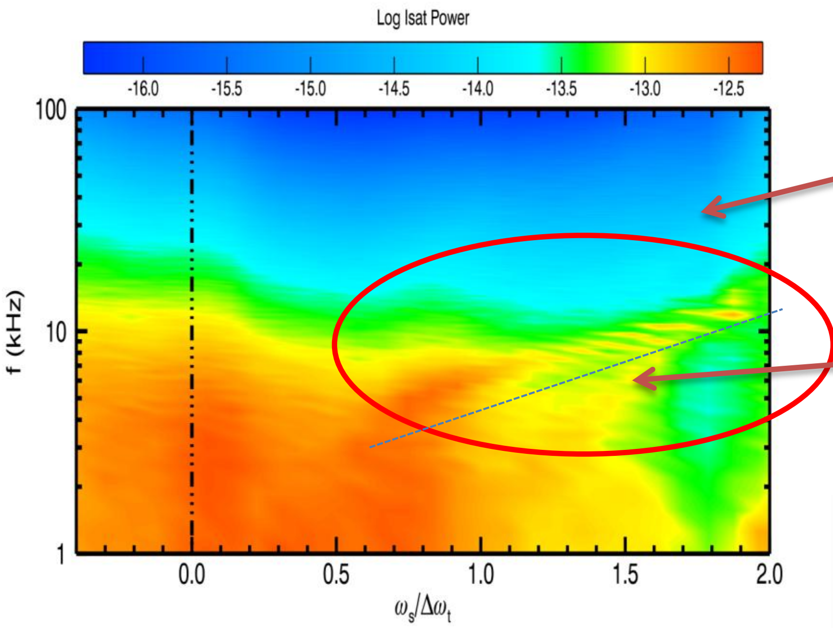
-Coherent mode pattern visible in high shear

Radial correlation length decreases with shear



Scaling here compared to a –(1/3) power law as predicted by the BDT model

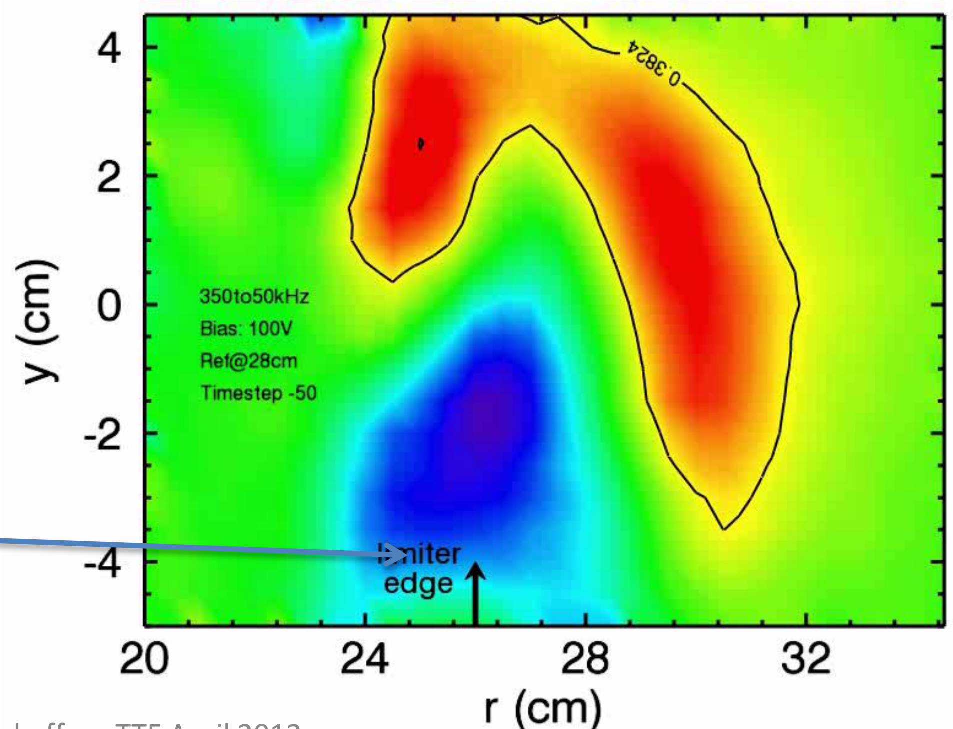
A coherent mode emerges with high flow



Coherent mode emerges at about 8kHz, just as shearing rate = decorrealtion rate

Mode increases in frequency linearly with shearing rate, exhibits banding at highest shears

Mode sits on limiter edge, where flow peaks → suggestive of rotational interchange mode



Future Work

- Explore differences between current rotation results and previous results:
  – Does crossphase suppression of flux change with B-field?
  – What causes the spectral separation in suppression physics (crossphase vs. fluctuation reduction)?
  – Do limiter boundary conditions play a role?
- Repeat detailed transport modeling. Model density profiles to make comparisons to classical, Bohm transport
- Study changes to wavenumber spectrum
- Determine origin and effects (if any) of coherent mode observed in high flow/high shear states
- Fluid simulations in BOUT++ (see B. Friedman’s talk, Thursday)

Summary

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