Characteristics of Edge Turbulence in HSX

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Abstract

Langmuir probes have been used to measure electrostatic fluctuations in the edge plasma of the University of Wisconsin-Madison Helically Symmetric eXperiment (HSX) stellarator. The measured floating potential and transport profiles display a complex dependence on line averaged density. At densities below ~1.7×10^{12} cm^{-3}, transport is measured to be inward at the edge. Above this density, the measured transport is outward, with the direction change experimentally explained by the direction change in measured phase velocity. Floating potential profiles indicate a change in radial electric field from positive to negative above this density threshold. Data has also been acquired with a probe that has access to the high field side of the plasma edge in a region of good curvature. Initial measurements with this probe (below the threshold density stated above) .

Outline of this Poster

- Description of probes and measurement locations
- HSX plasma operation

- Density dependence of measured profiles and transport
- Comparison of low field side and high field side data

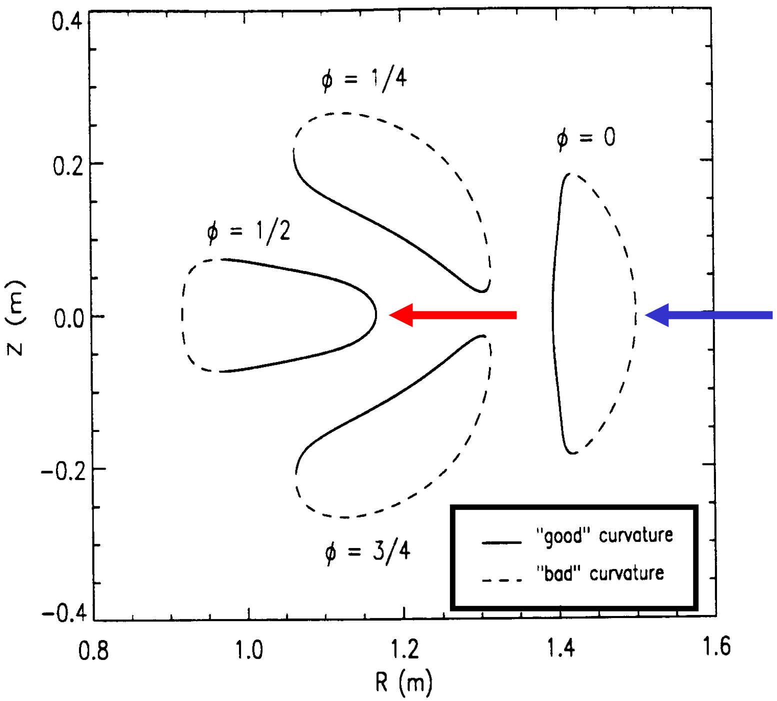
- Conclusions

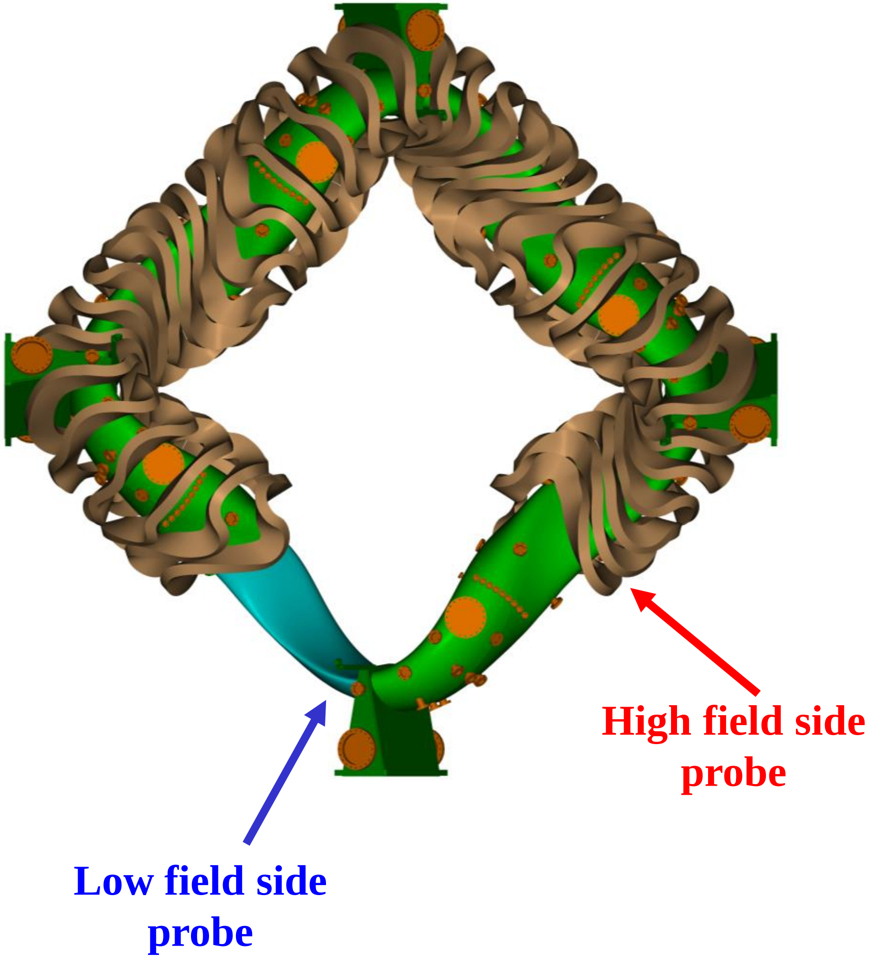
HSX Uniquely Allows Probe Access to Regions of Good and Bad Curvature

- Fluctuation probes located:

  (1) on the low field side (LFS) near a box port,

  (2) on the high field side (HFS) near a joint flange.

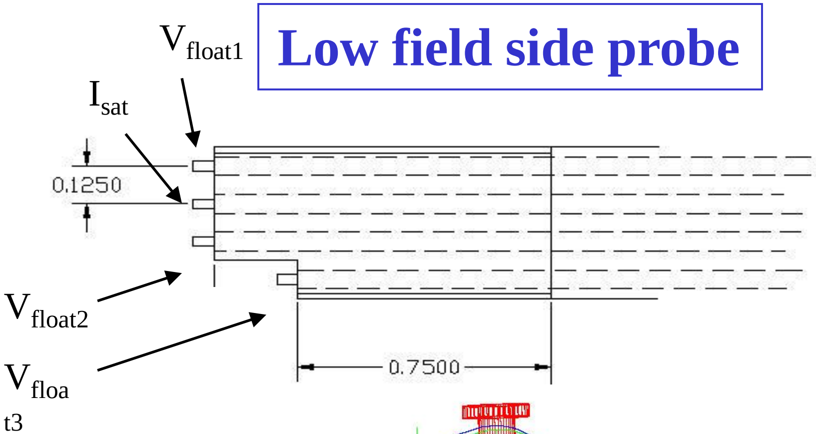


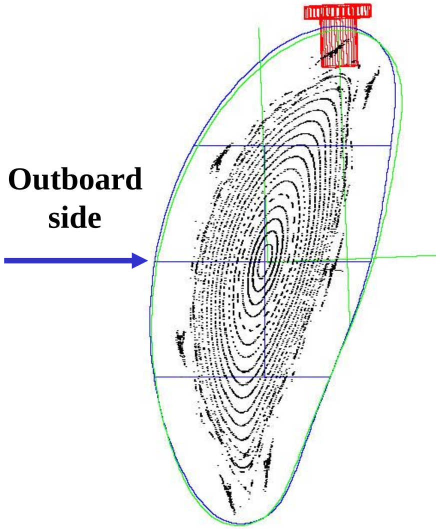


Probes Used

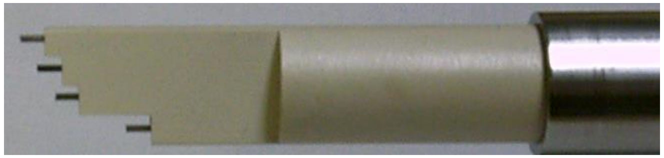
- Four tungsten probe tips (3.2 mm × 0.74 mm) separated poloidally by 3.2 mm
- Fourth tip recessed radially 6.4 mm.
- Three of four probe tips are roughly aligned on a vacuum flux surface.

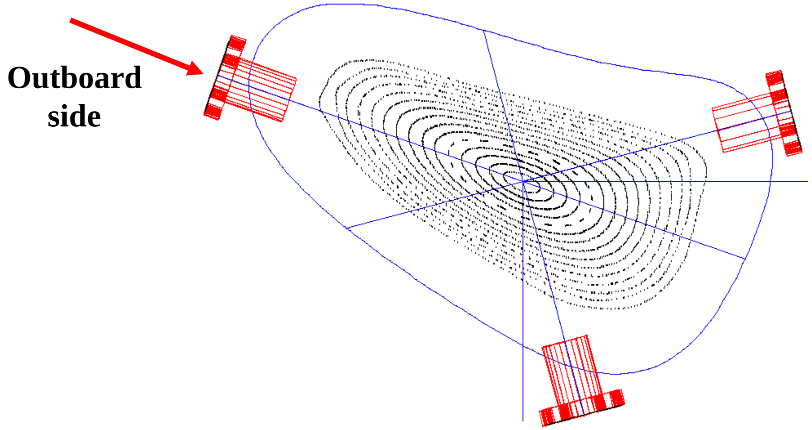
Low field side probe





High field side probe





Estimation of Particle Transport

- Particle flux from electrostatic fluctuations is estimated via

$$\Gamma(t) = \langle n`(t) V_r`(t) \rangle = \langle n`(t) E_\theta`(t) \rangle / B_\phi$$

where $E_\theta = -\nabla V_{float} = (V_{f2} - V_{f1})/d$

$n = I_{sat}/(0.6 e A_{probe} c_s)$

- Alternatively (Powers, Nucl. Fusion 14 (1974) 749)…

$$\Gamma(f) = \mathrm{Re}\{N^*(f) E_\theta(f)\}/B = |P_{nE\theta}(f)| \cos[\alpha_{nE\theta}(f)]/B$$

- -or-

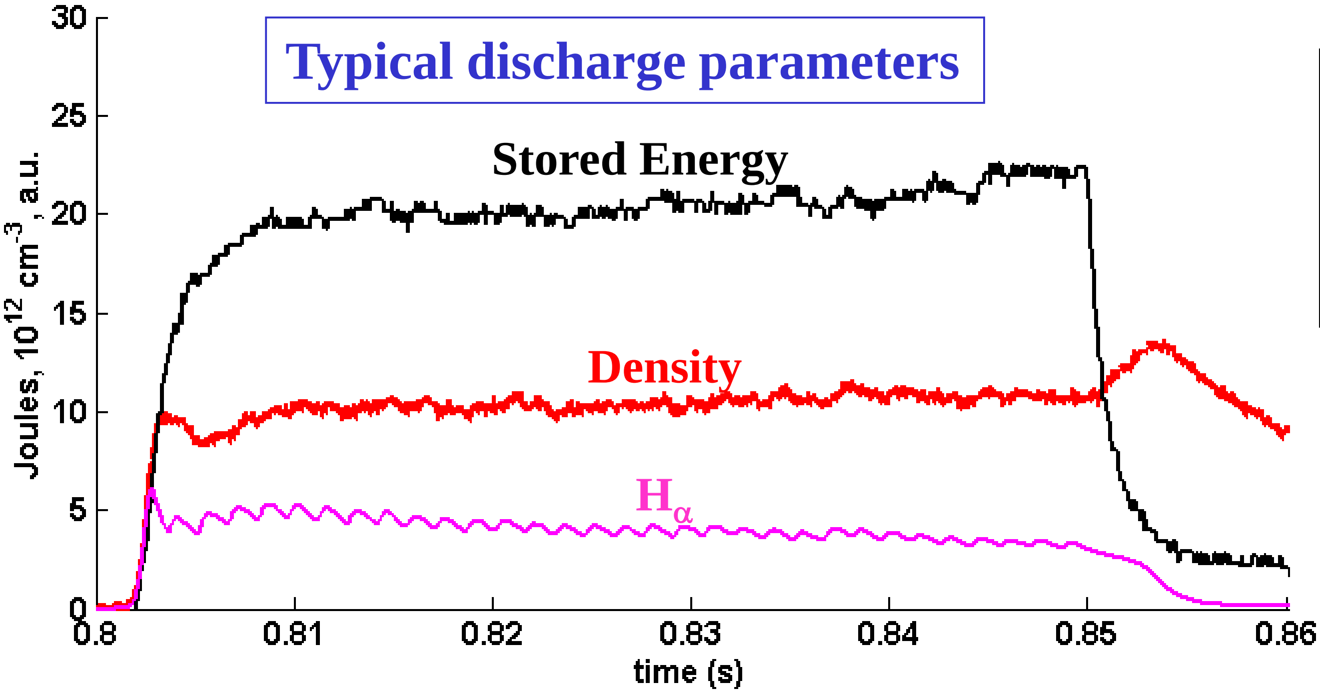
$$\Gamma(f) = k_\theta(f)\, \gamma_{n\phi}(f) |N(f)||\Phi(f)| \sin(\alpha_{n\phi}(f)) / B$$

- T_e fluctuations have been neglected.

HSX Plasma

- HSX |B| spectrum is quasi-helically symmetric (n=4, m=1), resulting in a predicted reduction of neoclassical transport.
- Anomalous transport is expected to dominate.
- A n=4, m=0 mirror field can be added to break the symmetry.

- Typical line averaged density between $3 \times 10^{11} - 2.5 \times 10^{12}$ cm^{-3}.
- Stored energies ~20 J for QHS and Mirror configurations (50 kW of 28 GHz ECH).



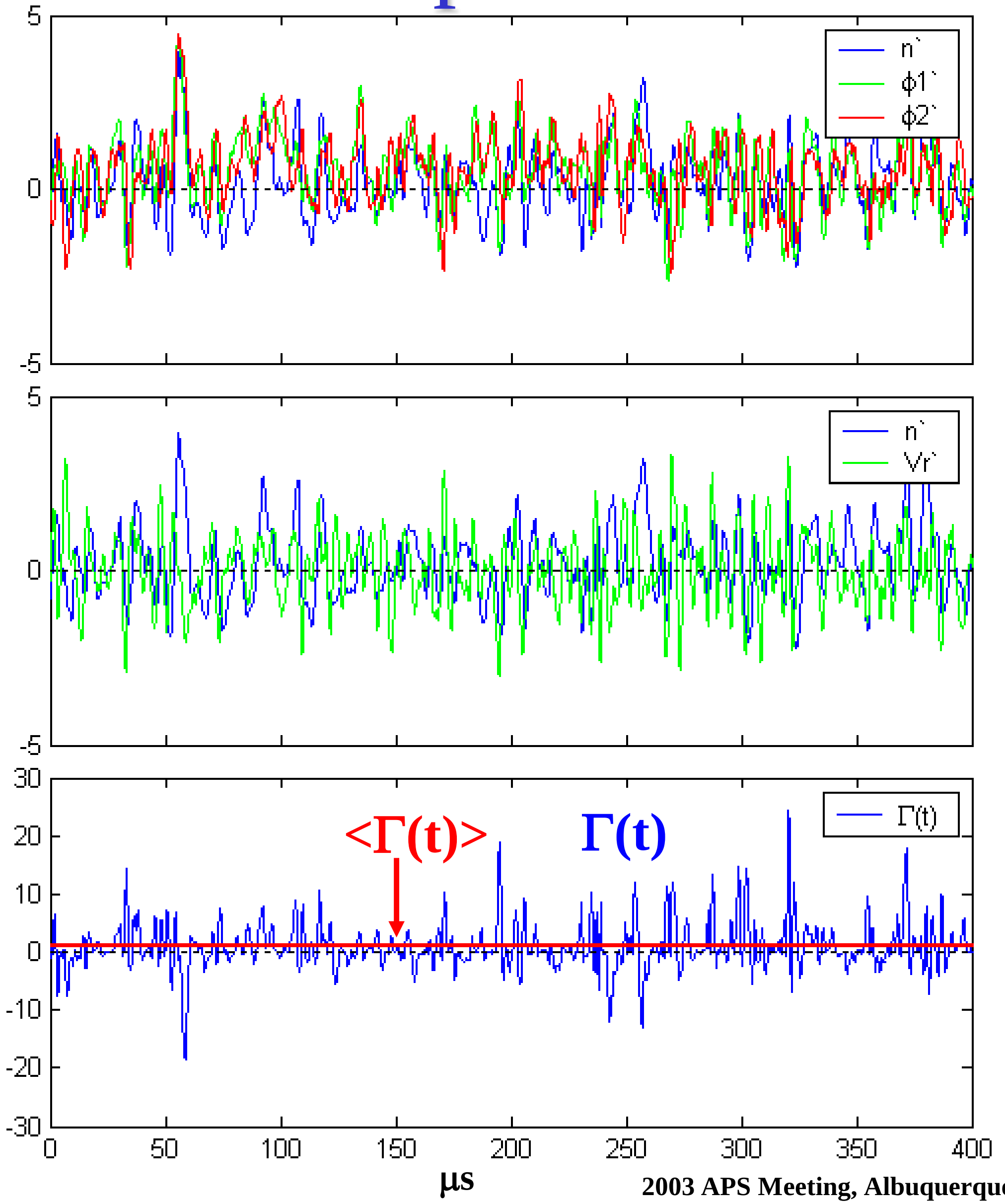
Edge parameters

T_e ~ 40 eV

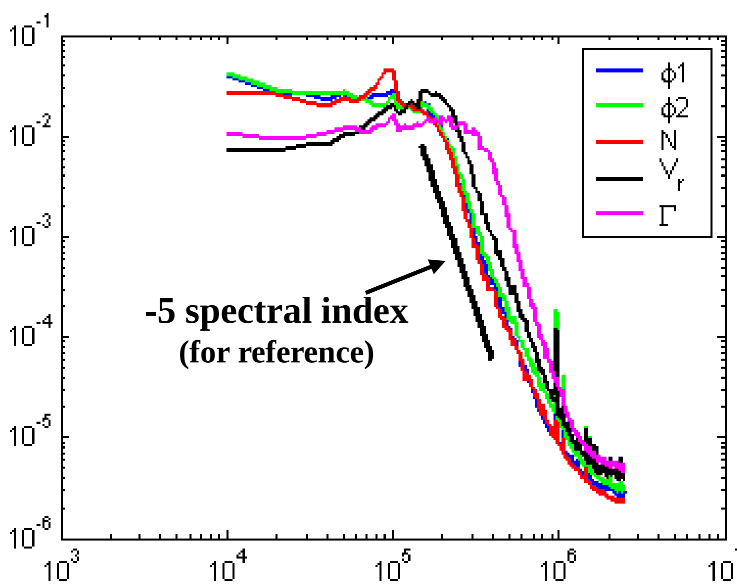
B ~ 0.45 T

ρ_s ~ 1.5 mm

Raw Probe Data Displays Large Fluctuation Amplitudes and Fast Time Scales

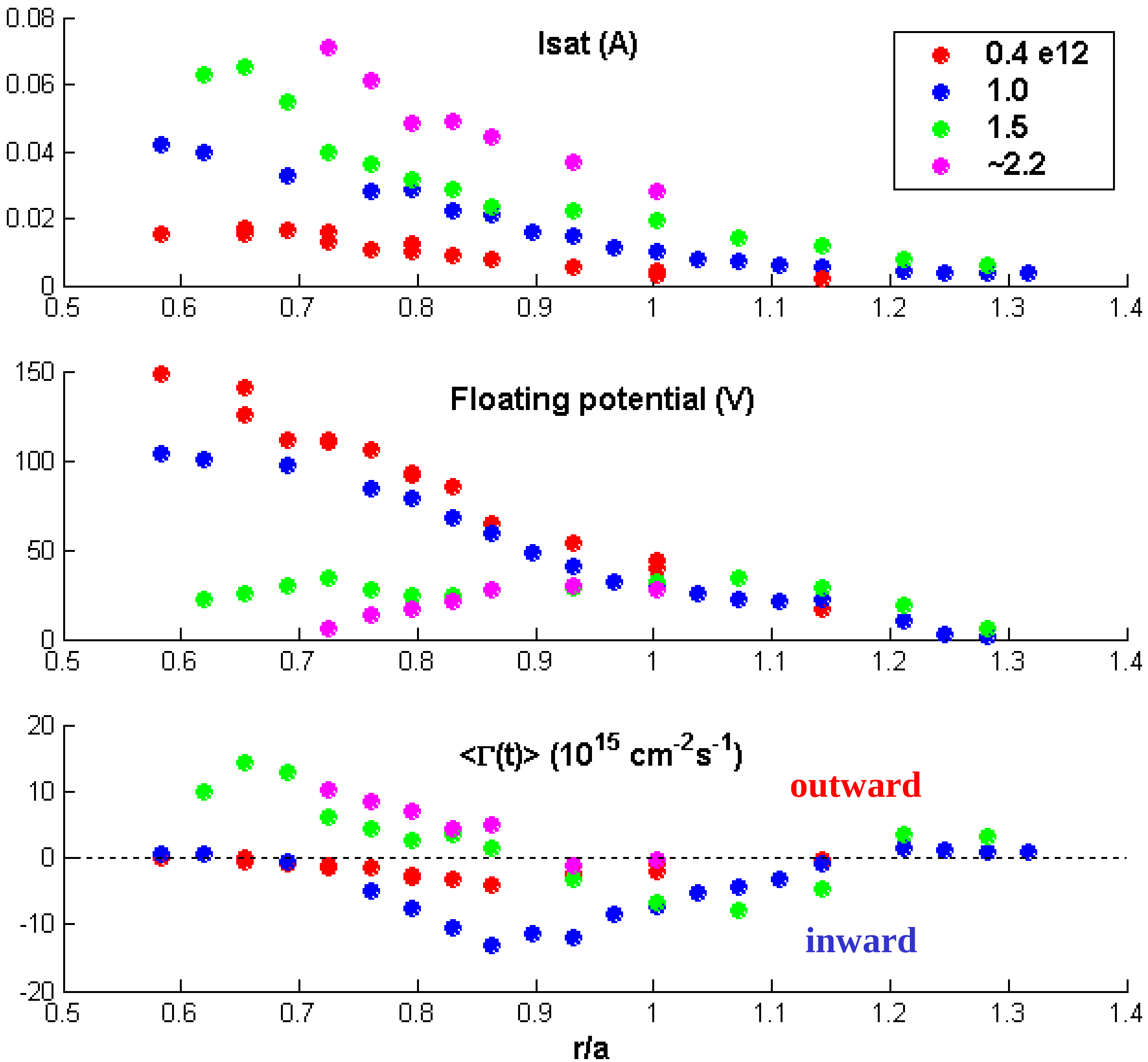


- Time series similar to other magnetic toroidal experiments
- Electrostatic transport bursty in nature
- Power spectra indicate broad frequencies.



Mean Φ_{float} & Γ Profiles Display Complex Dependence on Density

- I_{sat} profiles roughly overlap when normalize by density.
- Floating potential profiles indicate E_r transitions from positive to negative at some density.
- Measured particle transport is inward at lower densities.



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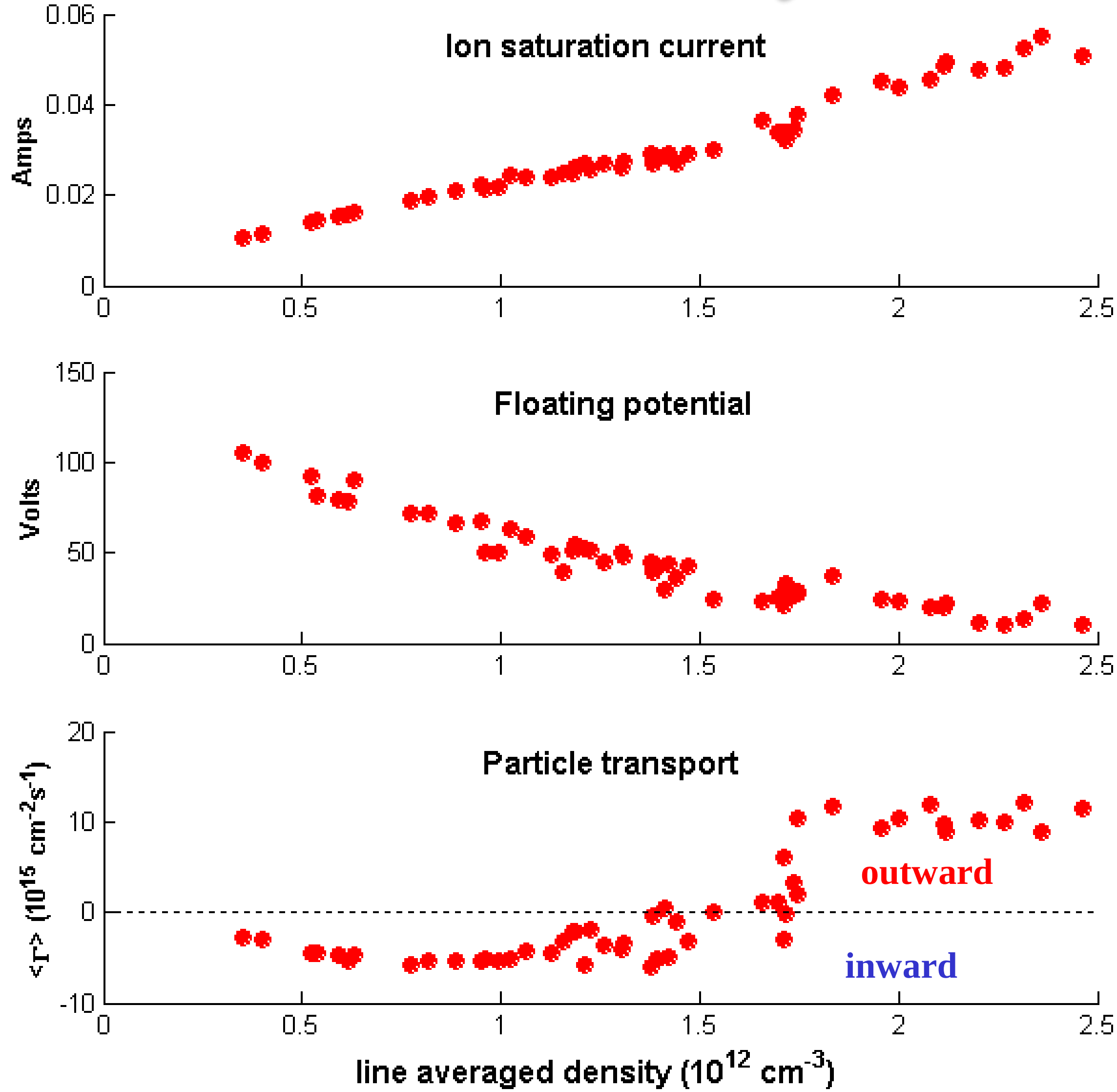
Mean Φ_{float} & Γ Display Complex Dependence on Density

- Density scan performed with probe located at r/a ~ 0.8

- Floating potential continuously drops $\rightarrow$ reduction in E_r.

- Measured particle transport is inward at line averaged densities below ~1.7 $\times$ 10^{12} cm^{-3}.



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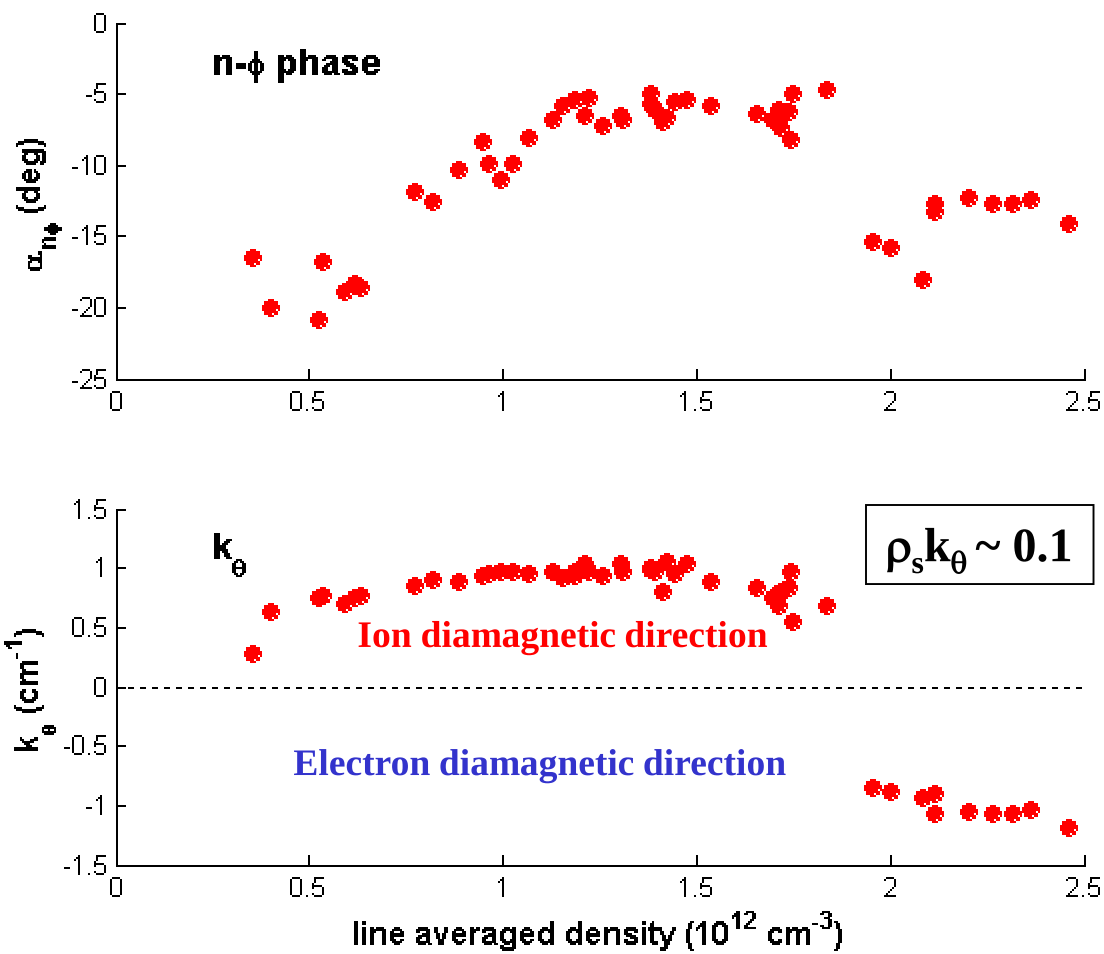
Change in Transport Direction Corresponds With Phase Velocity (k_θ)

- Power weighted n-ϕ phase remains negative.
- Power weighted poloidal wavenumber changes direction, indicating change in phase velocity direction.
- $\alpha_{n\phi}$ sign remains same

  k_θ changes sign

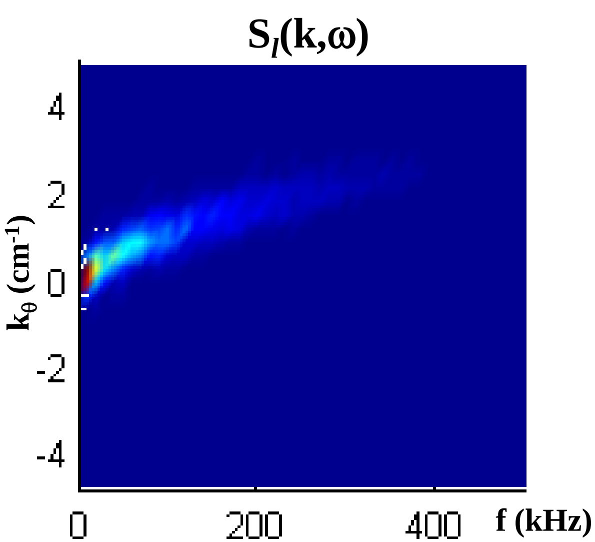
$\Rightarrow$ **$\Gamma \sim k_\theta \sin(\alpha_{n\phi})$ changes sign**

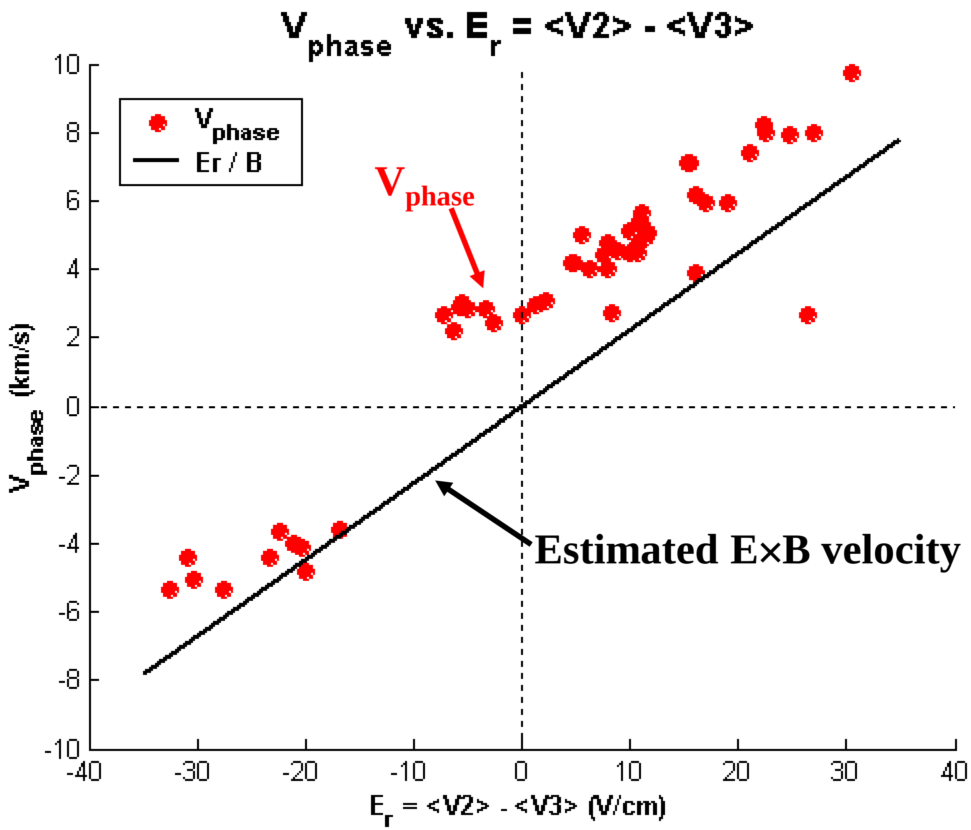


Phase Velocity is Correlated with the Local E_r Measured by Φ_{float}

- Two tips measuring floating potential radially separated 6 mm to estimate E_r (no T_e dependence included).
- Poloidal phase velocity calculated using two probe method (Levinson et al., Nucl. Fusion 24 (1984) 527).

$$V_{phase} = \sum_{\omega,k_\theta} (\omega/k_\theta) S_l(k_\theta,\omega)$$





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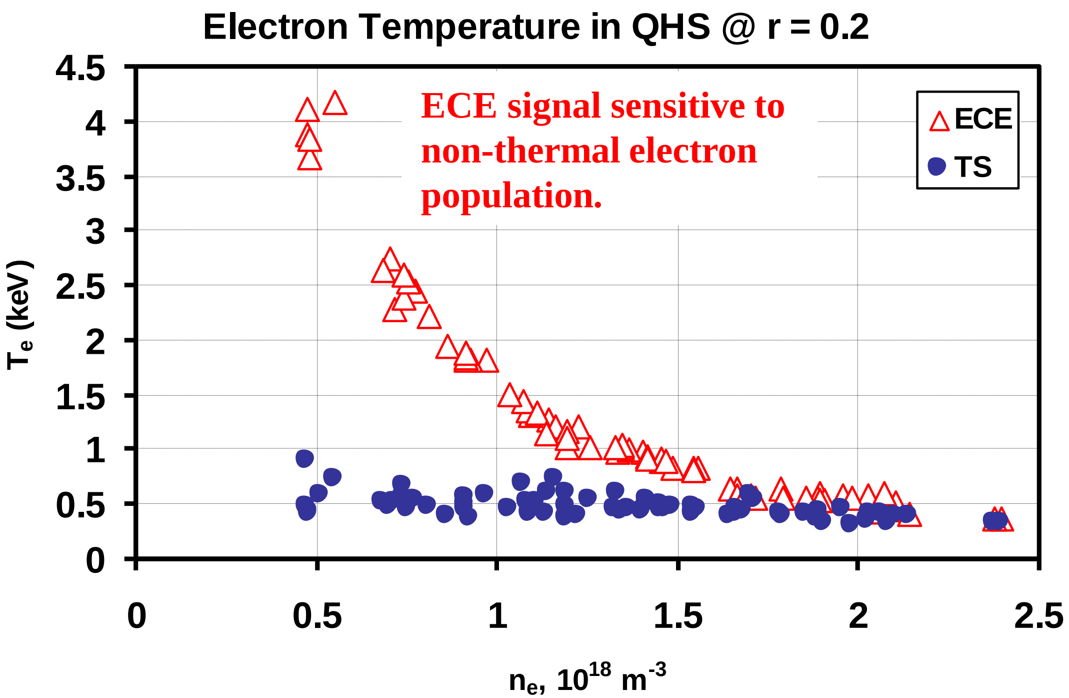
Evidence for a Non-thermal Electron Population

- Comparison of ECE and TS data suggests the existence of non-thermal electrons at lower density plasmas.
- Discrepancy disappears near line averaged densities of ~1.7 - 2.0 × 10^{12} cm^{-3}.

- See K. Likin's poster for more information on ECE, and K. Zhai for Thomson Scattering.



How Does the Existence of Non-thermal Electrons Complicate the Interpretation of Langmuir Probe Data?

- Why the change in fluctuation induced electrostatic transport direction?

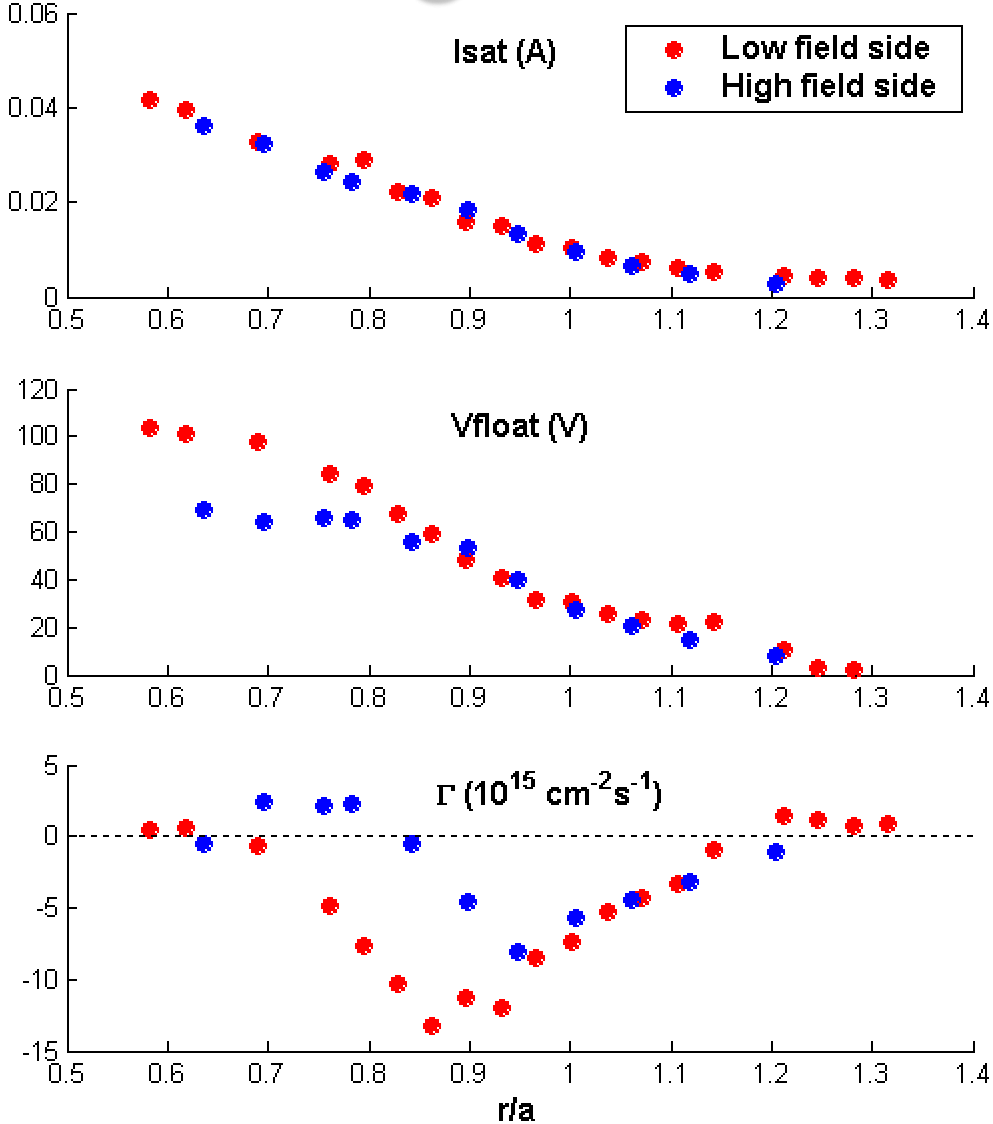
- Does the population of super-thermal electrons complicate probe interpretation via:
  - Non-saturated I_{sat} measurement
  - Secondary electron emission contaminating the floating potential measurement
  - Phase relation of I_{sat} and V_{float} (e.g., T_e fluctuations)

- Or do the super-thermals affect the equilibrium $E_r \rightarrow V_{ph}/k_\theta \rightarrow \Gamma$

- These are currently unanswered questions.

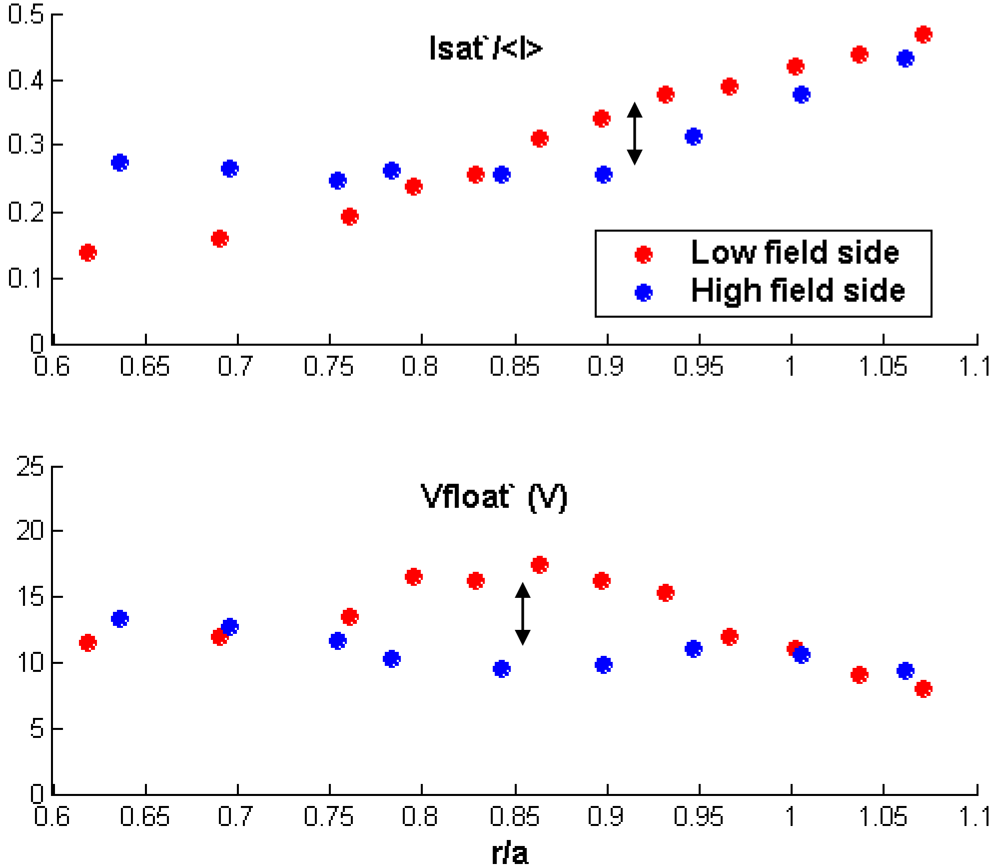
HSX

A Comparison of Low Field Side and High Field Side Probe Data



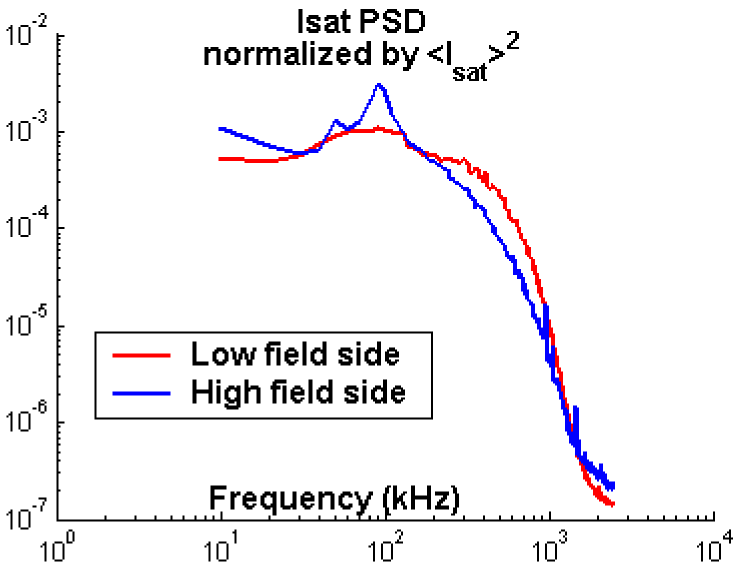
- This data is at a "lower" density - 1.0×10^{12} cm^{-3}.
- I_{sat} profiles overlap in r/a coordinates (determined by flux surface mapping and experimentally choosing a separatrix).
- Floating potentials agree outside r/a ~ 0.8.
- Because of expanded flux surfaces, the high field side probe is more perturbative for r/a < 0.8.
- Transport is similar, but smaller in magnitude at high field side.

Fluctuation Amplitudes Differ Between LFS & HFS probes at the Edge

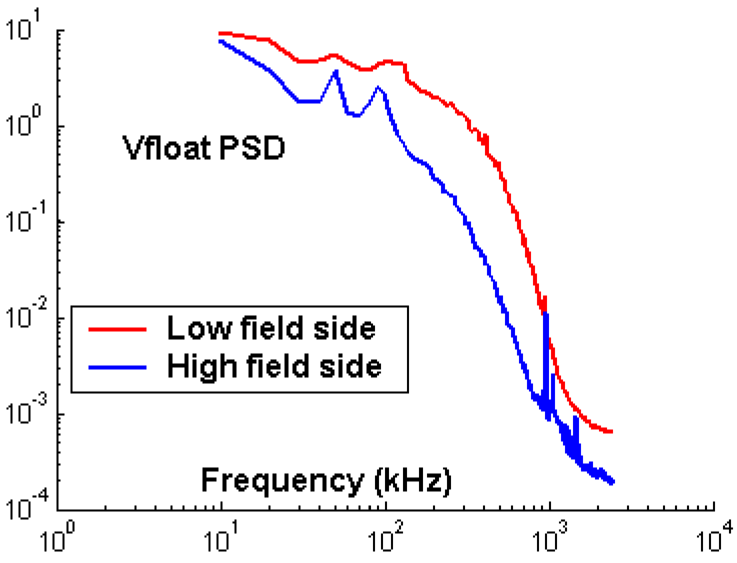


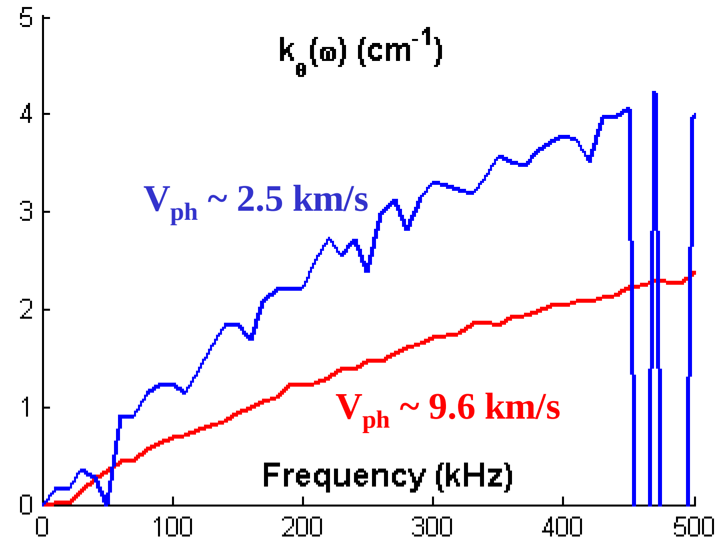
- In the edge region (0.85 < r/a < 1.0), fluctuation amplitudes differ between LFS and HFS data.
- I_{sat}`/<$I_{sat}$> reduced about 25% on HFS, $V_f$` reduced a factor of ~2.
- HSX has a low % hill outside r/a ~ 0.8.
- Within r/a = 0.8, I_{sat}`/<I_{sat}> deviates substantially – HFS probe perturbation?

At r/a ~ 0.85,

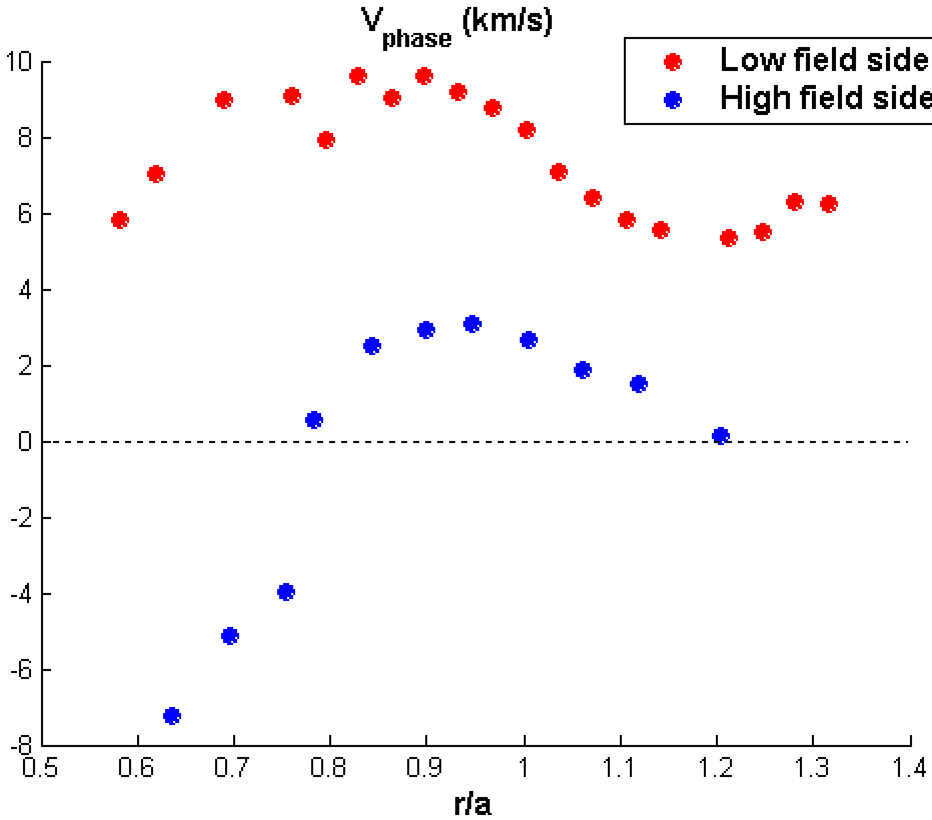


- Fluctuations are distributed over lower frequencies on the high field side – less Doppler shift due to reduced E_r (expanded flux surfaces) and therefore smaller E×B drift.
- This is evident in V_{ph} & k_θ.
- Two peaks apparent on the HFS measurements, f ~ 45 & 90 kHz.





Phase Velocities on High Field Side are Reduced



- Because of expanded flux surfaces on the high field side, $E_r = dV/dr$ is smaller $\rightarrow V_{phase}$ is smaller.

Conclusions

Continuing Work

- Further characterize the more thermal plasmas at densities $\geq 2 \times 10^{12}$ cm^{-3}.
- Investigate the effects of biased electrode discharges on turbulent fluctuations and ES particle transport.
- With the flexibility of the auxiliary coil set, measure the effect of magnetic well depth on electrostatic fluctuation amplitudes and transport.

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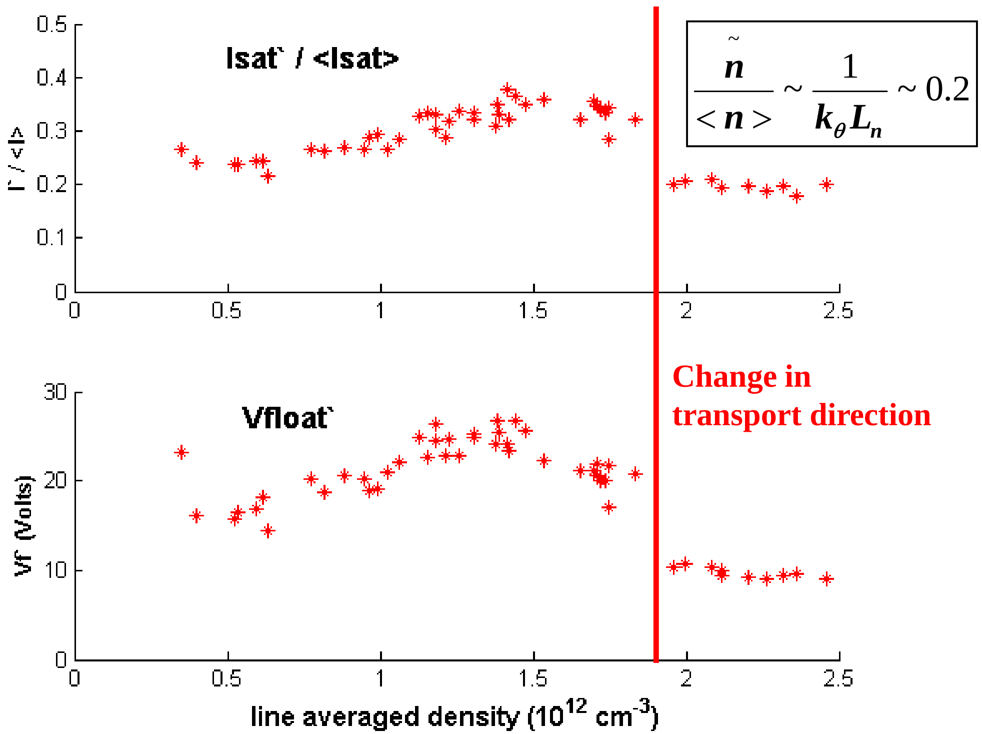
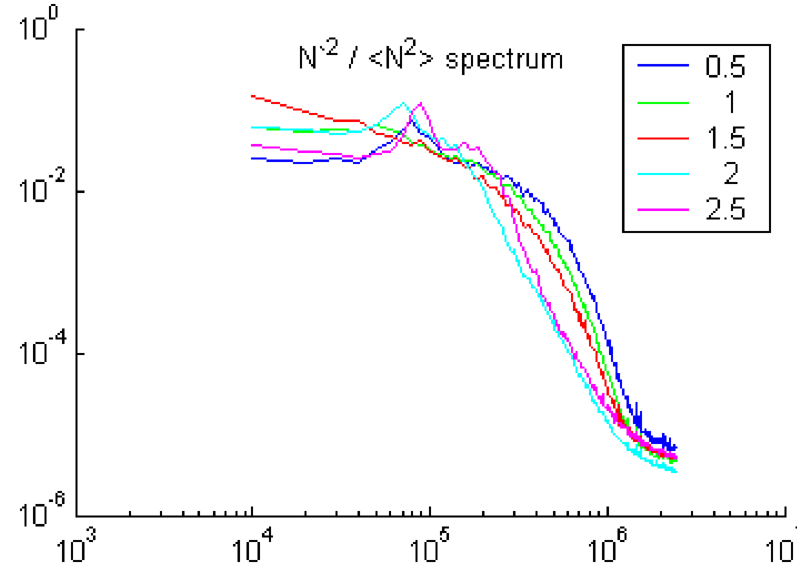
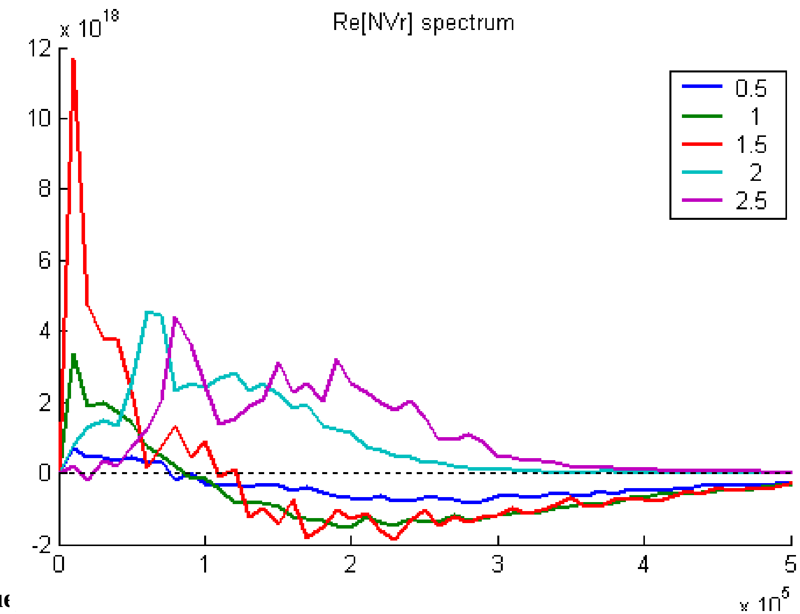
Fluctuation Amplitudes and Spectra Also Change with Density

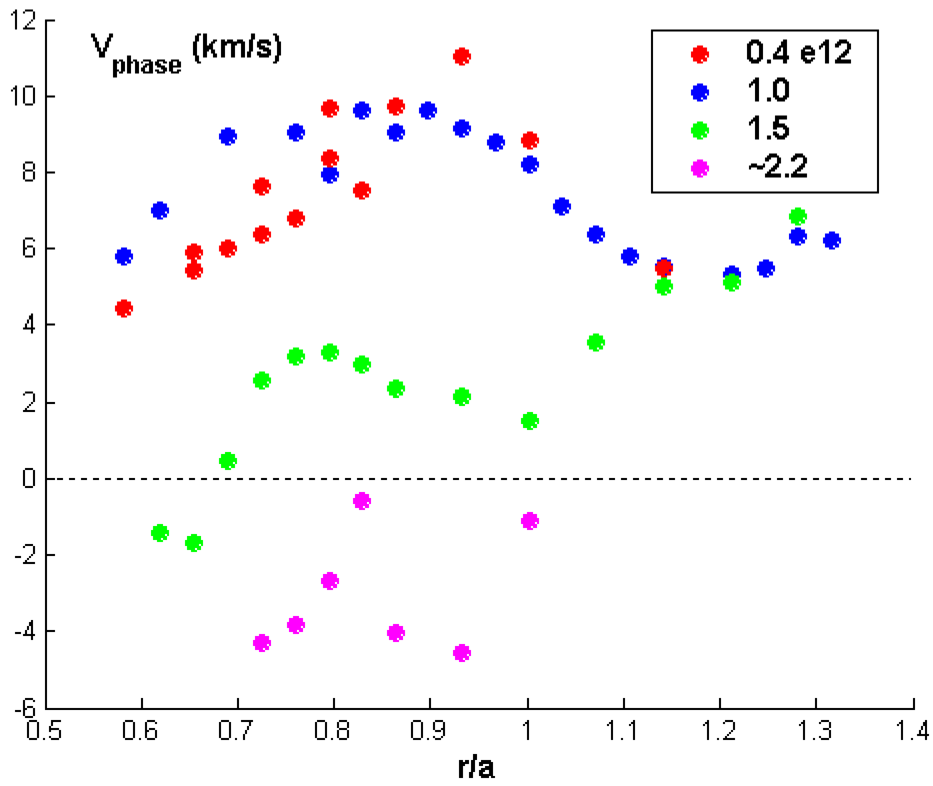






- V_{float} and I_{sat} fluctuation amplitudes decrease above ~1.7×10^{12} cm^{-3}.
- A large reduction in high frequencies (f>200 kHz) for I_{sat}.

V_{phase} profiles



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