Relationship of SOL Turbulence to SOL Width in Alcator C-Mod

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Goal: understand origin of SOL widths and learn how to predict them for future devices

Present talk: initial results for density in “far-SOL” at C-Mod outer midplane

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Simple Models for SOL Width

- Cross-field heat & particle transport due to SOL turbulence, parallel transport classical
- Turbulence structure nearly constant along B
- SOL width $\lambda$ is combination of $\perp$ and II motion
  - diffusive: $\lambda_n \sim (D_\perp \tau_{\|,n})^{1/2}$
  - convective: $\lambda_n \sim v_r \tau_{\|,n}$ [used here]
- Caveats: parallel flows, ionization, poloidal dependences, kinetic effects, etc.
GPI Movies of Outer Midplane SOL

- Gas puff imaging (GPI) measures $D_\alpha$ viewing along local $B$
- These movies have 250,000 frames/sec at 64x64 pixels

$I=0.6$ MA, $B=3.8$ T  
$I=1.1$ MA, $B=6$ T
Radial Turbulence Velocity

• For each point in image, first calculate cross-correlation with nearby points, averaged over 10 msec

\[ C_{12}(\Delta R, \Delta z, \Delta t) = \sum_t S_1(\cdot,0,0,t) \cdot S_2(\Delta R, \Delta z, t+\Delta t) \]

• Then get the average radial velocity from \( \Delta R \) at peak in \( C_{12} \) for a given delay time \( \Delta t \) (result \( \sim \) independent of \( \Delta t \))

• Tentatively assume this is average convective velocity \( v_r \)
  - requires parallel variations negligible \( (L_{\parallel}/v_{\parallel} \gg \tau_{\text{auto}}) \)
  - this velocity is not necessarily the same as \( \Gamma_r/n \)

(being tested with BOUT, see Sechrest, Munsat CP8.00008)
Radial Turbulence Velocity Profiles

- Peak correlation $C_{12} \sim 0.6-0.9$ over $\Delta t = 1$ frame in $\rho \sim 1-2$ cm
- Inferred radial velocity $v_r \sim 100-300$ m/s (out) in $\rho \sim 1-2$ cm

![Graphs showing peak correlation $C_{12}$ and radial velocity $v_r$ vs. radial distance into SOL (cm)]
Radial Velocity vs. Plasma Current

- Scan I at constant $q(a)$ & $L_{||}$, Ohmic LSN, moderate density
- Within this range $\rho=1-2$ cm, $n \sim 10^{19}$ m$^{-3}$ and $T_e \sim 20$ eV
Inferred Density SOL Width

- Using $\lambda_n \sim v_r \tau_{LL} \sim v_r (L_{LL}/v_{II,n})$, with $v_{II,n} \sim 0.5\xi c_s \sim 2 \times 10^6$ cm/s
  
  $[\xi c_s = \text{warm ion sound speed, from Fundamenski et al, Nuc. Fus. 2007}]

- Using $L_{LL} \sim 5$ m (~3-5 m cw, ~10-20 m ccw) @ $\rho=1$-2 cm

$\lambda_n$ inferred from $v_r$ model is 
$\sim x3$ larger than measured

But $L_{LL}$ and $v_{II,n}$ uncertain 
by at least a factor of 2, 
$=> v_r$ uncertain by $\sim x3$
Comparison with Blob Theory

- Simple analytic blob models for “sheath-connected” ES and RX-EM blobs (Krasheninnikov, D’Ippolito, Myra, JPP 2008)

- Using $\delta_b \sim L_p/1.6$, $L_{\parallel} \sim 500$ cm (both uncertain by $\sim x2$)

analytic blob model $v_r$ are x2-3 higher than GPI $v_r$ (but are only intended to be approximate)

isolated blobs may have higher speed than the convective $v_r$

(Krasheninnikov et al, PoP 2009)
Summary and Conclusions

- Density SOL width inferred from radial SOL turbulence velocity is \( \times 3 \) larger than measured density SOL
- Analytic blob models predict SOL turbulence velocity \( \times 2-3 \) larger than measured turbulence velocity

\[ \Rightarrow \] need better estimates for \( \tau_\parallel \) to calculate \( \lambda_n \) from \( v_r \)
\[ \Rightarrow \] need SOL turbulence simulations to understand \( v_r \)

- Many other issues of SOL width are not yet resolved:
  - how well does the GPI \( v_r \) represent convective flow ?
  - does \( \lambda_n \) scale with \( v_r \) for other discharges / radii ?
  - does SOL width vary with poloidal angle along B ?
  - what is the relationship of \( \lambda_{Te} \) and \( \lambda_q \) to GPI \( v_r \) ?
  - is parallel heat and particle flux really classical ?