Edge Sheared Flows and Blob Dynamics

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Motivation & Background

- Sheared flows are believed to be important for the L-H, and H-L transitions.
- Edge sheared flows play a dual role
  - regulating the turbulence (and hence the power flux crossing the separatrix)
  - controlling the character of emitted structures such as blob-filaments.
- Blob generation and dynamics impacts:
  - the (near-separatrix) scrape-off-layer (SOL) width, which is critical for ITER power handling in the divertor
  - far SOL blob interaction with plasma-facing components
GPI blob-trails analysis tool

- Use relative GPI intensity $\delta I/\langle I \rangle$ as the signal to analyze (in 2D space + time)
- For each frame: locate local maxima (blobs), fit ellipse to each
- Track the motion and structure evolution from frame to frame
- Analyze and compare data from
  - NSTX
  - C-Mod
  - SOLT simulations
Experimental blob trails
(low power Ohmic and L-mode)

NSTX

SH139444; 266 to 268 msec and MinHt > 1.

• Some blob trails show:
  – reversal of $v_y$ near the separatrix
  – “bouncing” off the separatrix

• Some trails show very complicated trajectories, esp. C-Mod high $v_{ei}$

Alcator C-Mod high $v_{ei}$

SH1100824017: 70 to 80 msec and MinHt > 1.30
Statistical data from blob tracking
(low power Ohmic and L-mode)

NSTX

- Mean flow is + (e-direction) in edge; - (i-direction) in SOL
- Deviations are as large or larger than the means, esp. C-Mod high $v_{ei}$
Experimental inputs to seeded blob simulations

<table>
<thead>
<tr>
<th></th>
<th>NSTX 139444</th>
<th>C-MOD 1100824017</th>
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</thead>
<tbody>
<tr>
<td>comment</td>
<td>ohmic</td>
<td>ohmic high $v_{ei}$</td>
</tr>
<tr>
<td>$n_{e,sep}$ (cm$^{-3}$)</td>
<td>$5.8 \times 10^{12}$</td>
<td>$1.0 \times 10^{14}$</td>
</tr>
<tr>
<td>$T_{e,sep}$ (eV)</td>
<td>19.</td>
<td>47.</td>
</tr>
<tr>
<td>$\rho_{s,sep}$ (cm)</td>
<td>0.26</td>
<td>0.025</td>
</tr>
<tr>
<td>$\Lambda_{SOL} \sim v_e^*(m_e/m_i)^{1/2}$</td>
<td>0.3 – 0.8</td>
<td>1-3</td>
</tr>
<tr>
<td>blob size $a_{b,sep}$ (cm)</td>
<td>$2.2 \pm 0.5$</td>
<td>$0.4 \pm 0.1$</td>
</tr>
<tr>
<td>blob amp $\delta I/I_{sep}$</td>
<td>0 – 1.6</td>
<td>0 – 0.6</td>
</tr>
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profiles
Simulation: physics model


Scrape-Off-Layer Turbulence (SOLT) code

- 2D fluid turbulence code: model SOL in outer midplane
  - classical parallel + turbulent cross-field transport
- Evolves $n_e, T_e, \Phi$ with parallel closure relations
  - sheath connected, with flux limits, plus collisional regimes
- Strongly nonlinear: $\delta n/n \sim 1 \Rightarrow$ blobs
- Model supports drift waves, curvature-driven interchange modes, sheath instabilities

Present Work:

- Take plasma profiles and connection lengths from NSTX and Alcator C-Mod shots
- Hand-seed blobs as initial condition for simulation, and track their motion
- Compare blob tracks in experiment and simulation
- NSTX base case parameters (mostly so far)
- Some C-Mod cases (labeled)
Seeded blob simulation results

Small amplitude blobs “bounce” off the separatrix, large ones are ejected

- Background \( <v_y> \) E×B flows small here. The effect must be related to either shear in electron diamagnetic flow, or the sharp change in sheath conductivity at the separatrix
- Ejected blob reverses \( v_y \) in SOL (see next slide). Note elliptical deformation
- (Small seeded blob induces a larger blob which does get ejected)
Blobs motion is influenced by wave velocity and Reynolds-charge dynamics as well as background E×B flow

- In edge region $v_{*e}$ is positive and carries the blob (similar to Horton drift vortex)
  - Wave $v_g$ probably relevant here (need to verify)
- Ejected blob reverses $v_y$ in SOL due to tilting of charge dipole
  - see blob track on previous slide
  - accentuates existing flow gradient (incl. $v_{*e}$ gradient)
Blob trapping vs. ejection controlled by strength of blob charge dipole relative to flow shear

- Blob charge dipole here is influenced by changing:
  - amplitude (previous slide)
  - viscosity
  - collisionality (parallel currents and sheath draining of charge)
  - friction (charge dissipation from cross-field currents, e.g. X-points)
- Likely competition: blob vorticity vs. flow shear vorticity (apparently taking account of wave $v_g$ shear?)
  - $v_{yExB}' << v_{yblob}'$ in all these cases

- C. Mass track
- max amp track
Parallel-disconnected blobs exhibit complex shapes and trajectories

- Base case NSTX parameters are marginally sheath connected
- Collisional parallel disconnection induced here by artificially taking $Z_{\text{eff}} \rightarrow \infty \Rightarrow \text{“inertial” blob regime}$
- Disconnected limit may be relevant to C-Mod (more complexity is seen in experimental data, and in simulation below)
Edge drift-wave dynamics influences blob behavior

- Vary DW adiabaticity parameter $\alpha_{dw} = (0, 1, 10) \times \text{base} \_ \text{case}$

  weak $\alpha_{dw}$ ⇒ strong ejection, no $v_g$-shear, no $v_y$ reversal at separatrix
  - note Reynolds induced $v_E$
  - asymmetric sheath response to $+$ vs. $-$ charge ⇒ $v_y < 0$
  - sheath $T_e$ rotation ⇒ $v_y < 0$

  moderate $\alpha_{dw}$ ⇒ $v_y$ reversal

  strong $\alpha_{dw}$ ⇒ trapped blob
  - DW inhibits charge dipole
  - also $v_g$ shear layer
Shear in $v_{\text{group}}$ may influence Reynolds flow shear

- Seed blobs at two different locations and examine resulting flow generation
- C-Mod parameters and profiles

- Blob a) remains trapped while b) is ejected
- Reynolds generated flow shear (of $v_E$) follows tilt from shear of $v_{\text{gr}}$
- $p_y$ conservation $\Rightarrow$ bipolar
**Blobs have a tendency to follow background \( E \times B \) flows in the SOL**

- Influence of \( E \times B \) flows is on top of other mechanisms discussed
- Stronger for flows with shear length > blob scale size
- Flows imposed by specifying sheath potential \( \Phi \) (\( \neq 3T_e \) midplane)

### Imposed Flows

- Imposed \( \langle v_y \rangle > 0 \)
- Imposed \( \langle v_y \rangle < 0 \)
**Strong shear layers trap the blob**

- Direction important (co or counter to DW tilt?, blob spin?)
- Trajectory changed not just by rapid $v_y$, but $v_x$ actually affected, and can reverse

- Imposed $<v_y> > 0$
  
  between dashed brown lines

- Imposed $<v_y> = 0$

- Imposed $<v_y> < 0$
Conclusions

• Many features seen in blob tracking data can be reproduced from seeded blob simulations
  – size and scale of flows
  – dominant flow direction in edge (electron) and SOL (ion) for NSTX
  – $v_y$ reversal of individual tracks
  – blobs bouncing off the separatrix
  – blob tracking and/or ejection depending on parameters
  – elliptical blob deformations near shear layers
  – complex trajectories especially in collisional cases (like C-Mod)

• New dynamic effects on blob motion and shear flow generation have been identified
  – blob-scale inhomogeneities $\Rightarrow$ charge dipole tilt $\Rightarrow v_{y,\text{blob}}$ (can give $v_y$ reversal)
  – shear in background group velocity may influence sense of Reynolds flows
  – blobs do not always follow background $E\times B$ flows, or net flows

• Other effects studied but not shown:
  – Effect of initial conditions on blob vorticity decays rapidly, especially dipole; less so for monopole (spin) vorticity.
  – Blob amplitude and scale size may affect $v_{y,\text{blob}}$ and how closely the blob tracks background $v_E$ and $v_{gr}$ (preliminary)