Edge Sheared Flows and Blob Dynamics

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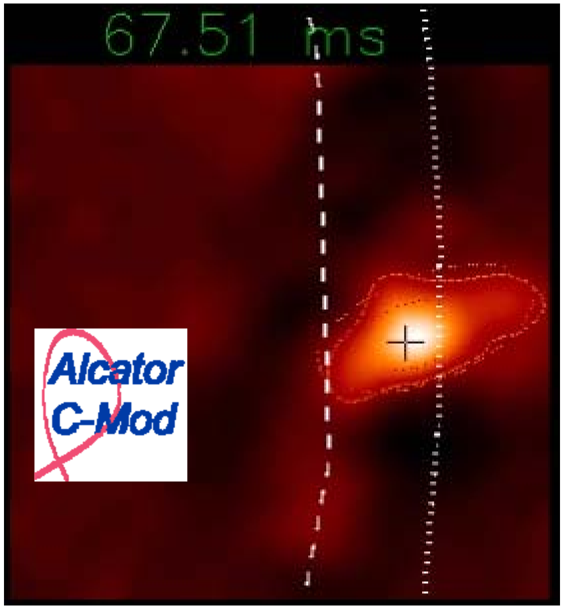
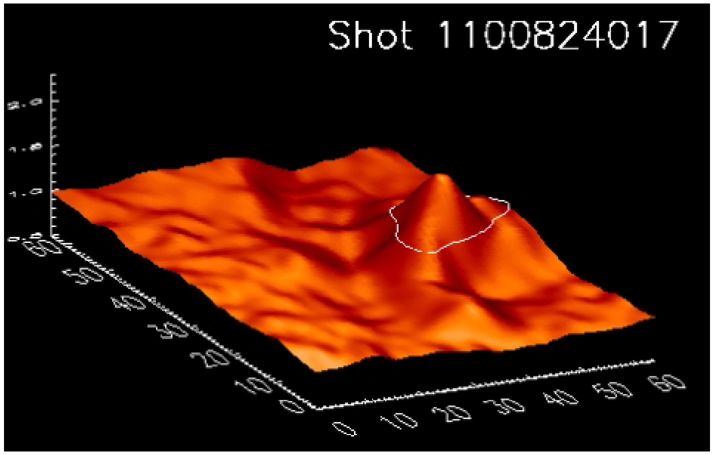
Motivation & Background

- 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

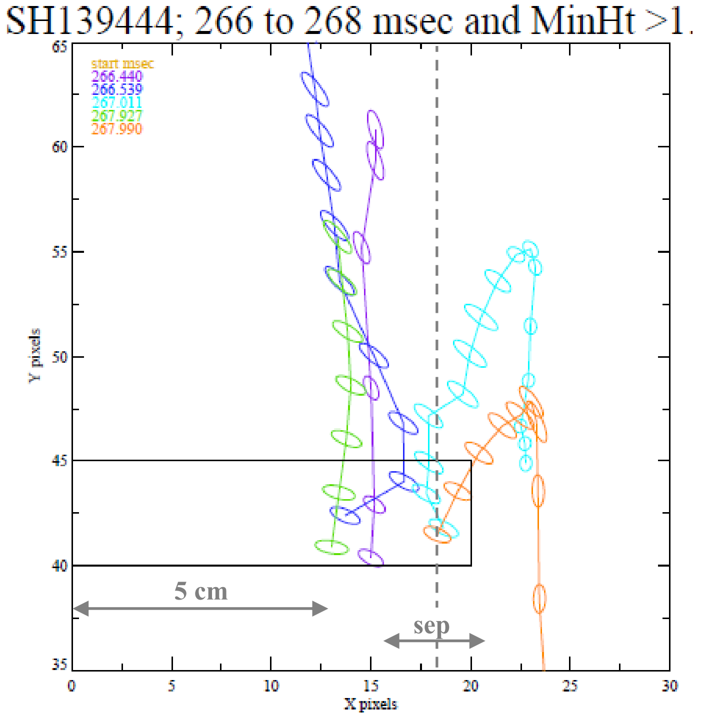




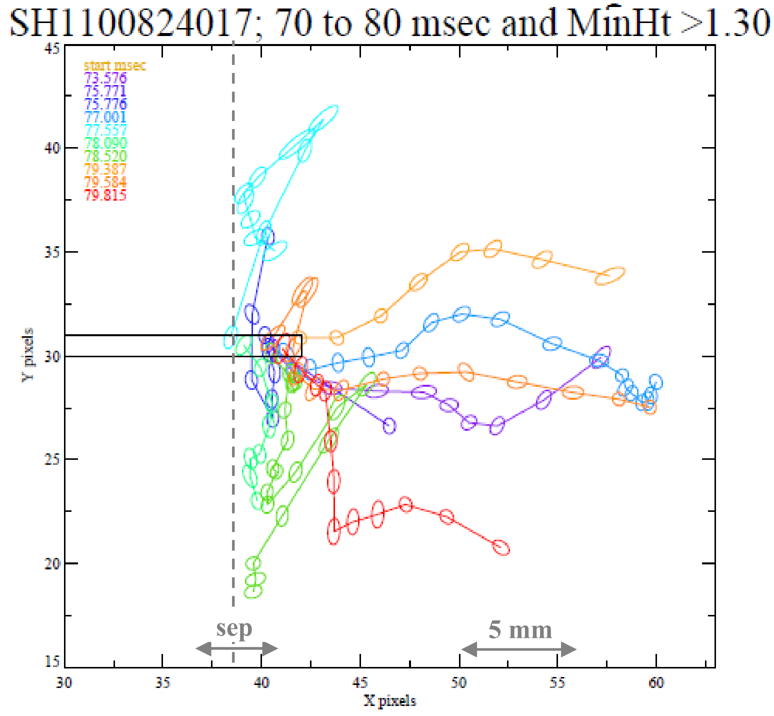
- Use relative GPI intensity $\delta I/\langle I\rangle$ as the signal to analyze (in 2D space + time)
- For each frame: locate local maxima (blobs), fit ellipse to each
- Track the motion and structure evolution from frame to frame
- Analyze and compare data from
  - NSTX
  - C-Mod
  - SOLT simulations

Experimental blob trails
(low power Ohmic and L-mode)

NSTX



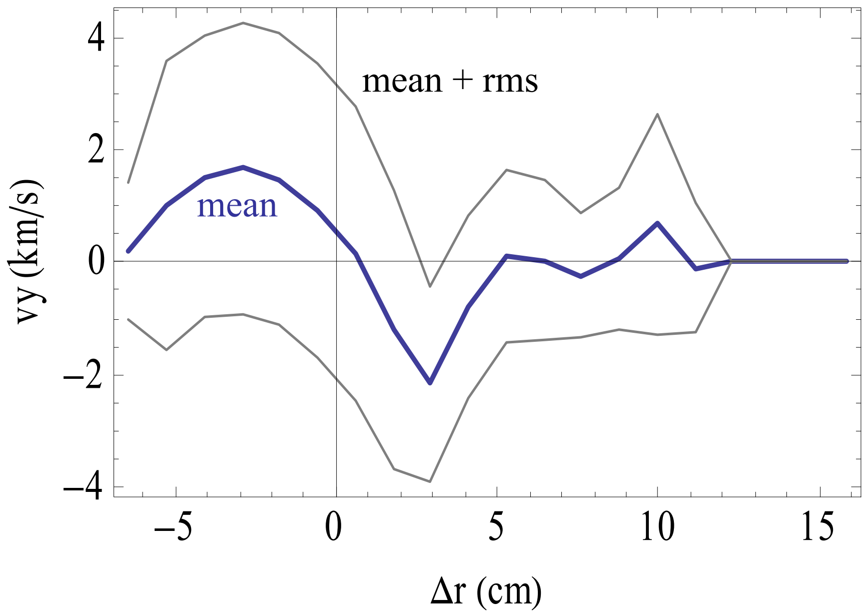
Alcator C-Mod high ν_{ei}



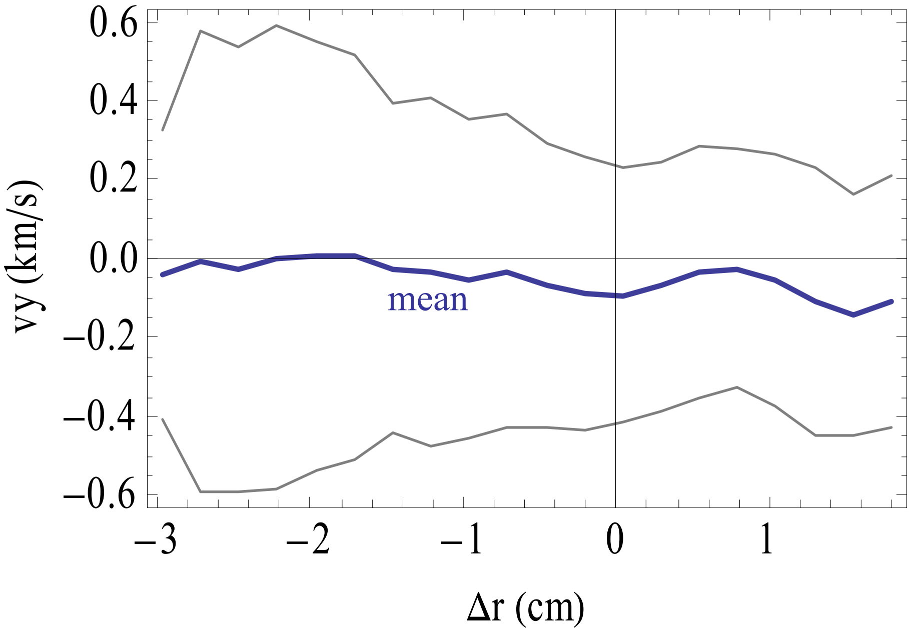
- Some blob trails show:
  - reversal of v_y near the separatrix
  - "bouncing" off the separatrix
- Some trails show very complicated trajectories, esp. C-Mod high ν_{ei}

Statistical data from blob tracking (low power Ohmic and L-mode)

NSTX



Alcator C-Mod high ν_{ei}

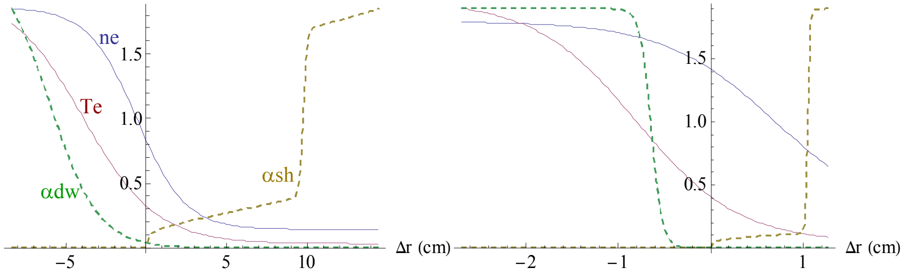


- NSTX: Mean flow is + (e-direction) in edge; - (i-direction) in SOL
- Deviations are as large or larger than the means, esp. C-Mod high ν_{ei}

Experimental inputs to seeded blob simulations

	NSTX 139444	C-MOD 1100824017
comment	ohmic	ohmic high ν_{ei}
$n_{e,sep}$ (cm^{-3})	5.8×10^{12}	1.0×10^{14}
$T_{e,sep}$ (eV)	19.	47.
$\rho_{s,sep}$ (cm)	0.26	0.025
$\Lambda_{SOL} \sim \nu_{e*}(m_e/m_i)^{1/2}$	0.3 – 0.8	1-3
blob size $a_{b,sep}$ (cm)	2.2 ± 0.5	0.4 ± 0.1
blob amp $\delta I/\langle I\rangle\vert_{sep}$	0 – 1.6	0 – 0.6

profiles



Simulation: physics model

D. A. Russell, et al, Phys. Plasmas **16**, 122304 (2009)

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, Φ 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:

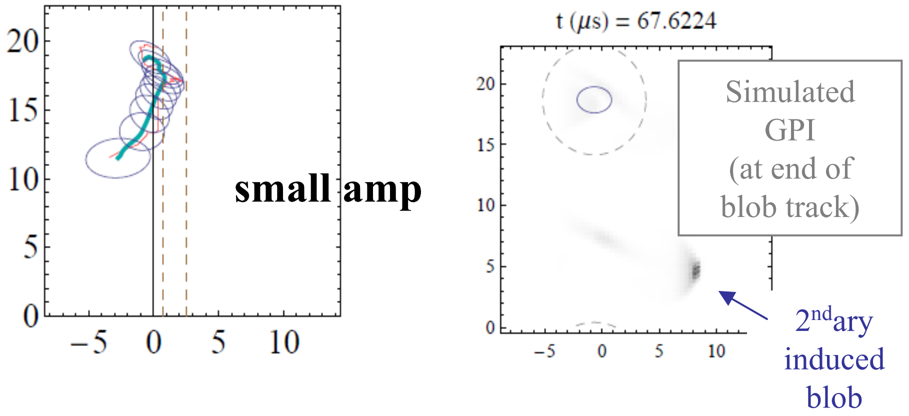
- **Take plasma profiles and connection lengths from NSTX and Alcator C-Mod shots**
- **Hand-seed blobs as initial condition for simulation, and track their motion**
- **Compare blob tracks in experiment and simulation**
- **NSTX base case parameters (mostly so far)**
- **Some C-Mod cases (labeled)**

Seeded blob simulation results

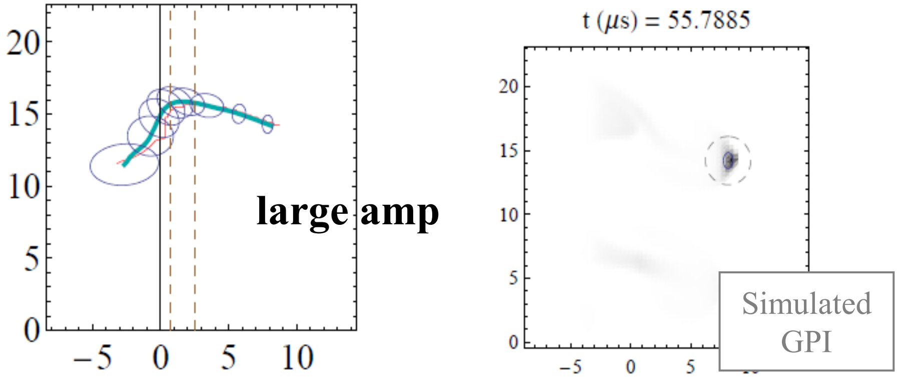
Small amplitude blobs “bounce” off the separatrix, large ones are ejected

- 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)

$(n,T)_{blob} = 0.1 * (n,T)_{sep}$ 014_1.2



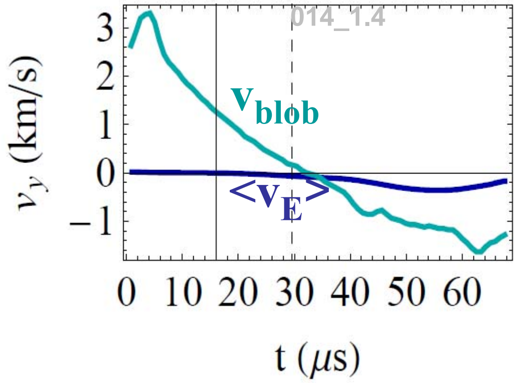
$(n,T)_{blob} = 0.4 * (n,T)_{sep}$ 014_1.4

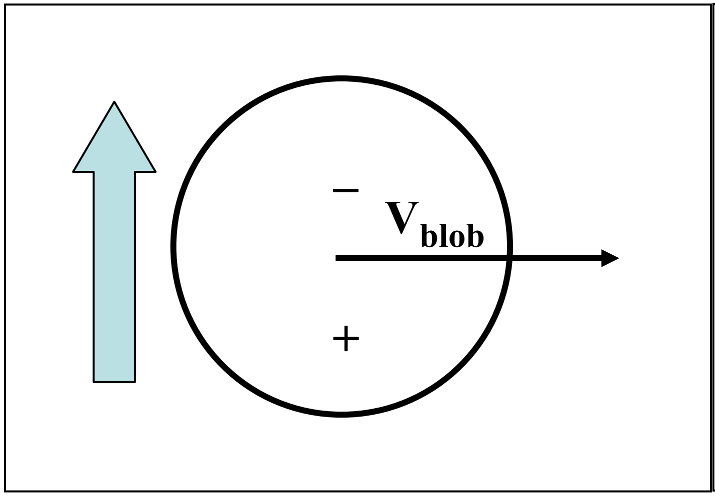


Lodestar

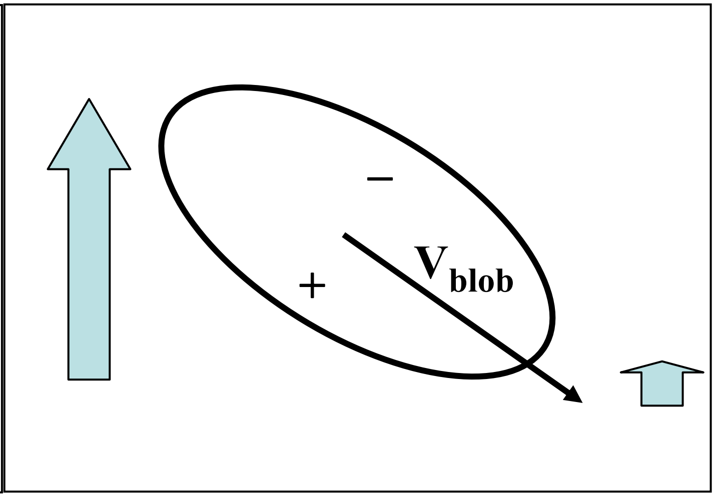
Blobs motion is influenced by wave velocity and Reynolds-charge dynamics as well as background E×B flow

- 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)





t_1 in edge



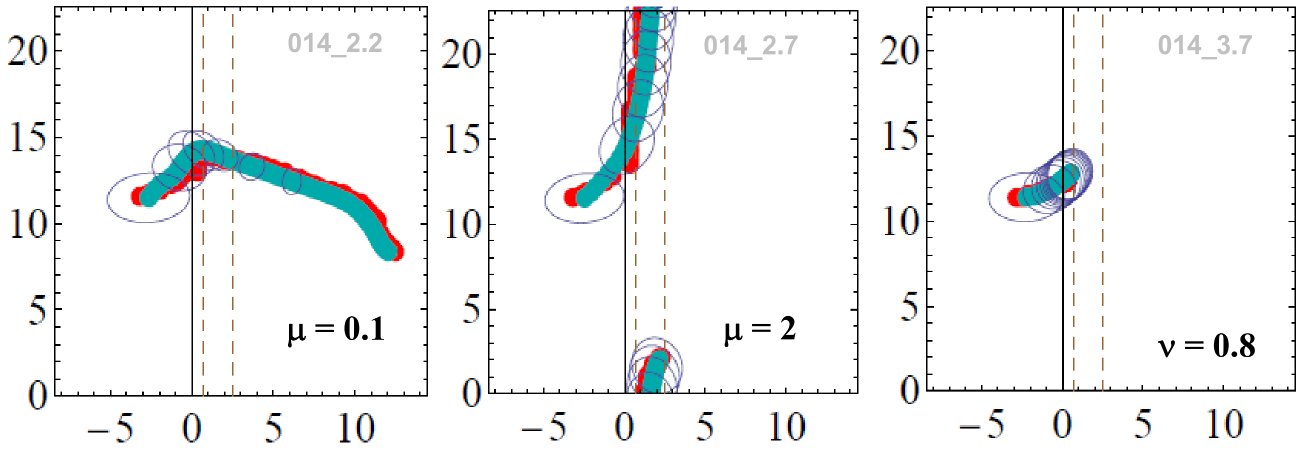
t_2 crossing separatrix

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

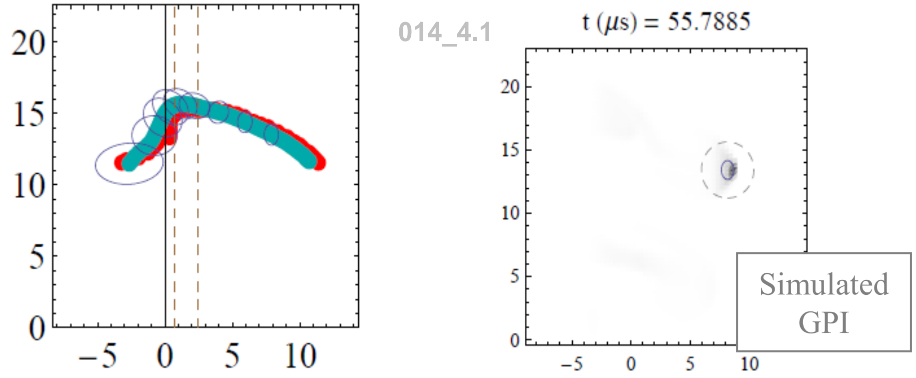
● C. Mass track

● max amp track

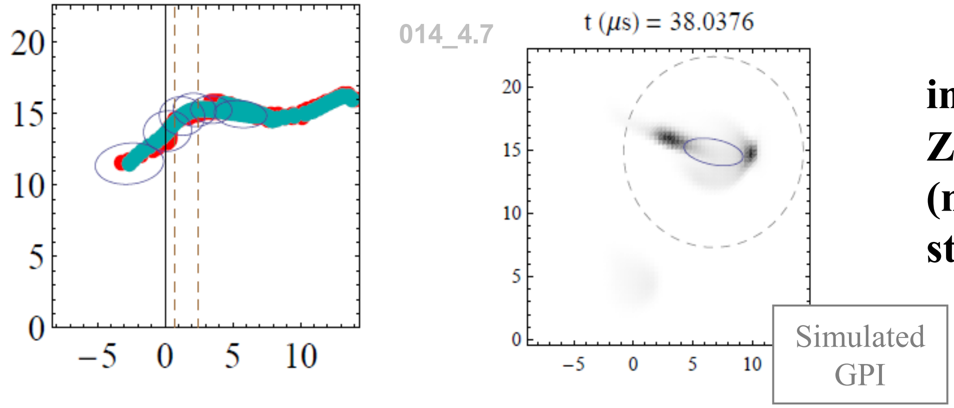


Parallel-disconnected blobs exhibit complex shapes and trajectories

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



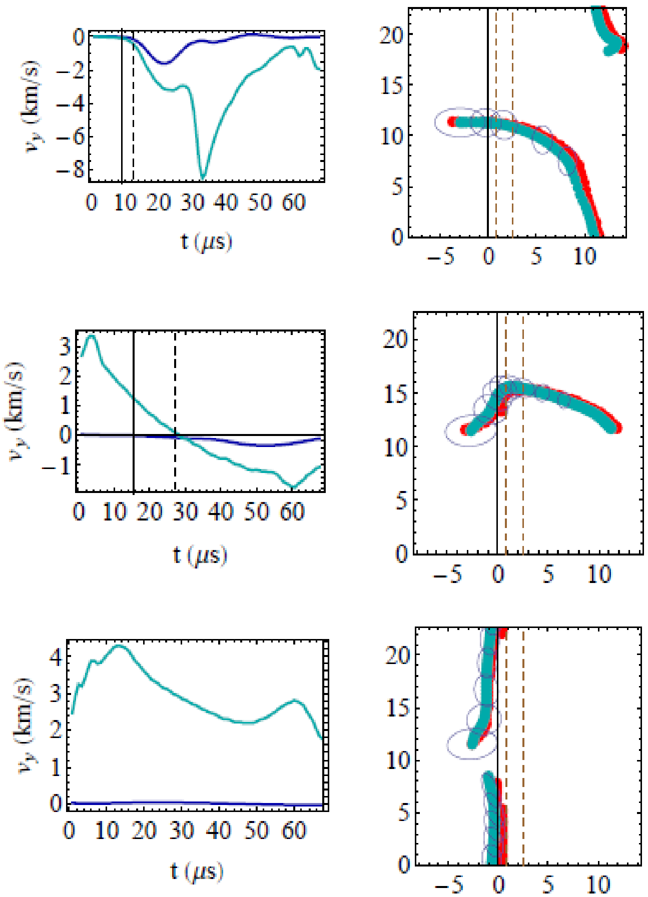
sheath-connected
Zeff = 0



inertial (disconnected)
Zeff = ∞
(note more complex structure)

Edge drift-wave dynamics influences blob behavior

- Vary DW adiabaticity parameter α_{dw} = (0, 1, 10) * base_case



weak $\alpha_{dw} \Rightarrow$ strong ejection, no vg-shear, no v_y reversal *at separatrix*

  - note Reynolds induced v_E
  - asymmetric sheath response to + vs. – charge $\Rightarrow v_y < 0$
  - sheath Te rotation $\Rightarrow v_y < 0$

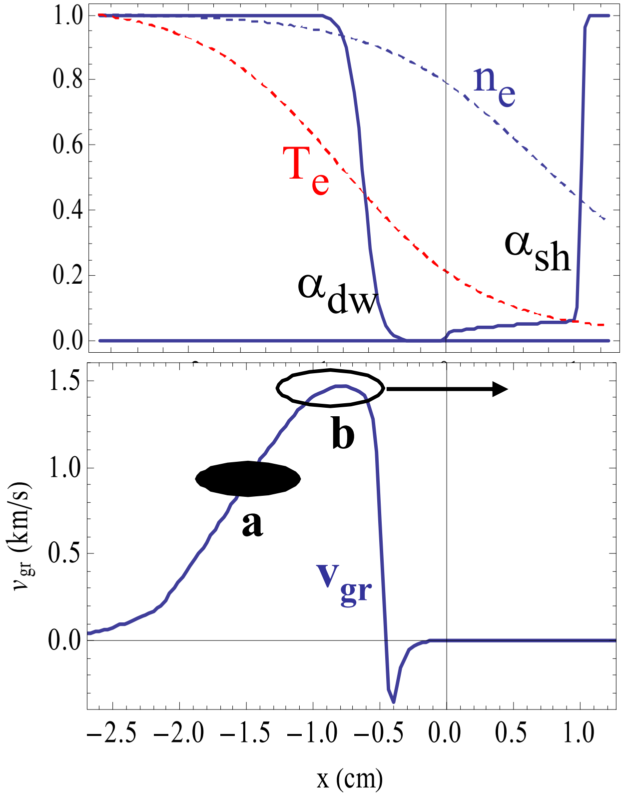
moderate $\alpha_{dw} \Rightarrow v_y$ reversal

strong $\alpha_{dw} \Rightarrow$ trapped blob

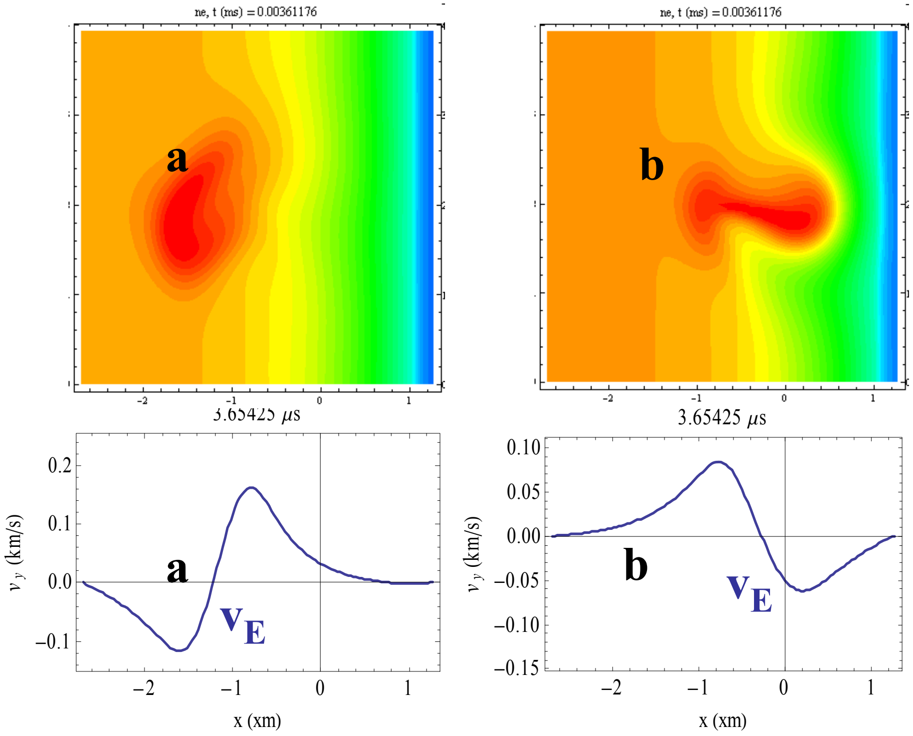
  - DW inhibits charge dipole
  - also v_g shear layer

Shear in v_{group} may influence Reynolds flow shear

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

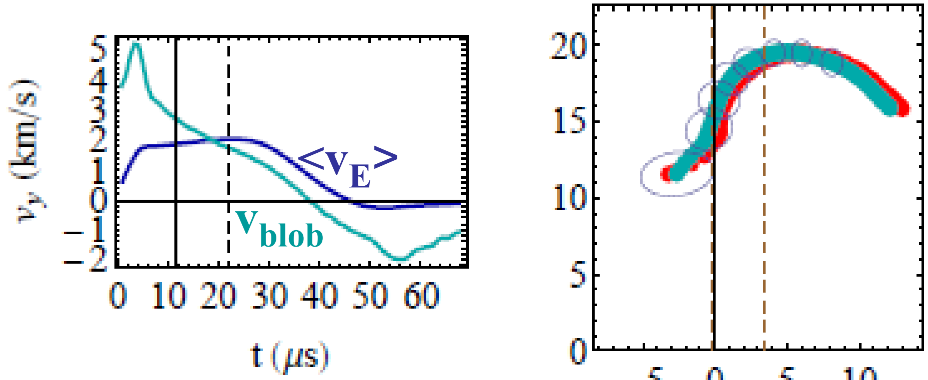


- Blob a) remains trapped while b) is ejected
- Reynolds generated flow shear (of v_E) follows tilt from shear of v_{gr}
- p_y conservation ⇒ bipolar

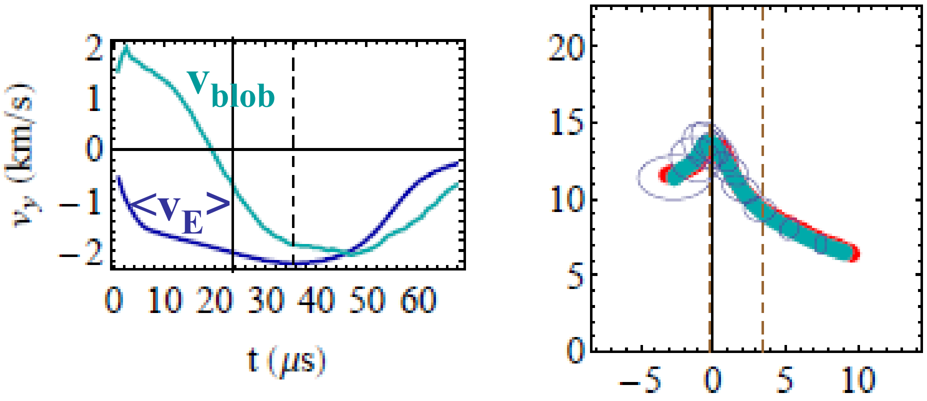


Blobs have a tendency to follow background E×B flows in the SOL

- Influence of E×B flows is on top of other mechanisms discussed
- Stronger for flows with shear length > blob scale size
- Flows imposed by specifying sheath potential Φ (≠3Te midplane)



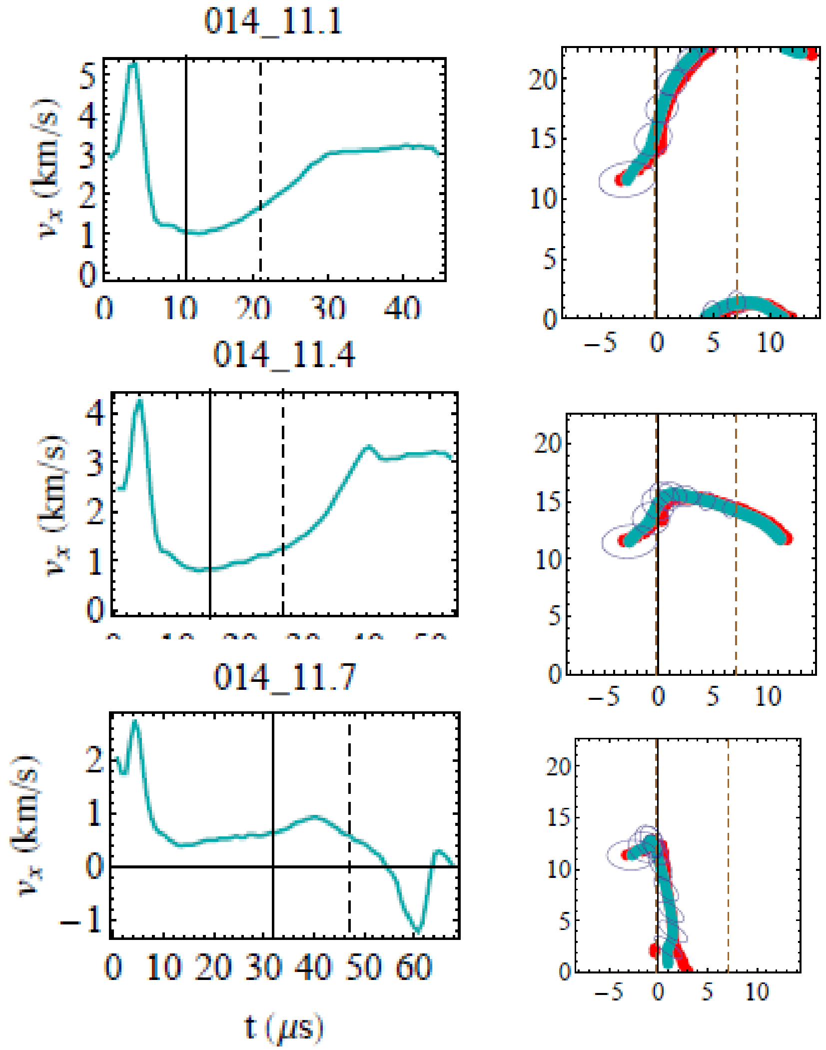
imposed $\langle v_y \rangle > 0$



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 $\langle v_y \rangle > 0$

between dashed brown lines

imposed $\langle v_y \rangle = 0$

imposed $\langle v_y \rangle < 0$

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 ⇒ charge dipole tilt ⇒ $v_{y,blob}$ (can give v_y reversal)
  - shear in background group velocity may influence sense of Reynolds flows
  - blobs do not always follow background E×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 $v_{y,blob}$ and how closely the blob tracks background v_E and v_{gr} (preliminary)