Large amplitude blob propagation in the Alcator C-Mod scrape-off-layer

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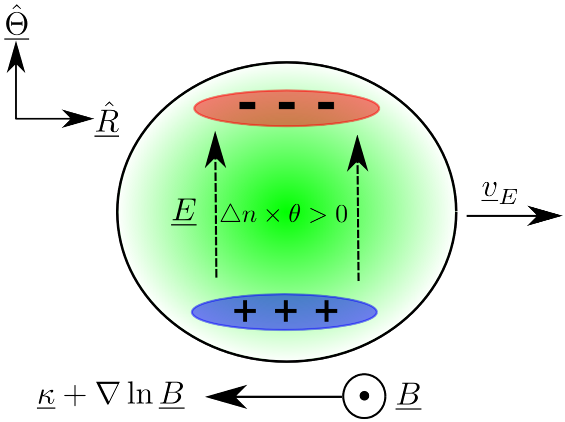
Outline

Theory predicts blob velocity scaling with varying cross-field size.
Do blobs observed in Alcator C-Mod adhere to this scaling?

Interchange model



$$\frac{d}{dt} n = 0$$

$$\nabla \cdot \mathbf{J}_\perp = -\nabla \cdot \mathbf{J}_\parallel$$

Interchange model

Average equations along **B**, assume blob has no structure along **B**:

$$\left(\frac{\partial}{\partial t} + \mathbf{b} \times \nabla\phi \cdot \nabla\right) \ln n = \kappa \left(\nabla_\perp^2 \ln n - (\nabla_\perp \ln n)^2\right)$$

$$\left(\frac{\partial}{\partial t} + \mathbf{b} \times \nabla\phi \cdot \nabla\right) \Omega + \frac{\partial \ln n}{\partial y} = \mu \nabla_\perp^2 \Omega + \Lambda\phi$$

$$\Omega = \nabla_\perp^2 \phi$$

$$n = N + \triangle n \times \theta(x, y)$$

Normalization: $x \to x' = x/\ell$, $t \to t' = \gamma_0 t$

Inertial term
Polarization current

Interchange term
Mag. curvature + ∇**B** drifts
Causes polarization of blob structure

Parallel currents
Sheath dissipation parameter
$\Lambda = \frac{c_s \ell^2}{\gamma_0 L_{\shortparallel} \rho_s^2} \sim \ell^{5/2}$

Inertial velocity scaling: $V \sim \sqrt{\ell}$

Curvature and $\nabla\mathbf{B}$ currents are balanced by polarization currents, $\Lambda \ll 1$

$$\underbrace{\left(\frac{\partial}{\partial t} + \hat{z} \times \nabla\phi \cdot \nabla\right)\Omega}_{\sim V^2} + \underbrace{\frac{\partial \ln n}{\partial y}}_{\sim \frac{\triangle n}{N+\triangle n}} = \mu\nabla_\perp^2\Omega + \Lambda\Phi$$

$$\Rightarrow V^2 \sim \triangle n/N + \triangle n.$$

Velocity scaling for small ℓ

$$\frac{V}{C_s} \sim \left(\frac{2\ell}{R}\frac{\triangle n}{N+\triangle n}\right)^{1/2}$$

Garcia et al., Phys. of Plasma **13** 082309 (2006)

Sheath dissipated velocity scaling: $V \sim \ell^{-2}$

Curvature and $\nabla \mathbf{B}$ currents are balanced by parallel currents, $\Lambda \gg 1$

$$\left(\frac{\partial}{\partial t} + \hat{z} \times \nabla\phi \cdot \nabla\right)\Omega + \underbrace{\frac{\partial \ln n}{\partial y}}_{\sim \frac{\triangle n}{N + \triangle n}} = \mu \nabla_\perp^2 \Omega + \underbrace{\Lambda \Phi}_{\sim V}$$

$\Rightarrow V \sim 1/\Lambda$, when assuming large $\triangle n$.

Dimensional velocity scaling for large ℓ

$$\frac{V}{C_s} \sim \frac{2 L_{\shortparallel} \rho_s^2}{R \ell^2}$$

S. I. Krasheninnikov, Phys. Letters A **283** (2001) 368-370

Does V scale for intermediate ℓ?

For small Λ: $V \sim \ell^{1/2}$ For large Λ: $V \sim \ell^{-2}$

The scaling in between is found by balancing all terms:

$$\underbrace{\left(\frac{\partial}{\partial t} + \hat{z} \times \nabla\phi \cdot \nabla\right)\Omega}_{\sim V^2} + \underbrace{\frac{\partial \ln n}{\partial y}}_{\sim \frac{\triangle n}{N+\triangle n}} = \mu \nabla_\perp^2 \Omega + \underbrace{\Lambda\Phi}_{\sim V}$$

Assuming all terms are of order unity, this defines a length scale where filaments assume maximum velocity:

$$\Lambda = \left(\frac{\ell}{\ell_*}\right)^{5/2} = 1 \Rightarrow \ell_* = \left(\frac{2L_{\shortparallel}^2 \rho_s^4}{R}\right)^{1/5}$$

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$$\underbrace{\left(\frac{\partial}{\partial t} + \hat{z} \times \nabla\phi \cdot \nabla\right)\Omega}_{\sim V^2} + \underbrace{\frac{\partial \ln n}{\partial y}}_{\sim \frac{\triangle n}{N+\triangle n} c_2} = \mu \nabla_\perp^2 \Omega + \underbrace{\Lambda\Phi}_{\sim V c_1}$$

Write balance of terms as a quadratic equation in V.

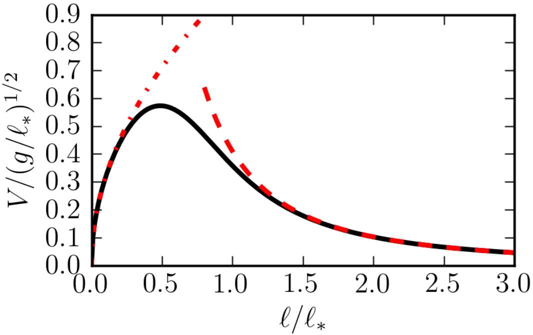
If we find c_1, c_2, we have $V(\Lambda)$ for a given $\triangle n / N + \triangle n$.

$$V^2 + c_1 \Lambda V + c_2 \frac{\triangle n}{N + \triangle n} = 0$$

Blob velocity scaling with ℓ

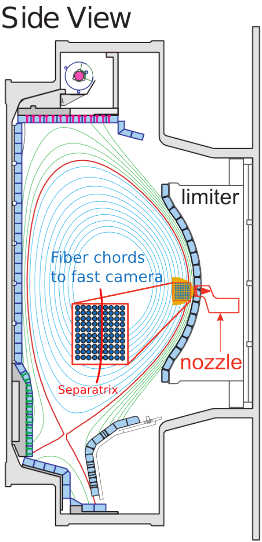
Determine c_1, c_2 from numerical simulations of blob propagation with varying Λ and fixed $\triangle n$.

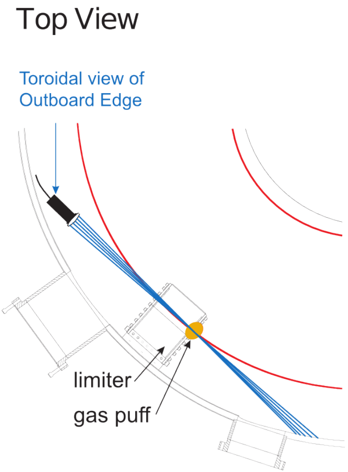
$$\frac{V}{V_*} = \frac{c_2}{2}\left(\frac{\ell}{\ell_*}\right)^3 \left[-1 + \sqrt{1 + \frac{4c_1}{c_2}\left(\frac{\ell_*}{\ell}\right)^5 \frac{\triangle n/N}{1+\triangle n/N}}\right]$$



R. Kube and O.E. Garcia, Phys. Plasm. **18** 102314 (2011)

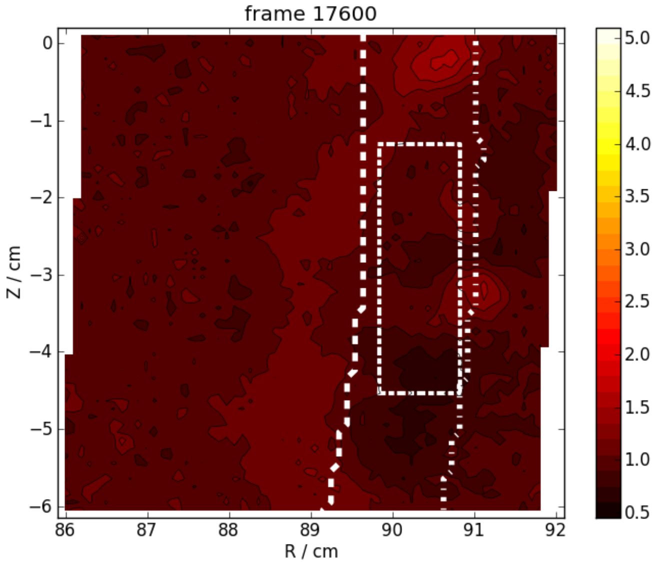
Gas-puff imaging (GPI): localized picture of the turbulence



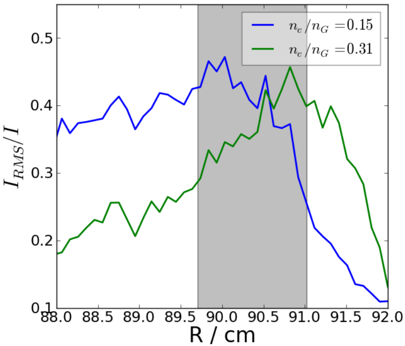


Measure atomic line emission intensity from neutral gas puff (He) with fast camera @ 396kHz framerate, 2 μs integration time.

Blob tracking method developed



Fluctuations in SOL are different for GPI and Probes



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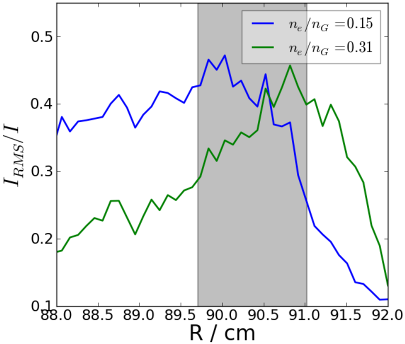

$I = I_0 \times f(n_e, T_e)$, neglects T_e for length analysis.

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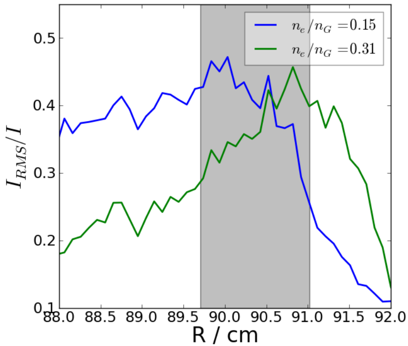


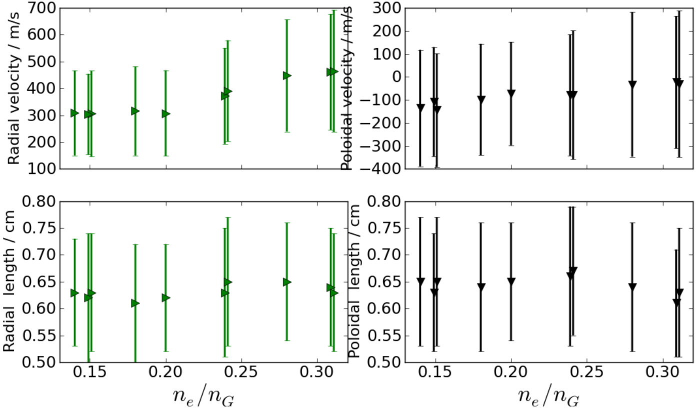
$I = I_0 \times f(n_e, T_e)$, neglects T_e for length analysis.

Identify blobs as fluctuations exceeding a threshold $\zeta = 1.5 \ldots 2.5$ in a triggering domain in the SOL:

$$I(r_i, z_i, t) \geq \zeta \times I_{RMS}(r_i, z_i) \quad \forall (r_i, z_i) \in \text{ triggering domain}$$

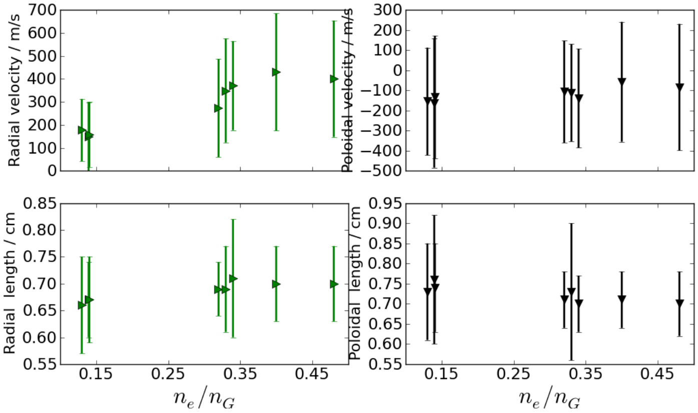
Blob velocity and size statistics

Shots # 1100803005 - # 1100803020, $B = 4.0\mathrm{T}$, $I_p = 0.6\mathrm{MA}$, LSN, Ohmic L-Mode.



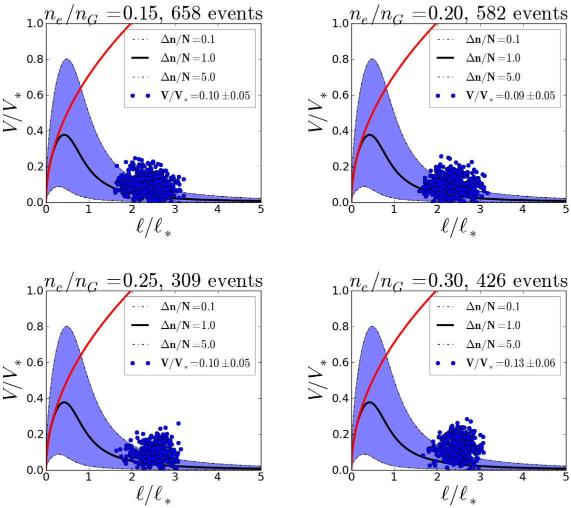
Blob velocity and size statistics

Shots # 1120217008 - # 1120217021, $B = 5.4\mathrm{T}$, $I_p = 0.8\mathrm{MA}$, LSN, Ohmic L-Mode.



Comparison to velocity scaling

Shots # 1100803005 - # 1100803020, $B = 4.0T$, $I_p = 0.6MA$, LSN, Ohmic L-Mode.



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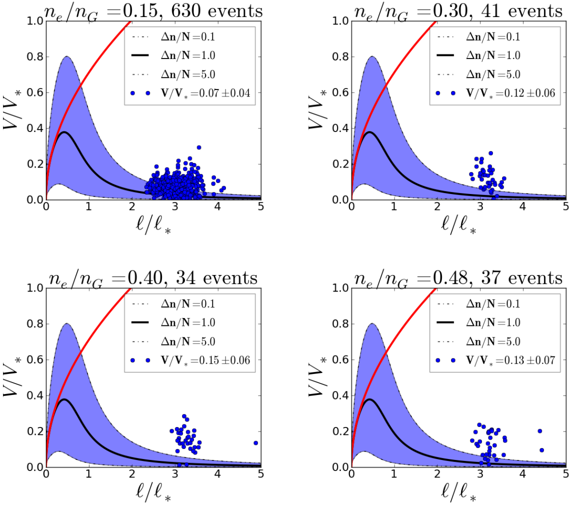

Conclusion and next steps

Results and conclusion

1. Blob tracking routine developed and successfully applied to GPI data
2. GPI data complements probe data with superior spatial resolution and good time resolution.
3. Blob velocities increase with $\bar{n}_e$, blob sizes remain constant
4. Blobs velocities adhere less to sheath-dissipated scaling for increasing $\bar{n}_e$. We need to account for their parallel structure.
5. Cond. avg. results compare favorably with results from correlation analysis

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Future work

- Radial I_{sat}- and V_{fl}-profiles from scanning probe downstream and at divertor for varying $\bar{n}_e$.