Reduced simulations of boundary turbulence in NSTX

J.R. Myra, D.A. Russell, D.A. D'Ippolito, *Lodestar*,
R. Maqueda, *Nova Photonics*,
V. Soukhanovskii, *LLNL*,
S.J. Zweben, *PPPL*

- theory background
- summary of experiment
- turbulence simulations
- future work

⇒

- basic blob physics
- SOL width & convection
- divertor gas puff

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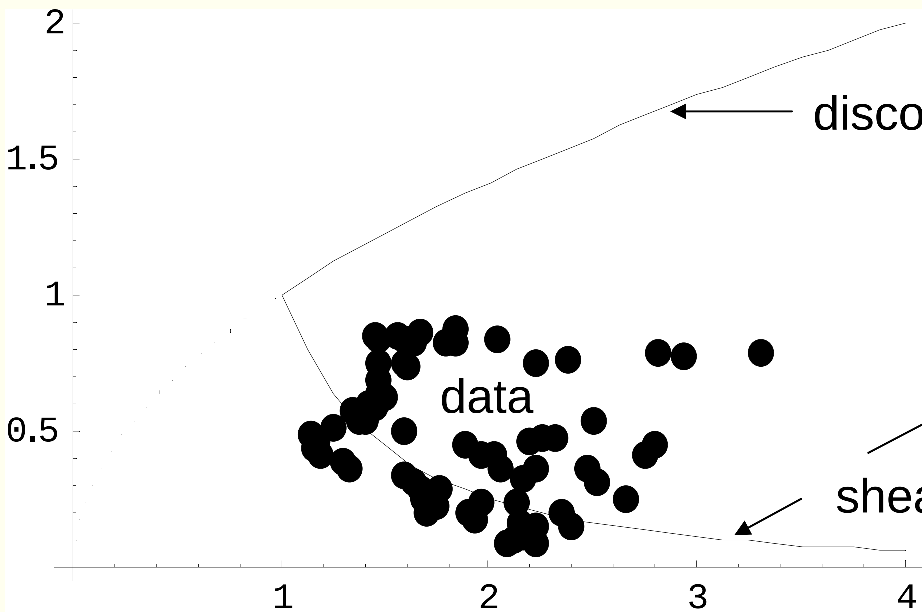
Blob velocity bounds verified from the GPI imaging analysis

- analytical blob velocity bounds verified from the GPI imaging analysis (Myra et al., IAEA Chengdu, 2006)
- parameter controlling regime is collisionality ⇒ disconnection
- increasing collisionality should speed blobs up & broaden SOL

$$\hat{v} = \frac{v_r}{v_*}$$



$$\frac{1}{\hat{a}^2} < \frac{v_r}{v_*} < \hat{a}^{1/2}$$

$$\hat{a} = \frac{a_b}{a_*}$$

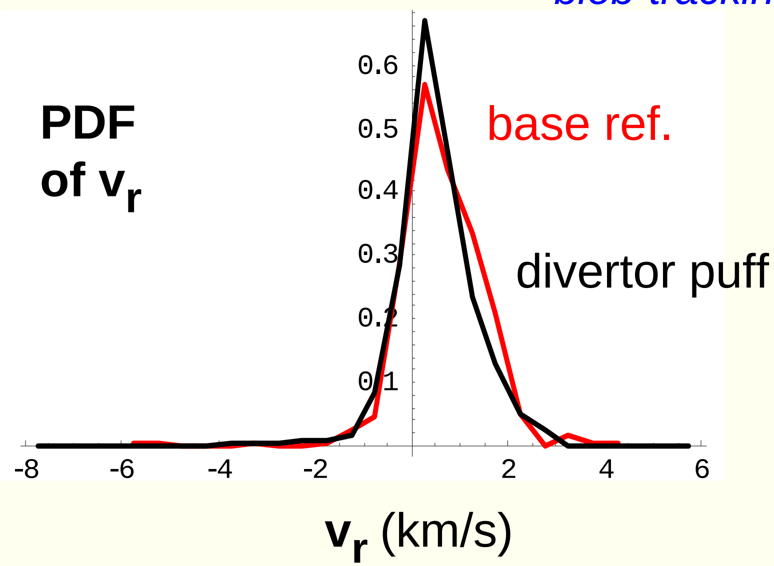
$$a_* = L_{\|}^{2/5} \rho_s^{4/5} / R^{1/5}$$

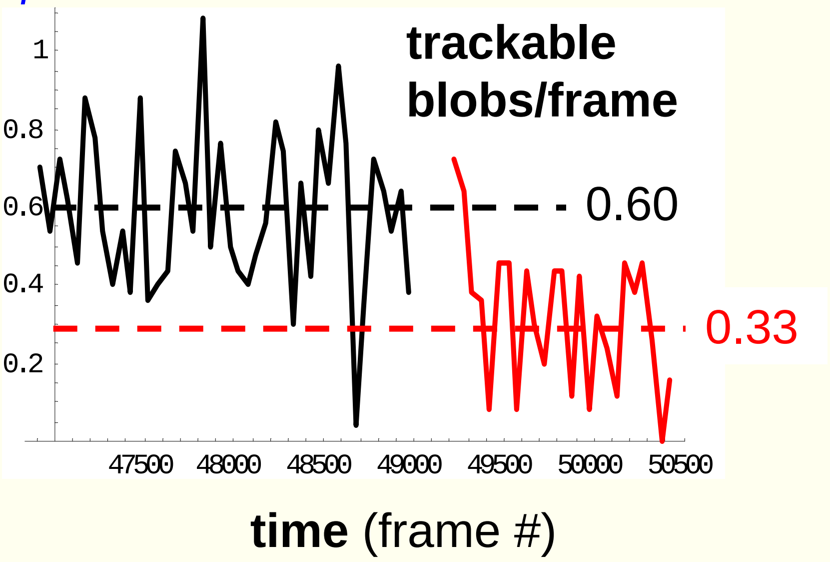
$$v_* = c_s \left(\frac{a_*}{R} \right)^{1/2}$$

Proposal: increase blob velocity (⇒ SOL width) by X-point gas puff

- piggy-backed on XP-708
  - “Divertor heat flux reduction and detachment” [V. Soukhanovskii]
  - with mid-plane GPI [R. Maqueda]
- expected blob velocity increase not (yet) observed
  - still checking some issues
- possible increase in blob production rate
  - flux increased but due to blob production rate not blob speed ??

blob-tracking - Maqueda





SOLT (Scrape-off-Layer Turbulence)
2-D fluid turbulence code

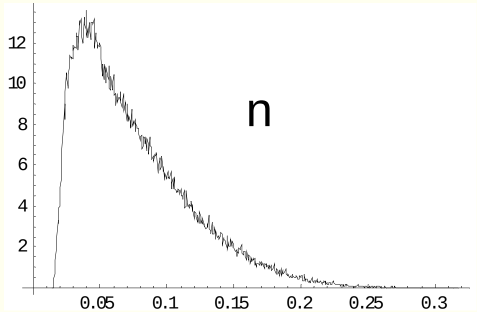
- nonlinear coupled equations for
  - density
  - temperature *(in progress, some results here are for T = const)*
  - potential (vorticity)
  - zonally-averaged momentum
- features
  - momentum conserving: $<nv_y>$ vs. d/dx $<v_y>$ competition
  - drift-wave, sheath, curvature, Kelvin-Helmoltz instabilities
  - order unity fluctuations, blobs …

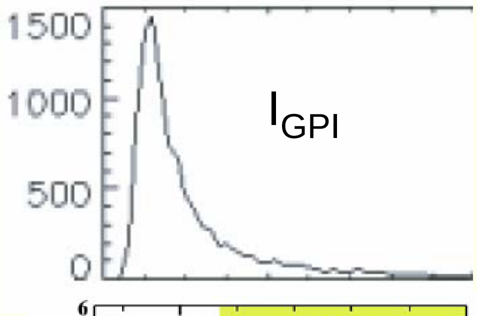
- use the SOLT code to
  - check analytical blob velocity scalings
  - compute blob production rate

SOLT turbulence code reproduces generic features of boundary turbulence observed in experiments

SOLT code | **NSTX + others**

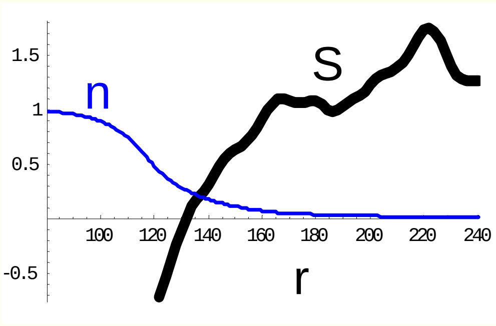
PDF of fluctuations

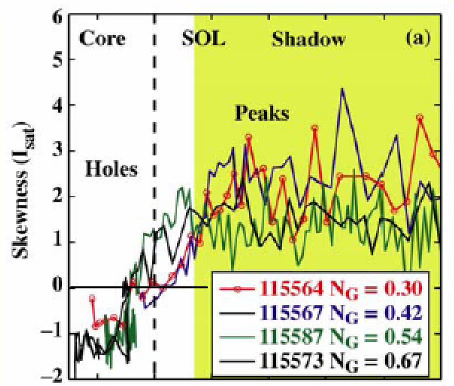




Zweben, 2004

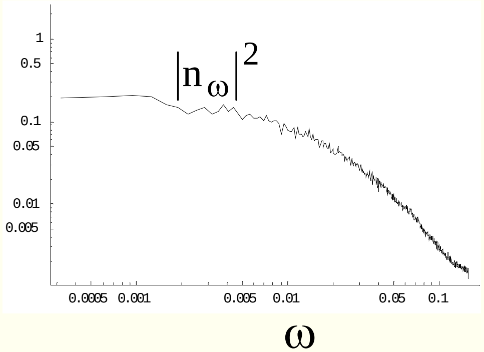
Skewness vs. radius

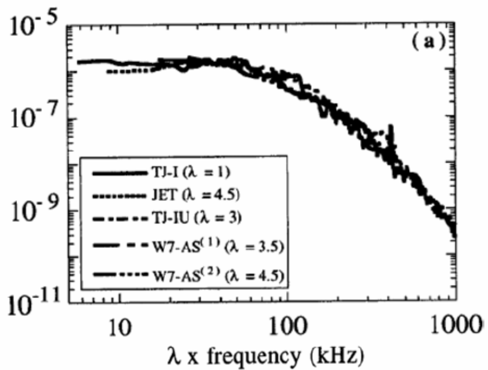




Boedo, 2006

Freq. spectrum



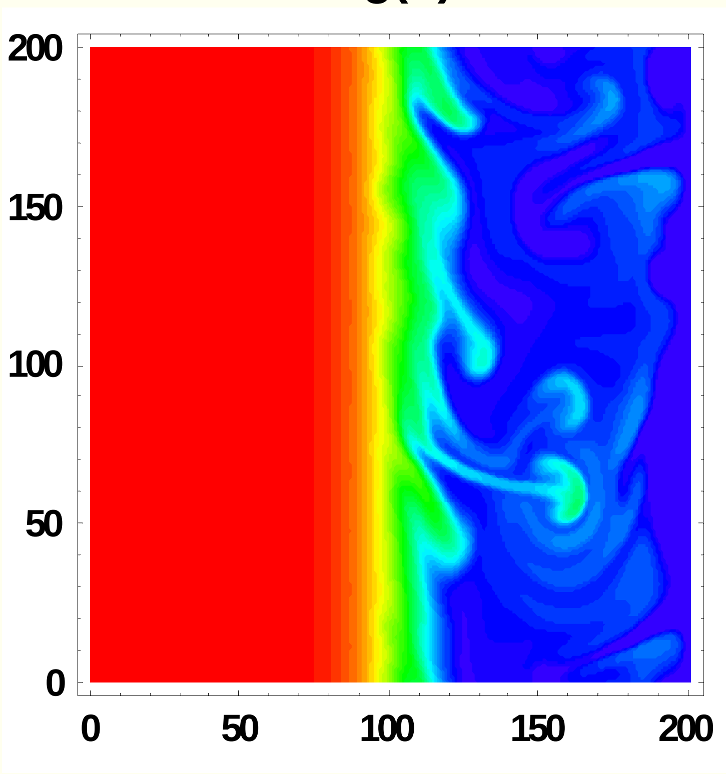


Zweben, 2007

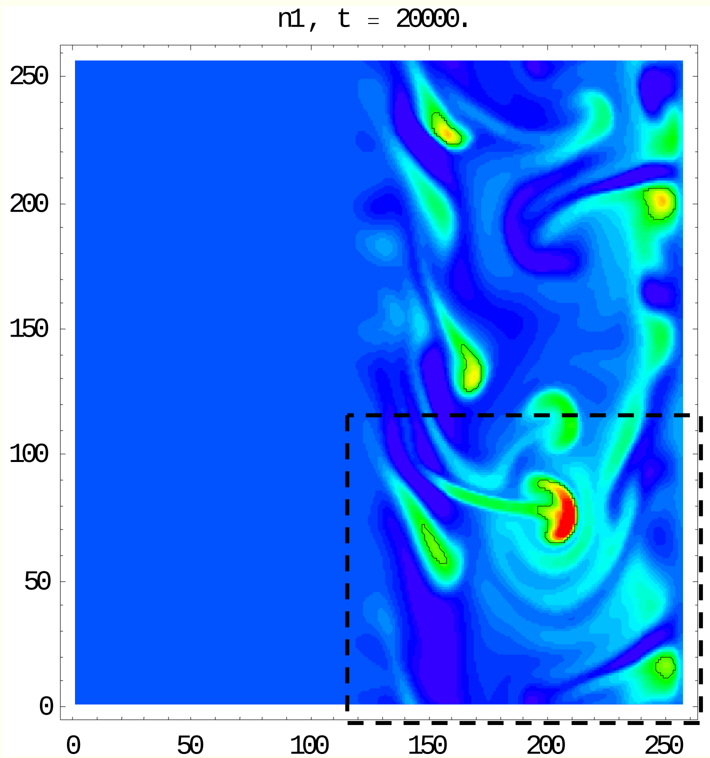
SOLT code movie frames show blob formation and ejection

- coherent blobs are formed
- blob ejection is intermittent
- order unity density fluctuations in far SOL
- visual appearance of movies approximates GPI

log(n)

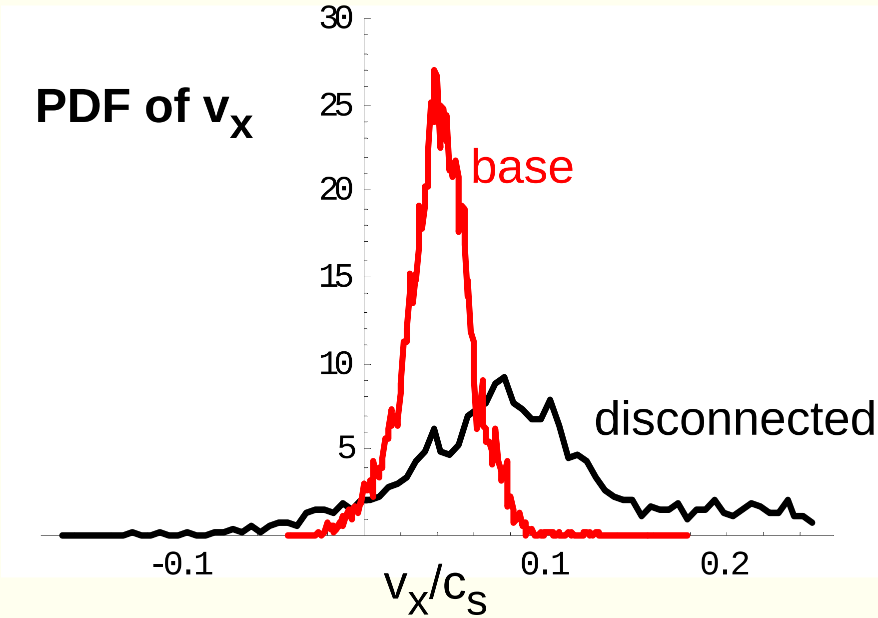


δn/<n>



Simulations show that radial blob velocity *should* increase with disconnection (gas puff, detachment, …)

- sheath conductivity present in base case (connected/attached)
- turn off sheath conductivity to model disconnection/detachment

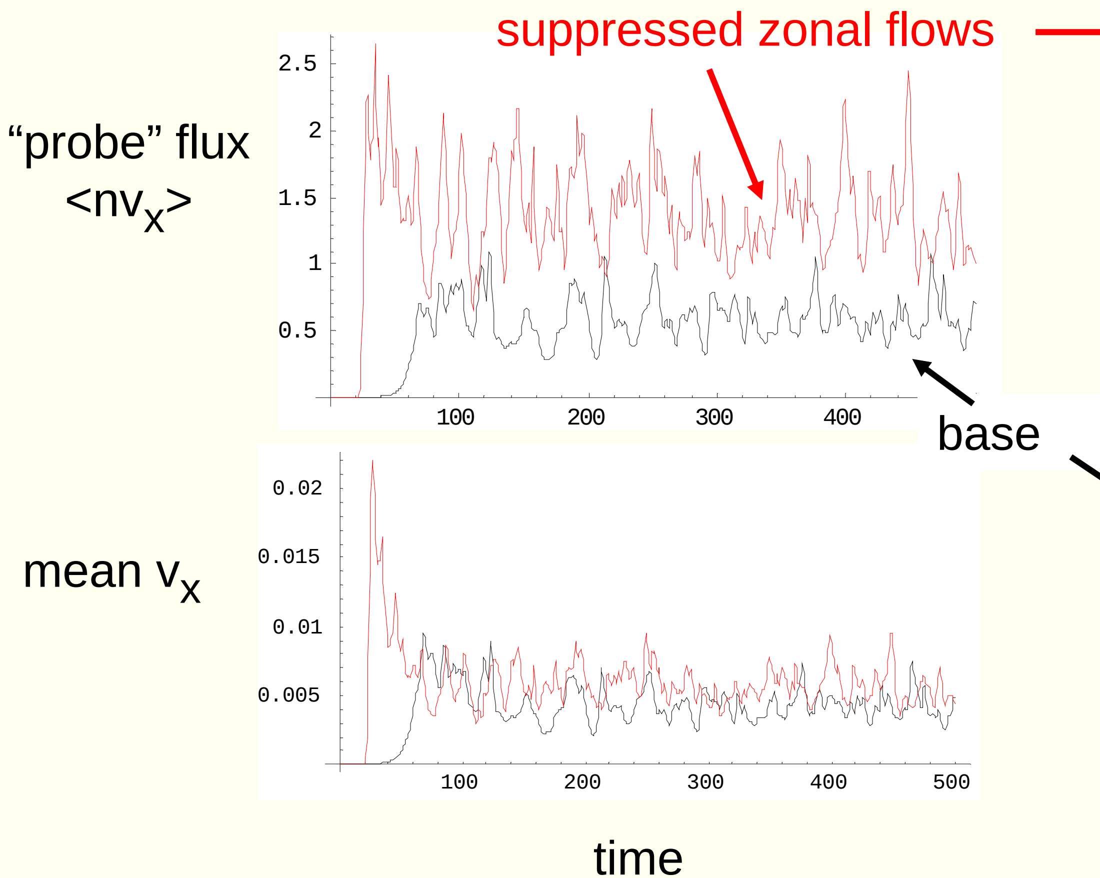


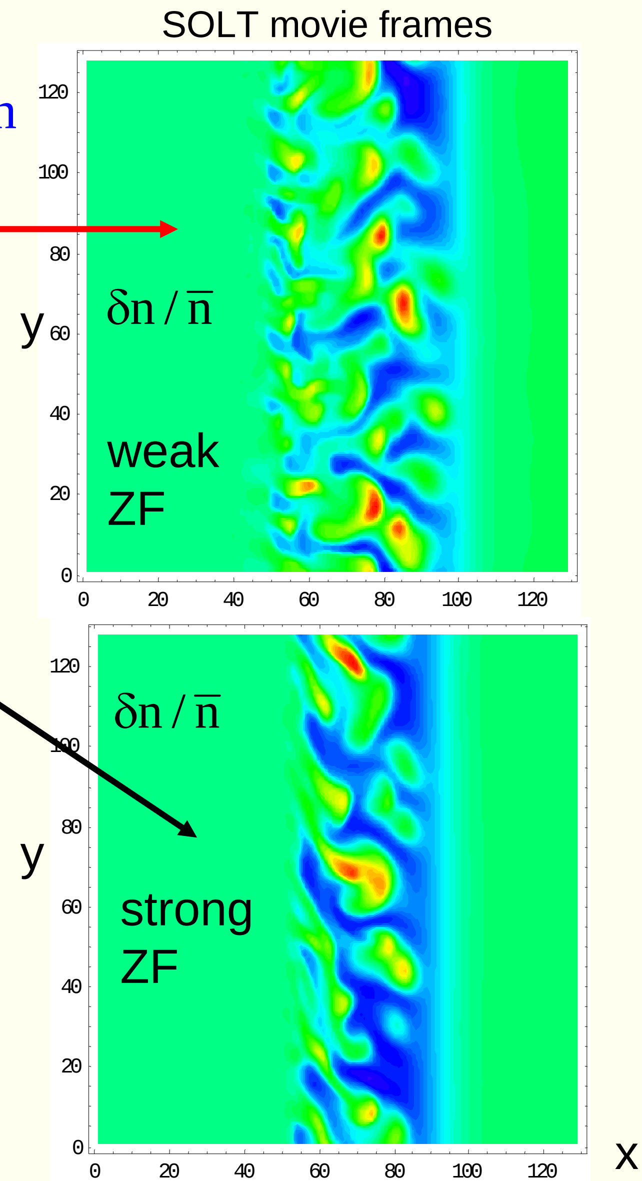
Vx/Cs	mean	std-dev
base	0.040	0.019
disconnected	0.083	0.066

- turbulence code confirms previous analytical scaling estimates of blob velocity
- … with significant spread in PDF from $v \cdot \nabla\nabla^2\Phi$
- v_x increase not seen in experiment

Suppression of zonal flows ⇒ increased blob production

- neutral gas injection could provide extra friction which reduces edge rotation and zonal flows
- plausible hypothesis for experimental observation



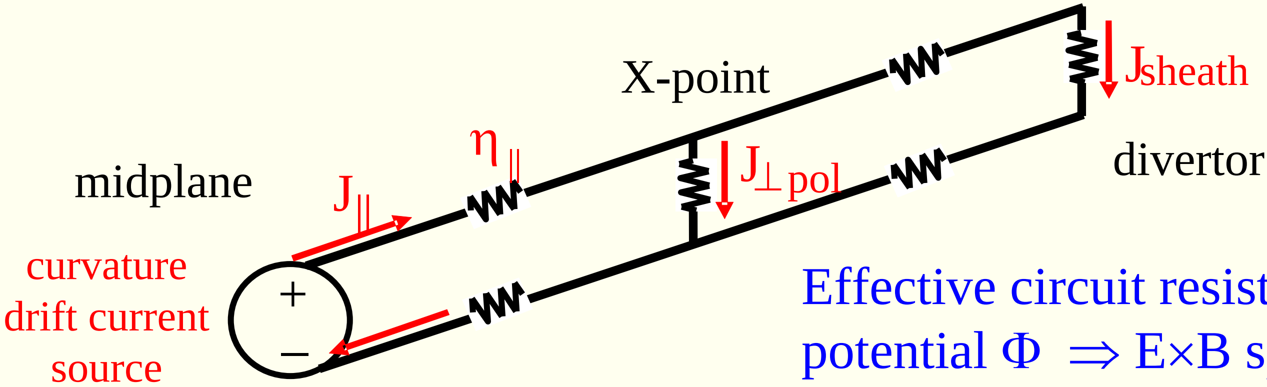


Summary

- SOLT code
  - can reproduce many generic experimentally observed features of SOL turbulence (PDFs, skewness profiles, freq. spectra)
- Blob speed-up with disconnection
  - seen in SOLT run, and analytical theory
  - not seen in experiment
- Fundamental prediction of blob theory & simulation remains to be confirmed by experiment
  - Future work: solve this puzzle
    - better shots to compare (was ref. shot attached & puff shot detached?)
    - compare ELMs
    - challenge to theory (is there a problem, or compensating effect)
- Blob production rate increased when zonal flows suppressed in simulations (possibly relation to experiment, neutral friction?)
- Also with these tools can:
  - characterize v_x and a_b distributions
  - develop synthetic GPI diagnostic

Backup slides

Electrical circuit of blob



Effective circuit resistance ⇒ potential Φ ⇒ $E \times B$ speed v_x

- increased parallel resistivity ($\eta_{\|} \propto \Lambda$) increases circuit resistance
- current loops are forced to close locally at midplane or at X-point
- blobs disconnect from divertor plate sheaths and move faster
- cold gas puff in X-pt region could accomplish this
  - directly observe v_r increase with GPI
  - should increase SOL width
- disconnection, increased ⊥ thermal flux, related to SOL density limit physics:
  - D.A. D'Ippolito and J.R. Myra, Phys. Plasmas **13**, 062503 (2006).
- electrical disconnection vs. thermal (detachment)

Characteristic blob size and speed

- blob size and speed are often given relative to Bohm units, ρ_s and c_s
- theoretical invariance arguments suggest a different *natural* scaling taking into account the physics of
  - cross-field ion polarization currents (vorticity advection)
  - parallel current flow into sheaths
  - grad-B and curvature driven currents

$$a_* = L_{\|}^{2/5} \rho_s^{4/5} / R^{1/5} \qquad v_* = c_s \left(\frac{a_*}{R} \right)^{1/2}$$

- $a_b > a_* \Rightarrow$ parallel current to sheath balances curvature
- $a_b < a_* \Rightarrow$ ion polarization current balances curvature
- v_* is the E×B drift speed (due to curvature-induced charge polarization) for a blob with $a_b = a_*$
- a_* is the most stable blob size

Equations of the SOLT model

vorticity

$$\partial_t \nabla^2 \tilde{\phi} = \left\{ -\mathbf{v}_E \cdot \nabla \nabla^2 \phi + \alpha_{DW} \frac{\overline{T}^{3/2}}{\overline{n}} \{\phi - T \ln(n)\} + \alpha_{sh} \sqrt{T} \left[1 - e^{\Lambda_B - \phi/T} \right] - \frac{\beta}{n} \partial_y (nT) + \hat{\mu} \nabla^4 \phi \right\}$$

density

$$(\partial_t + \mathbf{v}_E \cdot \nabla) n = \alpha_{DW} \overline{T}^{3/2} \{\phi - T \ln(n)\} - \alpha_{sh} n \sqrt{T}\, e^{\Lambda_B - \phi/T} + S_n + D \nabla^2 n$$

temperature

$$(\partial_t + \mathbf{v}_E \cdot \nabla) T = -\alpha_{sh} s_E T^{3/2} e^{\Lambda_B - \phi/T} + S_T + D \nabla^2 T$$

zonal momentum

$$\partial_t \langle n v_y \rangle + \partial_x \langle n v_x v_y \rangle = \int dx \left\langle \alpha_{sh} n \sqrt{T} \left[1 - e^{\Lambda_B - \phi/T} \right] \right\rangle + \overline{\mu} \partial_x^2 \langle v_y \rangle + S_\phi$$