Physics of SOL Broadening by Turbulence and Structures

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Collaborators

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Outline

- The Problem
- SOL Broadening by Turbulence Spreading (N.B. New results since ‘22)
- Simulation Results re: Spreading
- Experimental Results re: Spreading (DIII-D)

  3+4 sneak preview: spreading flux tracks fluctuation skewness!
- G.R.E. and Blob-Void Production
- What is a Blob/Void ? → Some Physics !

Background

- Conventional Wisdom of SOL:

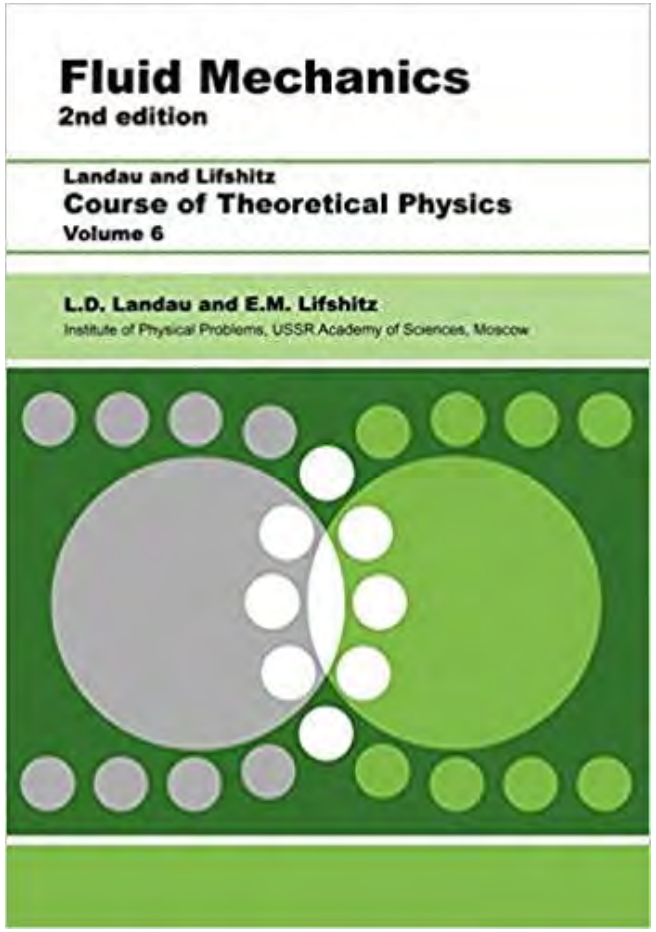
  (cf: Stangeby...)

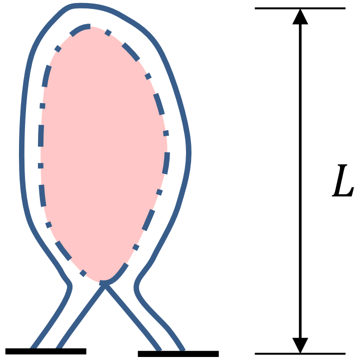
  - Turbulent Boundary Layer, ala’ Blasius, with D due turbulence
  - $\delta \sim (D\tau)^{1/2}, \tau \approx L_c/V_{th}$
  - $D \;\; \leftrightarrow$ local production by SOL instability process

    → familiar approach, D ala’ QL

- Features:

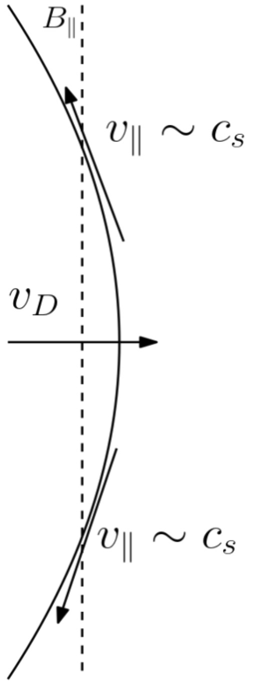
  - Open magnetic lines → dwell time τ limited by transit, conduction, ala’ Blasius
  - Intermittency → “Blobs” etc. Observed. Physics?





Background, cont’d

- But... Heuristic Drift (HD) Model (Goldston +)
  - $V \sim V_{\text{curv}}$, $\tau \sim L_c/V_{thi}$, $\boxed{\lambda \sim \epsilon\,\rho_{\theta i}}$ → SOL width
  - Pathetically small
  - Pessimistic B_θ scaling, yet high I_p for confinement
  - Fits lots of data.... (Brunner ’18, Silvagni ‘20)



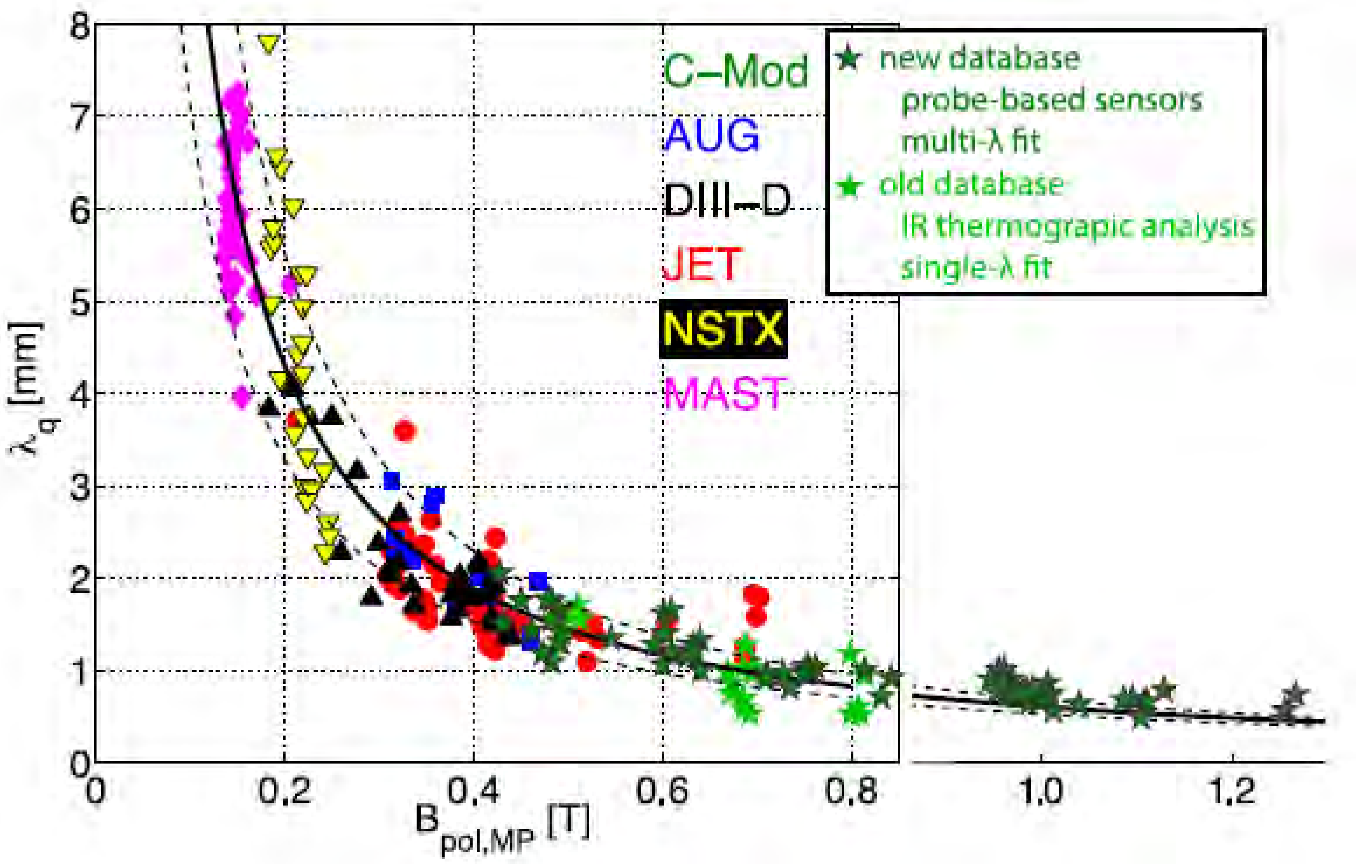
- Why does neoclassical work? → ExB shear suppresses SOL modes i.e.

$$\gamma_{\text{interchange}} \sim \frac{c_s}{(R_c\lambda)^{\frac{1}{2}}} - \boxed{\frac{3T_{edge}}{|e|\lambda^2}}$$

shearing ←→ strong λ^{-2} scaling

from: $\frac{c_s}{(R_c\lambda)^{\frac{1}{2}}} - \langle V_E\rangle'$

Background: HD Works in H-mode



"Brunner Plot"

HD is Bad News…

Background, cont’d

- THE Existential Problem... (Kikuchi, Sonoma TTF):

Desire ⟨ Confinement → H-mode ←→ ExB shear
Power Handling → broader heat load, etc

→ Both to be good !

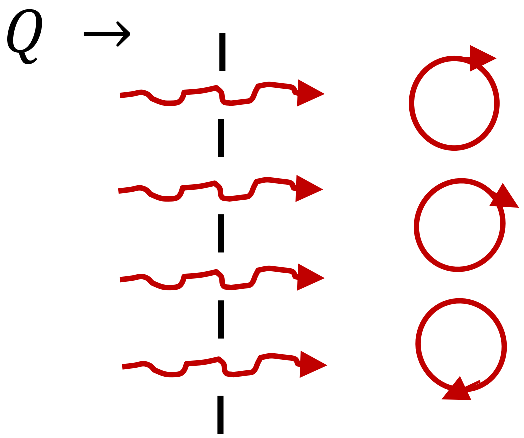
How reconcile? – Pay for power mgmt with confinement ?!

- Spurred:
  - Exploration of turbulent boundary states with improved confinement: Grassy ELM, WPQHM, I-mode, Neg. D ... re-visit ITB + L-mode edge?
  - SOL width now key part of the story
  - Simulations, Visualizations (XGC, BOUT...) ~ “Go” to ITER and all be well
- But... What’s the Physics ?? How is the SOL broadened?

Some Theory

SOL BL Problem

- SOL Excitation
  - Local production (SOL instabililties) – Q driven
  - Turbulence energy influx from pedestal
- Key Questions:
  - Local drive vs spreading ratio → Ra
  - Is the SOL usually dominated by turbulence spreading?
  - How far can entrainment penetrate a stable SOL → SOL broadening?
  - Effects ExB shear, role structures ?



local production

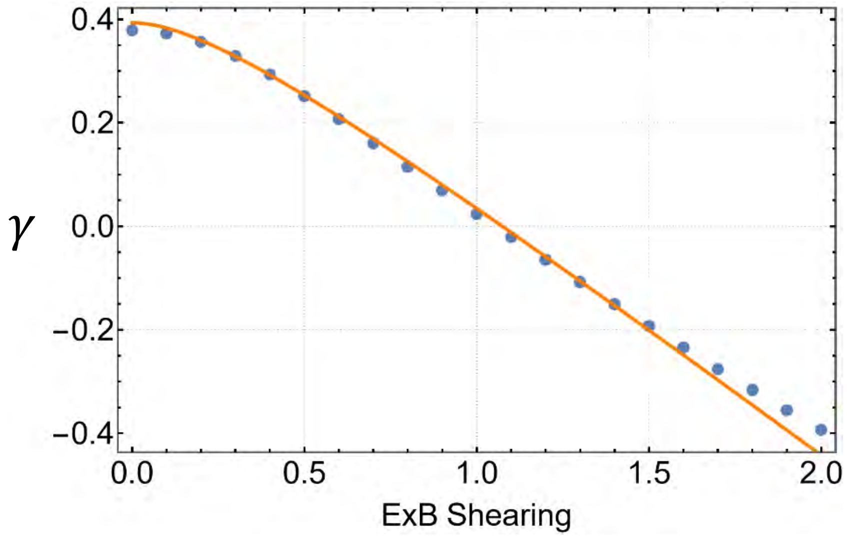
Physics Issues – Part II

[C.f. Chu, P.D., Guo, NF 2022]

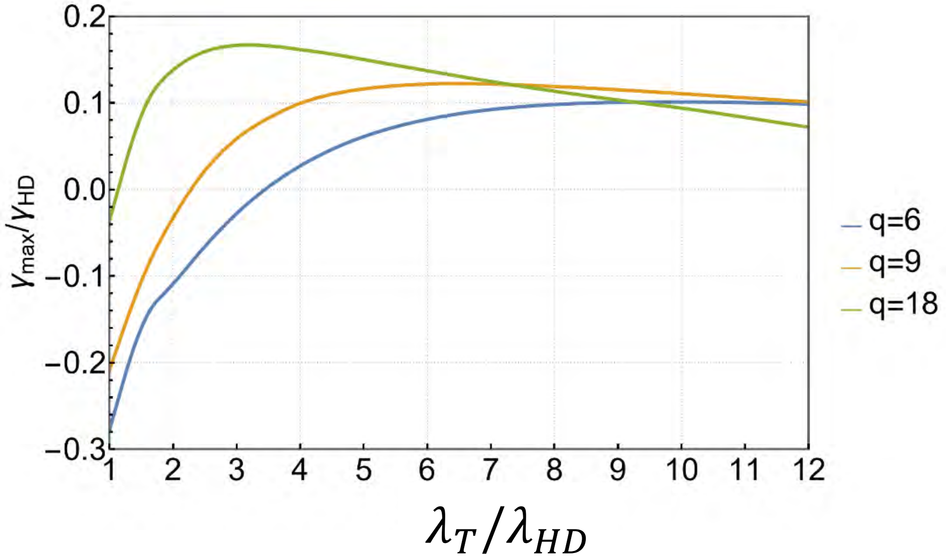
- How calculate SOL width for turbulent pedestal but a locally stable SOL?
  - spreading penetration depth
  - must recover HD in WTT limit
- ➡ Scaling and cross-over of λ_q relative HD model
- ➡ What is effect/impact of barrier on spreading mechanism?
- Can SOL broadening and good confinement be reconciled ?

Model 1 – Stable SOL – Linear Theory

- Standard drift-interchange with sheath boundary conditions + ExB shear (after Myra + Krash.)



Linear Growth Rate of a specific mode (fixed k_y) v.s. $E \times B$ shear at $q = 5, \beta = 0.001, k_y \cdot \lambda_{HD} = 1.58$.



Maximal Linear Growth Rate of Interchange Mode in the SOL v.s. normalized layer width λ_D/λ_{HD} at different SOL safety factor q (with $\beta = 0.001$)

- Relevant H-mode ExB shear strongly stabilizing $\gamma_{HD} = c_s/(\lambda_{HD}R)^{1/2}$
- Need λ/λ_{HD} well above unity for SOL instability. $V_E' \approx \frac{3T_e}{|e|\lambda^2}$ → layer width sets shear

Model 2 – Two Multiple Adjacent Regions

- "Box Model" – after Z.B. Guo, P.D.

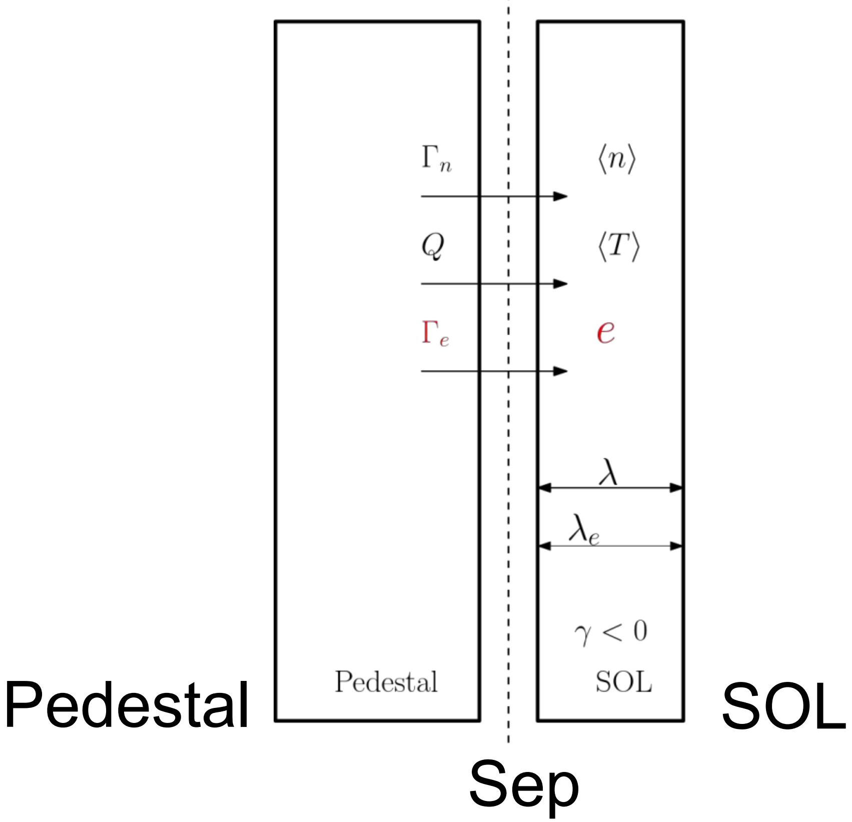


Illustration of Two Box Model: SOL driven by particle flux, heat flux and intensity flux (Γ_e) from the pedestal. The horizontal axis is the radial direction, and vertical axis is the poloidal direction.

- Key Point:
  - Spreading flux from pedestal can enter stable SOL
  - Depth of penetration ➔ extent of SOL broadening

➔ Problem in one of entrainment/penetration

Width of Stable SOL

- Fluid particle: $\frac{dr}{dt} = V_{Dr} + \tilde{V}$

drift

fluctuating velocity

- Dwell time: $\tau_{\parallel}$

Dwell time $\tau_{\parallel}$
constrains excursion

- $\delta^2 = \langle (\int (V_D + \tilde{V}) dt)(\int (V_D + \tilde{V}) dt) \rangle$

$\langle (\mathrm{step})^2 \rangle$

$$= V_D^2 \tau_{\parallel}^2 + \langle \tilde{V}^2 \rangle \tau_c \tau_{\parallel}$$

correlation time
modest turbulence ↔ $\tau_c \geq \tau_{\parallel}$

$$= \lambda_{HD}^2 + \varepsilon \tau_{\parallel}^2$$

turbulence energy density

See also
Fokker-Planck analysis
i.e. drift + diffusion

- So $\boxed{\lambda = [\lambda_{HD}^2 + \varepsilon \tau_{\parallel}^2]^{1/2}}$ → <u>SOL width</u> [Effects add in quadrature]
- How compute ε ? → turbulence energy in SOL. Need relate to pedestal
- N.B. Can write: $\lambda = [\lambda_{HD}^2 + \lambda_e^2]^{1/2}$ λ_e is turbulent width

Calculating the SOL Turbulence Energy 1

- Need compute Γ_e effect on SOL levels
- $K - \epsilon$ type model, mean field approach (c.f. Gurcan, P.D. '05 et seq)
  - Can treat various NL processes via σ, κ
  - Exploit conservative form model
- $\partial_t \varepsilon = \gamma\varepsilon - \sigma\varepsilon^{1+\kappa} - \partial_x \Gamma_e$ → Spreading, turbulence energy flux

NL transfer $\gamma_{NL} \sim \sigma\varepsilon^{\kappa}$

* Growth $\gamma < 0$
here contains shear + sheath

→ • N.B.: No Fickian model of Γ_e employed, yet

- Readily extended to 2D, improved production model, etc.

Calculating the SOL Turbulence Energy 2

- Integrate ε equation $\int_0^\lambda$; “constant e” approximation
- Take quantities = layer average
- $\Gamma_{e,0} + \lambda_e \gamma \varepsilon = \lambda_e \, \sigma \, \varepsilon^{1+\kappa}$

Separatrix fluctuation energy flux → Single parameter characterizing spreading

So for $\gamma < 0$,

$$\boxed{\Gamma_{e,0} = \lambda_e |\gamma| \varepsilon + \sigma \lambda_e \varepsilon^{1+\kappa}}$$

λ_e = layer width for ε

$\Gamma_{e,0}$ vs linear + nonlinear damping

- Ultimately leads to recursive calculation of Γ_e

Calculating the SOL Turbulence Energy 3

[Mean Field Theory]

- Full system:

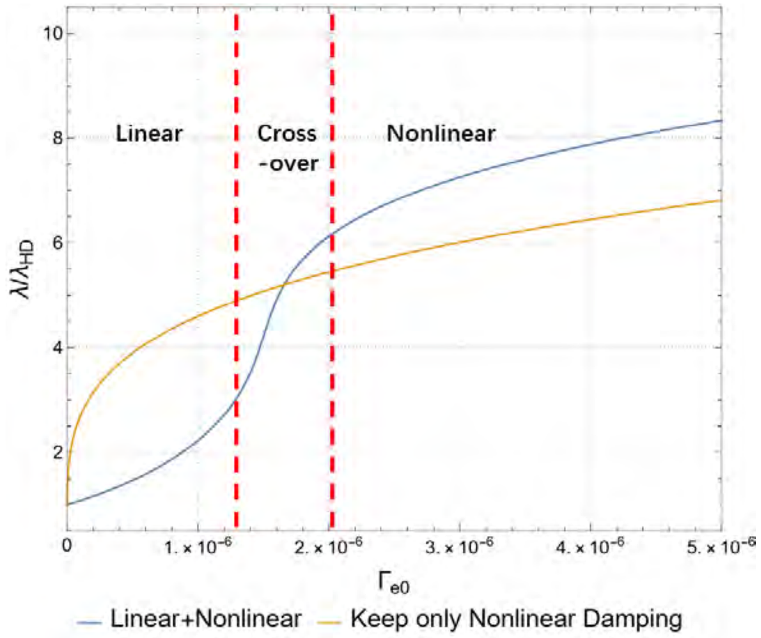
$$\boxed{\begin{aligned} \Gamma_{e,0} &= \lambda_e |\gamma| \varepsilon + \sigma \lambda_e \varepsilon^{1+\kappa} \\ \lambda_e &= \left[\lambda_{HD}^2 + \varepsilon \tau_{\parallel}^2\right]^{1/2} \end{aligned}}$$

Simple model of turbulent SOL broadening

- $\Gamma_{0,e}$ is single control parameter characterizing spreading
- $\tilde{\Gamma}_{0,e}$? Expect $\tilde{\Gamma}_e \sim \Gamma_0$

SOL width Broadening vs $\Gamma_{e,0}$

- SOL width broadens due spreading



(blue) (orange)

λ/λ_{HD} plotted against the intensity flux Γ_{e0} from the pedestal at $q = 4, \beta = 0.001, \kappa = 0.5, \sigma = 0.6$

Variation indicates need for detailed scaling analysis

- Clear decomposition into
  - Weak broadening regime → shear dominated
  - Cross-over regime
  - Strong broadening regime

  ➔ NL damping vs spreading $\Big\}$ relevant

- Cross-over for:

  $\langle \tilde{V}^2 \rangle \sim V_D^2$ ➔ cross-over $\Gamma_{0,e}$

- Cross-over for $\tilde{V} \sim O(\epsilon) V_*$

SOL Width: Some Analysis

Have $\Gamma_{e,0} = |\gamma| e \lambda_e + \lambda_e \sigma e^{1+\kappa}$

a) Damping dominated

$\Gamma_e \approx |\gamma| \, \lambda_e \, e \qquad \lambda_q^2 = \lambda_e^2 + \lambda_{HD}^2$

$$\boxed{\lambda_q = \left[\lambda_{HD}^2 + \left(\frac{\Gamma_e \tau_\parallel^2}{|\gamma|} \right)^{2/3} \right]^{1/2}}$$

- Spreading enters only via Γ_e at sep.
- Shearing via $|\gamma|$
- τ scalings → $\tau_\parallel$ vs $\tau_\parallel^{2/3}$ → current scaling of λ_e weaker

SOL Width: Some Analysis, Cont'd

b) NL dominated

$\Gamma_e \approx \lambda_e \, \sigma \, e^{1+\kappa}$ $\qquad$ $\lambda_q^2 = \lambda_e^2 + \lambda_{HD}^2$

$$\boxed{\lambda_q = \left[\lambda_{HD}^2 + \left(\frac{\Gamma_e}{\sigma}\right)^{2/(3+4\kappa)} \tau_{\|}^{[4(1+\kappa)/(3+2\kappa)]}\right]^{1/2}}$$

– weaker Γ_e scaling, $\lambda_q \sim (\Gamma_e/\sigma)^{1/5}$; STT

– $\tau_{\|}^{3/4}$ vs $\tau_{\|}$ → weaker current scaling

The Question

- What is Γ_e ? How characterize ? ←→ Flux-Gradient Relation?
- Conventional Wisdom:

$$\Gamma_e \approx -D(e)\frac{\partial e}{\partial x} \rightarrow \frac{D_0 e^{\alpha+1}}{f(V_E')}/w_{ped}$$ as in CDG ‘22

But: “ The conventional wisdom is little more than convention”

— J.K. Galbraith

- See computation, experiment…

Some Simulation Results

(cf. Nami Li, X.-Q. Xu, P.D.; submitted)

➔ BOUT++ → pedestal + SOL

➔ 6 field model ("Braginskii for 21st century")

➔ Focus on weak peeling mode turbulence in pedestal

→ MHD turbulence state → small/grassy ELM, also WPQHM

3D Counterpart of Brunner (λ_q vs B_θ)

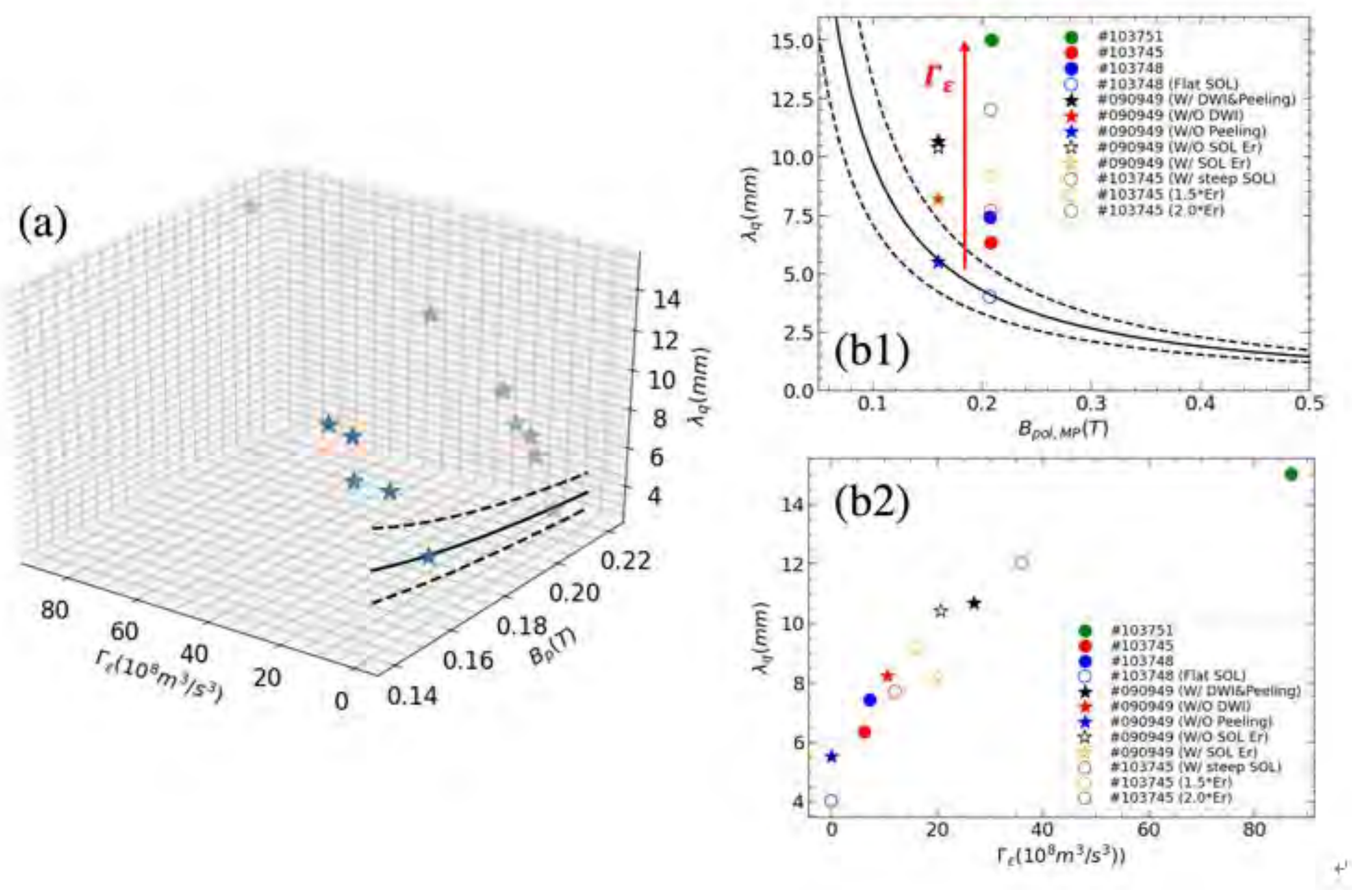


Fig. 3. (a) 3D plot of heat flux width λ_q vs poloidal magnetic field B_p and fluctuation energy density flux Γ_ε; (b) 2D plot of heat flux width λ_q vs poloidal magnetic field B_p (b1) and fluctuation energy density flux Γ_ε (b2).

3D Brunner Plot – Comments

- λ_q rises with Γ_e
- Low Γ_e , λ_q tracks hyperbola
- Large Γ_e , λ_q rises above Brunner/Goldston hyperbola
- λ_q grows with Γ_e

Spreading as Mixing Process ?

- Conjecture that λ_q should increase with <u>pedestal</u> mixing length ➔ Γ_e

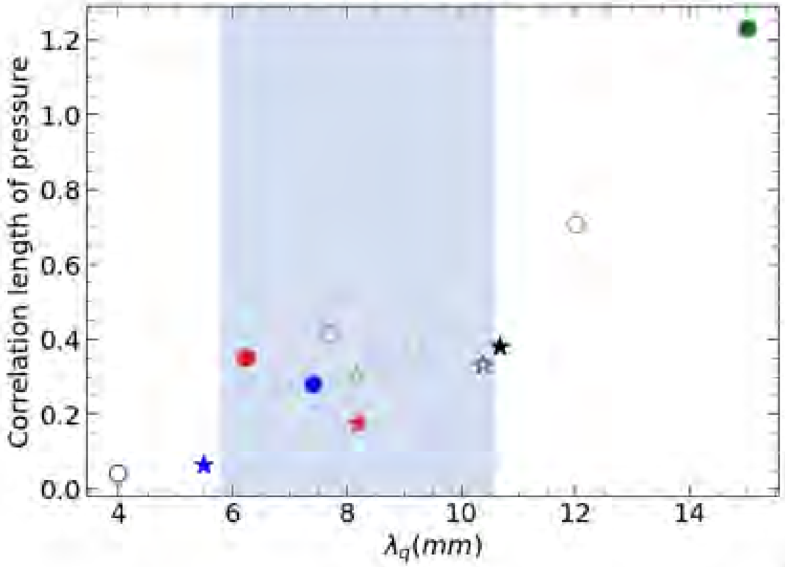


Fig 4. Radial correlation length of pressure near the separatrix vs. heat flux width λ_q.

- Note division into
  - drift dominated
  - cross-over (blue)
  - turbulent

Relate Spreading to Pedestal Conditions

N.B.

- Γ_e rises with pedestal ∇P_0 ←→ increased drive
- Collisionality dependence Γ_e:
  - high → no bootstrap current → ballooning → smaller l_{mix}
  - low → strong bootstrap → peeling → larger l_{mix}

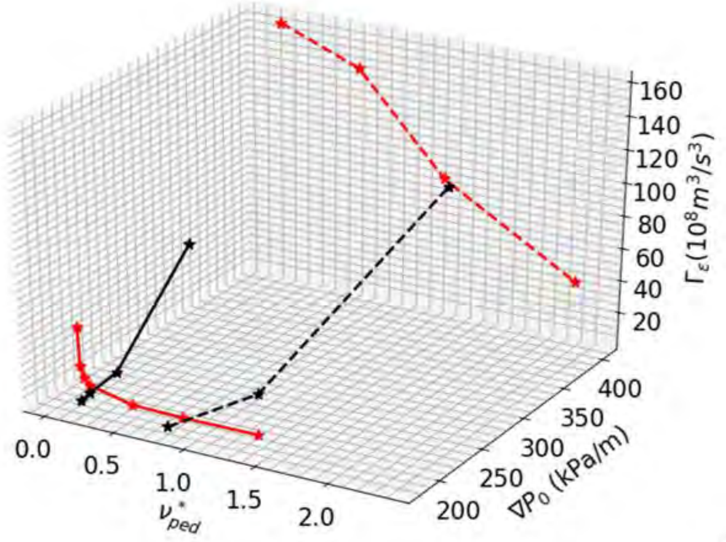


Fig. 7. 3D plot of fluctuation energy density flux Γ_ε vs pedestal peak pressure gradient ∇P_0 and υ^*_{ped}; black curves are ∇P_0 scan with low collisionality $\upsilon^*_{ped} = 0.108$ (solid curve) and high collisionality $\upsilon^*_{ped} = 1$ (dashed curve); red curves are υ^*_{ped} scan with small $\nabla P_0 \sim 200\ kPa/m$ (solid curve) and large $\nabla P_0 \sim 400\ kPa/m$ (dashed curve).

Fundamental Physics of Γ_e

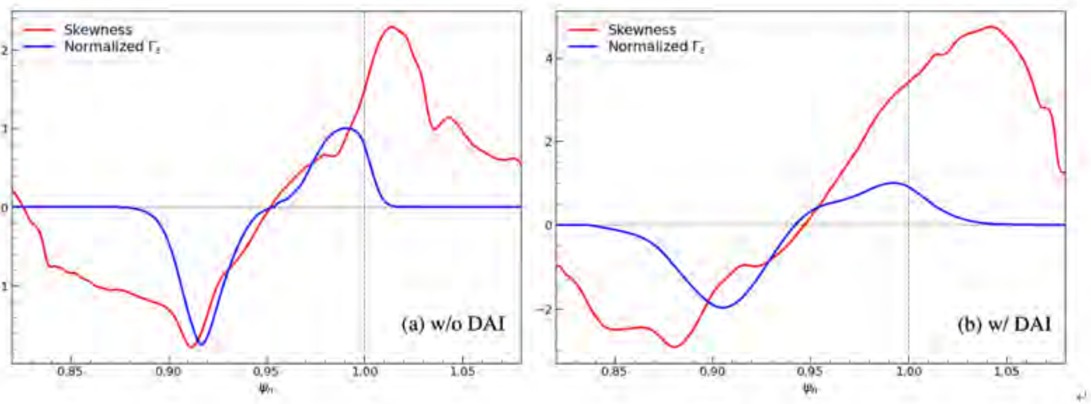


Fig. 6 Radial profiles of normalized fluctuation energy density flux Γ_ε (blue) and skewness (red) for without (a) and with (b) drift-Alfvén instability. Here fluctuation energy density flux is normalized to the max value for each case.

- Γ_e spreading tracks $\tilde{P}$ skewness
  - Outward for $s > 0$ → "blobs"
  - Inward for $s < 0$ → "voids"
- Zero-crossings Γ_e, s in excellent agreement

Fundamental Physics of Γ_e, cont'd

- Spreading appears likely linked to “coherent structures”
- Likely intermittent (skewness, kurtosis related)
- Related study (Z. Li); $Ku \sim 0.4$, so ➔ if Fokker-Planck analysis

$$\frac{\partial e}{\partial t} = -\frac{\partial}{\partial x}(Ve) + \cancel{\frac{\partial^2}{\partial x^2}(De)}$$

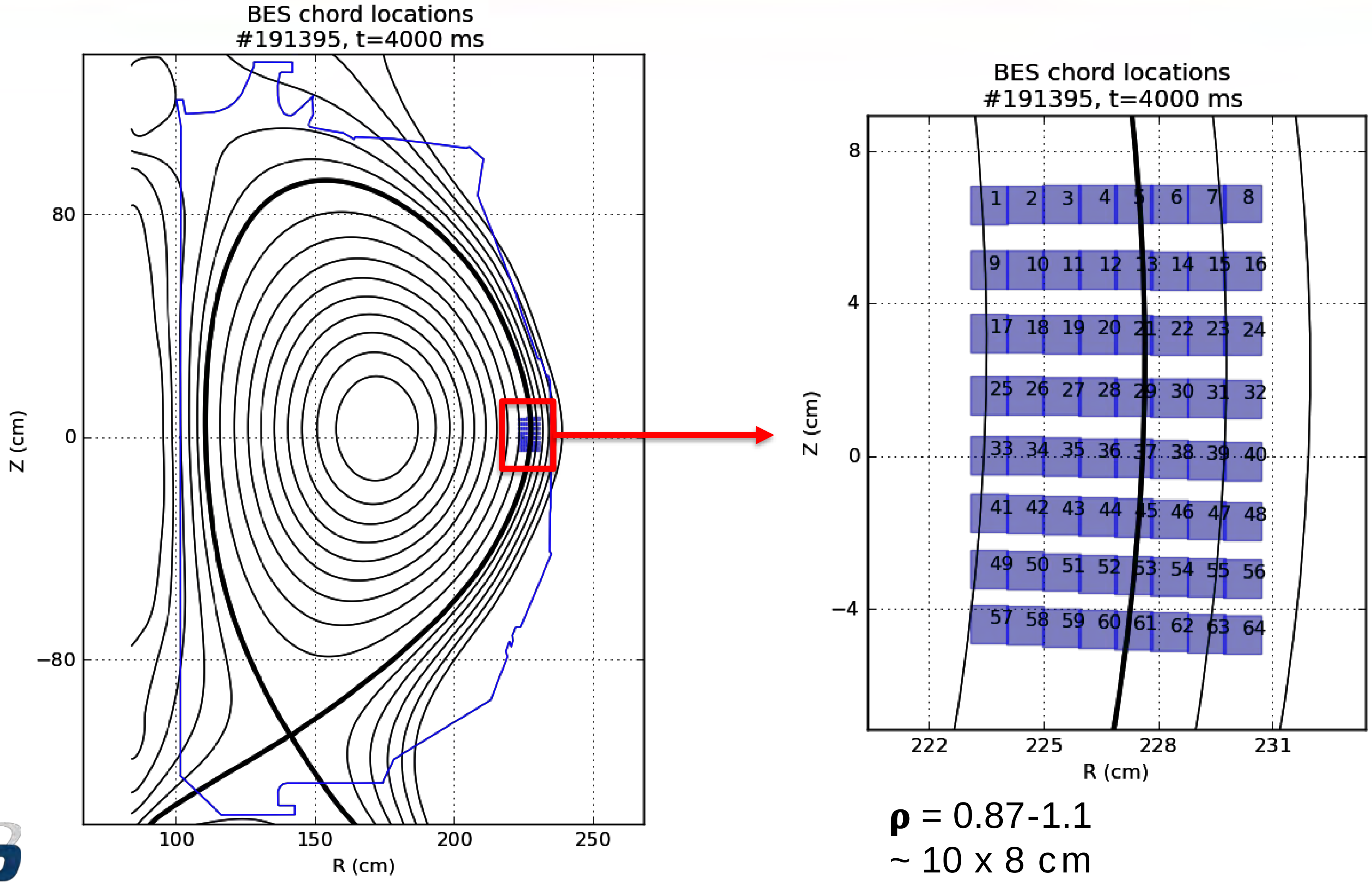
Convective !?

Relate V to pedestal gradient relaxation event (GRE) ?!

Why would one think of this?

Some Experimental Data

BES allows measuring **δ**n/n at the plasma edge



ρ = 0.87-1.1

~ 10 x 8 cm

Turbulence intensity flux $\langle \widetilde{V}_R \tilde{n}^2 \rangle$ is negative inside and positive outside the separatrix

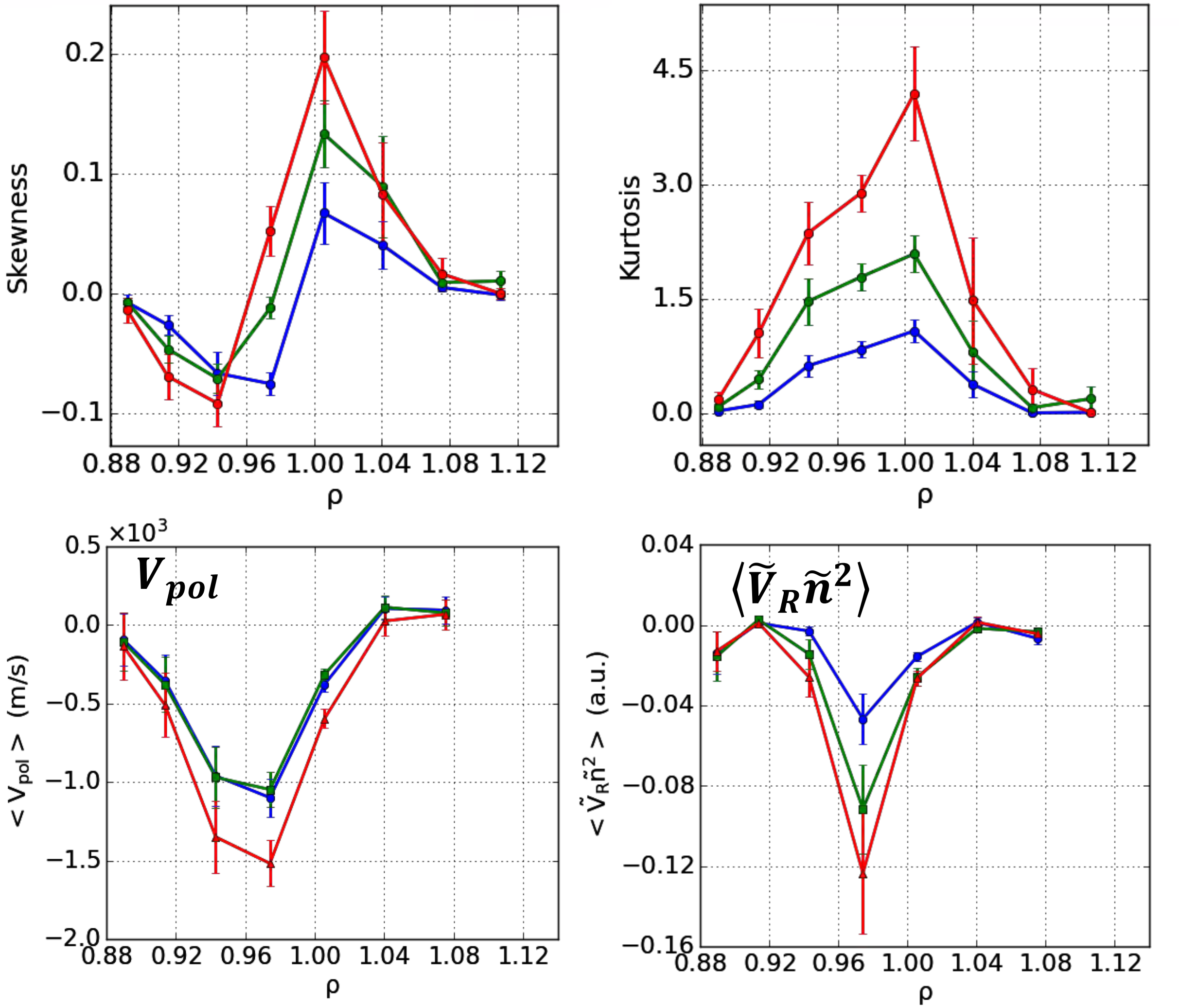
- Negative skewness of $\tilde{n}$ inside the separatrix and positive skewness outside indicate the prevalence of negative density fluctuations (voids) inside the separatrix and positive (blobs) outside.

- The formation zone of blob-void pairs (zero skewness) is located at ρ~0.96-0.98.

- Turbulence intensity flux $\langle \widetilde{V}_R \tilde{n}^2 \rangle$, measured using 2D BES, shows an inward turbulence spreading inside the separatrix while outside, the turbulence spreading is outward towards the SOL.

#192095, NBI power ramp, f=20-120 kHz

P_{NBI} = 1.2-1.7-2.5 MW, $\bar{n}_e$ = 3.1-3.1-3.4 × 10^{19} m^{-3}



What is going on ?

➔ Gradient Relaxation Events and SOL Broadening

<u>or</u>

“Interesting Things come in pairs”

➔ <u>More Theory</u>

General Question:

"Is there a connection between turbulence spreading and blob-void pairs of structures?"

Introduction, cont'd

- Foundation: Physics of turbulence spreading, avalanches, etc.

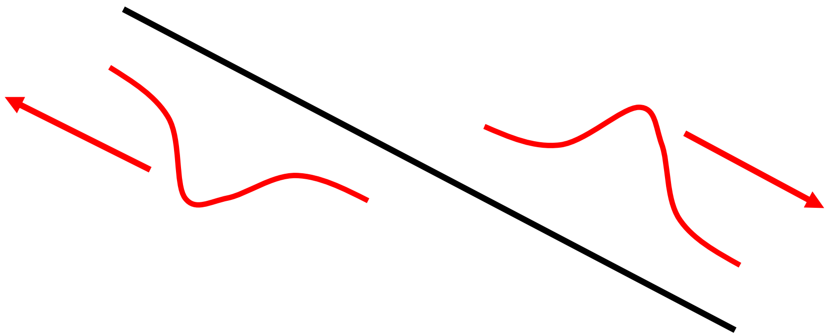
- Avalanches
- Spreading

observed

- M. Choi, 2018 (KSTAR) ECEI
- Khabanov, 2023 (DIII-D) BES velocimetry i.e. $\langle \tilde{V}_r \tilde{n}^2 \rangle$

Introduction, cont'd

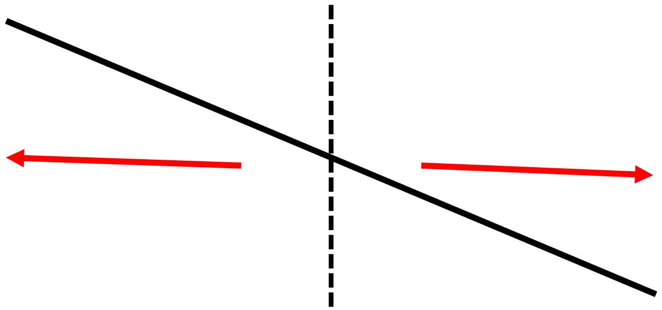
- Avalanches → opposite propagation of bumps and voids



P.D. + Hahm '95 et seq.

N.B.: bump and void propagation observed → Choi, 2018

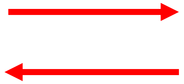
- Hint of opposite $\langle \tilde{v}_r \tilde{n}^2 \rangle$ spreading pulses near sep.

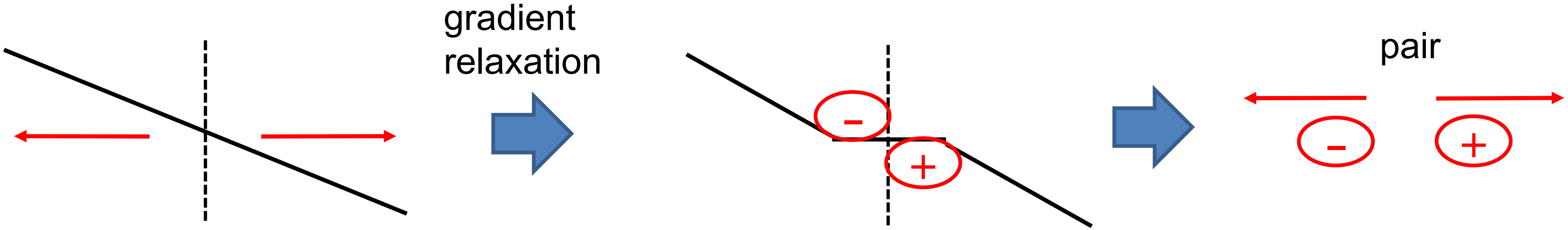


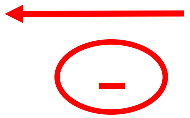
Khabanov
See also: Ting Long

- Recent results consistent with long history…

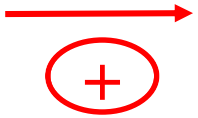
Introduction, cont’d

- Why the  ?
- Edge gradient relaxation event (GRE)



-  → inward propagating “void” or “hole”

←→ Conservative advection

-  → outward propagating “clump” or “blob”
- GRE sets initial impulse to blob, void

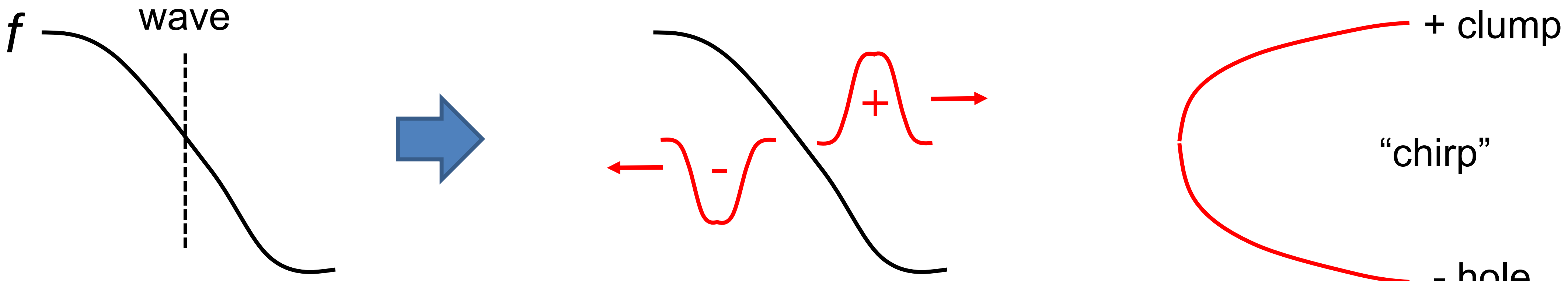
Related: B+B Model (1996→)

- 1D Vlasov mock up of EP resonant instability

or

B-O-T

“turbulence spreading”
in phase space



strong resonance

clump-hole pair

- N.B. BB speak and draw “clump-hole pair” but <u>calculate</u> via 3 wave coupling

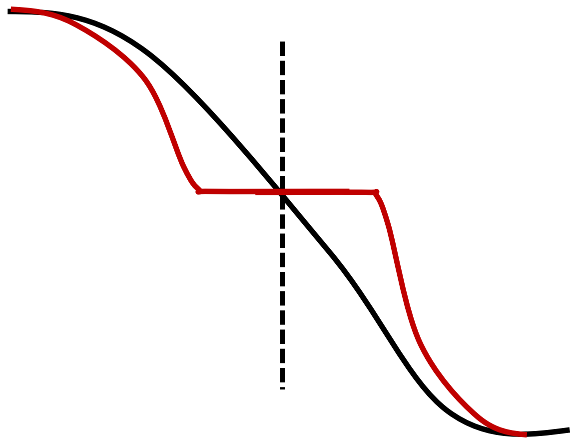
  ➔ considerable restriction on domain applicability

- Common element: relaxation → structure <u>pair</u> production and propagation

Related: B+B Model, cont'd (Ackn: V. Duarte)

- Recent variation on B + B: Lilley & Nyquist, 2014
  - Key: Plateau in $\langle f \rangle$ → <u>negative energy wave</u>

    Plateau ←→ akin to beam ➔ NEW



  - Negative energy waves easily destabilized by residual dissipation
- Clump hole pair generated → erodes plateau
- Suggest strong mixing (GRE) can initiate blob-void pair. Negative energy waves generic!

Related: B+B Model, cont'd

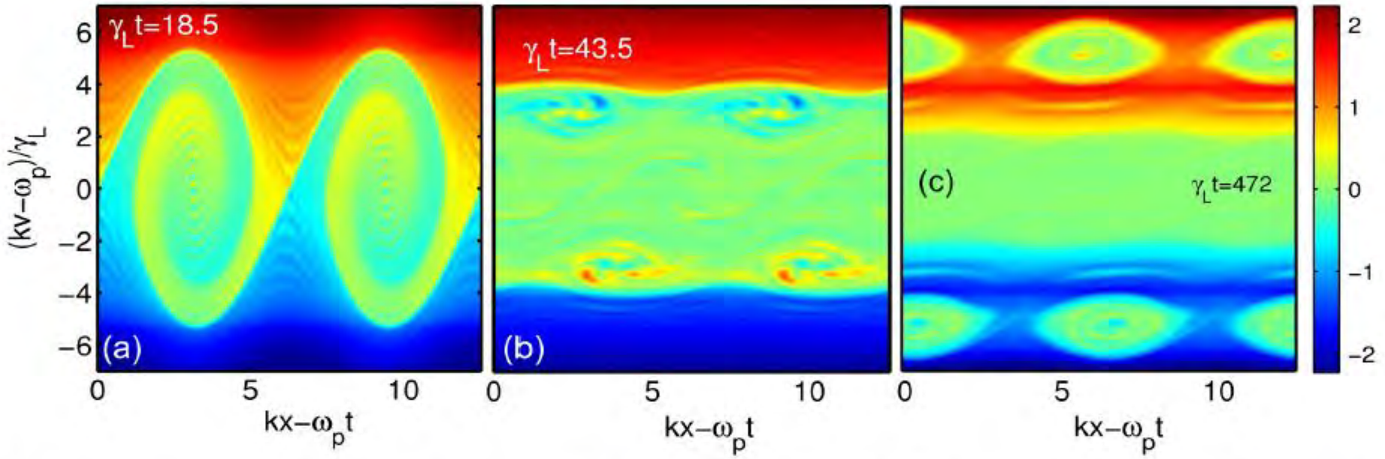


FIG. 2 (color online). Snapshots of the resonant fast particle distribution function for $\gamma_d/\gamma_L = 0.1$ that display (a) the initial phase mixing followed by (b) the almost spatially uniform plateau with sideband trapping regions forming close to the edge, and finally (c) a detaching hole-clump pair. Obtained using BOT [10,20].

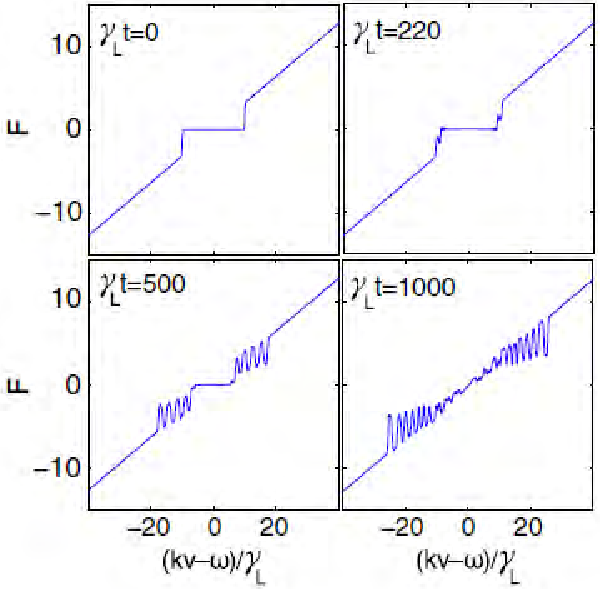


FIG. 5 (color online). Spatially averaged distribution function evolved using the BOT code [10,20] for $\gamma_d/\gamma_L = 2$, $k\Delta v/\gamma_L = 10$ and initial normalized amplitude $\omega_B^2/\gamma_L^2 = 10^{-6}$. The unstable plateau generates holes and clumps that eventually completely erode the plateau state.

But…

- If speaking of blobs, voids, structures etc…

➔

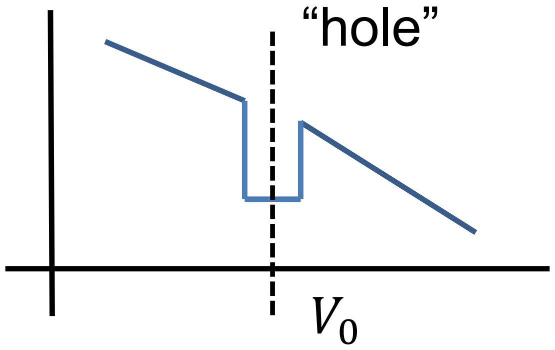
- “What makes a blob a blob ?”

⇔ Physics of self-coherence?

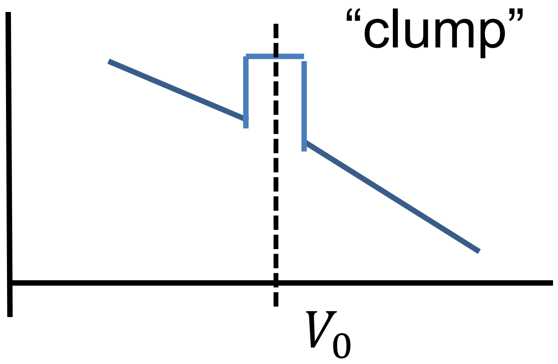
- N.B. I have <u>never</u> received a satisfactory answer to this question…

Blob-Void Pair: Basic Structure

- What makes a coherent structure "coherent" ?
- Clue: Vlasov Plasma



Or



$$\left.\begin{array}{l}\tilde{f}\\ \Delta V\end{array}\right\}$$

$\langle f \rangle = f_0 + \tilde{f}$ ↔ structure distorts equilibrium

- then: $-(\omega - kv)\tilde{f} = -\frac{q}{m}k\hat{\phi}\frac{\partial}{\partial v}\left[f_0 + \tilde{f}\right]$

$$\nabla^2\phi = -4\pi n_0 q \int f\, dv$$

- and standard analysis, ala' 'waterbag model' collisionless gravitation cf: Berk + '60s, Dupree '82

Blob-Void, cont'd

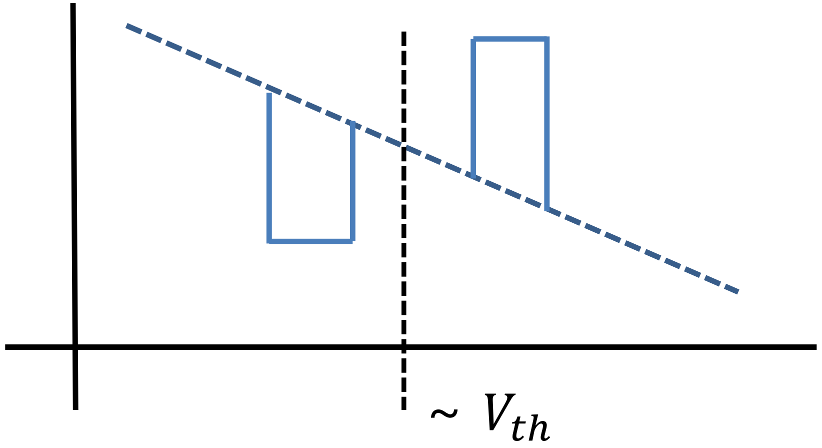
→ $$(\omega - kV_0)^2 = \frac{2\omega_p^2}{k} \frac{\tilde{f}\Delta V}{\epsilon(k,kV_0)} + k^2(\Delta V)^2$$

screening

dispersion of structure

- key: $\tilde{f}\Delta V$ → strength/charge sign $\tilde{f}$ → $\gtrless$ 0

  screening $\epsilon(k, kV_0)$ → $\gtrless$ 0



→

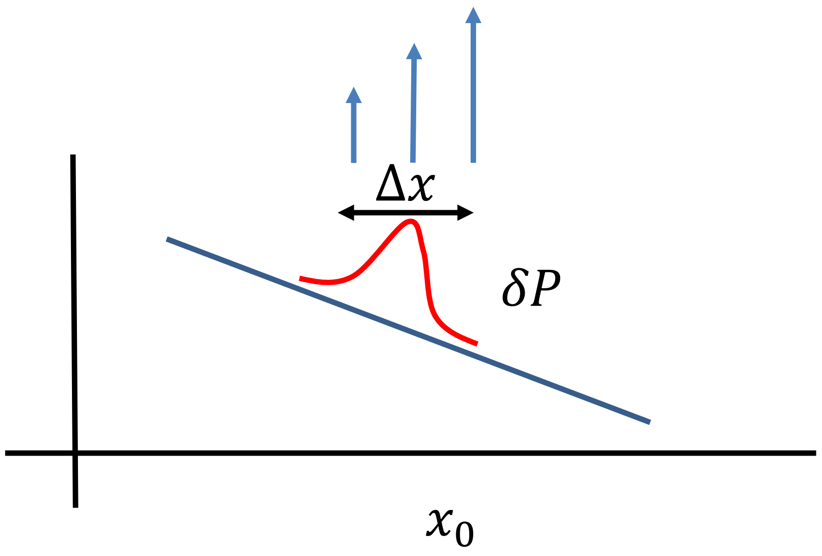
- "clump" : $\epsilon < 0$ for $\tilde{f}$ > 0 → $V_0 > V_{th}$
- "hole" : $\epsilon > 0$ for $\tilde{f}$ < 0 → $V_0 < V_{th}$

- N.B.: Coherence ←→ Self-field induced attraction overcomes streaming apart

Blob-Void, cont'd

- Relevant example: Pressure Blob in Shear Flow

$$-i(\omega - kV_0)\hat{P} = -\hat{V}_r \frac{\partial}{\partial r}\left[\langle P_0\rangle + \delta P\right]$$ δP in shear flow



$$-i(\omega - kV_0)\nabla_\perp^2\hat{\phi} = -\kappa\,\nabla_y\hat{P}$$

$$\nabla_\perp^2\,\hat{\phi} \;-\; \frac{\kappa\nabla_y\tilde{V}_r\,\partial_r P_0}{(\omega - kV_0)^2} = \frac{\kappa\nabla_y\tilde{V}_r\,\partial_r\delta P}{(\omega - kV_0)^2}$$

$$\hat{\phi} = \int dx'\,G(x,x')\,\frac{\kappa k^2\,\hat{\phi}\,\delta P(x')}{\left(\omega - kV_0(x')\right)^2}$$ N.B. After Taylor-Goldstein Eqn.

→ screened structure. Base state need not be unstable!

→ with box model, considerable simplification possible

$$\partial_r\delta P \;=\Delta P\left[\delta(x - x_0 + \Delta x) \;-\delta(x - x_0 - \Delta x)\right]$$

Blob-Void, cont'd

$$\rightarrow \ \phi(x) = G(x,x_0)\,\kappa\, k^2\, \phi(x_0)\Delta P \left[\frac{1}{\left(\omega - kV_0(x_0-\Delta x)\right)^2} - \frac{1}{\left(\omega - kV_0(x_0+\Delta x)\right)^2}\right]$$

- So for $x \sim x_0$:

$$\boxed{(\omega - kV_0)^2 = \overset{\textcircled{1}}{k^2\, V_0'^2\,(\Delta x)^2} \ - \overset{\textcircled{2}}{\left[2G\kappa k^2(\Delta P)\left(V_{ph} - V_0\right)k^2 V_0'\,\Delta x\right]^{\frac{1}{2}}}}$$

- Competition:
  - Shear across structure ←→ dispersion ①
  - ΔP → strength – blob size
  - G → screening by system ②

$\Delta x \equiv$ radial extent

- Does blob hold itself? together vs shear ? → key question !

→ competition of 1, 2

Blob-Void, cont'd

- The critical balance:

$$\frac{\Delta P}{\Delta x} \rightarrow \frac{\text{Blob size}}{\text{Blob extent}}$$

$$\neq \;\; \partial\langle P\rangle/\partial r$$

$$G\,\kappa\,\Delta P\left(V_{ph}-V_0\right) \text{ vs } V_0'^2(\Delta x)V_0'$$

➔ $\frac{G\kappa\Delta P/\Delta x}{V_0'^2}$ vs $\left[\left(V_{ph}-V_0\right)^{-1}V_0'\Delta x\right]$ ~ O(1)

←→ Richardson # (screened) for blob ~ 1

Ri = ω_B^2/V'^2 → buoy energy vs shear

- Consistent with qualitative expectations of marginality. Note screening enters !
- Blob vs Void → sign G ! (screening) → structure ExB shear layer, resonance

←→ location relative to shear layer ($V_{ph}=\omega/k$ vs $V_0(x)$) matters

N.B.: Begs question of SOL blob data vs Ri → unanswered

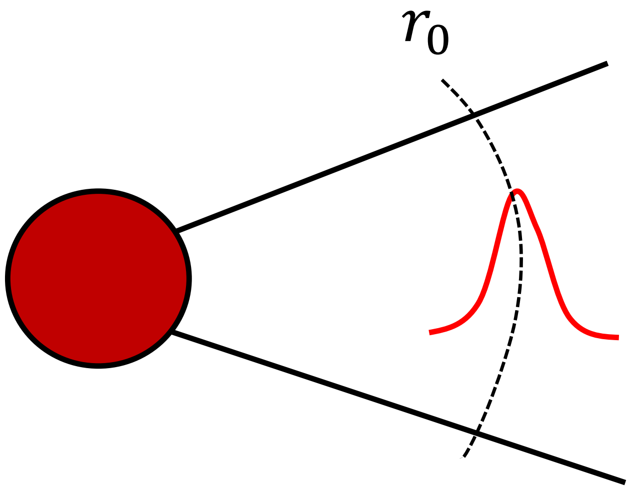
N.B.: Boedo 2003, et. seq noted pronounced effect of shearing on blob population

B) Blob-Void, cont'd

- Message: Can formulate physically meaningful coherecy or 'self-binding' criterion for blobs, voids in base state
- ~ Richardson # criterion interesting
  - amplitude ΔP and extent Δx combine vs shear ➔ minimal structural characterization. Screening enters.
  - how does it fare vs data?, simulation?

    Serious answer possible
- Need better understanding of role of resonance between V_{ph} and $V_0(x)$

From "Blobs" to "Bump"



- Samantha Chen +, TTF '23
  - density bump in disk
  - modifies PV profile ➔ stability etc. to Rossby wave
  - Rossby wave ➔ momentum transport ➔ accretion
- When would localized $\delta\beta(r)$ self-bind for Rossby wave system?
- i.e. $\omega = -k_x\beta/k^2$ now $\beta \rightarrow \beta + \delta\beta(x)$ ← localized defect. Persistence?
- so $\left(\omega - kV_0(x)\right) k_\perp^2\phi = -k_x\left(\beta + \delta\beta(x_0)\right)\phi$

From "Blobs" to "Bump", cont'd

- Similar analysis ➔

$$(\omega - kV_0)^2 = (k_x V_0' \Delta x)^2 + G\ k_x^2 V_0' \Delta\beta \Delta x$$

(shearing) (self-field of bump)

- Critical competition:

$\boxed{V_0' \quad \text{vs} \quad G\ \Delta\beta / \Delta x}$ set bump size, scale

- Relevance to staircases ? i.e. staircase as array of bumps ?

Thoughts for Experiment and Analysis

- Pulse propagation studies in SOL environments, i.e. Tubes?
- Track blob-void:
  - Pair size distribution. Plot vs GRE strength
  - Separation speed and growth. Plot vs. GRE strength

    → momentum relation ?
- Test Ri scaling of ejected blob distribution via electrode bias-driven shear layer (JTEXT)

Discussion

- Turbulent pedestals have many advantages

  i.e. Grassy ELM, WPQHM, I-mode, Neg. Triang, L-mode+ITB

- Confinement Trade-offs?
- Best road forward for burning plasma?

Thanks for Attention !

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