

Edge instability regimes:
application to
the quasi-coherent mode and blob transport

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Summary and Conclusions

Edge instability regimes in presence of X-points

- ideal, resistive ballooning, resistive X-pt, sheath-connected
- outgoing/evanescent wave for X-point physics: WKB and Born limits
- scalings of linear growth rate \Rightarrow blob convective velocity

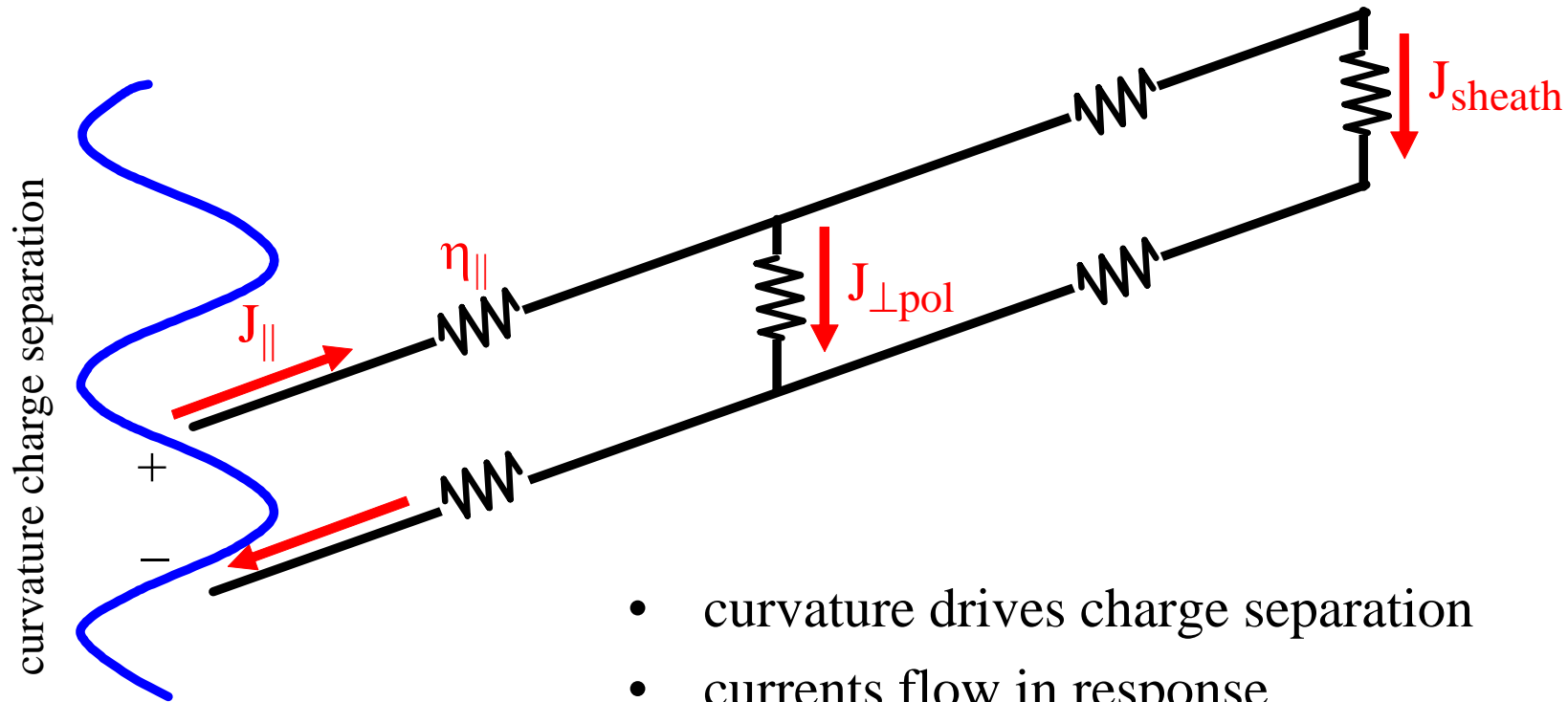
Hypothesis for Quasi-Coherent (QC) mode

- regimes + BOUT simulations [Mazurenko PRL 2002, Umansky 2005]
- the QC mode is an RX-EM (electromagnetic) mode
- analytical scalings: qualitative agreement with C-Mod (& a problem?)

Edge plasma phase space (α_{mhd} , α_d) and the EDA

- regimes + FLR assumption
- X-point physics adds a new regime to the edge parameter space
- the new regime is postulated to be the EDA regime

Current loops control regime



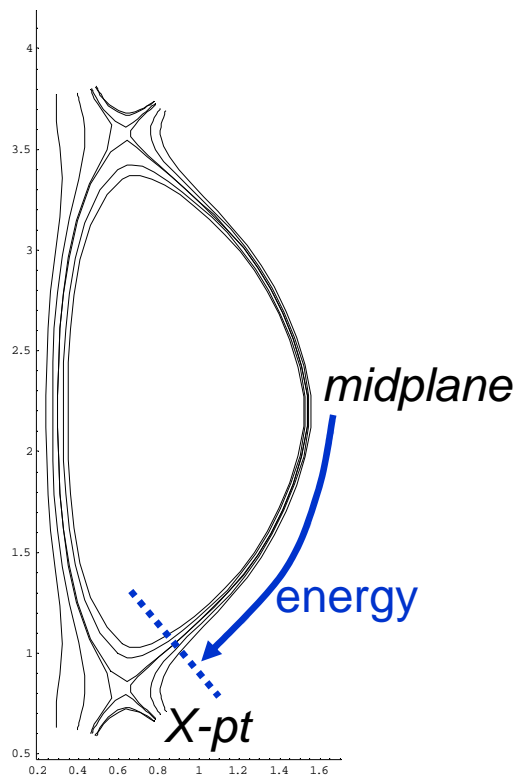
- curvature drives charge separation
- currents flow in response
- current loops close
 - J_{\perp} (e.g. J_{pol} at midplane, X-pts)
 - at the sheath
- strong ballooning, interchange: analytic

Outgoing-evanescent waves along B

\Rightarrow analytical model for X-pt physics

Ryutov and Cohen, Contrib. Plasma Phys. **44**, 168 (2004)

Krasheninnikov, Ryutov, and Yu, J. Plasma Fusion Res. (2004)



- 2 regions; wave energy: midplane \rightarrow X-pts
- **midplane**: inertia, curvature drive, J_{\parallel}
- **X-pt** region: resistive B diffusion, inertia
- J_{\parallel} **boundary condition** at entrance to X-pt region:

$$\left(\frac{J_{\parallel bc}}{\phi} \right) = \frac{-i v_a k_{\perp}^2 \rho_s^2 (\omega - \omega_{*en})}{\omega (\omega - \omega_{*en} + i\omega_{\eta})} \left(\frac{1}{\phi} \nabla_{\parallel} \phi \right)$$

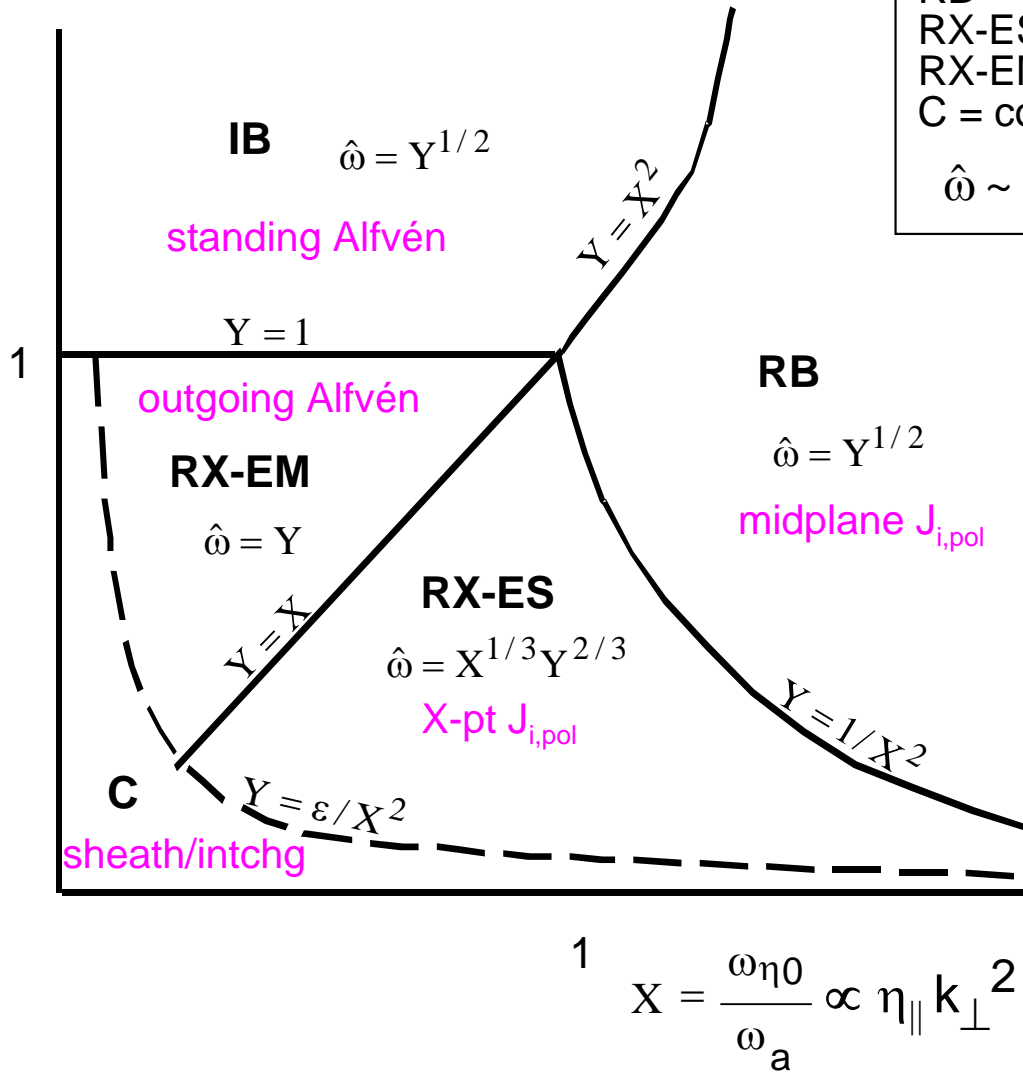
- analytic solutions are possible in 2 limits
 - WKB
 - “Born”
- solutions decay beyond X-pt



Regime diagram (WKB limit)

$$Y = \frac{\gamma_{\text{mhd}}^2}{\omega_a^2} \propto \kappa \nabla \rho$$

MHD drive ↑



IB = ideal strong ballooning
 RB = resistive strong ballooning
 RX-ES = electrostatic resistive X-pt
 RX-EM = electromagnetic resistive X-pt
 C = connected.

$$\hat{\omega} \sim \gamma / \omega_a = \text{dim'less growth rate}$$

Blob application

$$\frac{\partial}{\partial t} \sim v_E \cdot \nabla$$

$$\gamma \rightarrow c\Phi / a_b^2 B$$

e.g. sheath-C

$$v_x \sim 2.9 \times 10^{10} \frac{q T_e^{3/2}}{a_b^2 B^2}$$

Quasi-Coherent mode and the EDA

- k_* \Rightarrow where FLR starts to matter $\omega_{*i} \equiv k_* v_{*i} = \gamma$
- modes stabilize first at large $X \propto k_{\perp}^2$
- *Postulate for existence of the QC mode and EDA:*
 k_* lies in the RX-ES regime
 - \Rightarrow instability of the RX-EM modes
 - $L_n v_e > R \omega_a \beta (m_e / m_i)$ EDA boundary
 - \Rightarrow FLR-stabilized RB branch
(otherwise L-mode: Rogers & Drake)

Qualitatively compares well to C-Mod

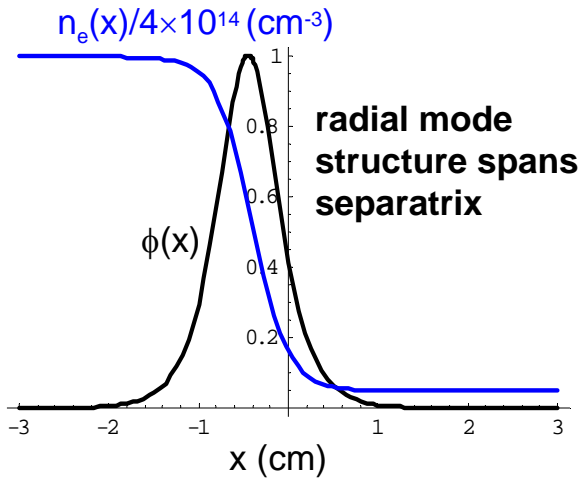
Greenwald 1999; Snipes 2001; Terry 2004

$$5.5 \times 10^{-7} \frac{(L_n / \rho_{\theta i}) f_{\text{mhd}}^2 q^2 n_e^{1/2}}{(a/R) T_i^{3/2} T_e^{1/2}} > 1$$

EDA boundary

- order-of-magnitude for typical EDA parameters: LHS ~ 1
- favors **high q, larger L_n** (than ELMy H), weakly favors **larger n_e**
- favors **stably shaped plasmas** (larger f_{mhd})
 - moderate δ and high q_{95} [Miller PoP 1996]
- favors higher neutral gas (\Rightarrow **lower edge T**)
- RX-EM mode has **electromagnetic** component as observed for QC
- QC mode is at **top/bottom and on outboard** side of torus
 - \Rightarrow curvature driven, consistent with RX but not strong RB
- high- ω **broadband turbulence** in addition to QC mode; larger in L-mode
- similar to BOUT simulations
- **BUT:** RX-EM/ES (EDA) boundary **fragile** in this theory: WKB vs. Born

Radial mode structure of the QC mode

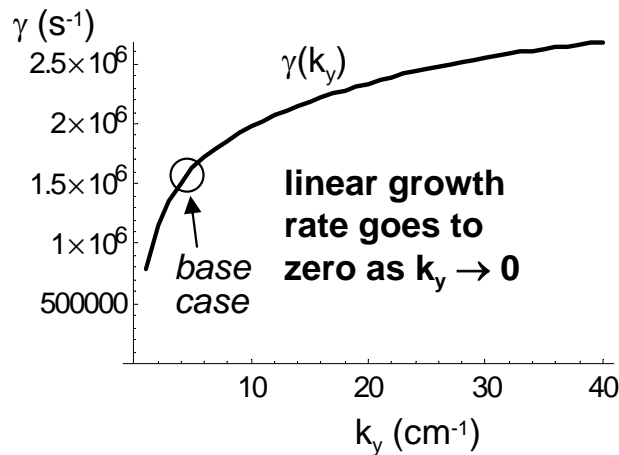
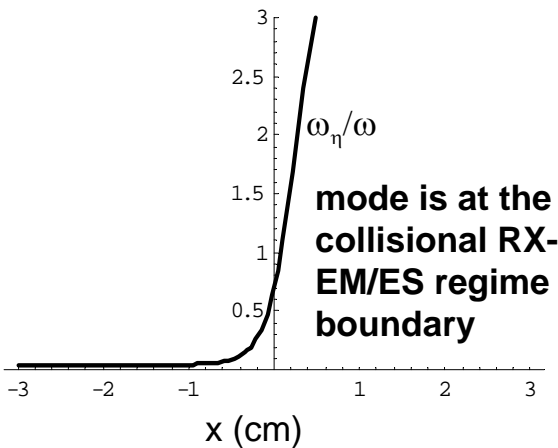


$$\frac{\partial^2 \phi}{\partial x^2} - k_y^2 \left(1 + \frac{\gamma_{\text{mhd}}^2}{F} \right) \phi = 0 \quad \text{eigenvalue equation}$$

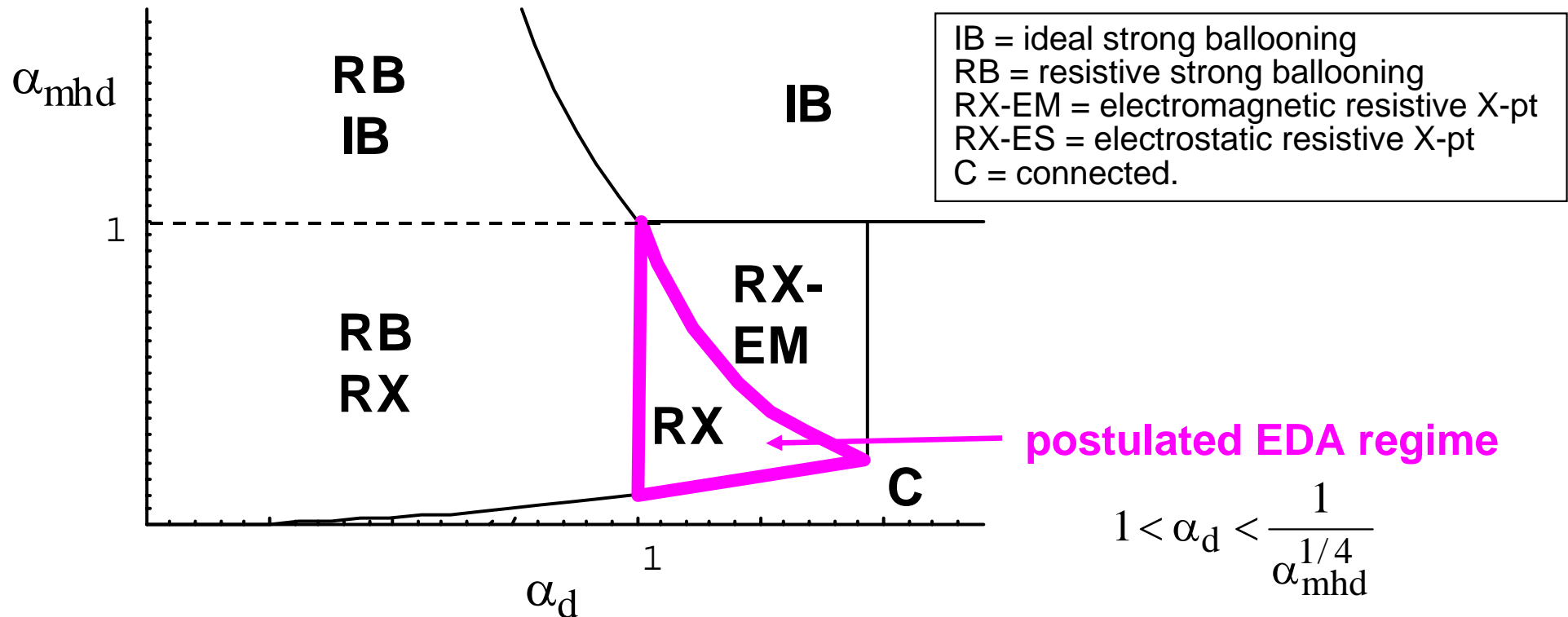
$$\gamma_{\text{mhd}}^2 = -\frac{2}{m_i n_e R} \frac{\partial p}{\partial x} \quad \text{curvature drive}$$

$$F = \omega(\omega - \omega_{*i}) + 2i\omega_a \left[\frac{\omega(\omega - \omega_{*i})(\omega - \omega_{*e})}{\omega - \omega_{*e} + i\omega_\eta} \right]^{1/2} \rightarrow 2i\omega_a \omega$$

(outgoing Alfvén)



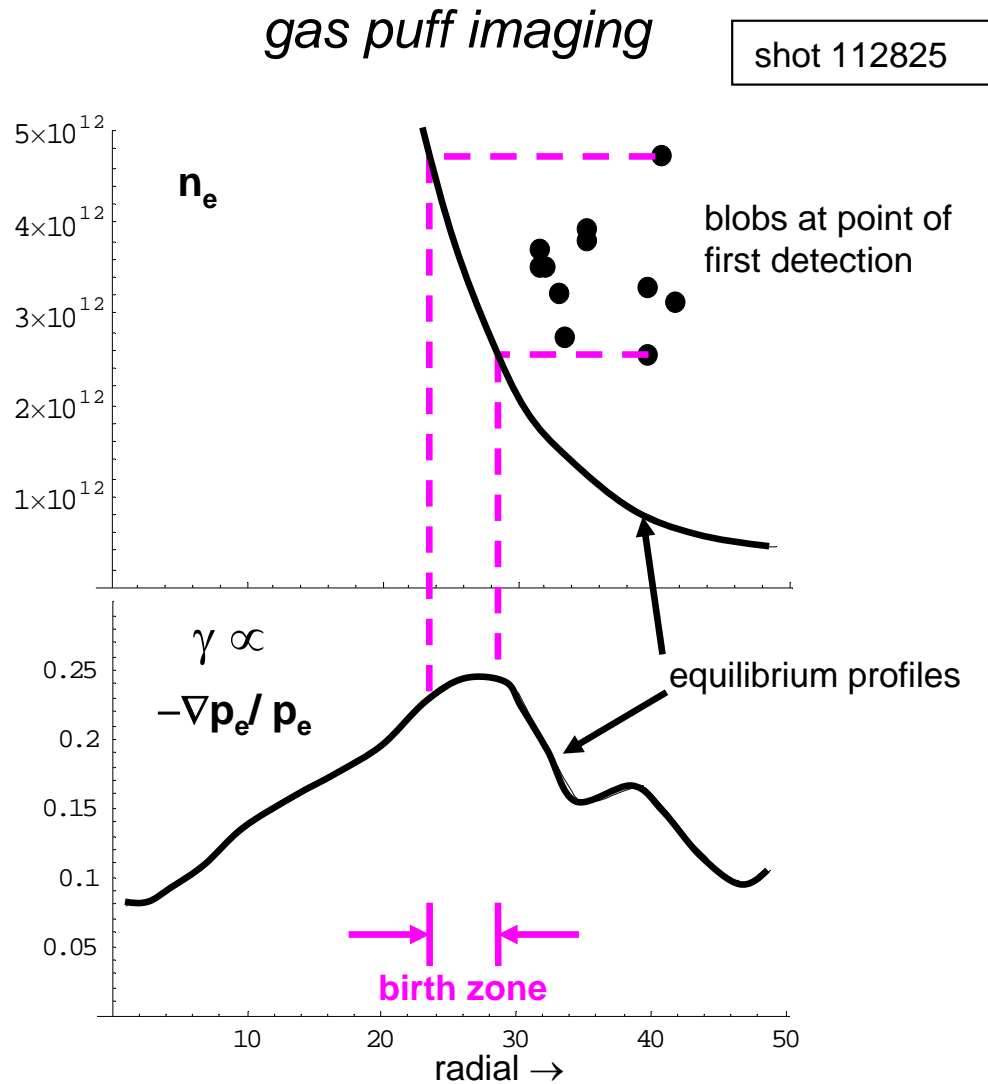
Edge phase space diagram with X-pt BCs



- eliminate k_{\perp} from (X, Y) regime diagram using FLR
- labels \Rightarrow types of modes that are unstable
 - RX \Rightarrow instability of both the RX-EM and RX-ES
- expect L-mode to the left; H-mode to the right [Rogers-Drake; Guzdar]
- X-pt physics adds a new wedge near the L-H boundary =? the EDA

NSTX: experimental tests of blob theory

with Zweben, Maqueda, Stotler, Boedo, Munsat



- goal: compare blob speeds in theory regimes with experiment
- Intensity $\Rightarrow n_e, T_e$ [Stotler, DEGAS]

first result

- blobs are born with a density (and temperature) characteristic of where the underlying linear instability peaks.