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

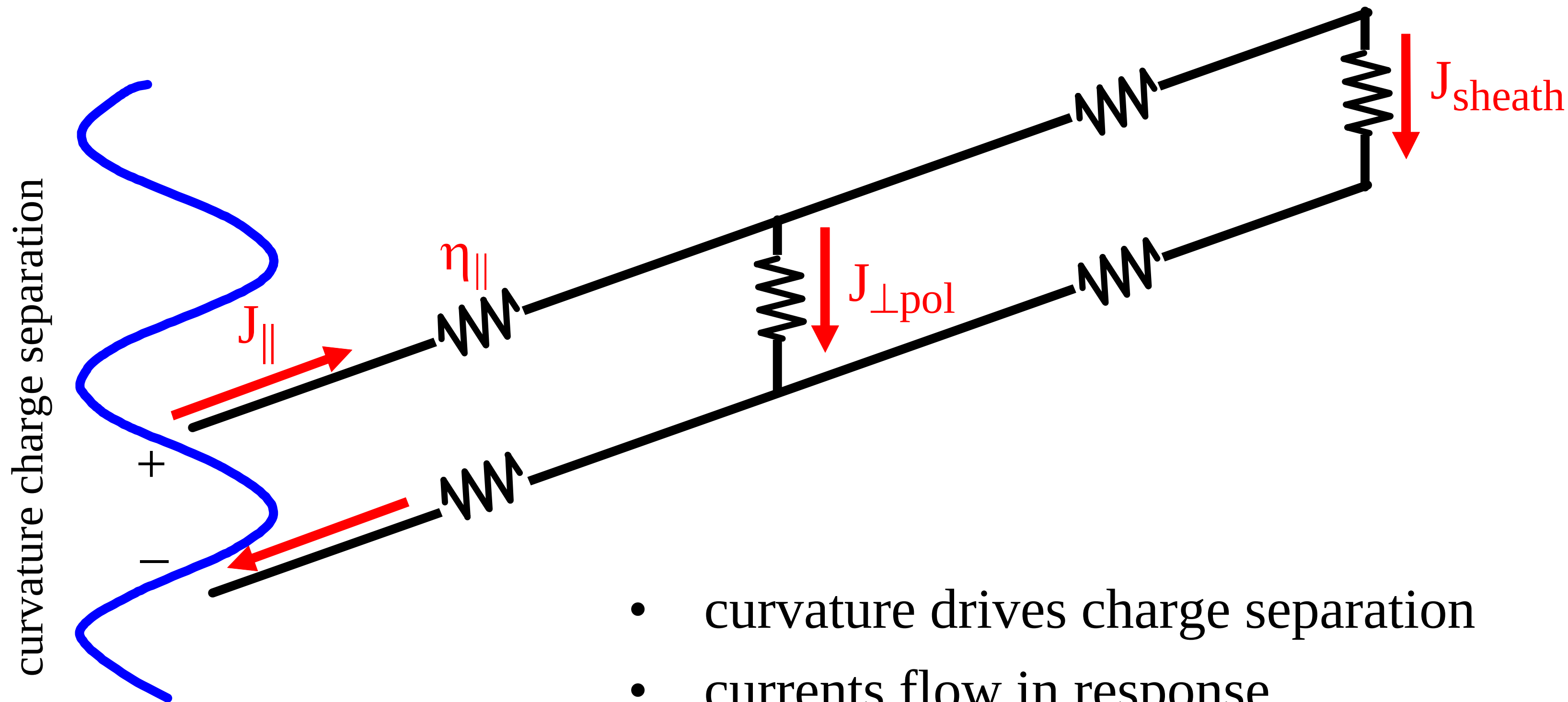
Hypothesis for Quasi-Coherent (QC) mode

- 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

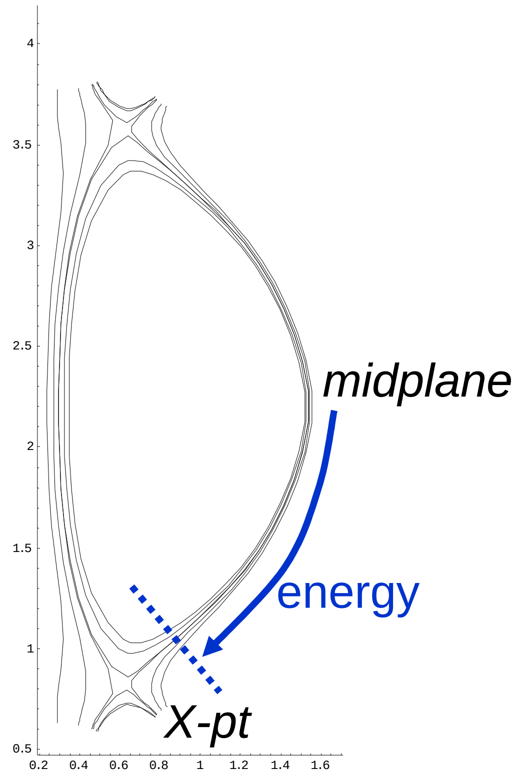
Current loops control regime



- 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
⇒ 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 → X-pts
- **midplane**: inertia, curvature drive, $J_{||}$
- **X-pt** region: resistive B diffusion, inertia
- $J_{||}$ **boundary condition** at entrance to X-pt region:

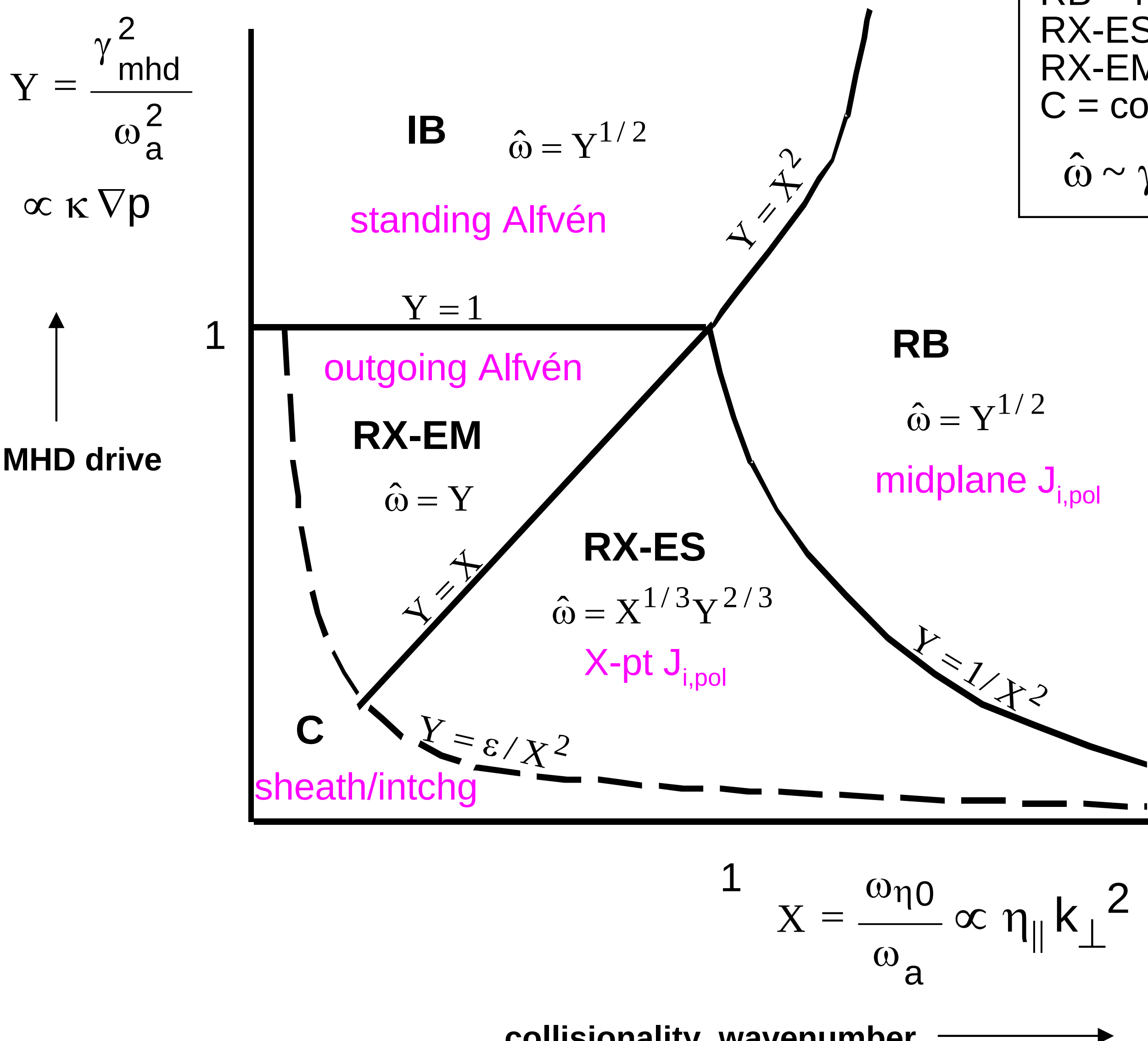
$$\left(\frac{J_{||bc}}{\phi}\right) = \frac{-i v_a k_\perp^2 \rho_s^2 (\omega - \omega_{*en})}{\omega(\omega - \omega_{*en} + i\omega_\eta)} \left(\frac{1}{\phi} \nabla_{||} \phi\right)$$

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

Regime diagram (WKB limit)

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

$\hat{\omega} \sim \gamma / \omega_a$ = 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

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

Lodestar/Myra/TTF/2005

Quasi-Coherent mode and the EDA

- $k_* \Rightarrow$ where FLR starts to matter $\qquad \omega_{*i} \equiv k_* v_{*i} = \gamma$
- 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

  $$L_n \nu_e > R \omega_a \beta (m_e / m_i)$$

  EDA boundary

  $\Rightarrow$ FLR-stabilized RB branch

  (otherwise L-mode: Rogers & Drake)

Qualitatively compares well to C-Mod

Greenwald 1999; Snipes 2001; Terry 2004

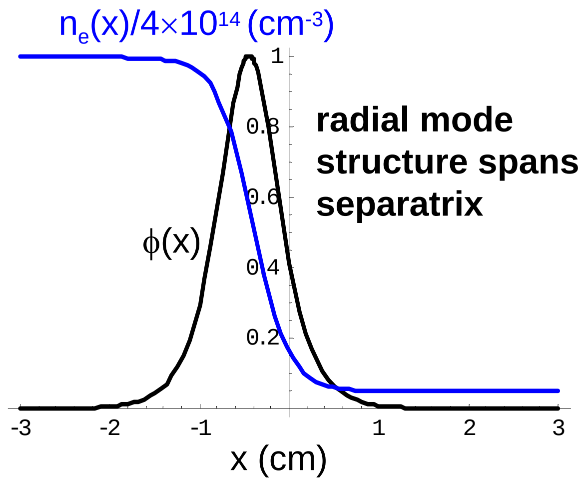
$$5.5\times10^{-7}\,\frac{(L_n/\rho_{\theta i})f_{mhd}^2 q^2 n_e^{1/2}}{(a/R)T_i^{3/2}T_e^{1/2}} > 1$$

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 (⇒ **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

  ⇒ 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



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

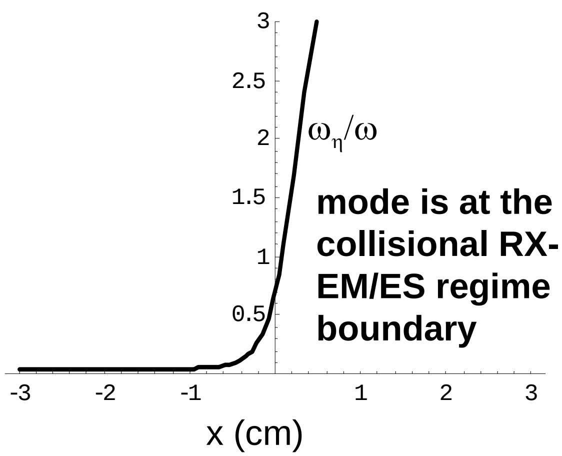
eigenvalue equation

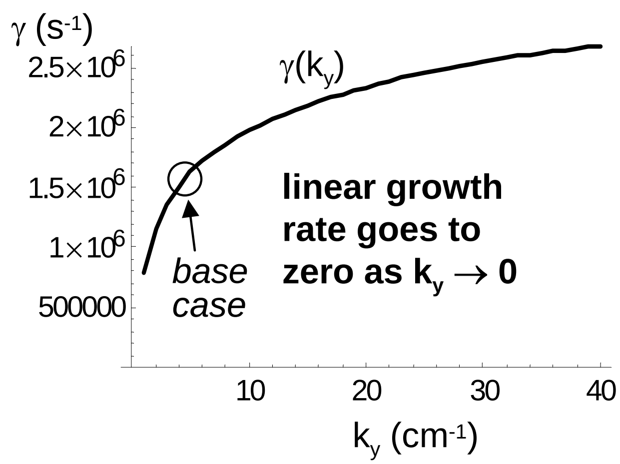
$$\gamma_{mhd}^2 = -\frac{2}{m_i n_e R}\frac{\partial p}{\partial x}$$

curvature drive

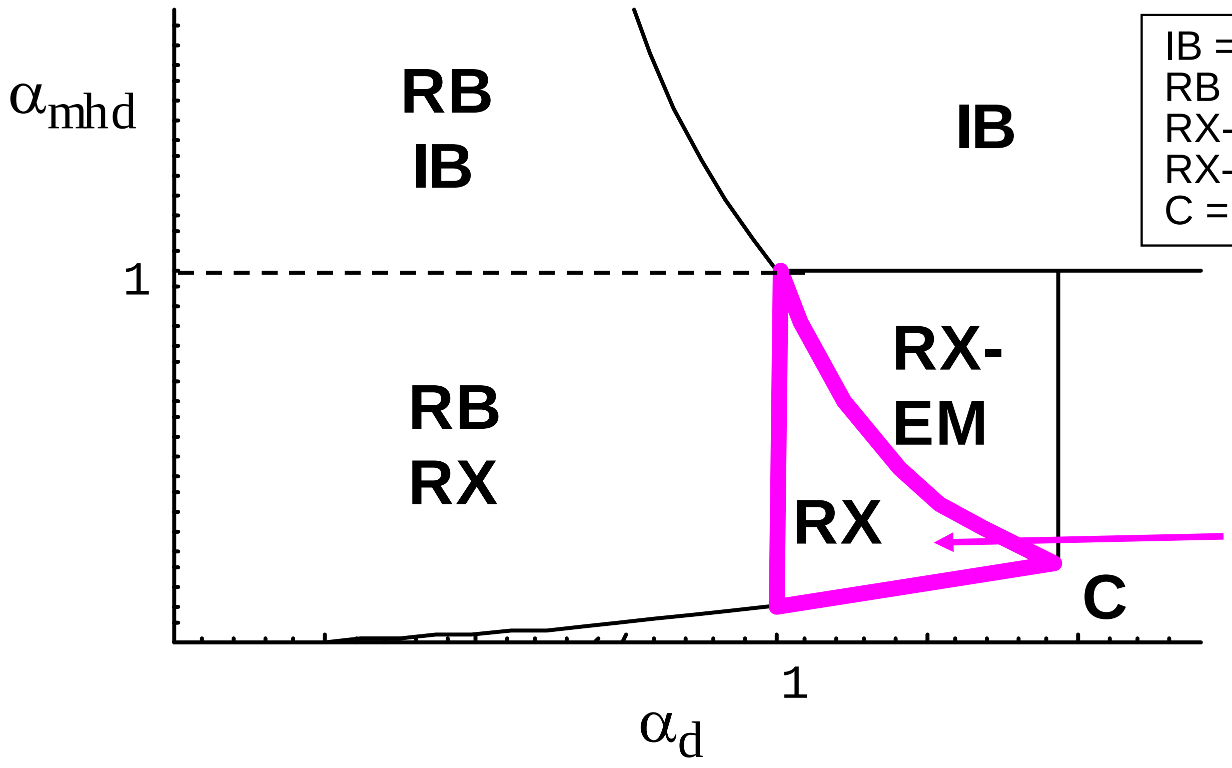
$$F = \omega(\omega-\omega_{*i}) + 2i\omega_a\left[\frac{\omega(\omega-\omega_{*i})(\omega-\omega_{*e})}{\omega-\omega_{*e}+i\omega_\eta}\right]^{1/2} \to 2i\omega_a\omega$$

(outgoing Alfvén)





Edge phase space diagram with X-pt BCs



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postulated EDA regime

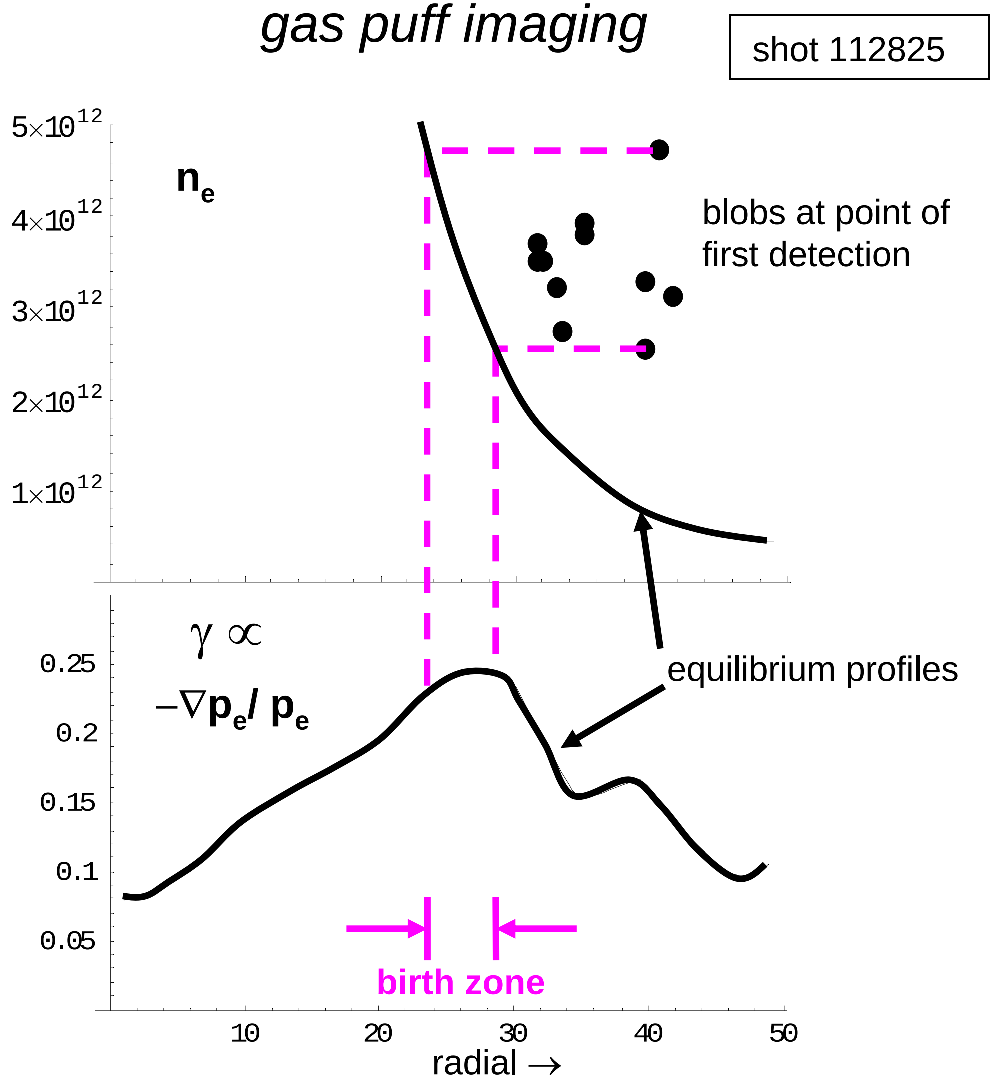
$$1 < \alpha_d < \frac{1}{\alpha_{mhd}^{1/4}}$$

- 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

gas puff imaging



- 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.