NOTES ON ELMS

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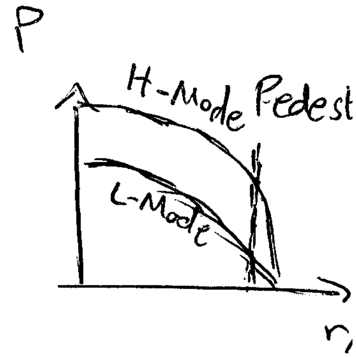
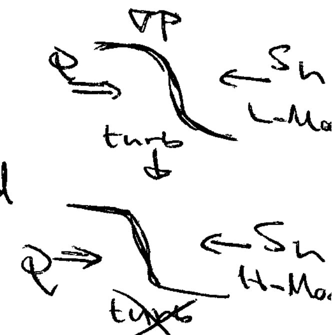
PHYS 235 Course

Summery:

ELM is an activity which evolves as a short, intense heat load on the plates in tokamak's high-confinement regime and causes erosion of divertor materials. Edge Pressure gredient will decrease until plasma becomes Stable. And this cycle can continue indefinitely. This energy dump to divertors (up to 10% of plasma energy) can be very distructive for tokamaks, such as [illegible] study and control of ELMS becomes importa

In magnetically confined plasma when heating power level exceeds the threshold, it spontaneously enter from low confinement mode (L-Mode) to high confinement mode (H-Mode) in which magnetic confinement time (τ_E) is enhanced (usually by factor of 2).

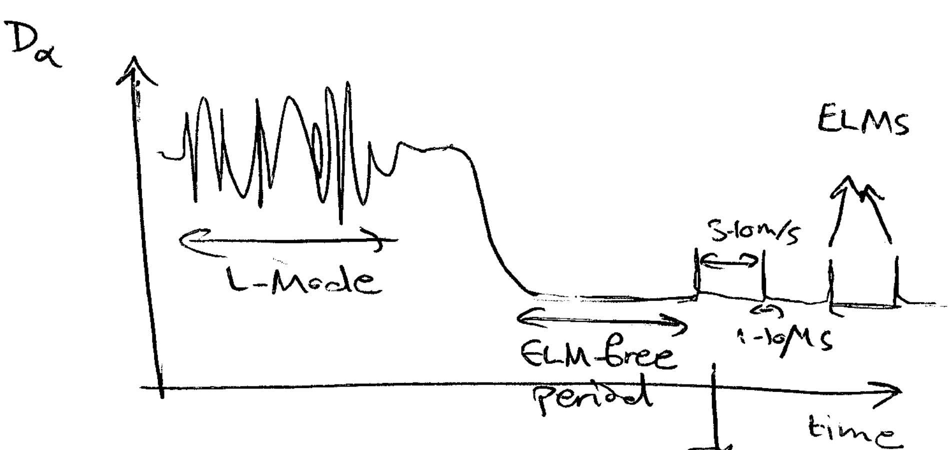




H-Mode
↓
turbulence extenguishes by shear!

ASDEX → ELM
PDX → ERPs
↓
Edge Relaxation Phenomena

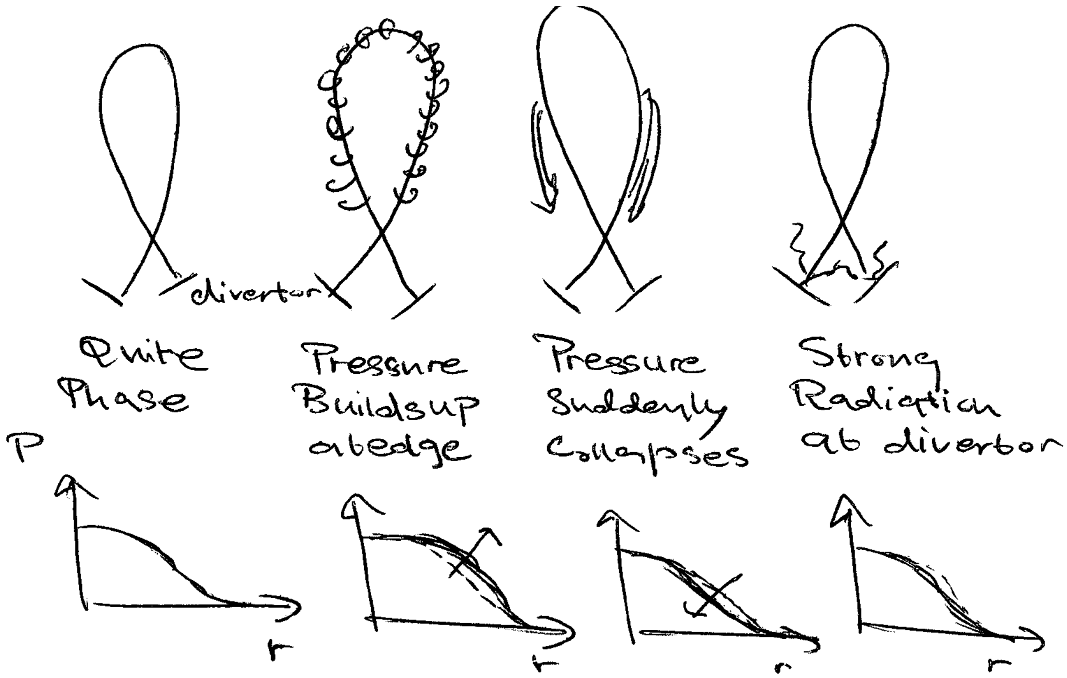
ELMs (Edge Localized Modes):



Dα Bursts (Quasi-Regular)
↓
ELMS
↓
$\Delta W / W \lesssim 10\%$
Dumping ~10% energy in a burst!
(Concern of ITER)

...literature:

ASDEX Review (80's)
Zohm Review (90's)
P. Snyder (2002)
Connor + Wilson (Theory)



- Pedestal is Relaxed!
- Fast dump of heat & particle into divertor.
- filaments | - ECEI
  | - MAST
- Enormous transient heat load
- Damage Plasma Facing Component (PFC

TRADE OFF BETWEEN
CONFINEMENT ⟺ HEAT LOADING
IS H-Mode Good?

Solve { Mitigation & Control
Alternatives to H-Mode

Alternatives to H-Mode
→ I-Mode?

Type of ELM:

- Type I (Giant, most relevant) } (Peeling Ballooning Modes)
- Type II (Grassy ELM, lower burst, higher frequency) }
- Type III (weaker, Smaller)

Peeling Ballooning Modes ↓

$\nabla P < \nabla P_{ideal}$

$w_{ELM} \uparrow$ as $P_{in} \uparrow$

$P_{in} \gg P_{in\,crit}$ needed for L→H Transition

Type III: (Resistive Ballooning Modes?) ↓

$w_{ELM} \downarrow$ as $P_{in} \uparrow$

$P \gg P_{crit\,L \to H}$

Poorer Confinement

$\nabla P < \nabla P_{crit}$

Current design of ITER can't handle type I ELM!!!
↓
Mitigation!

There are other types of ELMs
↓
useless to list zoology!!

Dynamics:

Ideal MHD ⇒ Peeling - Ballooning Mode

Peeling ↓ kink

Ballooning ↓ Interchange + Bending

using energy principle:

$$Q = \nabla \times \xi \times B$$

$$\delta W = \int d^3x \left[\frac{\vec{Q}^2}{4\pi} + J \cdot (\vec{\xi} \times \vec{Q}) + \vec{\xi} \cdot \nabla P (\nabla \cdot \vec{\xi}) + \cdots \right]$$

$$\Rightarrow \delta W = \int \frac{\ldots}{2} \left[Q_\perp^2 - \frac{J_\parallel}{B_0} (\xi_\perp \times B_0) \cdot Q_\perp \right.$$

$$\left. - 2 (\xi_\perp \cdot \nabla p_0)(\xi \cdot \kappa) + \ldots \right]$$

↓

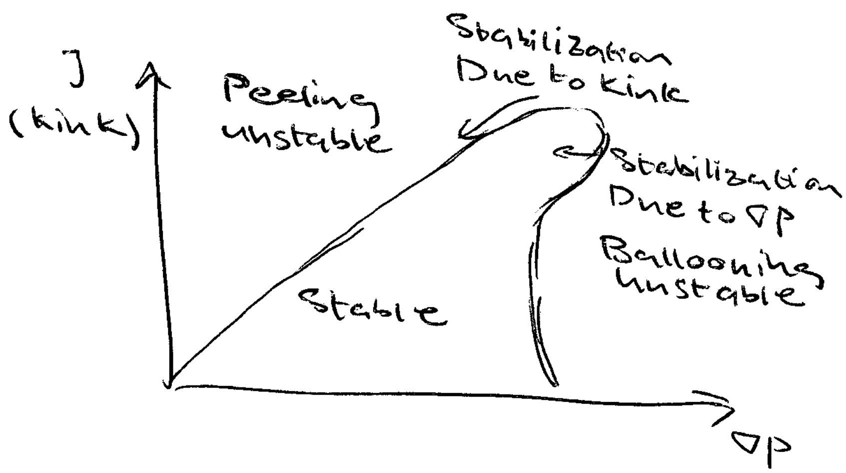
∇p drive

Ballooning: fight between $\frac{k B v_A^2}{L p}$ vs. $\frac{v_A^2}{(Rq)^2}$

Peeling: Surf. kink.

kink ~ $J_\parallel$

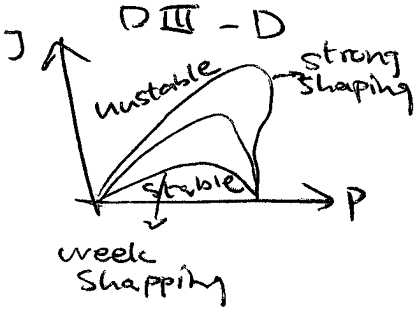
$J_{BS} \sim \nabla P$



Shaping, etc. ← are important

↓

DIII-D



Ideal → Burst → Why crash?

↳ experiment: Multimode (Classen)

↳ theory: Subcritical instability (bifurcations!)

↓

Wilson + Cowley

↓

Theoritically failed!

o
o
o
o

Modes first or bursts first?

↓

unanswered!

$\frac{d}{dt} \mathcal{E}_T = -T + K \langle \tilde{v}_r \delta p \rangle$

↳ very fast phase

$\gamma(r)$

growth rate curve! — turbulence vs. Burst?

↓

Sensitive to ∇p at the edge!

↓

Transport behavior in H-mode

↓

Open Question!

[P.W. Xi]

→ hyper resistivity [Xu, 2010]

$E_{\parallel} = -\frac{1}{c}\frac{\partial A_{\parallel}}{\partial t} - \nabla_{\parallel}\varphi = \eta J - \mu \nabla^2 J_{\parallel}$

⇒ ELM Mitigation & Suppression:

So, we wish to mitigate or suppress ELMs without confinement degredation!

Players
- RMP (Resonant Magnetic Perturbation) (DIII-D Evans)
- Injection
  - Pallets (Lang ASDEX, Baylor DIII-D)
  - SMBI (Yao, Xiao, Bai EAST)

[M. Kikuchi, TTF 2013]

I. RMP

→ IVCC Coil

↳ stick it into plasma

↳ small stochastic field

↳ cool off ∇p

↓

narrow success on ELM suppression

RMP on L→H Transition tradeoff

P_{thresh} ↑

RMP changes particle confinement,

relieves ∇n.

&

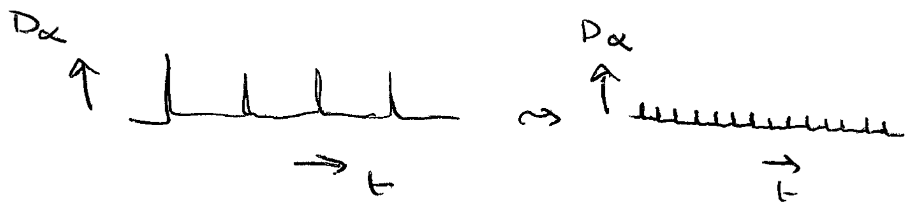
Is intrinsic rotation enough? → No!!

(Evans DIII-D)

II. Pallet Pacing

Small ballooning instead of big Type I ELM,

by shooting in pallets.

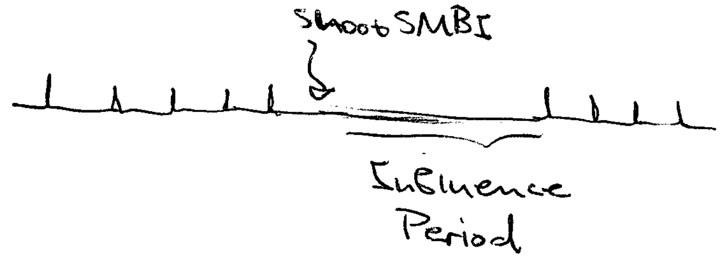


III. SMBI (Supersonic Molecular Beam Injection)

$\Delta W \downarrow$ $\quad w_{ELM} \uparrow$

QH-Mode?

(Zan, EAST IAEA, 2012)



References:

[1] PHYS 235 Lecture, by Prof. Diamond

[2] European Fusion development Agreement (EFDA) websity, www.edfa.org

[3] Yunfeng Liang, "ELM control in Tokamak Pulses", 4th ITER International Summer School

[4] T. Ozeki, et. al., "Plasma shaping, edge ballooning stability and ELM behaviour in DIII-D", Nuclear Fusion 30, 1990