Current understanding of tokamak plasma eruption control and the consequences for ITER

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Talk Outline

1. Background understanding of type-I Edge Localised Modes (**ELMs**)
2. Problems ELMs cause & ITER's requirements
3. Methods for ELM control on ITER
   i. Resonant magnetic perturbations (RMPs)
   ii. Pellet injection
   iii. Vertical kicks
4. Alternatives

1. Background understanding of ELMs

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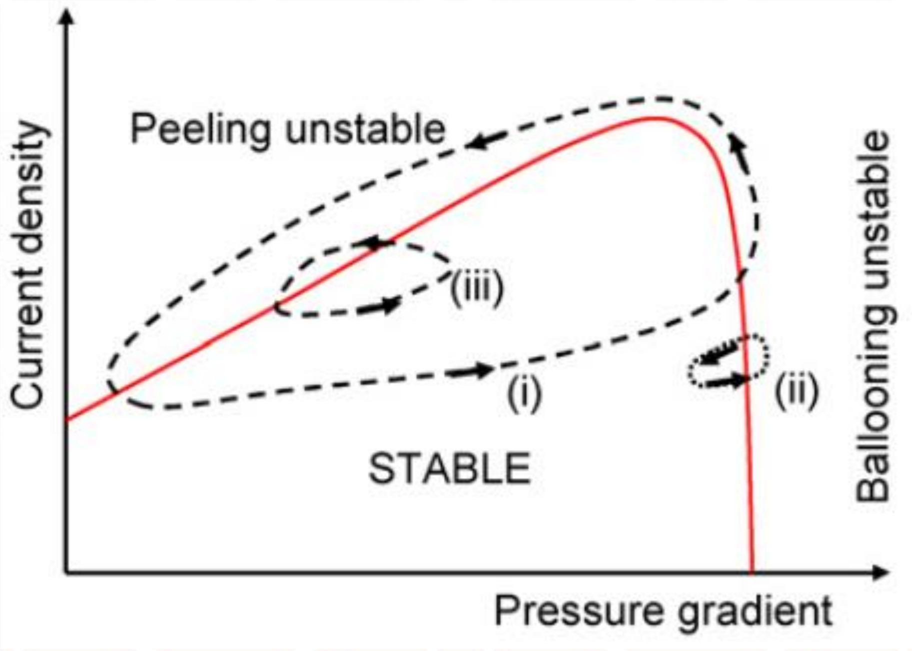
- ➢Generic to tokamaks in H-mode
- ➢Edge pedestal gradient is inherently unstable
- ➢Thought to be caused by Peeling-Ballooning mode instabilities
  - ➢ELM causes crash, cycle repeats

Type-I ELM cycles



H. Wilson Plas. Phys. 48 2006

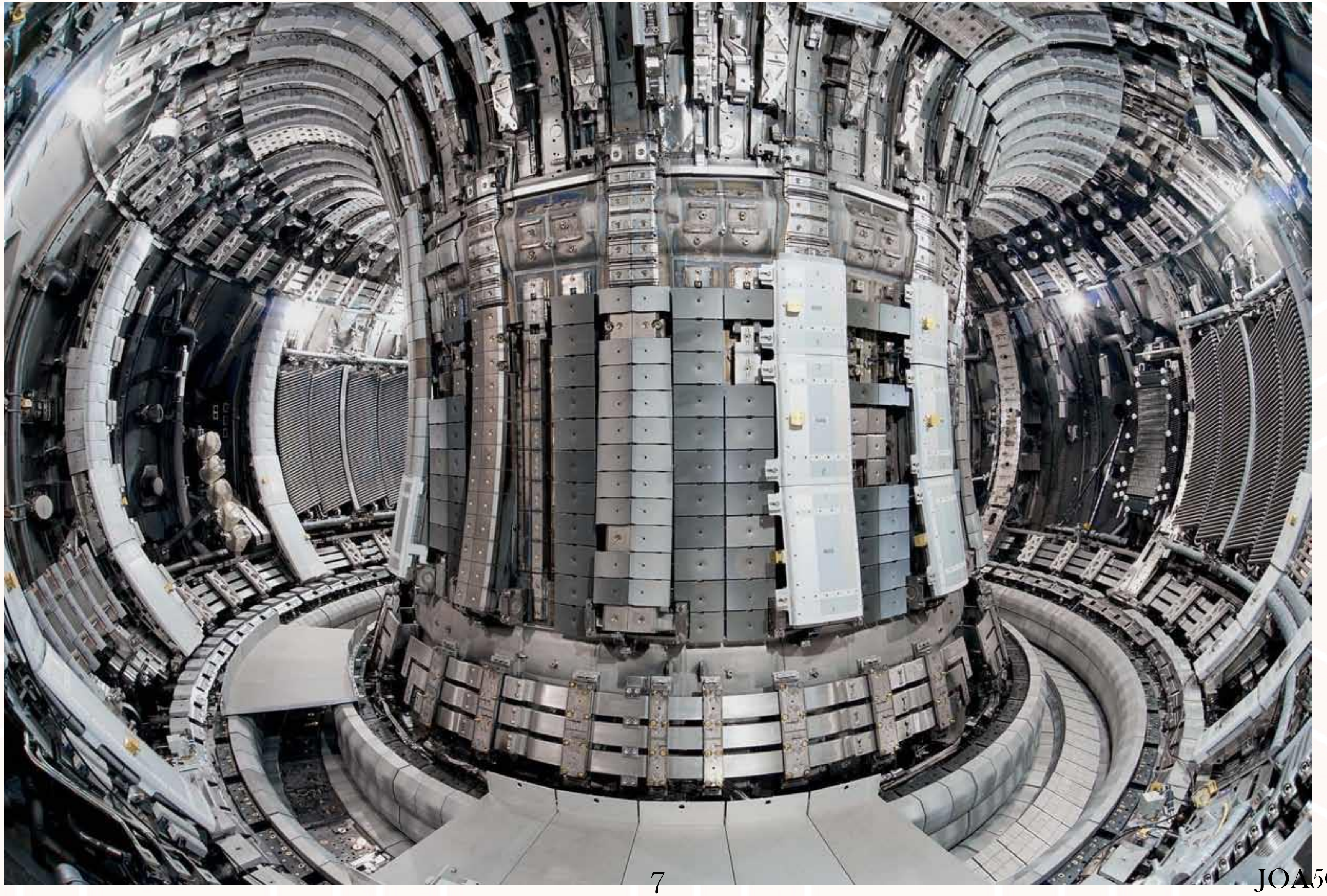
1. Background understanding of ELMs

$$f_{ELM}\Delta W_{ELM} = (0.2 - 0.4)P_{SOL}$$

A. Leonard Journal of Nuclear Materials **266** 1999

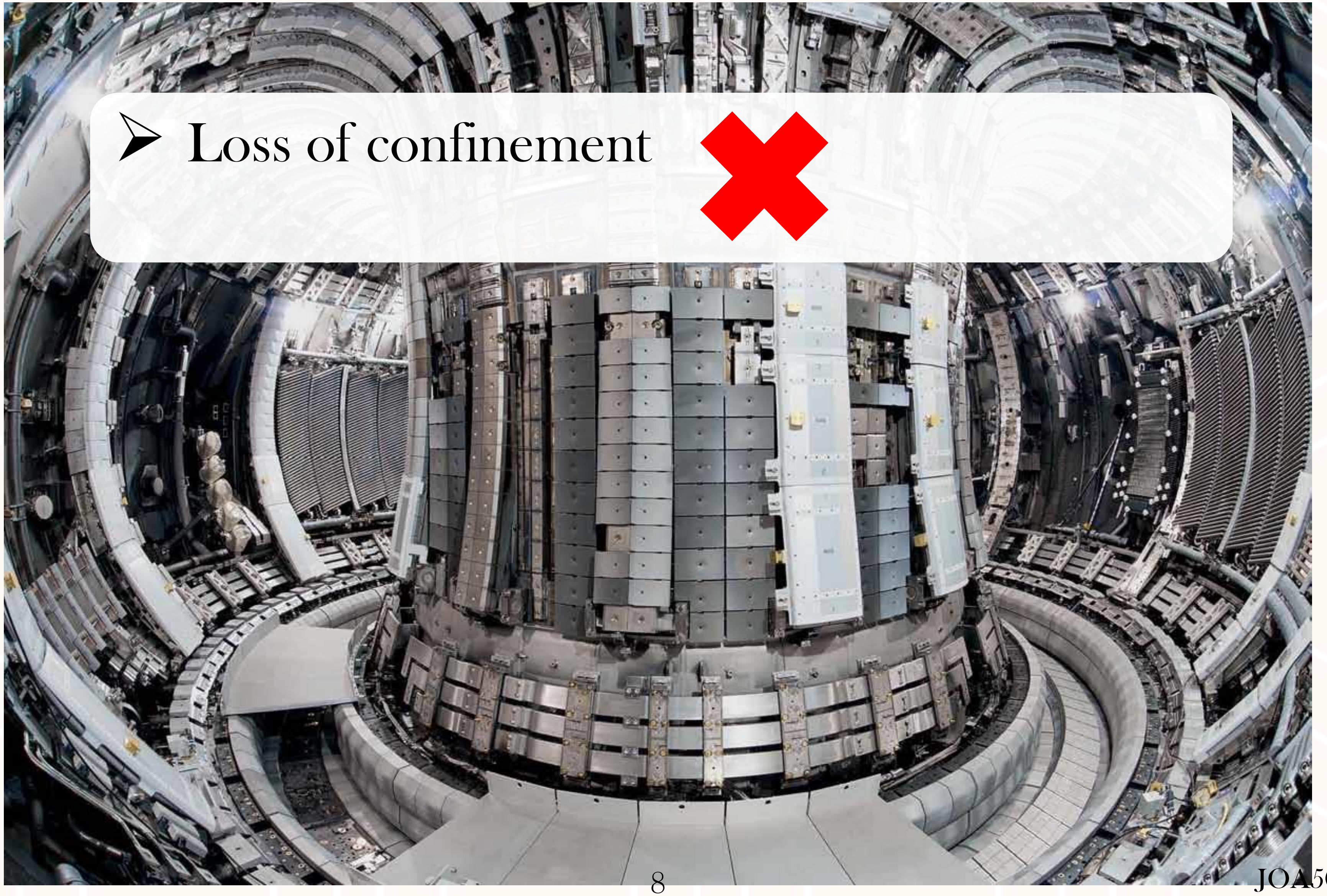
- Several tokamaks have corroborated this scaling for ELM frequency, $\mathbf{f_{ELM}}$
- $\mathbf{\Delta W_{ELM}}$ is the ELM energy

2. Problems ELMs cause



2. Problems ELMs cause

- Loss of confinement



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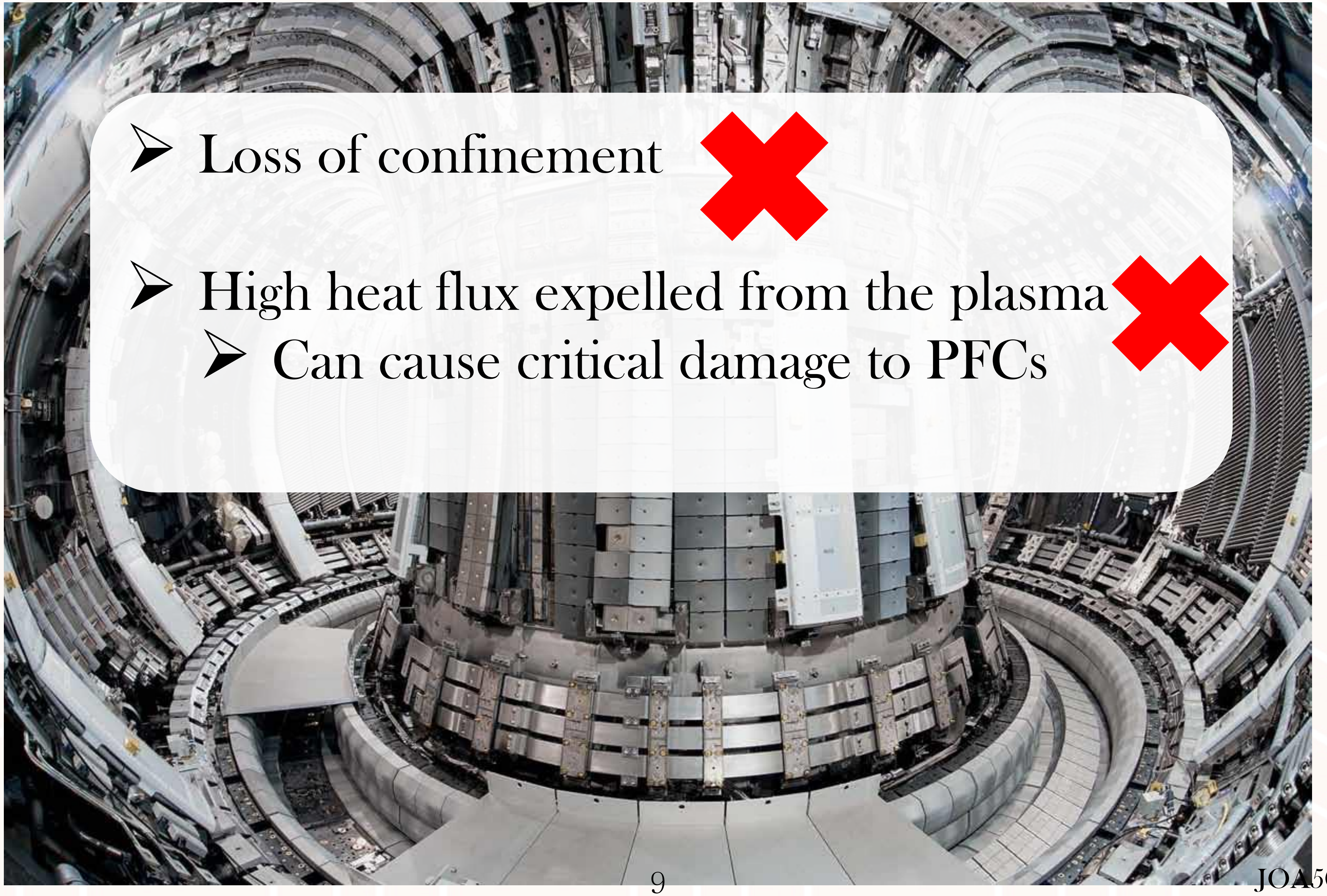

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- High heat flux expelled from the plasma
  - Can cause critical damage to PFCs

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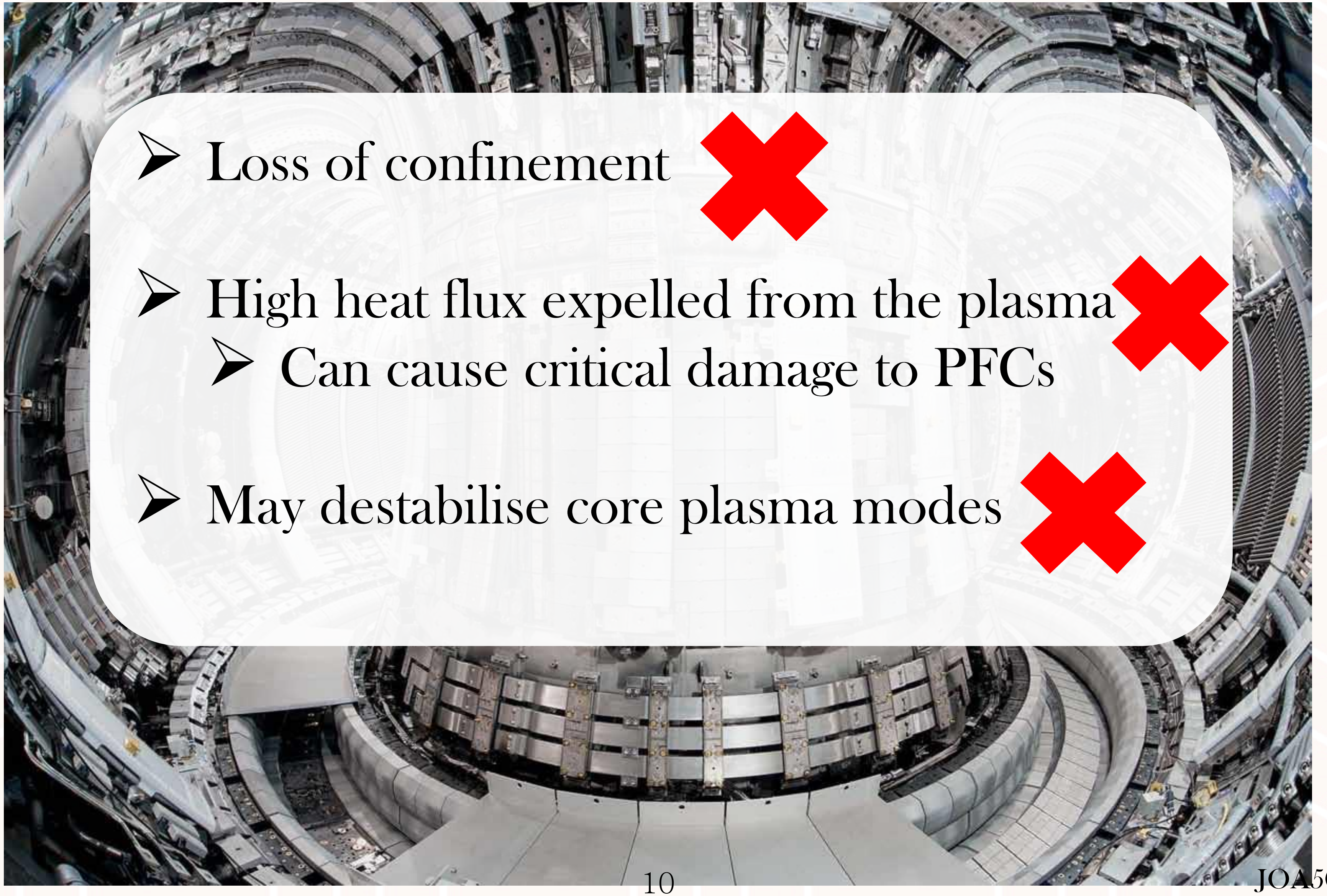

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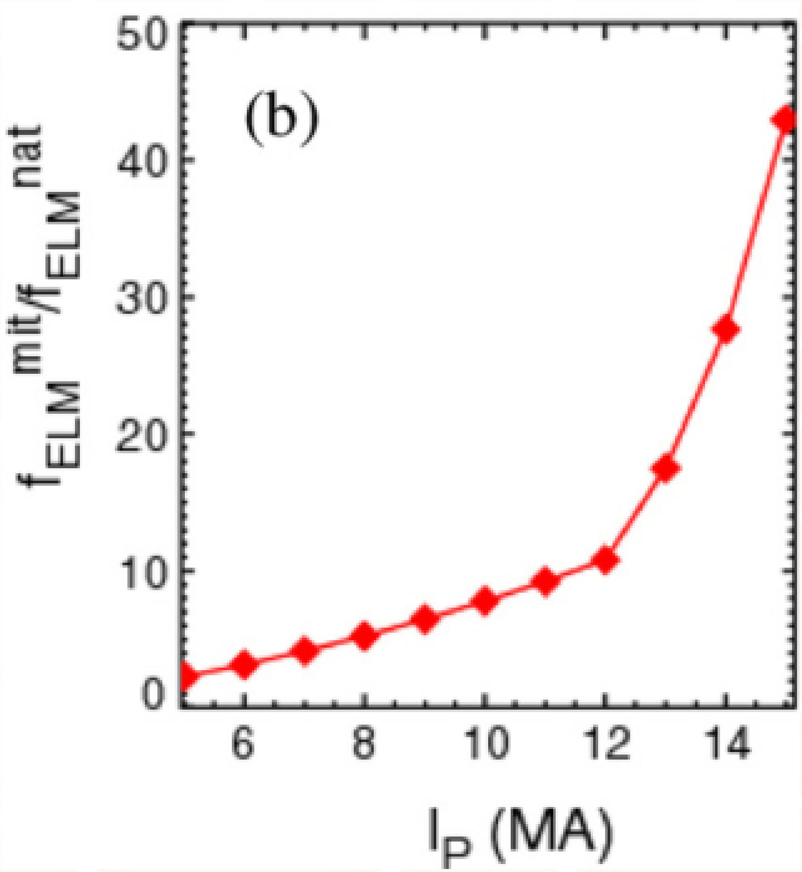
2. Problems ELMs cause

- Loss of confinement
- High heat flux expelled from the plasma
  - Can cause critical damage to PFCs
- May destabilise core plasma modes
- However they reduce plasma impurity levels

2. ITER's requirements

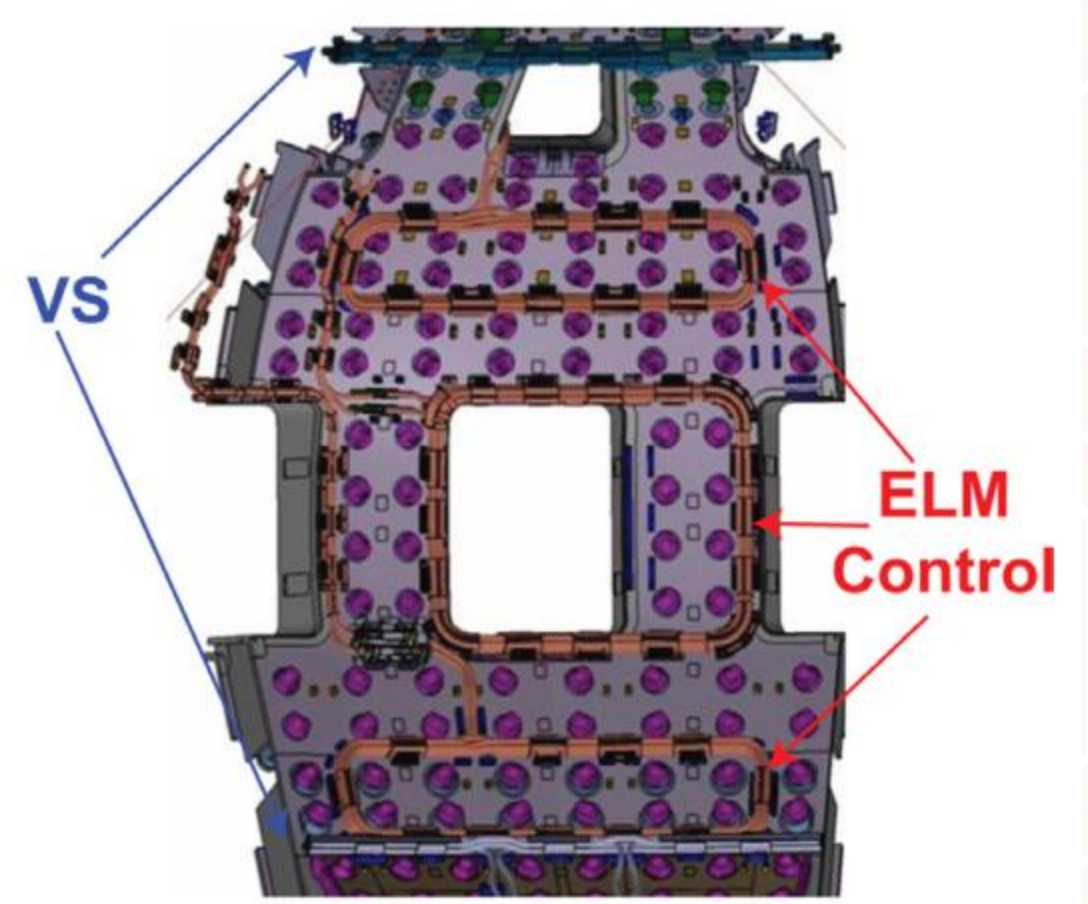
- Natural ELMs on ITER could release up to 20 MJ
  - **The first wall can tolerate < 1 MJ eruptions**
- Target operation: 15 MA
  - AT LEAST need a sustained **>40** times f_{ELM} increase



A. Kirk Phys. Rev. Lett. 108.25 2013

3. Methods for ELM control on ITER

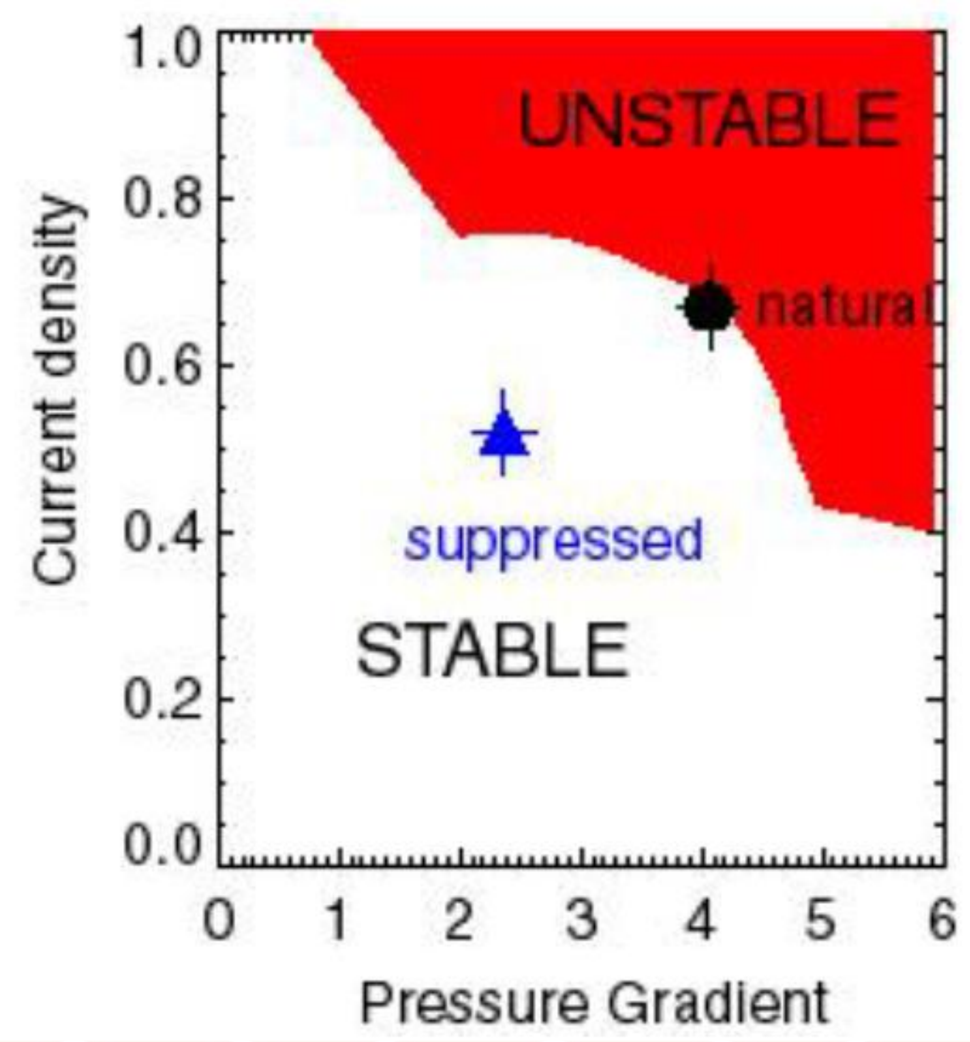
- ➢Vertical stability coils already included
- ➢27 RMP coils added to design
- ➢Pellet injectors also added



P. Lang *Nuclear Fusion* 53.4 2013

3. i) RMPs (Resonant Magnetic Perturbations)

- ➢Suppress ELMs by keeping below PB stability limit



A Kirk Frontiers Lectures 2016

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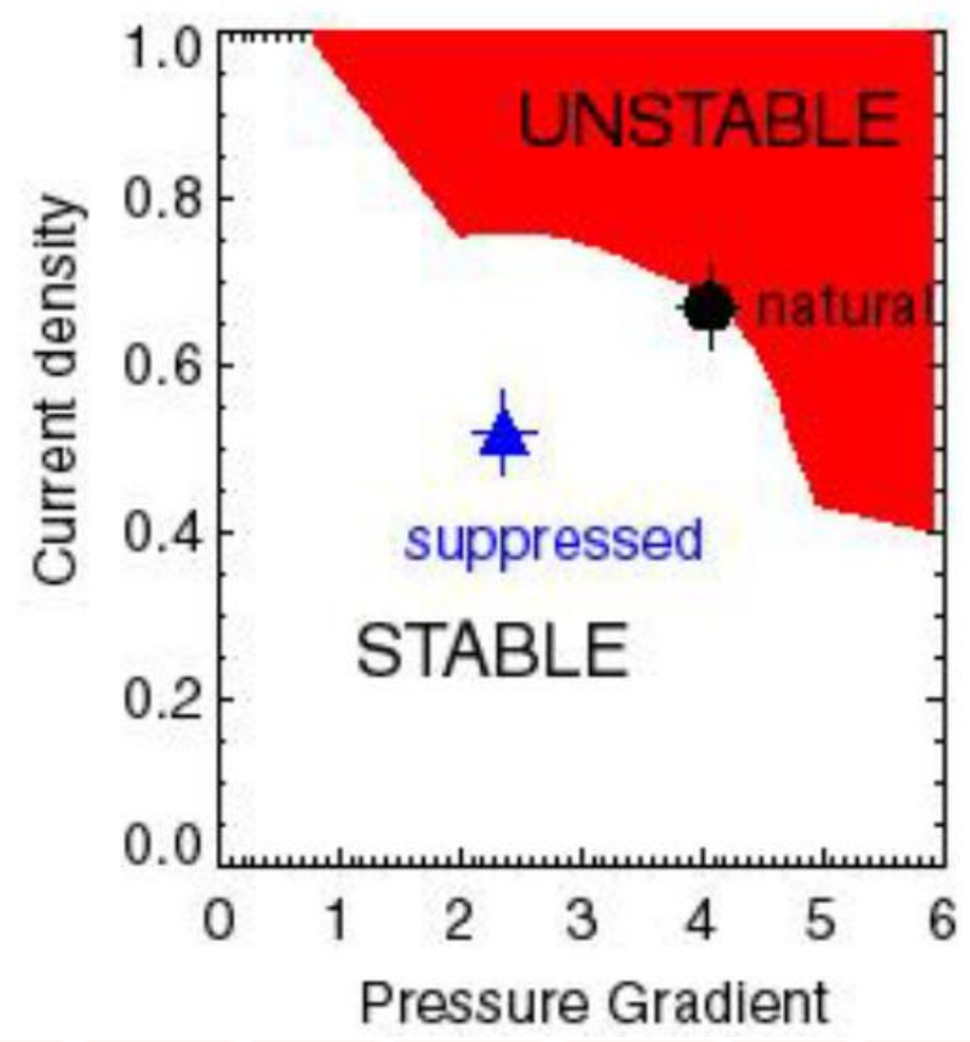

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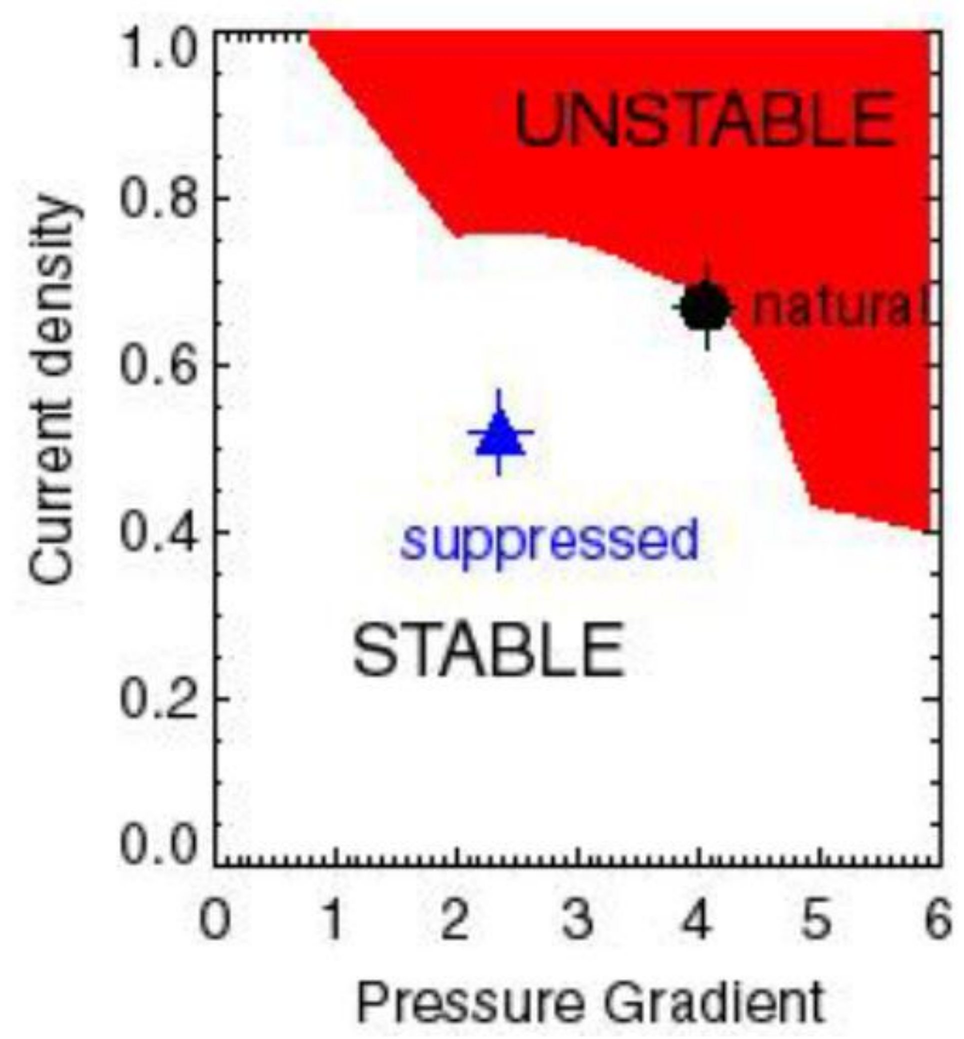
3. i) RMPs (Resonant Magnetic Perturbations)

- Suppress ELMs by keeping below PB stability limit
- Small perturbations ≈ 10^{-4} T
- Perturbations must be toroidally cycled to keep divertor damage uniform



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3. ii) Pellet Injection (PI)

- Mitigation by increasing $\mathbf{f_{ELM}}$ → less damage to PFCs
- Mechanism not fully understood
- Heavily dependent on time since last ELM

Pellet mass from framing camera (au) \ Time since previous natural ELM (ms)	<5	5-10	10-15	15-20	>20
>10	86%	57%	100%	100%	100%
8-10	86%	60%	100%	90%	100%
6-8	72%	85%	56%	80%	100%
4-6	65%	75%	67%	88%	100%
<4	38%	61%	67%	100%	100%

I. Chapman *Plas. Phys. Cont. Fus.* 58 1 2016

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iii) Vertical Kicks (VKs)

- Control by pacing the frequency of ELMs
- Vertical stability coils
- Plasma moves ≈ 2% of minor radius

2nd: Partial RMP suppression + VK/PI mitigation

1st: Complete, sustained RMP suppression

3rd: Sustained VK/PI mitigation with f_{ELM} above threshold

4. Alternatives

- QH-mode or I-mode
  - High fusion performance without ELMs!
    - (but with enhanced transport!)

- Sounds worth investigating

Thank you for listening!