Experimental activity on MHD instabilities in EXTRAP T2R

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OUTLINE

- **General Introduction**:

  (1) Fusion experiments in Europe
  (2) The goals of EXTRAP T2R

- **Fusion plasma instabilities: some examples**

  (1) Resistive Wall Modes (RWMs)
  (2) Tearing Modes (TMs) and magnetic islands
  (3) Edge Localized Modes (ELMs)

- **How to control/mitigate instabilities?**

  Technique developed and studied in EXTRAP T2R:
  feedback control of instabilities with a set of active and sensor coils

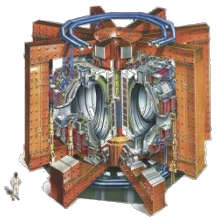
  (1) Feedback stabilization on RWMs
  (2) Studies relevant to ELM mitigation

- **Conclusions**

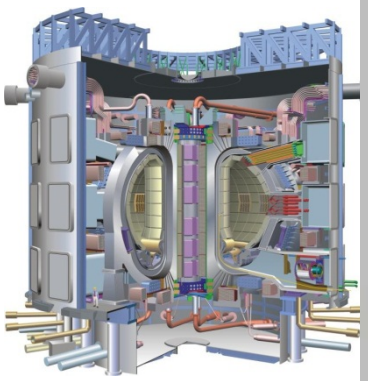
Fusion Experiments in Europe

- Europe has several working fusion experiments
- JET is the largest
- ITER is the next step (one of its goal is to achieve Q>10)
- The Swedish experiment is EXTRAP T2R in KTH

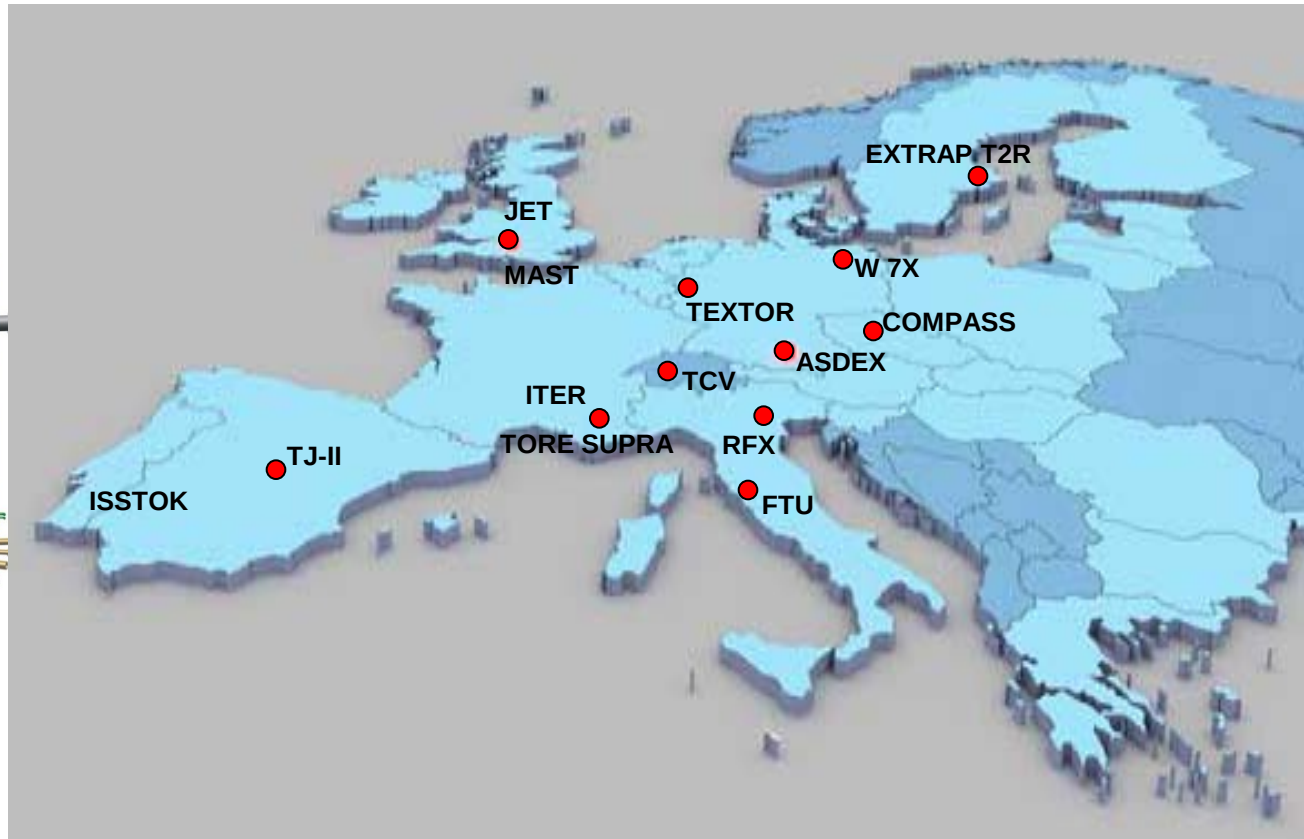
JET
$B_\phi \approx 3T$
$T \approx 5keV$



ITER
$B_\phi \approx 10T$
$T \approx 10\text{-}15keV$



EXTRAP T2R
$B_\phi \approx 0.1T$
$T \approx 0.5keV$



Fusion Experiments in Europe

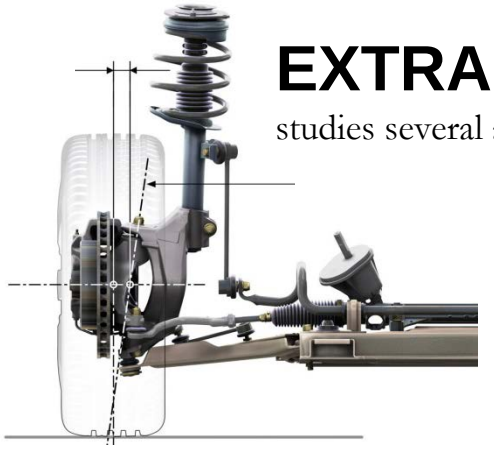
- Each experiment studies a different aspect of fusion plasma physics and technology

ITER

JET

studies several aspects of the engine

SHOCK ABSORBER



EXTRAP T2R

studies several aspects of the shock absorber

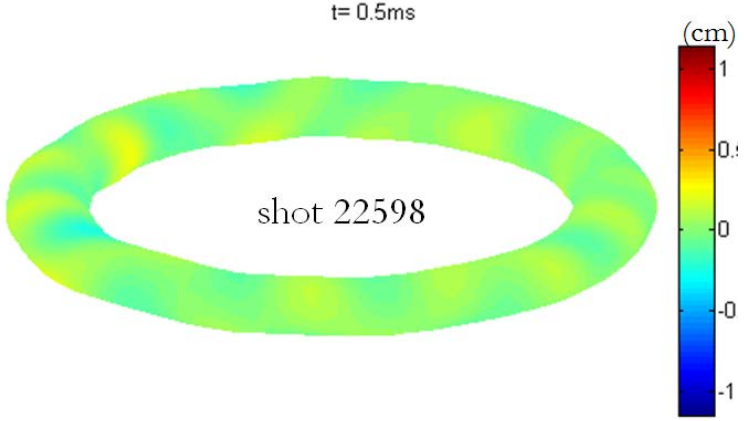
If the ITER "shock absorber"
will not work properly, ITER will not go far

Plasma instabilities: RWMs

- The Resistive Wall Mode (RWM) is a plasma instability that grows with a time scale related to the magnetic field penetration through the wall.
- RWMs limit plasma confinement and lead to disruptions (sudden loss of the stored energy into the experimental device)

a disruption in JET

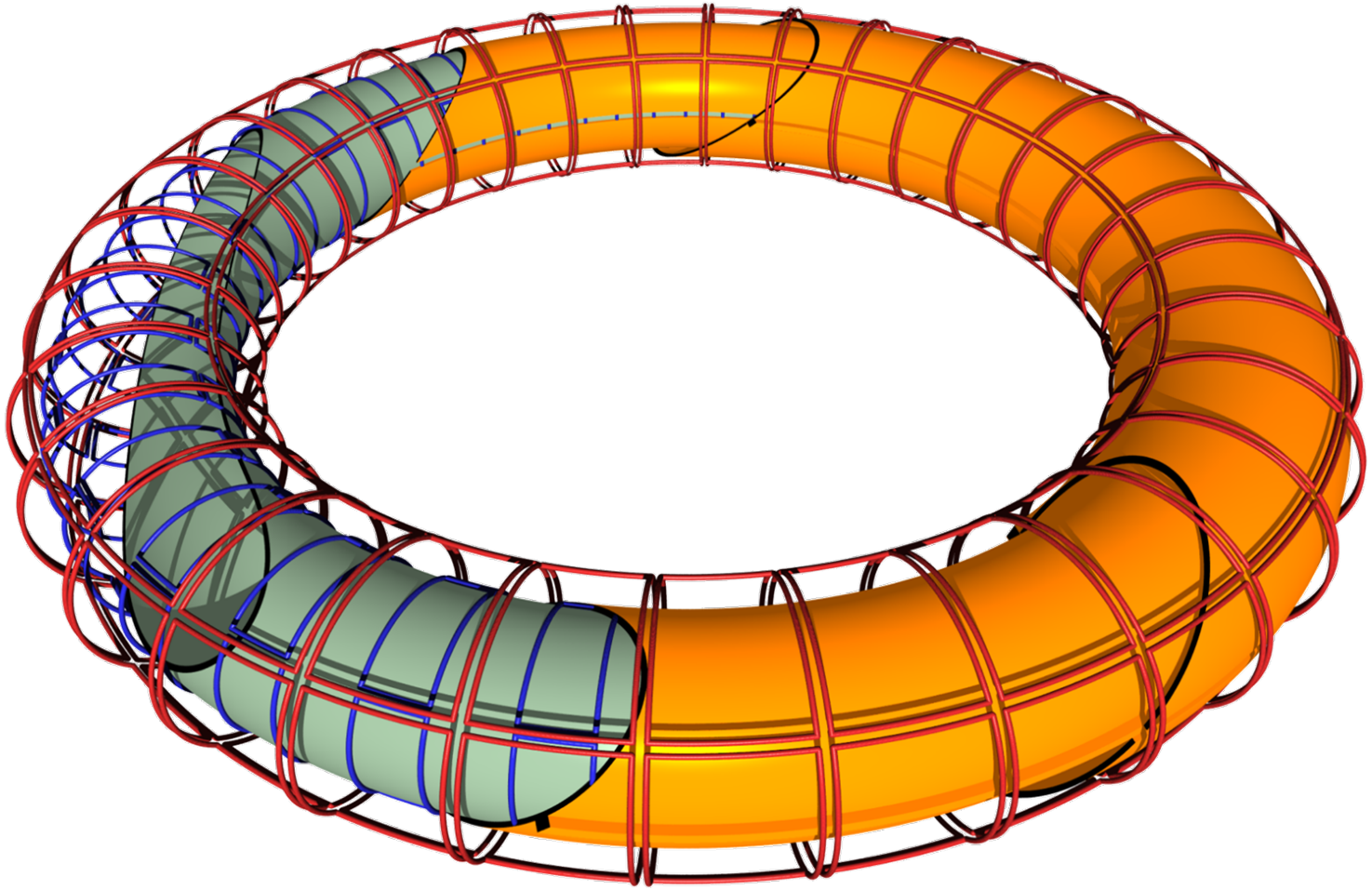
plasma deformation due to RWMs in EXTRAP T2R



- RWMs must be controlled and/or suppressed.

RWM control in EXTRAP T2R:

the feedback system



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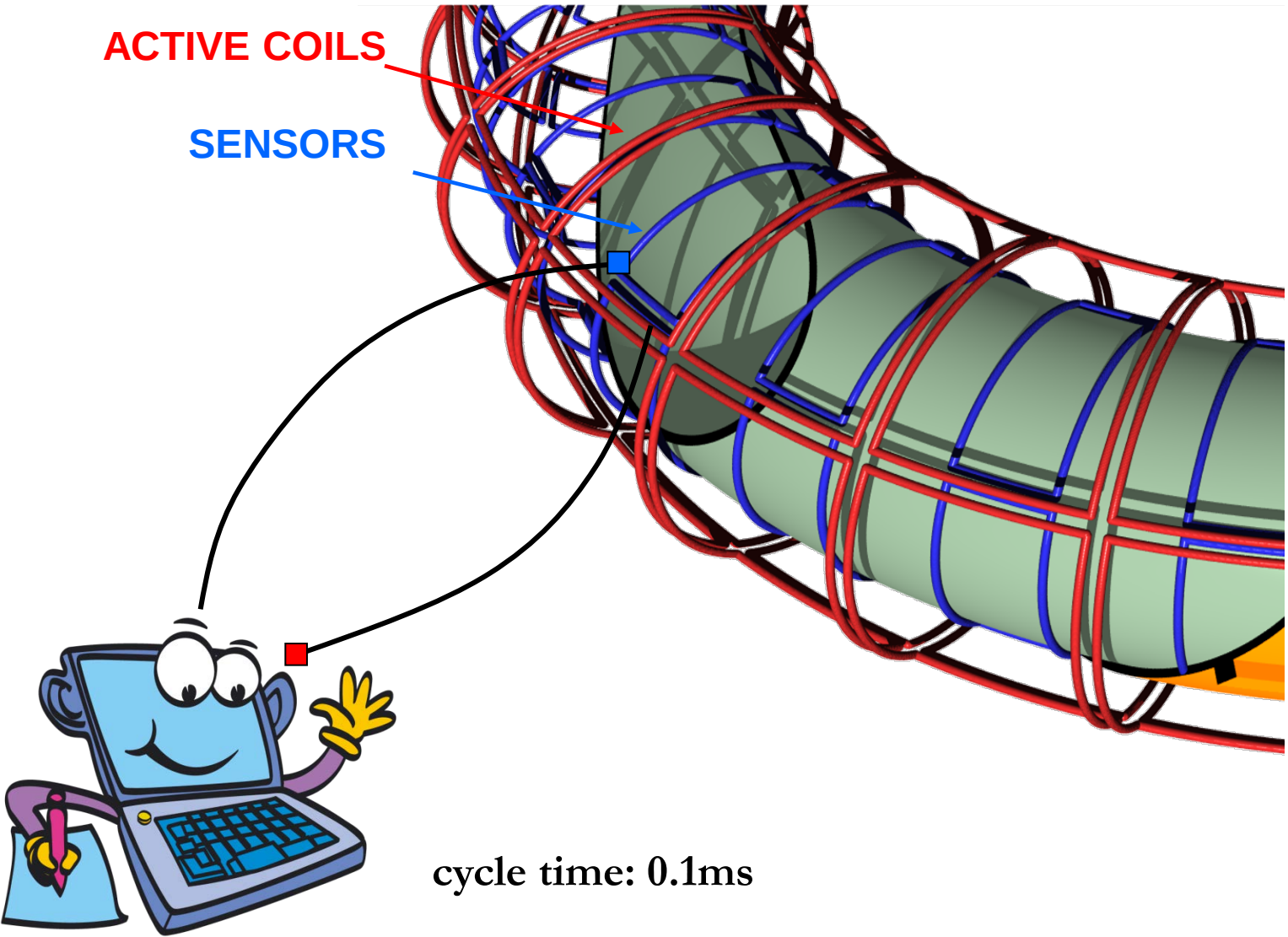
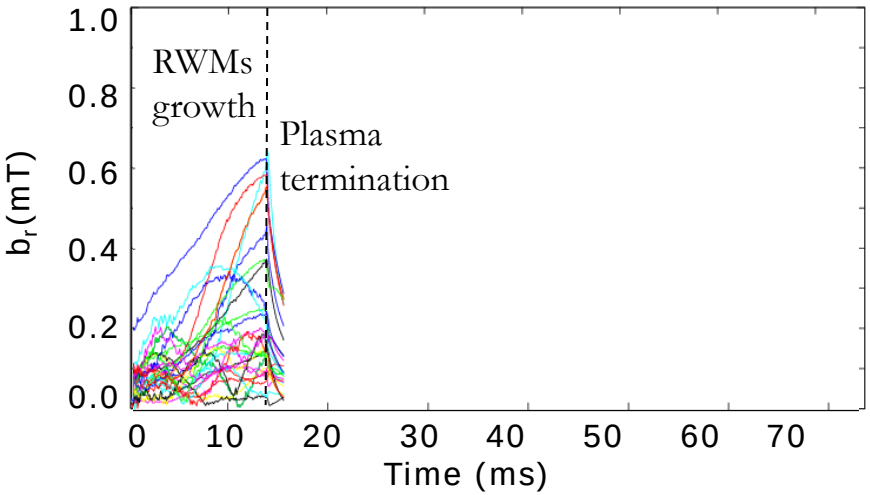
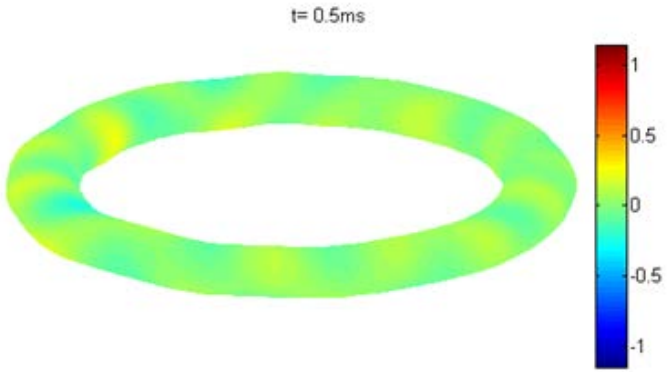


cycle time: 0.1ms

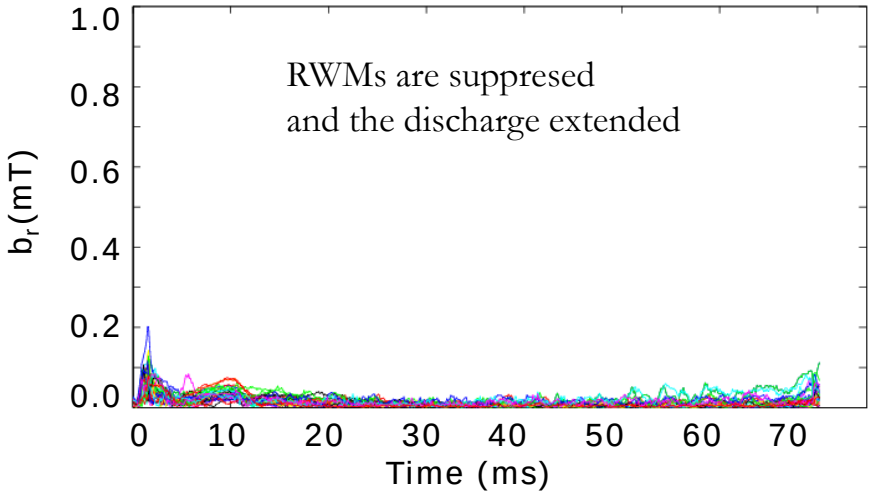
RWM control in EXTRAP T2R

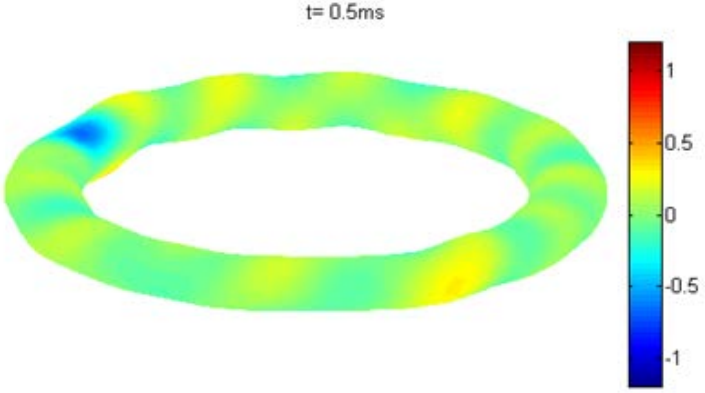
No feedback





With feedback



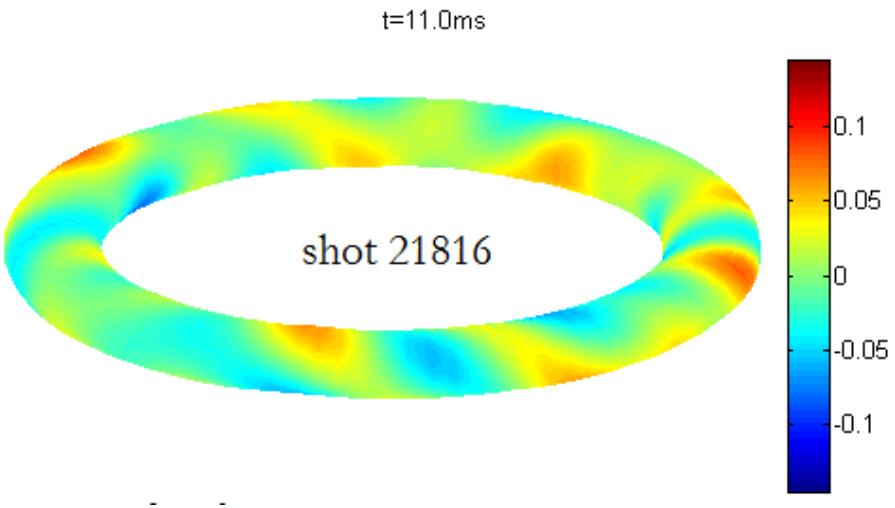


[Brunsell P. *et al*, PRL 225001, **93** (2004)]
[Frassinetti L. *et al*, NF 063018, **51** (2011)]

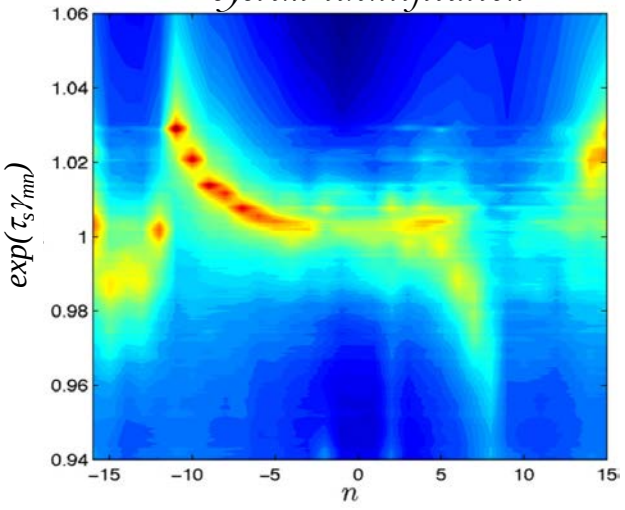
Example of advanced feedback techniques:

SYSTEM IDENTIFICATION

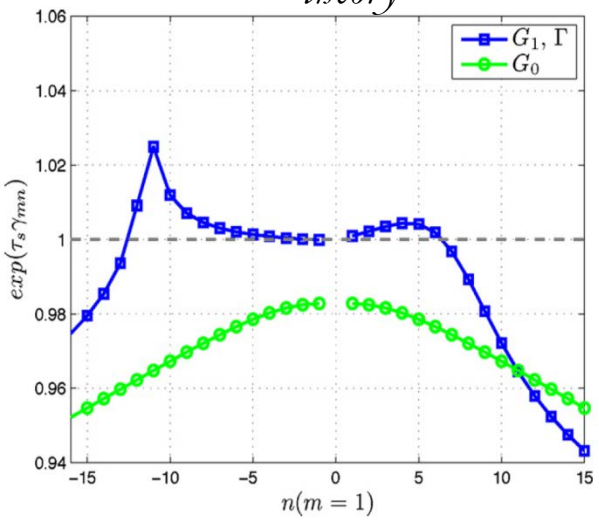
- For an optimal control, the knowledge of the RWM growth rate is necessary
- In ITER, RWMs cannot be left "free to grow" or they might damage the machine.
- EXTRAP T2R has tested a method (dither injection) to suppress RWM and simultaneously estimates the growth rate.
- Good agreement of the growth rates between experimental system identification and theory.



system identification



theory

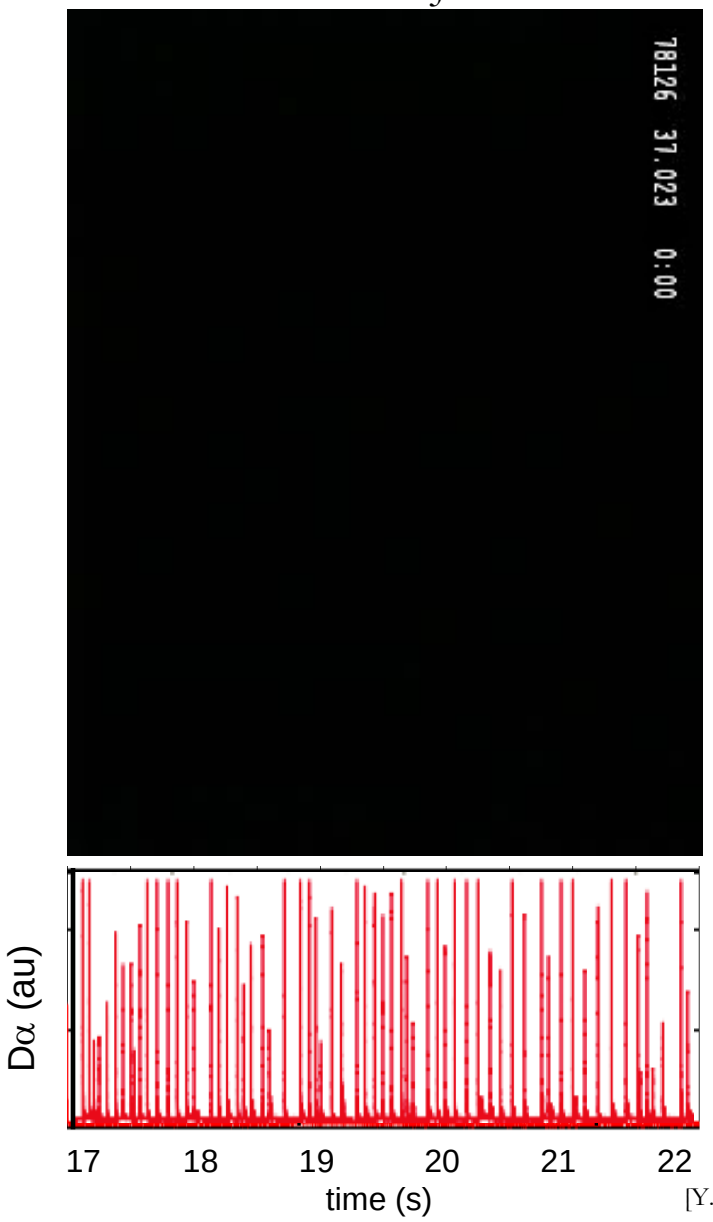


[Olofsson E. *et al.*, PPCF **54** 094005 (2012)]

Plasma instabilities: ELMs

- Edge Localized Modes (ELMs) are a plasma instability that produce significant energy losses towards the wall.
- These energy losses will damage the ITER plasma facing components.
- External resonant magnetic perturbations (RMPs) are used to suppress/mitigate ELMs

ELMs in JET



[Y. Liang, NF 2010]

Plasma instabilities: ELMs

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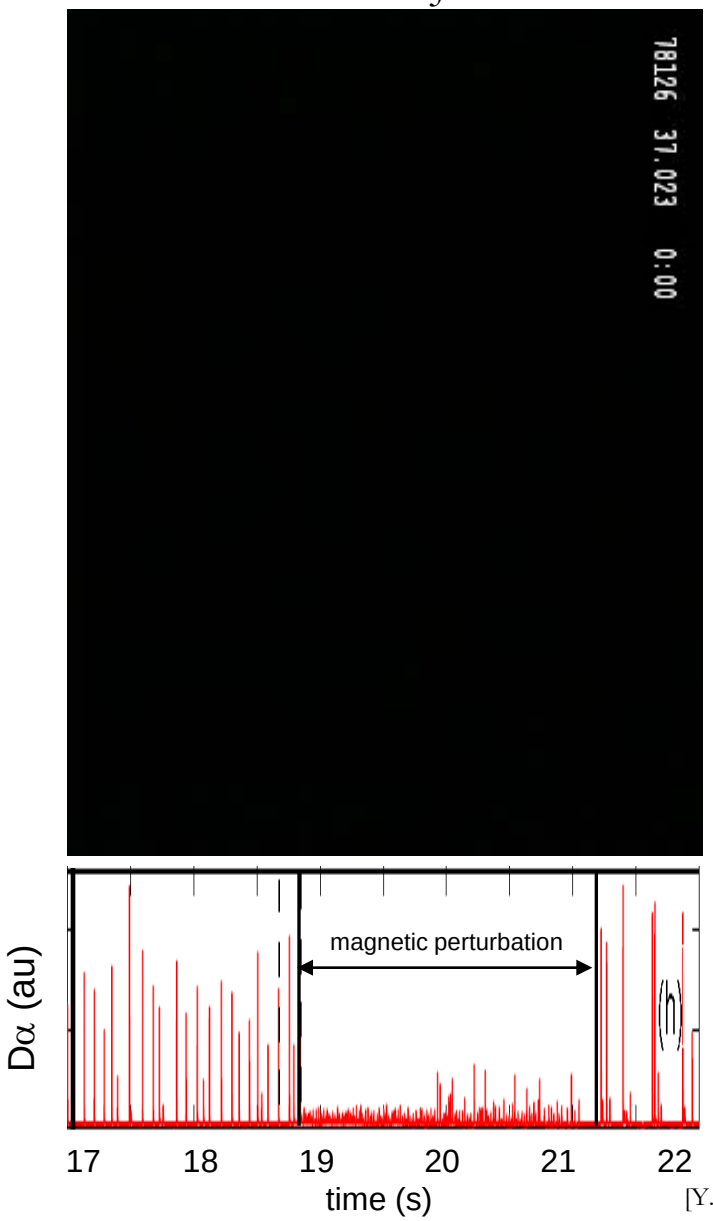
- These energy losses will damage the ITER plasma facing components.
- External resonant magnetic perturbations (RMPs) are used to suppress/mitigate ELMs
- Unfortunately, RMPs produce the braking of plasma velocity (high velocity is necessary for MHD stability and PWI minimization).
- The braking mechanism is still under investigation.
  EXTRAP T2R is contributing to the understanding of the braking mechanism.

ELMs in JET



[Y. Liang, NF 2010]

Plasma braking in EXTRAP T2R

- Several theoretical studies investigate the braking mechanism.

1- **Resonant** perturbation: electromagnetic torque

$$T_{EM} = c\, b_{TM}^{m,n} b_{RMP}^{m,n}\, \delta\left(r - r_s\right)$$

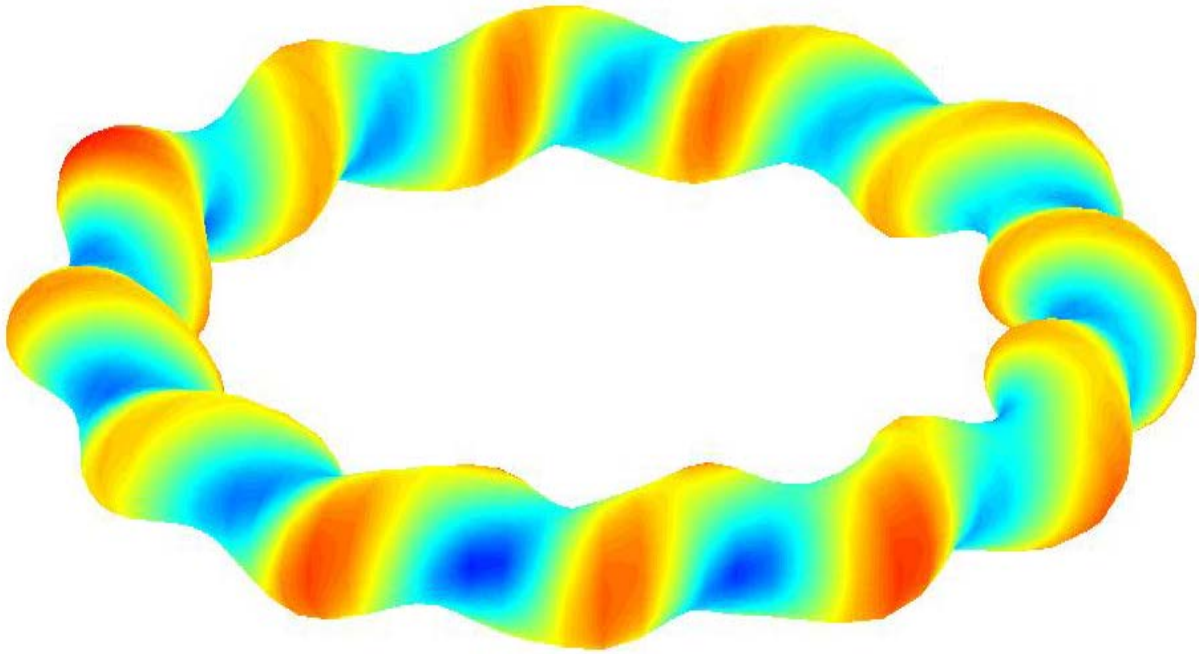
[Fitzpatrick and Yu, PoP 3610, **7** (2000)]

2- **non-resonant** perturbation: NTV theory

[Shaing et al., PoP 082506, **15** (2008)]

- With EXTRAP T2R feedback system we can apply perturbations both resonant and non-resonant single harmonics and experimentally study the braking mechanisms.

shot 21359



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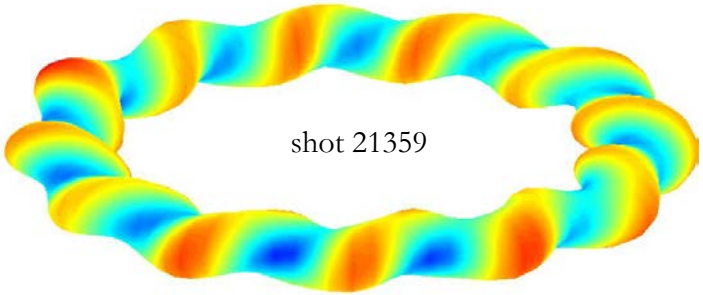

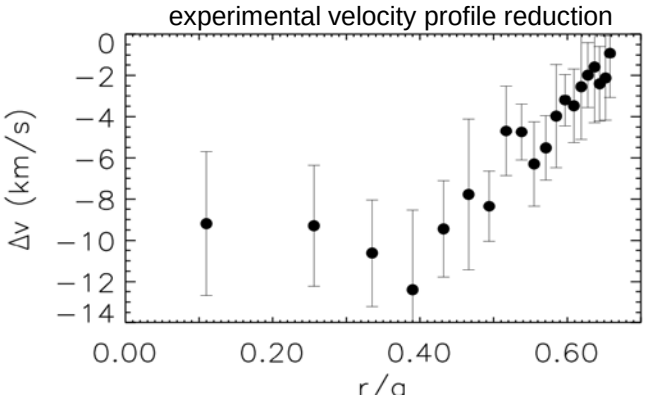

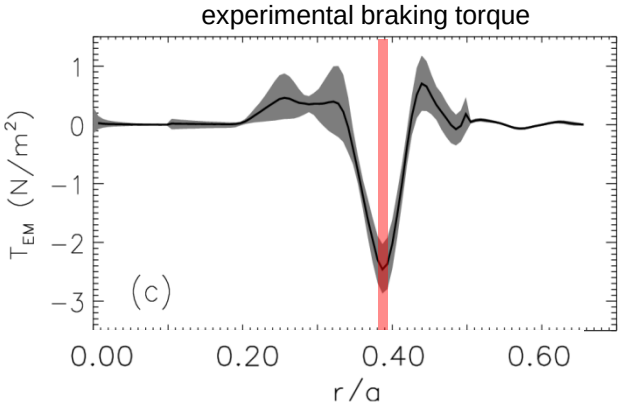

[Frassinetti L., NF 103014, **52** (2012)]

CONCLUSIONS

- (Most of the)Plasma instabilities must be controlled.
- EXTRAP T2R is a useful experiment to develop and test new techniques for instability control in view of successful ITER operation.
- EXTRAP T2R and its feedback system (along with the research team…) is:
  - testing the feasibility of multiple RWMs stabilization
  - developing advanced feedback algorithms for the optimization of instability control.
  - performing studies on the physical mechanisms related to the interaction of external magnetic perturbation with the plasma.