Resonant magnetic perturbation effect on the tearing mode dynamics in EXTRAP T2R: experimental results and modeling

L. Frassinetti, K.E.J. Olofsson, P.R. Brunsell, J.R. Drake

Alfvén Laboratory,
Royal Institute of Technology KTH
Stockholm

OUTLINE

- **Resonant magnetic perturbation (RMP)**

  Why are RMPs important?
  Why are RMPs studied in EXTRAP T2R?

- **EXTRAP T2R**

  Machine
  Diagnostics
  Feedback system

- **Experimental results**

  TM dynamics with low RMP amplitude
  TM dynamics with high RMP amplitude
  TM locking to a RMP

- **Modelling results**

  Fitzpatrick theory
  Interpretation of experimental results

WHY ARE RMPs IMPORTANT?

1. Neo-classical tearing mode stabilization

RMP can interact with the NTM with stabilizing effects

RMP can rotate a locked mode to move the O-point in the best position for ECCD stabilization

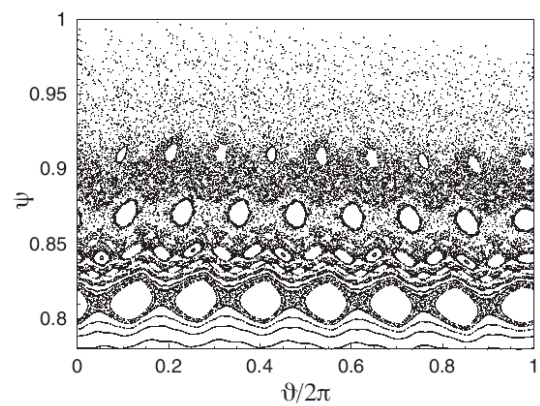
[La Haye, PoP 9, 2051 (2002)]
[Volpe, PoP 16, 102052 (2009)]

2. ELM suppression:

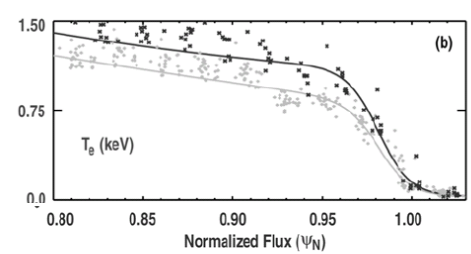
RMPs can produce stochasticity in the plasma outer region

the pressure gradient is reduced and the ELM effect mitigated.

DIIID [Evans, NF 2008, 48 024002]
JET [Liang, PRL 2007, 98 265004]



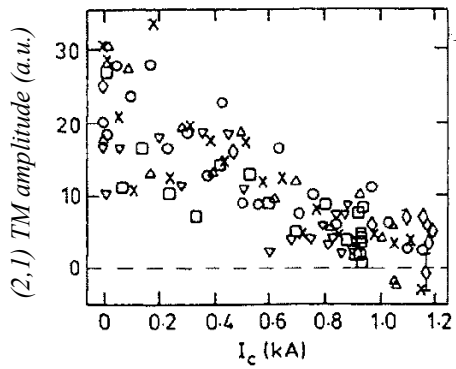
[Abdullaev, PoP 16, 030701 (2009)]



[Evans, NF 2008, 48 024002]

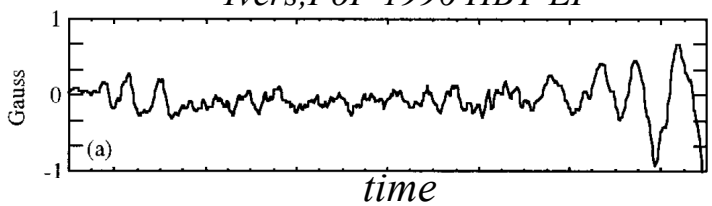
WHY TO STUDY RMP?

1. The mechanisms for ELM mitigation are not yet totally understood
2. There are many theoretical papers that investigate the interaction between an RMP and a TM



Hender NF 1992
COMPASS-C

Ivers,PoP 1996 HBT-EP



3. But recently, not so many experimental results directly investigate the RMP effect on TMs

WHY TO STUDY RMP in EXTRAP T2R?

1. EXTRAP T2R plasma is characterized by rotating TMs
2. RMPs can be easily produced with EXTRAP T2R feedback system

$\Rightarrow$ EXTRAP T2R is a good device to test new feedback algorithms and study the MHD mode response to external perturbations

EXTRAP T2R

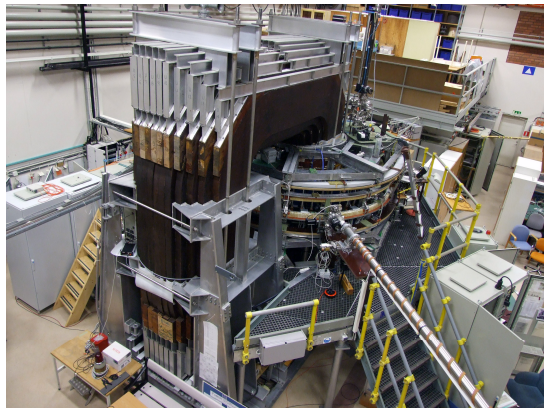
The device

EXTRAP T2R is a RFP with:

- R=1.24m
- a=0.18m

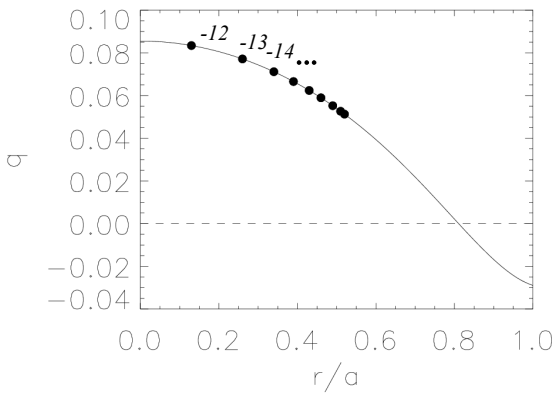
- $I_p \approx$ 80-150kA
- $n_e \approx 10^{19} m^{-3}$
- $T_e \approx$ 200-400eV

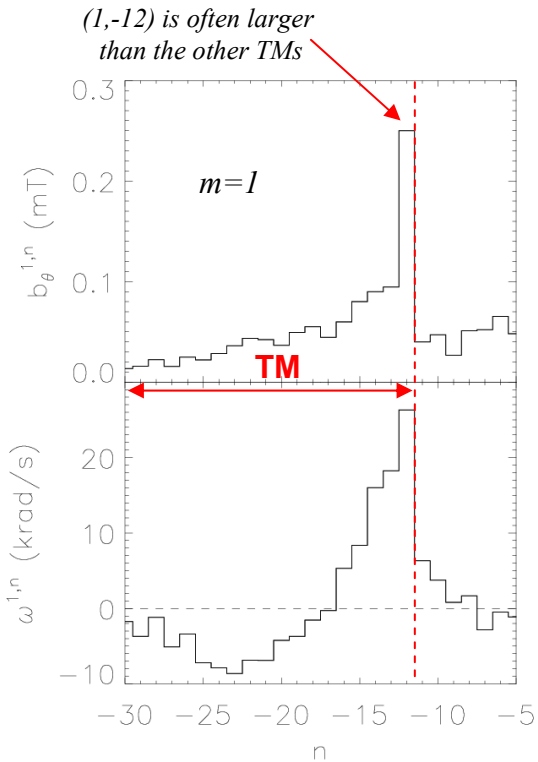
- $t_{pulse} \approx$ 20ms (no FeedBack)
- $t_{pulse} \approx$ 90ms (with IS)

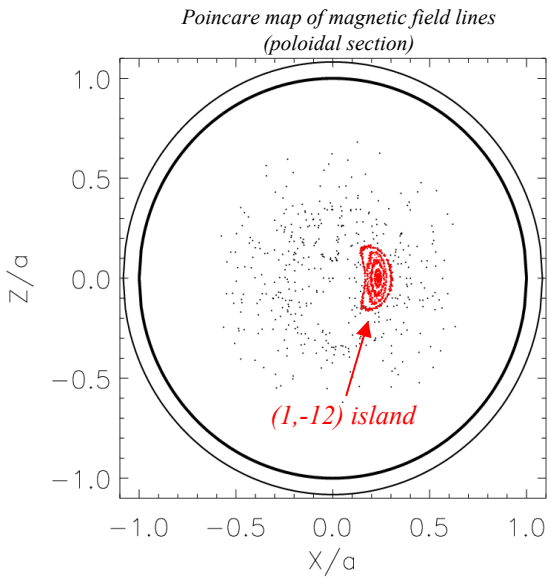


TM diagnostic

$b_\theta \Rightarrow$ 4 poloidal x 64 toroidal local sensors *(m=1 connected)* located inside the shell. Sensitive to fast rotation.

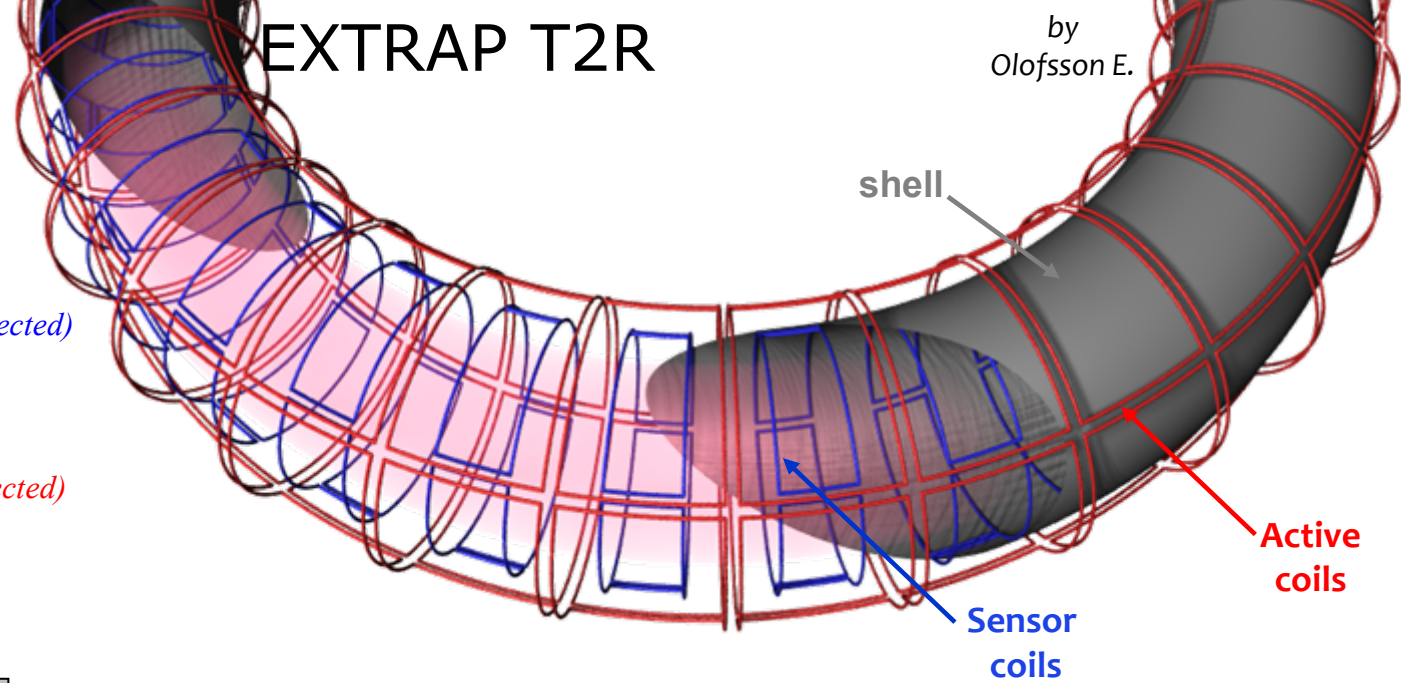


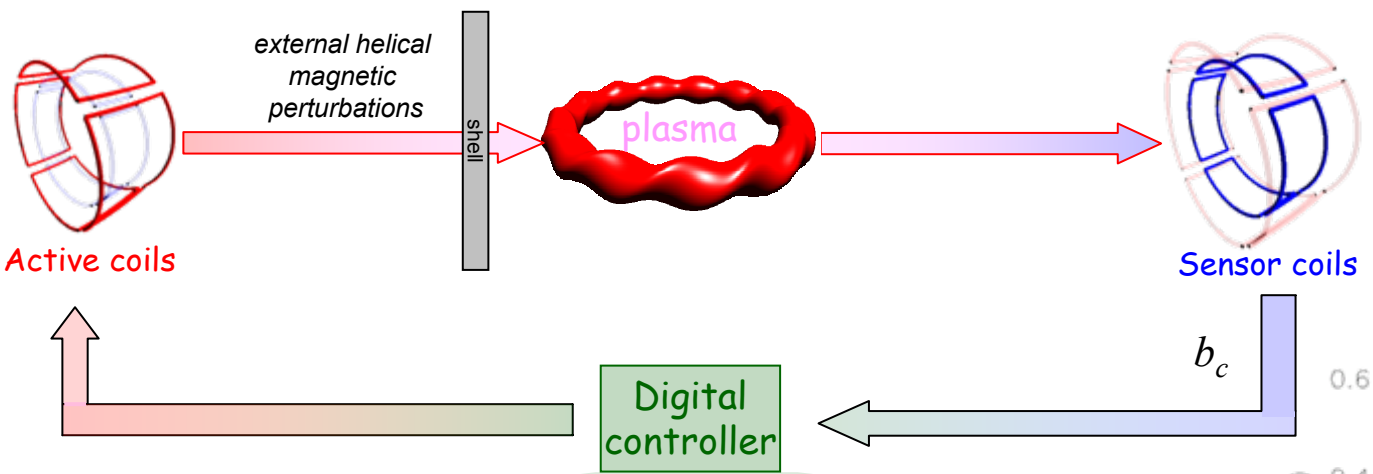




The feedback

- $\tau_{shell} \approx 13.8$ms *(nominal)*
- **SENSOR COILS**
  4 poloidal x 32 toroidal
  sensor saddle coils *(m=1 connected)*
  located inside the shell
- **ACTIVE COILS**
  4 poloidal x 32 toroidal
  active saddle coils *(m=1 connected)*
  located outside the shell
- **DIGITAL CONTROLLER**

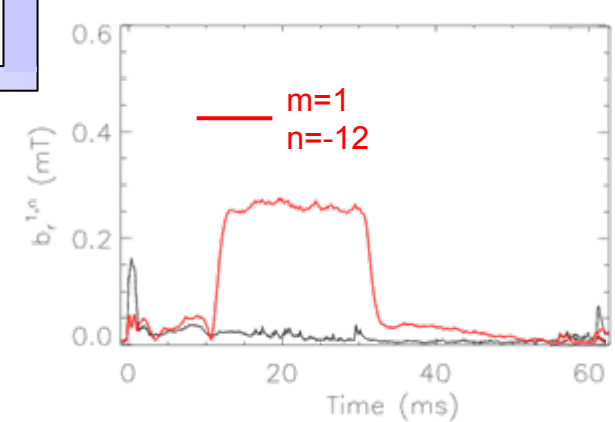




input
to active coils

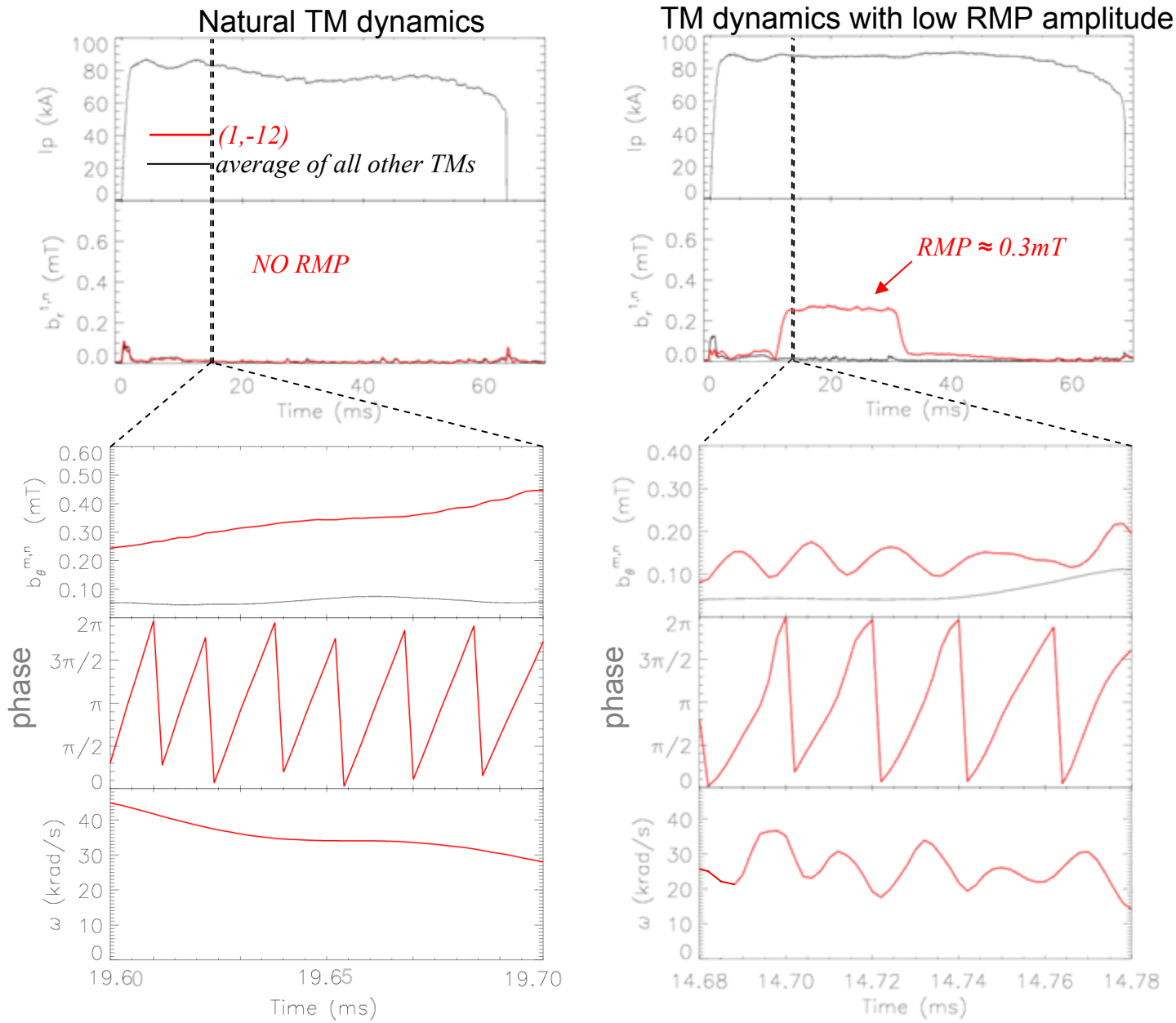
Fourier harmonics
in real time

$$V_c(t) \Leftarrow V_{1,n} \Leftarrow min[\ |b_{1,n}(t)\text{-}ref|\ ] \qquad b_{1,n} \Leftarrow b_c$$



[Olofsson, Fusion Engineering and Design 84, 1455 (2009)]

TM DYNAMICS



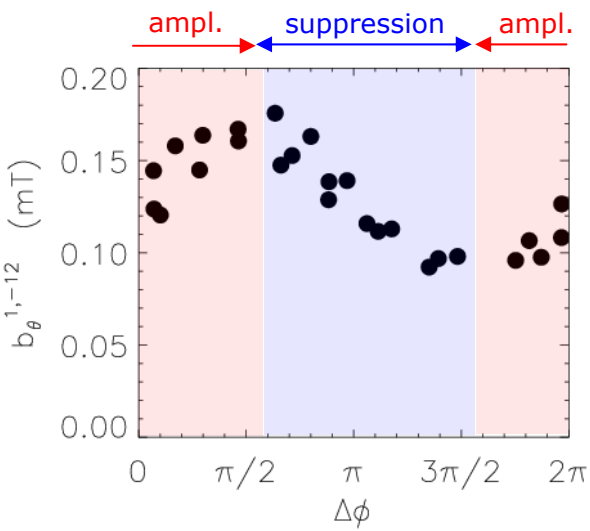
RMP effect on the rotating TM:

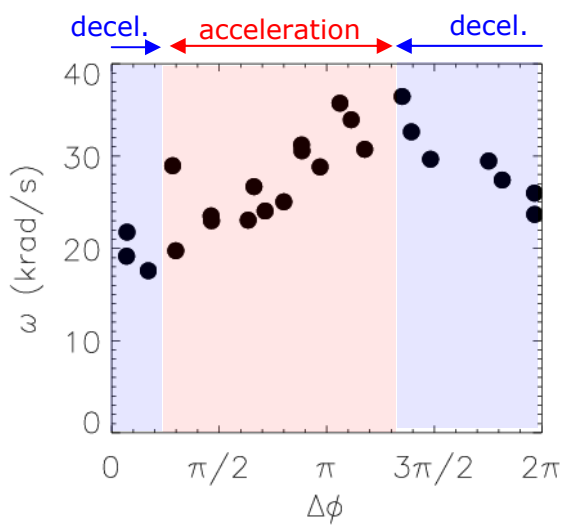
1- amplitude: "modulated"

2- velocity: "modulated"

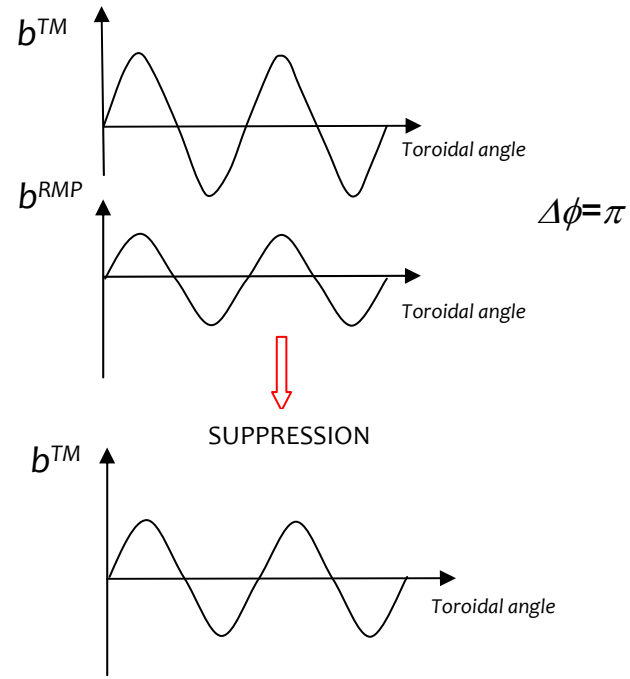
TM DYNAMICS with low RMP amplitude

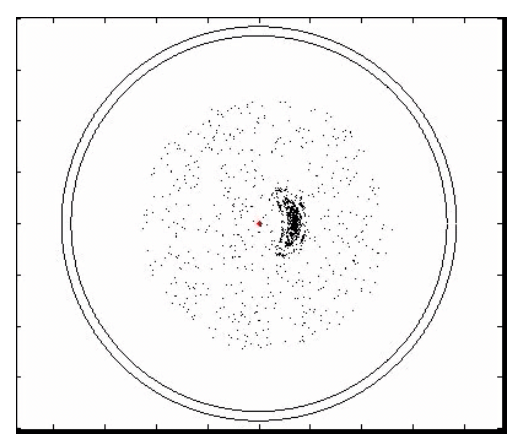
TM **amplitude** and **velocity** are **correlated** with the **phase shift** between TM and RMP



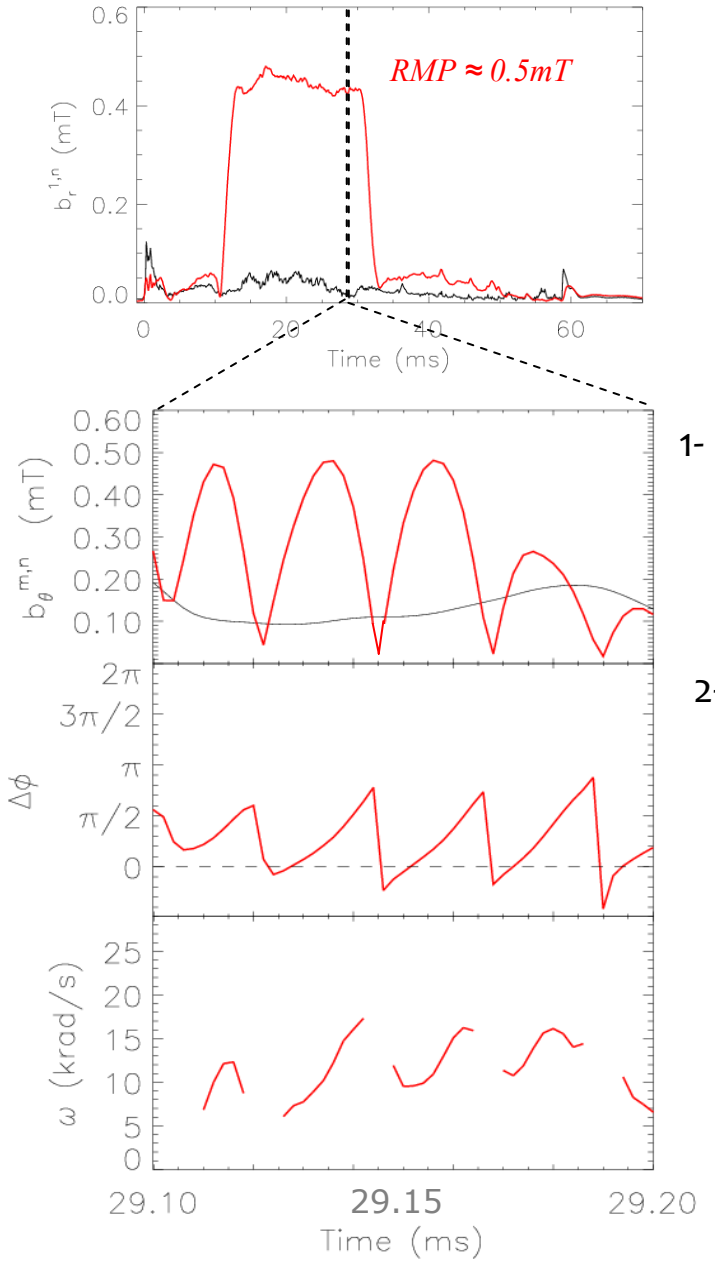


Phenomenological explanation (wrong!)



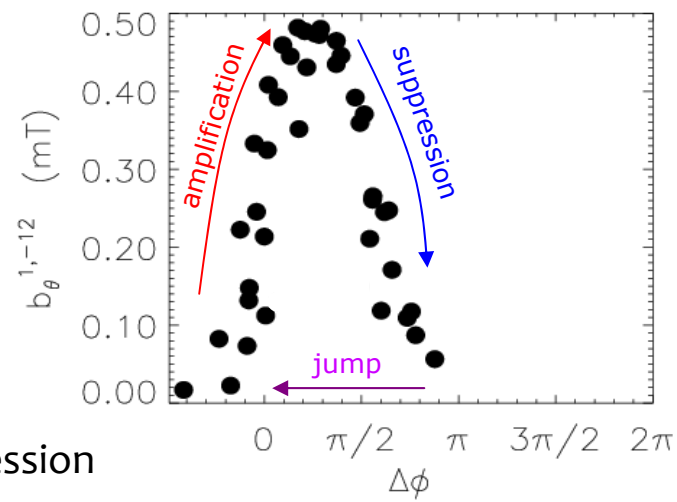


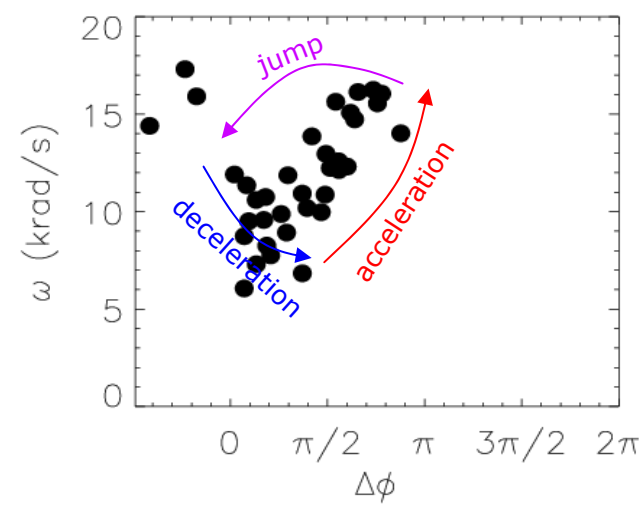
TM DYNAMICS with high RMP amplitude



1- High oscillation
with "complete" suppression

2- phase jumps





MODELLING

*Based on Fitzpatrick [Phys. Plasmas **8** 4489 (2001)]*

3 coupled partial differential equations:

1. TM evolution

$$\frac{\Lambda_1}{2}\tau_R\frac{d(W/r_s)}{dt} = E_1 - \lambda_s^2\Lambda_1\left(\frac{W}{4r_s}\right)\ln\left(\frac{4r_s}{W}\right) + \left(\frac{W_c}{W}\right)^2\cos(\Delta\phi)$$

$$W_c = c\sqrt{b_r^{RMP}}$$

$$W = c\sqrt{b_r^{TM}}$$

2. Torque balance

$$\rho\frac{\partial\Delta\Omega}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(r\mu\frac{\partial\Delta\Omega}{\partial r}\right) + \frac{T_{EM}}{4\pi^2 R_0^3}\delta(r - r_s)$$

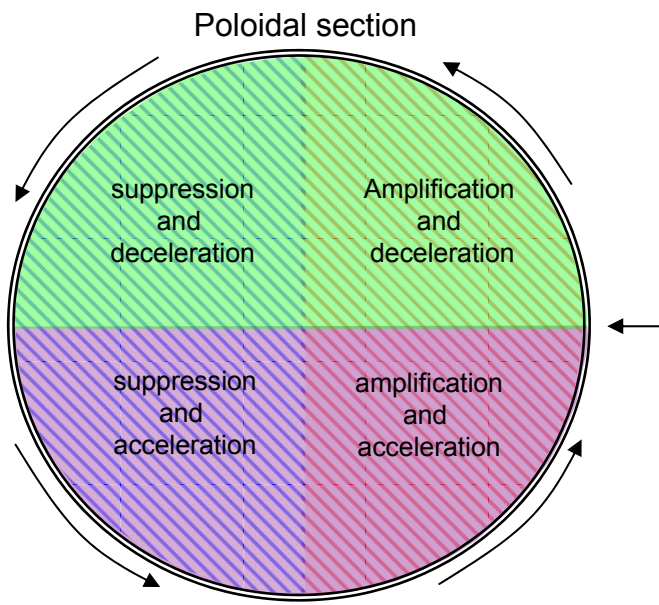
Viscous torque *EM torque*

with

$$T_{EM} = -\kappa_1\frac{c_1\omega\tau_w}{1 + c_2\omega^2\tau_w^2}\left(b_r^{TM}\right)^2 - \kappa_2\sin(\Delta\phi)\left|b_r^{TM}\right|\left|b_r^{RMP}\right|$$

braking torque due to eddy currents In the wall generated by the rotating TM

braking torque due to interaction of the rotating TM with the static RMP



3. Helical velocity

$$\Delta\dot{\phi} = \Delta\Omega + v_0$$

MODELLING the LOW RMP case

$n_e(0)=0.9x10^{19}m^{-3}$

FREE PARAMETERS

$\tau_R=0.1ms$

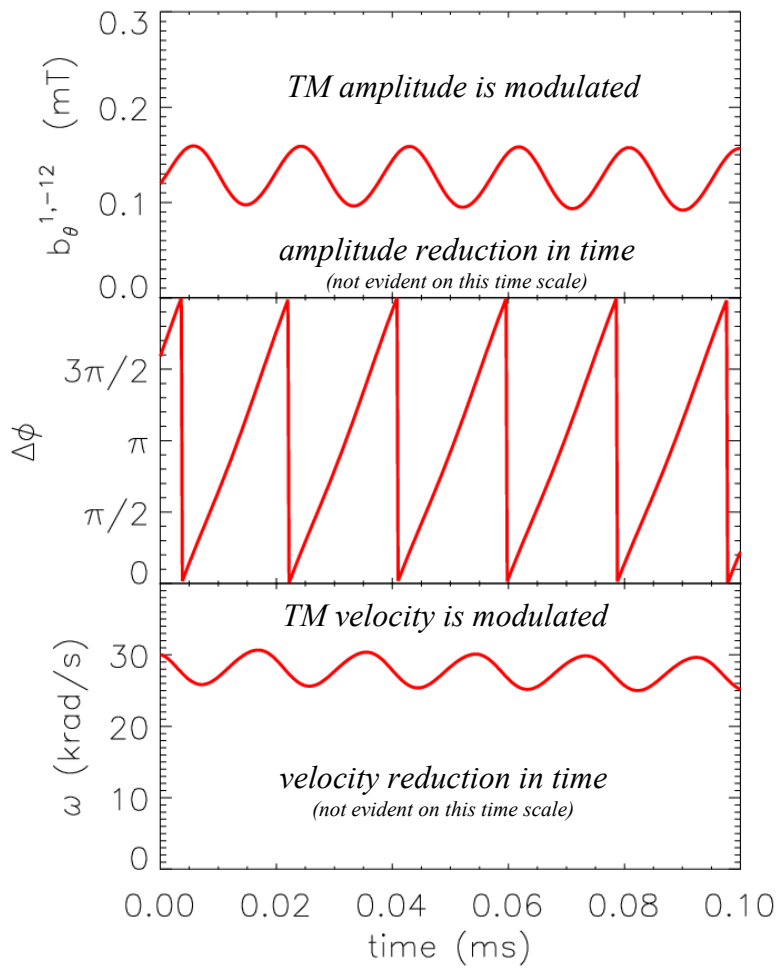
$\nu=0.65\ 10^{-7}\ kg/(m\cdot s)$

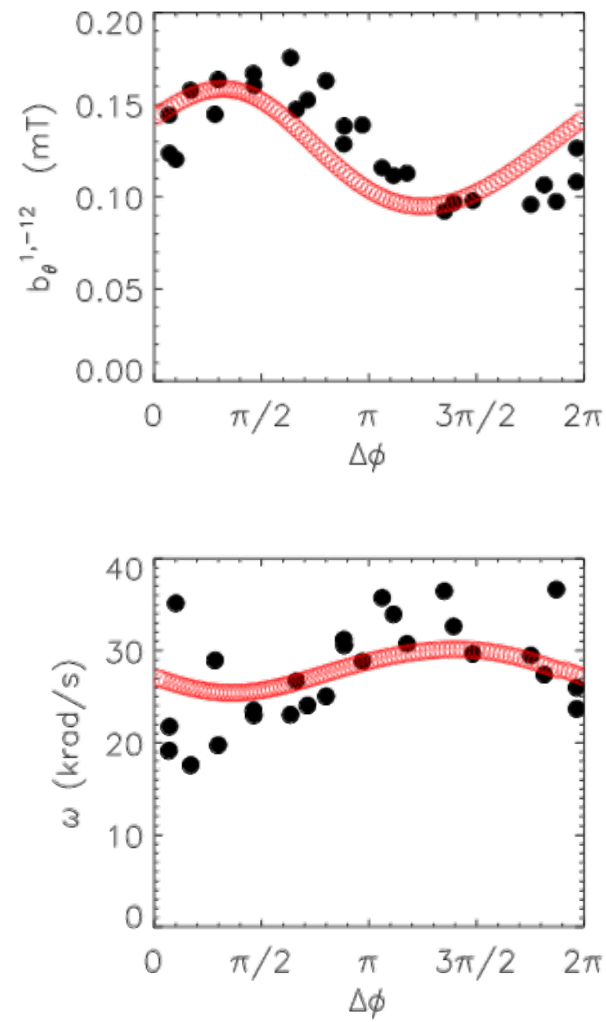
INITIAL CONDITIONS

$\omega_0=30krad/s$

$b_\theta^{TM}(0)=0.12mT$

$b_r^{RMP}=0.3mT$





Reasonable agreement between model and experiment

MODELLING the HIGH RMP case

$n_e(0)=0.9x10^{19}m^{-3}$

FREE PARAMETERS

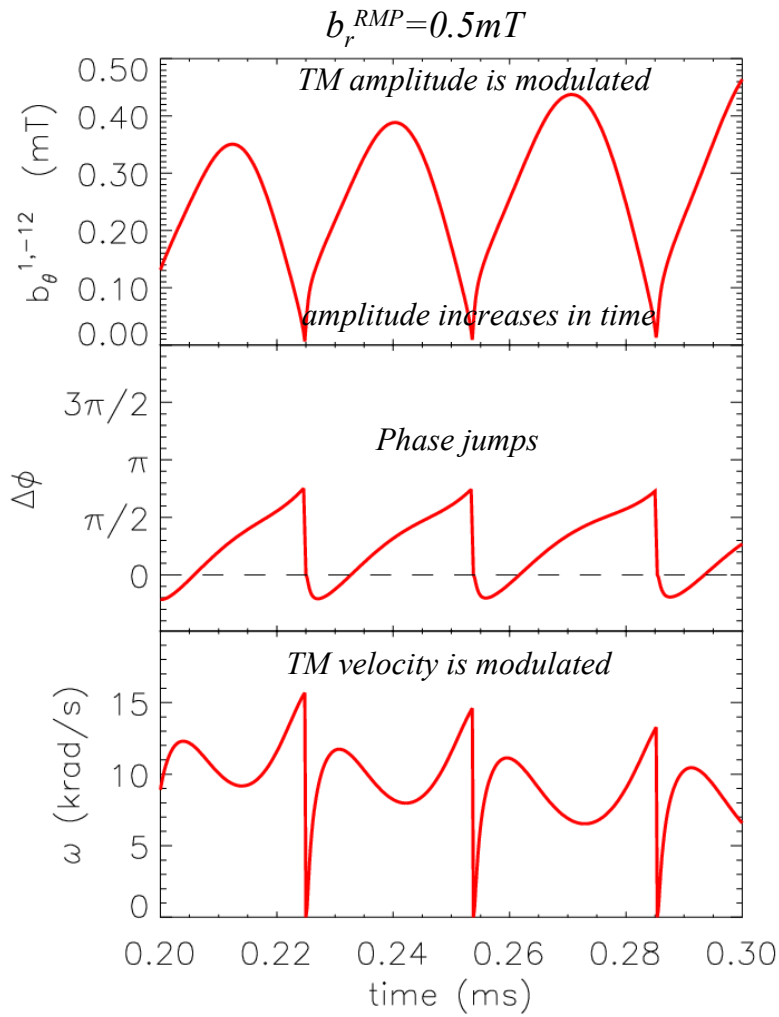
$\tau_R=0.1ms$

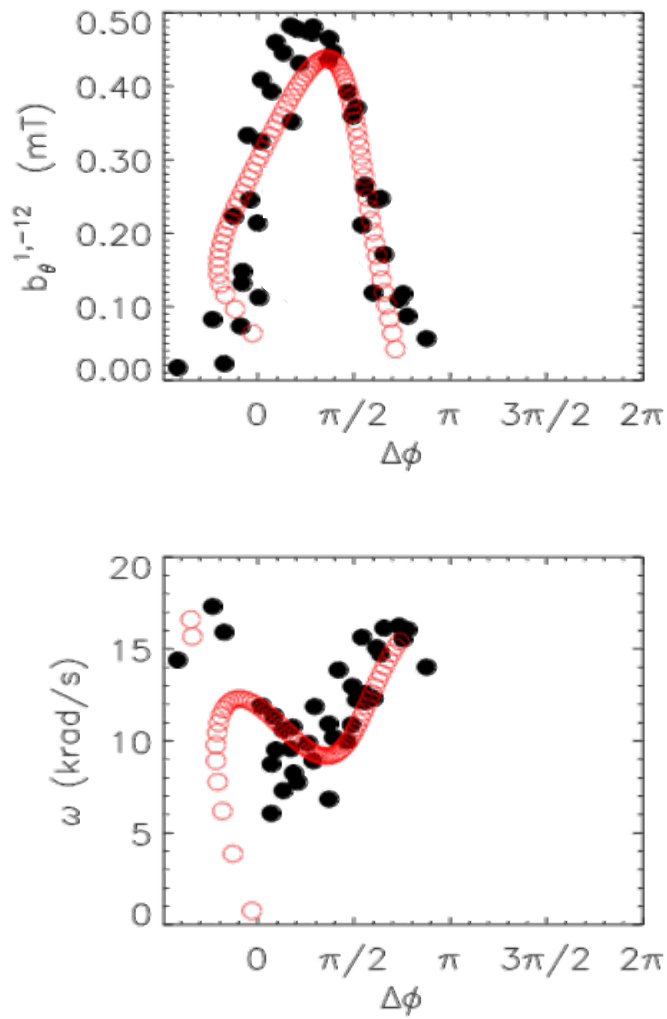
$\nu=0.65\ 10^{-7}\ kg/(m\cdot s)$

INITIAL CONDITIONS

$\omega_0=50krad/s$

$b_\theta^{TM}(0)=0.01mT$





Reasonable agreement between model and experiment

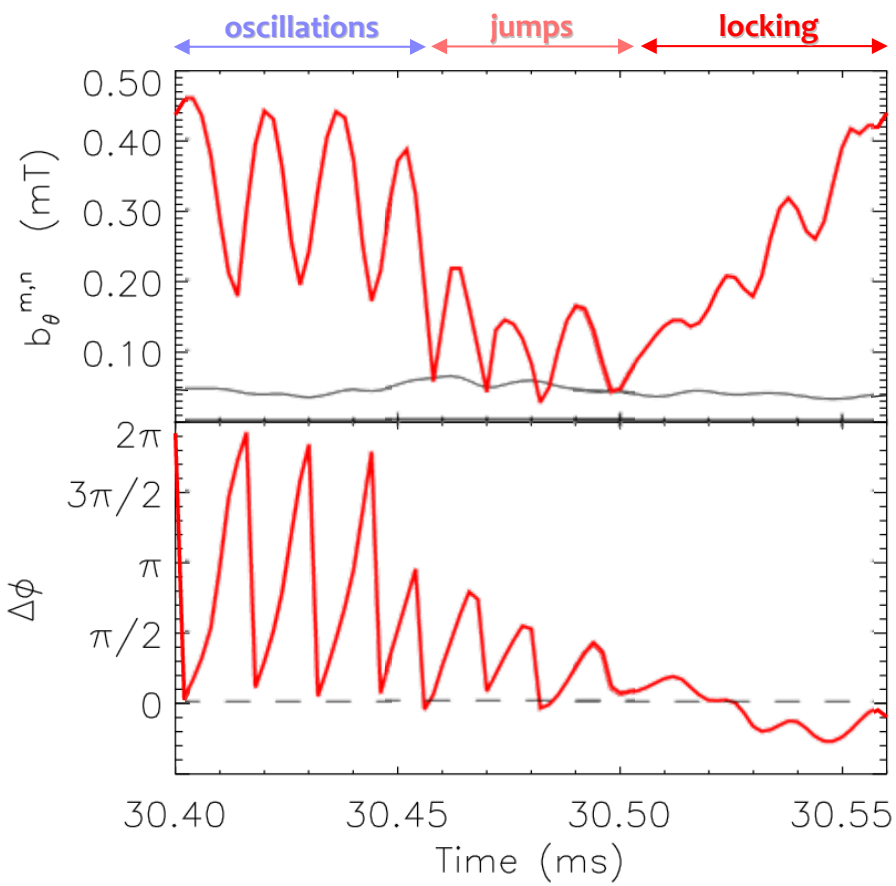
TM LOCKING TO A RMP

-**Low RMP** amplitude ⇒ "weak" **oscillation** in the TM amplitude and velocity

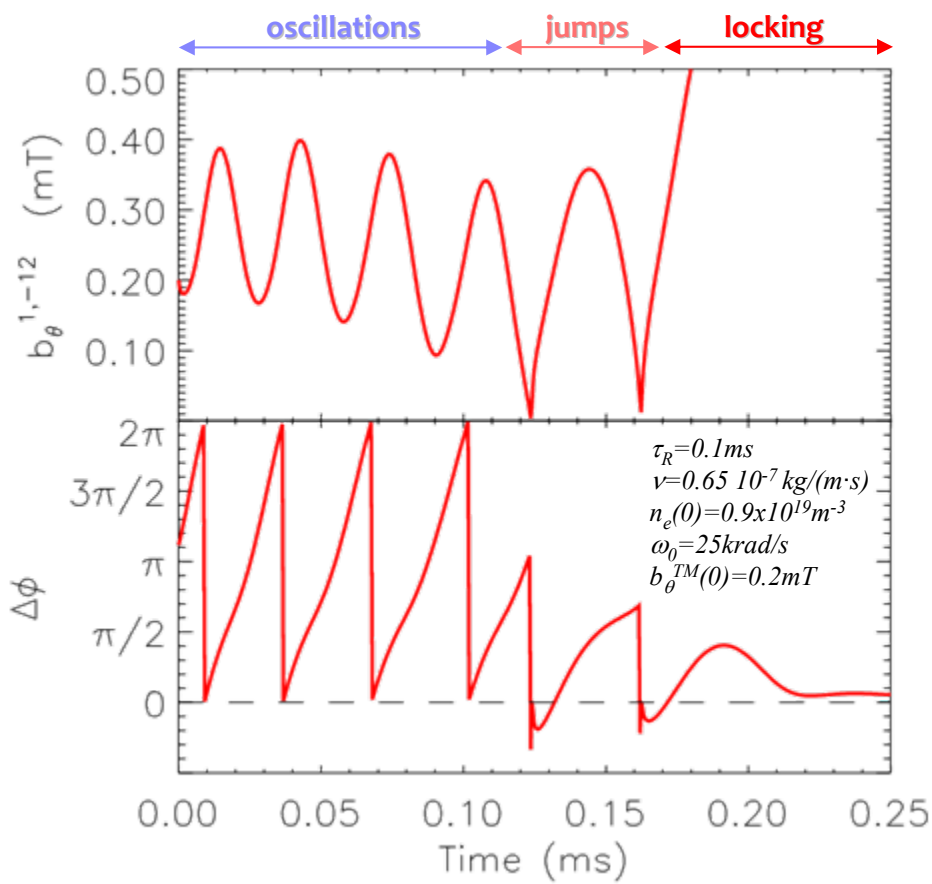
-**High RMP** amplitude ⇒ "strong" modulation in the TM amplitude and **phase jumps**

IS IT ALWAYS SO SIMPLE?

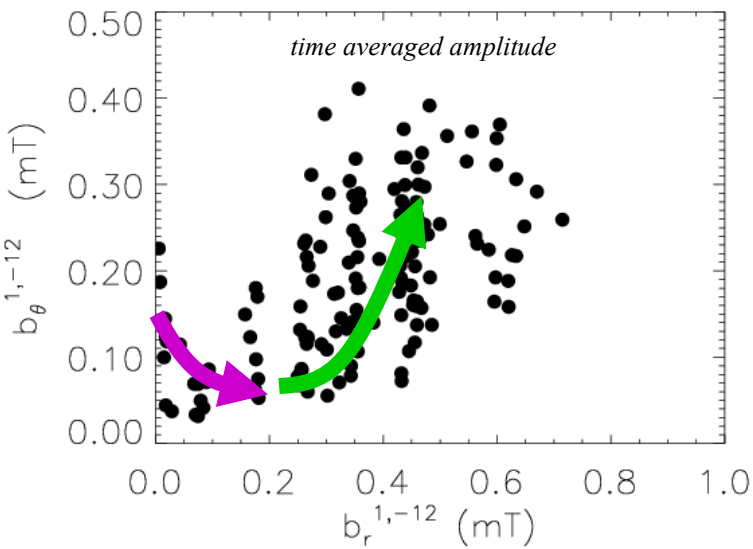
EXPERIMENT $b_r^{RMP}=0.4mT$



MODEL $b_r^{RMP}=0.4mT$



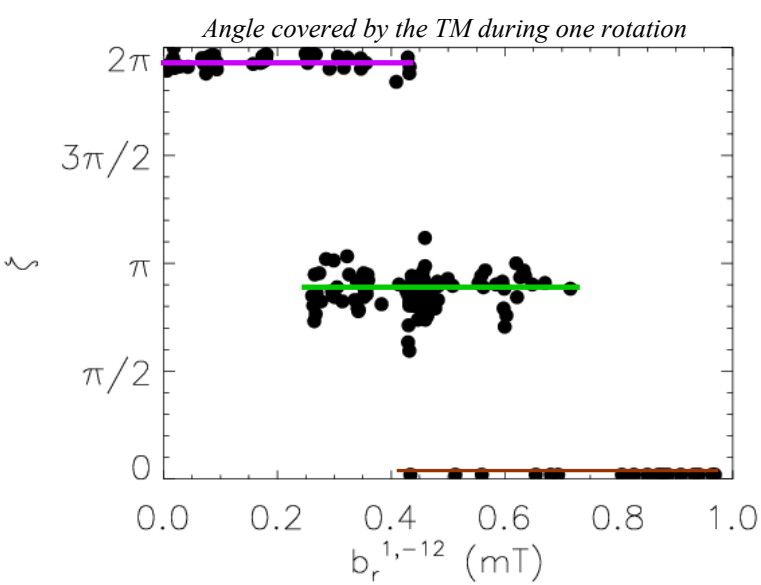
SCALING OF THE TM DYNAMIC PROPERTIES WITH THE RMP AMPLITUDE



TM amplitude:

1- **Suppression** for "low" RMP amplitudes

2- **Amplification** for "high" RMP amplitudes



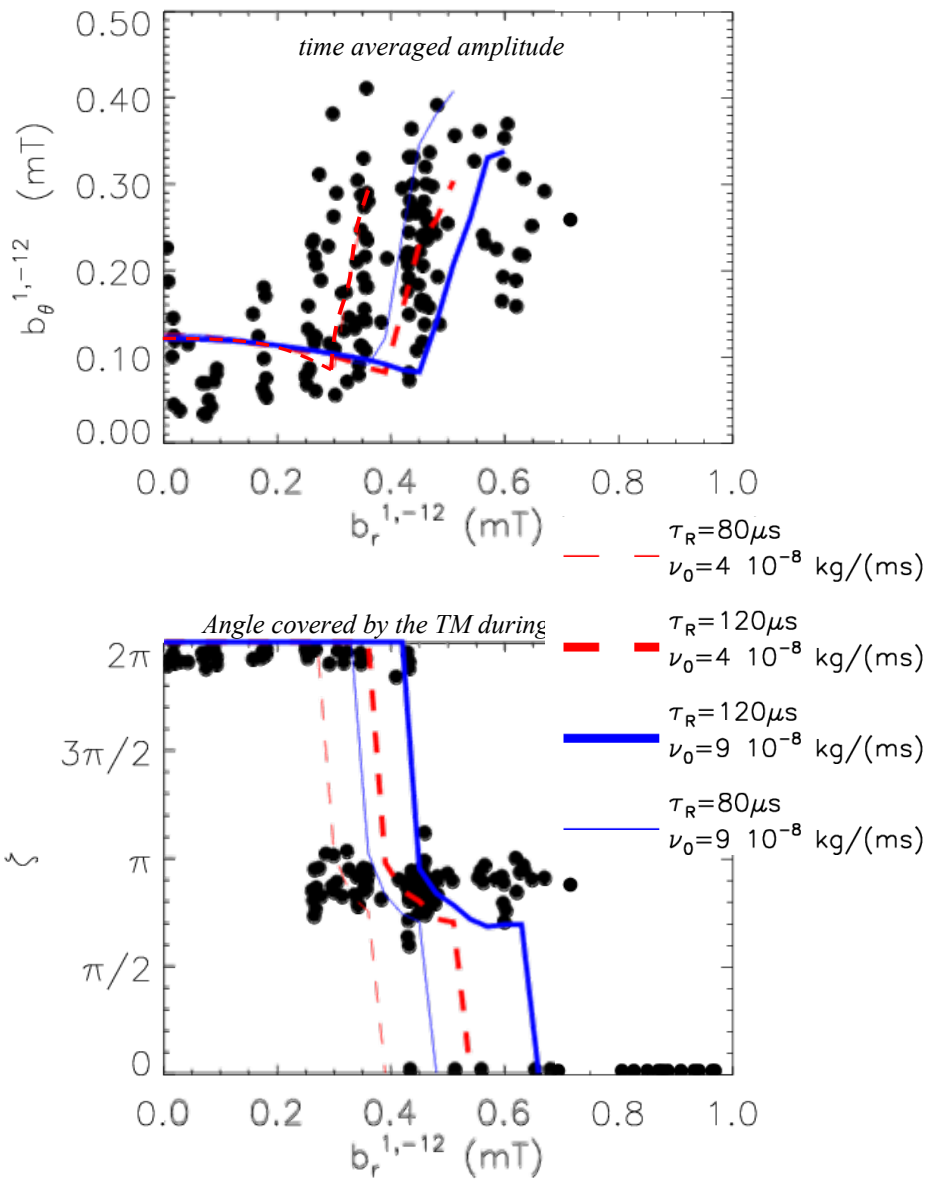
TM dynamics:

1- **Full rotation** for "low" RMP amplitudes

2- **Jumps** for "high" RMP amplitudes

3- **Locking** for "very high" RMP amplitudes

SCALING OF THE TM DYNAMIC PROPERTIES WITH THE RMP AMPLITUDE



TM amplitude:

1- **Suppression** for "low" RMP amplitudes

2- **Amplification** for "high" RMP amplitudes

TM dynamics:

1- **Full rotation** for "low" RMP amplitudes

2- **Jumps** for "high" RMP amplitudes

3- **Locking** for "very high" RMP amplitudes

CONCLUSIONS

- An external RMP can affect the rotating TM and the corresponding magnetic island

- The **RMP produces**:
  TM amplitude amplification or suppression
  TM velocity acceleration or deceleration
  depending on the phase shift

- "Low" RMP amplitude ⇒ "weak" **oscillation** in the TM amplitude and velocity
- "High" RMP amplitude ⇒ "strong" modulation in the TM amplitude and **phase jumps**
- The locking to a RMP can be a complicated mechanism

- The **Fitzpatrick model** gives a **reasonable explanation** of these phenomena
  It is a useful tool for testing advanced feedback algorithm for TM control

- Work in progress and future work:

  1- RMP with another helicity
  2- RMP effect on plasma flow
  3- …