EXTRAP T2R active coils as a tool for the study of 3D magnetic field effects on plasma dynamics

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OUTLINE

- **Experimental tools**:

  (1) EXTRAP T2R

  (2) The active coils and (some of) their capabilities,

  a tool for the study of 3D magnetic field effects:

- **Non-Resonant Magnetic Perturbations braking**

  (1) Plasma viscosity estimation (experimental)

  (2) Torque estimation (experimental)

  (3) Torque estimation (via NTV theory, by Y. Sun)

  (4) Comparison experimental results - theory

- **RMP screening**

  (1) Goal: to study the effect of the plasma flow on the RMP screening

  (2) The technique: how to modify the flow without affecting other plasma parameters?

  (3) Experimental results

  (4) Comparison with theoretical models (Fitzp.-Guo-Weal. and Rozhansky)

- **Error field assessment using external perturbations**

  see F. Volpe on Monday, 3.05pm

- **Conclusions**

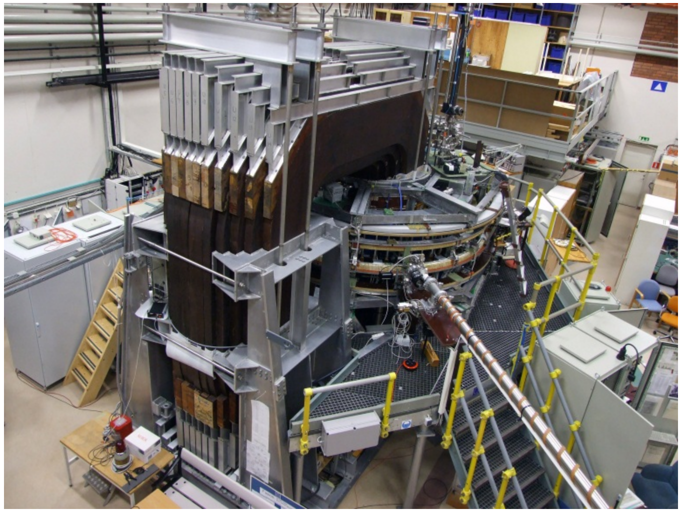
EXTRAP T2R

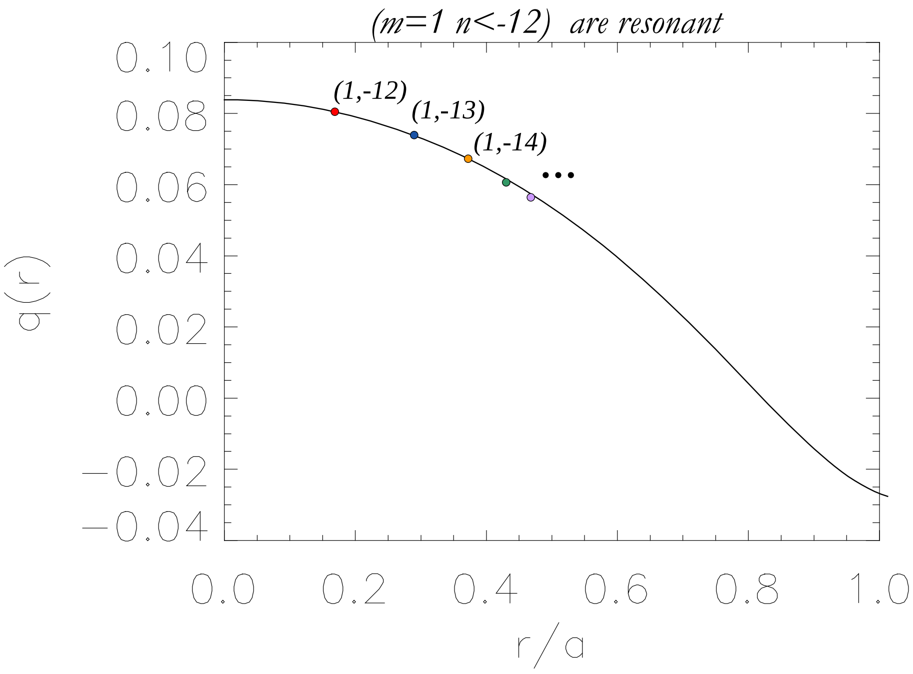
THE DEVICE

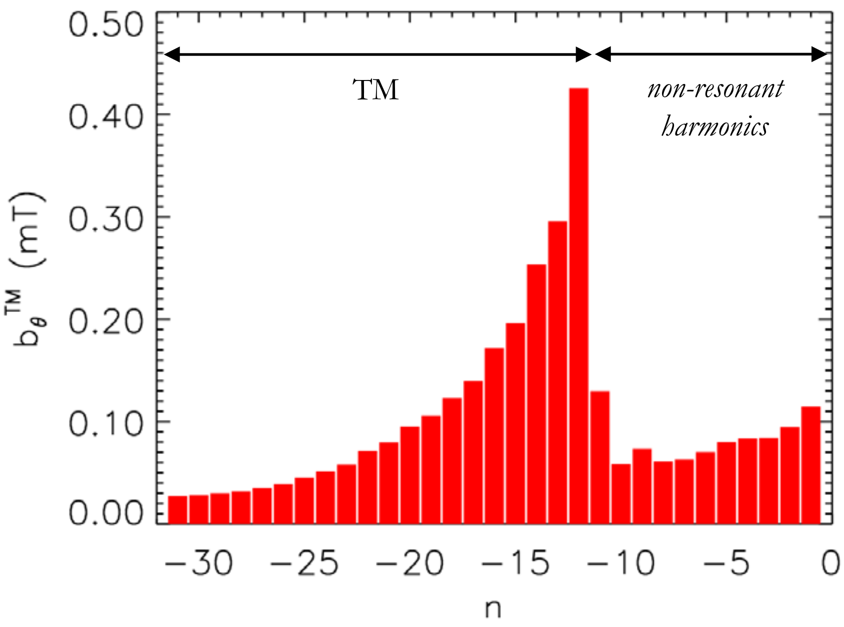
EXTRAP T2R is a RFP with:

- R=1.24m
- a=0.18m

- $I_p \approx$ 80-150kA
- $n_e \approx 10^{19} m^{-3}$
- $T_e \approx$ 200-400eV
- $t_{pulse} \approx$ 90ms

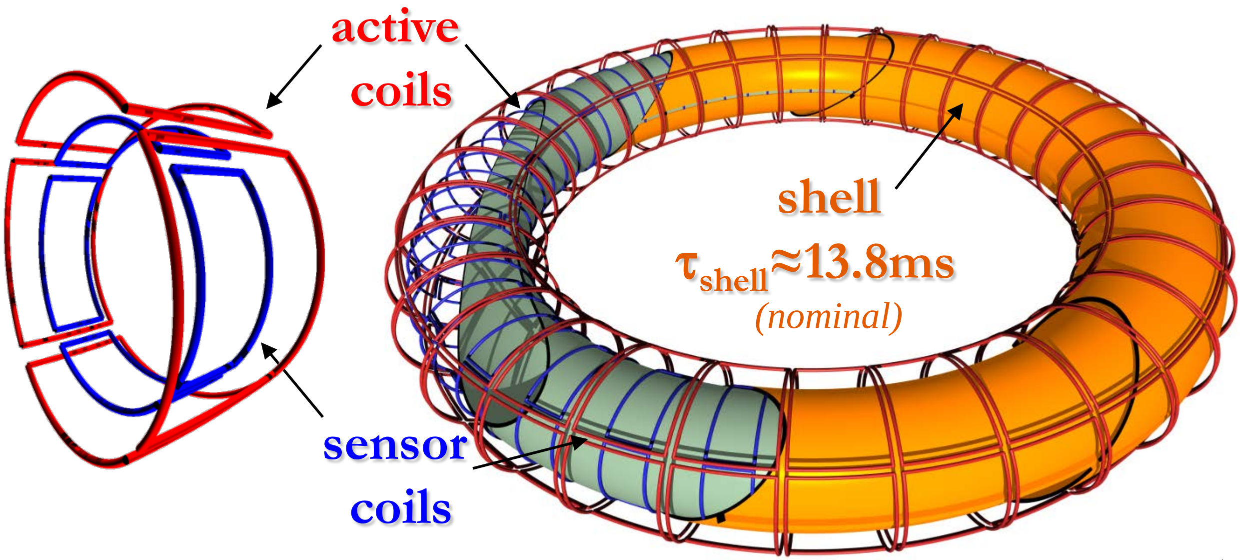


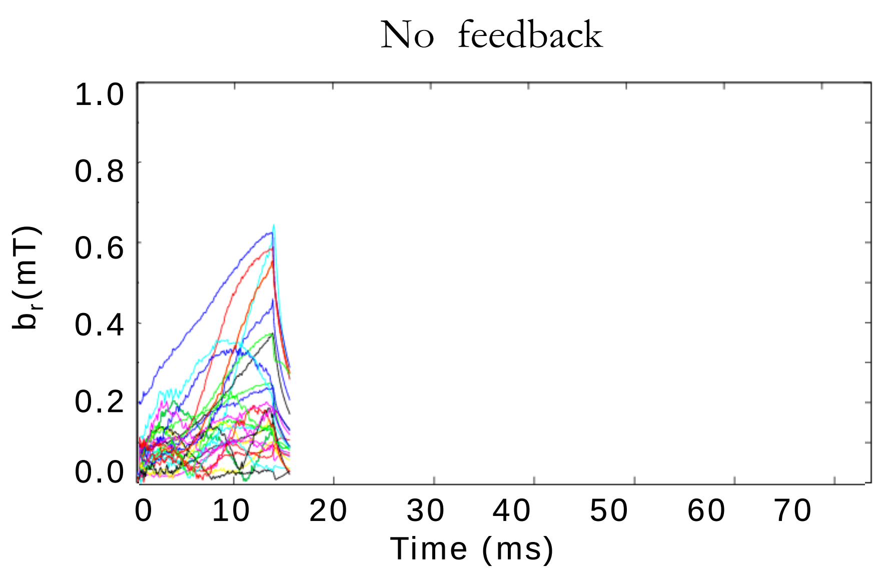


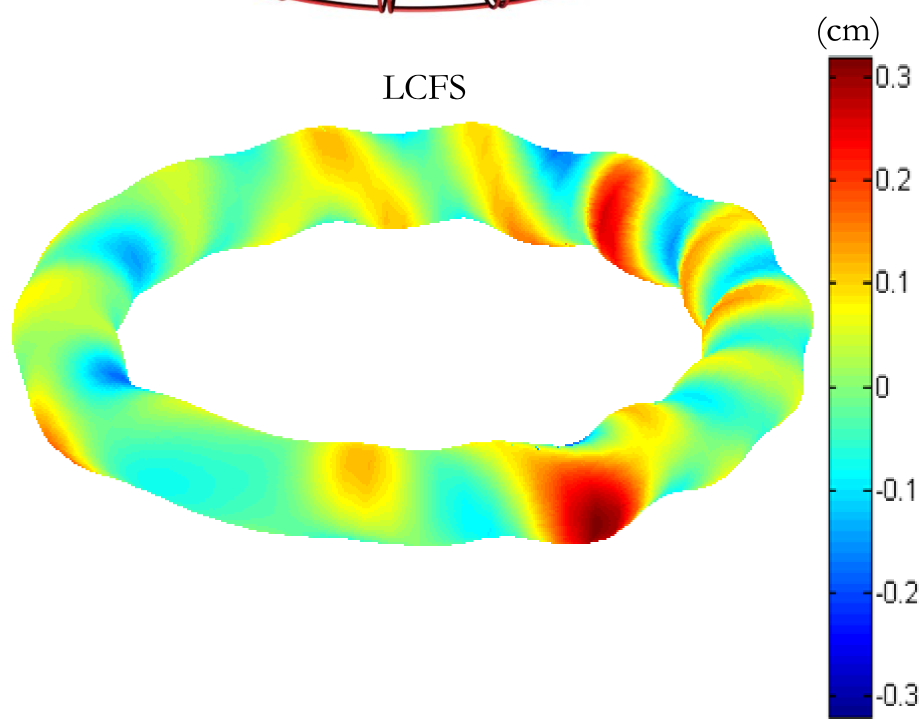


THE FEEDBACK SYSTEM

- **Sensor coils**
  4 poloidal x 32 toroidal
  located inside the shell
- Digital controller
- **Active coils**
  4 poloidal x 32 toroidal
  located outside the shell







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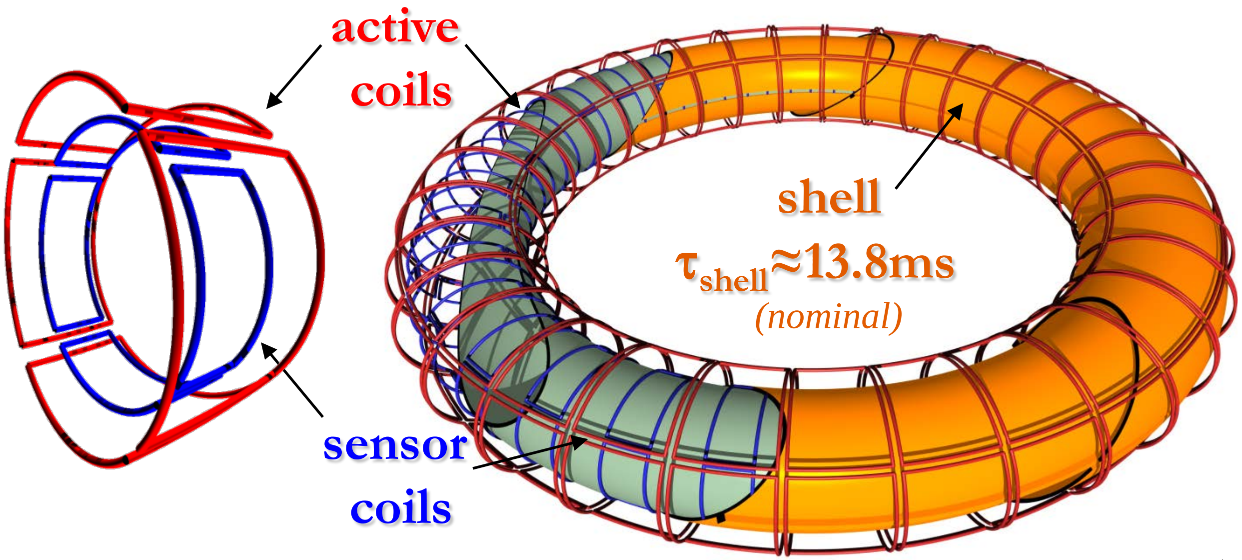
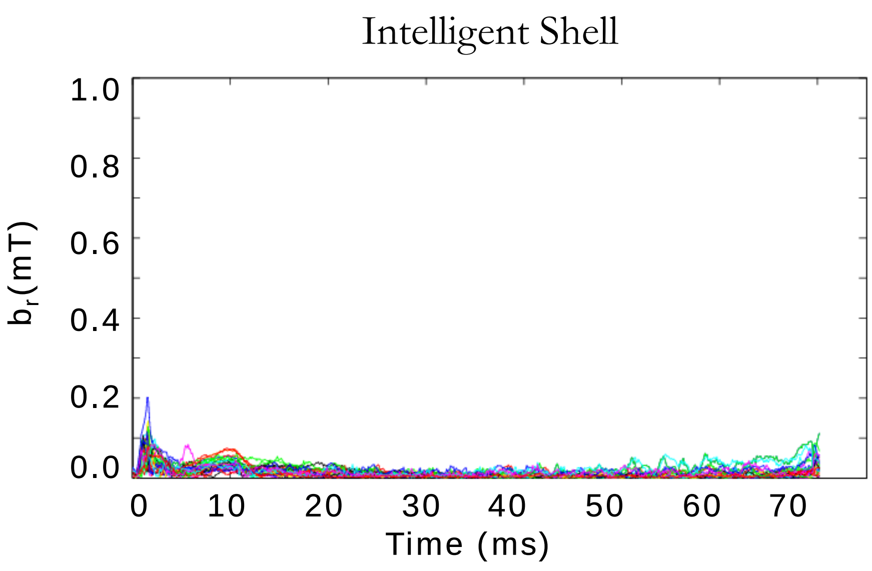
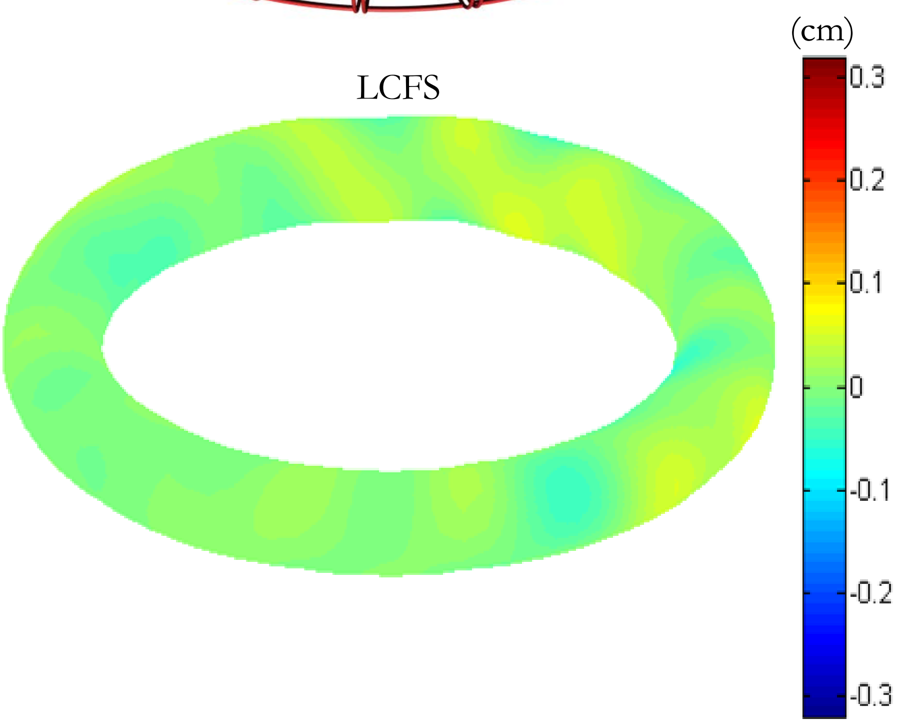


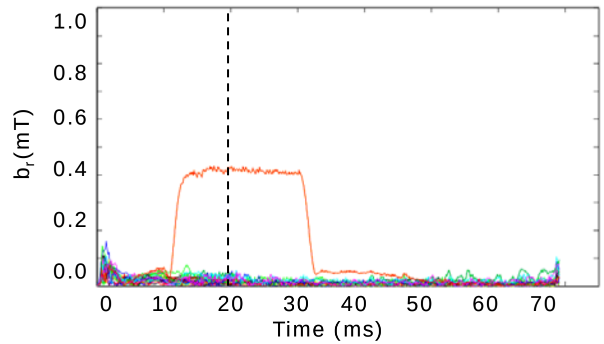




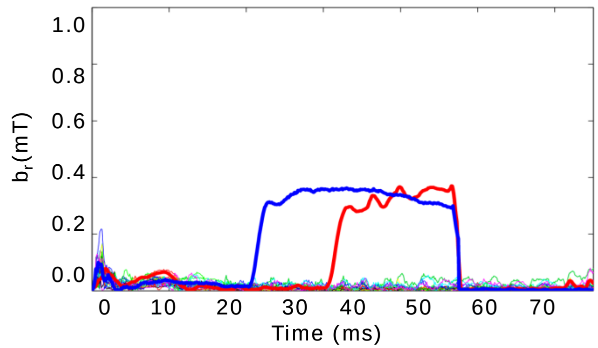
THE FEEDBACK SYSTEM

The RIS algorithm can be used to generate external perturbation
[Olofsson PPCF 104005, **52** (2010)]

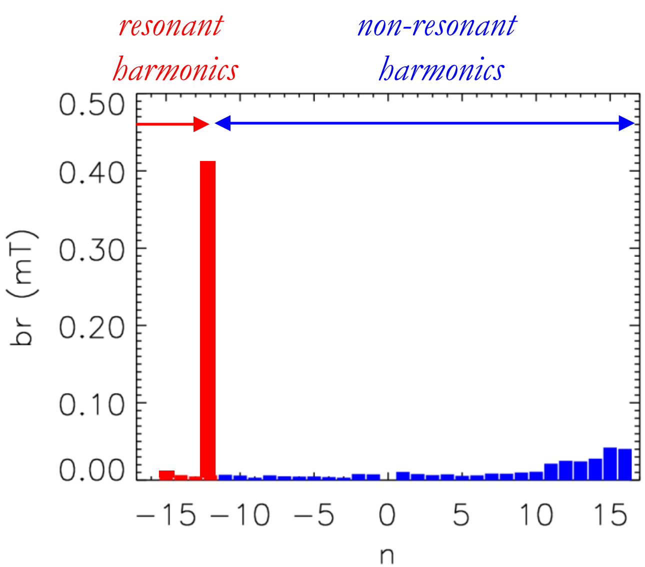
Intelligent Shell + RMP
(m,n)=(1,-12)

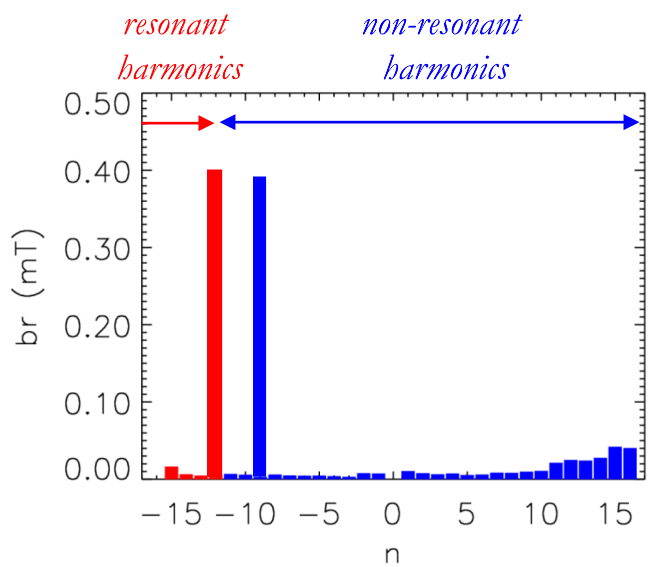


Intelligent Shell + RMP + non-RMP
(1,-12) and (1,-9)



- A single resonant perturbation
- Two or more perturbations





NON-RESONANT PERTURBATION BRAKING

- **Plasma flow braking via non-Resonant Magnetic Perturbations**

(1) Experimental viscosity estimation via RMP

Then, the viscosity will be used along with the torque balance equation to obtain:

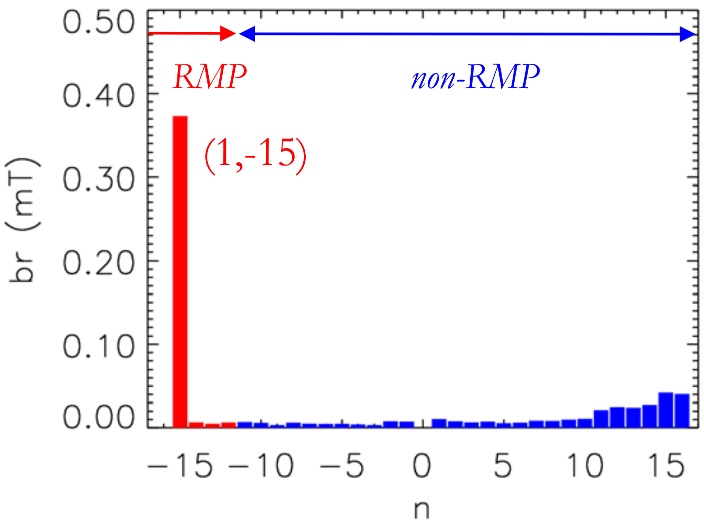
(2) Torque estimation from experimental data

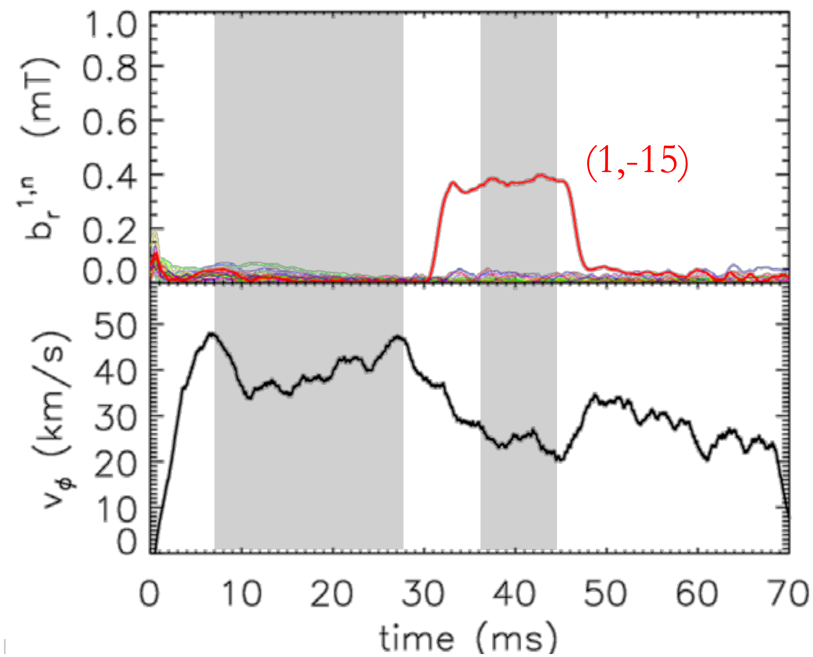
(3) Torque estimation (via NTV theory, by Y. Sun)

(4) Comparison experimental results – theory

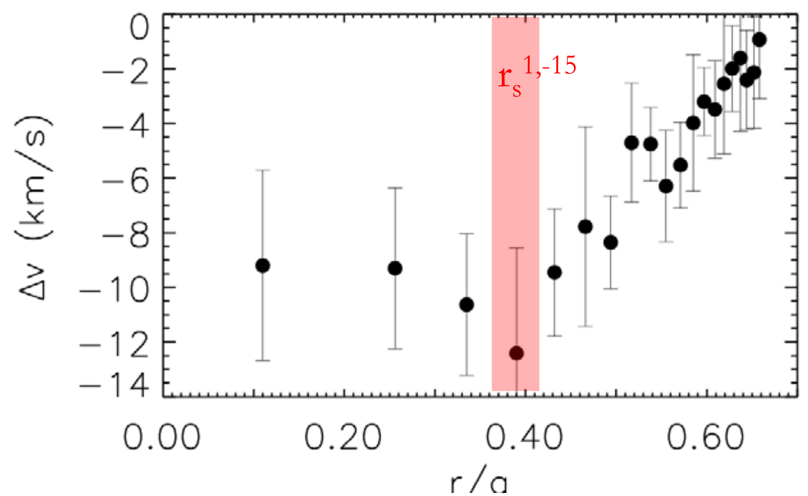
(5) Conclusion on Non-RMP braking

VISCOSITY ESTIMATION via RMP

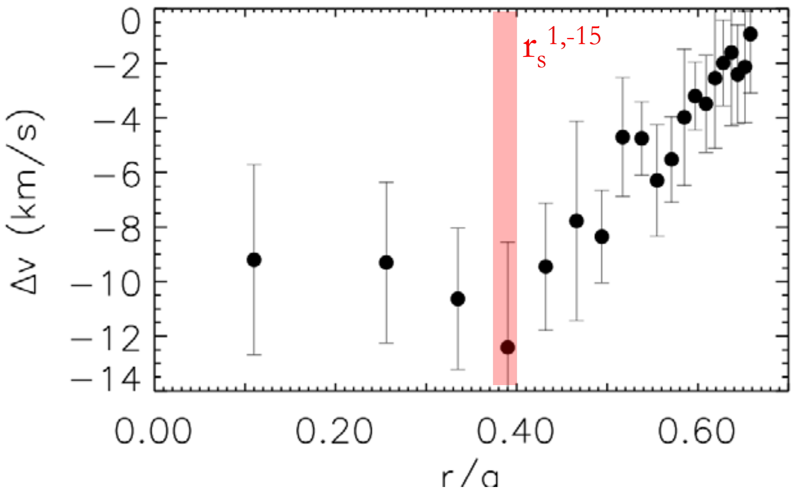


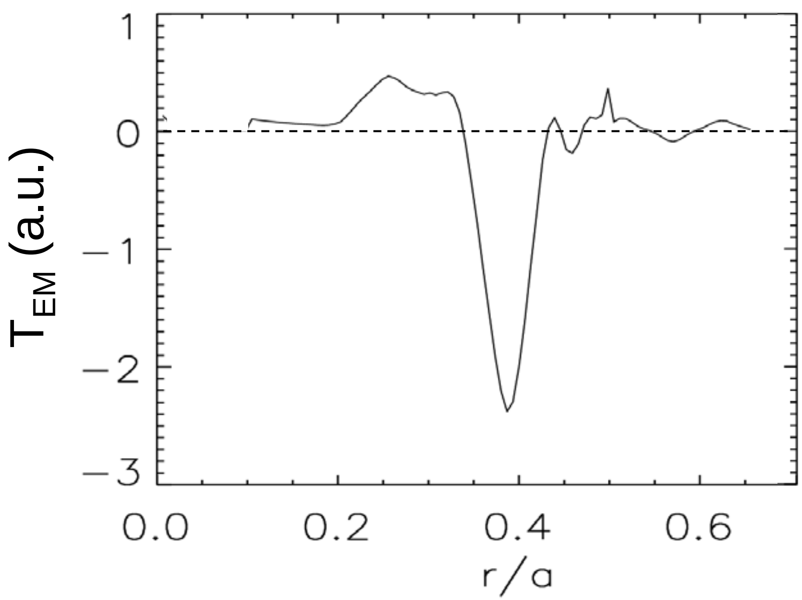


- RMPs produce plasma braking
- The maximum velocity reduction is localized at the resonance of the externally applied RMP



VISCOSITY ESTIMATION via RMP





- The viscosity ν_{kin} can be estimated via the torque balance:

$$\frac{R^2}{r}\frac{\partial}{\partial r}\left(r\nu_{kin}\frac{\partial\rho\Delta\omega}{\partial r}\right)=T_{EM}$$

- For a RMP, the torque might be obtained by:

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

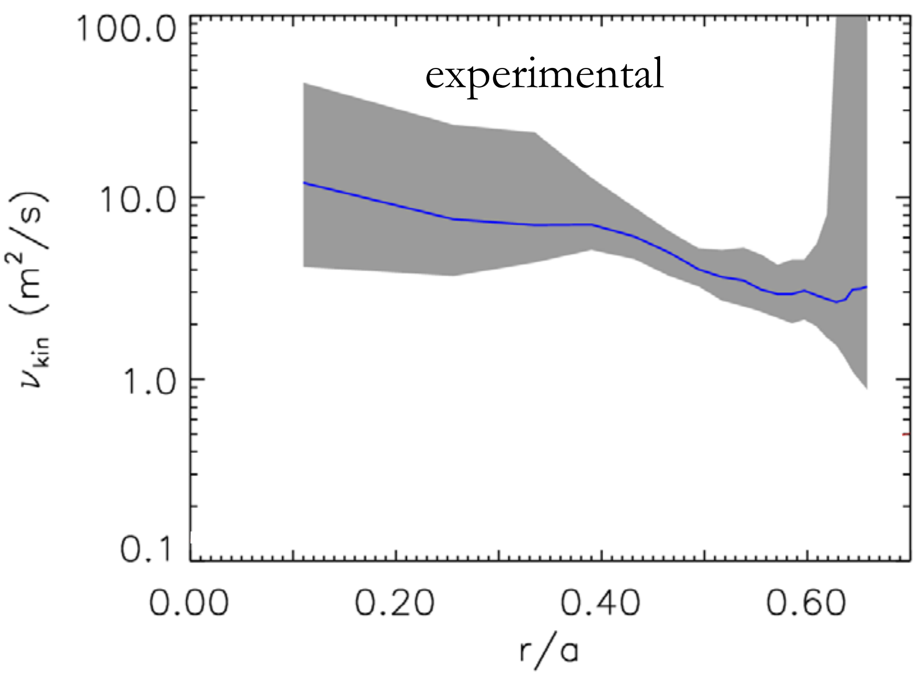
[Fitzpatrick and Yu, PoP 3610, **7** (2000)]

- Is it a reasonable expression?

  (1) Absolute value: reasonable from comparison theory-experiments, [Frassinetti et al., NF 035005, **50** (2010)]

  (2) Radial shape (delta-function): reasonable from the experimental profile of the velocity variation.

VISCOSITY ESTIMATION via RMP



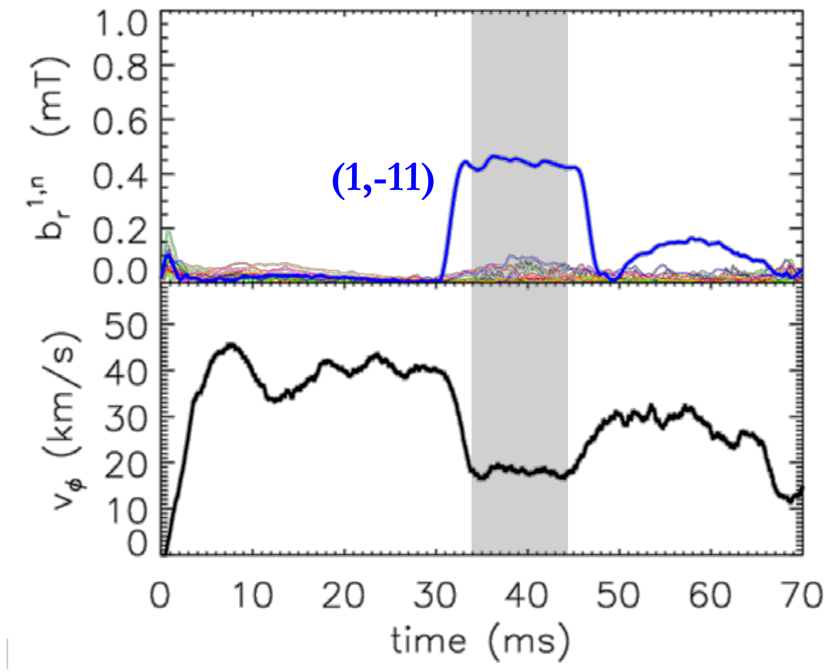
- The viscosity ν_{kin} can be estimated via the torque balance:

$$\frac{R^2}{r}\frac{\partial}{\partial r}\left(r\nu_{kin}\frac{\partial \rho \Delta\omega}{\partial r}\right) = T_{EM}$$

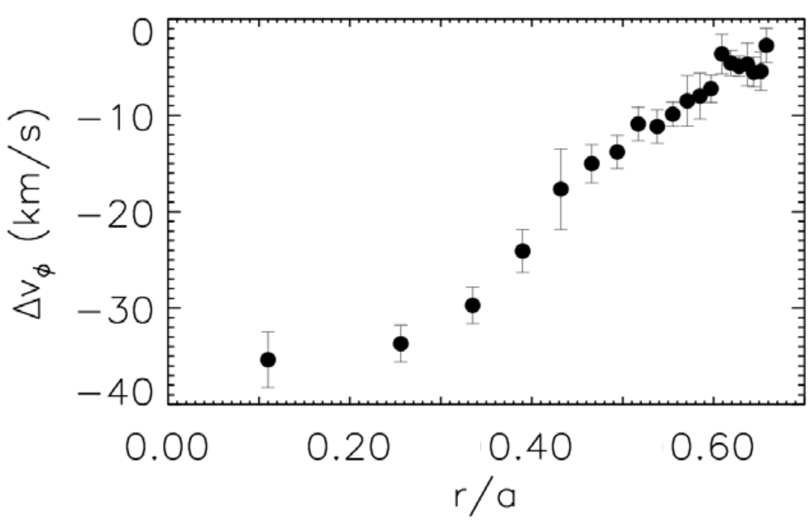
- T_{EM} is calculated from Fitzpatrick expression
- The velocity profile variation $\Delta\omega$ is from experimental measurements
- Uncertainty is estimated with a Monte Carlo approach
- The large uncertainty in the core is due to the almost flat Δv in the core
- The viscosity is larger than the classic value, but in agreement with earlier estimations.

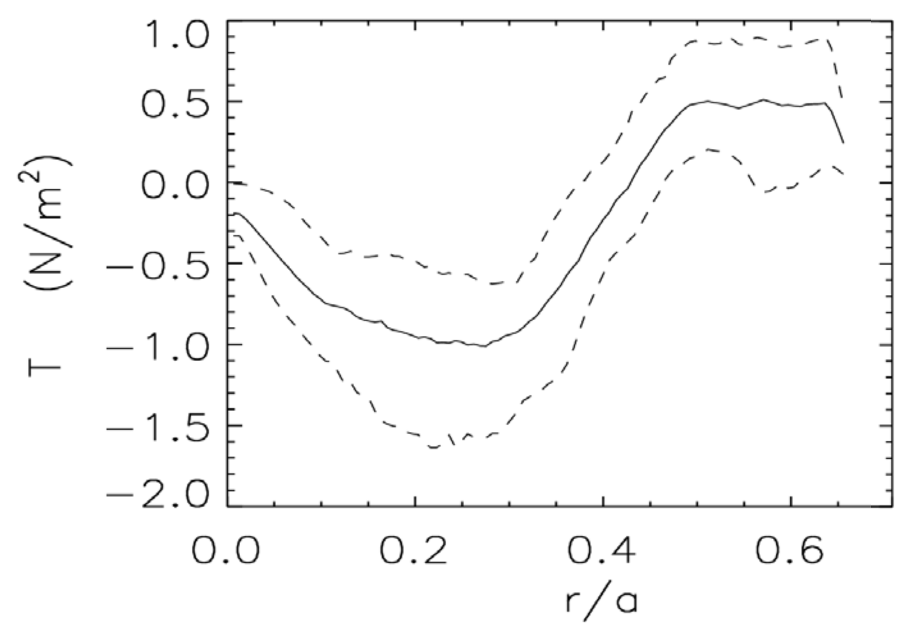
[Vianello et al., PRL 135001, **94** (2005)]
[Almagri et al., PoP 3982, **5** (1998)]

NON-RMP BRAKING

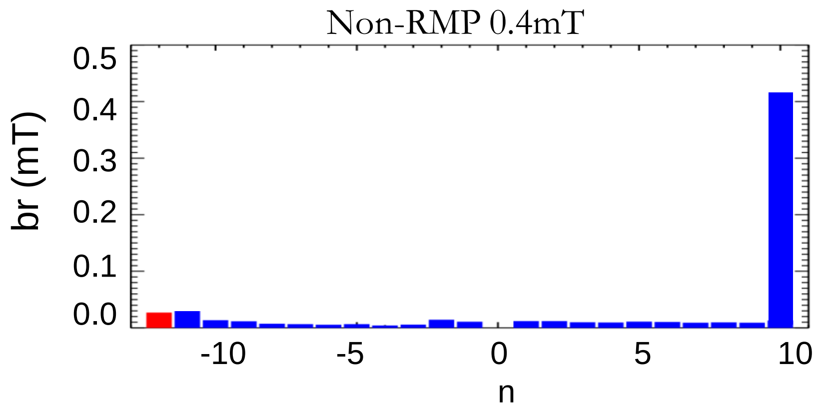


- Non-RMPs produce plasma braking
- The velocity braking is not localized in any radial position
- The torque is estimated from $\frac{R^2}{r}\frac{\partial}{\partial r}\left(r v_{kin}\frac{\partial \rho \Delta\omega}{\partial r}\right) = T$
- The torque is not localized in any specific position but is affects globally the entire core

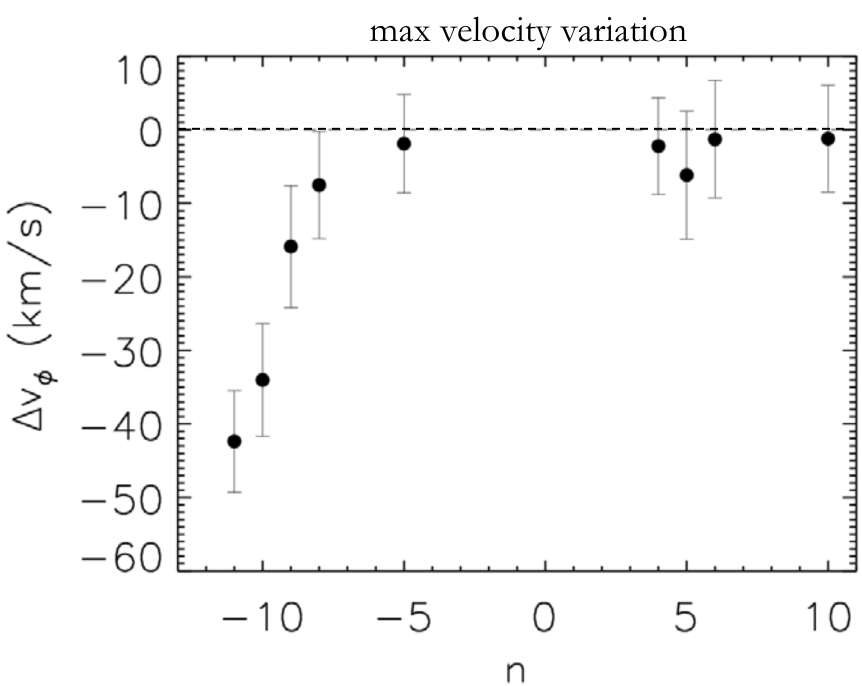


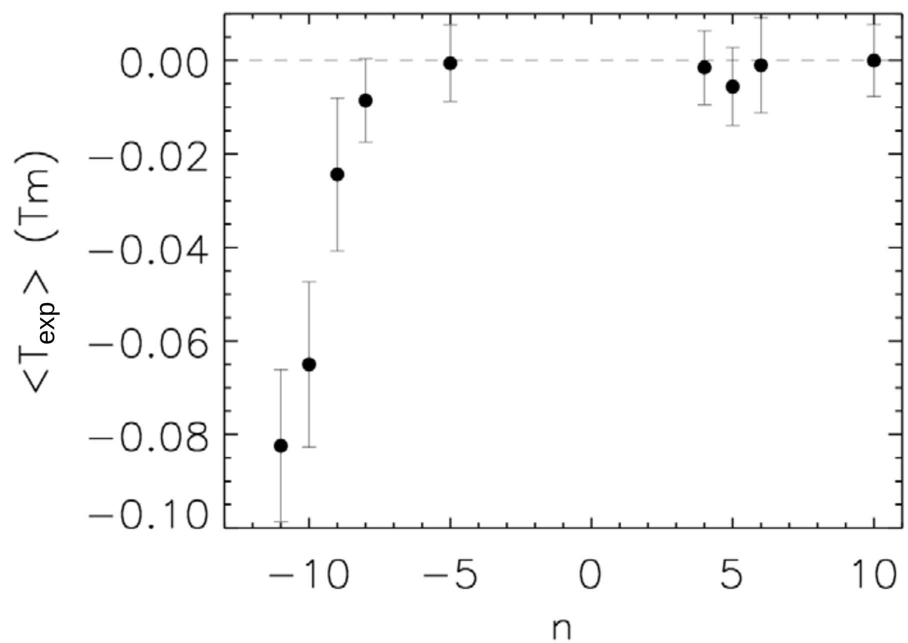


NON-RMP BRAKING



- The Non-RMP braking depends on the harmonic
- The more far from the resonant, the lower the braking
- The torque has a similar trend

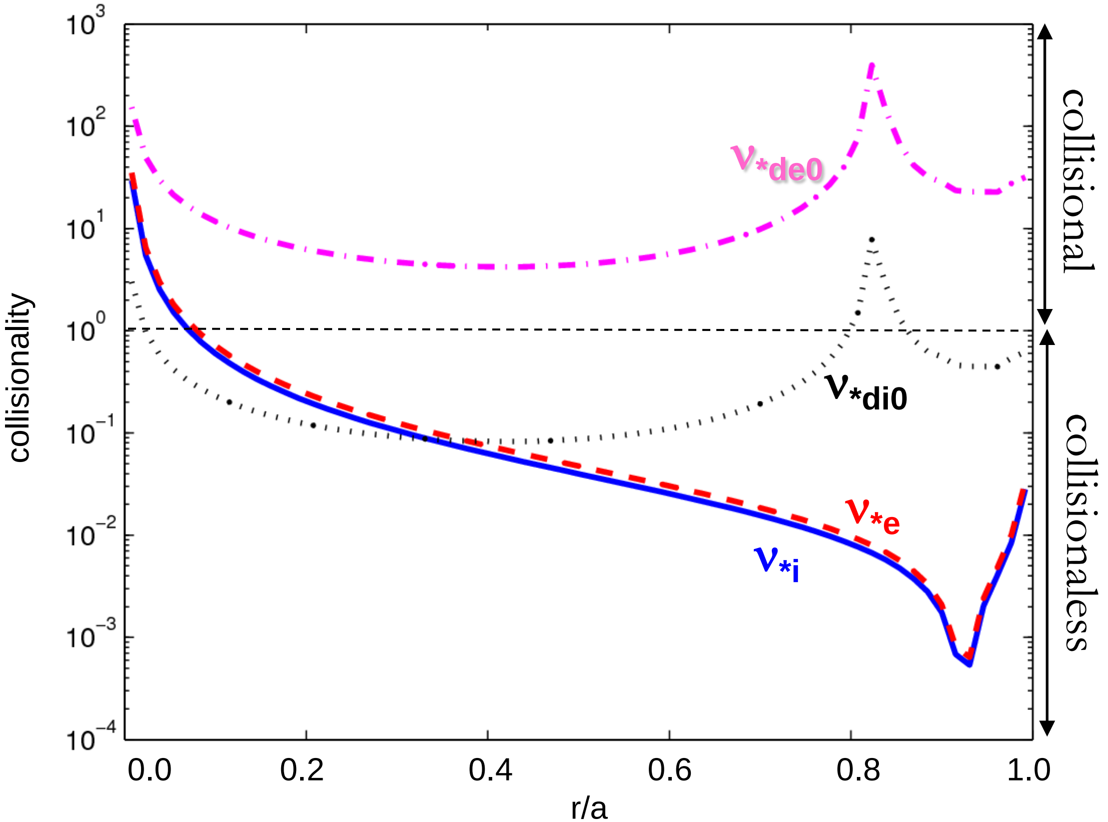




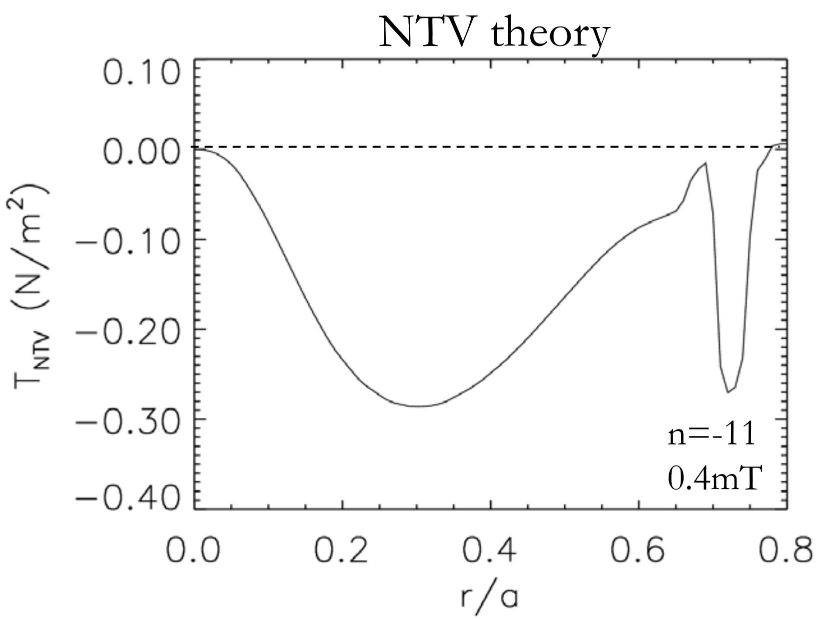
NTV THEORY APPLIED TO EXTRAP T2R

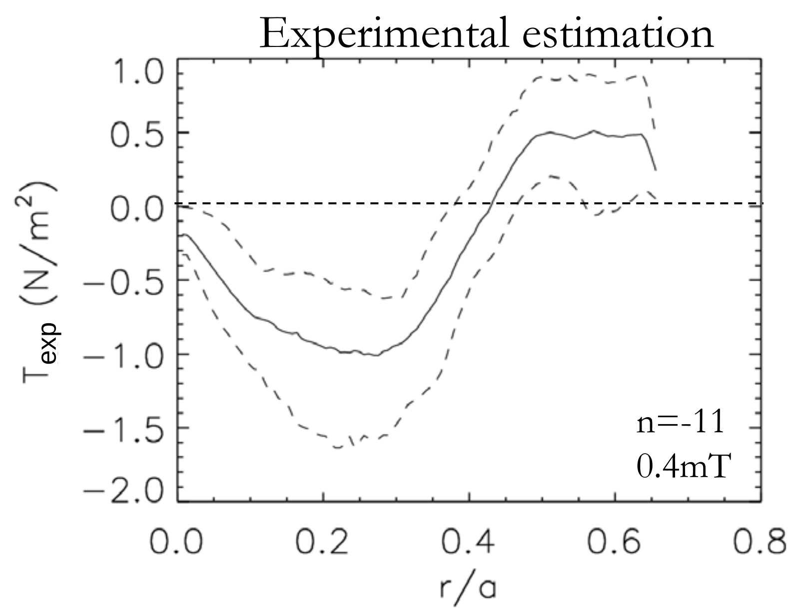
(by Y. Sun)

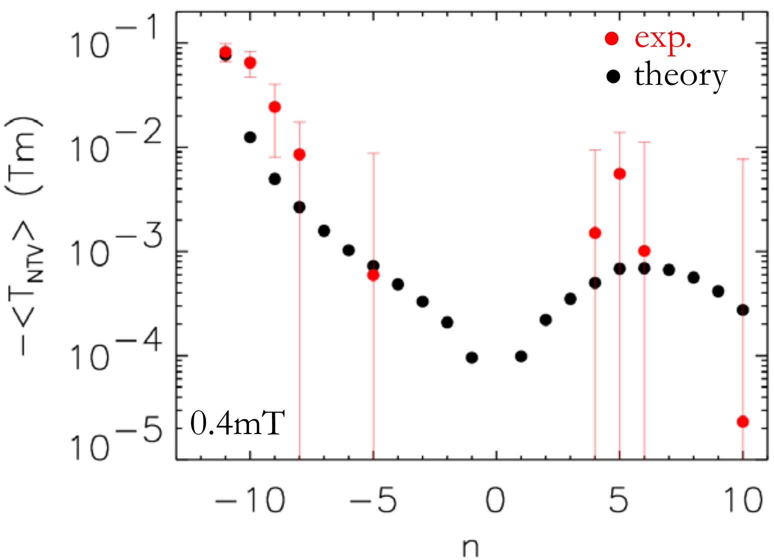
- <u>ASSUMPTION</u>: the NTV theory is valid in the RFP configuration
- The code for NTV torque calculation [Sun et al., NF 053015, **51** (2011)] has been adapted to EXTRAP T2R
- Ions and electrons are mainly in the collisionless regime
- Since $\nu_{*di0}<1$ ions are mainly in the $\sqrt{\nu}$ or super-banana regime.
- Since $\nu_{*de0}>1$ electrons are mainly in the $1/\nu$ regime



TORQUE COMPARISON







- Reasonable qualitative agreement in the profile.
- From a quantitative point of view, NTV torque is ≈3 times lower
- Reasonable qualitative trend versus the perturbation harmonic.

CONCLUSIONS and FUTURE WORK

- **Non RMP braking**

(1) The torque is estimated from experimental velocity braking

- the Non-RMP torque is not localized in any specific position but affects the entire core
- the Non-RMP torque decreases as the perturbation harmonic is more far from the resonance

(2) NTV theory has a reasonable qualitative agreement with the experimental results

(3) NTV theory predicts a torque 3-4 times lower than the one necessary to obtain the experimental braking

(4) Future work/open questions:

- Study the dependence on the non-RMP amplitude.
- The viscosity is estimated considering only the EM torque.
  Underestimation of the viscosity?
  Underestimation of experimental T_{NTV}?
- The NTV calculation for EXTRAP T2R needs to be extended to the resonant harmonics:
  How to consider the plasma response?
  How to consider the perturbation screening?

This leads us to the next topic…

RMP SCREENING

- **RMP screening**

(1) Motivation of the work:

does the plasma rotation affect the penetration of a RMP?

(2) The technique:

how to modify the plasma rotation without affecting other plasma parameters?
Using a non-RMP.

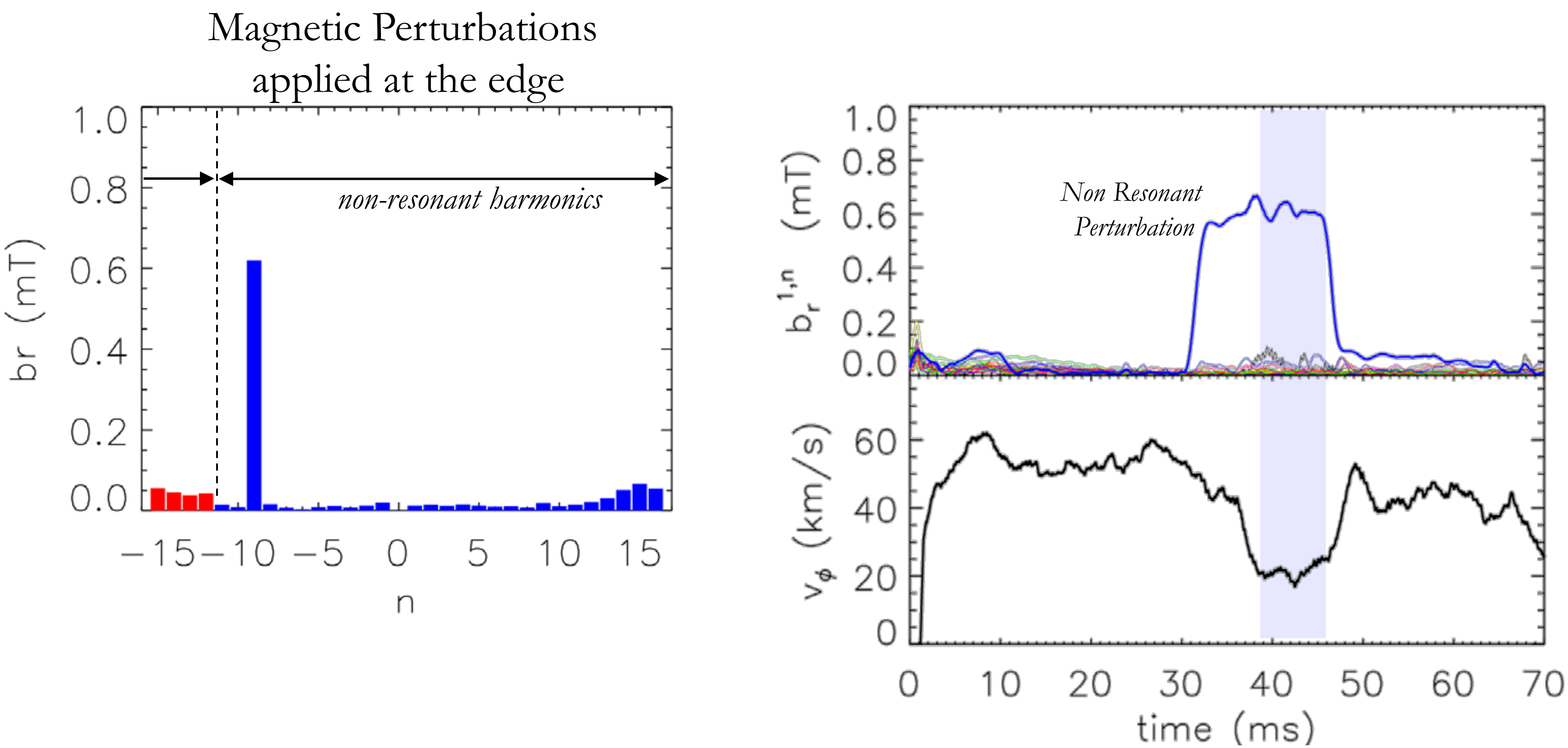
(3) Experimental results:

What to look? How to quantify the RMP effect?
By studying the interaction of a rotating TM with a stationary RMP field for varying plasma rotation velocity.

(4) Comparison with some theoretical models (preliminary):

- Fitzpatrick Guo Wealbroek models
- Rozhansky model

HOW TO CHANGE THE PLASMA ROTATION?



- Using a non-RMP, the plasma rotation can be modified
- Then, the RMP will be applied during the stationary phase

NON-RMP plus RMP

The technique:

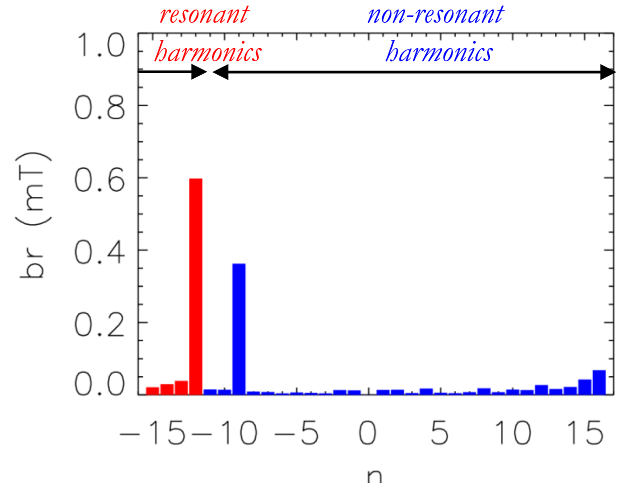
(1) Apply a non-RMP to obtain the “desired” velocity

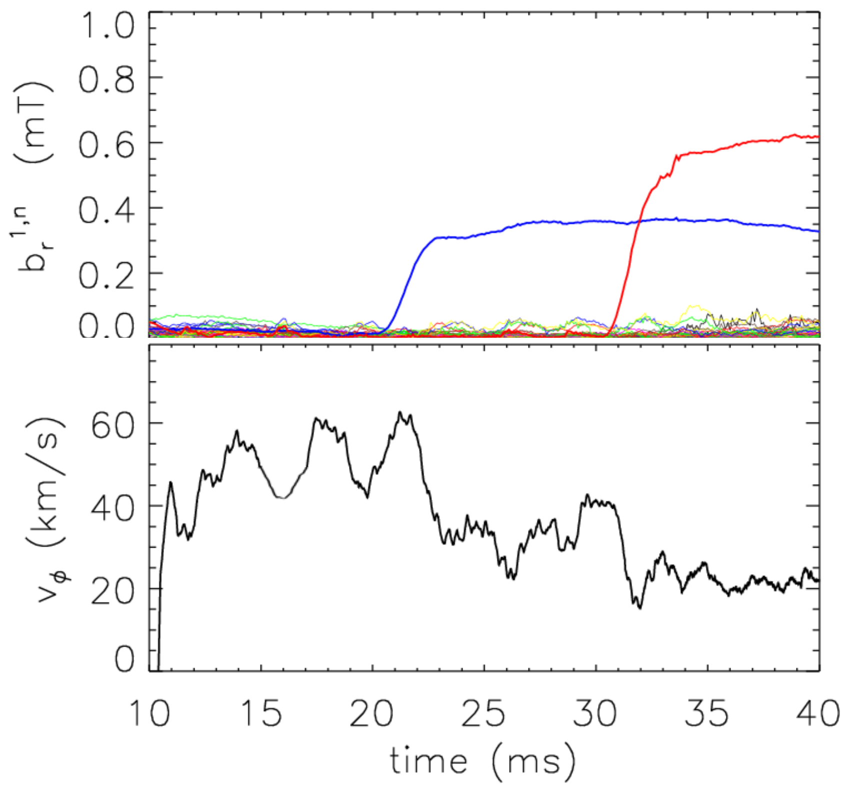
(2) Apply a RMP to study the TM response

The TM response will depend on:

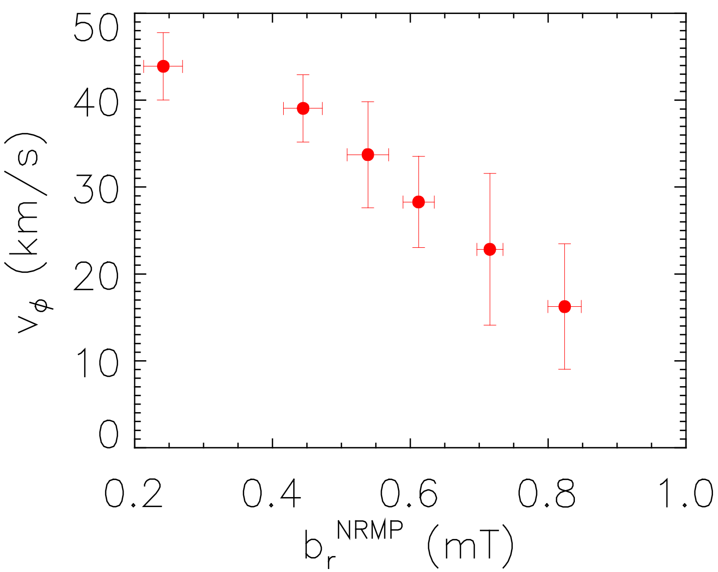
(a) the RMP (amplitude and harmonic)

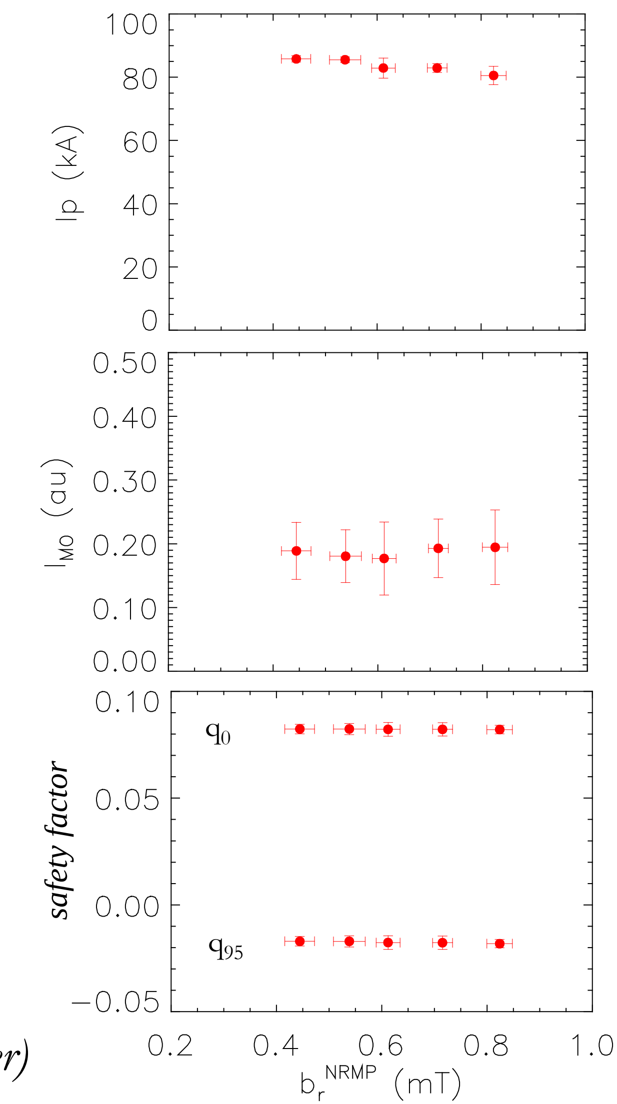
(b) the plasma rotation (if the screening occurs)





NON-RMP EFFECT ON PLASMA PARAMETERS





- By modifying the non-RMP amplitude, the plasma rotation is changed.

- NO significant variation in: (1) Ip
  (2) Impurities
  (3) Equilibrium
  (4) TM amplitude *(see later)*

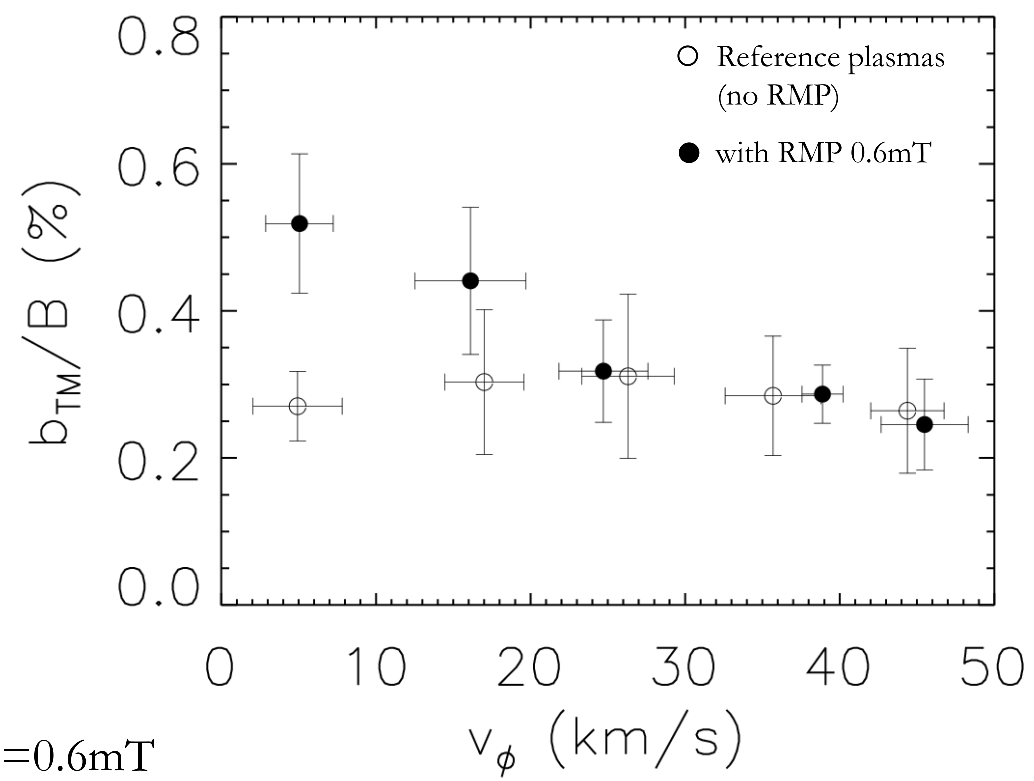
(as long as the perturbation is not too large)

EFFECT ON THE TEARING MODE

- **Reference plasmas:**

  (a) RMP is NOT applied
  (b) Non-RMP is used to change the plasma velocity

No effect on the TM amplitude



- **Plasmas with RMP:**

  (a) always the same RMP harmonic and RMP amplitude is used: $b_r^{1,-12}$=0.6mT

  (b) Non-RMP is used to change the plasma velocity

At high plasma rotation the RMP effect on the TM seems negligible. RMP Screening?

Comparison with theoretical models

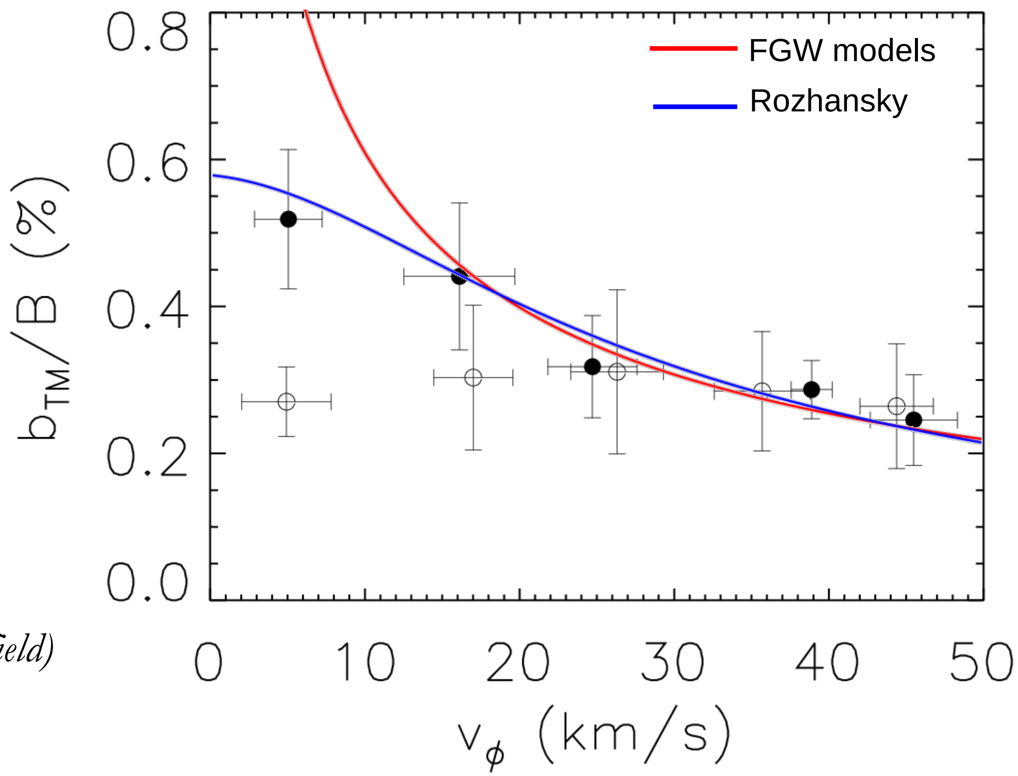
- Fitzpatrick, Guo, Wealbroek models:

*for example [Phys. Plasmas **8** 4489 (2001)]*

$$\Lambda \frac{\tau_R}{4 r_s} c |\dot{\Psi}_s| = f(|\Psi_s|) + \frac{E_v^s E_w^v}{|E_v^v|} \frac{|\Psi_w|}{\sqrt{|\Psi_s|}} \cos \omega t$$

assuming constant velocity and
large RMP amplitude, the solution is:

$$b_{TM} \approx \left(\frac{k}{\omega} b_r^{RMP} \right)^{2/3}$$



- Rozhansky model:

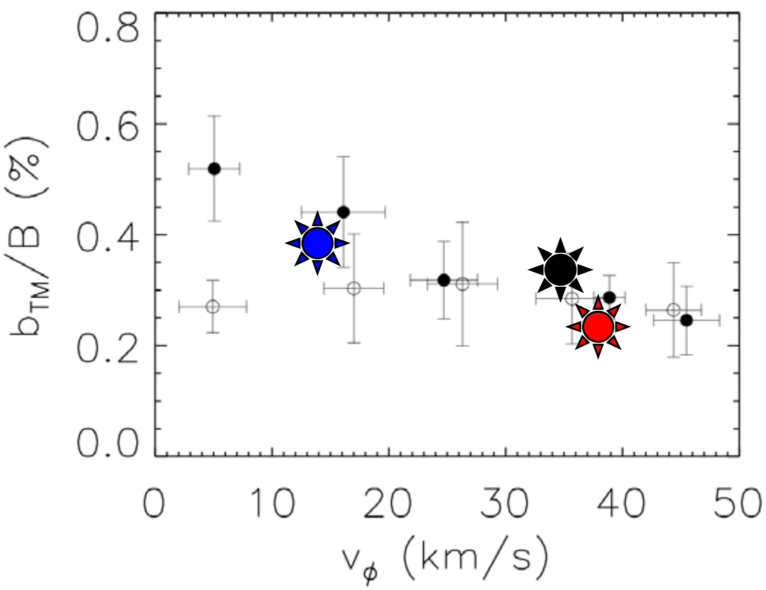
(it considers radial current of electrons in a stochastic field)

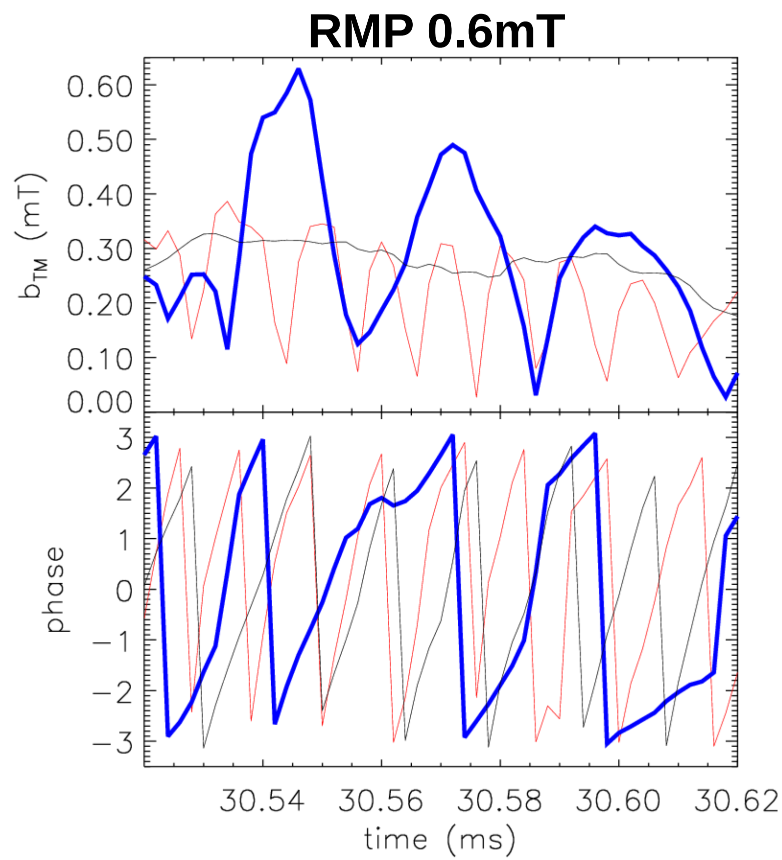
*[Nucl. Fusion **51** 083009 (2011)]*

$$\frac{b}{B} = \frac{1}{\sqrt{1 + f(B, T_e, n_e)\omega^2}} \frac{b_0^{RMP}}{B}$$

Both models can give a reasonable agreement with experimental data.
More detailed comparisons are in progress.

TM dynamics





- **Reference plasma:**
  - TM amplitude approximately constant

- **RMP 0.6mT and fast plasma rotation**
  - the RMP amplifies and suppress the TM depending of the phase

- **RMP 0.6mT and slow plasma rotation**
  - the TM is amplified and suppressed. But due to the lower rotation, the TM is in a positive phase relation with RMP for a longer time ⇒ stronger amplification

CONCLUSIONS and FUTURE WORK

- **Non-RMP braking**

(1) The torque is estimated from experimental velocity braking

- the Non-RMP torque is not localized in any specific position but affects the entire core
- the Non-RMP torque decreases as the perturbation harmonic is more far from the resonance

(2) NTV theory has a reasonable qualitative agreement with the experimental results

(3) NTV theory predicts a torque 3-4 times lower than the one necessary to obtain the experimental braking

- **RMP screening**

(1) Plasma rotation is modified by a applying a non-RMP producing:

- velocity reduction
- no significant effect on equilibrium and TM amplitude

(2) The same technique is used applying a RMP with constant amplitude

(3) The analysis of the TM amplitude shows a smaller effect of the RMP at high rotation: the plasma rotation clearly affects the dynamics of the TM

(4) Existing models seem to give a reasonable explanation

(5) Future work:

- increase of the statistic (more plasma shots) and of the velocity scan steps.
- study of different RMP harmonics
- more detailed comparison theory-experiment.