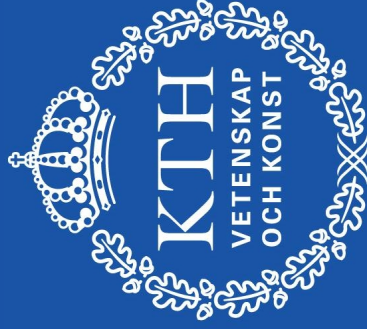


PLASMA BRAKING DUE TO EXTERNAL MAGNETIC PERTURBATIONS

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- **Experimental tools:**

- EXTRAP T2R reversed-field pinch and the main diagnostics
- The feedback system for the active control of magnetic perturbations
- Generation of resonant (and non-) magnetic perturbations.

- **Plasma flow and Tearing Modes (TM) dynamic without RMP**

- **TM dynamics with RMP**

- **Plasma flow and TM velocities with RMP**

- On long time scales (10ms) $\Rightarrow$ flow breaking
- On short time scales (0.1ms) $\Rightarrow$ phases of acceleration and deceleration

- **Modelling and viscosity profile estimation**

THE DEVICE

EXTRAP T2R is a RFP with:

- $R=1.24\text{m}$
- $a=0.18\text{m}$
- $I_p \approx 80\text{-}150\text{kA}$
- $n_e \approx 10^{19}\text{m}^{-3}$
- $T_e \approx 200\text{-}400\text{eV}$
- $t_{\text{pulse}} \approx 20\text{ms}$ (no FeedBack)
- $t_{\text{pulse}} \approx 90\text{ms}$ (with IS)

THE DIAGNOSTICS

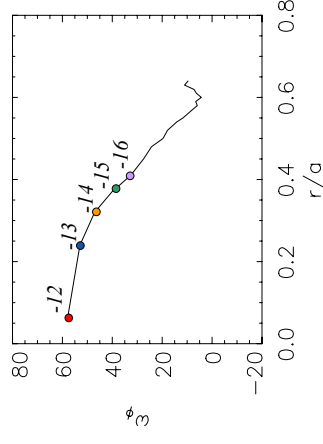
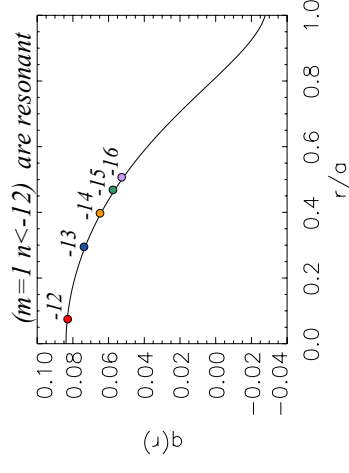
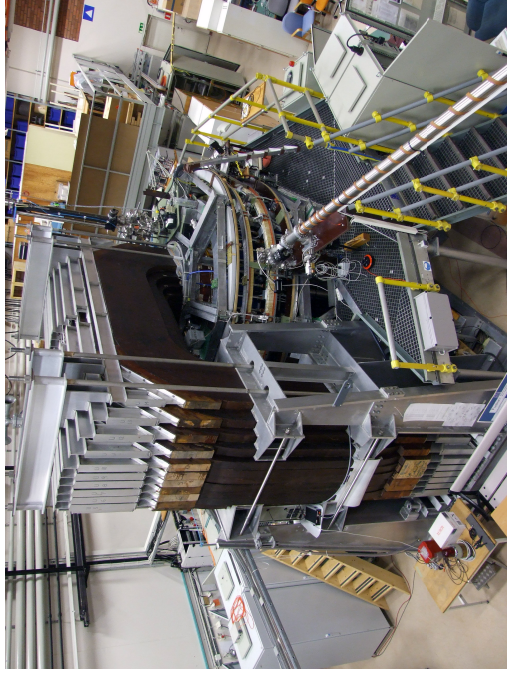
Tearing Modes:

$b_\theta \Rightarrow 4$ poloidal x 64 toroidal local sensors

Plasma flow

- Spectrometer for Doppler shift of ion lines
- Spectrometer for emissivity profile of impurities

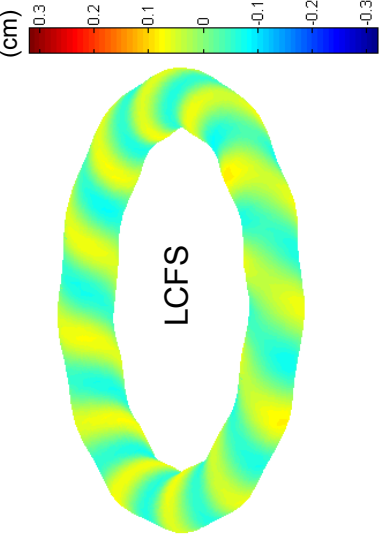
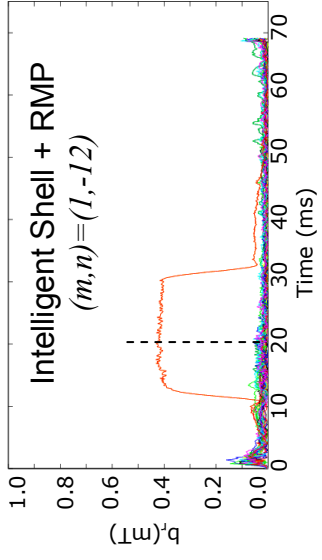
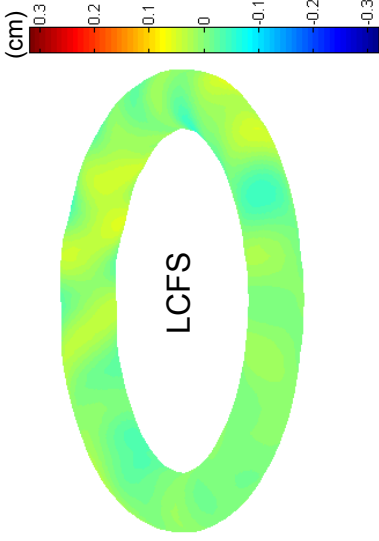
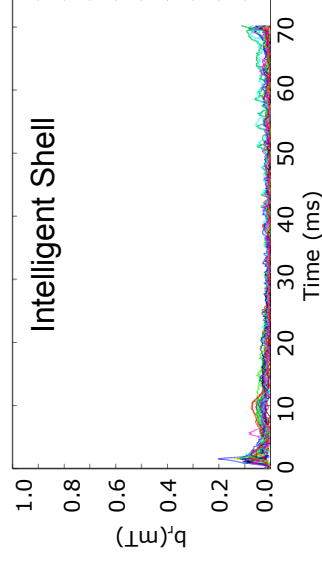
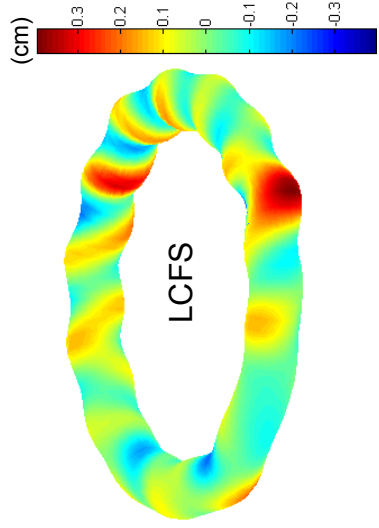
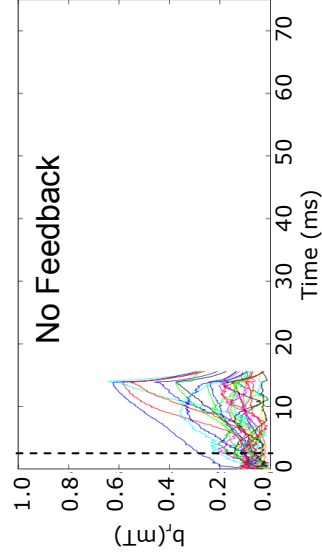
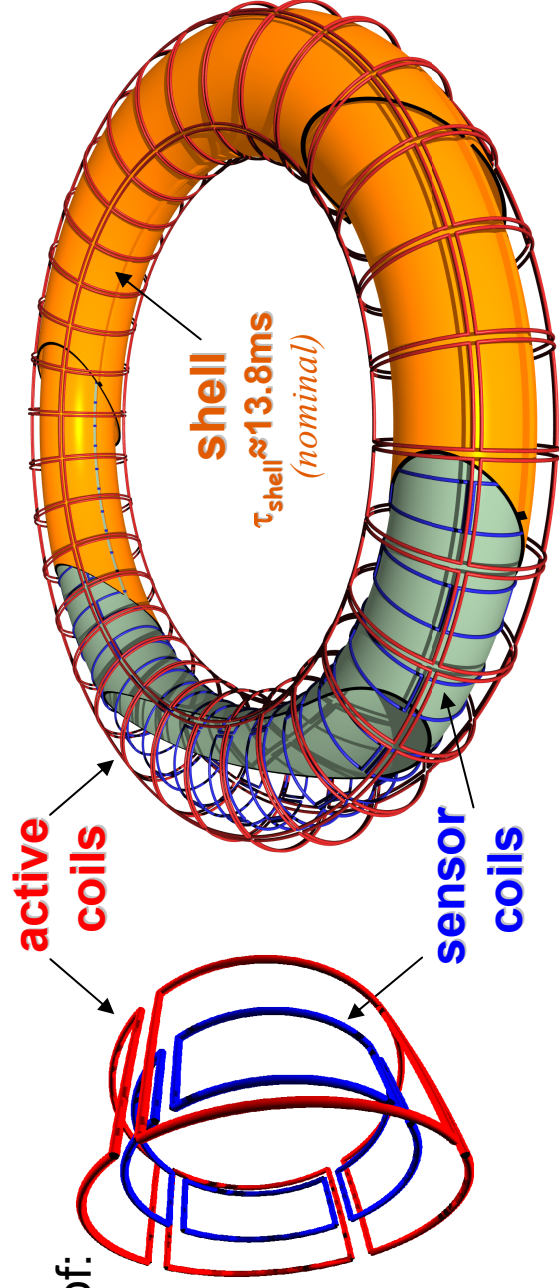
The flow is obtained by comparing the measured v_{ions} with the modelled v_{ions} .

$$v_i = \frac{\int_{-x_0}^{x_0} v(x) \cos \beta(x) \varepsilon_i(x) dx}{\langle \cos \beta \rangle \int_{-x_0}^{x_0} \varepsilon_i(x) dx}$$


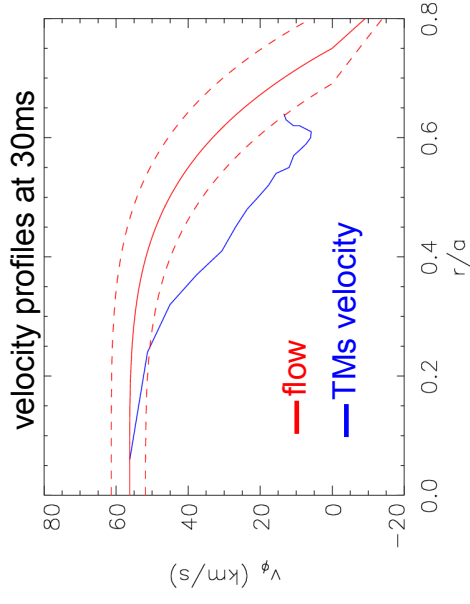
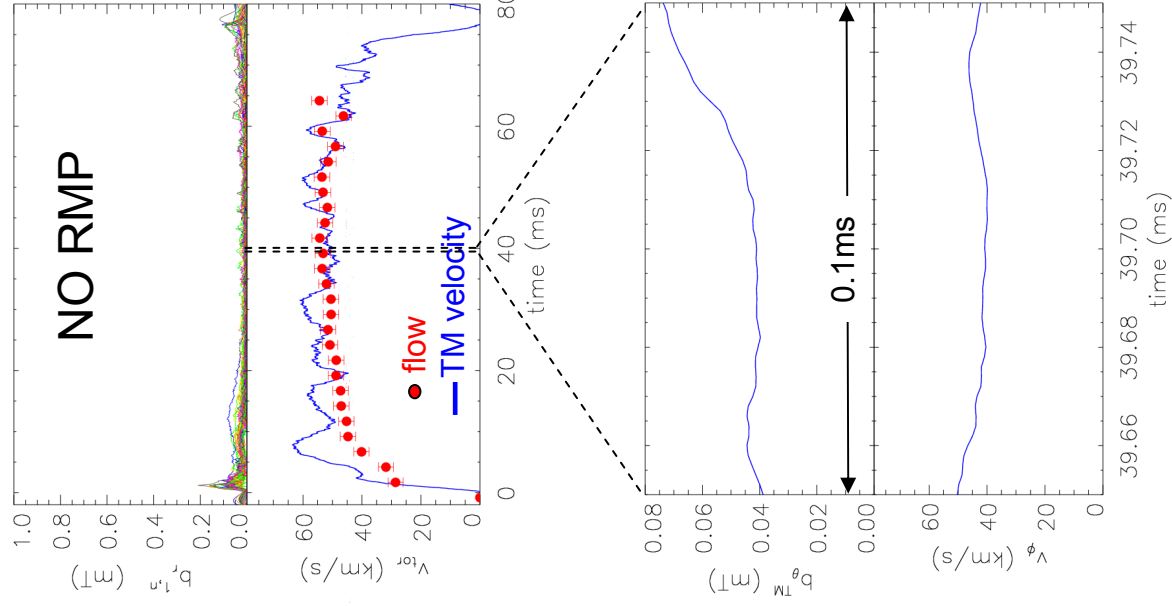
THE FEEDBACK SYSTEM

The system is composed of:

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



FLOW AND TM DYNAMICS WITH NO RMP

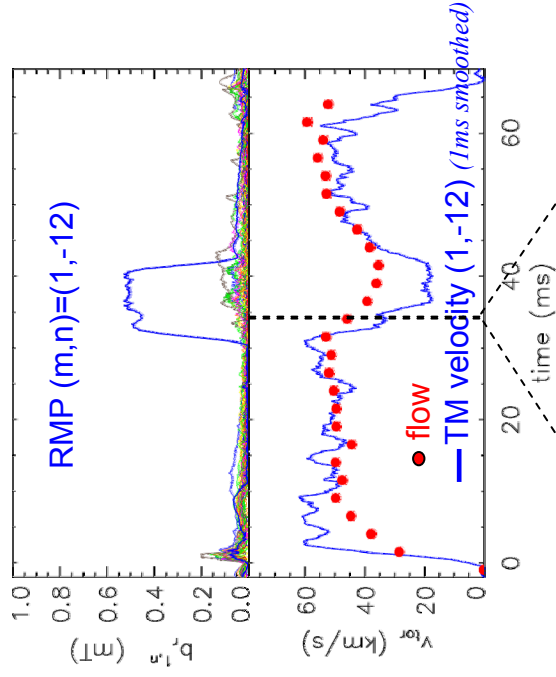


- plasma rotates with $v_{\phi} \approx 50 \text{ km/s}$
- TMs rotate with velocities comparable to the flow
- velocity is approximately steady during the flat-top both on:

- long time scale (10ms)

- short time scale (0.1ms)

FLOW AND TM DYNAMICS WITH RMP



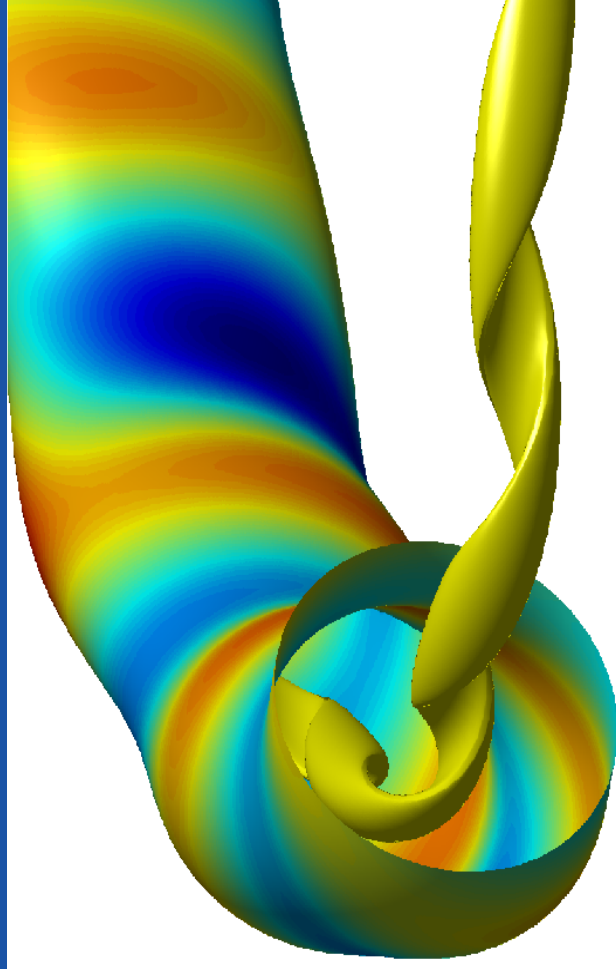
- braking of plasma flow

- On a long time scale (10ms):

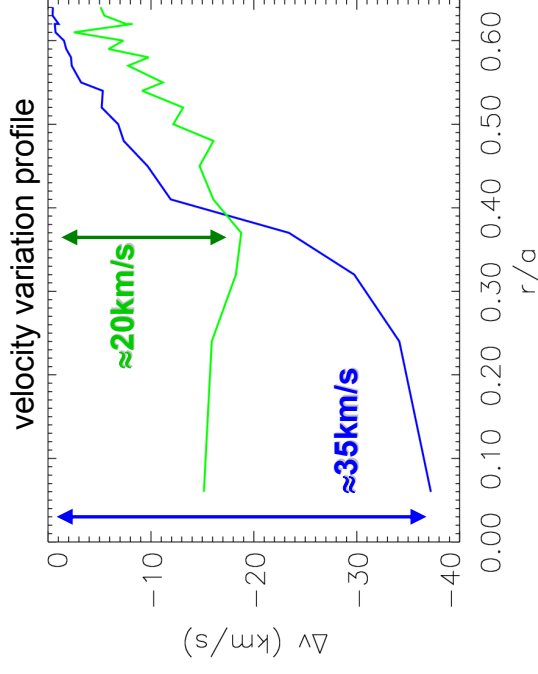
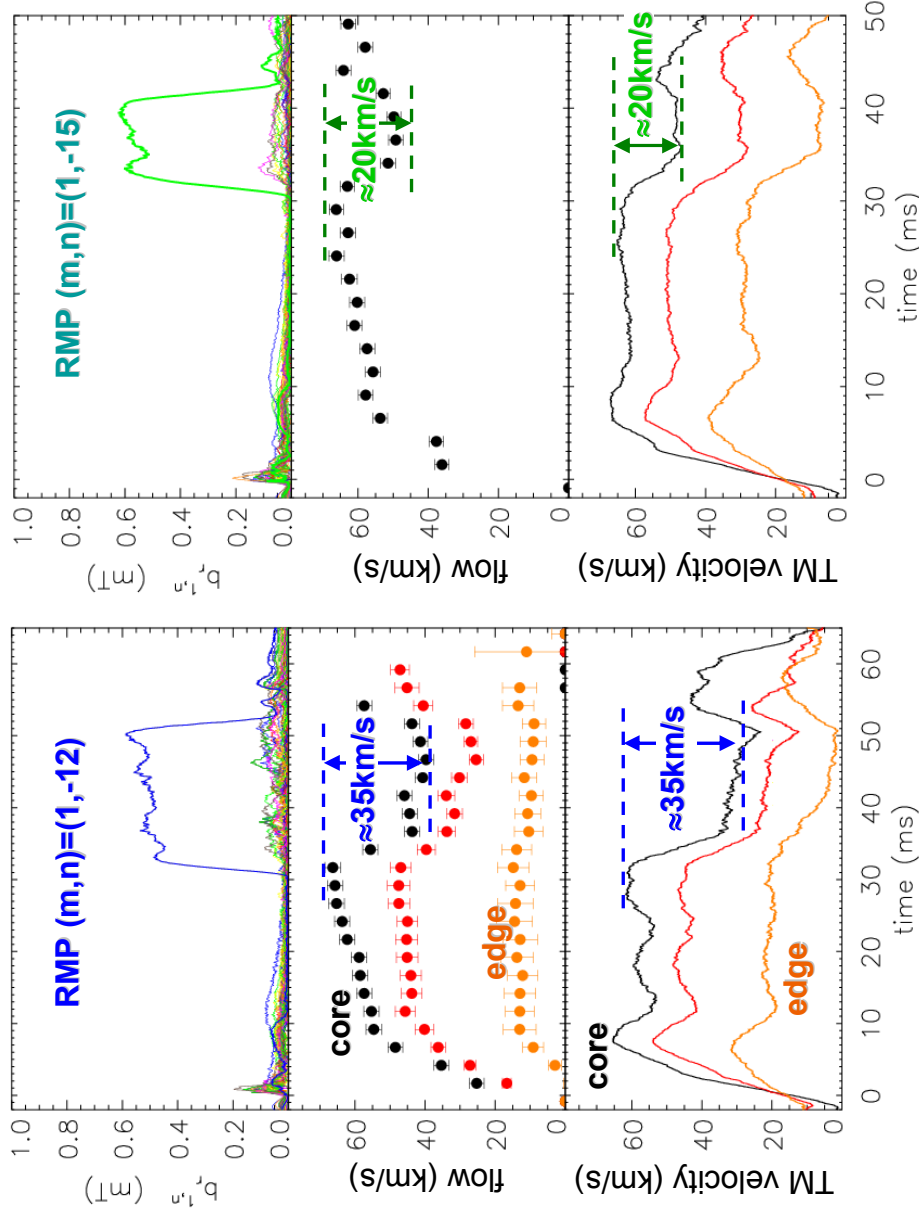
- braking of plasma velocity
- steady state reached after ≈ 5 ms

- On a short time scale (0.1ms)

- modulation of TM amplitude
- modulation of TM velocity

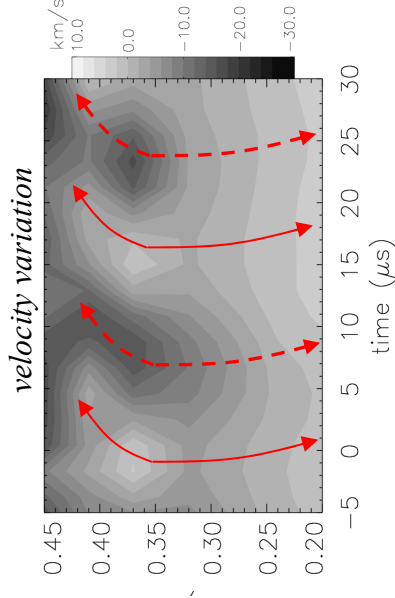
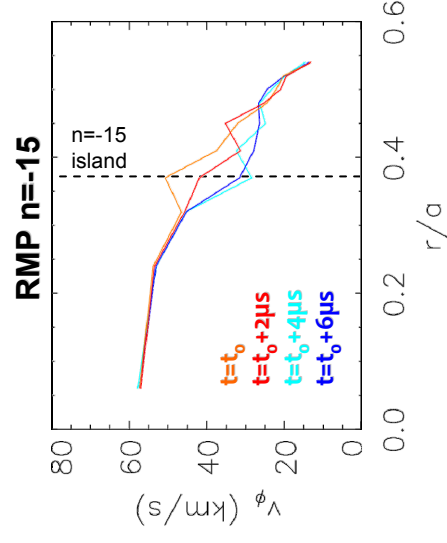
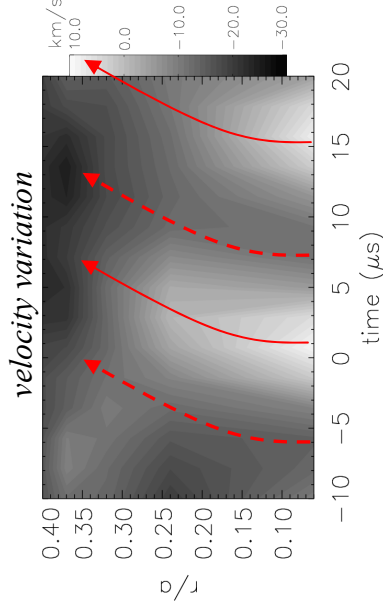
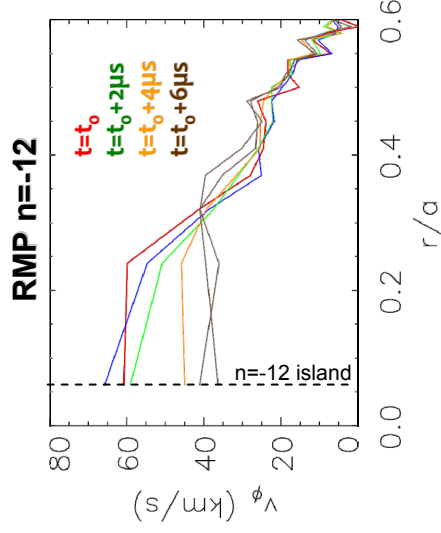
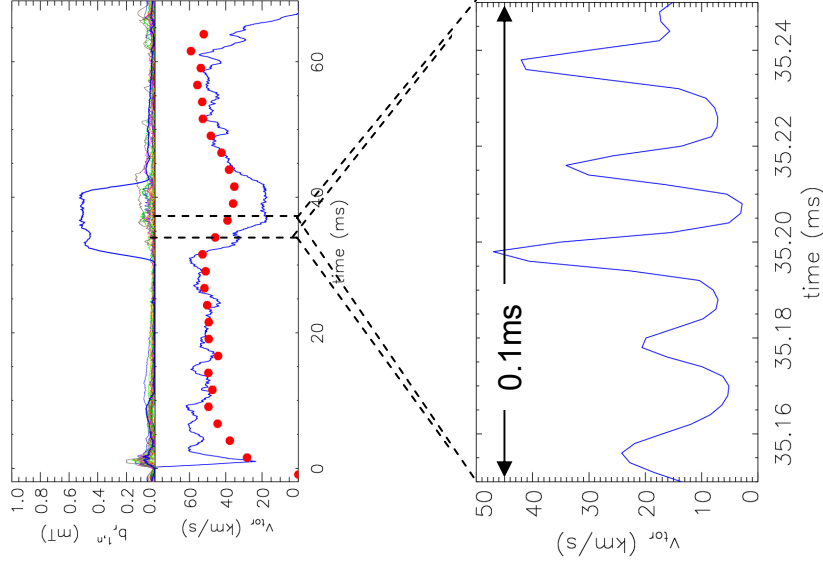


VELOCITY PROFILE WITH RMP



- Similar braking in the flow and in the TM velocity
- **Different RMP helicities** produce **different velocity braking**
- **Maximum braking** located at the **radius where the RMP helicity is resonant**

VELOCITY EVOLUTION WITH RMP



- The island is **not simply slowed down**
- It has **strong velocity modulations**

- The velocity **perturbation is mainly located at the island position**
- But then it “**spreads**” to the **surrounding plasma**

COMPARISON: MODEL-EXPERIMENT

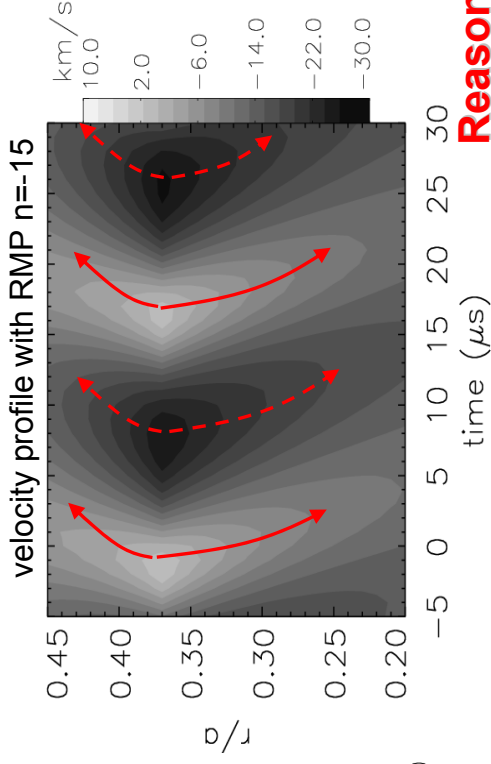
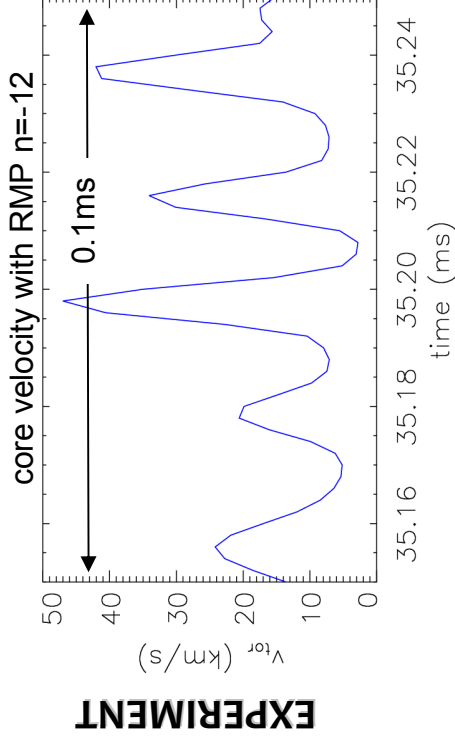
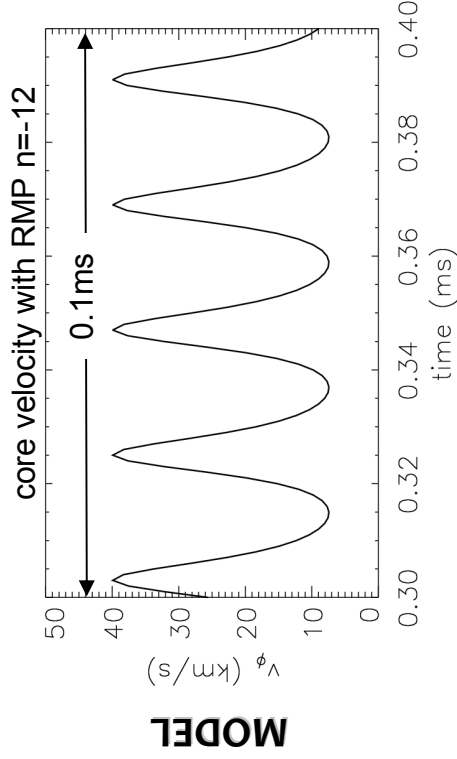
$$\rho \frac{\partial \Delta \Omega}{\partial t} = -\frac{1}{r} \frac{\partial}{\partial r} \left(r \mu \frac{\partial \Delta \Omega}{\partial r} \right) + \frac{T_{EM}^{m,n}}{4\pi R^3 r} \delta(r - r_s)$$

Data are modelled using the torque

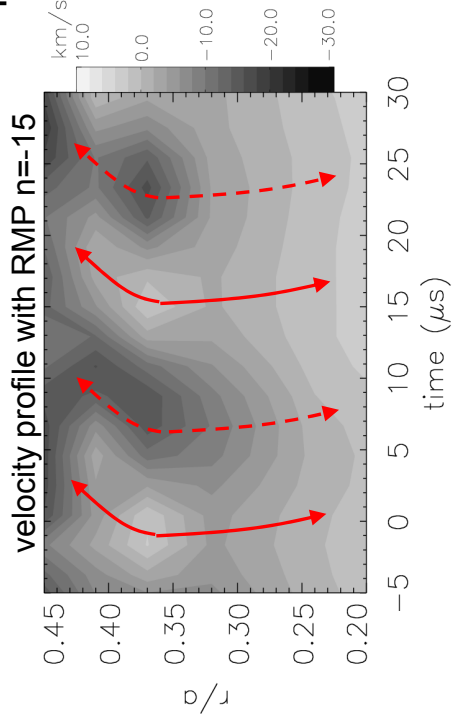
balance equation.

[Fitzpatrick et al. PoP 7, 3610 (2000)]

[Guo et al. PoP 9, 4685 (2002)]



Reasonable agreement
between modelled and
experimental data



VISCOSITY ESTIMATION

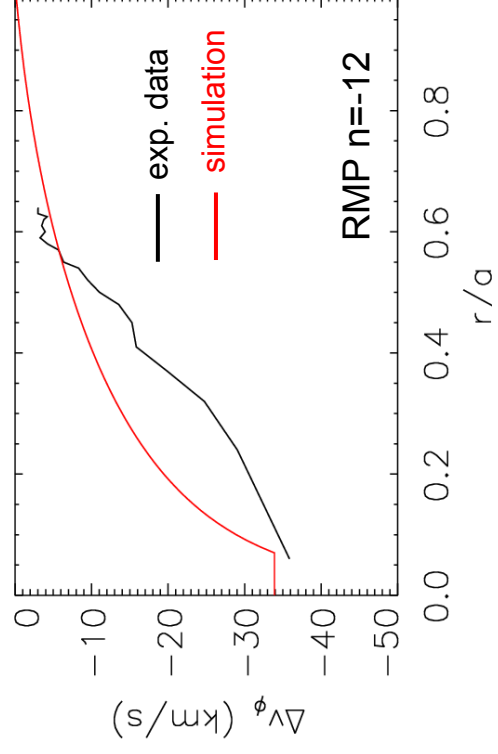
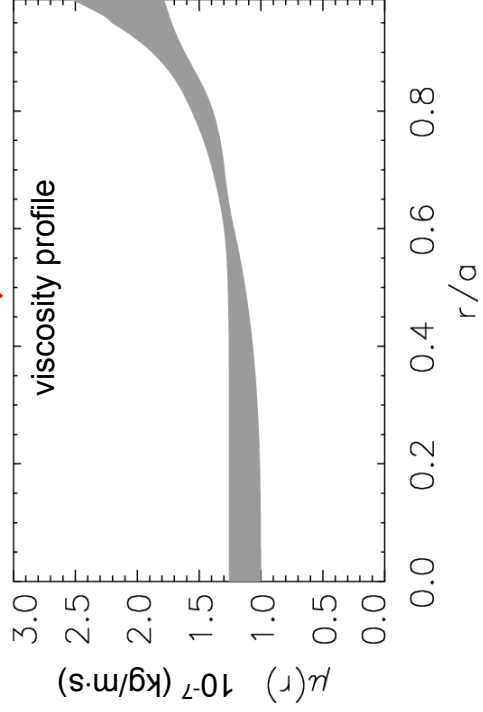
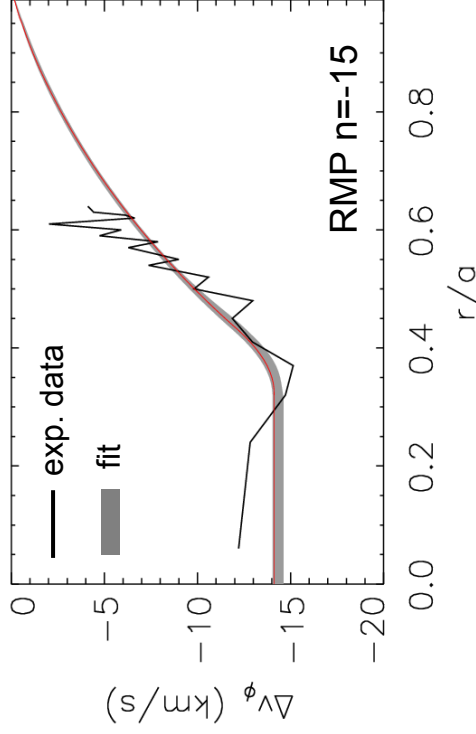
$$\rho \frac{\partial \Delta \Omega}{\partial t} = -\frac{1}{r} \frac{\partial}{\partial r} \left(r \mu \frac{\partial \Delta \Omega}{\partial r} \right) + \frac{T_{EM}^{m,n}}{4\pi R^3 r} \delta(r - r_s)$$

The viscosity profile is modelled using 3 free parameters

$$\mu(r) = \mu_0 (1 + cr^\alpha)$$

The free parameters are determined by comparing simulated and experimental velocity using a $n=-15$ RMP.

This viscosity profile is then used to simulate the effect of a $n=-12$ RMP. The agreement is not optimal.



CONCLUSIONS

- The RMP produces plasma flow and TM braking
- The braking phenomenon is a strong modulation of the plasma velocity composed of phases of acceleration and deceleration
- The maximum braking is located in the position where the RMP is resonant
- Experimental data can be reasonably modelled using the torque balance equation
- The estimated viscosity is approximately $10^{-7} \text{ kg/(m}\cdot\text{s)}$