"Nonlinear MHD simulations for the Reversed Field Pinch with active feedback"

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Consorzio RFX and CNR

- ***<u>3D MHD studies using (modified) DEBS code</u>***
- **R**esistive **W**all studies (external kinks)
- **Successful Feedback control** of modes (external and internal). **Drive** to selected **Single Helical states.**

DEBS code:

$$\frac{\partial \vec{A}}{\partial t} = -\eta \vec{J} + \vec{v} \times \vec{B}$$

$$\rho\left(\frac{\partial \vec{v}}{\partial t} + (\vec{v} \cdot \nabla)\vec{v}\right) = \vec{J} \times \vec{B} - \nabla p - \nu \nabla^2 \vec{v}$$

\+ mass evolution equation

\+ pressure evolution equation

\+ In. Cond. at t=0

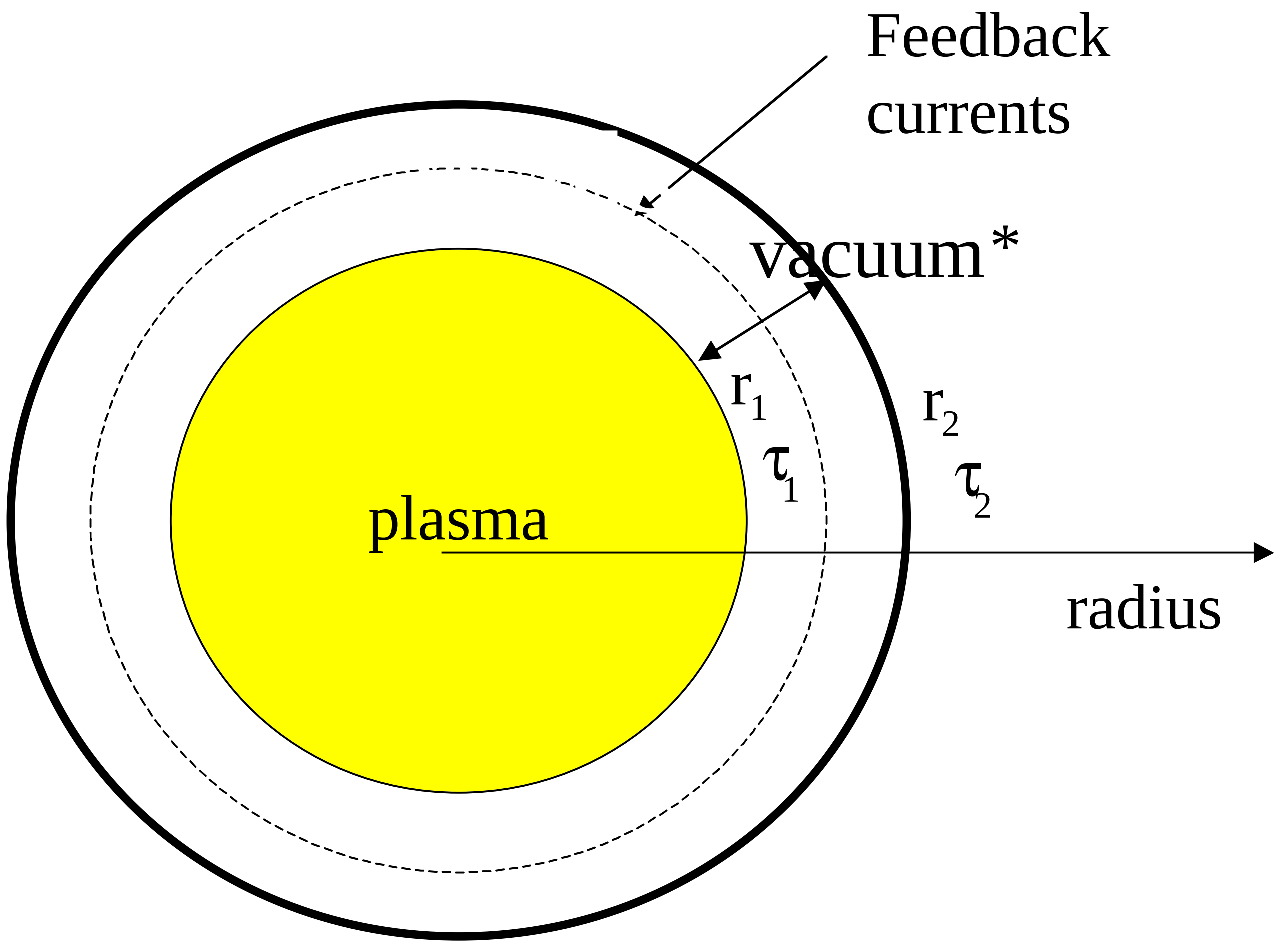
B.C

η, ν profiles specified

*cylindrical geometry

*3D : r finite difference, θ and z Fourier

*Pseudospectral: use of numerical FFT



*In vacuum analytical Bessel Functions solutions $I_m(kr)$ and $K_m(kr)$

BC in DEBS with feedback

- Thin shell BC at each metallic wall:

$$[B_n] = 0 \qquad \left[\frac{\partial B_n}{\partial n}\right] = \tau_w \frac{\partial B_n}{\partial t}$$

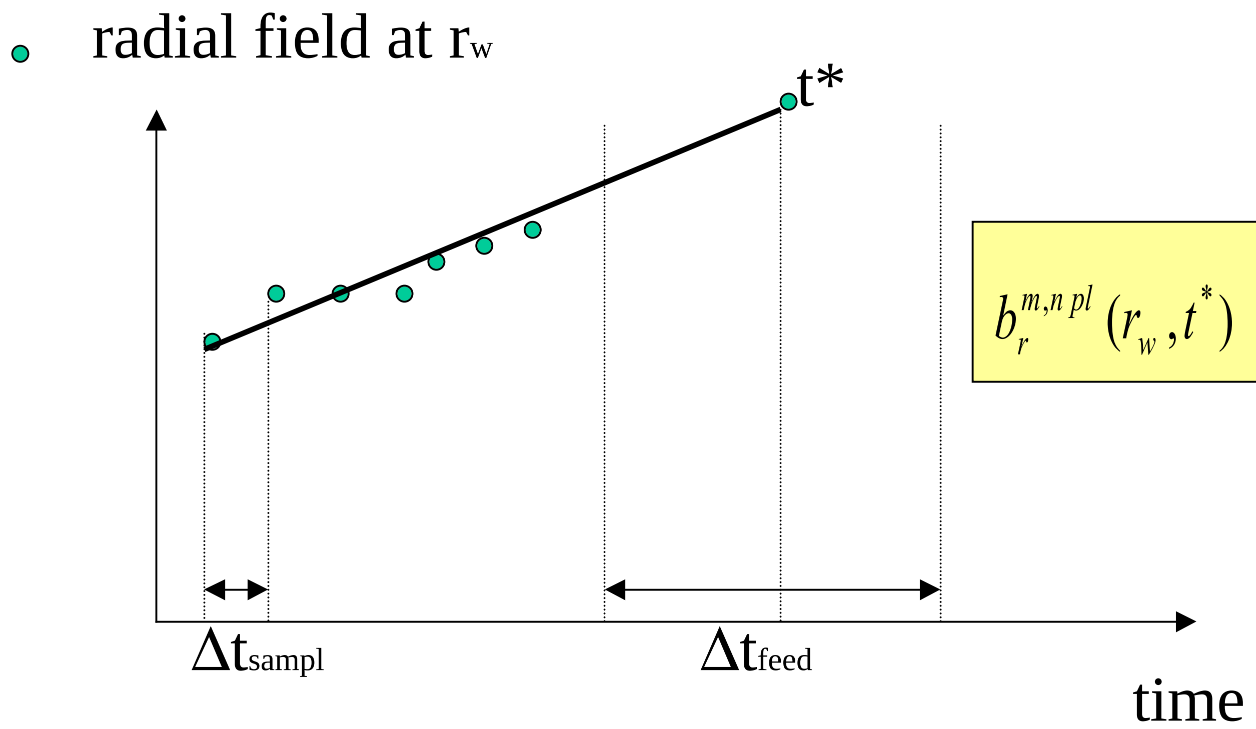
up to 2 resistive walls

- Condition at the coils:

$$\left[\vec{n} \times \vec{B}\right] = \mu_o \vec{K}$$

- coils field at plasma edge:

$$b_r^{feed}(r_w) = \frac{im}{r_w} a_\phi^{m,n}(r_w) J_\phi^{m,n} + \frac{in}{R} a_\theta^{m,n}(r_w) J_\theta^{m,n}$$



$$b_r^{m,n\,pl}(r_w, t^*) \; - \; b_r^{feed}(t) = f(t)$$

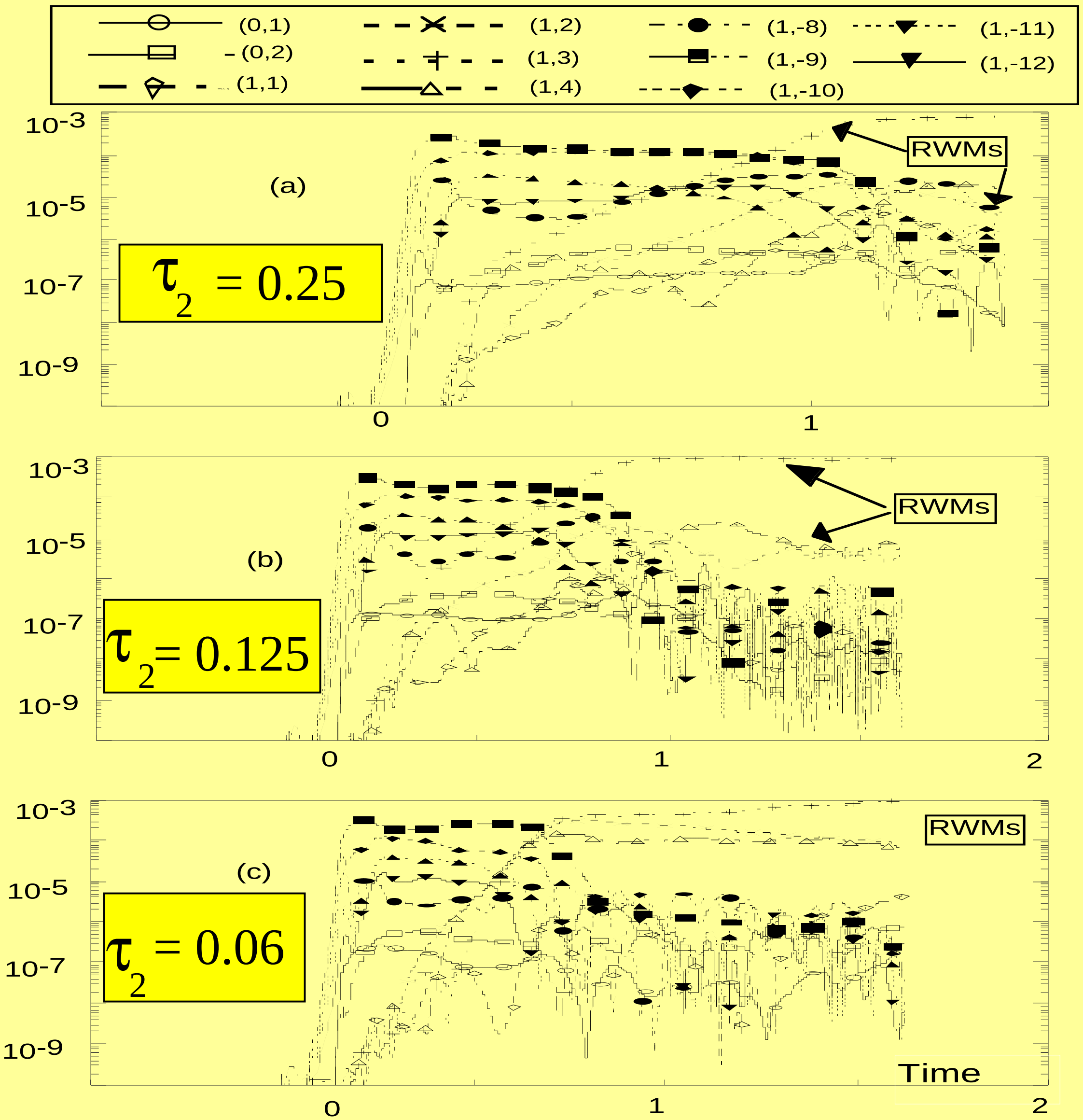
0

•Linear interpolation of sampled data

• fixed feedback during Δt_{feed} time window

R. Paccagnella, D. Schnack, M. Chu, Phys. of Plasmas **9** (2002) 234

MODE‘S ENERGIES



TIME

RWM simulations

m=1,n=1,2,3,4 are unstable

r_{coil} = 1.1

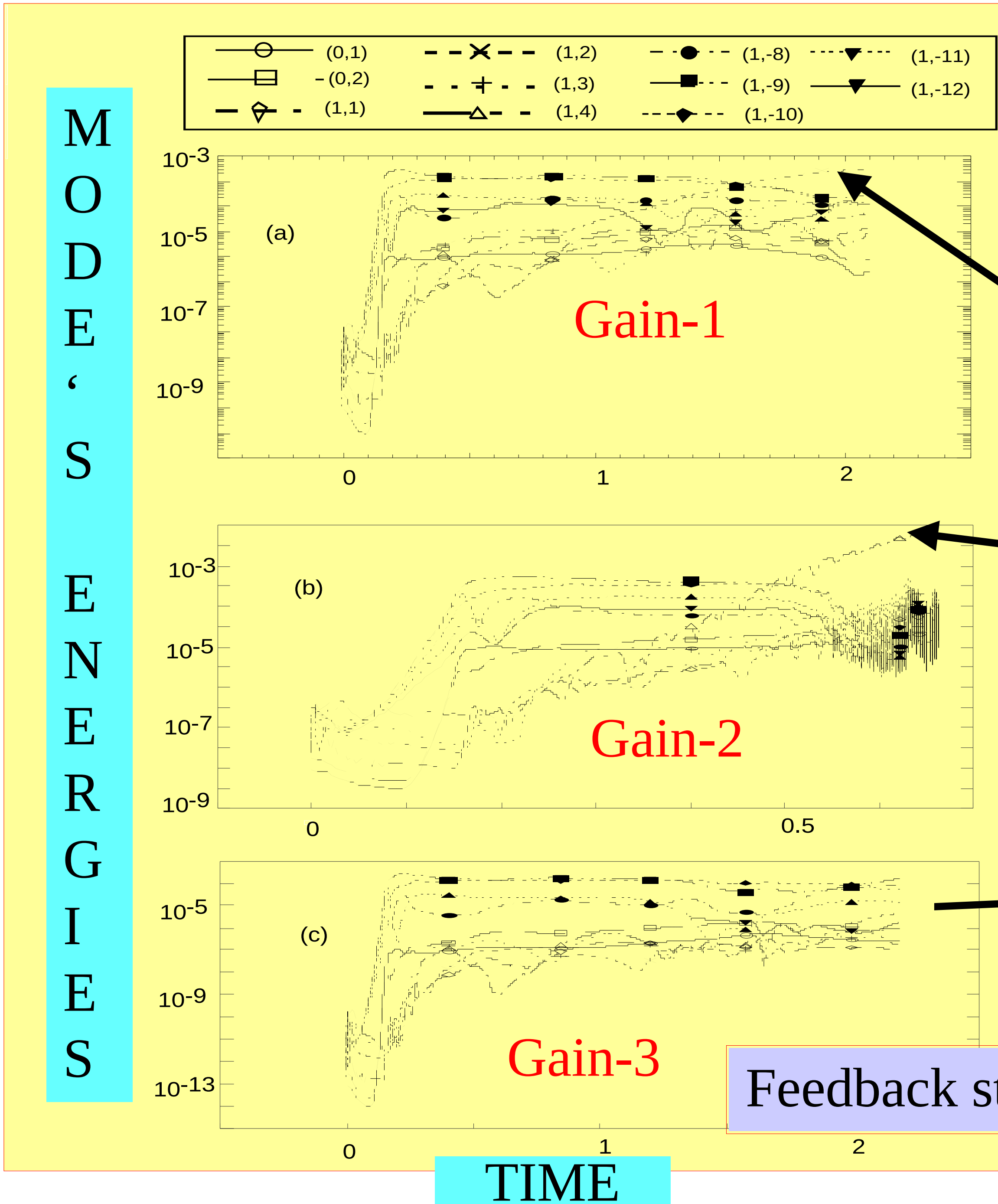
r_2 = 1.2

τ_1 = 0.05

$S=10^3$

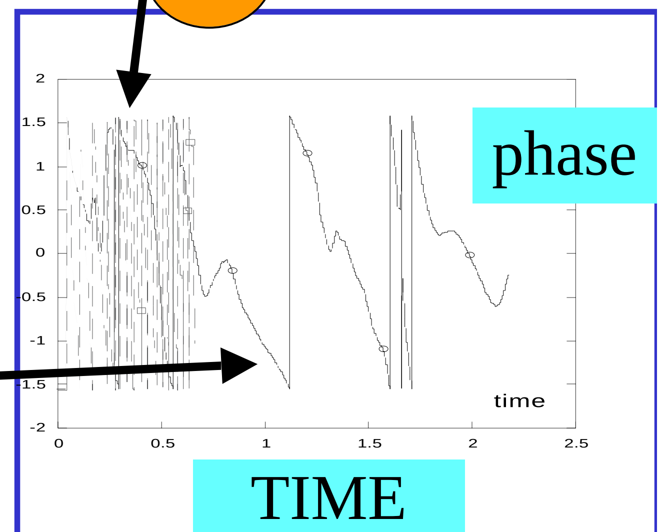
P=0.5

Feedback simulations
m=1
n=1,2,3,4
with **different Gains**



n=2

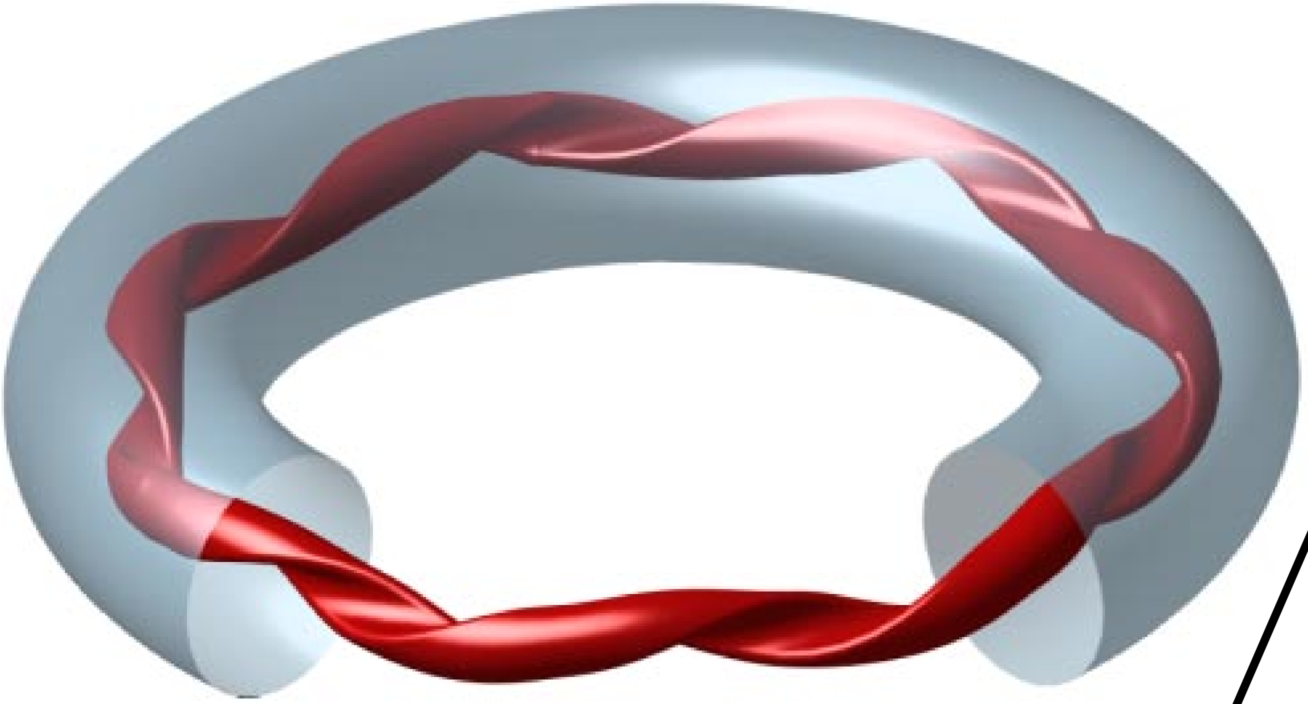
n=4

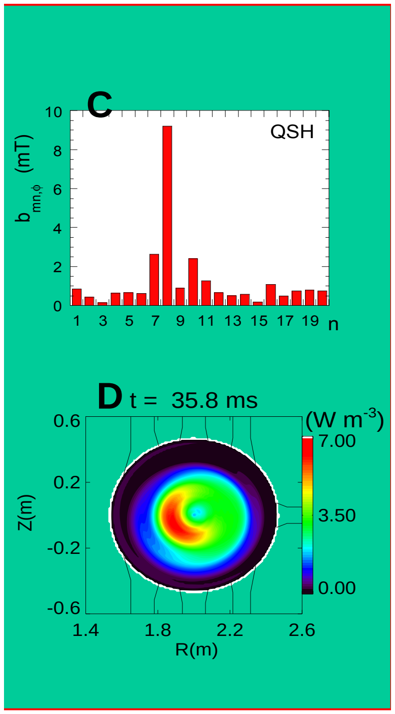


Feedback stabilized case

Single helical states in the RFP

(from χὰος to order)



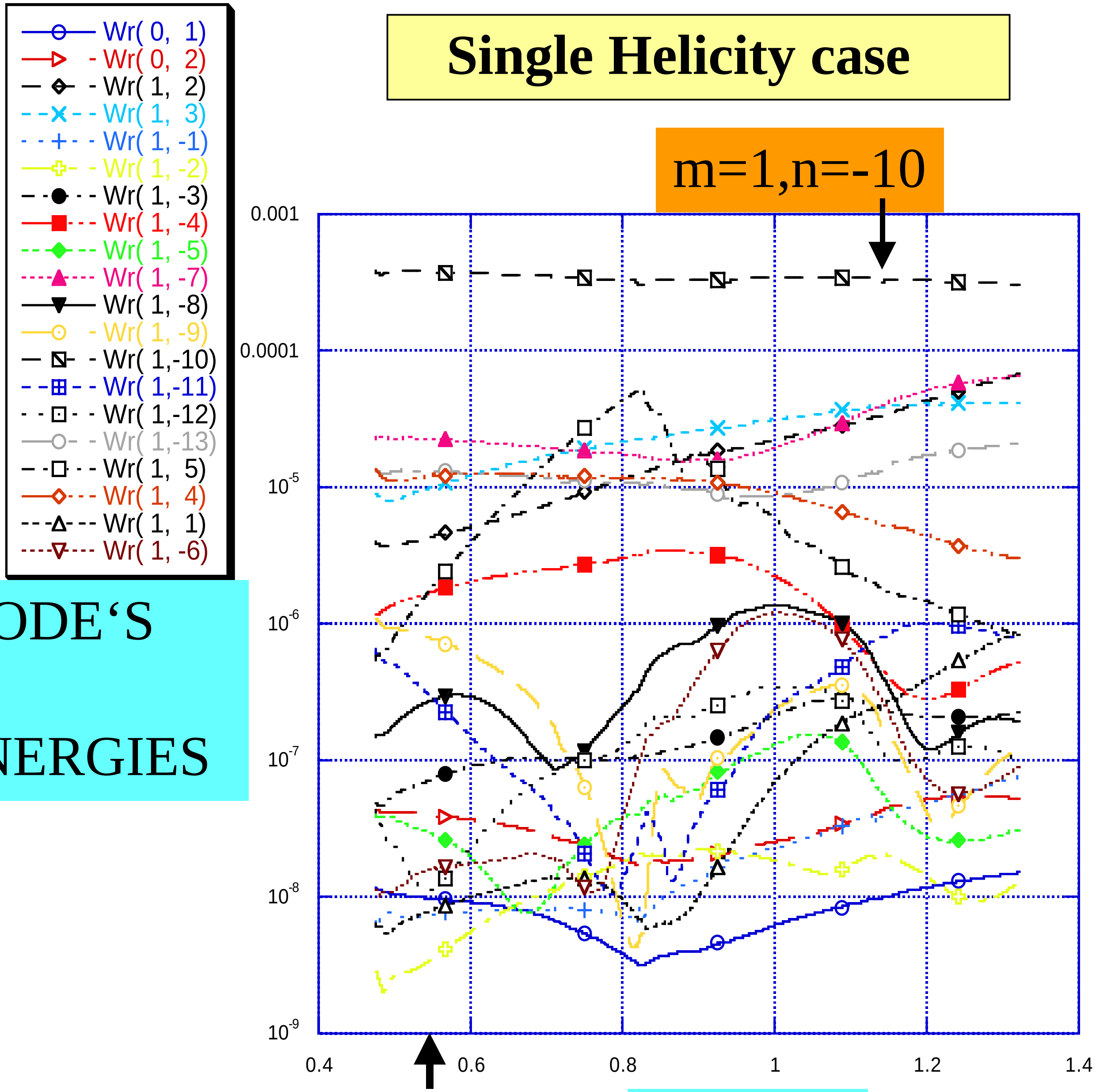


RFX

Numerically predicted and ... Experimentally ≈ found!

3D MHD Cappello&Paccagnella, Varenna (1990)

Single Helicity case



MODE'S

ENERGIES

RWMs if no feedback

TIME

Feedback
RWMs
suppression

$r_{coil} = 1.1$

$r_2 = 1.2$

$\tau_1 = 0.05$

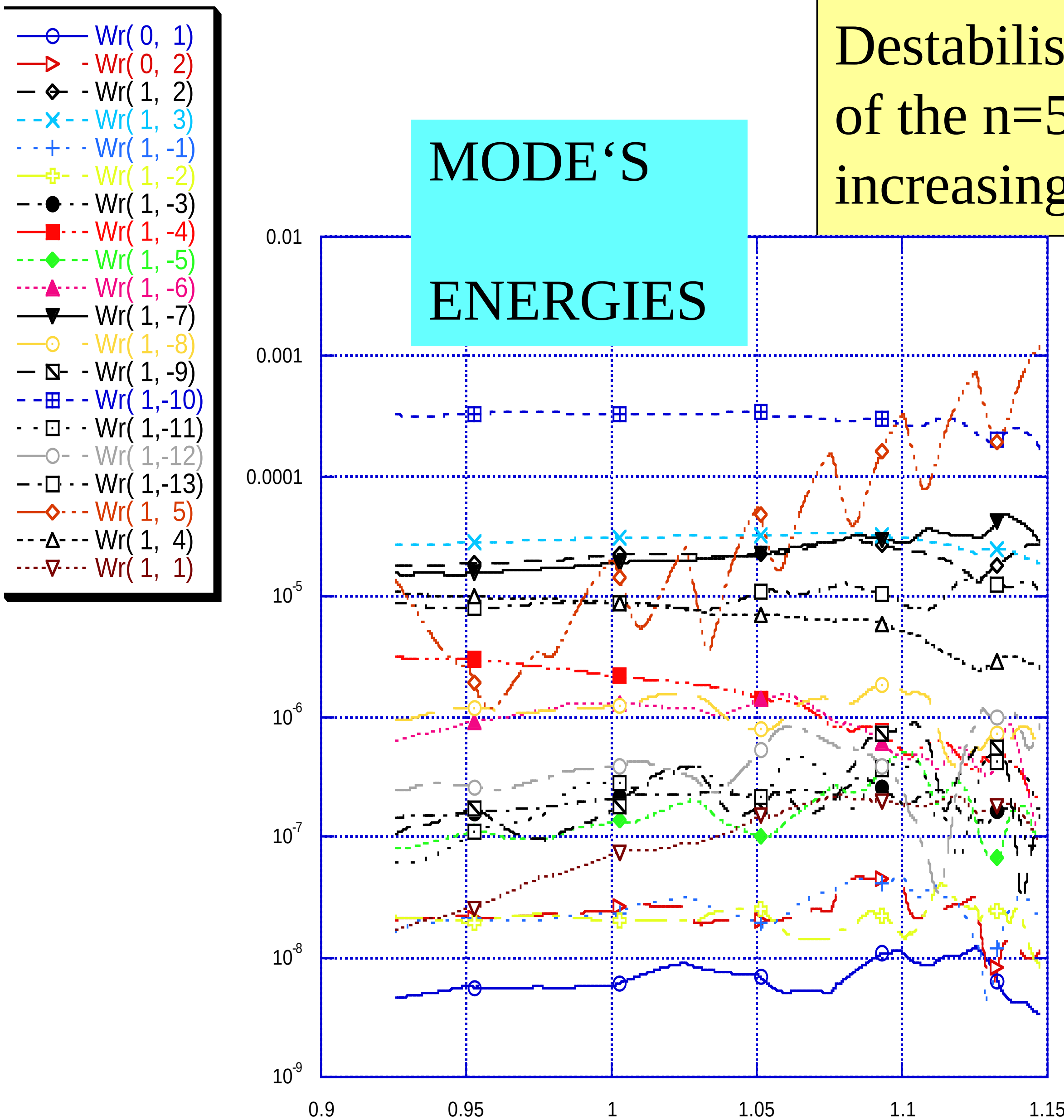
$\tau_2 = 0.25$

$S=3.3\ 10^3$

$P=8$

Destabilisation of the n=5 mode increasing the gain

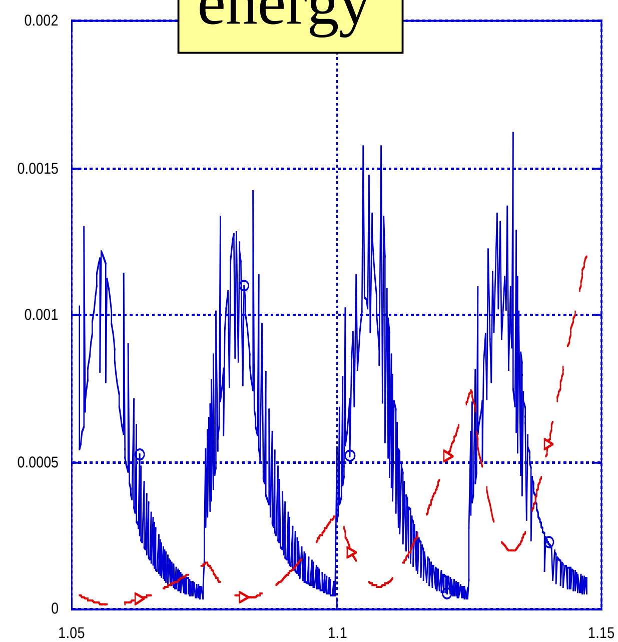
MODE'S ENERGIES



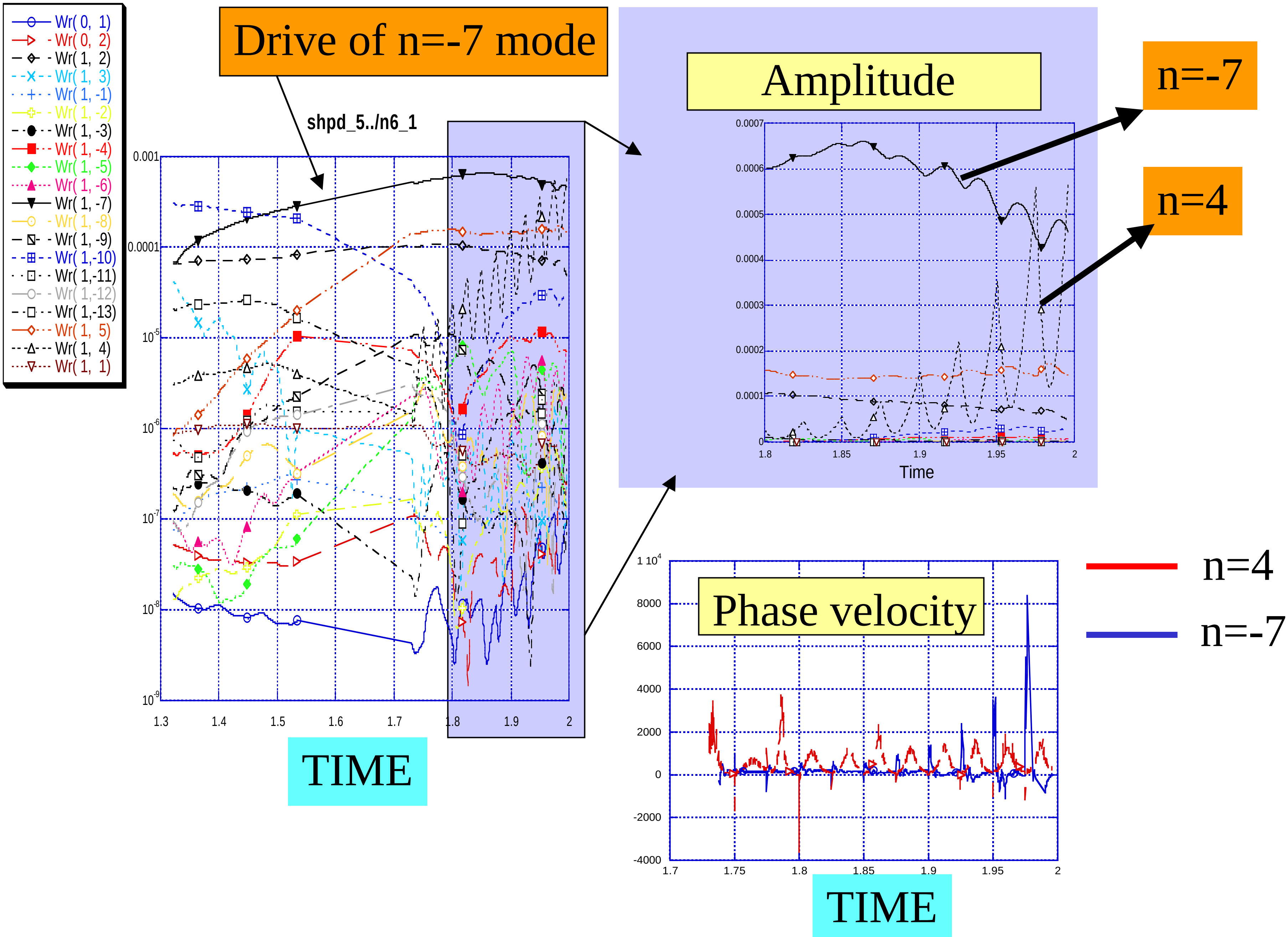
TIME

phase velocity

energy

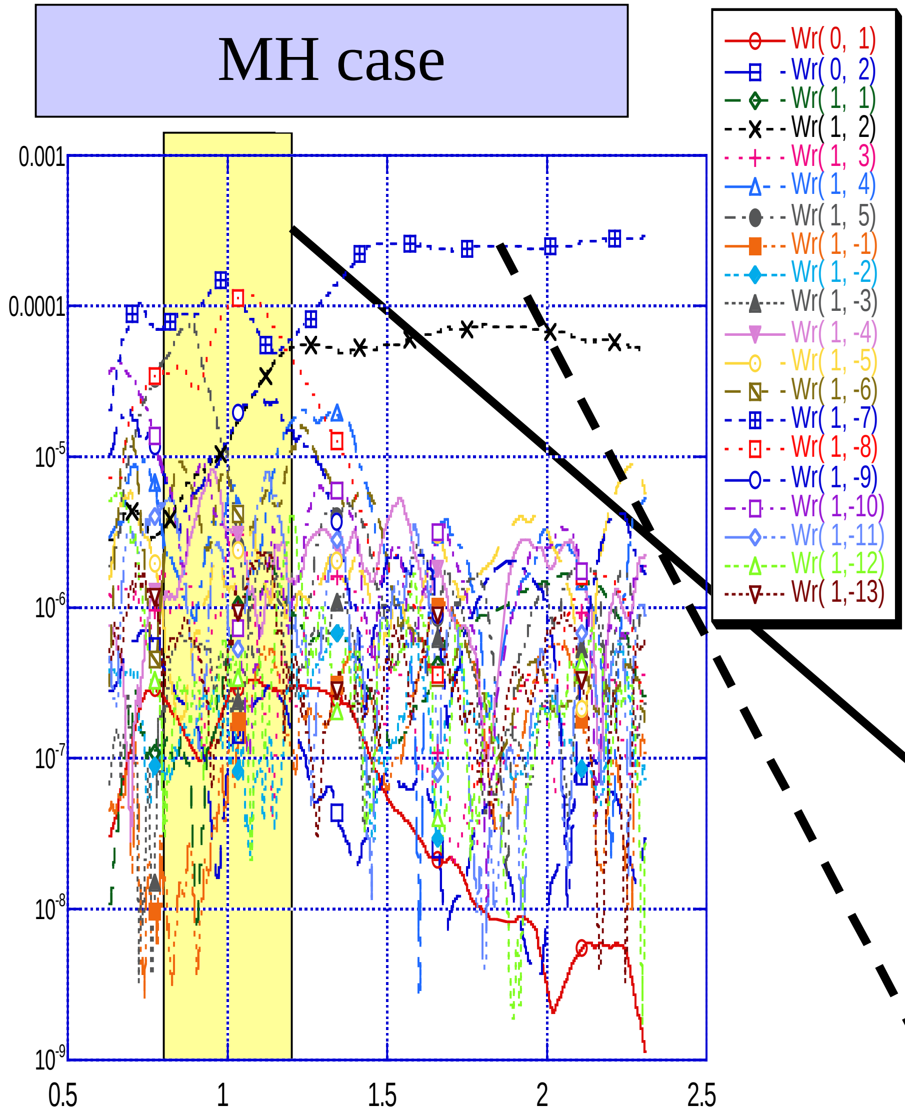


TIME



Drive of n=-7 mode
shpd_5../n6_1
Wr(0, 1)
Wr(0, 2)
Wr(1, 2)
Wr(1, 3)
Wr(1, -1)
Wr(1, -2)
Wr(1, -3)
Wr(1, -4)
Wr(1, -5)
Wr(1, -6)
Wr(1, -7)
Wr(1, -8)
Wr(1, -9)
Wr(1,-10)
Wr(1,-11)
Wr(1,-12)
Wr(1,-13)
Wr(1, 5)
Wr(1, 4)
Wr(1, 1)
TIME
Amplitude
Time
n=-7
n=4
Phase velocity
n=4
n=-7
TIME

MH case



TIME

Drive of n=-7 mode for a **Multi-helicity case** (at **low** dissipation

$S=3.3\ 10^{3}$

$P=0.5$

and **short** wall time constants

$\tau_1 = 0.05 \qquad \tau_2 = 0.06$

Careful adjustment of the gains during the initial phase needed

Successful **drive** and **sustainment** of m=1 n=-7

Conclusions

- RWM studies show the growth of low n modes after few (2-3) wall times
- good predictions of the linear theory for the growth rates and dominant modes

- **Feedback of external modes** has been shown to be **possible**, at R/a=4 and different walls time
- a few **n's (1,2,3,4,5)** should be considered
- **Drive of selected Single Helical state is possible even starting from MH states**