

Reconnection processes in 3D MHD modeling of Reversed Field Pinch magnetic self-organization

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ABSTRACT

Since the early 90ties, 3D nonlinear MHD studies have been developing a fundamental framework for the understanding of the Reversed Field Pinch (RFP) self-organization.
3D reconnection processes strongly characterize the pinch dynamics both in low and high dissipation regimes (Lundquist/Hartmann number).
This is particularly evident during the so-called **sawtooth activity** observed in both Multiple and Quasi Helical regimes where **the natural kinking of the current carrying plasma column triggers nearly periodic relaxations associated with localized shrinking/collapse of the global magnetic field perturbation**.
We here provide a survey of the typical magnetic reconnection manifestation in **nonlinear visco-resistive MHD**:

- Magnetic into kinetic energy conversion - possibly providing ion heating,
- 3D current sheets formation and related flow patterns,
- Mode phase locking, (toroidal collapse of the helix),
- Excitation of Alfvén waves,
- **Pacing of the sawtooth cycle of both RFP & Tokamak** by suitable Resonant or Non resonant Magnetic Perturbation

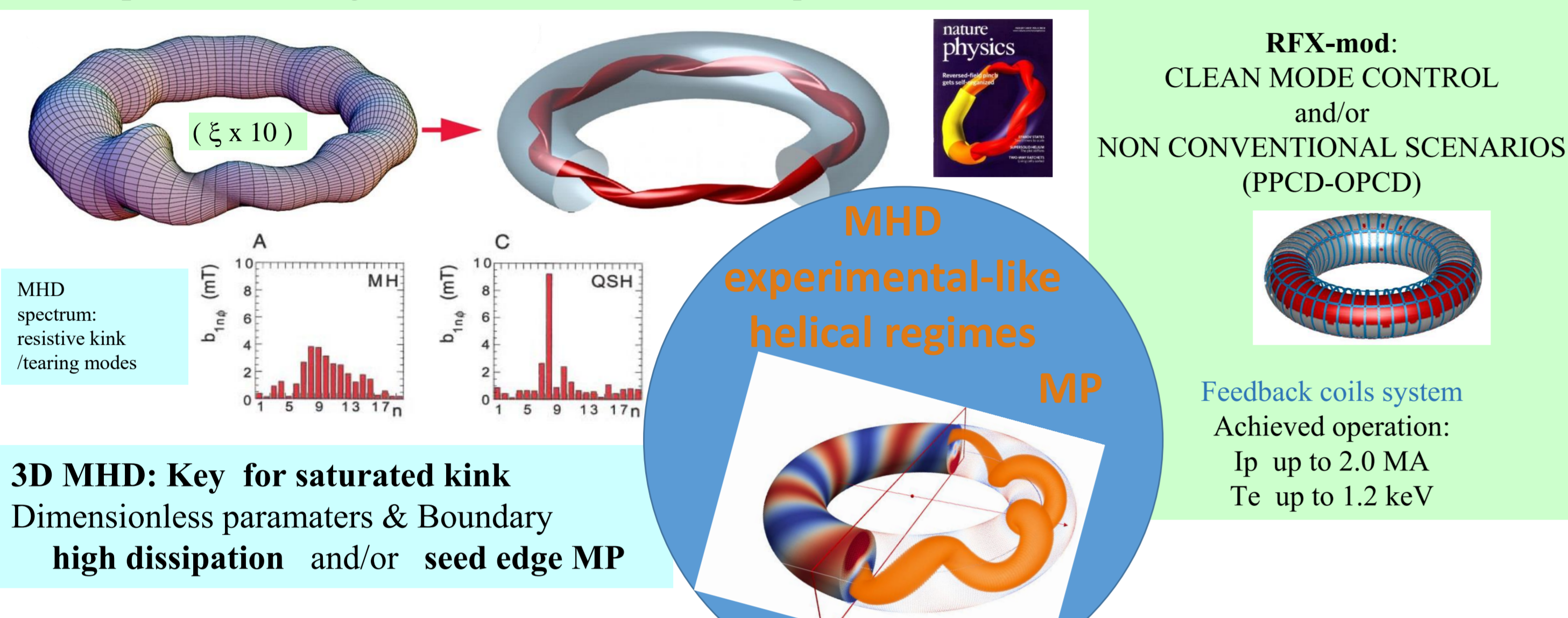
Some open issues, Ongoing work:

Relaxation-Reconnection processes are governed by DIMENSIONLESS PARAMETERS (v/η) & Boundary constraints (RMP)

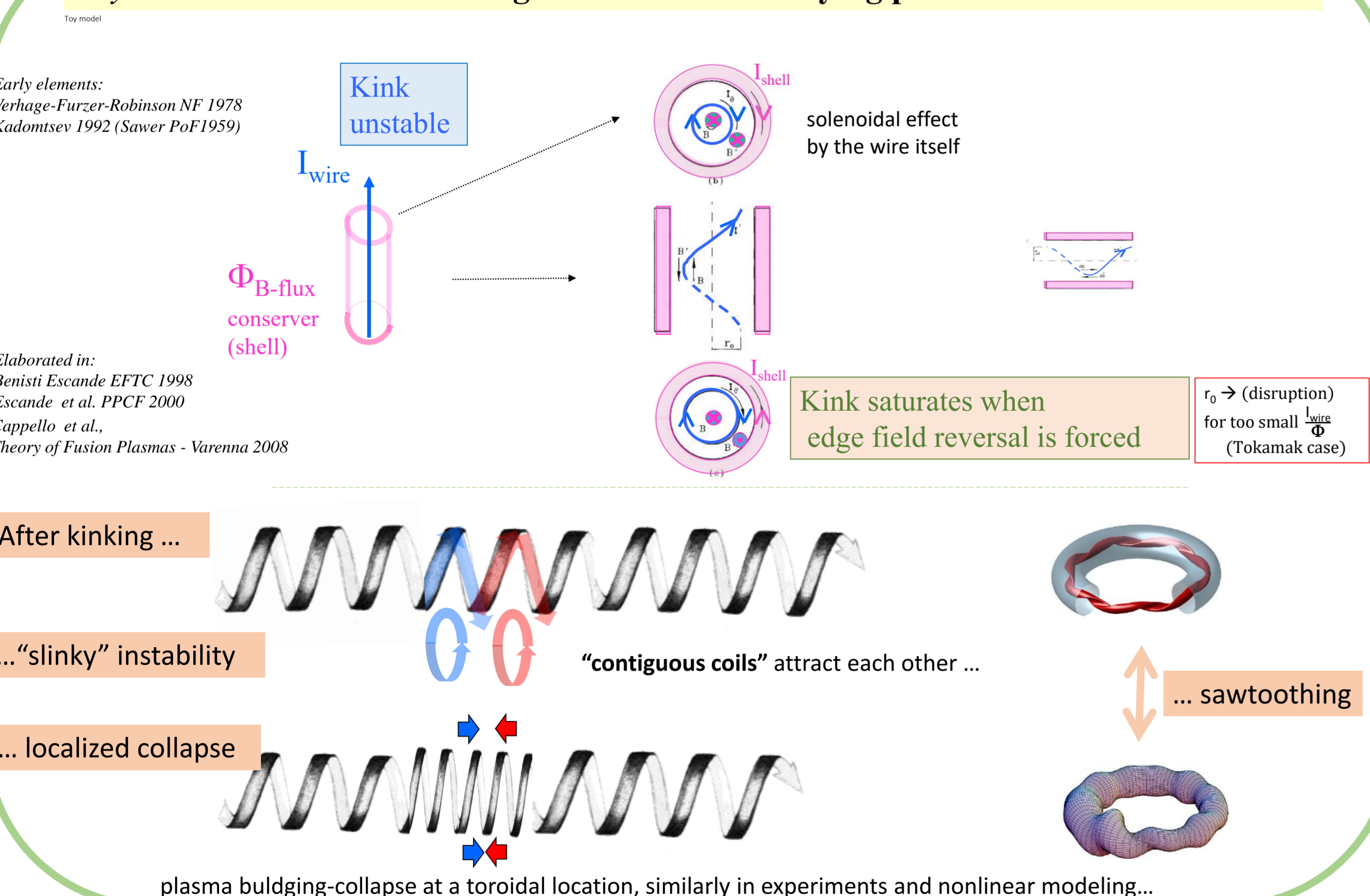
- Assessing **realistic Boundary Conditions**
Verification SpeCyl – PIXIE3D (Chacon-LosAlamos) and proof of principle studies on free-boundary modes
– THIS CONFERENCE Spinicci Bonfiglio et al, AIP Advances 2023
- Addressing **profile impact sensitivity** and estimate of experimental **effective Hartmann $H = (v/\eta)^{-1/2}$**
Heuristic approach (momentum transport in plasmas is a longstanding open issue)
– THIS CONFERENCE Vivenzi et al, Theory Fusion Plasmas 2022 JPCS – Vivenzi et al PoP 2023
– THIS CONFERENCE Veranda et al Plasma flow and QSH regimes transition
- Further develop **analogies RFP – Tokamak**
Alfvén waves excitation at sawtoothing (ohmic)
– THIS CONFERENCE Kryzhanovskyy Bonfiglio et al, Nuclear Fusion 2022, Kryzhanovskyy et al, paper under revision
- **What is the mechanism of “anomalous” ion heating in RFPs (observed at sawtoothing)?**
non resonant Alfvén wave particle interaction Sattin Escande paper in preparation
- Assessing **magnetic topology characterization** - Lagrangian Coherent Structures validation on experimental eITB
follow up of Veranda et al, NF 2017

INTRODUCTION

RFP experiments: at high current ↔ ordered KINKED plasma - advanced operation with Boundary Control

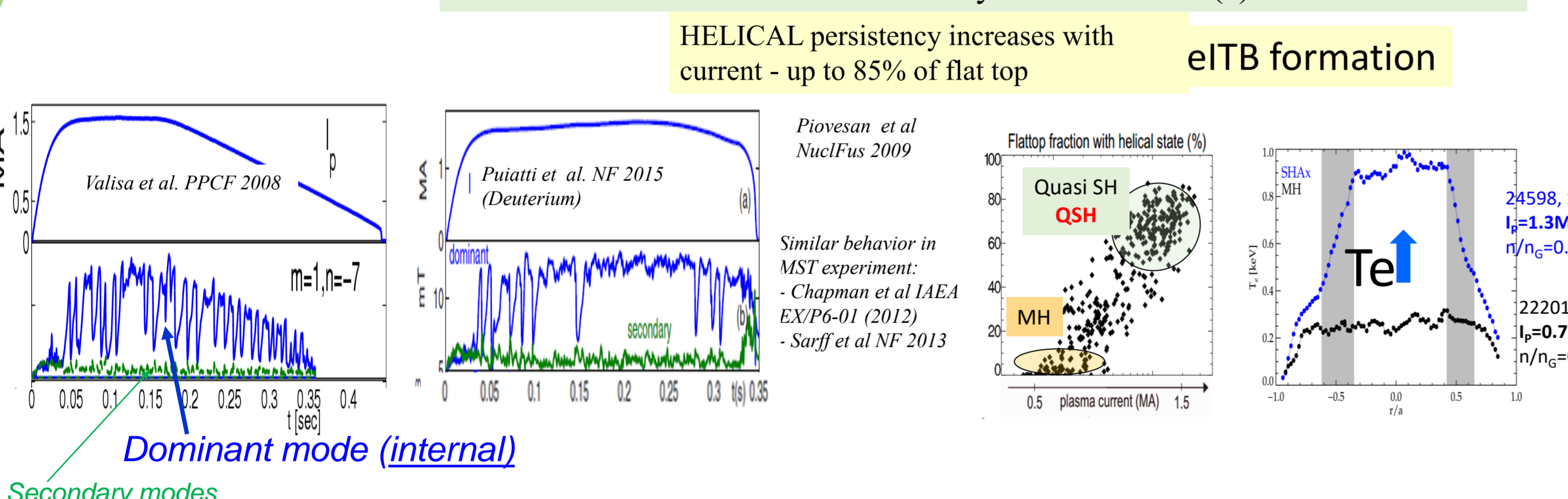


Toy model: the natural kinking of the current carrying plasmas in a flux conserver

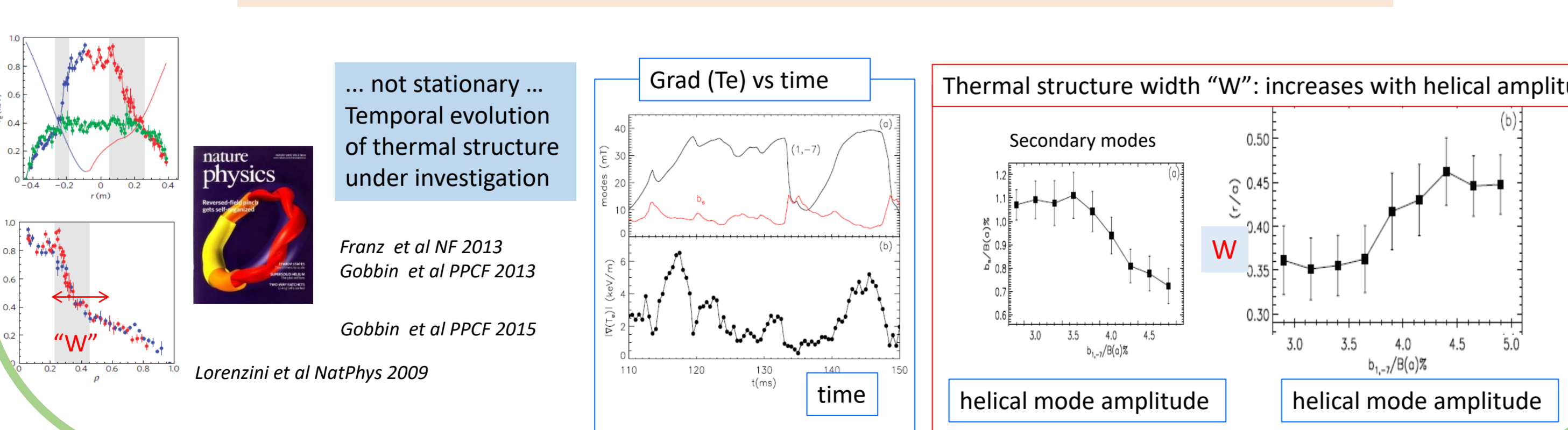


RFX-mod OVERVIEW

Intermittent Quasi Helical Regimes develop at high Ip, when feedback coils scheme system aims at $Br(a) = 0$

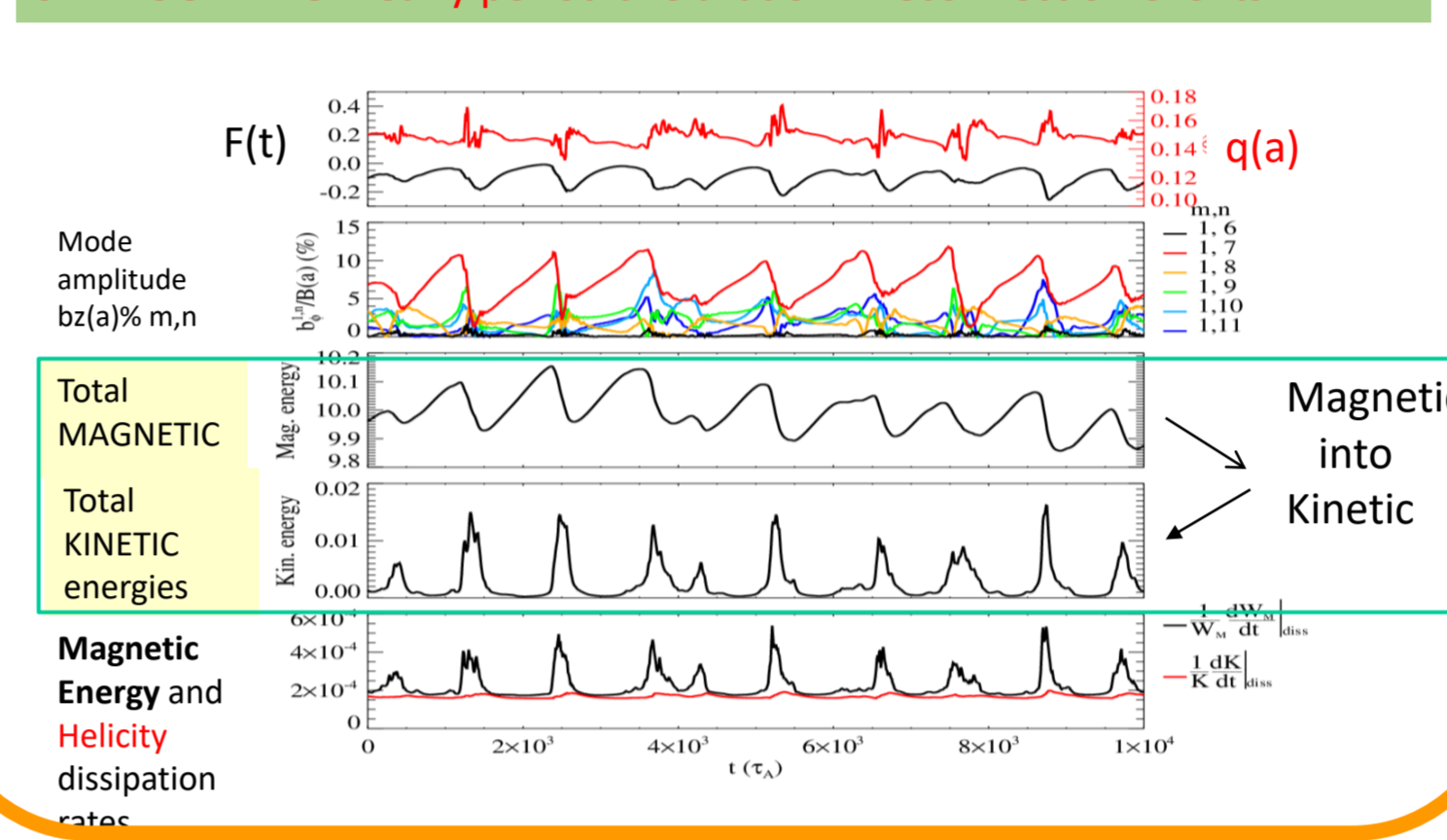


T_e, n_e get a helical shape - T_e steep gradients ...

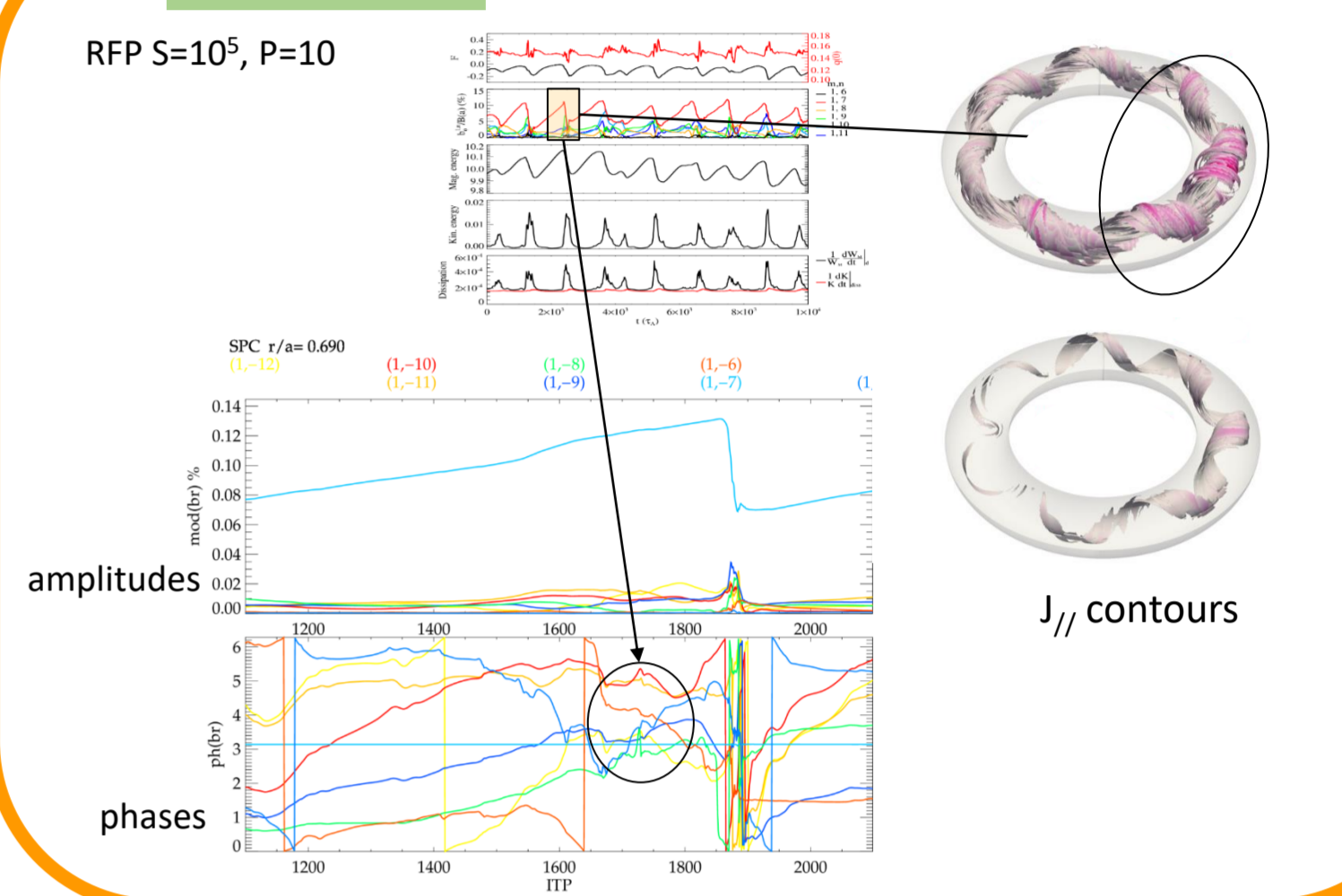


1996_NF_Cappello&Biskamp_Reconnection processes and scaling laws in RFP MHD
2004_PPCF_Cappello_Bifurcation in the MHD behaviour of a selforganizing system: the RFP
2008_Theory_Varenna Lausanne_Cappello et al The Reversed Field Pinch toward magnetic order: a genuine self-organization
2017_PPCF_Bonfiglio et al_Sawtooth mitigation in 3D MHD tokamak modelling with applied magnetic perturbations
2020_NF_Veranda et al_Helically self-organized pinches dynamical regimes and magnetic chaos healing
2022_RendFisAccIncei_Veranda et al_Magnetic reconnection in three-dimensional quasi-helical pinches
2022_NF_Kryzhanovskyy et al_Alfven RFP Tokamak Alfvén waves in reversed-field pinch and tokamak ohmic plasmas: nonlinear 3D MHD modeling and comparison with RFX-mod
2020_NF_Momo et al_The phenomenology of reconnection events in the reversed field pinch
2022_NF_Gobbin et al_Ion heating and energy balance during magnetic reconnection events in the RFX-mod experiment

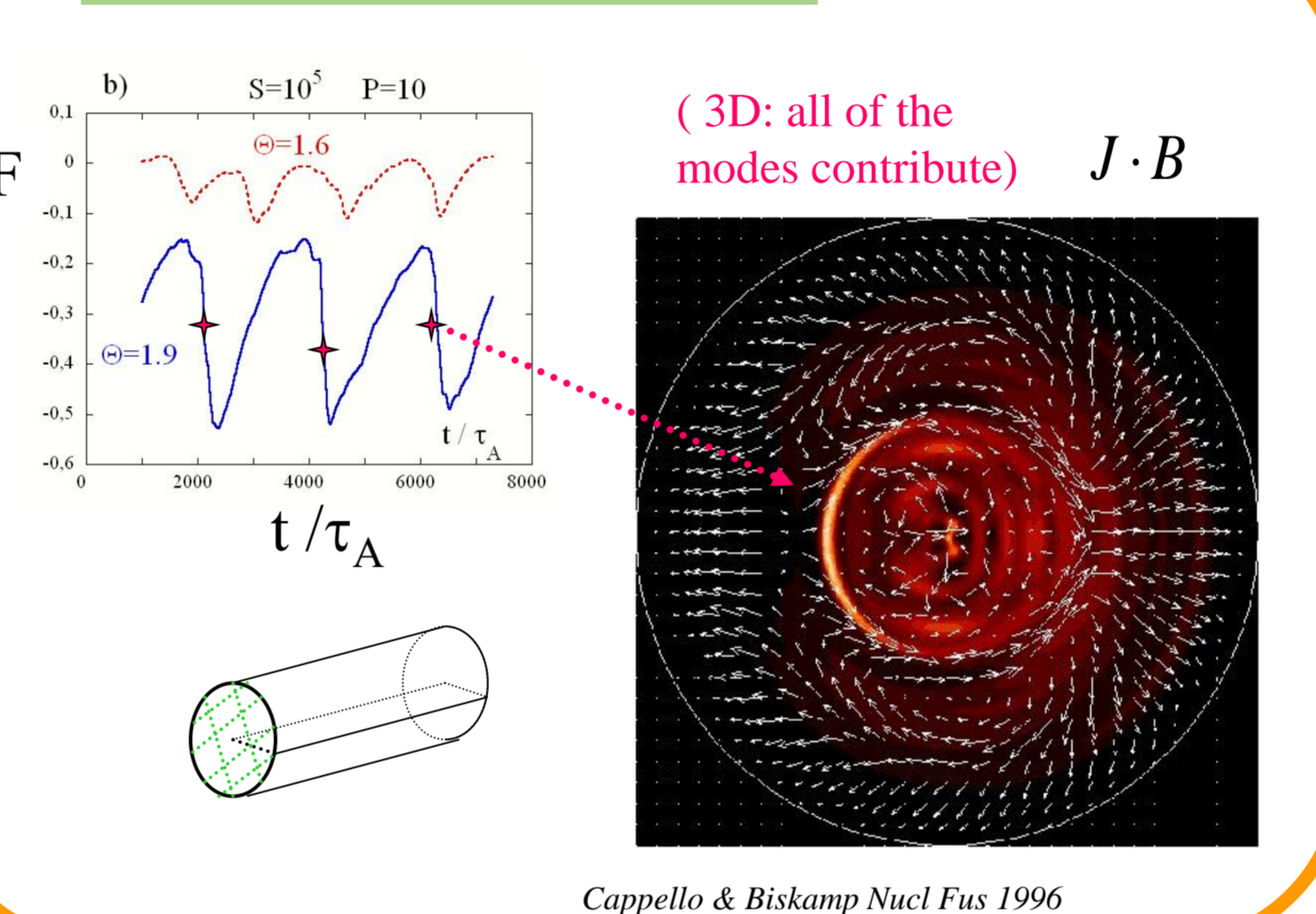
SAWTOOTHING: nearly periodic relaxation – reconnection events



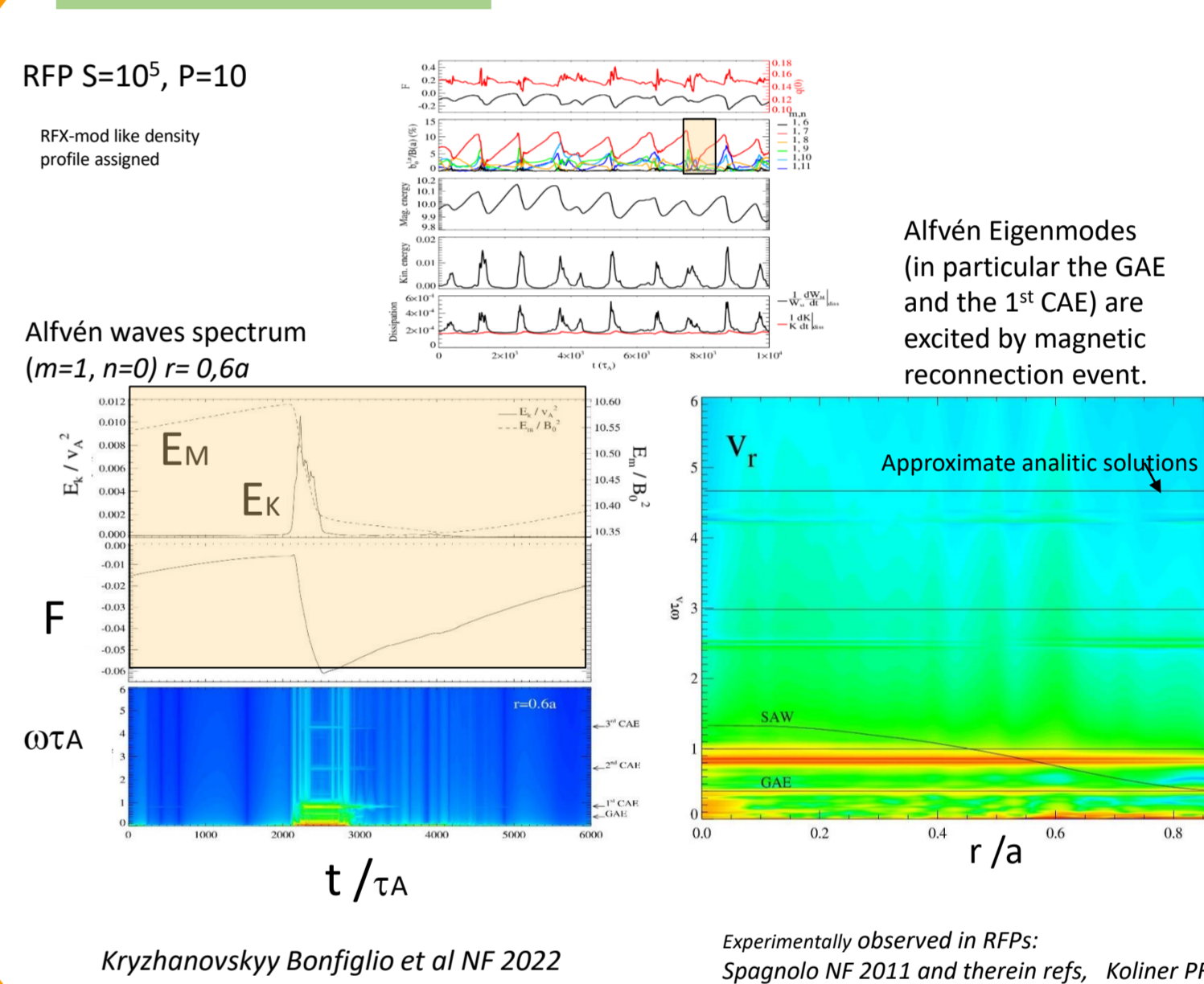
PHASE LOCKING



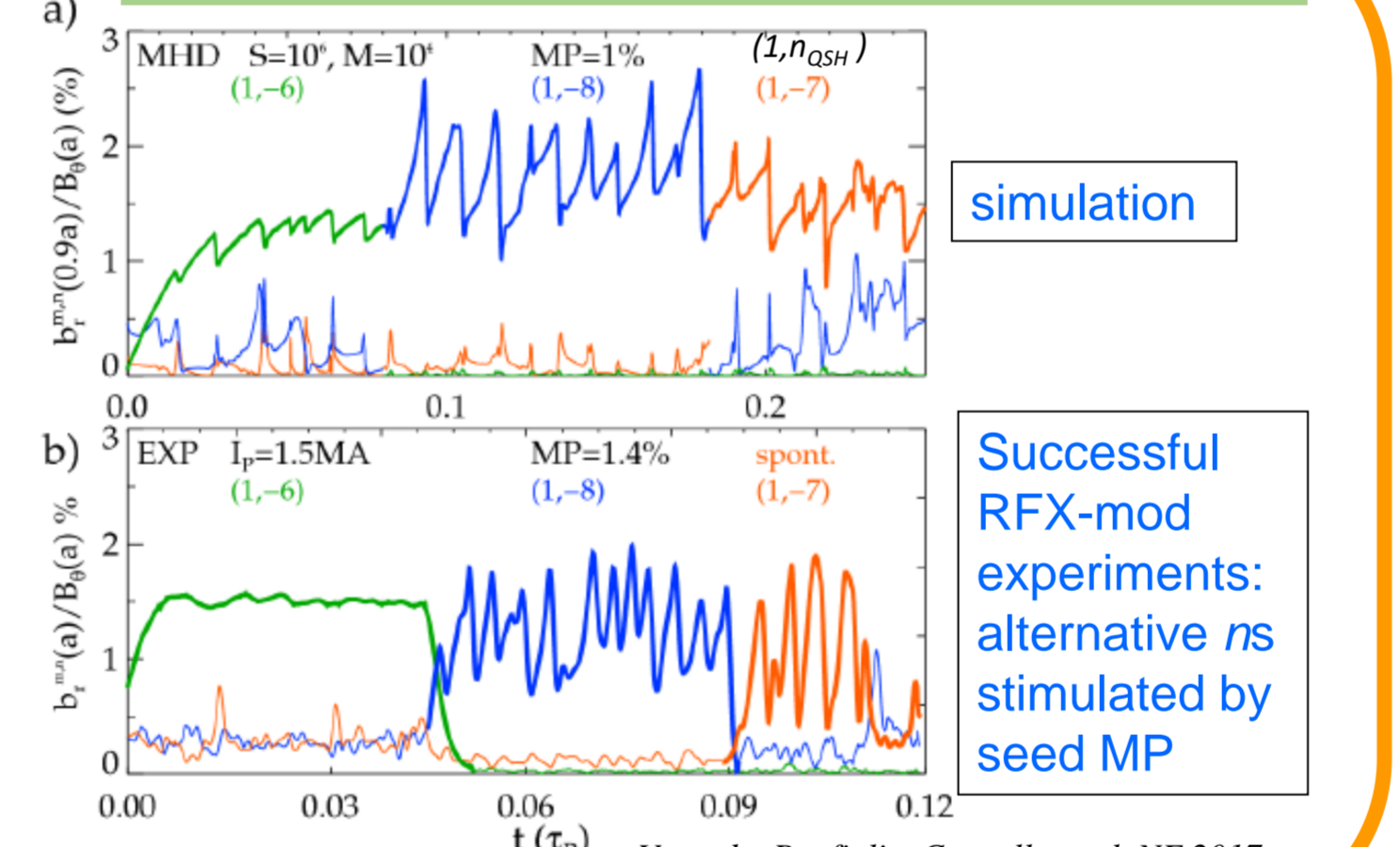
3D current sheets formation



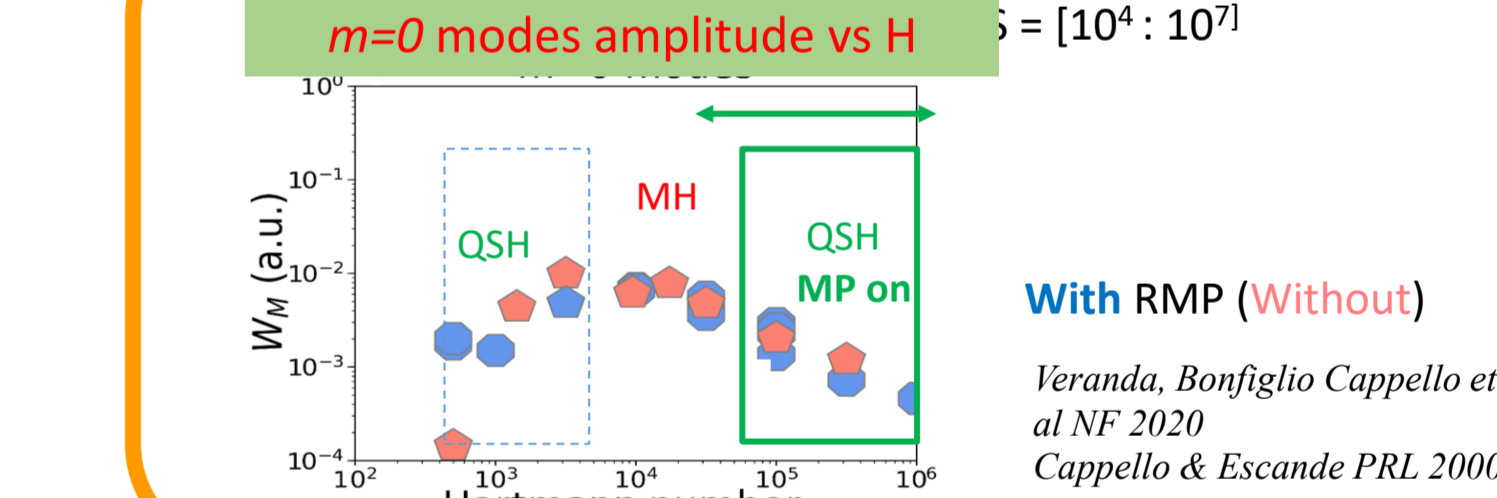
Alfvén Waves excitation



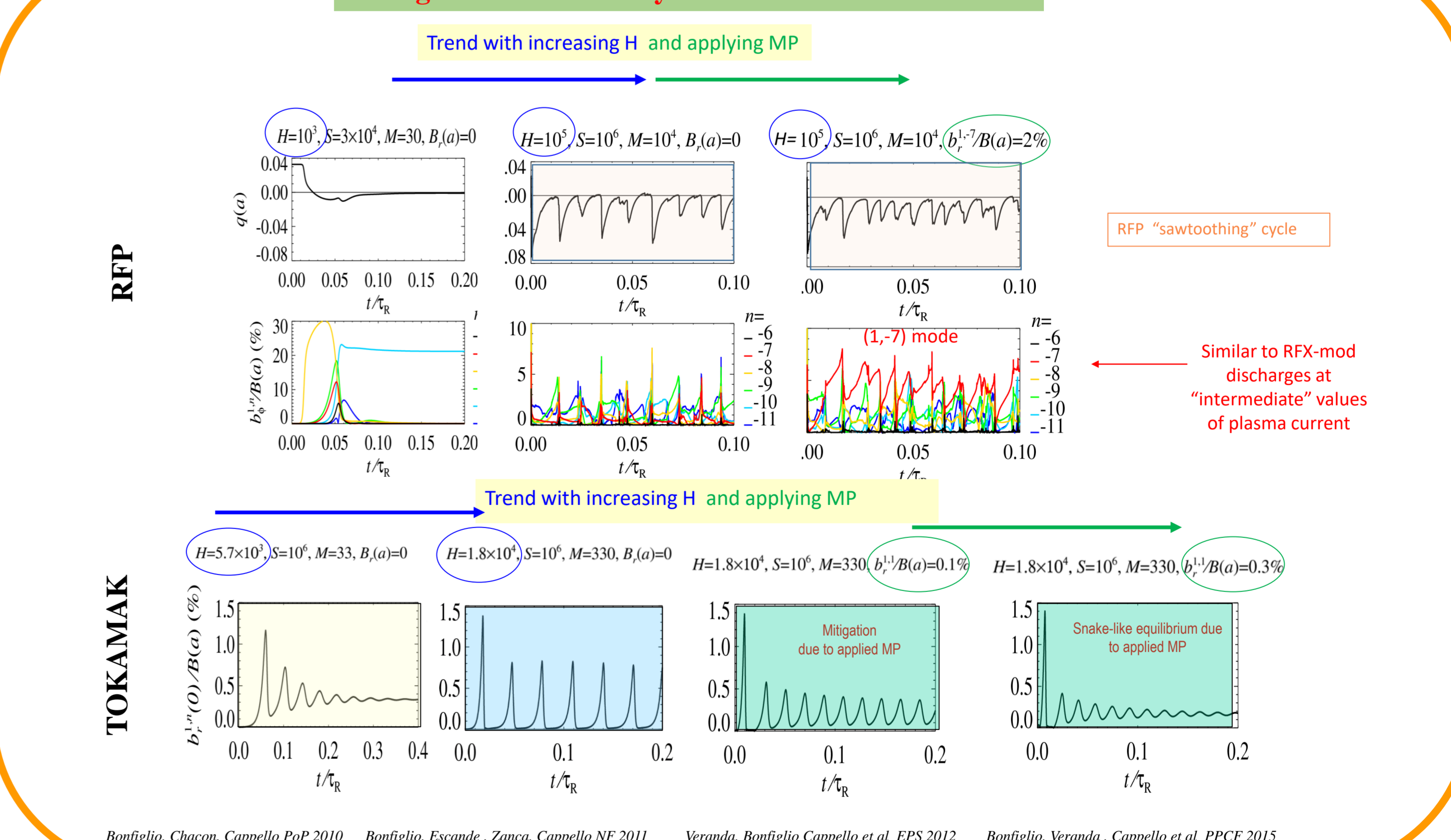
New helical regime, with different pitch $m/n = 1/n_{QSH}$



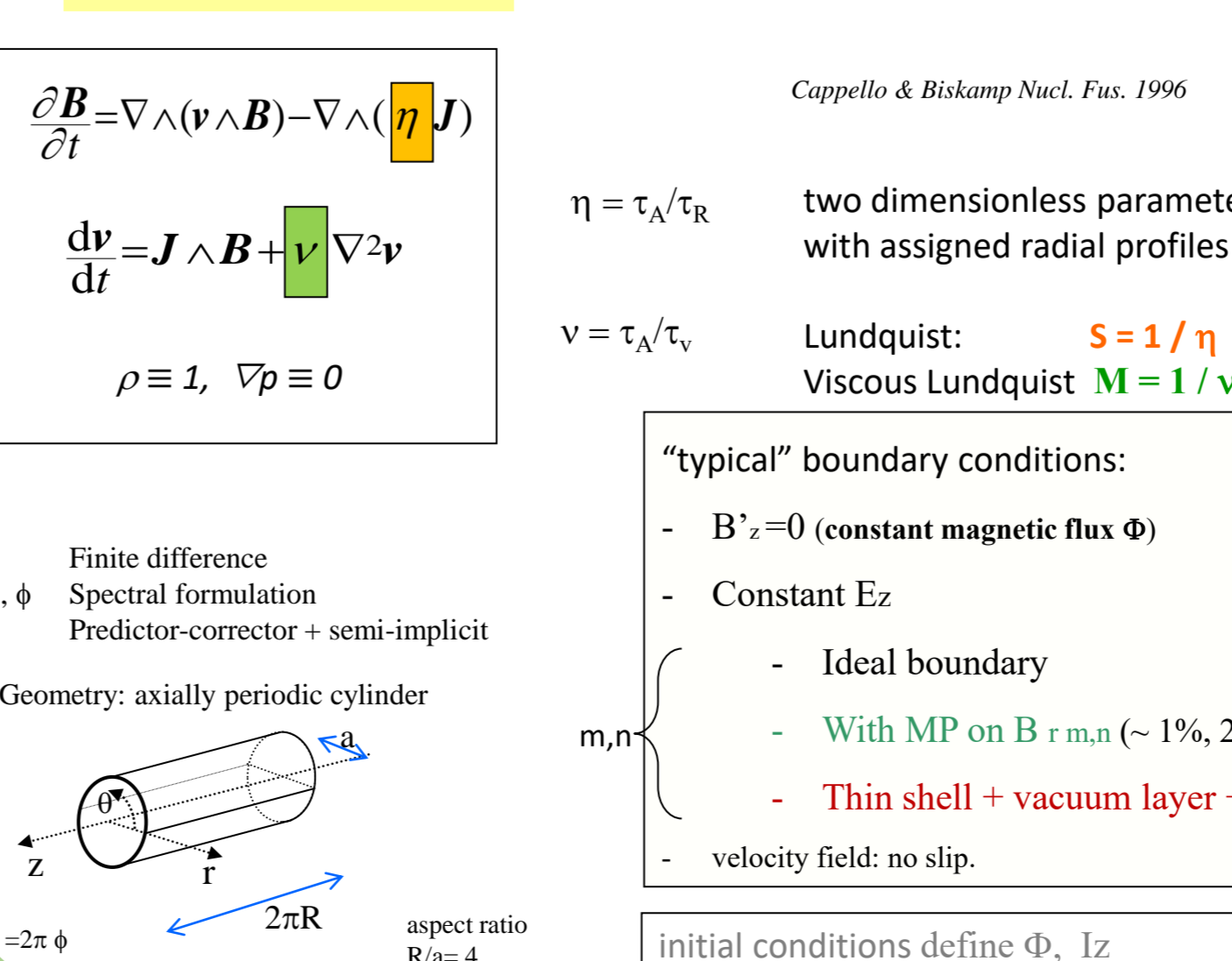
Dynamical Transition diagram: $m=0$ modes amplitude vs H



Pacing of the sawtooth cycle of both RFP & Tokamak



3D nonlinear MHD



Model equations transformed: The Hartmann number

