# Multiscale Synergies in Fusion Plasmas: Turbulence, MHD Modes, Fast Particles, and Alfvénic Instabilities

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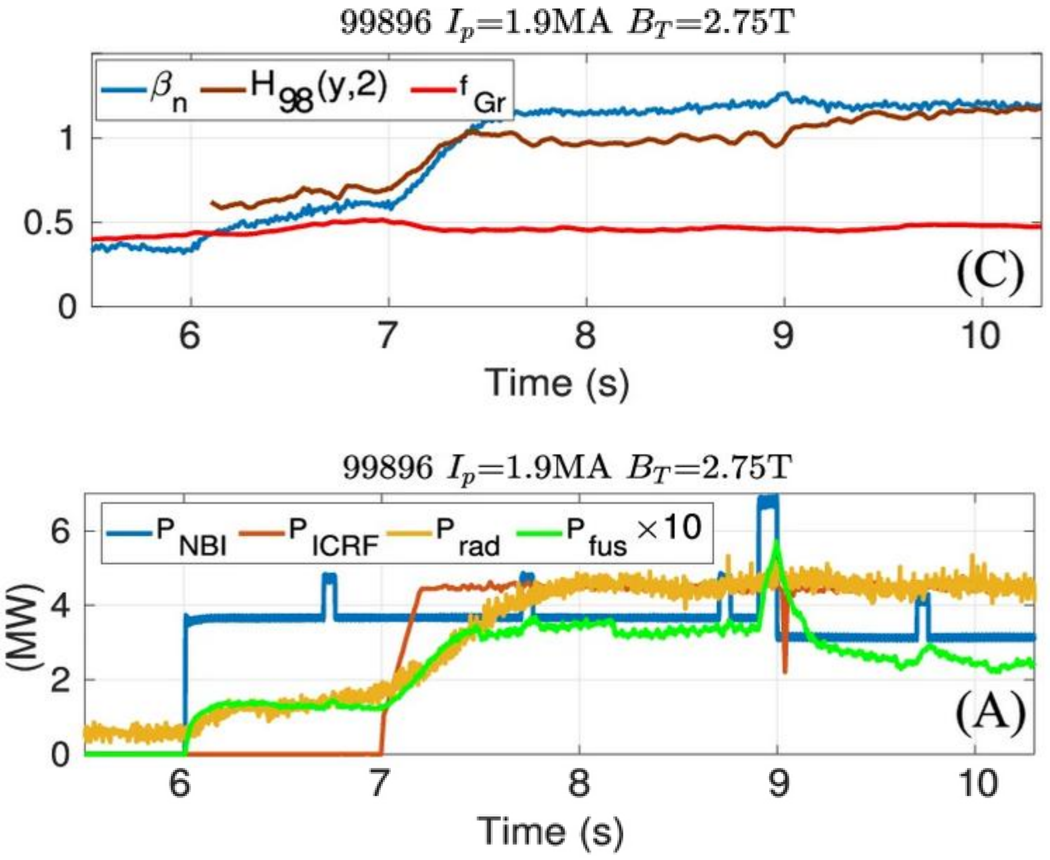
# Introduction

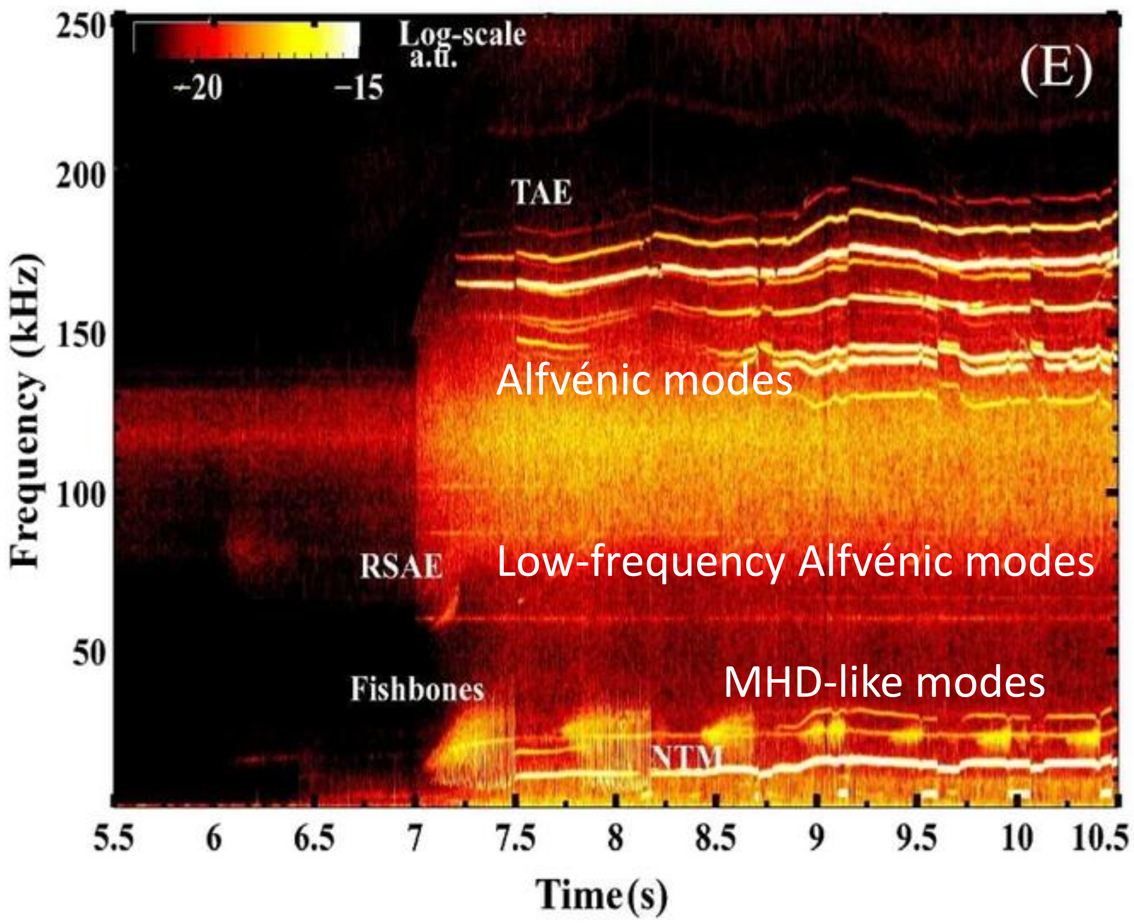
- Several experiments worldwide will produce burning plasmas (ITER, BEST, SPARC, Infinity, GIGA, Stellaris …).
- **Energetic particles** will be important for cross-couplings between micro- and macro-scales.
- **Turbulence and zonal structures** cannot be considered separately from **fast particles and Alfvénic modes**.
- MHD-type instabilities will also affect the plasma dynamics, turbulence, and transport in phase space.
- Plasma profile evolution becomes a **multi-scale nonlinear problem with global and kinetic contributions**.

**EUROfusion (TSVV-G) program:**

- Global nonlinear gyrokinetics as a minimal inclusive description addressing this problem within a single framework.
- Lower fidelity (reduced models): hybrid particle-MHD codes, phase-space transport codes (quasilinear and PSZS).
- Developing theory and codes for future burning-plasma fusion devices and dedicated ongoing experiments.

# TSVV-G background: experiment (JET, Deuterium-Tritium campaign)

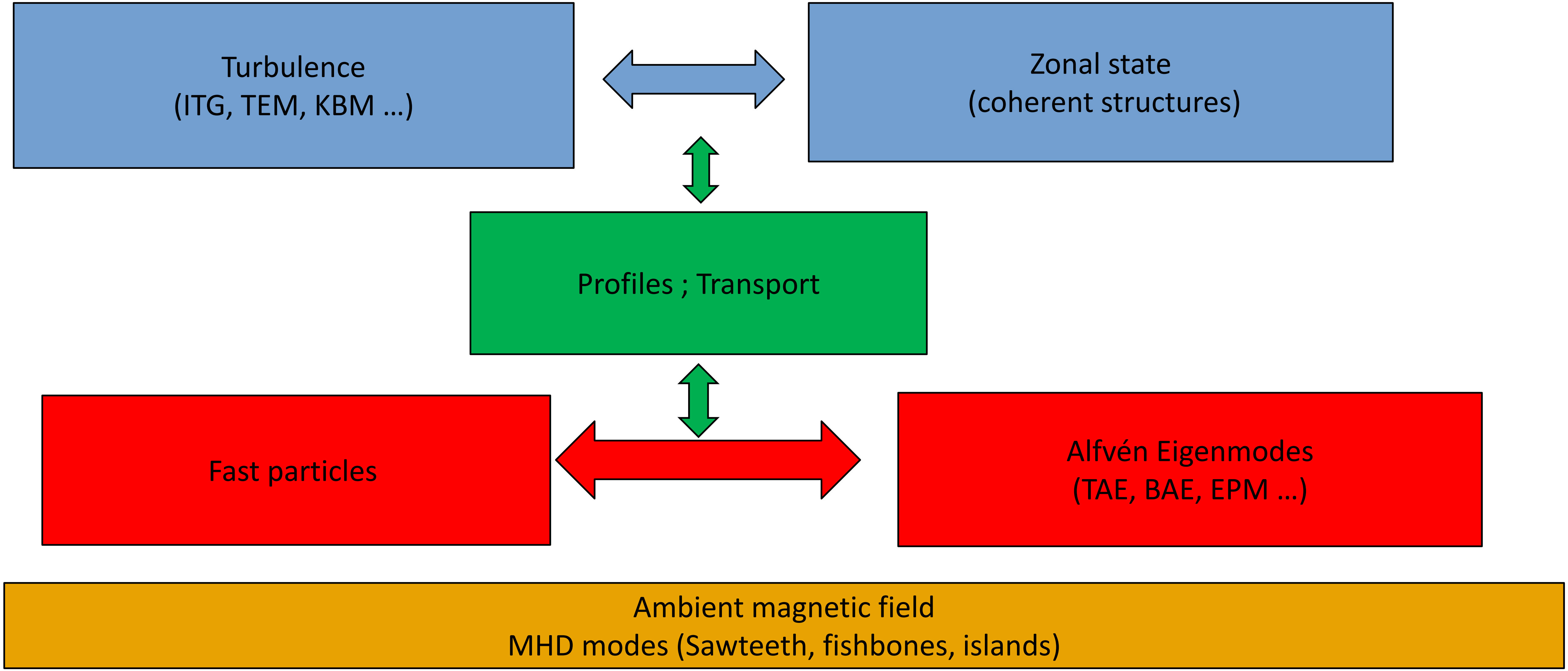


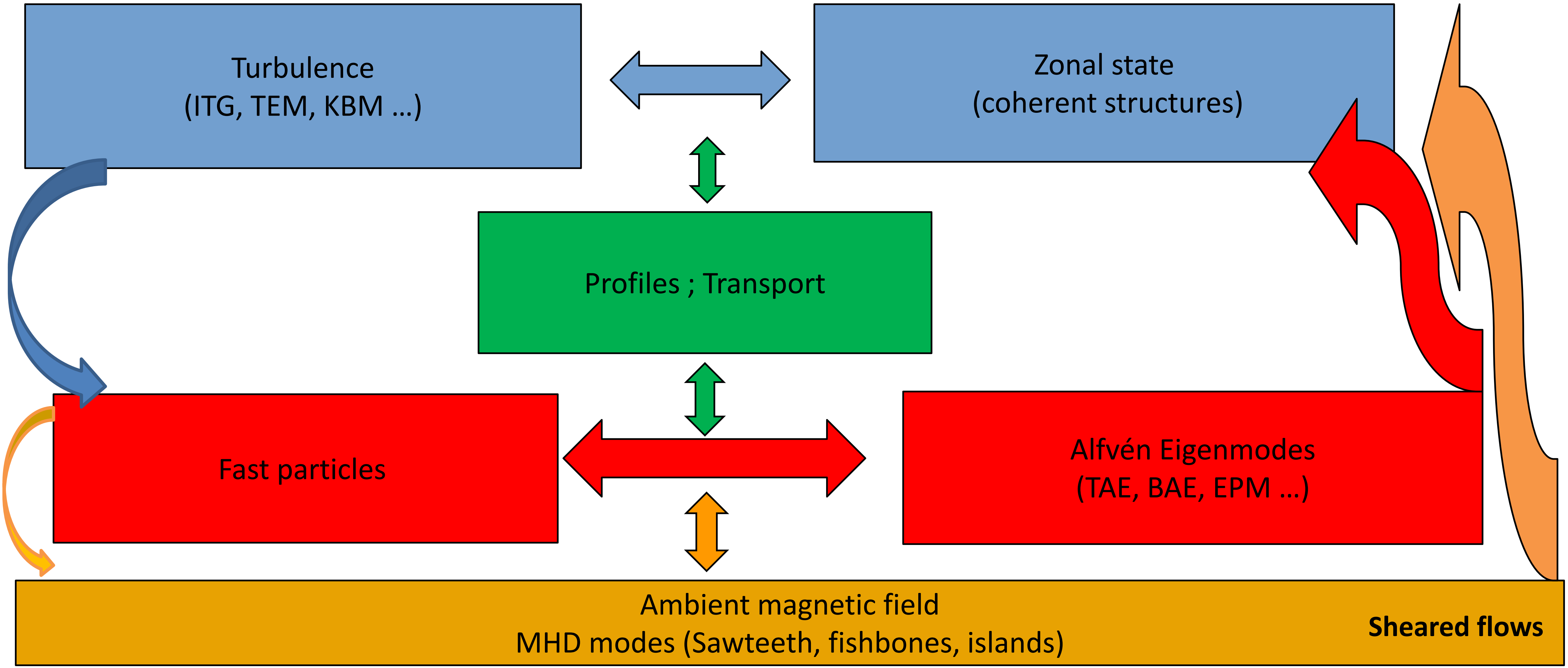

DT JET #99896: ICRF heating added at t ~ 7 s; confinement improvement and increased fusion reaction (fast ions).
Electromagnetic perturbations over a wide range of frequencies.
Heat transport significantly reduced because of the energetic-particle driven instabilities.

J. Garcia, Y. Kazakov, R. Coelho et al, Nature Communications [2024]

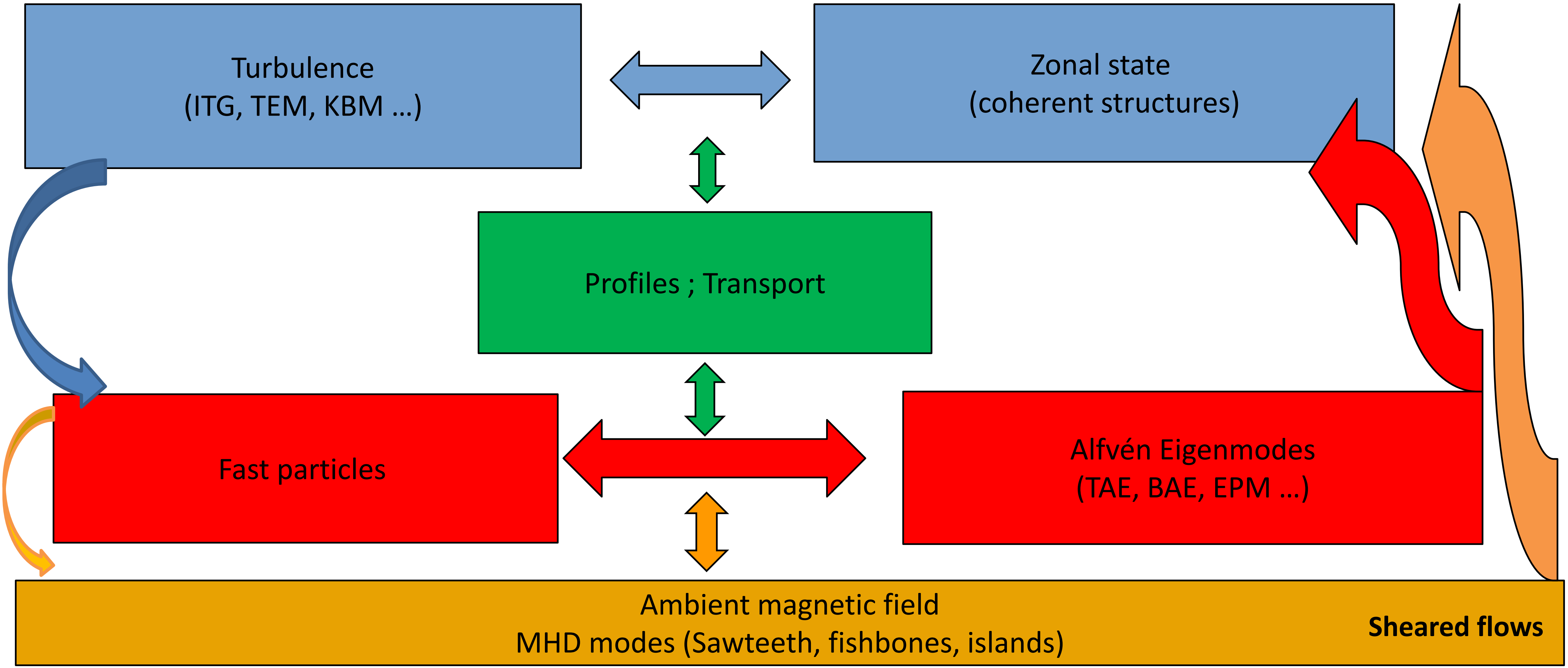
# Synergies and couplings



# Synergies and couplings



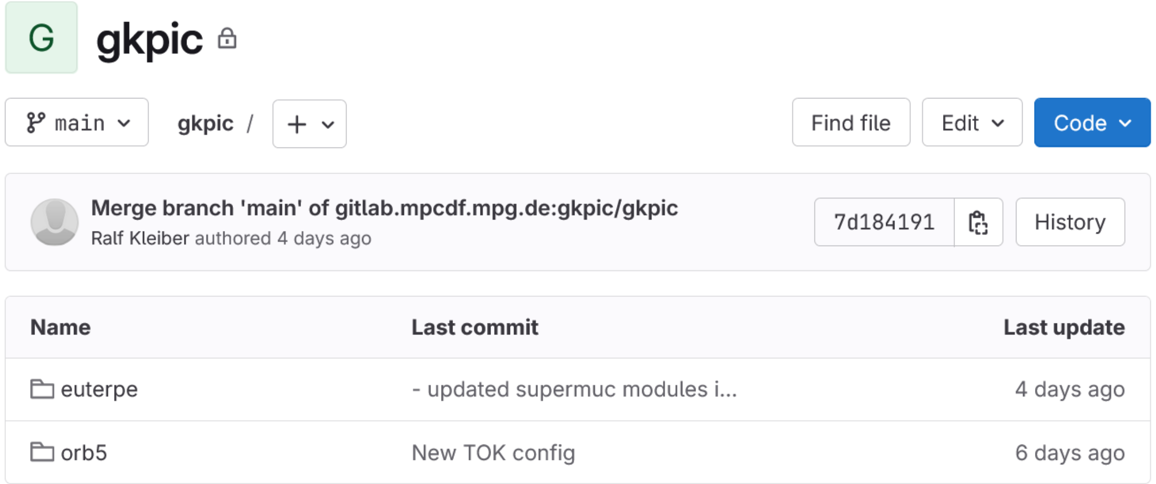
# Burning plasmas: complex interconnected system




Global NL gyrokinetic theory is a minimal inclusive description

# Gyrokinetic codes: ORB5 and EUTERPE codes

- Global nonlinear gyrokinetic particle-in-cell codes
- Electromagnetic, kinetic electrons, collision operators
- Arbitrary-wavelength solver, model for $\delta B_{||}$ available
- Both codes started at SPC EPFL Lausanne, closely related
- EUTERPE developed specifically for stellarator research
- Codes are supported by EUROfusion (e.g. E-TASC)
- Since June 2025: joint project, single repository
- The codes can further converge to a single codebase




ORB5-EUTERPE community (EU)


Developers and users in many EU fusion sites
Contributions from India (IPR) and Ukraine

**Crucial role played by EUROfusion!**
(ENR projects 2014-2024, TSVV-10)

# Cancellation problem

**„Symplectic“ formulation of gyrokinetics:**

$$\Gamma = q\boldsymbol{A}^* \cdot \mathrm{d}\boldsymbol{R} + \frac{B}{\Omega}\mu\,\mathrm{d}\theta + \langle A_\parallel\rangle \boldsymbol{b}\cdot\mathrm{d}\boldsymbol{R} - \left(\frac{mv_\parallel^2}{2} + \mu B + q\langle\phi\rangle\right)\mathrm{d}t$$

Problem: time derivative in equations of motion

$$\dot{v}_\parallel = -\frac{1}{m_s}\tilde{\boldsymbol{b}}^* \cdot \mu\nabla B - \frac{q_s}{m_s}\left(\tilde{\boldsymbol{b}}^* \cdot \nabla\langle\phi\rangle + \frac{\partial\left\langle A_\parallel\right\rangle}{\partial t}\right)$$

Not suitable for explicit solvers! Implicit too costly.

**Solution: mixed-variable formulation:**

$$A_\parallel = A_\parallel^{(\mathrm{s})} + A_\parallel^{(\mathrm{h})}$$ (split the magnetic potential)

$$\Gamma = q\boldsymbol{A}^* \cdot \mathrm{d}\boldsymbol{R} + \frac{m}{q}\mu\,\mathrm{d}\theta + q\left\langle A_\parallel^{(\mathrm{s})}\right\rangle \boldsymbol{b}\cdot\mathrm{d}\boldsymbol{R} - \left[\frac{mv_\parallel^2}{2} + \mu B + q\left\langle\phi - v_\parallel A_\parallel^{(\mathrm{h})}\right\rangle\right]\mathrm{d}t$$

$$\frac{\partial}{\partial t}A_\parallel^{(\mathrm{s})} + \boldsymbol{b}\cdot\nabla\phi = 0$$ (use new „freedom degree“)

[Mishchenko et al, PoP 2017]

**„Hamiltonian“ formulation of gyrokinetics:**

$$\Gamma = q\boldsymbol{A}^* \cdot \mathrm{d}\boldsymbol{R} + \frac{B}{\Omega}\mu\,\mathrm{d}\theta - \left(\frac{mp_\parallel^2}{2} + \mu B + q\left\langle\phi - p_\parallel A_\parallel\right\rangle\right)\mathrm{d}t$$

Problem: „fictitious“ terms in Ampere‘s law

$$\sum_{s=\mathrm{i,e,f}} \frac{\beta_s}{\rho_s^2}\langle\overline{A}_\parallel\rangle_s - \nabla_\perp^2 A_\parallel = \mu_0 \sum_{s=\mathrm{i,e,f}} j_{\parallel 1s}$$

These terms result from „adiabatic distribution function“

$$\bar{H}_1 = q_s\left\langle\phi - v_\parallel A_\parallel\right\rangle\ , \quad F_{\mathrm{e}}^{(\mathrm{ad})} = F_{0\mathrm{e}}\,\mathrm{e}^{-\bar{H}_1/T_{\mathrm{e}}} - F_{0\mathrm{e}} \approx -\frac{q_{\mathrm{e}}F_{0\mathrm{e}}}{T_{\mathrm{e}}}\left\langle\phi - v_\parallel A_\parallel\right\rangle$$

They correspond to the „adiabatic current“

$$\mu_0 \bar{j}_{\parallel s}^{(\mathrm{ad})} = \mu_0 q_s \int v_\parallel F_s^{(\mathrm{ad})}\mathrm{d}^3v = \frac{\mu_0 n_{0s} q_s^2}{m_s}A_\parallel = \frac{\beta_s}{\rho_s^2}A_\parallel$$

These „fictitious“ terms must cancel
(they do analytically)
Numerically: skin term is on grid;
current represented by particles

$$\frac{\beta_{\mathrm{e}}}{\rho_{\mathrm{e}}^2}A_\parallel = \frac{\mu_0 n_0 e^2}{m_{\mathrm{e}}}A_\parallel$$

Problem: „fictitious“ terms can be very large!

# Gyrokinetic equations in mixed-variables formulation

The equations include the gyrokinetic Vlasov equation:

$$\frac{\partial f_{1s}}{\partial t} + \dot{\boldsymbol{R}} \cdot \frac{\partial f_{1s}}{\partial \boldsymbol{R}} + \dot{v}_\parallel \frac{\partial f_{1s}}{\partial v_\parallel} = -\dot{\boldsymbol{R}}^{(1)} \cdot \frac{\partial F_{0s}}{\partial \boldsymbol{R}} - \dot{v}_\parallel^{(1)} \frac{\partial F_{0s}}{\partial v_\parallel} \,, \qquad (1)$$

the equations for the gyro-center orbits:

$$\dot{\boldsymbol{R}} = \dot{\boldsymbol{R}}^{(0)} + \dot{\boldsymbol{R}}^{(1)} \,, \quad \dot{v}_\parallel = \dot{v}_\parallel^{(0)} + \dot{v}_\parallel^{(1)} \qquad (2)$$

$$\dot{\boldsymbol{R}}^{(0)} = v_\parallel \boldsymbol{b}_0^* + \frac{1}{qB_\parallel^*} \boldsymbol{b} \times \mu \nabla B \,, \quad \dot{v}_\parallel^{(0)} = -\frac{\mu}{m} \boldsymbol{b}_0^* \cdot \nabla B \qquad (3)$$

$$\dot{\boldsymbol{R}}^{(1)} = \frac{\boldsymbol{b}}{B_\parallel^*} \times \nabla \left\langle \phi - v_\parallel A_\parallel^{(\mathrm{s})} - v_\parallel A_\parallel^{(\mathrm{h})} \right\rangle - \frac{q}{m} \langle A_\parallel^{(\mathrm{h})} \rangle \boldsymbol{b}_0^* \qquad (4)$$

$$\dot{v}_\parallel^{(1)} = -\frac{q}{m} \left[ \boldsymbol{b}^* \cdot \nabla \left\langle \phi - v_\parallel A_\parallel^{(\mathrm{h})} \right\rangle + \frac{\partial}{\partial t} \left\langle A_\parallel^{(\mathrm{s})} \right\rangle \right] - \frac{\mu}{m} \frac{\boldsymbol{b} \times \nabla B}{B_\parallel^*} \cdot \nabla \left\langle A_\parallel^{(\mathrm{s})} \right\rangle \qquad (5)$$

$$\boldsymbol{b}^* = \boldsymbol{b}_0^* + \frac{\nabla \langle A_\parallel^{(\mathrm{s})} \rangle \times \boldsymbol{b}}{B_\parallel^*} \,, \quad \boldsymbol{b}_0^* = \boldsymbol{b} + \frac{m v_\parallel}{q B_\parallel^*} \nabla \times \boldsymbol{b} \qquad (6)$$

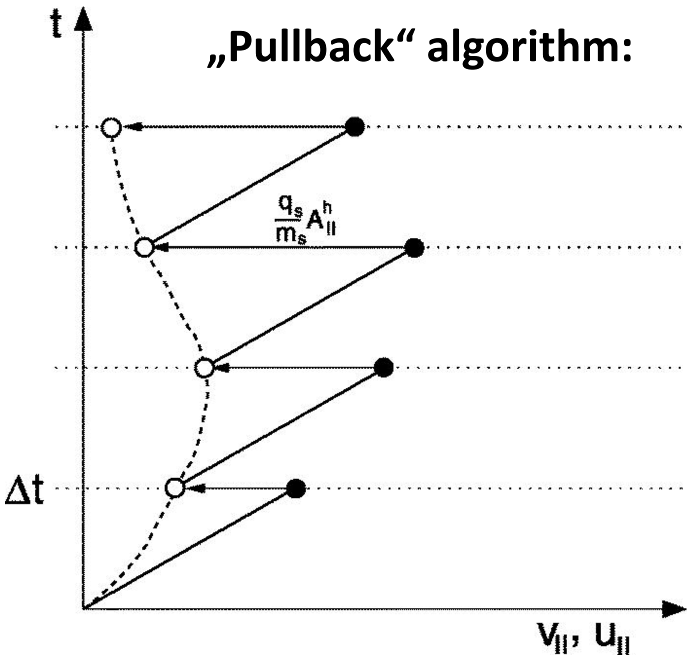
$$B_\parallel^* = B + \frac{m v_\parallel}{q} \boldsymbol{b} \cdot \nabla \times \boldsymbol{b} \,, \qquad (7)$$

**Field equations**:

$$-\nabla \cdot \left( \frac{n_0}{B\omega_{ci}} \nabla_\perp \phi \right) = \bar{n}_{1i} - \bar{n}_{1e}$$

$$\frac{\partial}{\partial t} A_\parallel^{(\mathrm{s})} + \boldsymbol{b} \cdot \nabla \phi = 0 \,, \qquad \sum_{s=i,e} \frac{\beta_s}{\rho_s^2} A_\parallel^{(\mathrm{h})} - \nabla_\perp^2 A_\parallel^{(\mathrm{h})} = \mu_0 \sum_{s=i,e} \bar{j}_{\parallel 1s} + \nabla_\perp^2 A_\parallel^{(\mathrm{s})}$$

## „Pullback“ algorithm:




At the end of every time step:

1) re-split magnetic potential

$$A_{\parallel(\mathrm{new})}^{(\mathrm{s})}(t_i) = A_\parallel(t_i) = A_{\parallel(\mathrm{old})}^{(\mathrm{s})}(t_i) + A_{\parallel(\mathrm{old})}^{(\mathrm{h})}(t_i)$$

$$A_{\parallel(\mathrm{new})}^{(\mathrm{h})}(t_i) = 0$$

2) re-define markers

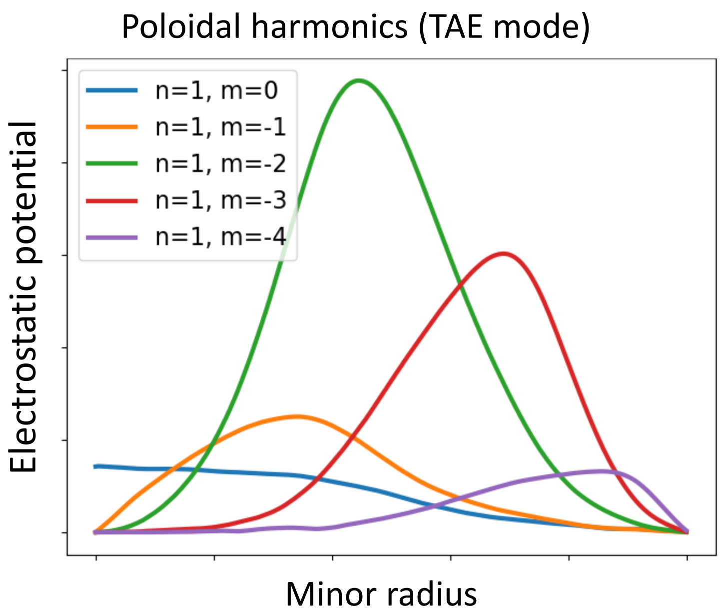
$$f_1^{(\mathrm{s})}(Z^{(\mathrm{s})}, A_\parallel) = f_1^{(\mathrm{m})}(Z^{(\mathrm{m})}, A_\parallel^{(s)}, A_\parallel^{(h)})$$

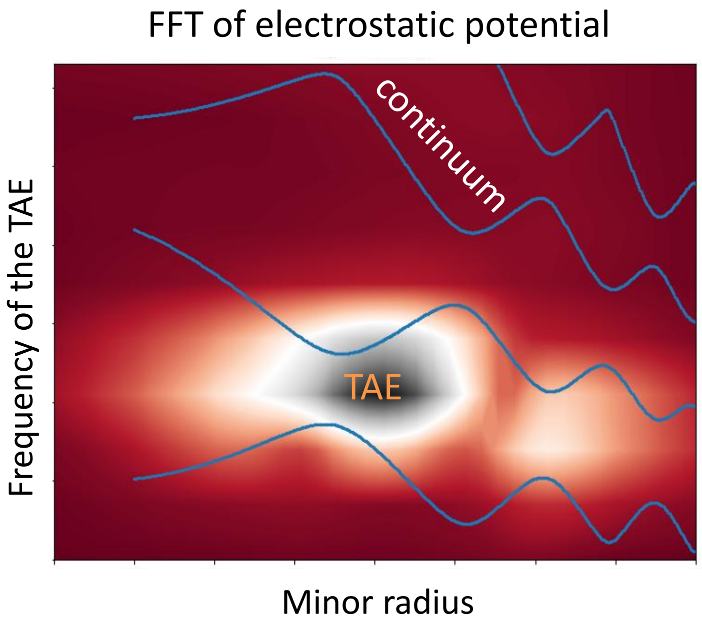
$$v_\parallel^{(\mathrm{s})} = v_\parallel^{(\mathrm{m})} - \frac{e}{m} \left\langle A_\parallel^{(\mathrm{h})} \right\rangle$$

[Mishchenko et al, PPCF 2021]

# Gyrokinetic simulations of chirping instabilities: wave-particle nonlinearity

ORB5



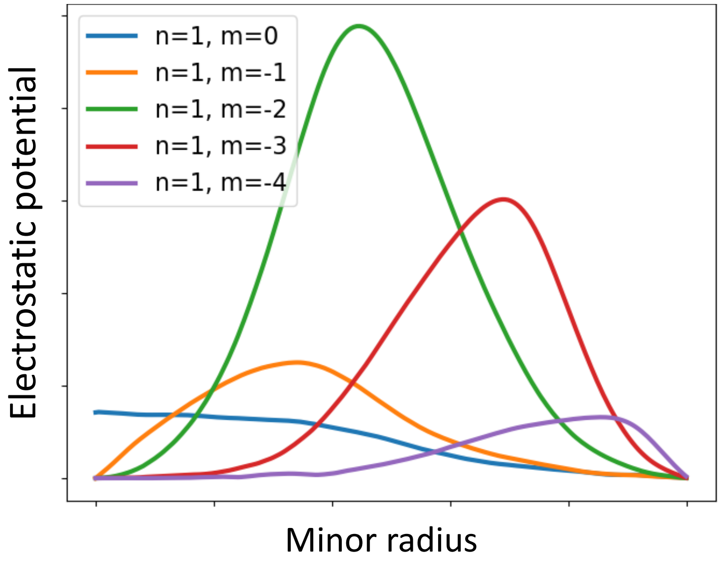

Energetic-particle driven TAE/EPM instabilities in TCV-shaped tokamak.

Coupled poloidal harmonics m = -2 and m = -3. Eigenmode frequency in the toroidal gap.

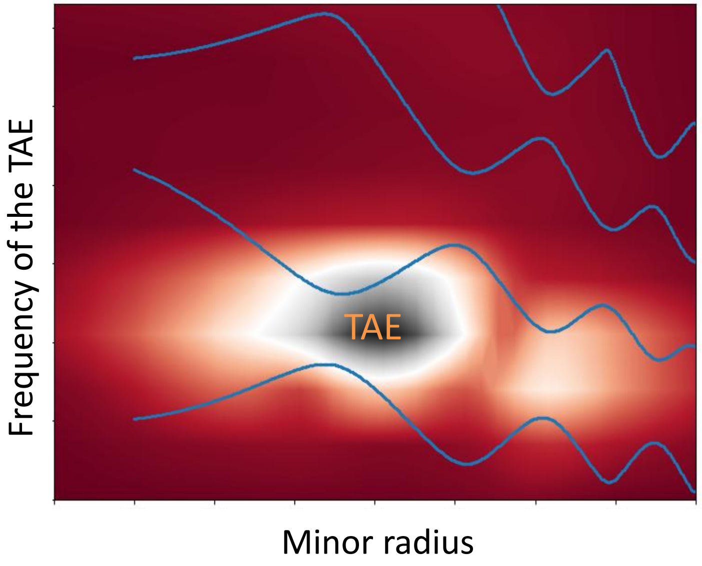
# Gyrokinetic simulations of chirping instabilities: wave-particle nonlinearity

**ORB5**

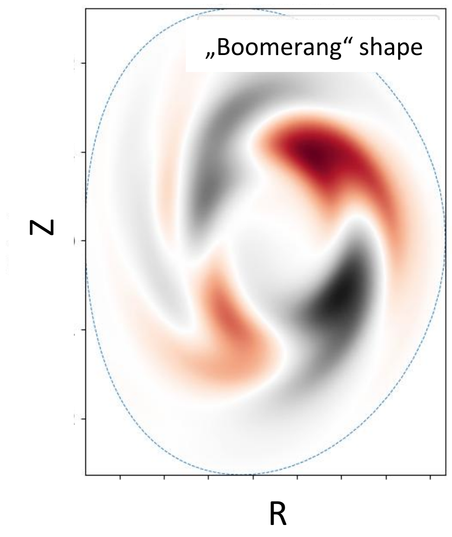
Poloidal harmonics (TAE mode)

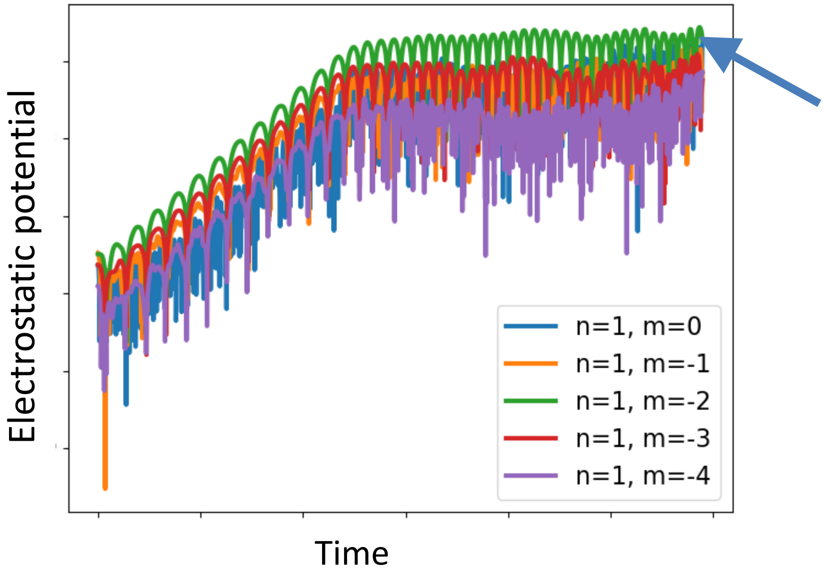



FFT of electrostatic potential




Electrostatic potential




Energetic-particle driven TAE/EPM instabilities in TCV-shaped tokamak.

Coupled poloidal harmonics m = -2 and m = -3. Eigenmode frequency in the toroidal gap.

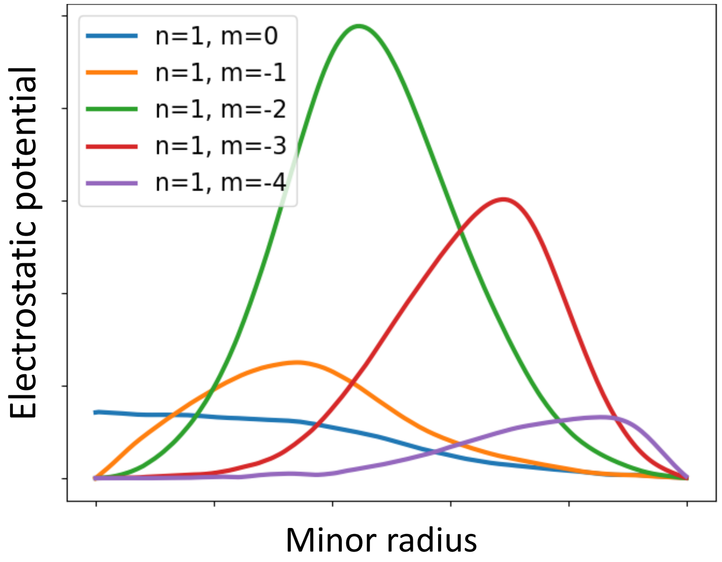
“Boomerang” shape of 2D mode structure caused by energetic-particle resonant response.

Saturation amplitude of the instability determines energetic-particle transport.

# Gyrokinetic simulations of chirping instabilities: wave-particle nonlinearity

**ORB5**

Poloidal harmonics (TAE mode)

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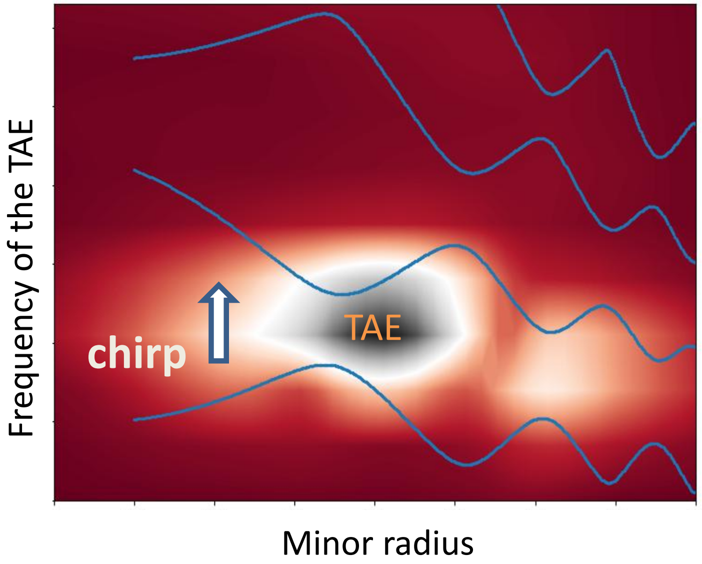


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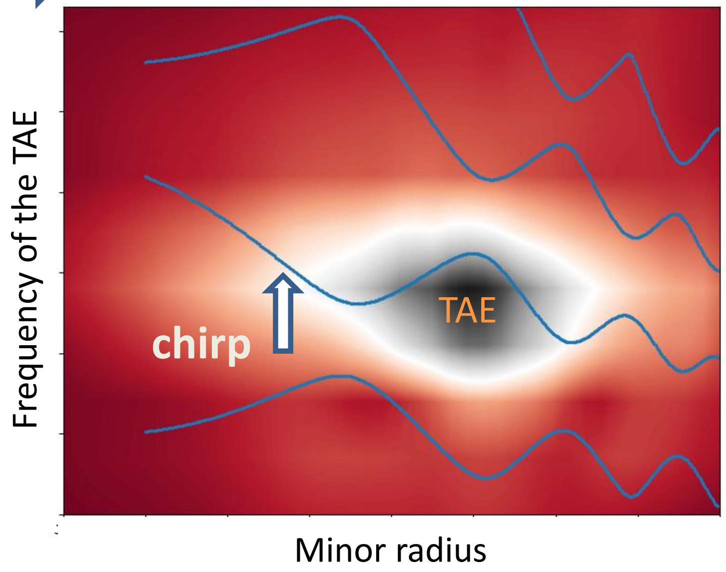
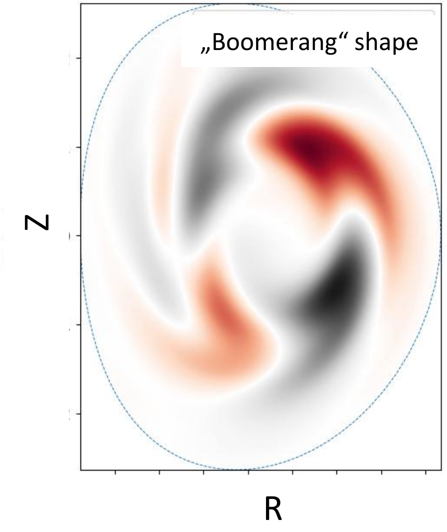
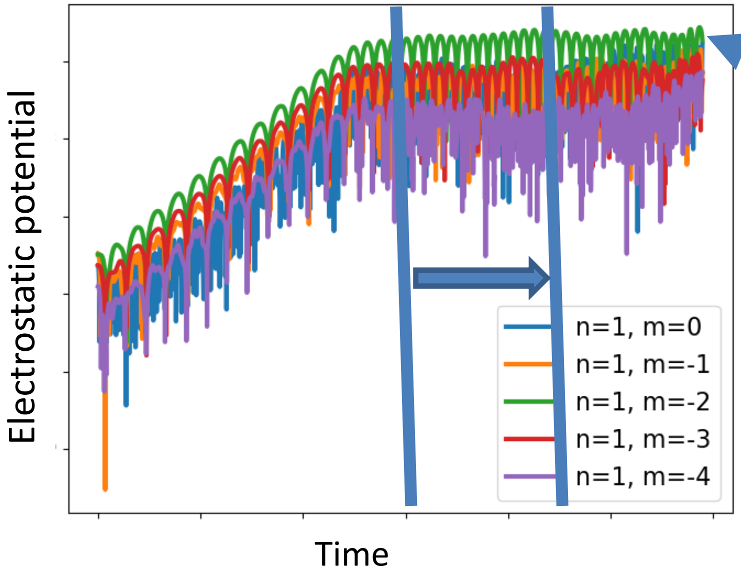



Electrostatic potential



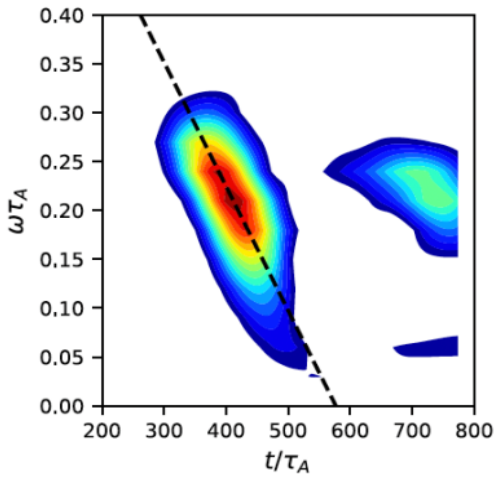

Saturation amplitude of the instability determines energetic-particle transport.

Chirping dynamics is observed for mode frequency: phase-space structures.

# Gyrokinetic simulations of chirping instabilities: wave-particle nonlinearity

**ORB5**

Comprehensive studies of the nonlinear frequency on Alfven modes driven by fast ions.
A large number of global gyrokinetic simulations performed with ORB5.
Plasma parameterers, energetic-particle parameters varied. Chirping rate follows universal dependency.

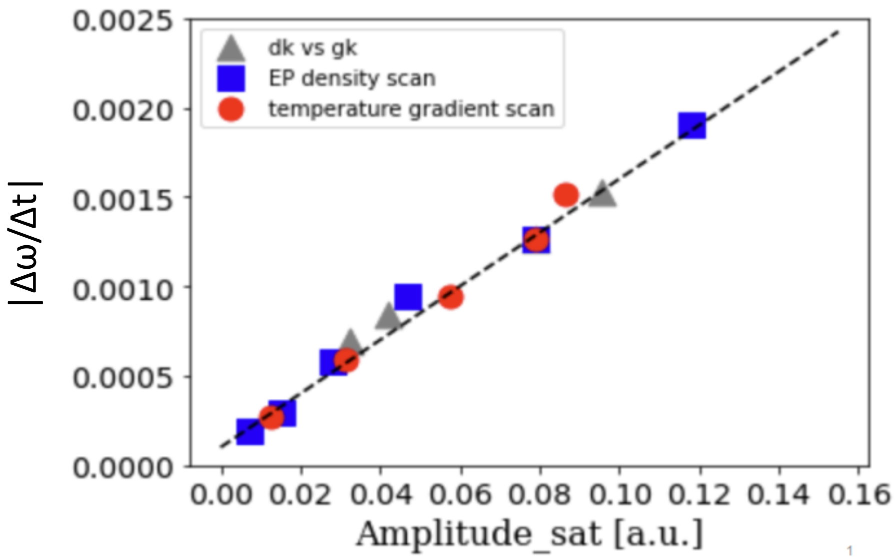



Time evolution of the mode frequency

various parameter scans to map chirping rate vs saturation amplitude

Energetic particle density, energy, …

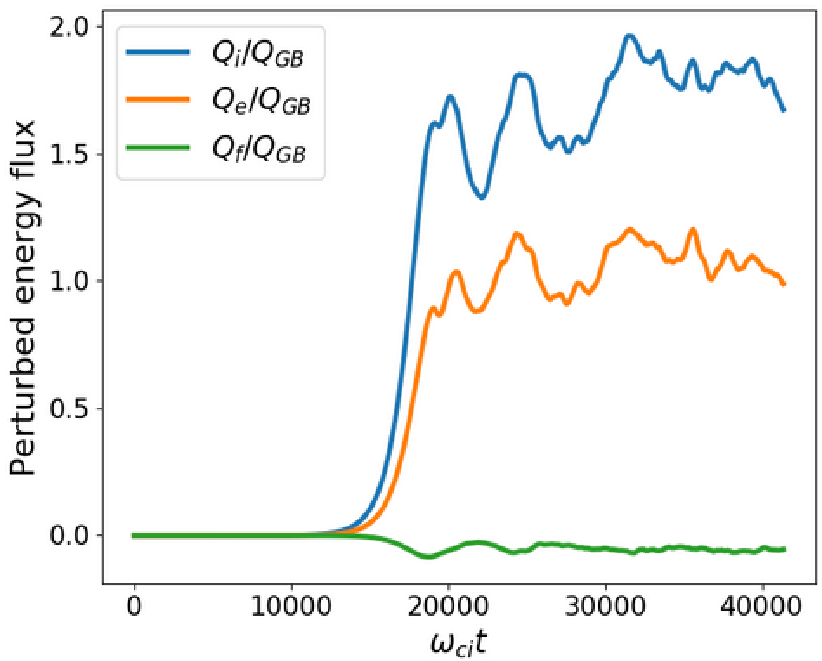
$\Delta\omega/\Delta t \sim A_{sat}$

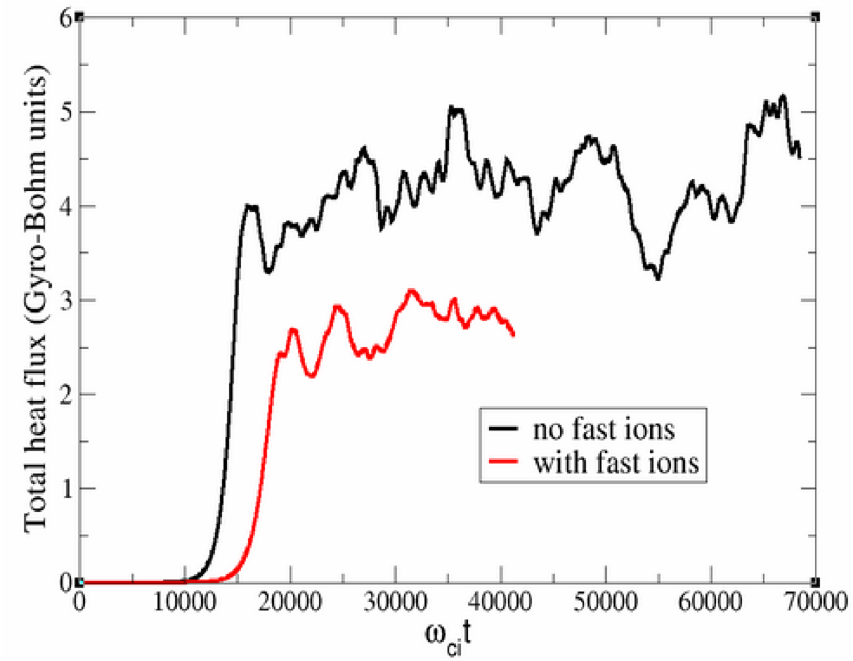


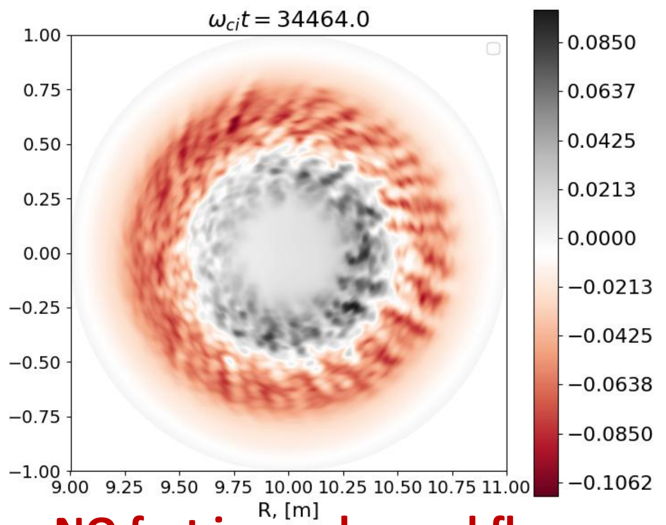

**Theory compared to simulations (verification):** chirping modes in presence of energetic particles. Chirping rate from simulations is proportional to saturation amplitude (as predicted theoretically, [Zonca et al., Varenna Conf. 2024])

# ORB5 code: effect of fast ions on core plasma energy confinement

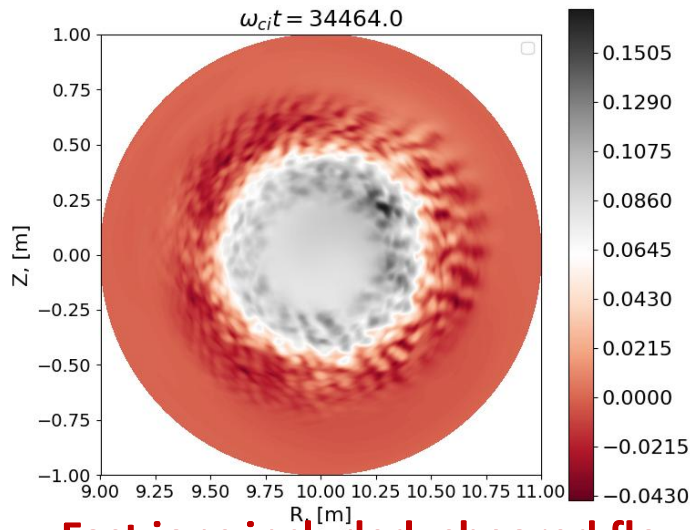
## ORB5




**NO fast ions: sheared flow**




**Fast ions included: sheared flow**

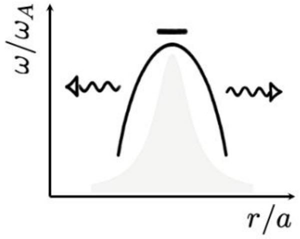
For $\boldsymbol{\beta_e = 0.1\%}$, fast-ion heat flux is small.

Total heat flux reduced by the fast ions!

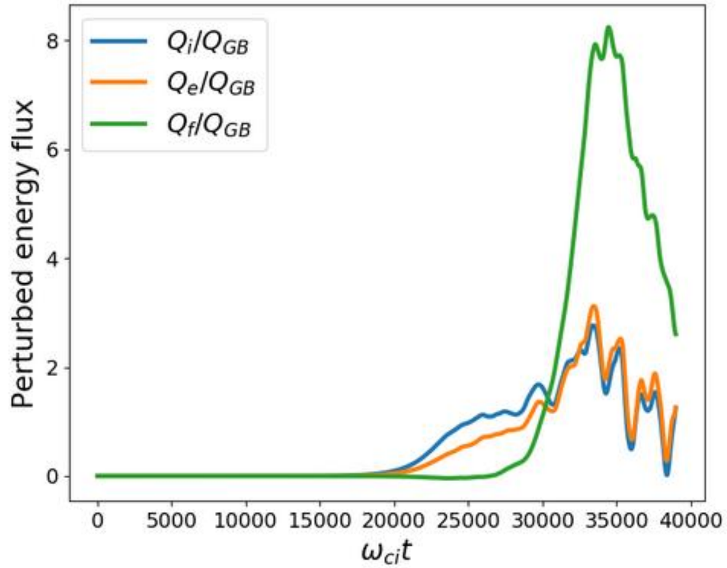
<u>Nonlinear gyrokinetic simulations with ORB5 code demonstrate clear fast-particle reduction in the heat flux for both the bulk ions and the electrons</u> (in agreement with earlier flux-tube results) $\boldsymbol{\beta_e = 0.1\%}$

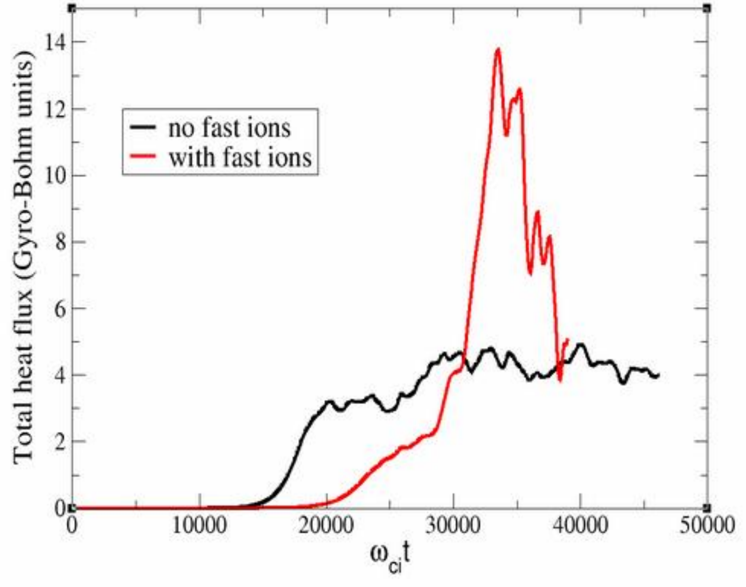
# ORB5 code: effect of fast ions on core plasma confinement

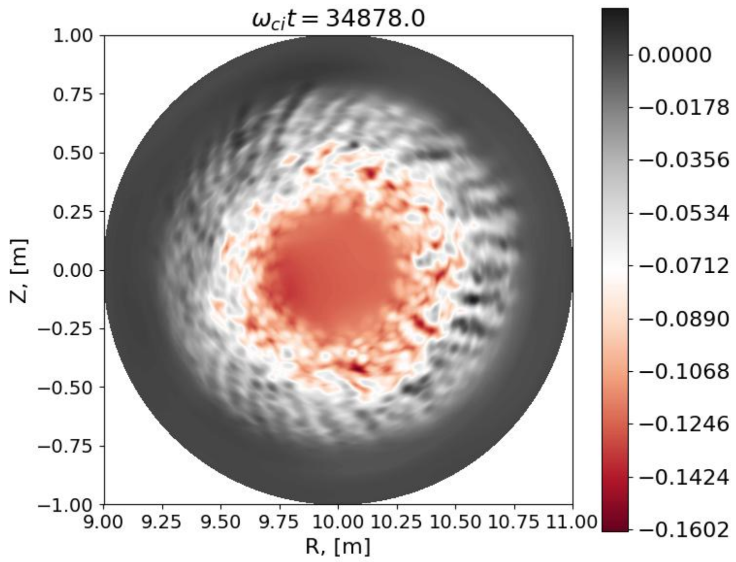
- For $\boldsymbol{\beta_e = 0.24\%}$, the dynamics is different. Fast ion heat flux is substantial. Total heat flux is not reduced
- Global Alfvenic mode (a BAE) develops driving fast ion energy flux. Work in progress!
- Properties of the Zonal State become increasingly more global as plasma $\beta$ is increased
- Mesoscale phenomena, such as kinetic Alfvén wave propagation, need to be captured for a correct description of the plasma dynamics

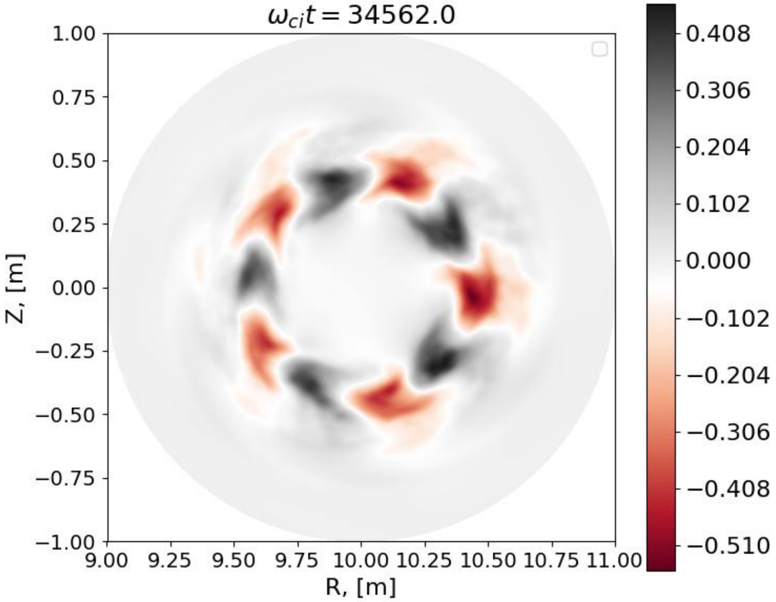



**ORB5**



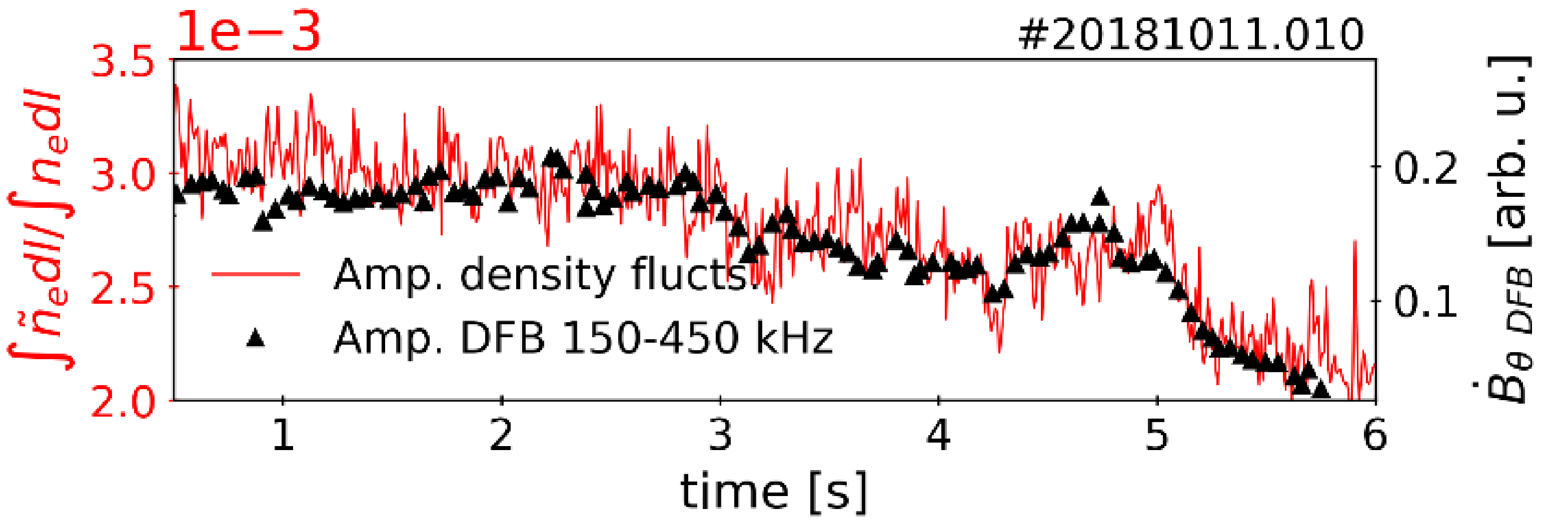




**No fast ions: sheared flow**

**Fast ions included: global (BAE) mode**

# Experiment: Alfvénic Modes and Electromagnetic Turbulence in Wendelstein 7-X



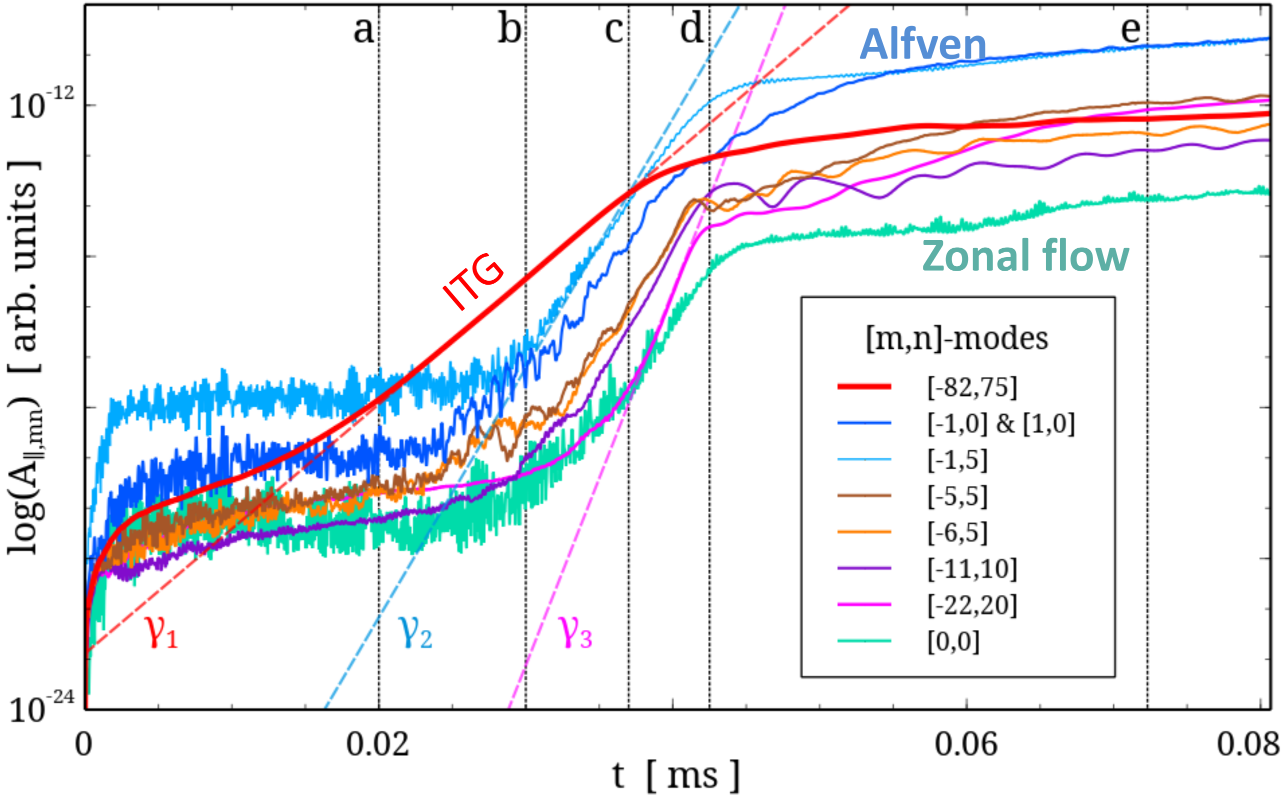

**Experimental Results:**

- predominant ITG turbulence observed in W7-X
- distinctive Alfvénic frequency band is often seen

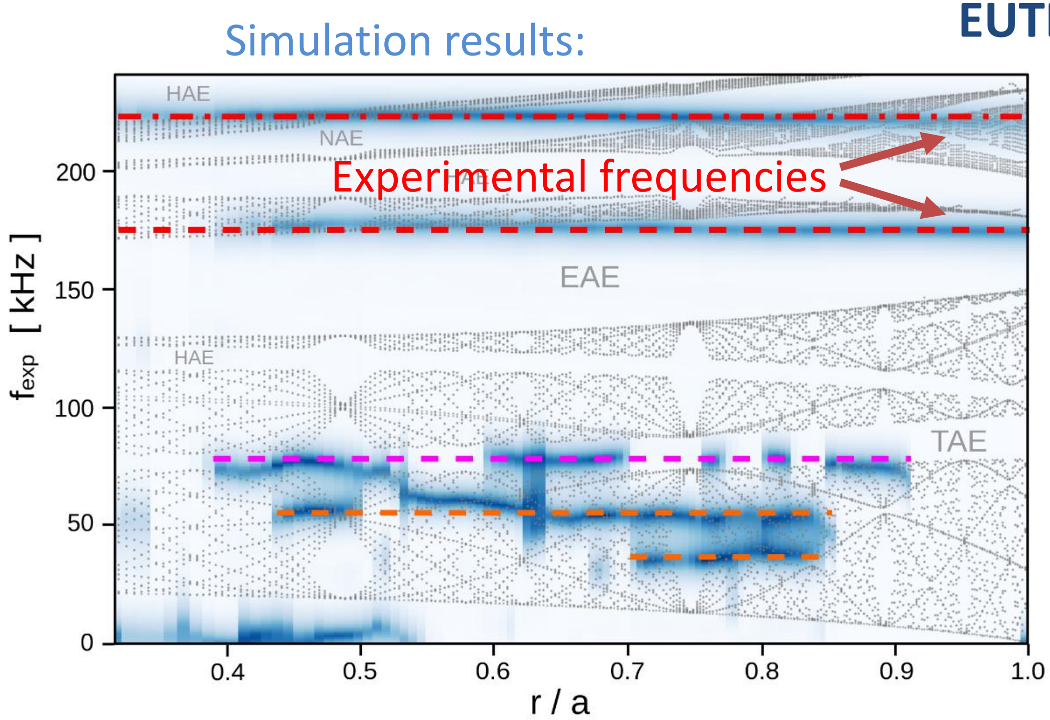
- temporal evolution of turbulence (PCI) and magnetic fluctuations (Mirnov) is very similar over entire discharges
- Alfvénic fluctuation amplitudes and turbulence level are correlated for many plasma discharges

**Hypothesis: Alfvénic fluctuations are nonlinearly driven by ITG turbulence in W7-X.**

# Simulations: Alfvénic Modes and Electromagnetic Turbulence in Wendelstein 7-X




**EUTERPE**




- early ITG (high-m) activity
- Zonal Flow & Alfvénic modes when ITG amplitude has passed threshold
- growth rate cascade $\gamma_1 : \gamma_2 : \gamma_3 = \gamma : 2\gamma : 3\gamma$ (similar to "beat-driven" ZFs)

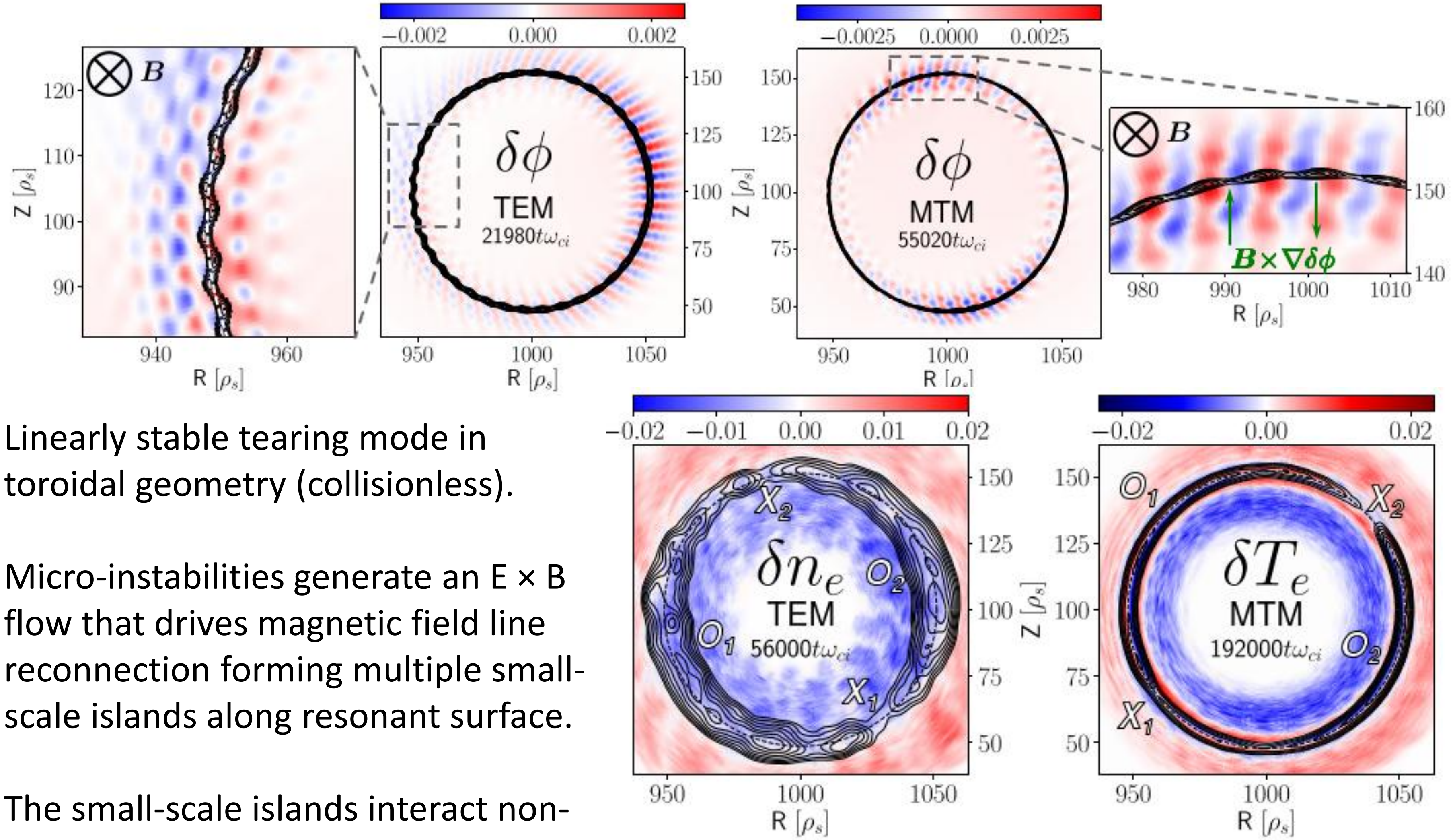
Gyrokinetic simulations recover experimental frequencies

The role of ITG activity:

1. ITG modes included in simulations → low-m Alfvénic modes nonlinearly excited
2. ITG modes excluded from simulations → low-m modes remain stable

# Turbulence-Driven Magnetic Islands in Toroidal Geometry

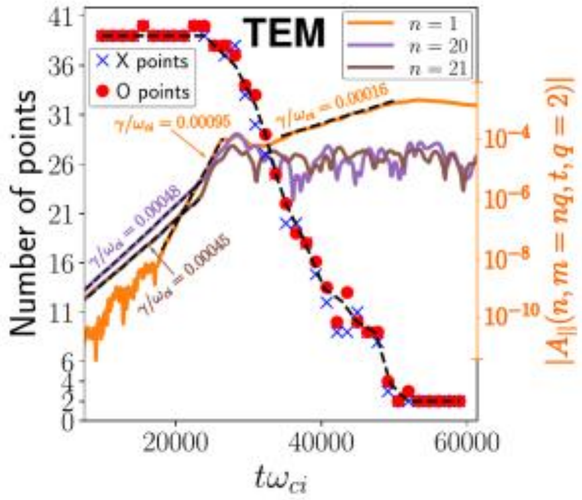
**ORB5**



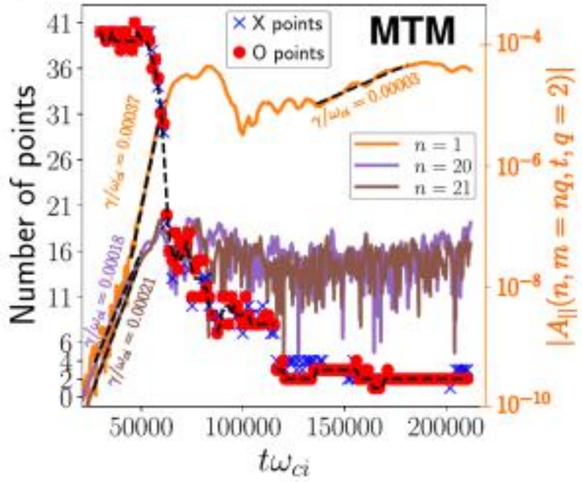

Linearly stable tearing mode in toroidal geometry (collisionless).

Micro-instabilities generate an E × B flow that drives magnetic field line reconnection forming multiple small-scale islands along resonant surface.

The small-scale islands interact non-linearly and eventually coalesce into a large-scale magnetic island.




(a) TEM case, $-R/L_n = 5$, $-R/L_{T_s} = 0$.

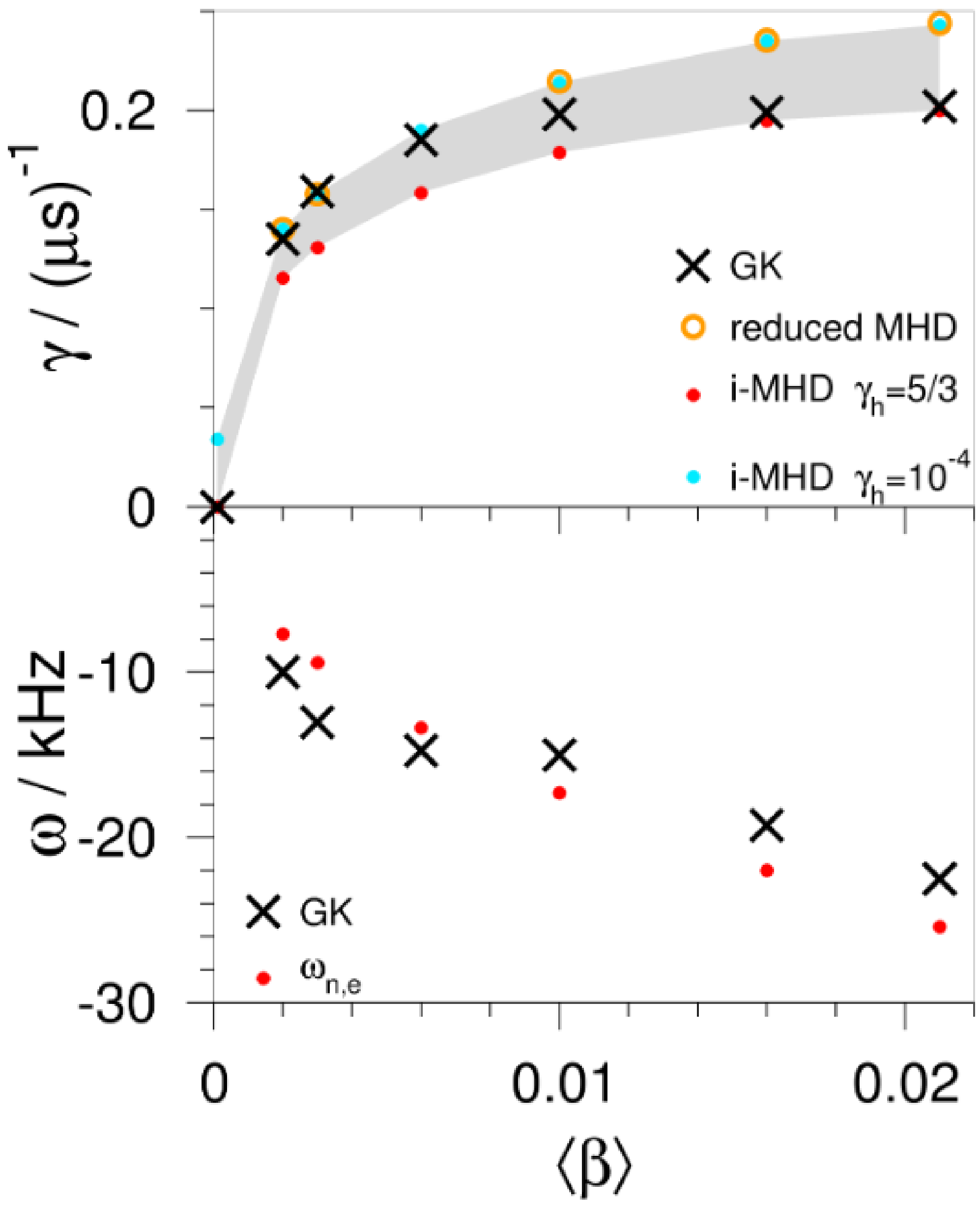


# Gyrokinetic simulations of MHD-unstable stellarator configurations

**EUTERPE**

- Consider 4-period stellarators:
  turning-ellipse configurations
- Choice: Mercier-unstable at finite β (not a reactor candidate)
- Perform full-torus GK simulations
- Find good agreement with MHD (CAS3D, CKA) in linear phase.

***First-ever benchmark of global MHD with global gyrokinetics in stellartors!***



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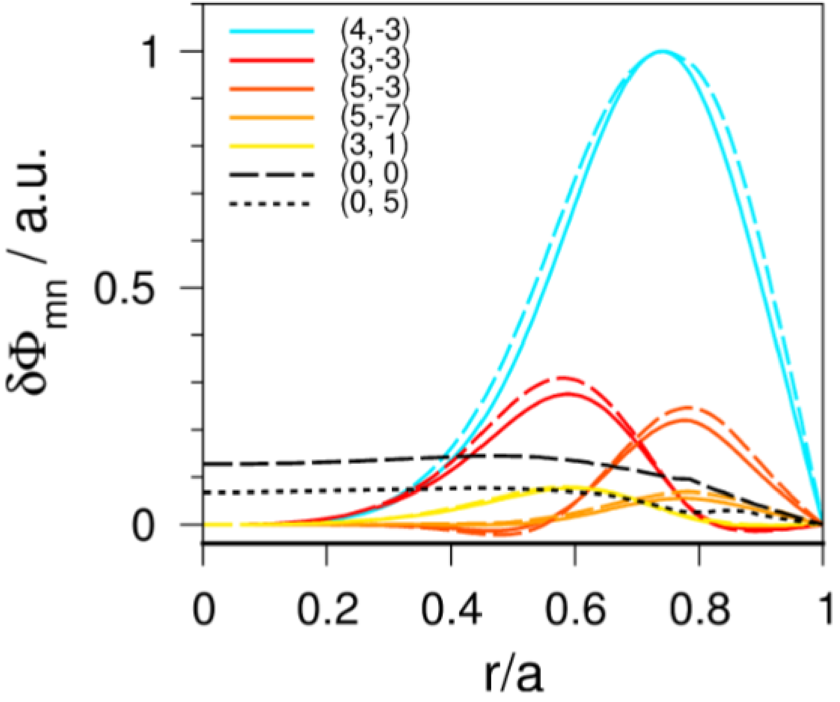
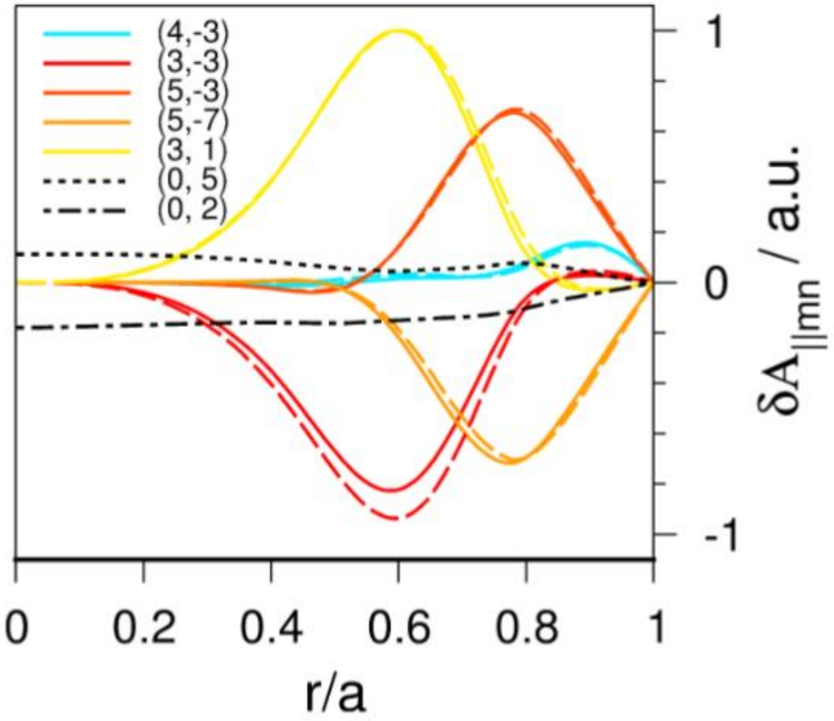



The ideal-MHD results (solid lines, $\gamma_h$ = 5/3), are compared to the gyrokinetic results (dashed).




**Very good agreement!**

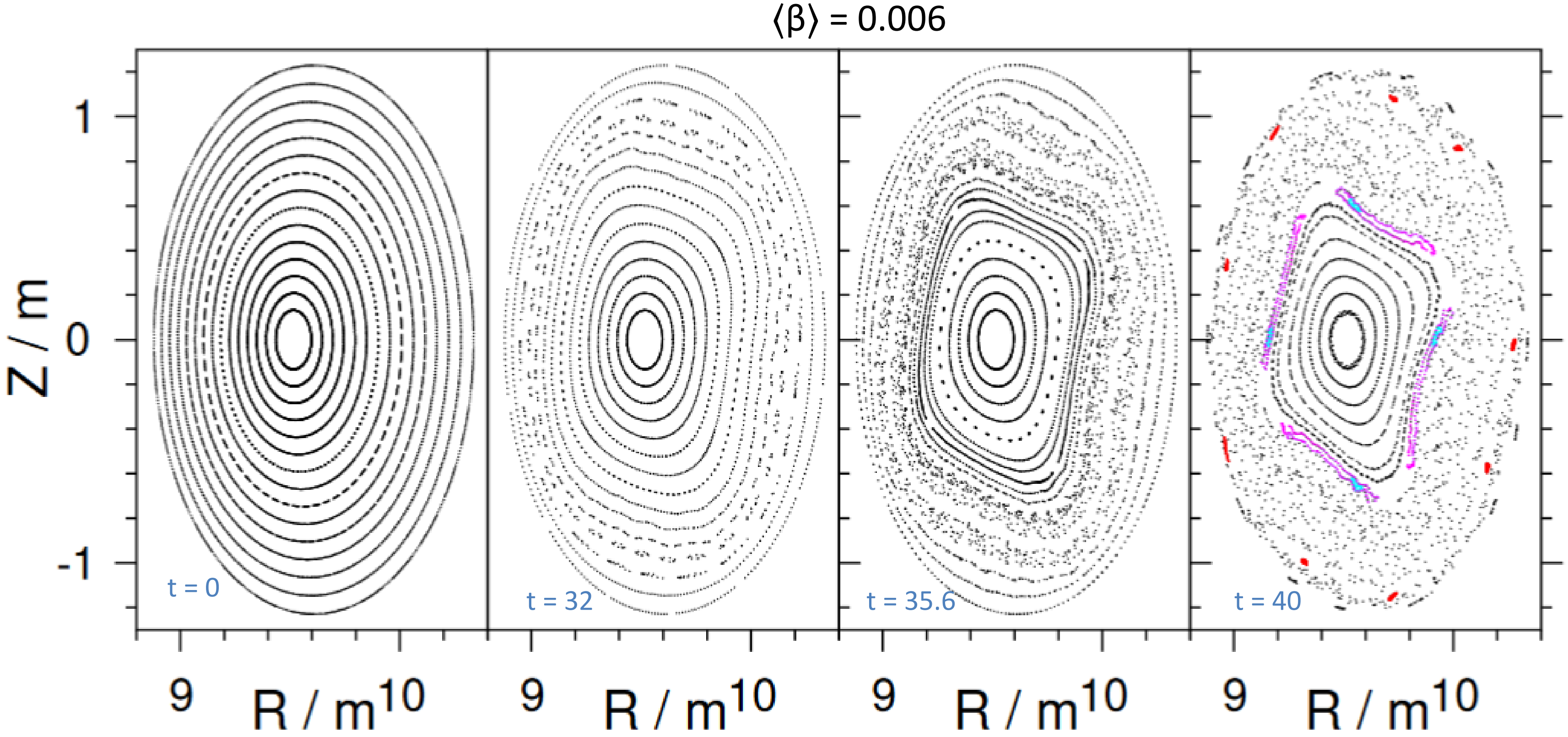
# Gyrokinetic simulations of MHD-unstable stellarator configurations

**EUTERPE**

Perturbed field-line tracing for GK magnetic field:
nonlinear growth of magnetic islands, ergodization

- Consider 4-period stellarator
- Choice: Mercier-unstable at finite β (not a reactor candidate)
- Perform full-torus GK simulations
- Find good agreement with MHD (CAS3D, CKA) in linear phase.

***First-ever benchmark of global MHD with global gyrokinetics in stellartors!***




**Soft decay of magnetic surfaces.**
**No disruptive dynamics!**
**Soft beta limit in stellarators.**

MHD instabilities in stellarator destroy flux surfaces.
Magnetic configuration is affected.

***First-ever fully gyrokinetic simulations of nonlinear MHD in stellarator plasmas!***

# Gyrokinetic simulations of turbulence in W7-X: magnetic configuration affected

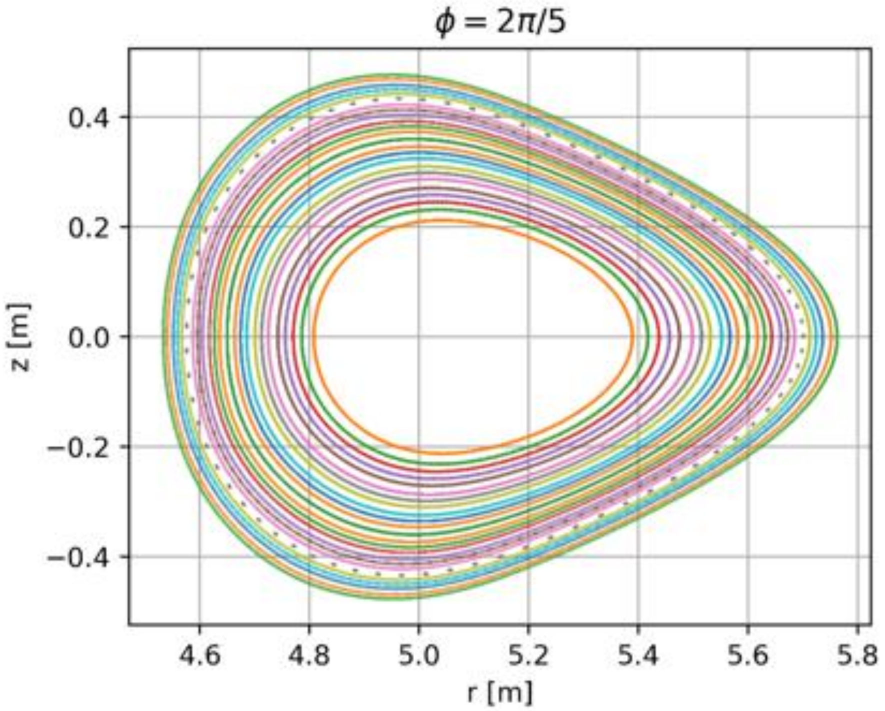
EM turbulence in Mercier-unstable W7-X configuration at β = 4%.

**EUTERPE**

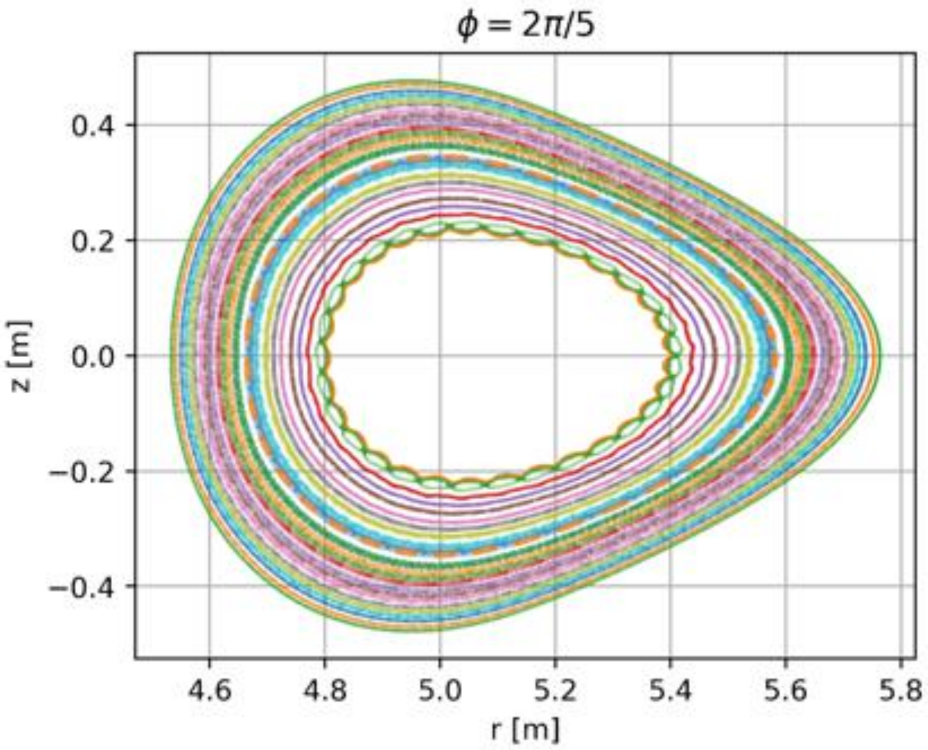
Turbulent evolution of total magnetic field (flux surfaces).

Turbulence leads to ergodization of flux surface.

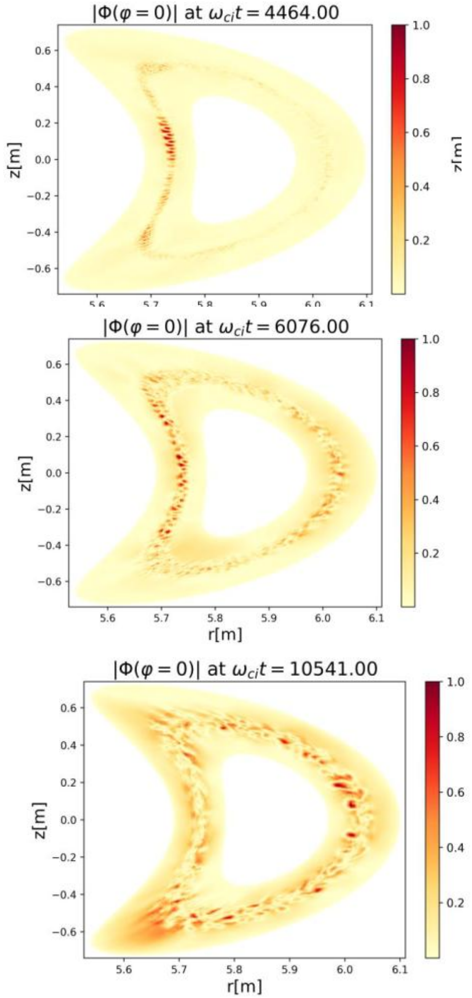
**Magnetic configuration is affected by EM turbulence.**




Linear phase




Noninear phase

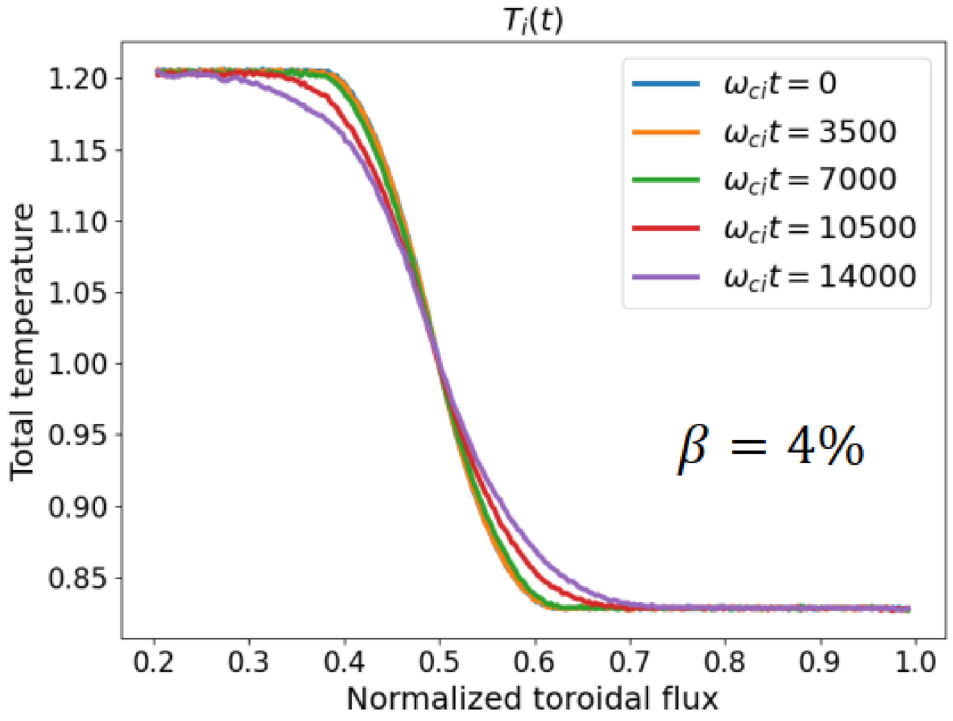


# Gyrokinetic simulations of turbulence in W7-X: magnetic configuration affected

EM turbulence in Mercier-unstable W7-X configuration at β = 4%.

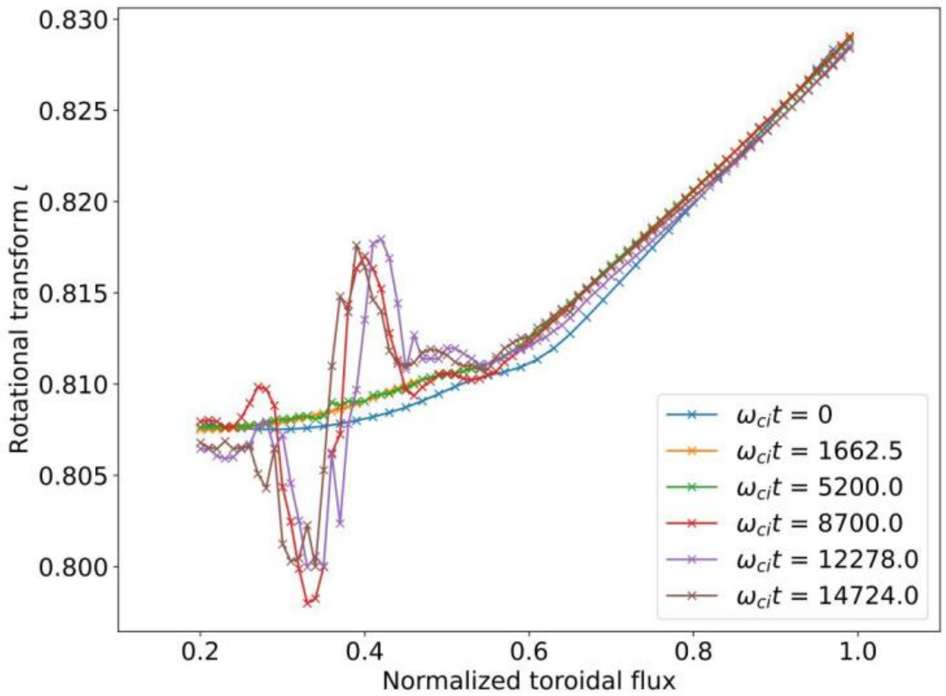
**EUTERPE**

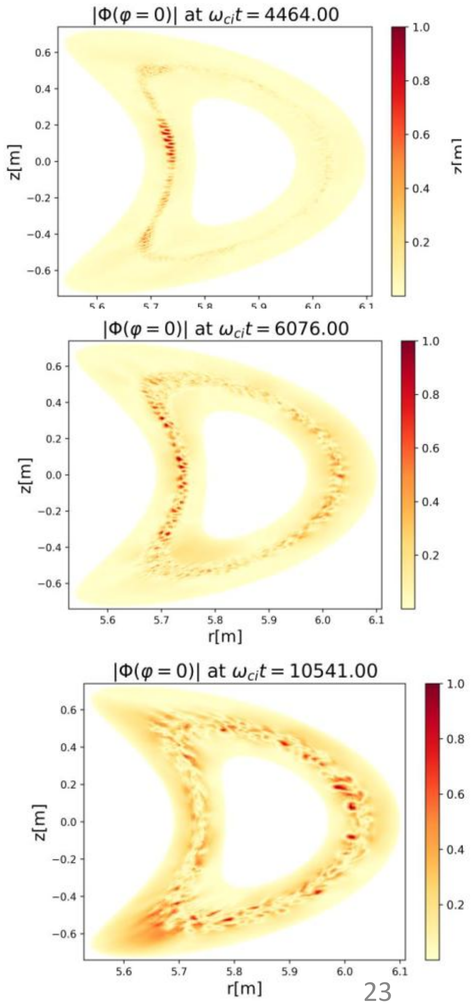
Turbulent evolution of temperature and safety factor profiles




Turbulence modifies rotation transform (safety factor).

**Magnetic configuration is affected by EM turbulence.**



# Conclusions

- Turbulence, zonal flows, Alfvénic modes, energetic particles, MHD-like perturbations coexist and affect each other
- Global nonlinear gyrokinetics is a minimal inclusive approach for this system
- ORB5 and EUTERPE codes provide such a framework; enabled by numerous improvements in algorithms
- First-in-kind simulations of nonlinear plasma evolution performed in tokamak and stellarator geometries
- Hybrid models (kinetic-fluid) and reduced models (quasilinear, PSZS) have also been developed
- EUROfusion software ecosystem will make a qualitative difference for future fusion reactor projects (public and private)

https://indico.euro-fusion.org/category/283/

## Outlook (TSVV-G):

**New contributors**: GYSELA and GENE in addition to ORB5/EUTERPE – all major GK codes represented; cooperation between teams, exchange of experience, favourable environment for scientific discovery
**Dissemination**: small associations (Greece and Ukraine) included in TSVV-G
**User communities for major codes (beyond TSVVs)**: XTOR-K, HYMAGYC, ORB5/EUTERPE, …

# Outlook: future steps for gyrokinetic codes (ORB5/EUTERPE, GENE, GYSELA)

Eulerian code GENE and semi-Lagrangian full-f code GYSELA join PIC codes ORB5/EUTERPE: verification and levereging each others strengths as elements of the overall EUROfusion (E-TASC) ecosystem

ORB5/EUTERPE applications:

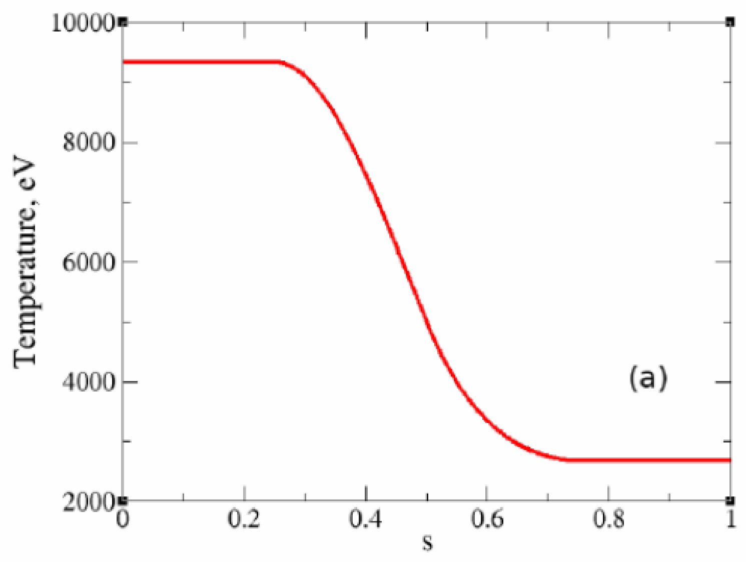
- Saturation amplitude studies using ORB5: AEs + EPs (+ turbulence)
- Effect of EPs/AEs on turbulence (e.g. via ZF generation): ORB5
- Kink/fishbone instability; effect of ZFs, interaction with turbulence: ORB5 and GENE
- Tearing instability and turbulence in tokamaks (turbulent cascades, island merging vs. island healing), in realistic geometry and including collisions: ORB5 and GENE
- Electromagnetic turbulence in stellarators, EP physics: EUTERPE

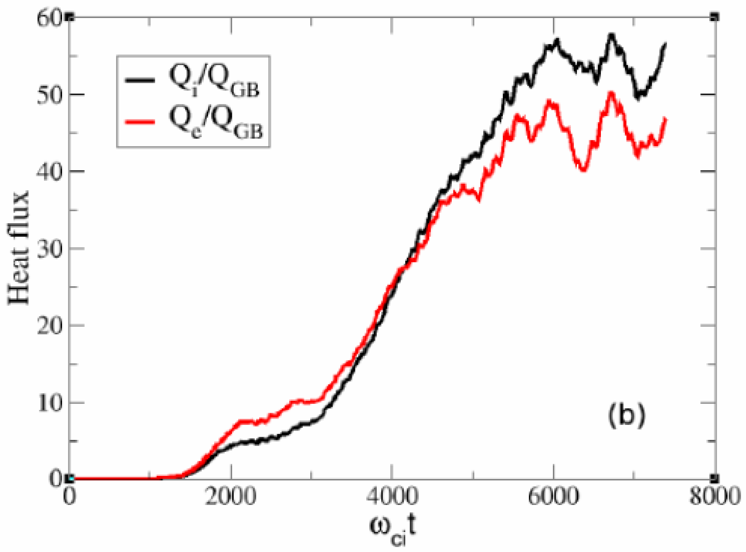
- ORB5/EUTERPE development:
  - adaptive control-variate in ORB5 (PSZS based, supported by neural networks)
  - Field-aligned finite elements in EUTERPE (collaboration with TRIMEG)
  - Further integration of the codes (already parts of a joint project; single git)

- GENE and GYSELA development and applications
  - AE + EP comparison (incl. performance) of GENE and GYSELA with PIC codes (ITPA, NL saturation, etc)
  - Realistic CoM distribution functions in GYSELA (following XTOR CoM distribution functions)
  - AE + EP + turbulence in ITER/DEMO

# BACKUP SLIDES

# Global simulations of EM turbulence: EUTERPE

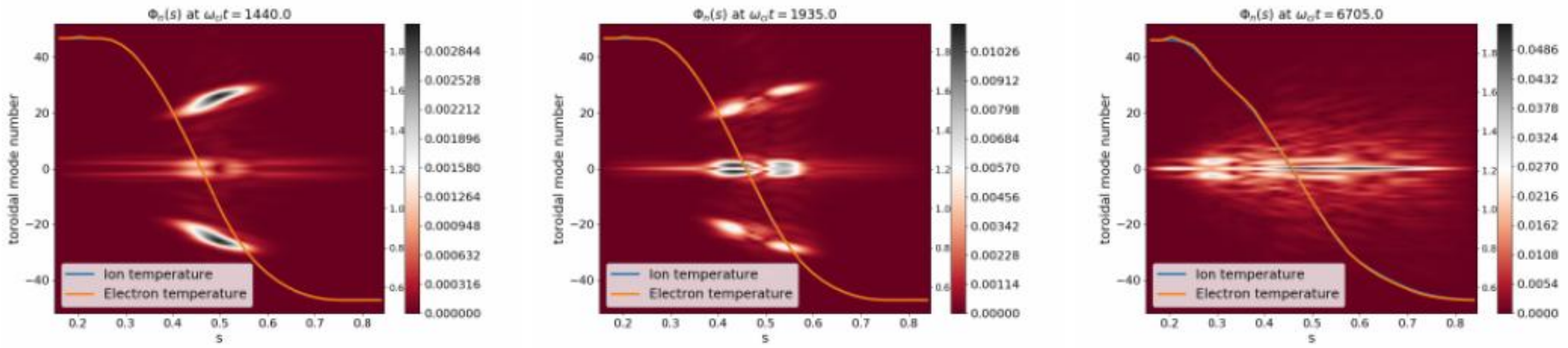



Realistic W7-X „UFM“ configuration

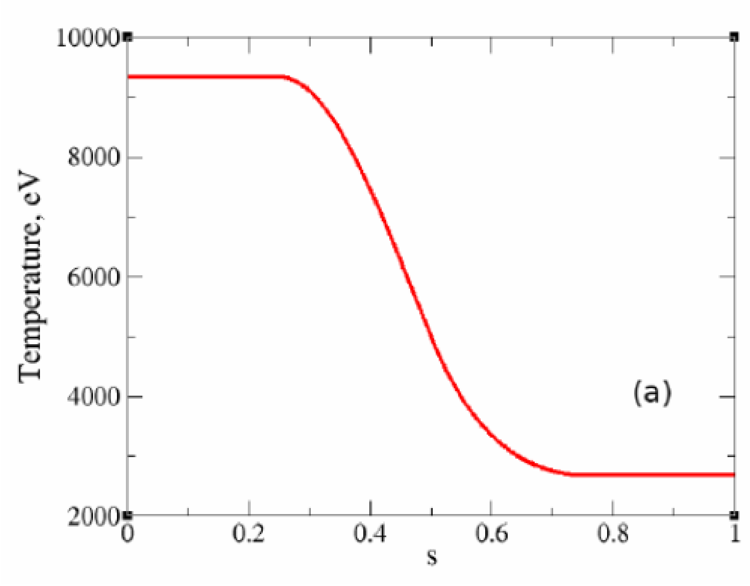
Global geometry is simulated
(no flux-tube issues at small $k_y \rho_i$)

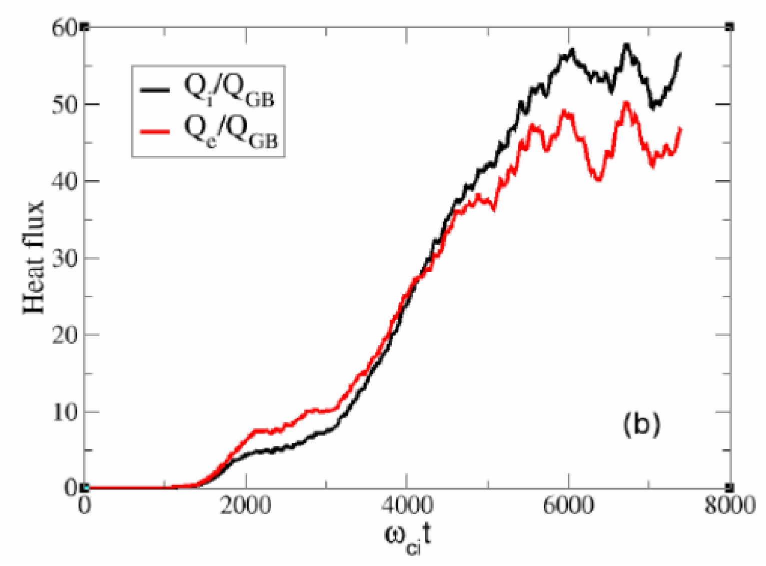
For more EUTERPE results, see poster of Y. Narbutt




[A. Mishchenko et al., *Plasma Phys. Control. Fusion* **64,** 104009 (2022)]

# Global simulations of EM turbulence: EUTERPE

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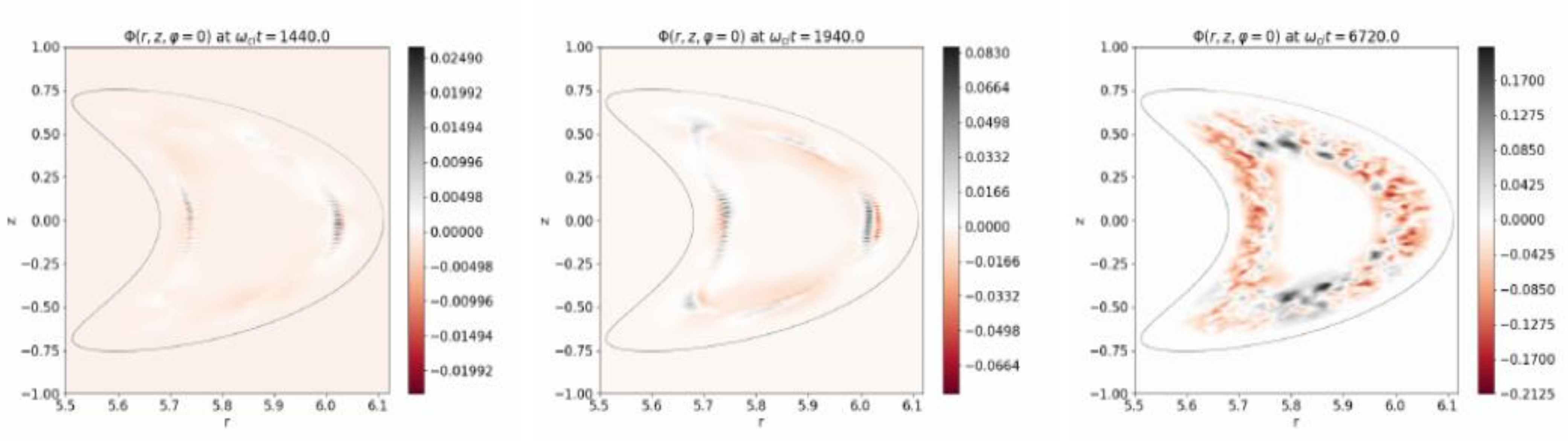
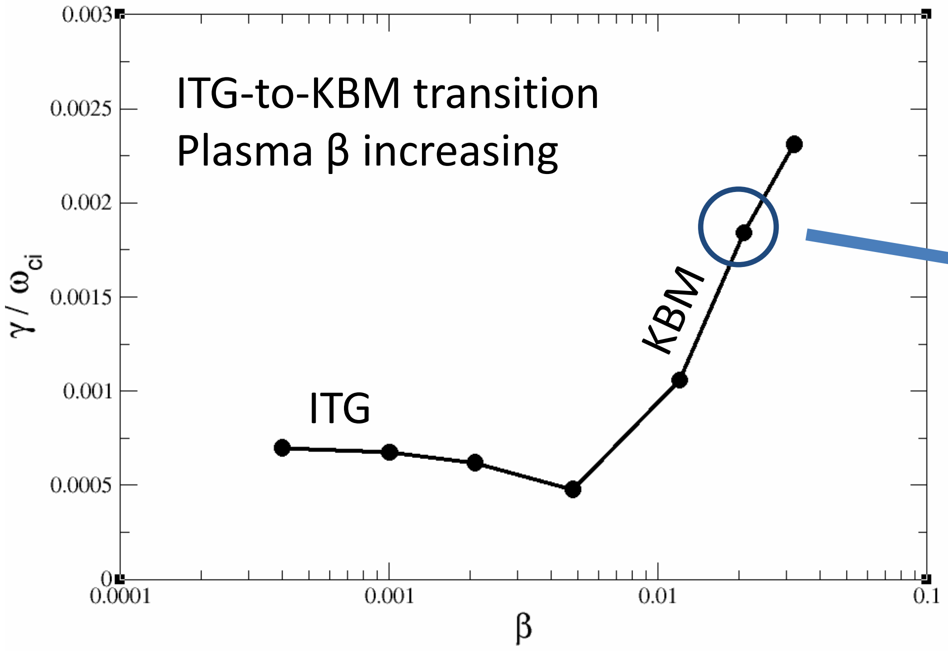
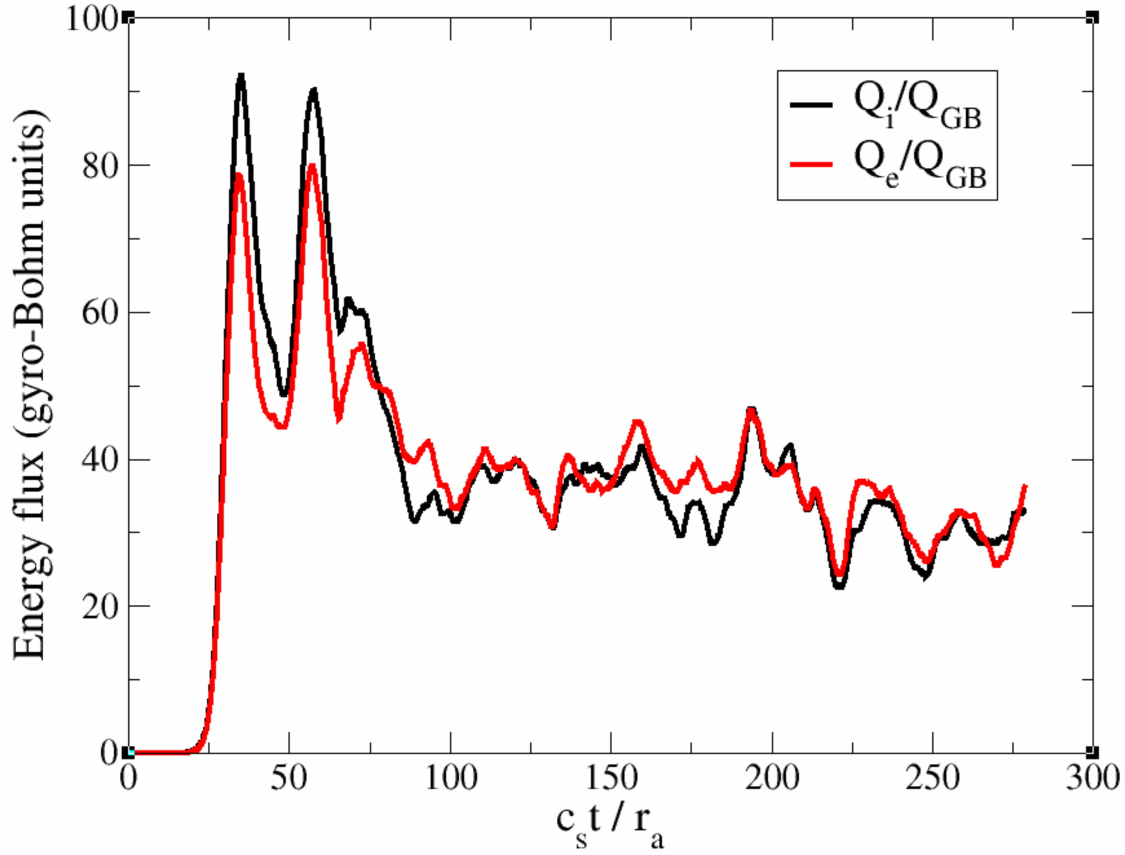



A. Mishchenko et al., *Plasma Phys. Control. Fusion* **64,** 104009 (2022)

# KBM saturation and profile relaxation

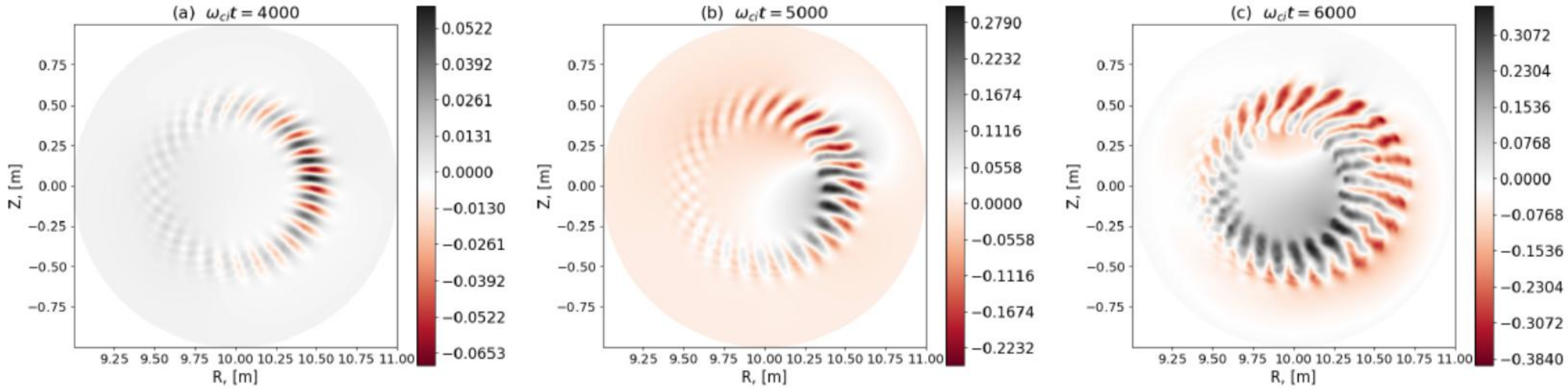


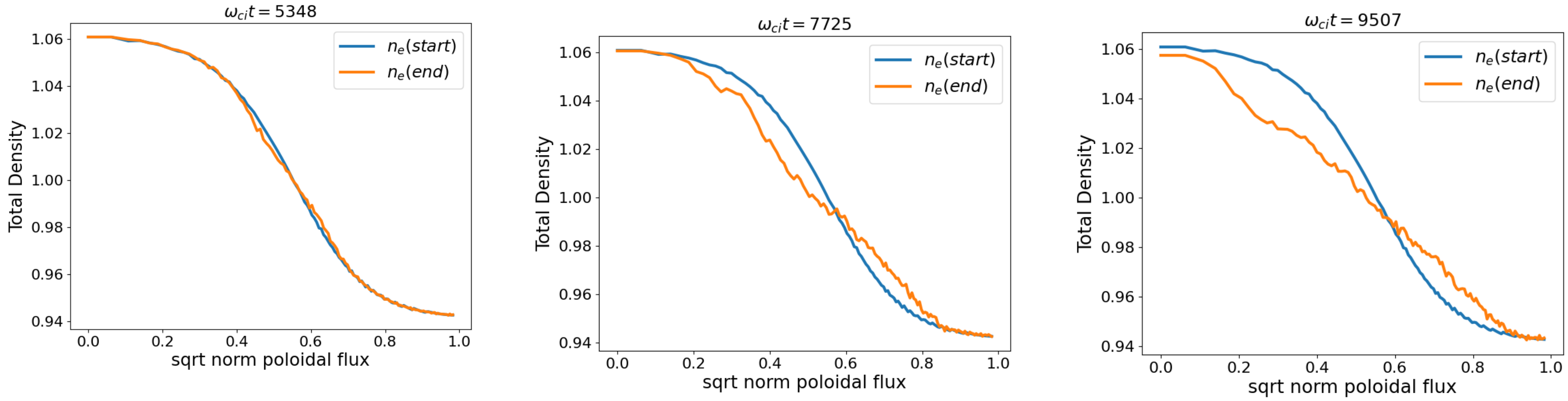




Global simulations (ORB5)

**No electromagnetic run-away in global setup!**

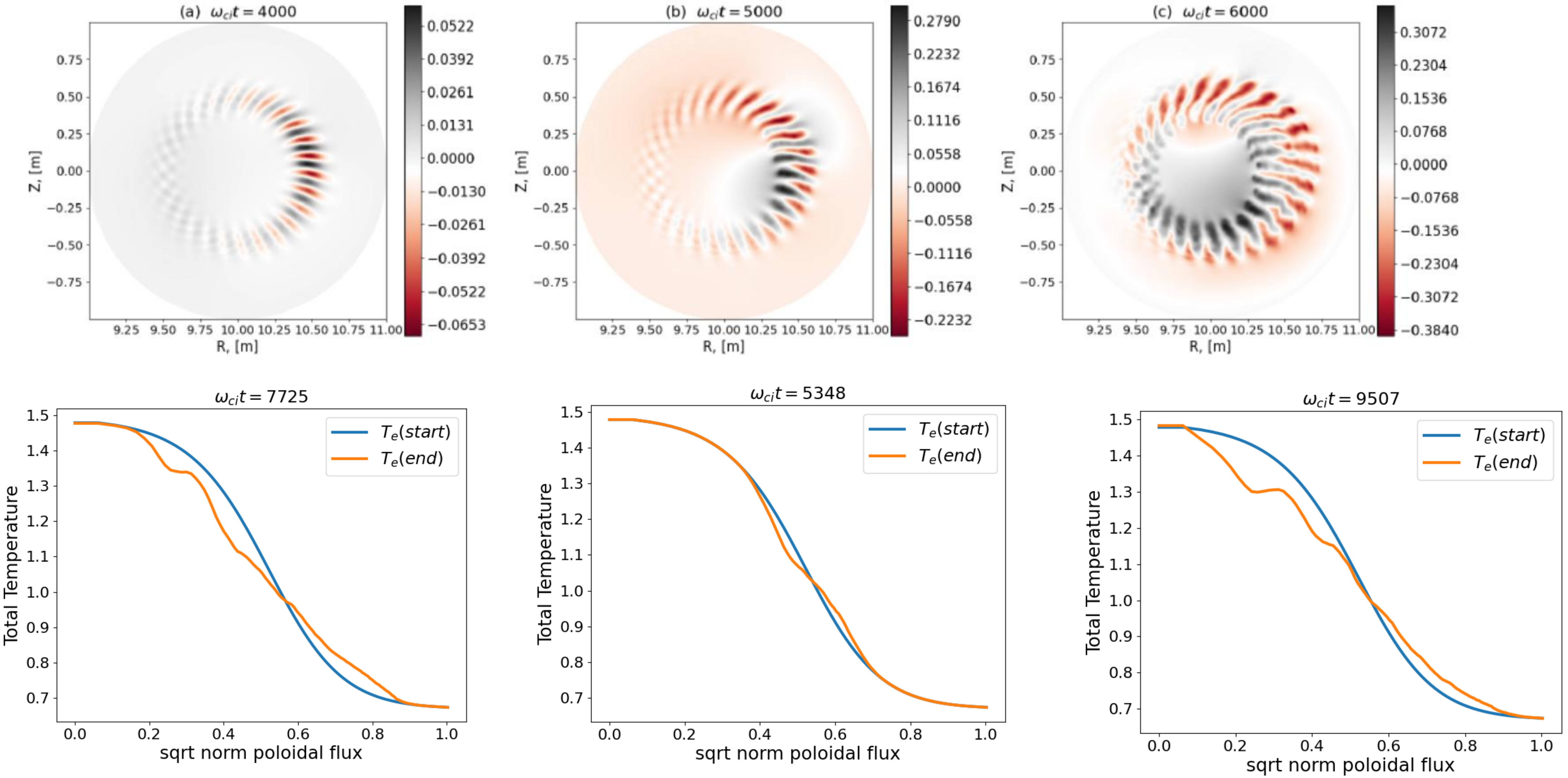
# KBM saturation and profile relaxation




**Global simulations with adaptive control variate are needed to capture the profile relaxation**

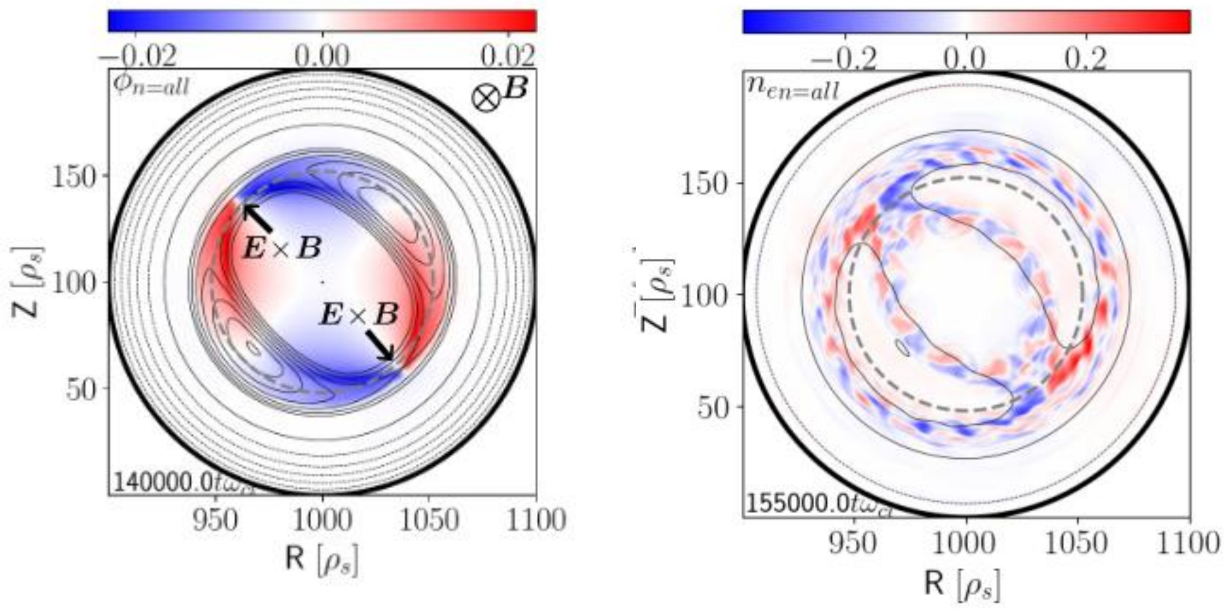
# KBM saturation and profile relaxation



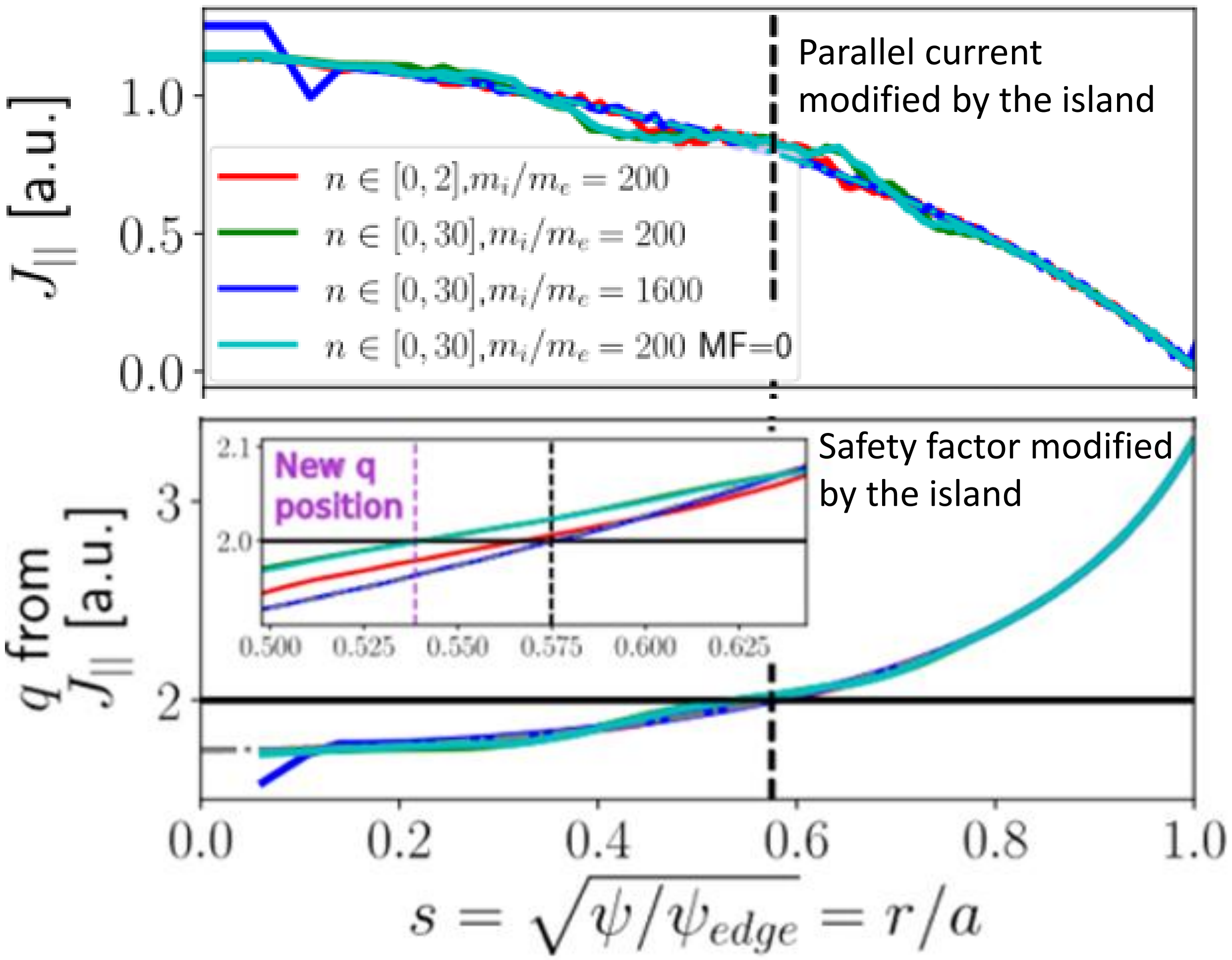

**Global simulations with adaptive control variate are needed to capture the profile relaxation**

# Tearing instability, turbulence, effect on magnetic configuration

ORB5




(a) Electrostatic potential $\phi$. (b) Electron density $n_e$.

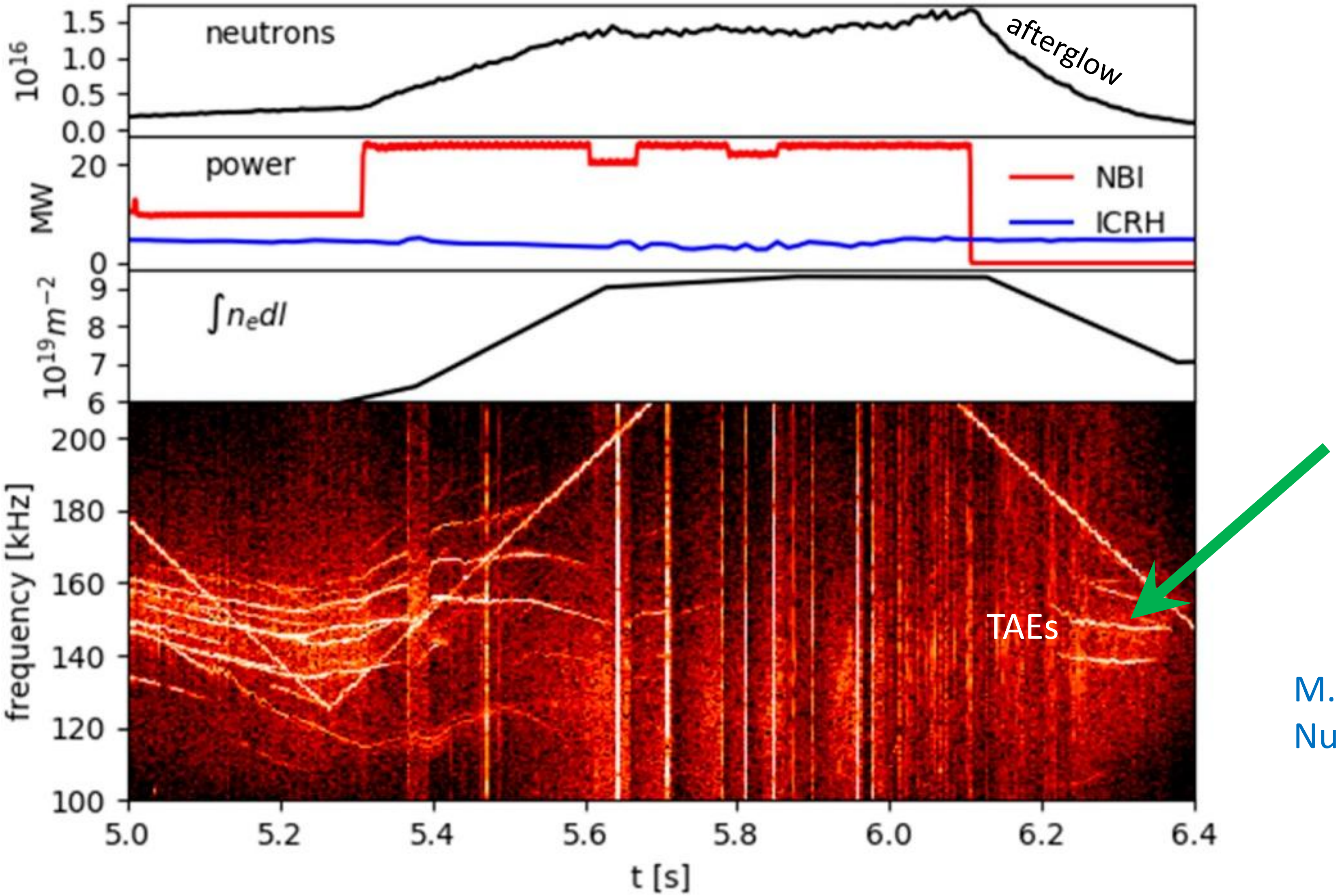



**Tearing instability generates islands**
**Islands generate flows**
**Flows become unstable (island saturation or healing).**

Tearing instability and turbulence coexist and interact
Magnetic configuration is affected (evolution of q profile)

**Islands perturb parallel current (zonal field).**
**Safety factor and local shear nonlinearly change.**
**Island growth is nonlinearly bound.**

# JET #92416: Toroidal Alfvén Eigenmodes seen in Deuterium-Deuterium experiment



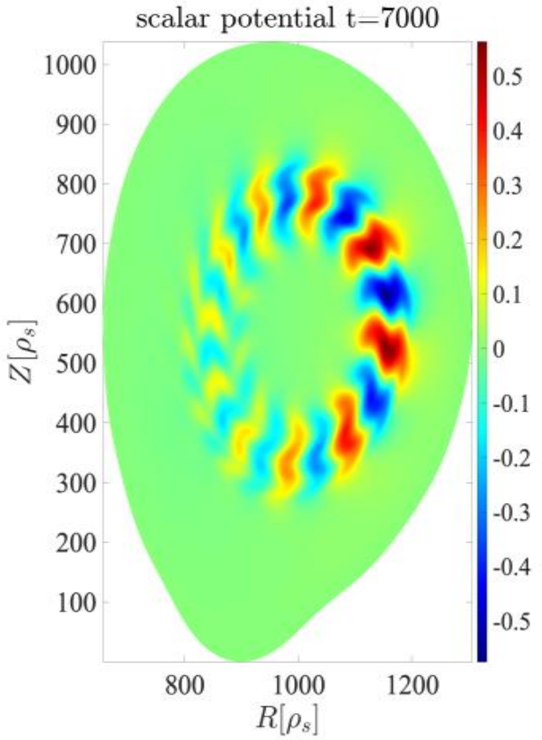

JET DD campaign, "afterglow experiment" shot #92416.

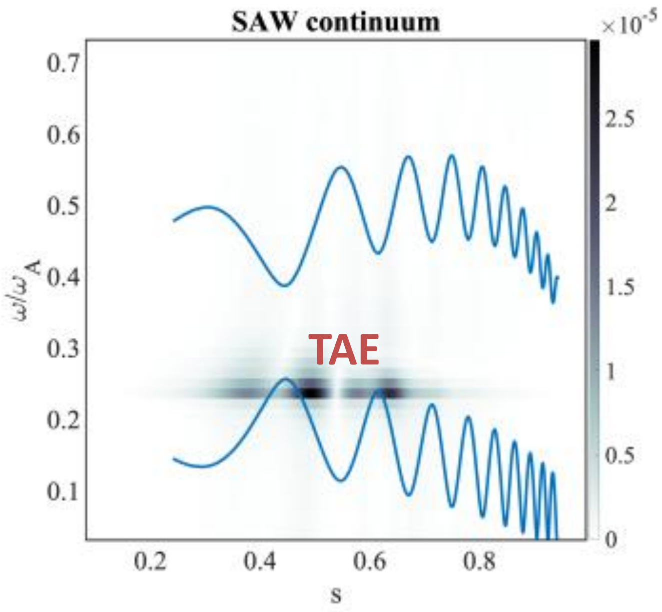
Experiment investigating plasma behavior after the main NBI heating pulse t > 6.1 s.

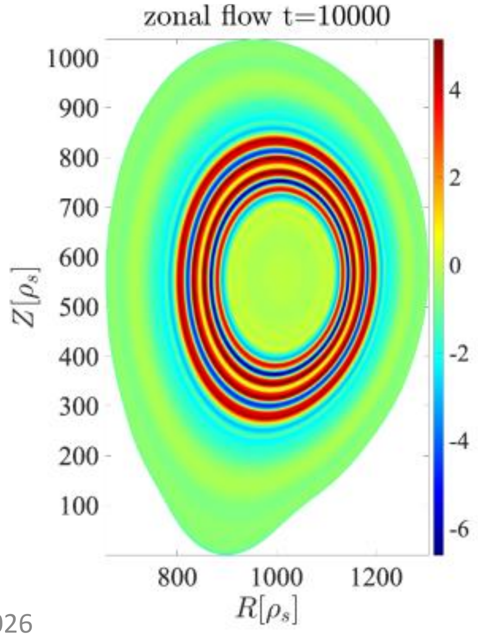
In this shot, TAEs were measured at the time 6.2 s of the discharge.

M. Fitzgerald, S.E. Sharapov, P. Siren, et al, Nuclear Fusion (2022)

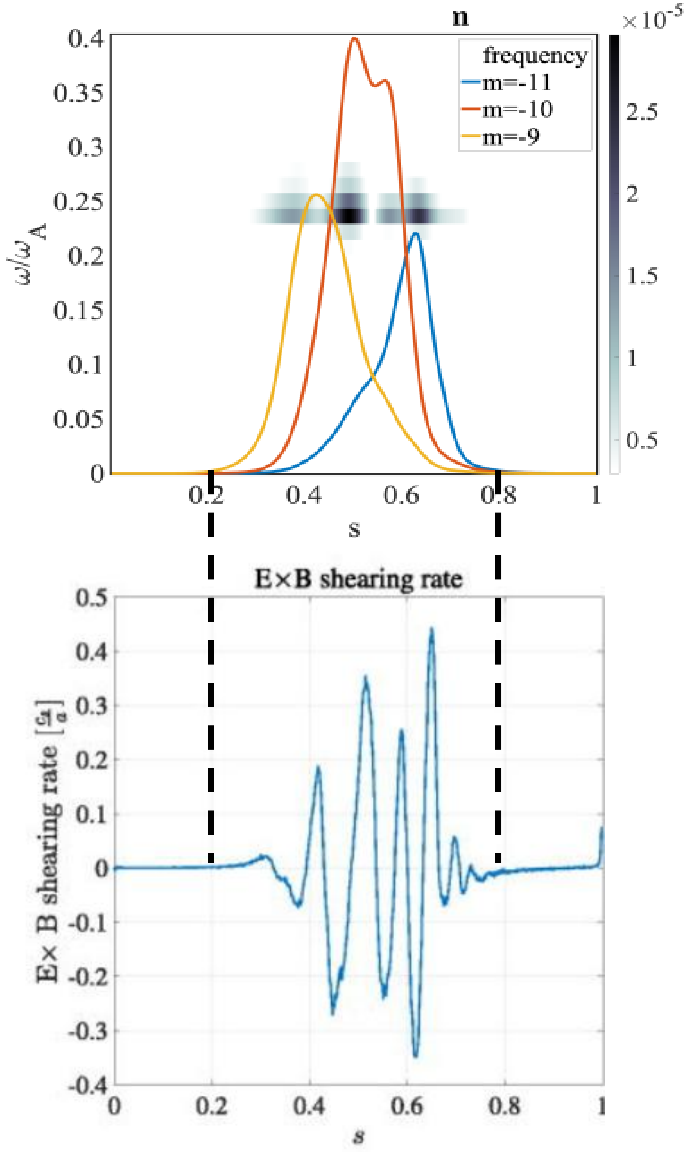
# JET #92416: TAE simulations, beat-driven zonal flows




ORB5

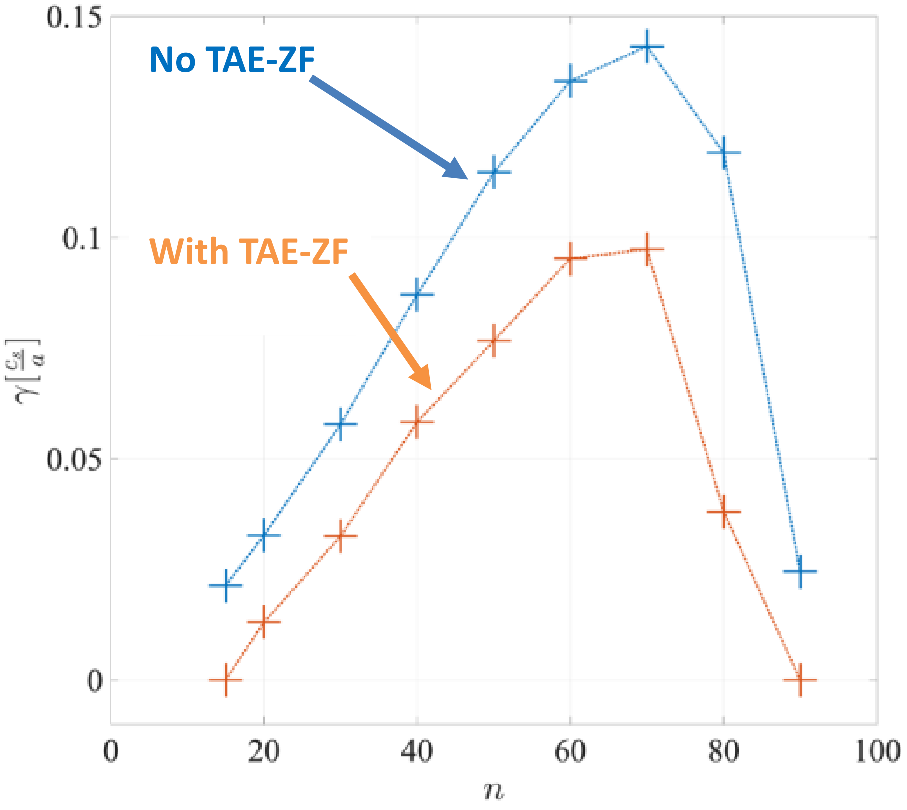


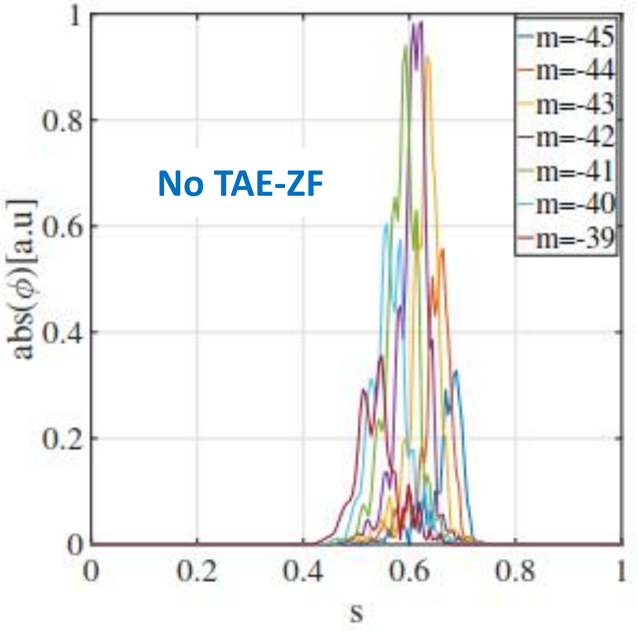

Fast-ion destabilized TAE generates beat-driven zonal flow (double growth rate of TAE).

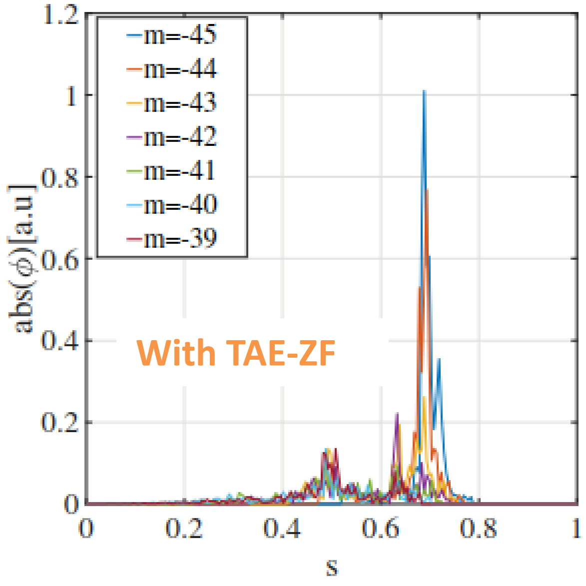
Radial location of zonal flow is determined by the TAE structure.

# JET #92416: ITG simulations, TAE-driven zonal flows suppresses ITG (mode structure)

**ORB5**



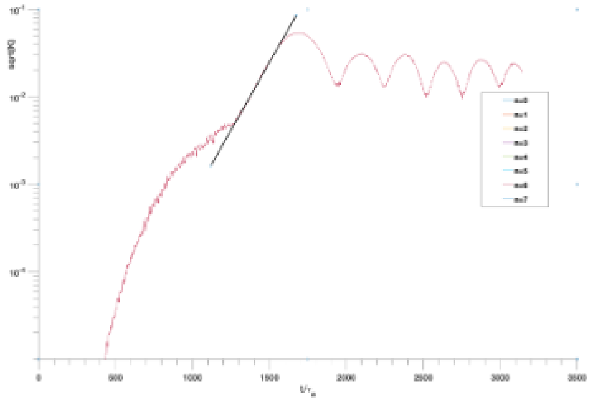



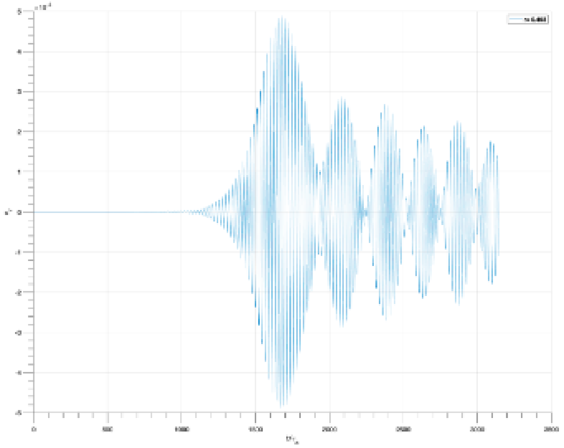



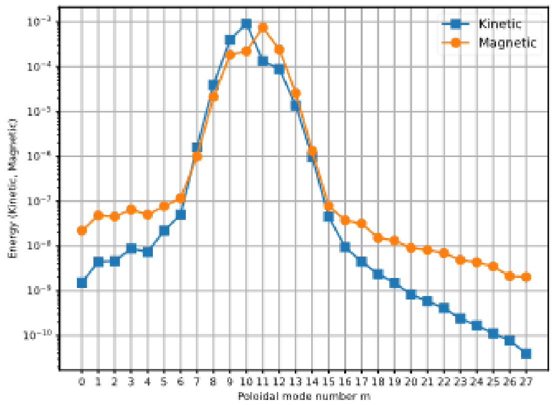

TAE-driven zonal flows strongly affect mode structure of ITGs

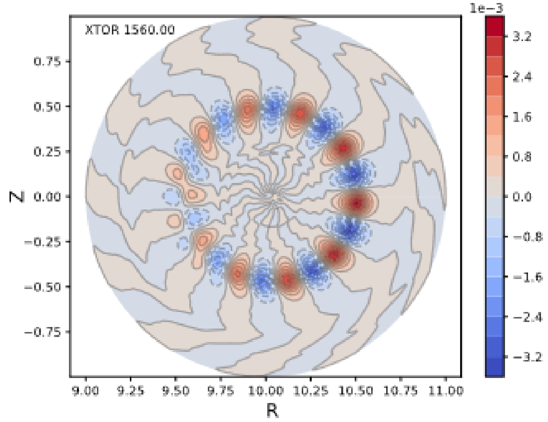
Beat-driven zonal flow mitigates ITG instability (antenna-emulated ZF)

# XTOR-K








**n=6 TAE evolution:**

Gamma = 2.18 x $10^4$ $s^{-1}$
Omega = 0.399 x $10^6$ rad/s

Compares well with
[Mishchenko 2009, Könies 2018]:

Gamma = 2.3 x $10^4$ +/-10% $s^{-1}$
Omega = 0.42 x $10^6$ rad/s

Omega ideal MHD eigenvalue code (CAS3D):
Omega = 0.401 x $10^6$ rad/s

# TSVV-G: background

Call for TSVV-G: Physics of Burning Plasmas

Develop a self-consistent description and corresponding simulation tools for the mutual interaction of energetic particles, MHD modes, turbulence, and kinetic plasma profiles in both tokamak and stellarator geometries.

Develop a theoretical understanding and validated interpretative/predictive capabilities (including reduced models) of burning plasma physics in both tokamak and stellarator geometries. The resulting reduced models are to be used in TSVV-H and TSVV-I.

Develop strategies to optimize the deposition of fusion alpha energy into the bulk plasma to enhance reactor performance.