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Intrinsic rotation drive in tokamaks: the competition between turbulence and magnetic braking.

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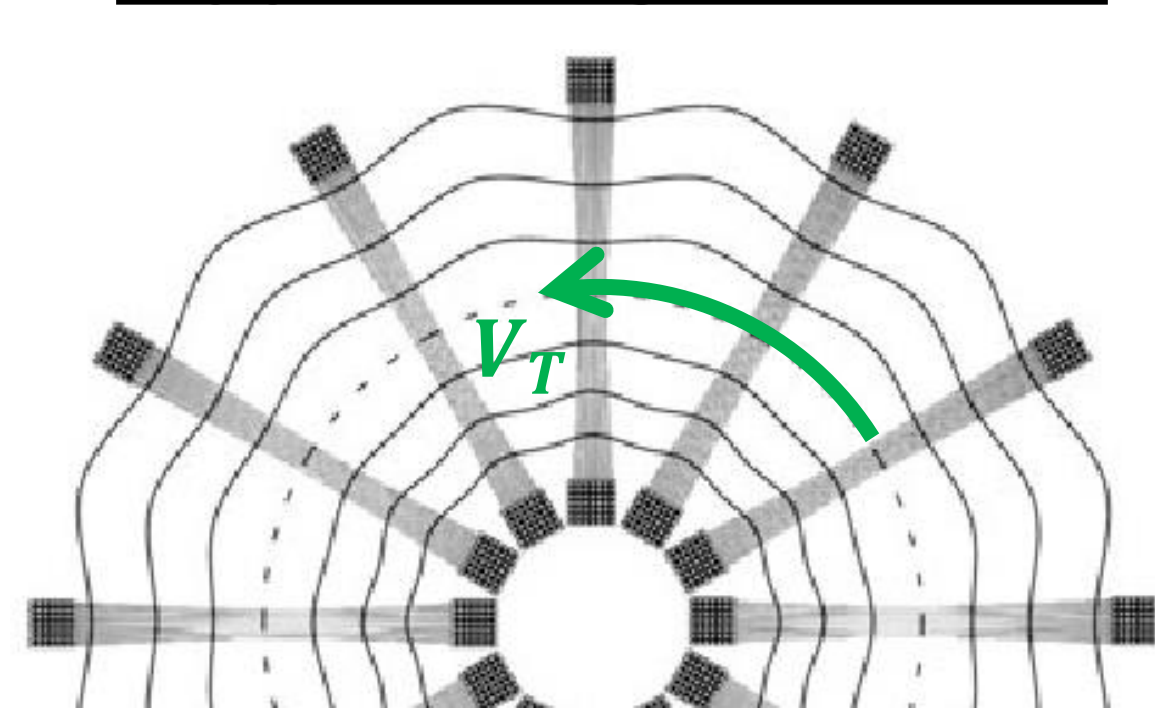
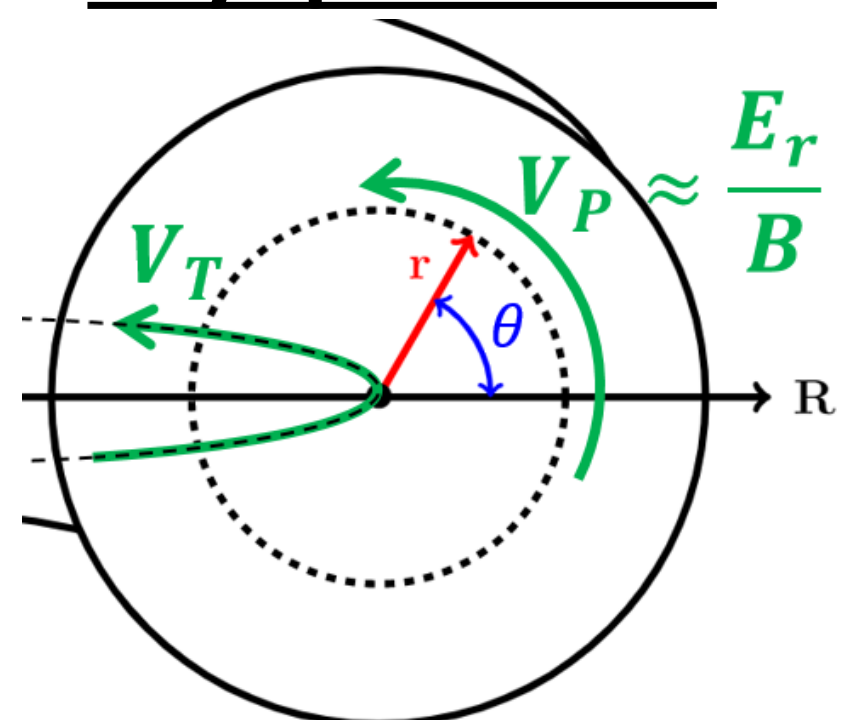
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Introduction

- Plasma rotation plays a key role in plasma confinement;
- Control of plasma rotation in reactor-sized tokamak is challenging;
- Intrinsic bulk plasma rotation is driven by **turbulence** and **magnetic braking** due to ripple

Key quantities

Rippled magnetic field



Intrinsic rotation mechanisms

- A reduced model [1] based on the mean toroidal velocity V_T reads :

$$\frac{\partial V_T}{\partial t} = \text{Magnetic braking} + \text{Turbulent torque}$$

Ripple constrains particle trajectories and collisional processes

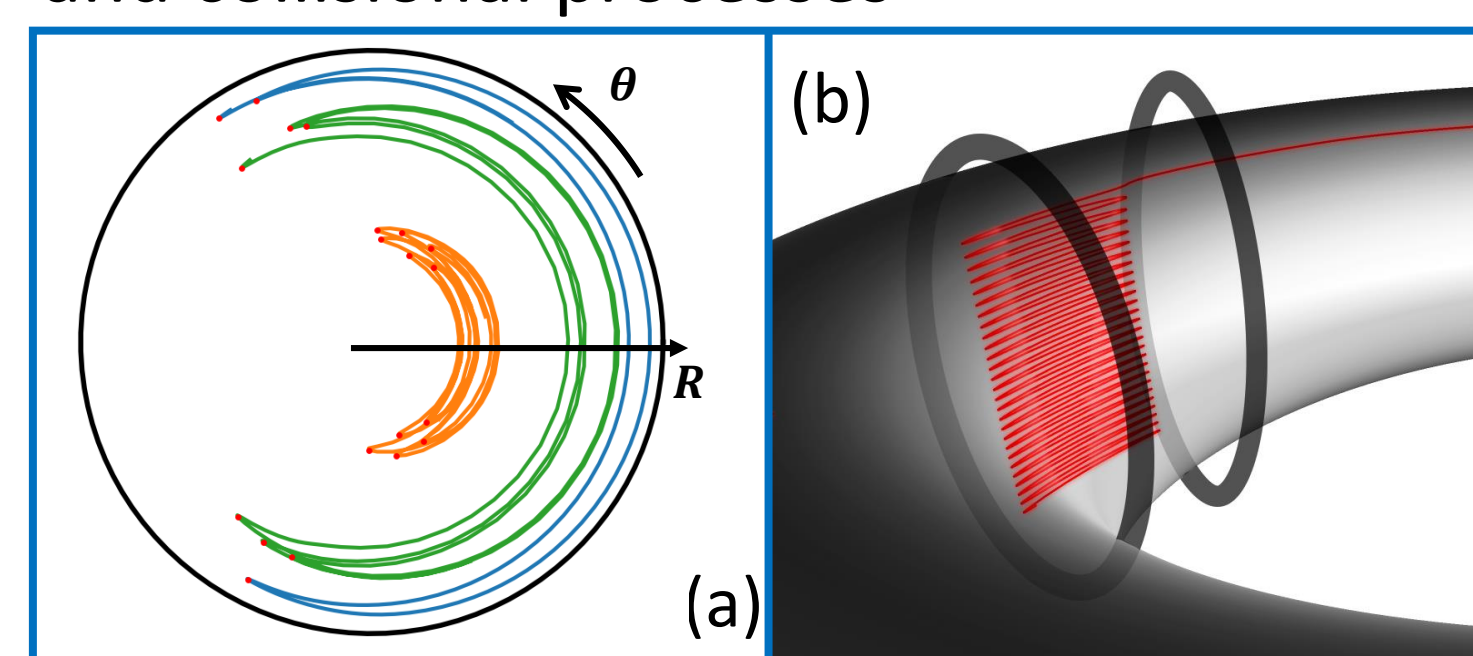


FIG.1 – Kinetic effects induced by ripple : drift of banana bounce points (a) and toroidal trapping between coils (b). Neoclassical friction v_ϕ comes from the collisions between trapped particles.

Turbulence constrains V_T through wave-particle interactions

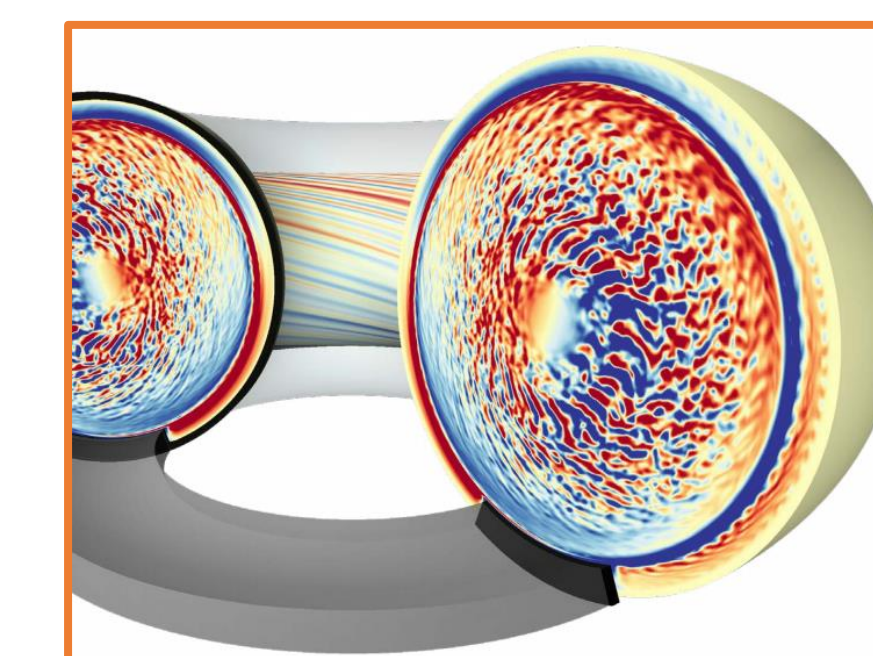


FIG.2 – Snapshot of the turbulent structures seen through a colormap on the electric potential. From rest, V_T grows due to wave-particle interactions.

Turbulence / Ripple competition

- Magnetic braking m imposes a finite velocity V_{neo} [2,3] $m = -v_\phi (V_T - V_{neo})$

Collisional friction

- Turbulence, through toroidal Reynolds stress Π , also imposes a finite velocity V_{turb} [4,5] due to particle-waves interactions:

$$\Pi = -\chi \frac{\partial V_T}{\partial r} + \nu V_T + \Pi_{res}$$

Viscosity Pinch Residual

- Competing forces $\partial_t V_T = m - r^{-1}(r\Pi)'$

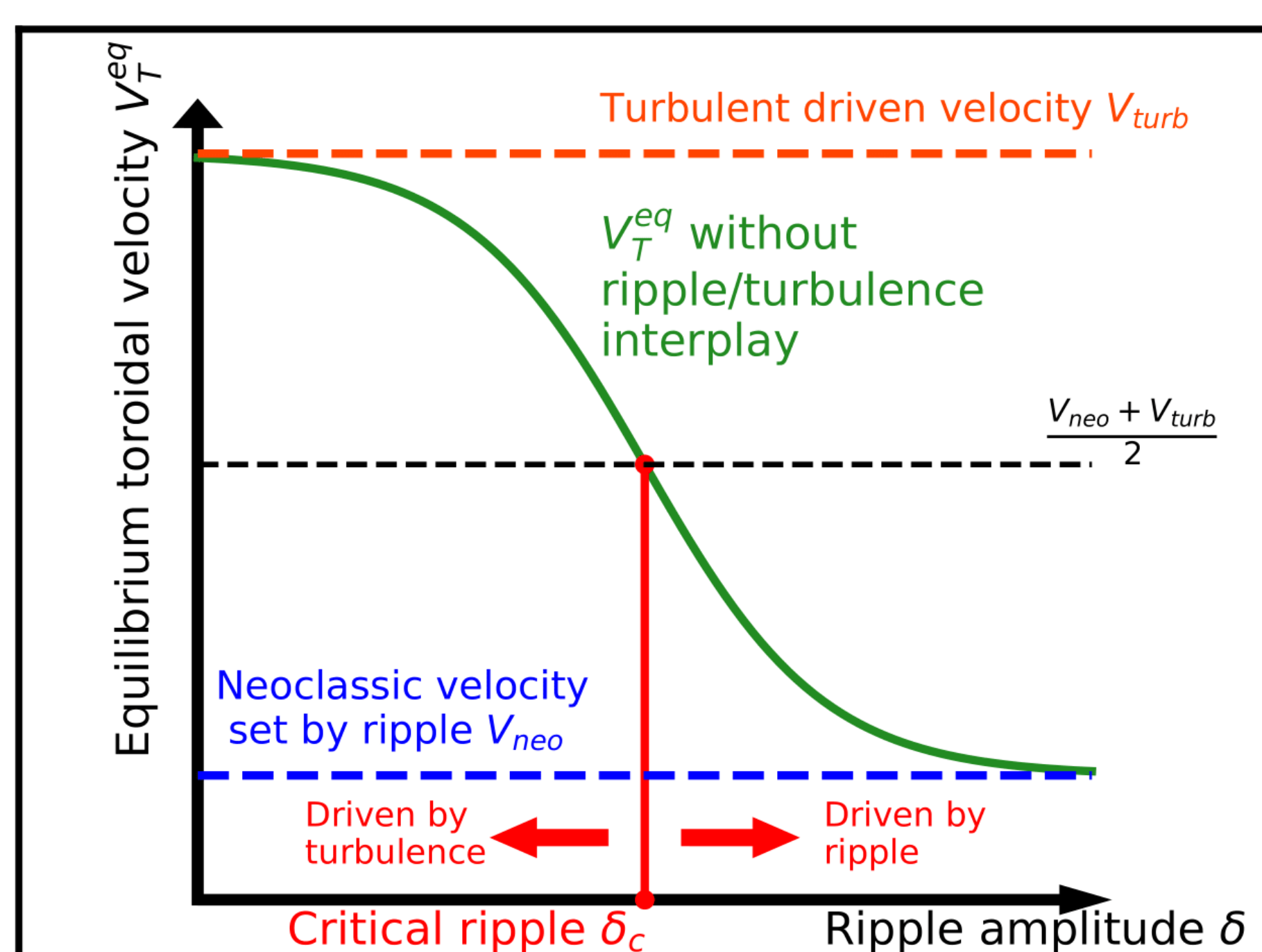


FIG.3 – Sketch of the modelled ripple/turbulence competition on the equilibrium toroidal velocity.

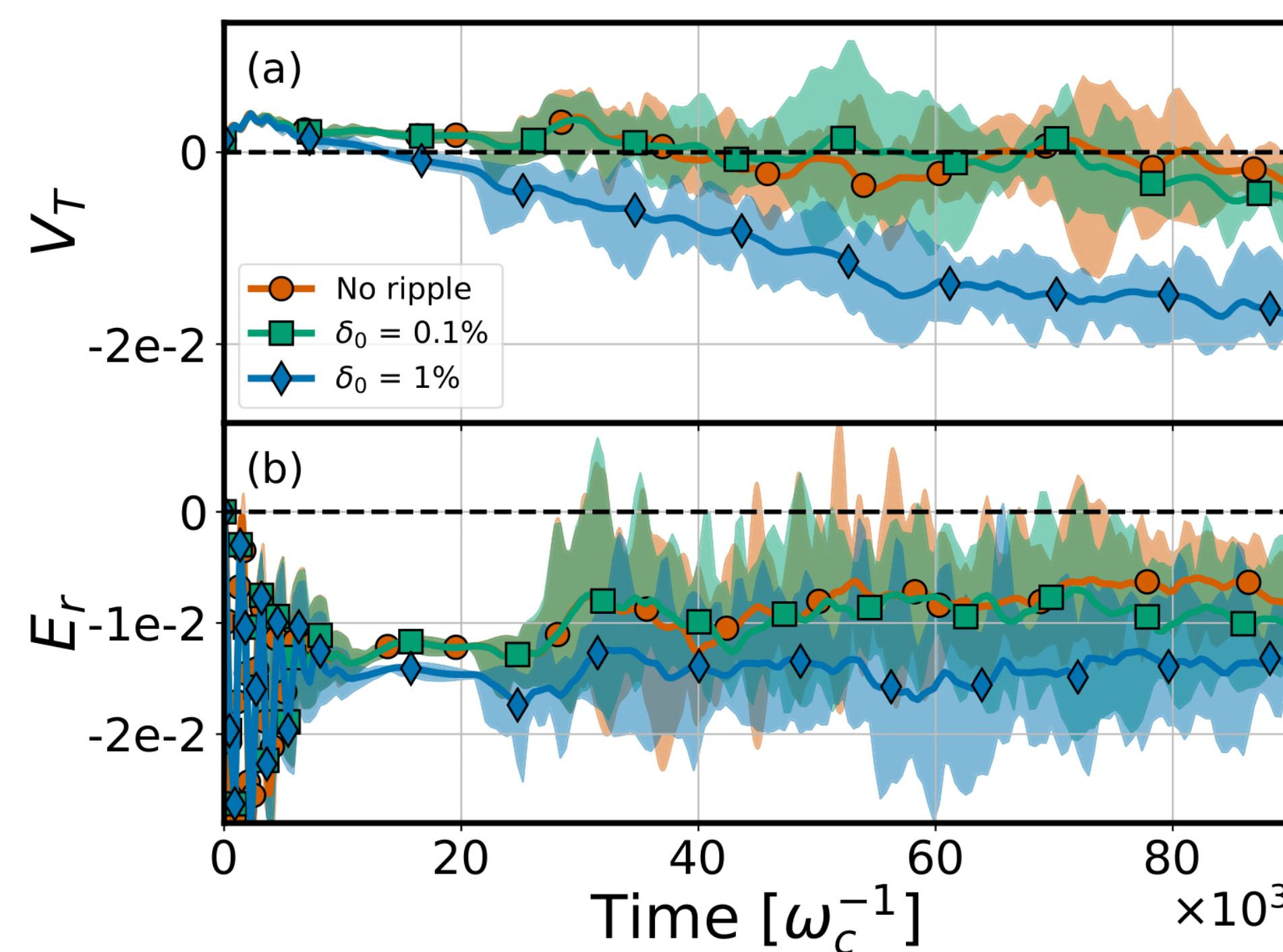


FIG.4 – Time evolution of V_T and E_r for different ripple amplitudes.

Critical ripple amplitude

- NTV controls the plasma rotation above a critical ripple amplitude δ_c

- Complete model gives the relation:

$$v_\phi(\delta_c) \approx \chi_{eff} / L_T^2$$

Temperature gradient's length

$$\text{With } \chi_{eff} \approx \chi + L_T \nu$$

- A simplified equation can be devised considering

- the gyroBohm scaling for χ_{eff}
- The ripple-plateau scaling for v_ϕ

$$\delta_c \sim \sqrt{N_c} \left(\frac{R}{L_T} \right)^{-3/2} \frac{\rho_i}{R}$$

Number of coils

Ion Larmor radius

Major radius

Conclusion

- Ripple \rightarrow responsible for a collisional friction that causes magnetic braking;

- Turbulence \rightarrow source of intrinsic rotation;

- Evolution of mean toroidal flow ruled by competing turbulent stress and ripple drag forces;

- Magnetic braking overcomes turbulent drive above a critical ripple amplitude δ_c

- Analytical prediction of δ_c , and simplified expression, are derived and validated numerically

- Main synergy comes from neoclassical effect on E_r' in presence of ripple, in turn modifying Π

Turbulence / Ripple synergy

- Only possible mechanism: mode coupling on the electric potential
- However, ripple only impacts non-resonant modes of the electric potential

Magnetic braking $\xleftrightarrow[\text{Significant}]{\text{Negligible}}$ Turbulence

- Strong impact of ripple on Π in simulation
- Π expected to vary with turbulent intensity shear I' and radial electric field shear E_r'
- In simulations, ripple weakly impacts I through mode-coupling of the electric potential
- Ripple changes E_r through collisional effects \rightarrow strong correlation with Π

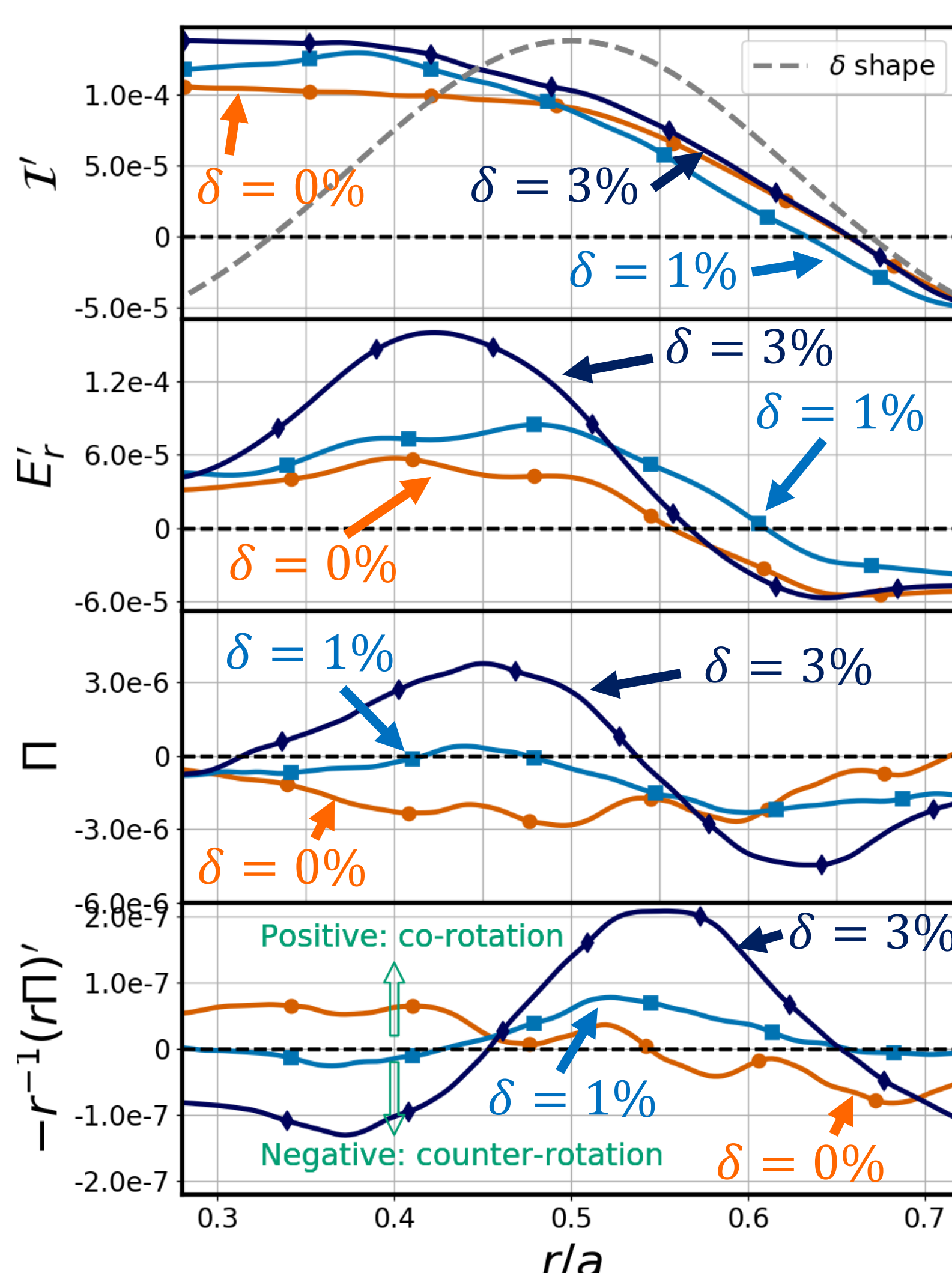


FIG.4 – Radial profiles of turbulent intensity shear, E_r' shear, residual stress and its divergence. These profiles are coarse-grained as detailed in [1].

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