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

R.Varenes<sup>1</sup>, X.Garbet<sup>1</sup>, L.Vermare<sup>2</sup>, Y.Sarazin<sup>1</sup>, G.Dif-Pradalier<sup>1</sup>, V.Grandgirard<sup>1</sup>, P.Ghendrih<sup>1</sup>, P.Donnel<sup>1</sup>, M.Peret<sup>2</sup>, K.Obrejan<sup>1</sup>, E.Bourne<sup>1</sup>

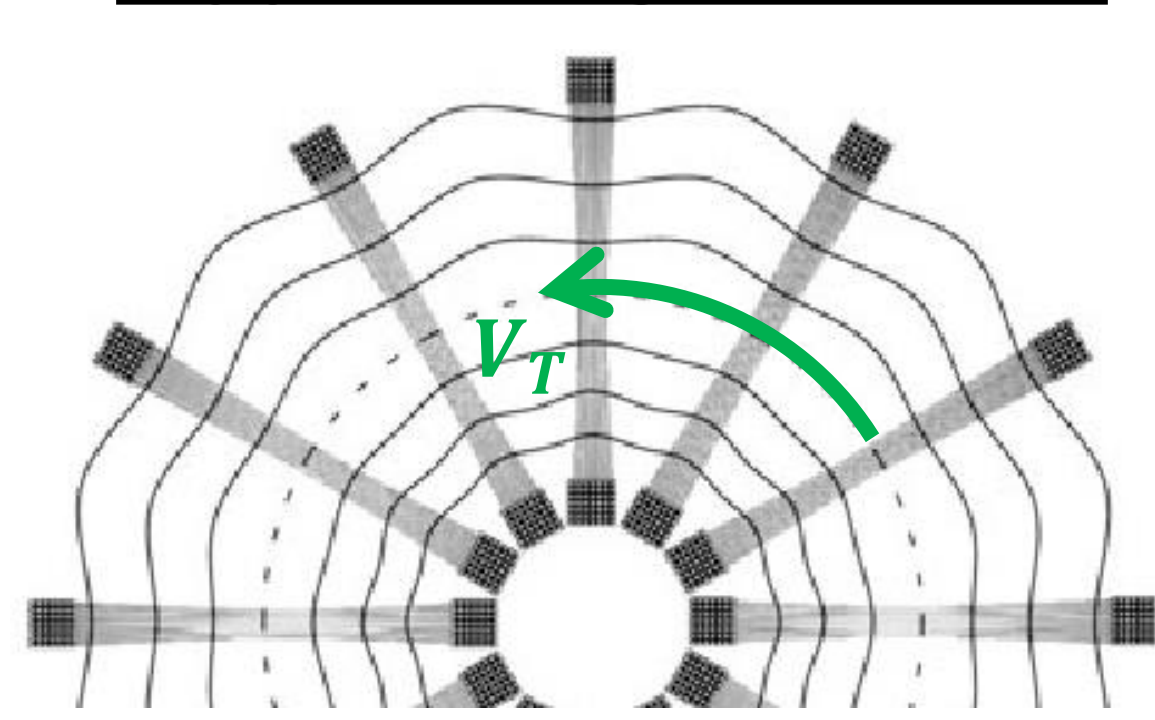
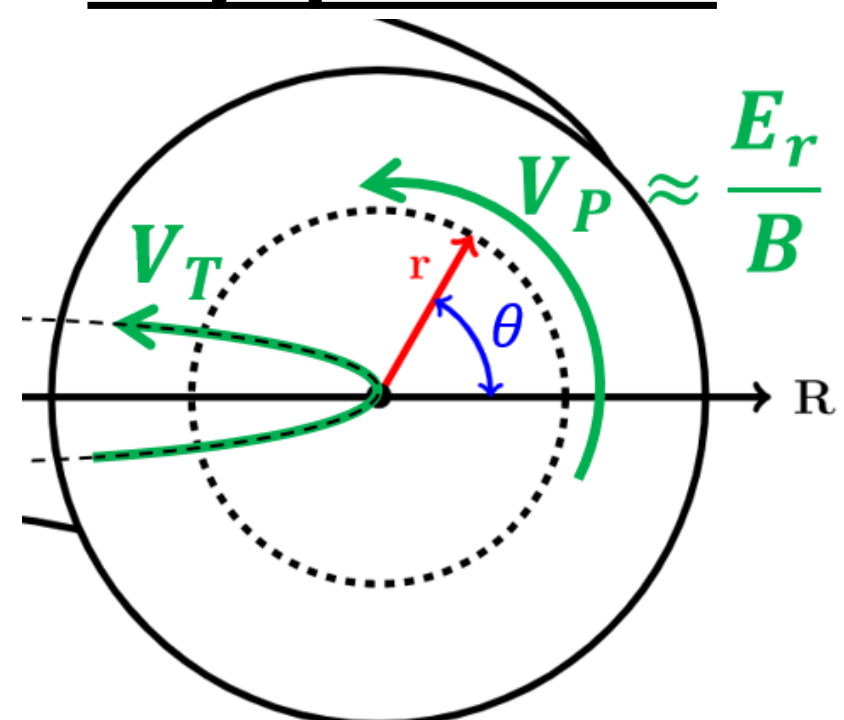
<sup>1</sup>CEA, IRFM, France <sup>2</sup>LPP, CNRS, Ecole polytechnique, France

## 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

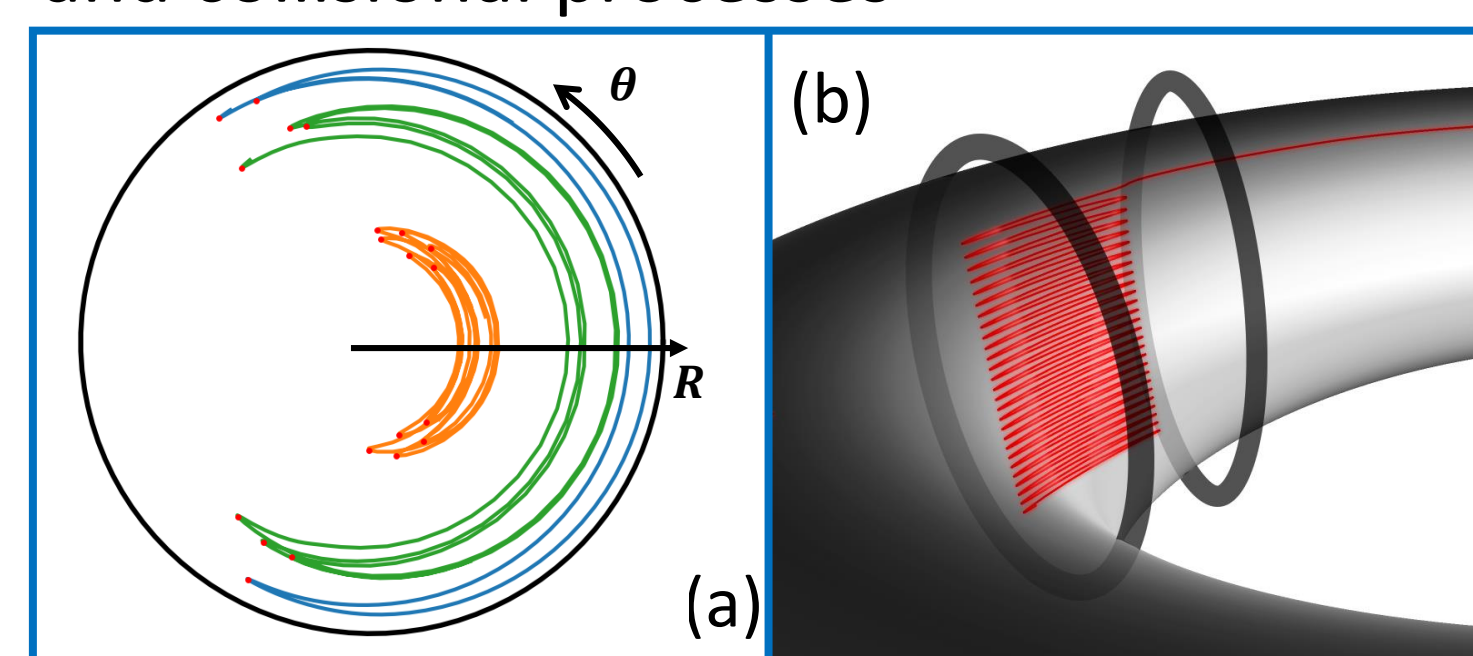


FIG.1 – Kinetic effects induced by ripple : drift of banana bounce points (a) and toroidal trapping between coils (b). Neoclassical friction  $v_\phi$  comes from the collisions between trapped particles.

Turbulence constrains  $V_T$  through wave-particle interactions

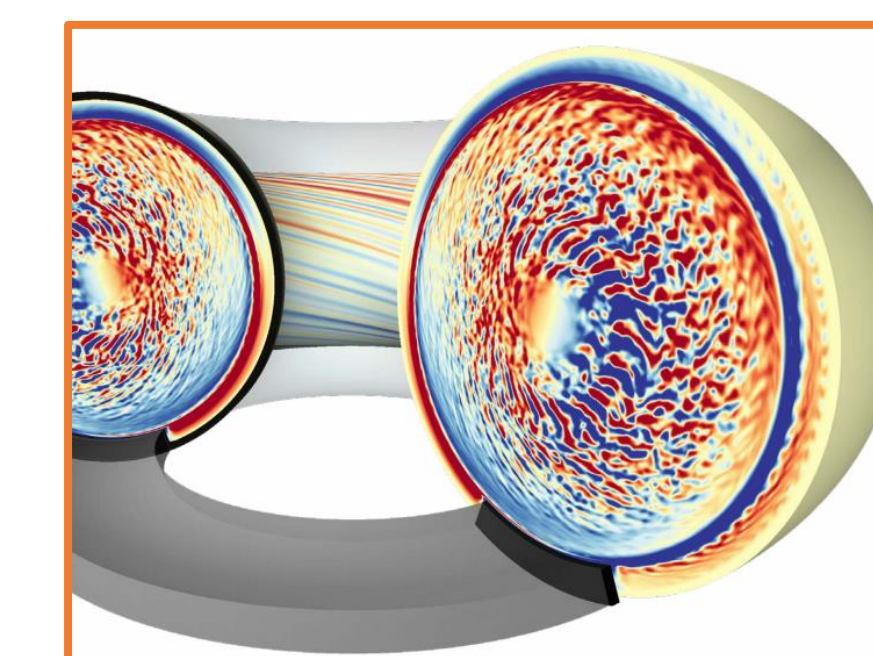


FIG.2 – Snapshot of the turbulent structures seen through a colormap on the electric potential. From rest,  $V_T$  grows due to wave-particle interactions.

## 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 Reynold stress  $\Pi$ , also imposes a finite velocity  $V_{turb}$  [4,5] due to particle-waves interactions:
- Competing forces  $\partial_t V_T = m - r^{-1}(r\Pi)'$

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

Viscosity Pinch Residual

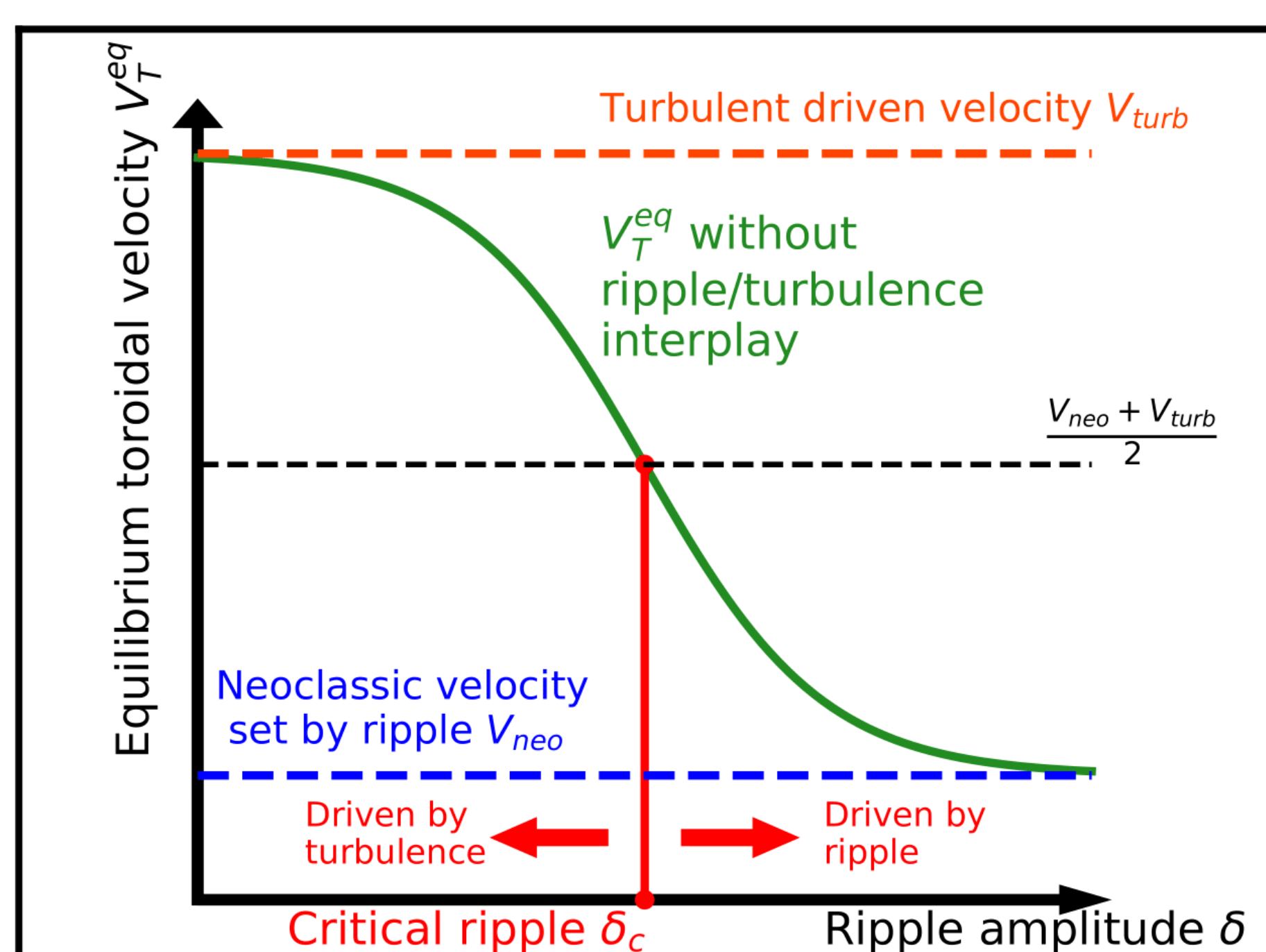


FIG.3 – Sketch of the modelled ripple/turbulence competition on the equilibrium toroidal velocity.

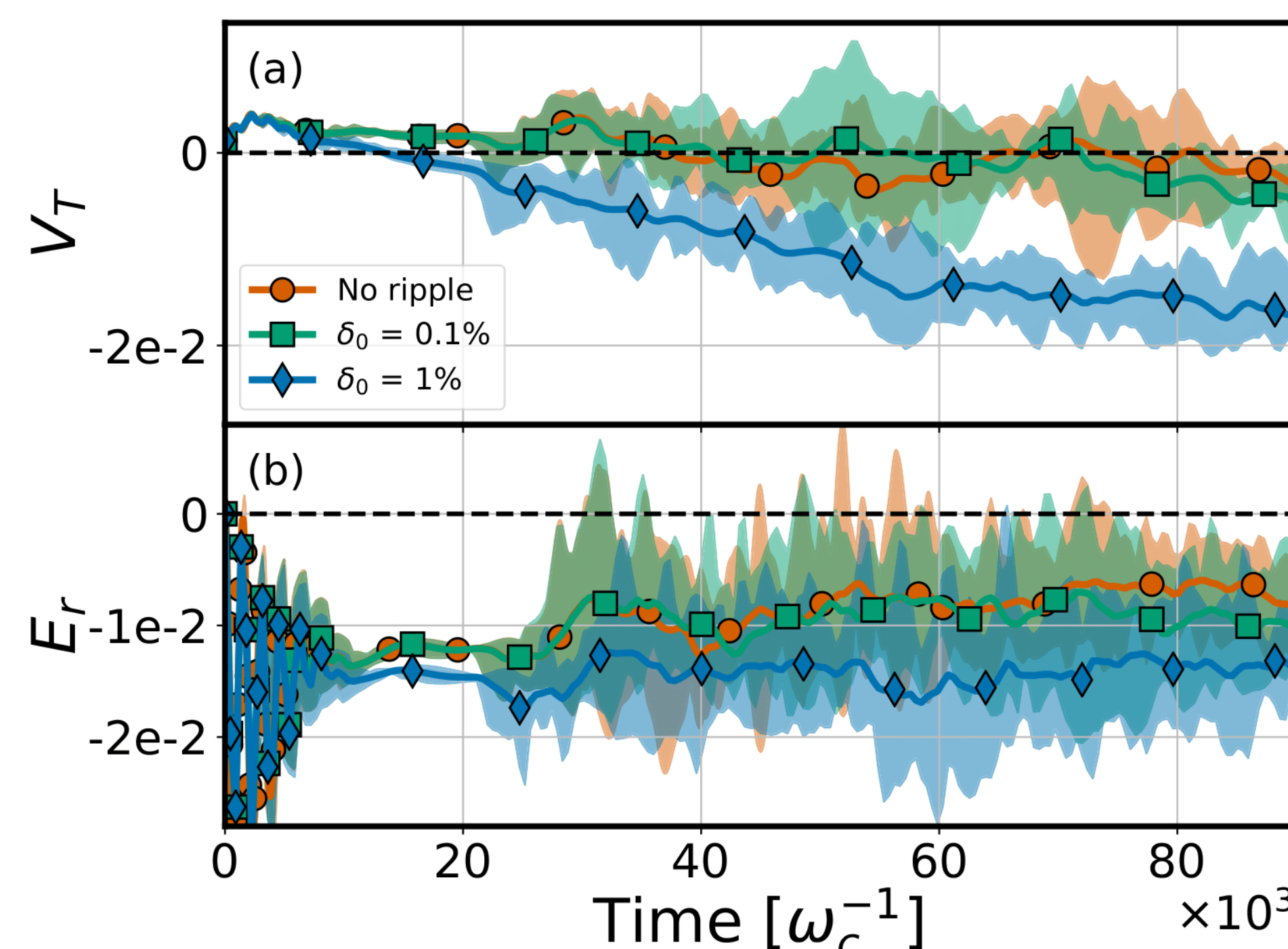


FIG.4 – Time evolution of  $V_T$  and  $E_r$  for different ripple amplitudes.

## Critical ripple amplitude

- NTV controls the plasma rotation above a critical ripple amplitude  $\delta_c$
- Complete model gives the relation:  
 $v_\phi(\delta_c) \approx \chi_{eff} / L_T^2$  ← Temperature gradient's length  
With  $\chi_{eff} \approx \chi + L_T \nu$

- A simplified equation can be devised considering
  - the gyroBohm scaling for  $\chi_{eff}$
  - The ripple-plateau scaling for  $v_\phi$

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

Number of coils ← Ion Larmor radius ← Major radius

## Conclusion

- Ripple → responsible for a collisional friction that causes magnetic braking;
- Turbulence → 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  $\delta_c$
- Analytical prediction of  $\delta_c$ , and simplified expression, are derived and validated numerically
- Main synergy comes from neoclassical effect on  $E_r'$  in presence of ripple, in turn modifying  $\Pi$

## Turbulence / Ripple synergy

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



- Strong impact of ripple on  $\Pi$  in simulation
- $\Pi$  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 → strong correlation with  $\Pi$

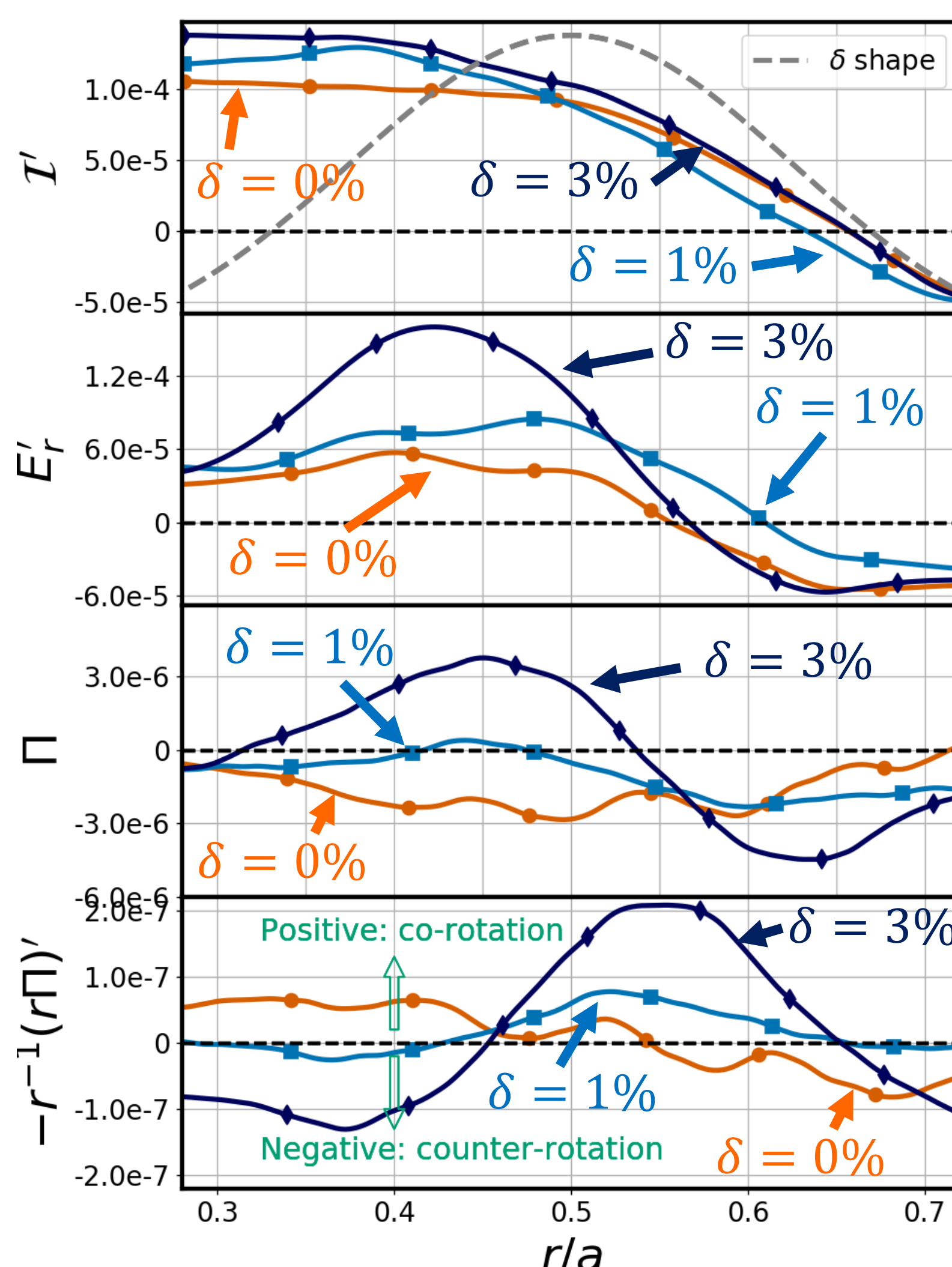


FIG.4 – Radial profiles of turbulent intensity shear,  $E_r$  shear, residual stress and its divergence. These profiles are coarse-grained as detailed in [1].

## References

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