EPFL

Effects of triangularity on boundary plasma turbulence

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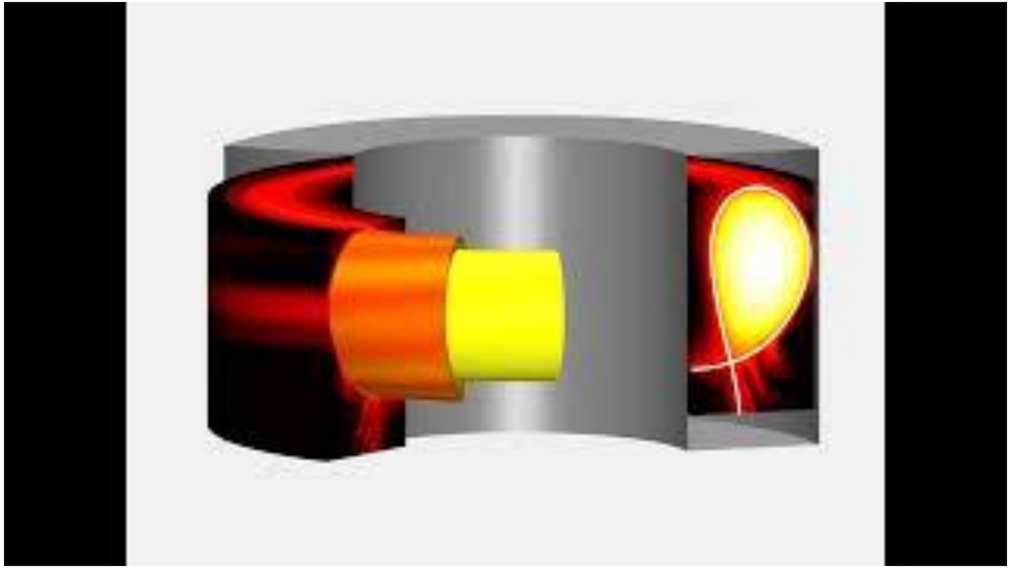
GBS deliverables and milestones with TSVV2

Within TSVV2, **the GBS code** aims for:

1. Effects of plasma shaping (elongation, **triangularity**) on boundary plasma turbulence
2. Alternative divertor configurations (ADCs) combined with plasma shaping
   - **Single-null (SN)** + NT, **double-null (DN)** + NT, snowflake (SF) + NT
3. Neutrals and impurities dynamics in shaped plasmas
   - **Detachment** in NT, neoclassical physics in NT
4. Theoretical scaling laws for boundary-related physics
   - power-decay length, density limit, HL-back transition, detachment threshold
5. Validation with experimental datasets, particularly with TCV

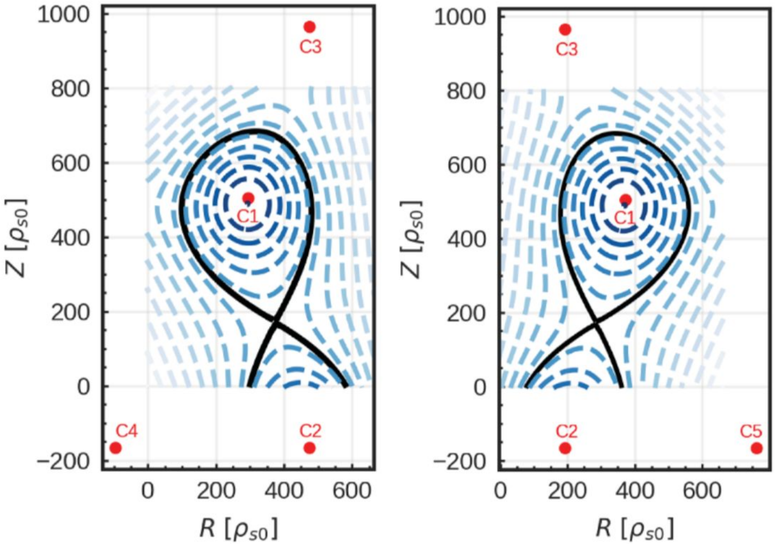
GBS code: ideal tool for plasma shaping



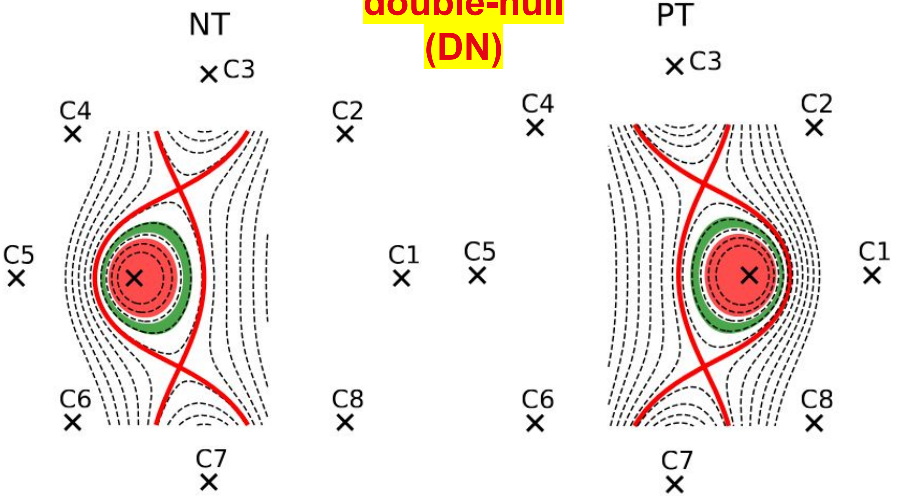
Nonlinear, global, flux-driven, two-fluid simulations.
Any arbitrary magnetic geometry can be addressed.
Kinetic neutrals allow for simulations to attain detached conditions.

Magnetic equilibria for PT and NT plasmas

single-null (SN)



double-null (DN)

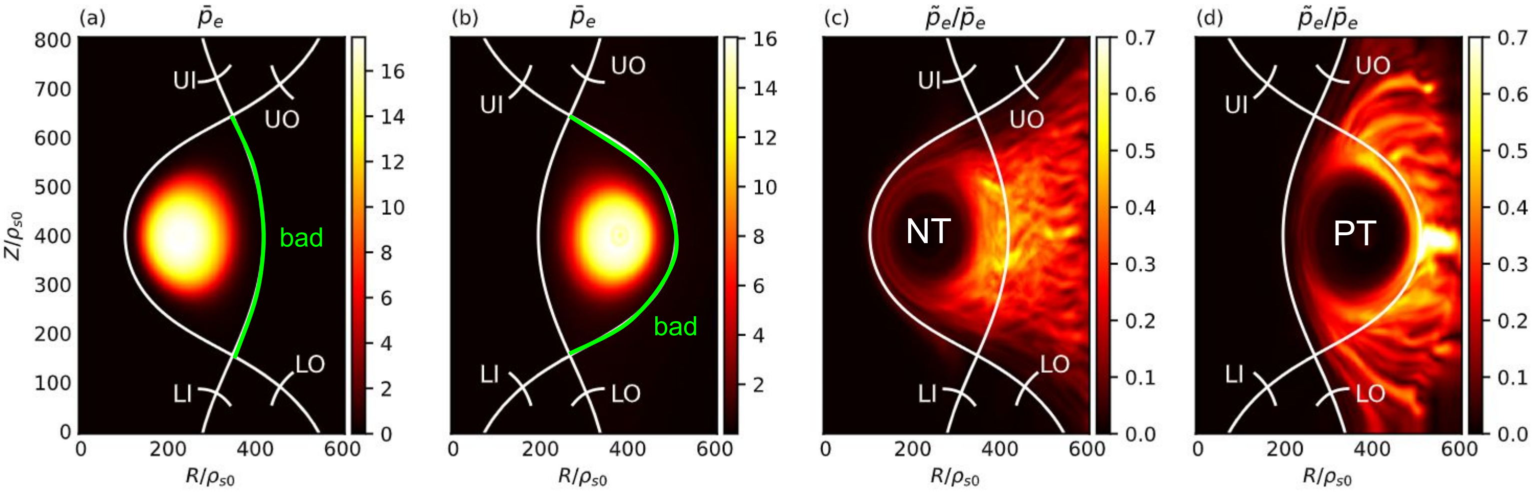


Magnetic geometries are generated using the current-carrying coils.

All parameters remain identical, except the triangularity; **PT** / **NT**

We investigate **how triangularity affects SOL plasma turbulence.**

Enhanced confinement in NT plasmas

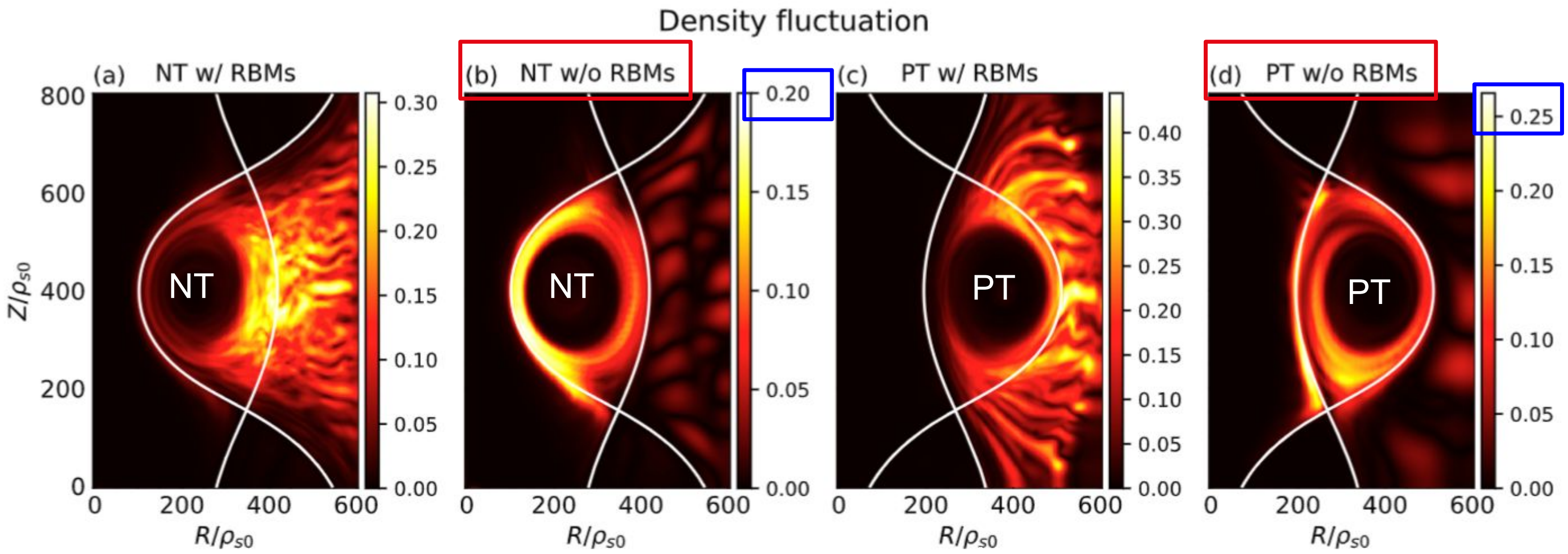


In L-mode plasmas, NT shows enhanced confinement: ⬆️ saturation, ⬇️ fluctuation

GBS L-mode simulations display **interchange-type (BMs)** dominant plasmas

- **PT** -> strong curvature & larger surfaces -> stay longer time in bad curvature
- **NT** -> smooth curvature & smaller surfaces -> stay less time in bad curvature

Evidence that RBMs is related to NT plasma reduction



We artificially **turned off the curvature operator** in the vorticity equation.

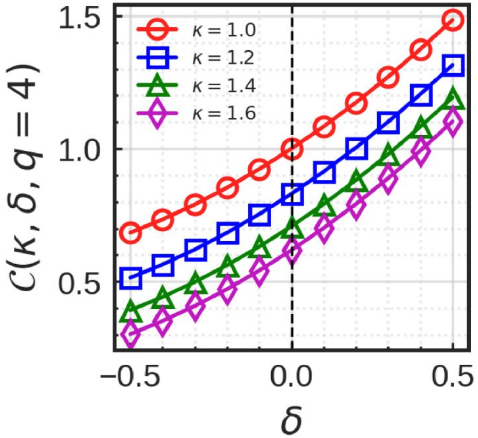
- Larger fluctuation in PT
- BMs dominant in PT -> reduced BMs in NT

Theoretical modelling based on reduced BMs

Steps are as follows:

1. We observed reduced SOL turbulence in NT plasmas, mainly due to BMs
2. BMs are driven by the effects of **pressure gradient** and **curvature**
3. Linear analysis leads to analytical expression of the growth rate RBMs
4. Geometrical formula leads to analytical expression of C at outer midplane
5. We combine (3) and (4) to include shaping effects in SOL turbulence

$$\gamma^2 = \gamma^2_{\mathrm{RBM}} \frac{\mathcal{C}(\kappa, \delta, q)}{3},$$



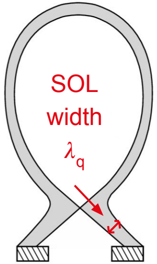
Reduced curvature in NT

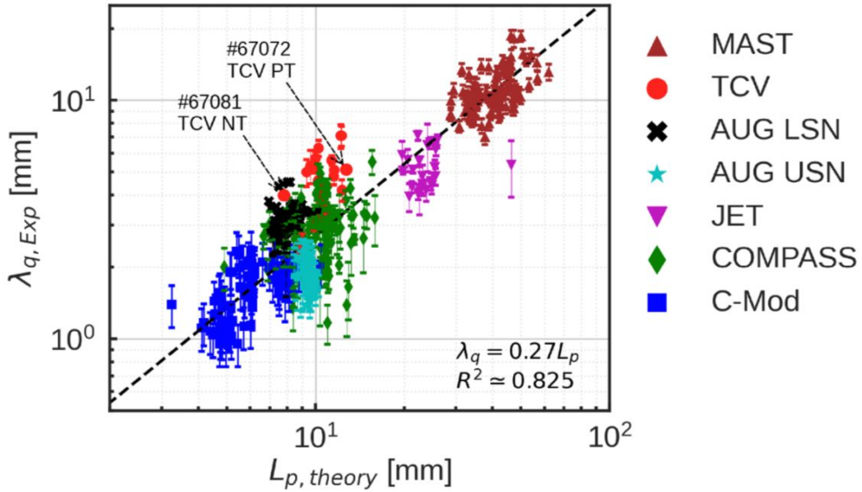
Theoretical scaling law for the SOL size, λ_q

We assume that all power crossing the separatrix reaches the targets

Reduced NT turbulence leads to small SOL size.

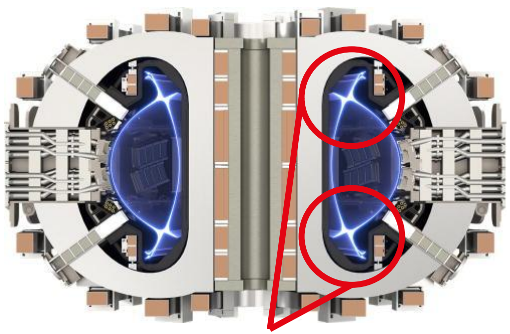
$$L_p \simeq 1.95\, C(\kappa,\delta,q)^{9/17} A^{1/17} q^{12/17} R_0^{7/17} P_{\mathrm{SOL}}^{-4/17} n_e^{10/17} \times B_T^{-12/17} L_\chi^{12/17},$$



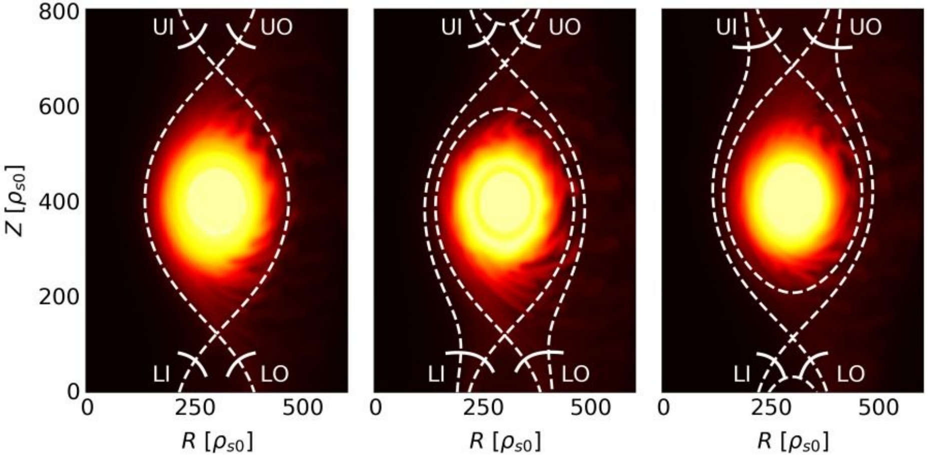


Consistent with experimental measurements

Power-asymmetry in DN configurations



Power is not evenly distributed



dR_{sep} = distance between inner and outer separatrices

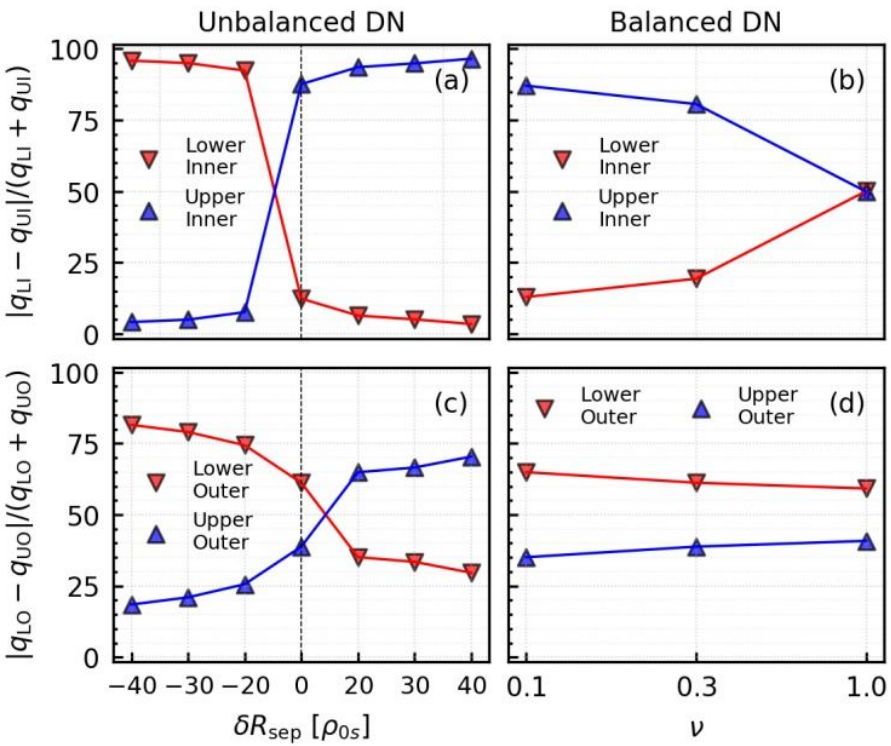
Even in perfect symmetric case, the upper-lower power is not evenly distributed.

Q) What is the physical mechanisms?

Q) What are the geometrical effects?

Q) Can we predict it?

Various factors drive up-down asymmetry in DN



Even in balanced **DN (dRsep=0)**, the heat flux is **not balanced** between the upper and lower targets

(1) **Increasing the value of dRsep** **enhances** the degree of asymmetry

(2) **Increasing plasma resistivity** (turbulent level) tends to **reduce** the degree of asymmetry

(3) Vertical diamagnetic drift **enhances** to up-down asymmetry

Scaling law for up-down power-sharing

Based on these observations **(1) dRsep (2) turbulence (3) diamag. drift** one can derive the analytical scaling law for power-sharing asymmetry.

$$|q_{LO} - q_{UO}| = q_{asym} = P_{SOL}\left[\alpha_{geo} + (1-\alpha_{geo})\alpha_d \alpha_{cst}\right]$$

$$L_p \sim 1.95 C(\kappa, \delta, q)^{9/17} A^{1/17} q^{12/17} R_0^{7/17} P_{SOL}^{-4/17} n_e^{10/17} B_T^{-12/17} L_\chi^{12/17}$$

$$\alpha_d \propto A^{-1/8} R_0^{1/12} B_T^{3/4} L_p^{-1/12} P_{SOL}^{-1/4} n^{-3/2} q^{-1}$$

q_ψ= total heat flux crossing the separatrix
α_d = dimensionless diamagnetic parameter
α_{geo} = effects of dR_{sep}, δ, κ

The scaling law is applicable for the prediction of power-sharing at the outer targets.

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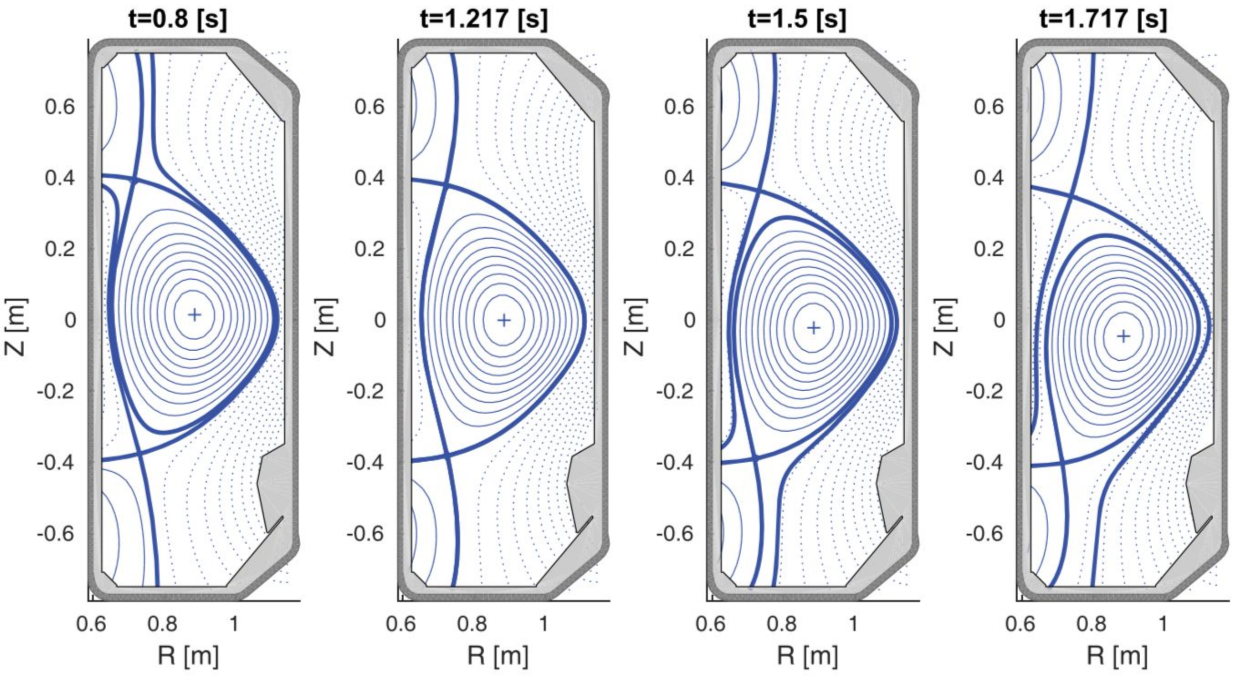
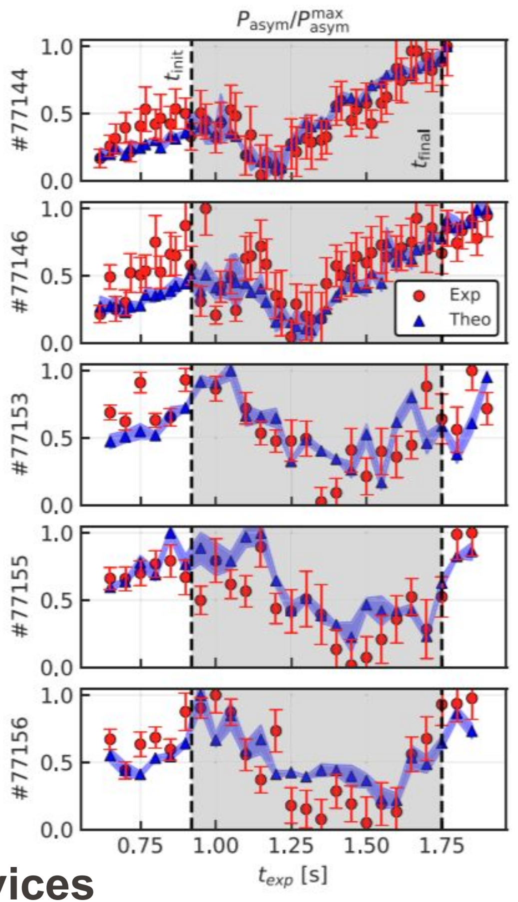
Validation of the scaling with TCV-DN discharges

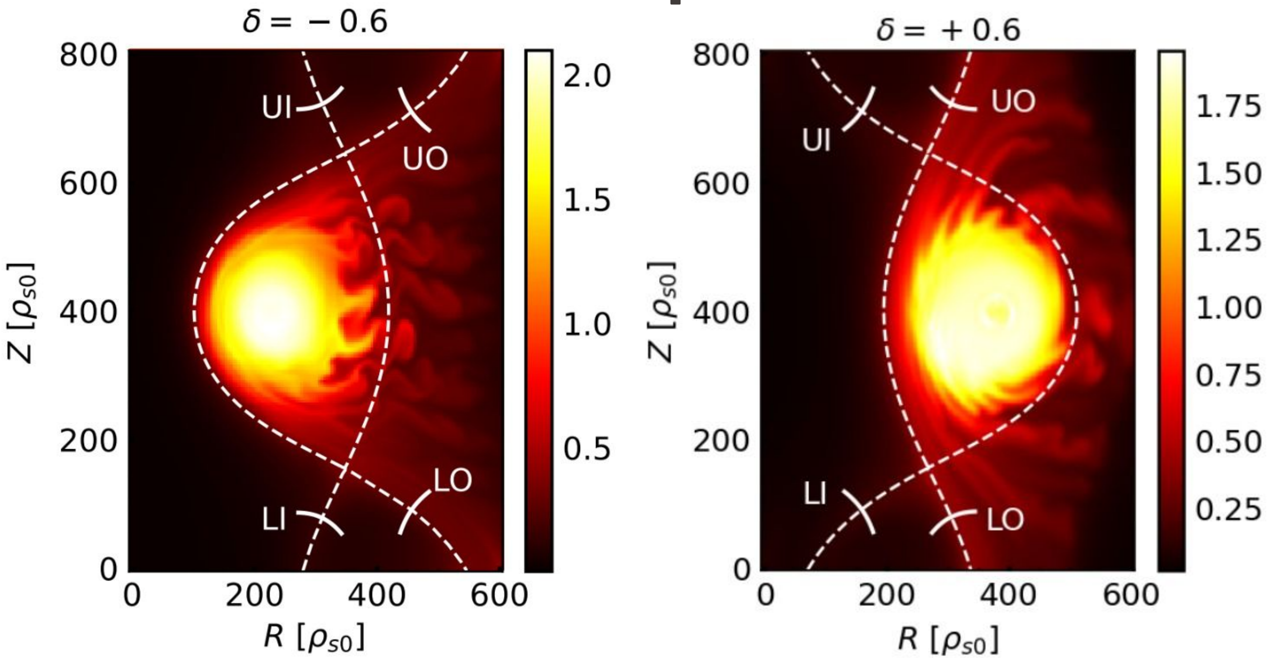


(a) $\delta R = 8$ [mm] (b) $\delta R = 0$ (c) $\delta R = -15$ [mm] (d) $\delta R = -29$ [mm]



This scaling law can be extrapolated to the future devices

Effects of NT in DN-SOL plasmas

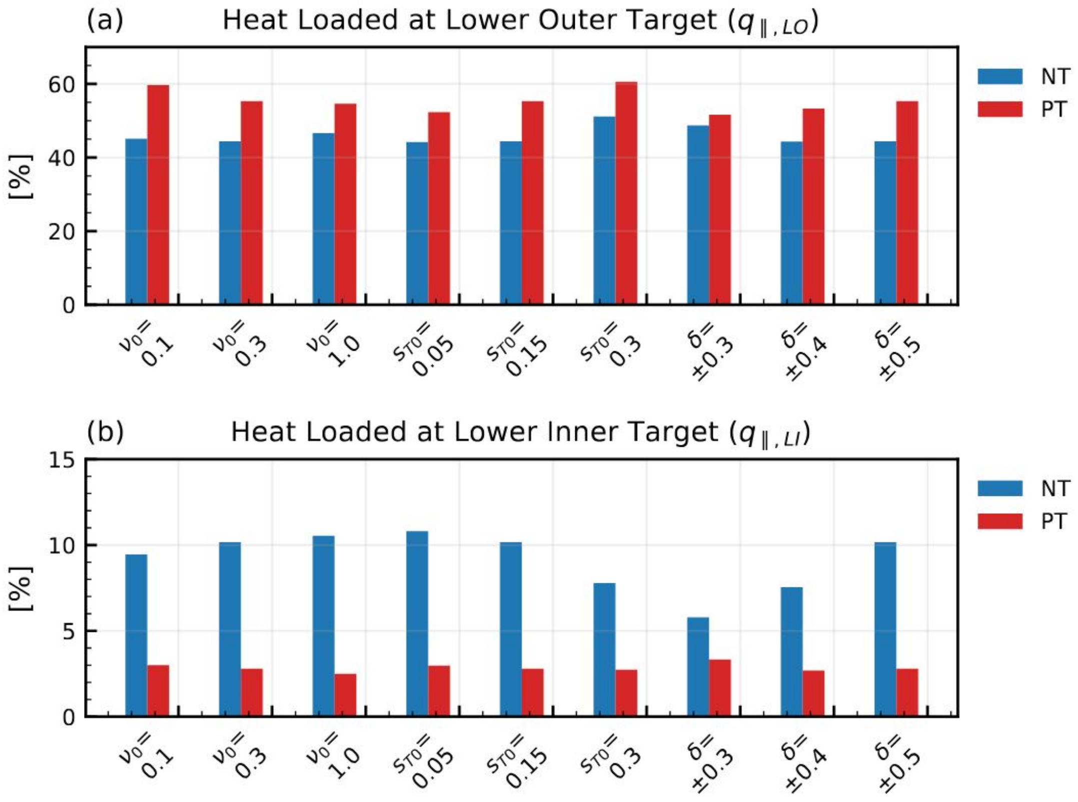


NT plasmas are found to reduce SOL turbulence

DN configurations provide four target plates, beneficial for power handling

Q) what if we combine these two?

Power load at the targets of DN PT/NT plasmas



The sign of B is set so that the majority of the heat flux flows to the lower targets.

NT plasmas exhibit reduced power loads on the targets.

However, there is **a stronger inner flux in NT**, which is **harder to control.**

This may be related to the **challenging NT detachment**

Effects of NT on blob dynamics

The two-region model is often used to describe blob dynamics.

This model uses the **interchange drive as the blob generation mechanisms**

NT will affect blob drive, thereby altering blob behaviours, **size** and **velocity**

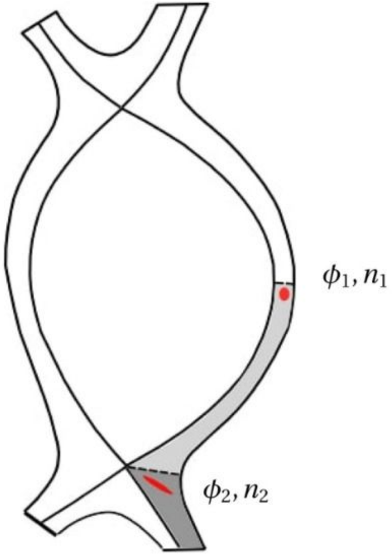
$$\frac{\partial \omega_1}{\partial t} + \frac{R_0}{\rho_{s0}}[\phi_1, \omega_1] = \frac{1}{n_1}\nabla_{\|} j_{\|1} + \frac{2T_{e1}}{n_1}\mathcal{C}(n_1)$$

$$\frac{\partial n_1}{\partial t} + \frac{R_0}{\rho_{s0}}[\phi_1, n_1] = 0$$

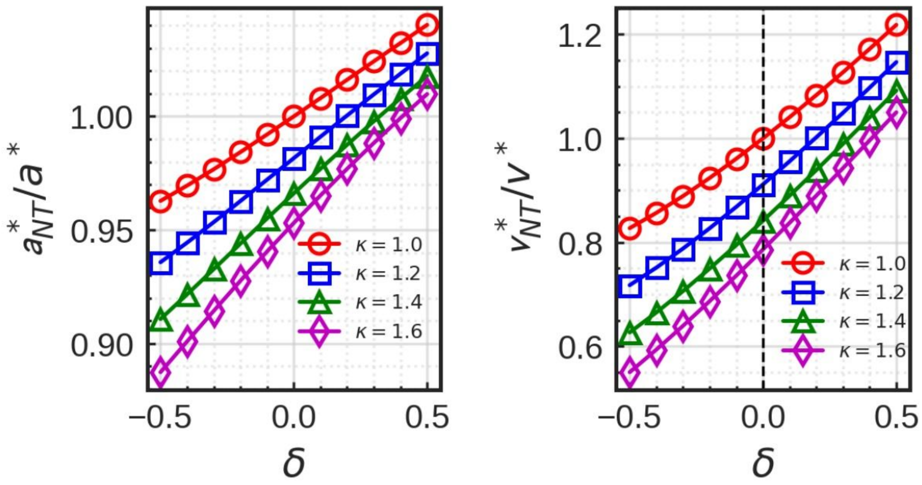
$$\frac{\partial \omega_2}{\partial t} + \frac{R_0}{\rho_{s0}}[\phi_2, \omega_2] = \frac{1}{n_2}\nabla_{\|} j_{\|2}$$

$$\frac{\partial n_2}{\partial t} + \frac{R_0}{\rho_{s0}}[\phi_2, n_2] = 0$$

Inter-change drive



Theoretical scaling for blob size and velocity



blob size

$$a^* \propto \mathcal{C}(q, \delta, \kappa)^{1/5} a^*_{\text{ref}},$$

$$v^* \propto \mathcal{C}(q, \delta, \kappa)^{1/2} v^*_{\text{ref}},$$

blob velocity

ref = scaling without shaping

Linearization of blob size leads to the derivation of the blob scaling law

NT plasmas are characterized by **smaller and slower blobs**
PT plasmas are characterized by **larger and faster blobs**

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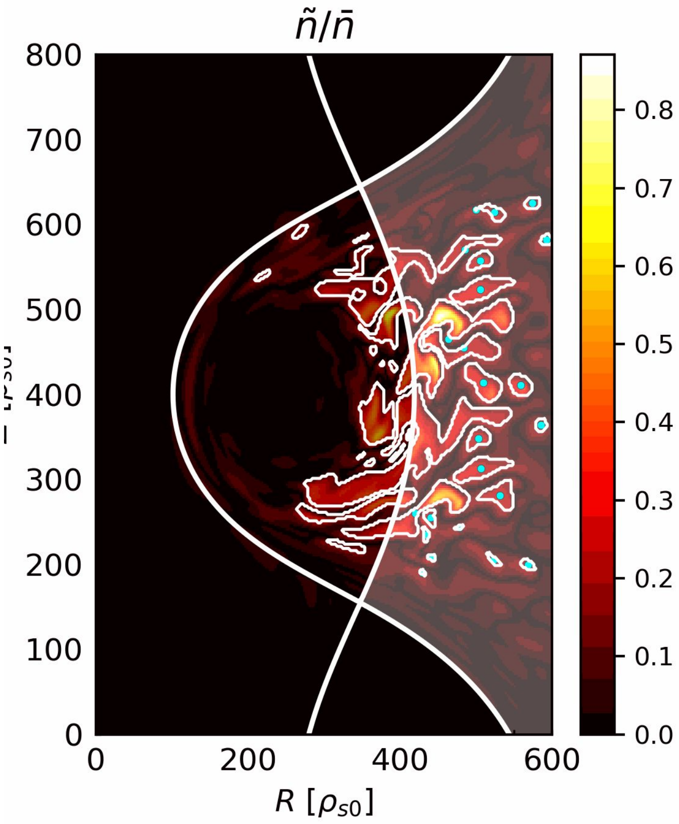
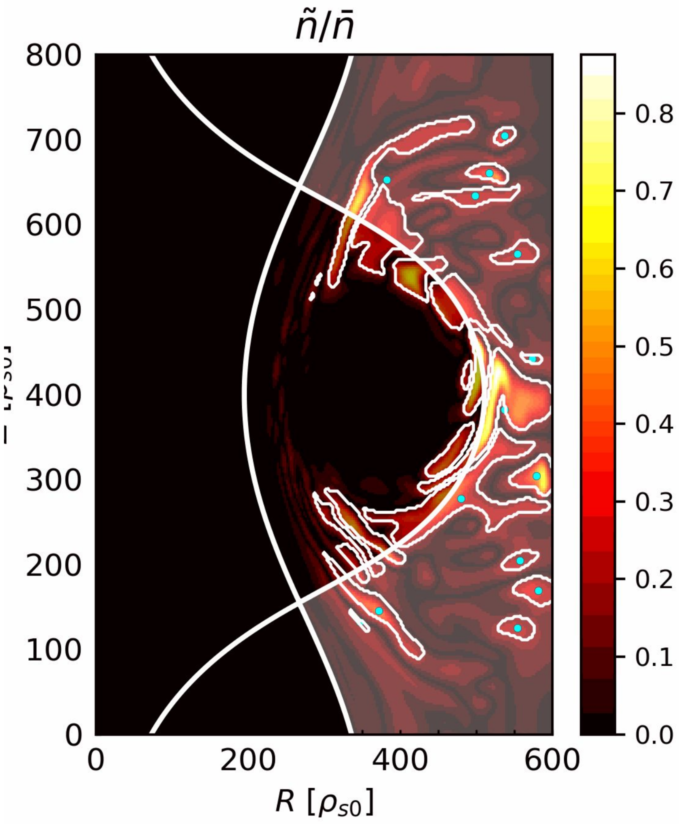
2D animation of blob dynamics

only bad curvature & outside separatrix blobs are detected





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Detection of blobs in NT/PT plasmas

	$\nu_0 = 0.1$		$\nu_0 = 0.3$		$\nu_0 = 1.0$		$s_{T0} = 0.05$		$s_{T0} = 0.15$		$s_{T0} = 0.3$	
	PT	NT	PT	NT	PT	NT	PT	NT	PT	NT	PT	NT
# Blobs	370	392	310	337	301	336	246	353	310	337	273	450
Size $[\rho_{s0}]$	7.66	7.03	8.89	7.12	9.96	7.85	9.95	7.69	8.89	7.12	7.01	6.21
Velocity $[c_{s0}]$	0.07	0.05	0.12	0.10	0.15	0.10	0.12	0.09	0.12	0.10	0.16	0.07

NT : smaller size, slower velocity, but **numerous blobs**

Nb of blobs is related to the shearing rate due to steep gradient in NT.

NT mitigated wall-interaction also observed in TCV experiments.

Other on-going works

Ongoing works

1. **Detachment in NT plasmas**: NT plasmas is harder to achieve the detachment

2. **Neoclassical physics in NT plasmas for impurity transport**: conventional NC theory assumes a circular flux surfaces. Shaping will change the analytical expressions.

3. **Theoretical scaling law for density limit & HL back-transition**: Reduced boundary turbulence allows us to contain more density.

4. **Up-down asymmetric triangularity**

5. **Effects of NT on electromagnetic & drift-wave**