A model of interchange turbulent transport across separatrix with sheared flows

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Context and motivations

- **Filamentary turbulent transport** is thought to be responsible of the **turbulent transport** across flux surfaces in tokamak plasma edges and scrape-off layers (SOL) as proposed by the isolated filament model (IF model)[1-3]
- Link between turbulent transport and **confinement properties** as SOL width or energy confinement time not fully understood
- **Interplay** between **turbulence & shear flow** : turbulence mitigation & shear flow generation through Reynolds stress → increase of confinement
- **Geometry** strongly impacts both transport & edge shear flow generation : **favourable/ unfavourable configuration** [4]

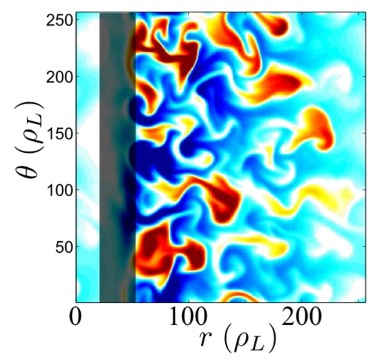
→ Analytical model of edge transport with shear flows is needed

Spectral Filament Model

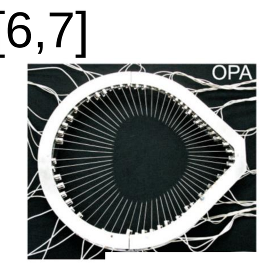
- TOKAM2D isothermal model : Braginskii's equation averaged on field line + flux conservation in scrape-off layer (SOL) [5] :

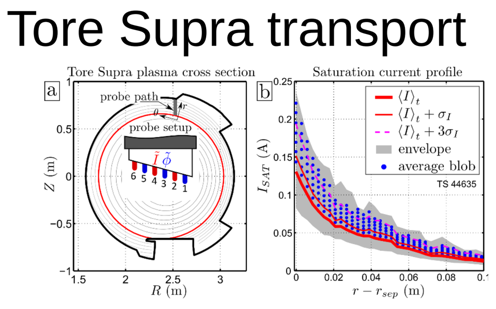
$$(\partial_t - D_\perp\Delta_\perp)n = [n,\Phi] - n\sigma_{||}e^{(\Lambda-\Phi)} + S$$

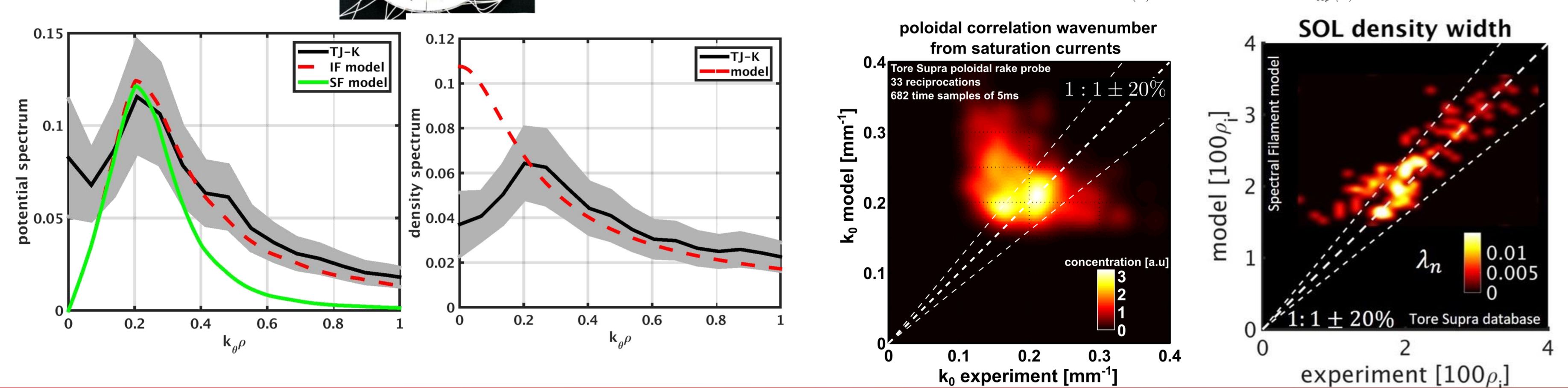
$$(\partial_t - \nu\Delta_\perp)\Delta_\perp\Phi = [\Delta_\perp\Phi,\Phi] + \sigma_{||}\left(1-e^{(\Lambda-\Phi)}\right) - \frac{g\partial_y n}{n}$$



- Quantitative description of limiter SOL properties [1,2] for :
  - Intermittent transport (blob)
  - Exponentially decaying equilibrium profiles
- Model reduction via poloidal spectra inspired from isolated filament model [3]
  - Sheath loss & mode coupling saturation phenomena
  - Allows prediction for transport observables
- Verified with a 2D non-linear flux-driven simulation database
- Recovers poloidal spectra from TJK discharge & Tore Supra transport observables [6,7]

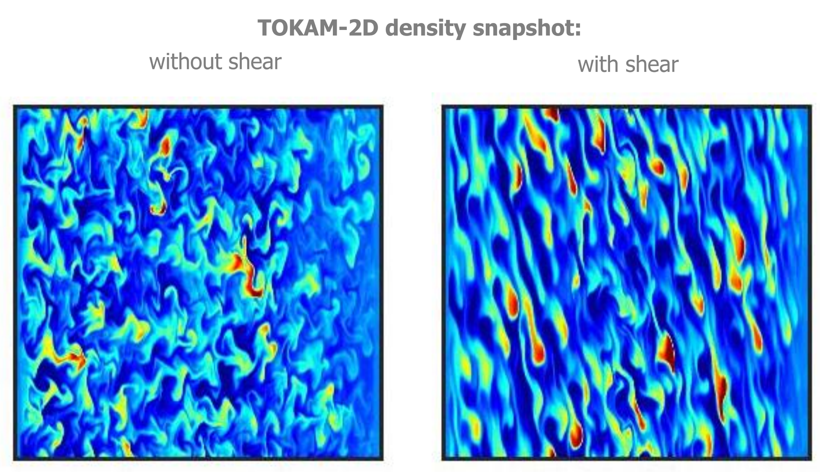




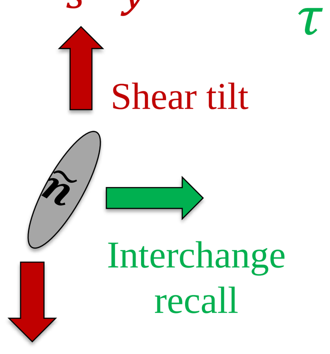


Sheared Spectral Filament Model

- Introduction of uniform **shear σ_s+ interchange recall → Constant tilt**



$$\partial_t k_x = -\sigma_s k_y - \frac{k_x - k_x^0}{\tau}$$

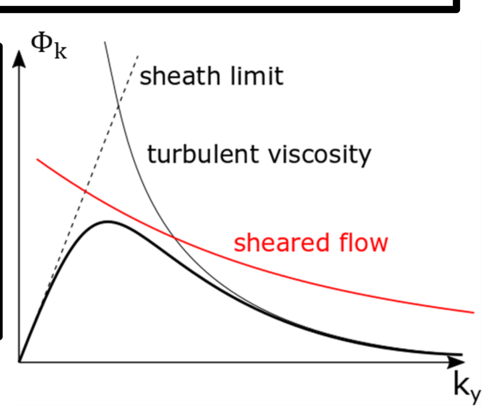


$$\Phi_k = \frac{\frac{gk_y}{k_0}}{\sigma_{||}\lambda_n\sqrt{1+\frac{k_y^2}{k_0^2}(1+\sigma_s^2\tau^2)}\left(1+\frac{2\sigma_s^2\tau^2}{\sigma_{||}\tau}k_y^2+\frac{1}{7}\frac{k_y^4}{k_0^4}\right)}$$

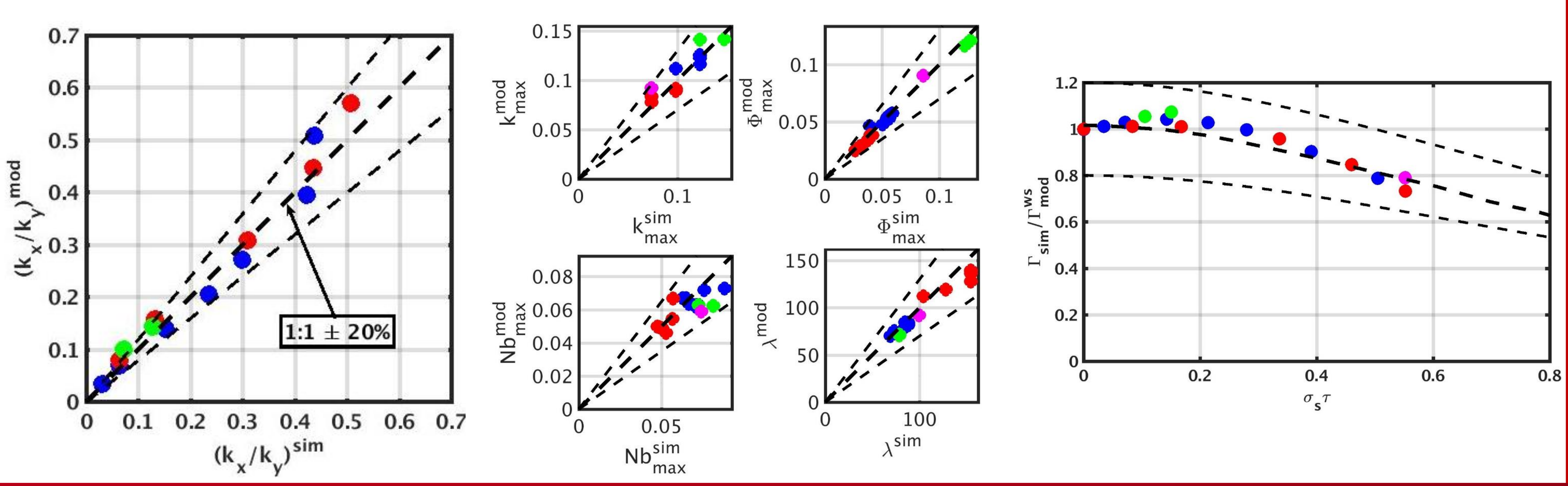
$$n_k = \frac{1}{\lambda_n k_0\sqrt{1+\frac{k_y^2}{k_0^2}(1+\sigma_s^2\tau^2)}}$$

$$\tau = 0.43\sqrt{\frac{\lambda_n}{g}} \qquad k_0 = \frac{1.06\sqrt{\sigma_{||}\tau}}{(1+\sigma_s^2\tau^2)^{0.25}}$$

Saturation phenomena :
Sheath losses
Turbulent viscosity
Reynolds stress
k^2 spectral energy spreading



- Verified against simulations (colors = pairs of $[g,\sigma_{||}]$)

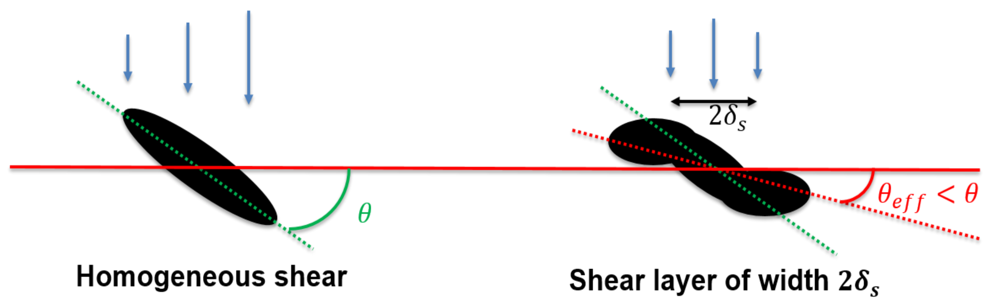


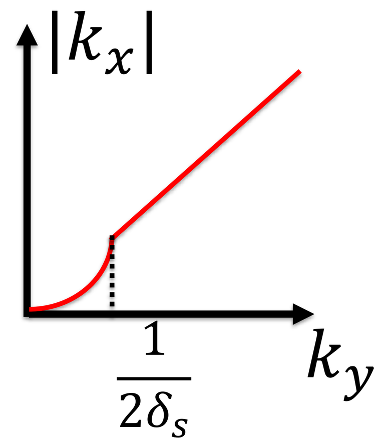
Impacts of the geometry on turbulence

- Pedestal structure size ~ $10\rho_L$ ~1cm ~ shear layer width δ_s

→ Mitigation of structure tilt

→ $k_x = f(\gamma_{E\times B}, \delta_s, k_y, \tau)$

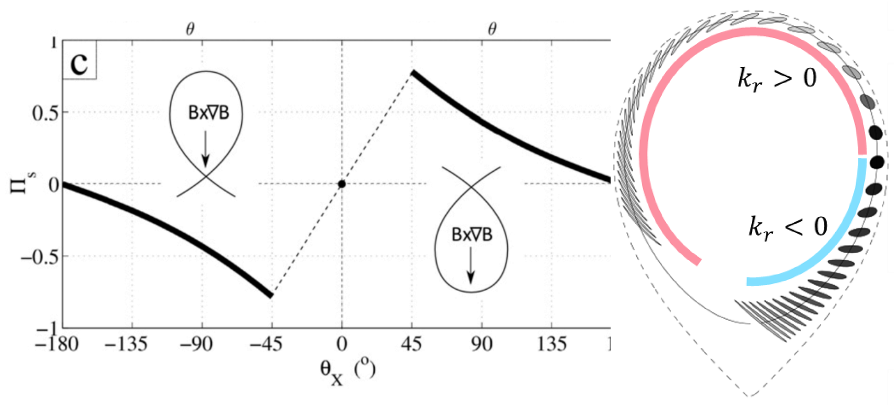




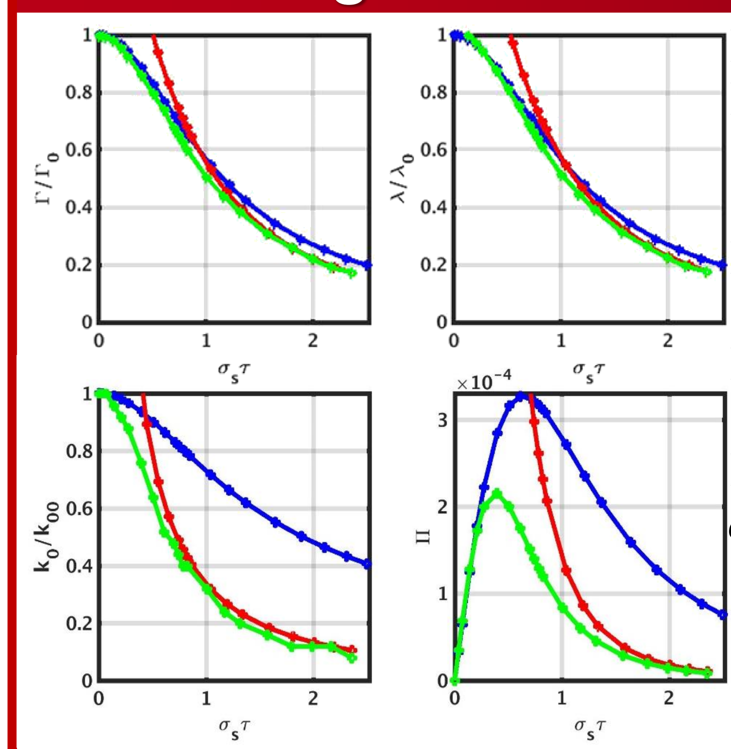
- **X-point or limiter :**

→ Non-zero flux surface average of magnetic shear induced tilt [8,9]

→ Magnetic shear induced Reynolds stress



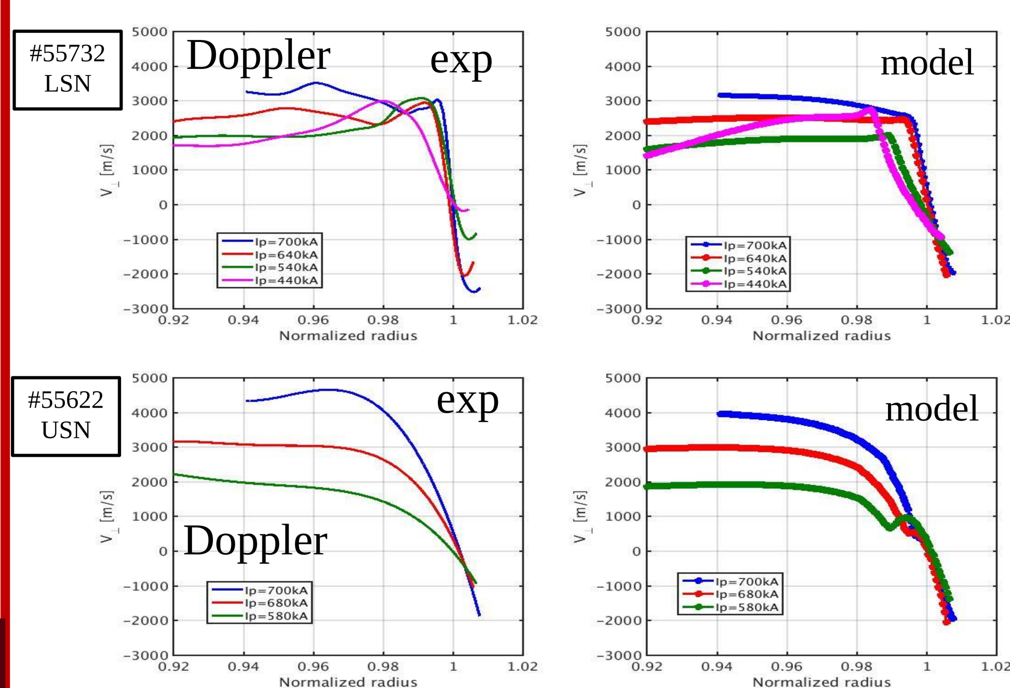
1D flow generation model : comparison with experiment



- **Weak** to **strong** shear regime transition @$\sigma_s\tau \approx 0.4$
- Reynolds stress increases with k [10]
  → k_0 decreases
- **Reynolds** stress shows **maximum** at regime transition
- Similar radial flux drops in both regimes
  → weak impact of Reynolds stress
- Decrease flux by factor 2 needs :
  $\sigma_s \approx [0.5-1]\times 10^{-2}w_i \approx 10^6 s^{-1}$
  →Corresponds to $\frac{10\ km.s^{-1}}{1\ cm}$ as for **L-H transition** in pedestal

$$\partial_t V_{E\times B} = -\partial_r \Pi_{turb} - (\nu - \chi\partial_r^2)(V_{E\times B} + V_i^{dia}) - \chi_{SOL}(V_{E\times B} - V_{E\times B}^{SOL})$$

SSF model — Neoclassical — Ion diamagnetic velocity — $-\frac{3\partial_r T_e}{ZB}$



- **WEST experiments** :

→ Impact of geometry on edge rotation
  - Unfav. config. (USN) deeper than fav. config. (LSN)

→Non standard feature
  - Difference vanishes @ high Ip
  - No clear well in unfav. config.
- **Model recovers both Ip & config. dependencies for edge rotation**

Conclusion and persepectives

- Derivation of a **model of edge turbulent transport** verified against simulations & validated against experiment
- Derivation of a model of **impact of background shear on interchange** :

→ **Spectral** model + structure **tilt** model

- Validation against 2D flux-driven simulations for turbulence properties (Φ_k, n_k, k_0)

& transport (Γ_r, λ)

- Impact of shear on density and potential perturbations phase shift not treated

→ does not seem to be important in our simulations

- **Spatial variation of shear** taken into account

→**1D model on shear flow generation by Reynolds stress** with **magnetic shear** :

→Validation of the 1D model against **WEST experiment**

→Recovery of **geometry** and **Ip dependencies** of edge rotation

References

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