Synergetic effects of collisions, turbulence and sawtooth crashes on impurity transport.

X. Garbet[1], J.H. Ahn[1], S. Breton[1], P. Donnel[1], D. Esteve[1], R.Guirlet[1], H.Lütjens[2], T. Nicolas[3], Y. Sarazin[1], C. Bourdelle[1], O. Février[1], G. Dif-Pradalier[1], P. Ghendrih[1], V. Grandgirard[1], G.Latu[1], J.F. Luciani[2], P.Maget[1], A. Marx[2], A. Smolyakov[4]

1) CEA, IRFM, F-13108 Saint Paul-lez-Durance, France

2) Centre de Physique Théorique, Ecole Polytechnique, CNRS, Palaiseau, France

3) Swiss Plasma Center, Switzerland

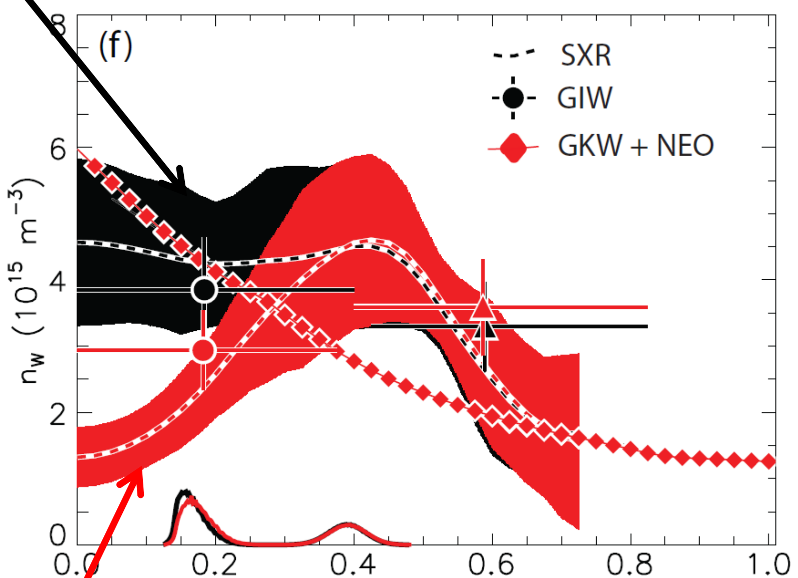
4) University of Saskatchewan, Saskatoon, Canada

Motivation : impurity transport

- Tungsten plasma facing components → impurity accumulation in the core ?
- Neoclassical and turbulence transport processes compete

  Casson 13, Angioni 14
- Interplay with MHD events : tearing modes, ELMs, sawtooth crashes Hender 16, Sertoli 15

After crash



Normalized minor radius

Before crash

Asdex Upgrade – tungsten density- Sertoli 15

Outline

1) Interaction between turbulent and neoclassical transport.

2) Interaction between sawtooth cycles and neoclassical transport.

Punchline : interplay between different contributions to impurity transport are mediated by large scale flows

Impurity transport modelled with gyrokinetics or MHD with closure

- Gyrokinetic description (GYSELA code) : $d_t F = C(F)$ + Poisson equation→ neoclassical and turbulent transport Grandgirard 16
- MHD equations (XTOR code) + impurity density and momentum equations Lütjens 10

pinch velocity

diffusion

$$= \langle N\mathbf{V} \rangle_{turb}$$

collisional friction force → neoclassical flux

$$\frac{\partial N}{\partial t} + \nabla \cdot (N\mathbf{V}) = \nabla \cdot (\mathcal{D} \nabla N - \mathcal{V} N)$$

$$Nm\left(\frac{\partial}{\partial t} + \mathbf{V} \cdot \nabla\right)\mathbf{V} = Ne\left(\mathbf{E} + \mathbf{V} \times \mathbf{B}\right) - \nabla \cdot \mathbf{\Pi} + \mathbf{R}$$

→ Pfirsch-Schlüter transport included in the fluid dynamics

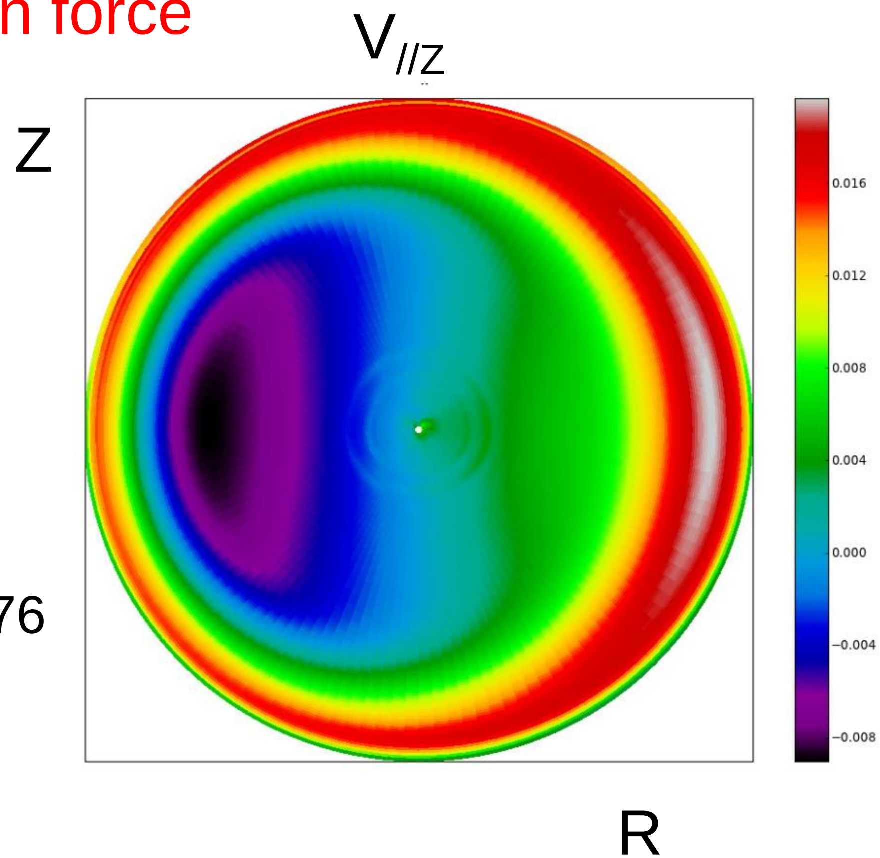
→ neoclassical and MHD transport

Impurity neoclassical flux is related to parallel friction force

- Neoclassical flux

// collisional friction force

$$\Gamma^{\psi} = -\frac{B_T R}{Ze}\left\langle \frac{R_{\parallel}}{B} \right\rangle$$



- Pfirsch-Schlüter convection cell due to perpendicular compressibility Hinton & Hazeltine 76

- controls Γ^{ψ} at high collisionality $\nu^*_Z>1$

Neoclassical thermal screening works against accumulation

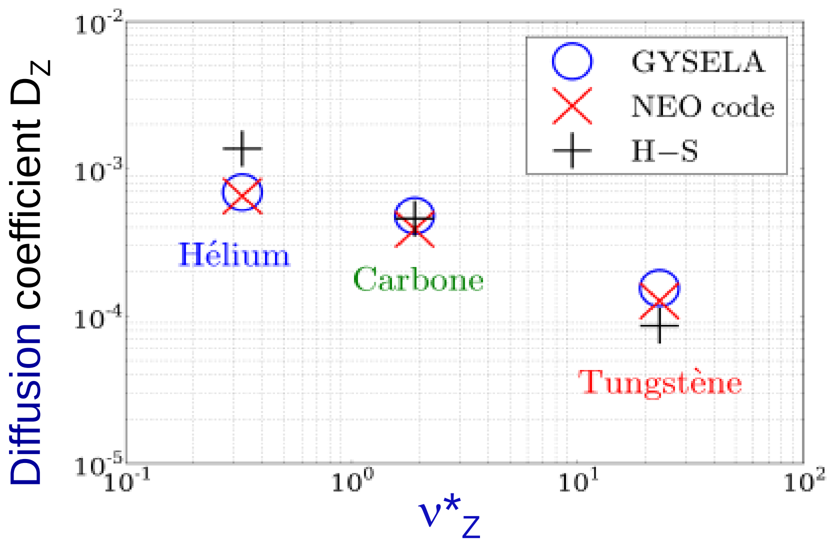
- General form of the impurity flux Hirshman & Sigmar 81

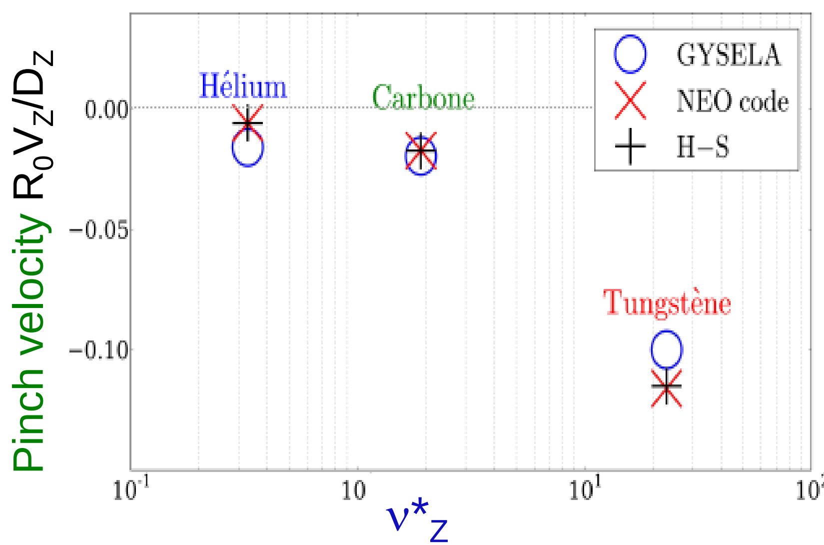
$$\frac{\Gamma_{Z\psi}}{D_{neo}N_Z} = -\frac{\partial \ln N_Z}{\partial r} + Z\frac{\partial \ln N_i}{\partial r} + HZ\frac{\partial \ln T_i}{\partial r}$$

Accumulation — Thermal screening

- Impurity collisional, ions weakly collisional→ **H = -1/2** Hirshman 76

- GYSELA benchmarked against theory and NEO code Belli 08





Neoclassical and turbulent transport processes are synergetic

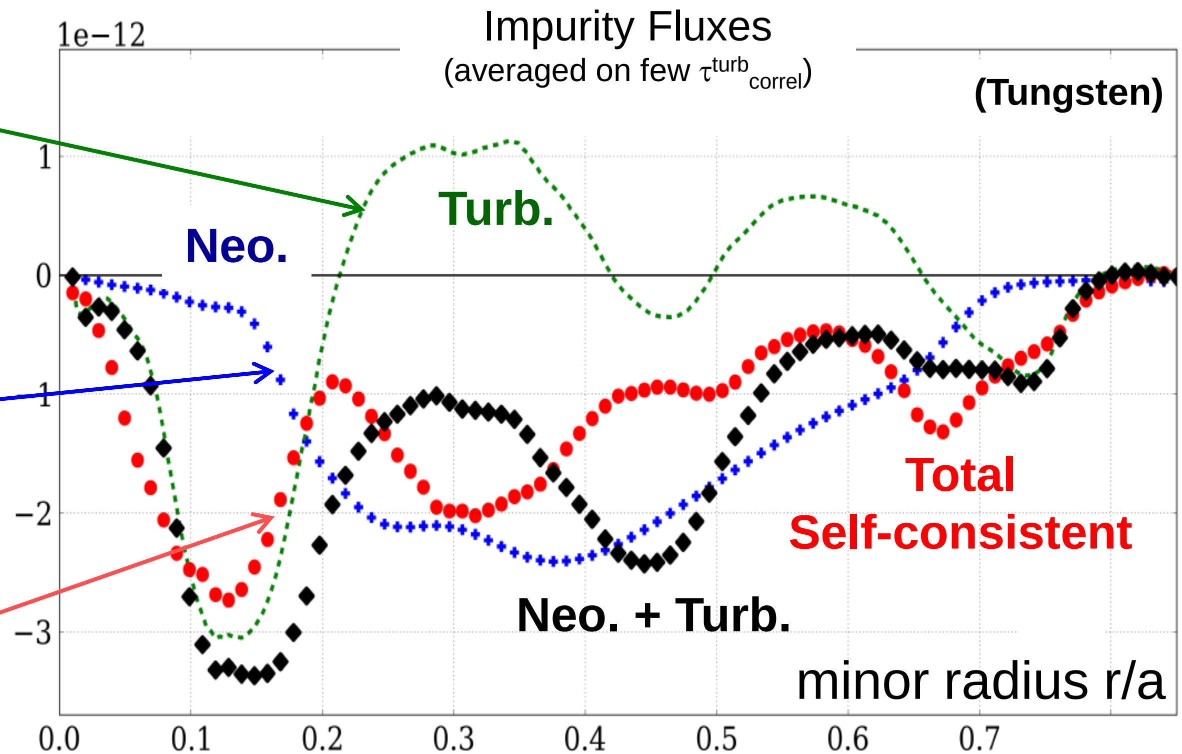
- Neoclassical and turbulent contributions isolated by playing with collisionality and symmetries

- Total flux ≠ neoclassical + turbulent

Turbulent, friction force $R_{//Z}=0$

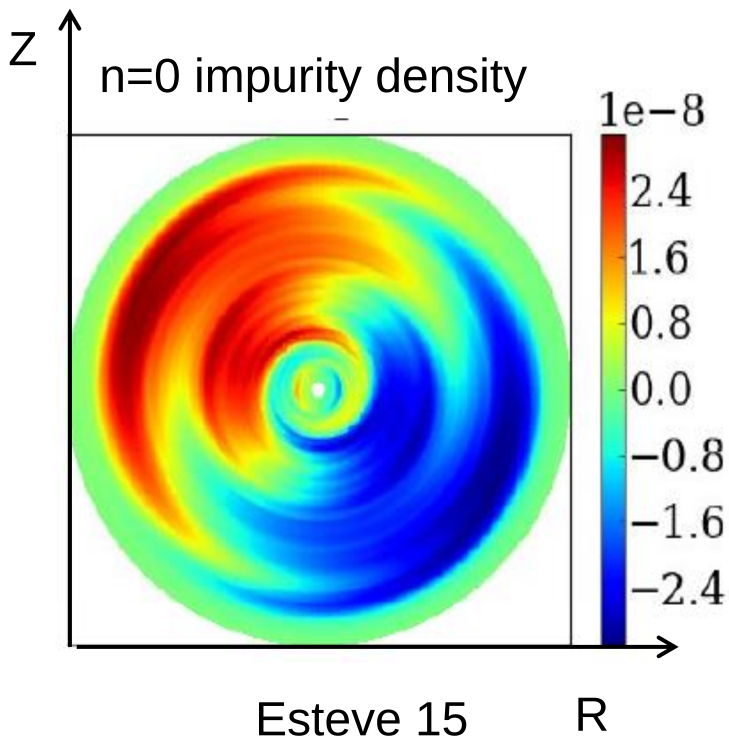
Neoclassical $R_{//Z}\neq 0$, axisymmetric n=0 modes only

Self-consistent $R_{//Z}\neq 0$, all modes

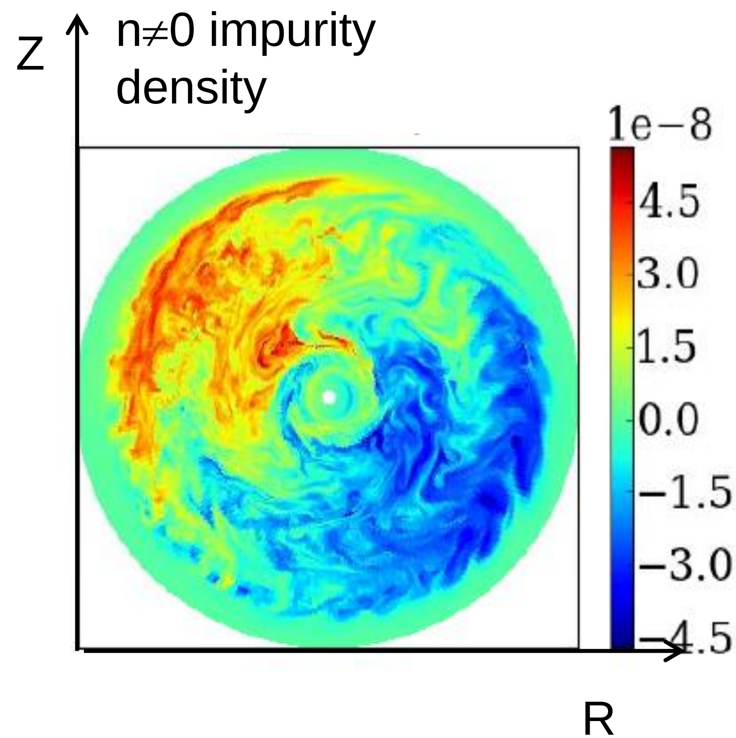


Interplay is mediated by poloidal convective cells

- Turbulent Reynolds stress → poloidal convective cells
- Poloidal asymmetries → change neoclassical impurity flux
- // momentum transport, turbulence self-regulation Diamond 05

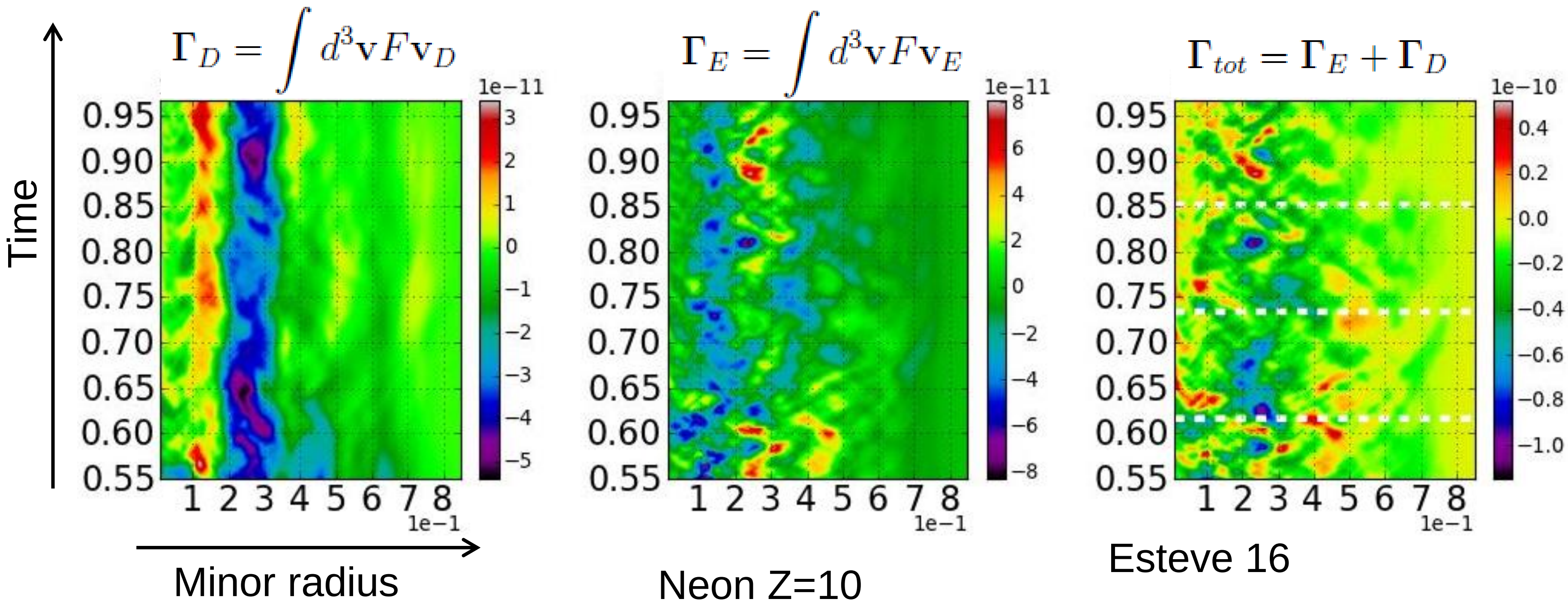


Esteve 15



Curvature and ExB fluxes are anticorrelated

- Anti-correlation due to poloidal convective cells
- Thermal screening factor H>-1/2 : consequence of static density poloidal asymmetries? Romanelli 98, Fülöp 99, Angioni 14, Breton 16



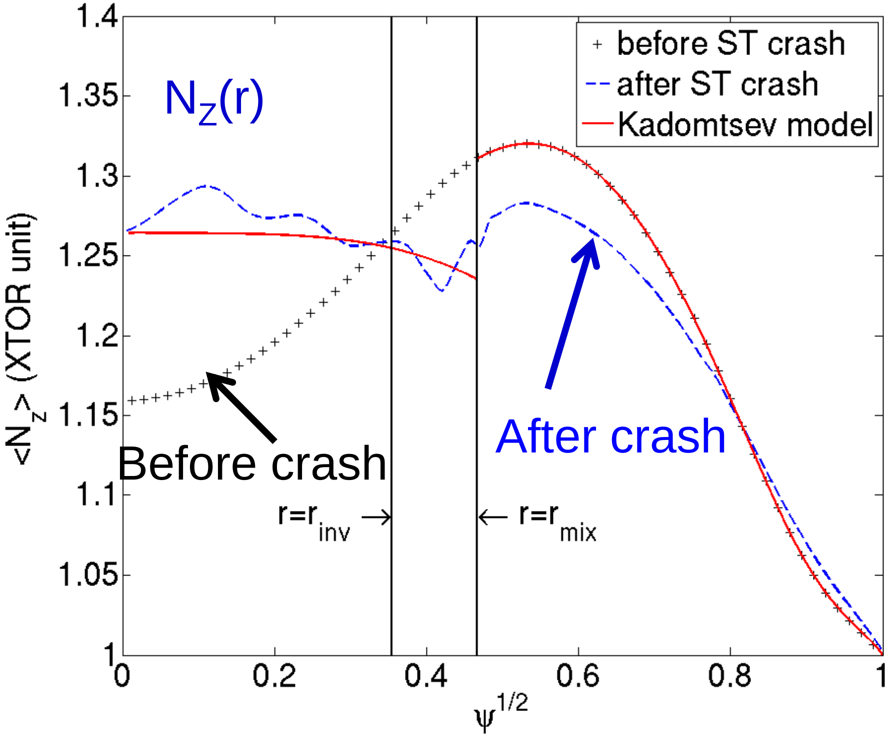
Neon Z=10

Esteve 16

Fast relaxation of the impurity density profile during a sawtooth crash

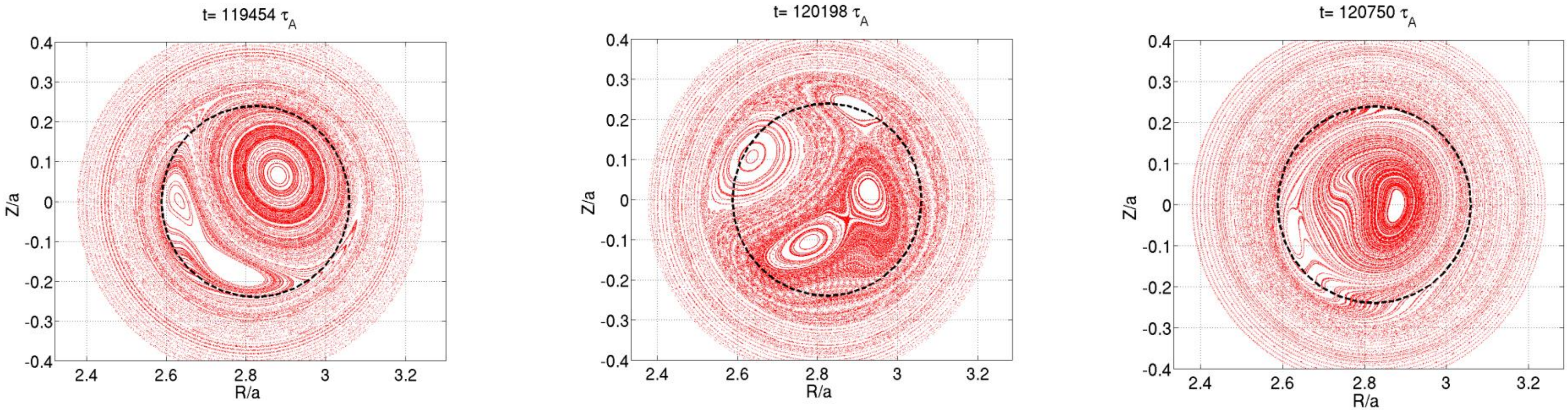
- $\nabla N_i=0$, $\nabla T_i\neq 0 \rightarrow$ screening
- Crash time << collision time → neoclassical transport processes inefficient during crash
- Post-crash profile consistent with Kadomtsev model Kadomtsev 75, Porcelli 96, Nicolas 15

Ahn 16



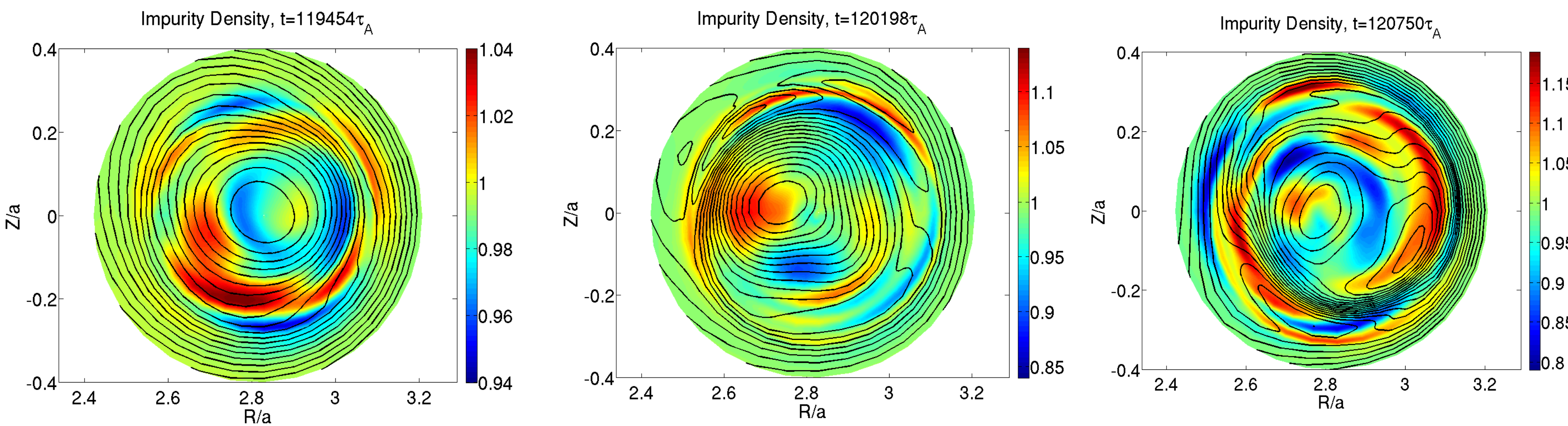
Normalized minor radius

ExB drift is the main cause of impurity transport during a sawtooth crash



Poincaré map of magnetic field lines

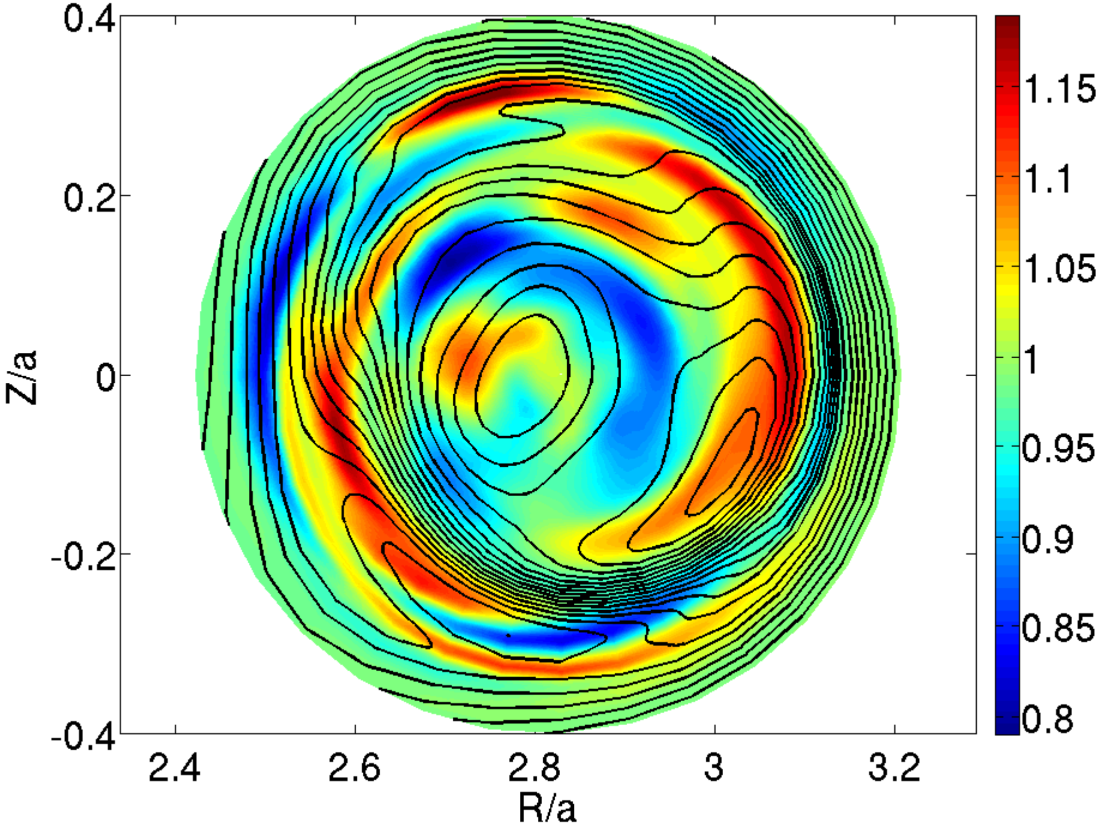
time →



Impurity density and stream function

ExB drift is the main cause of impurity transport during a sawtooth crash (cont.)

Impurity density and stream function



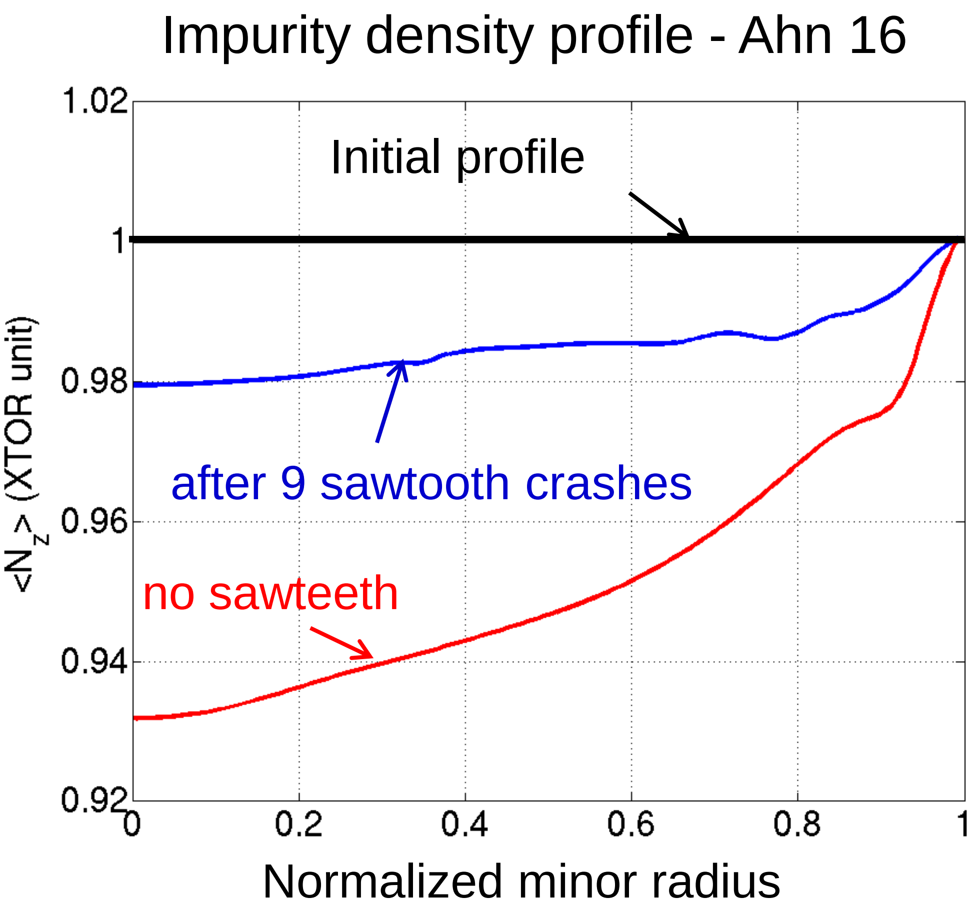
- ExB impurity flux ~10 flux due to magnetic flutter
- Consistent with SXR measurements on TFTR Nagayama 91

Sawteeth change the impurity profile on long time scales

- Neoclassical transport dominant during recovery phase, but ion temperature gradient is lower

→ weaker thermal screening effect

- Overall temperature profile flatter with sawteeth



Conclusion

- Interplay between turbulent and neoclassical transport processes:

- poloidal convective cells generated by turbulence → poloidal asymmetries – total flux ≠ turbulent + neoclassical calculated separately. Should play at low rotation speed (e.g. EAST, WEST, ITER)
- thermal screening gets weaker

- Sawteeth cycles affect neoclassical transport

- crashes flatten impurity density profile + lower main ion temperature gradient → thermal screening less efficient