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Work with Novatron Fusion Group
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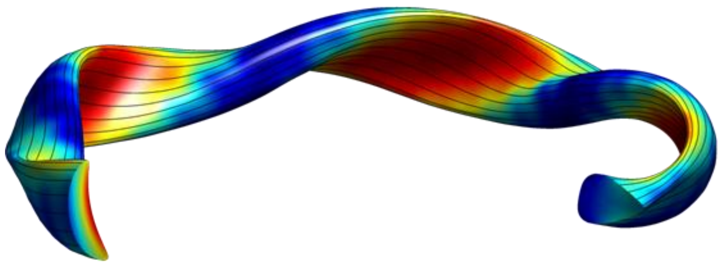
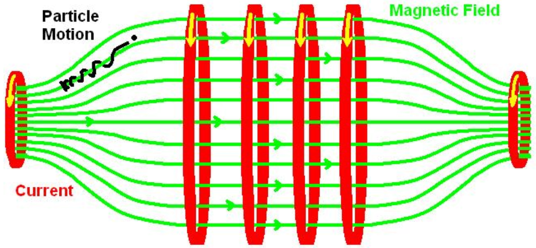
Research Interests

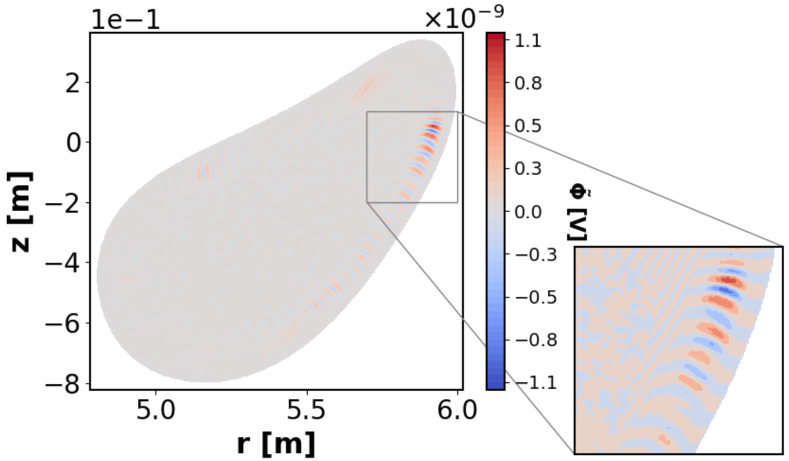


Wendelstein 7-X stellarator
IPP Greifswald, Germany

- Confinement in magnetic fusion plasmas.
- Study transport of particles and energy in tokamaks and stellarators
  - Turbulent transport → gyrokinetic modelling.
  - Collisional (“neoclassical”) transport → drift-kinetic modelling.
- Gyrokinetic simulations often numerically demanding but can scale well with parallelization.
- Drift-kinetic simulations significantly cheaper but usually also require supercomputers.

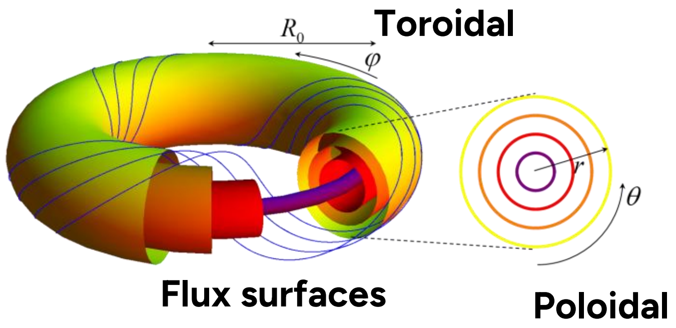
- Magnetic mirrors (open field lines) likely to need the same type of kinetic transport modelling when parallel confinement is good enough.





Electrostatic potential fluctuation over a cross-section in a gyrokinetic simulation of Wendelstein 7-X with the particle-in-cell code XGC.

Radial transport particles/energy in fusion plasmas



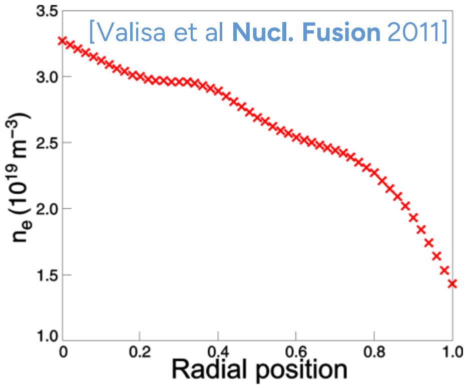
- The charged particles are tied to “flux surfaces” traced out by the magnetic field lines.
- To achieve ignition the energy confinement time should be long enough

⇒ minimize the radial transport.

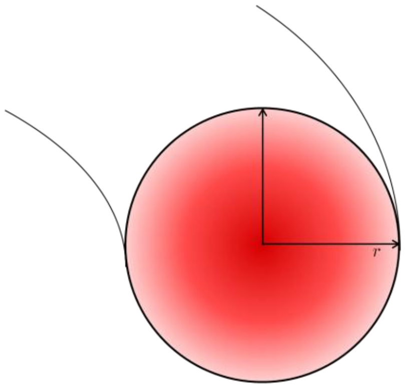
- The plasma profiles are normally “peaked”

⇒ large gradients of density ∇n and temperature ∇T drive transport outwards.

- The “free energy” available in the gradients also causes drift waves driving turbulent transport.

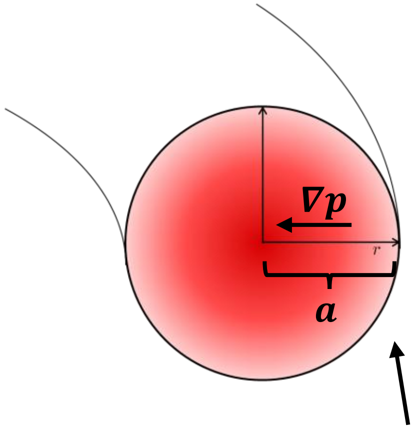


[Valisa et al **Nucl. Fusion** 2011]



Drift waves in fusion plasmas

- Destabilized by ion/electron magnetic drifts or by resonant parallel dynamics.
- The most common ones are the Ion Temperature Gradient mode (ITG) and the Trapped Electron mode (TEM):
    - Electrostatic, i.e., magnetic fluctuations neglected.
    - Driven by ∇n and ∇T.
    - Ion-scale turbulence.
    - Low frequency $\omega \sim (T_e/m_i)^{1/2}/a \ll \Omega_{ci}$.
    - Wave number $k_\perp \rho_i \lesssim 1$.



Bad magnetic curvature

- In some scenarios electron-scale turbulence, e.g., the Electron Temperature Gradient mode, is important but computationally expensive to simulate.
- Electromagnetic modes start to play a role for finite $\beta \equiv 2\mu_0 p/B^2$.

Gyrokinetic theory

- Distribution function and electromagnetic fields split into perturbed and equilibrium parts:

$$f_s = F_s + \delta f_s, \qquad \mathbf{E} = \mathbf{E}_0 + \delta\mathbf{E}, \qquad \mathbf{B} = \mathbf{B}_0 + \delta\mathbf{B}$$

Fokker-Planck equation

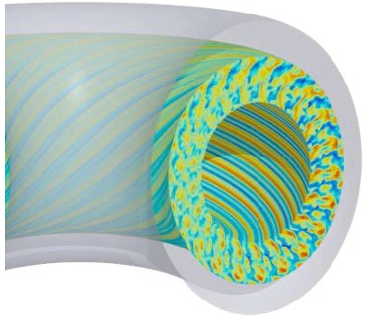
$$\left\{\frac{\partial}{\partial t} + \mathbf{v}\cdot\nabla + \frac{q_s}{m_s}\left[(\mathbf{E}_0 + \delta\mathbf{E}) + \mathbf{v}\times(\mathbf{B}_0 + \delta\mathbf{B})\right]\cdot\frac{\partial}{\partial\mathbf{v}}\right\}(F_s + \delta f_s) = C_s[F_s + \delta f_s]$$

Collision operator

- Expansion in $\rho_* = \rho_i/a$: $\frac{\delta f_s}{F_s} \sim \frac{k_\parallel}{k_\perp} \sim \frac{\omega}{\Omega_c} \sim \rho_*$.
  This expansion is not always good, e.g., in a pedestal with strong gradients.
- Average over gyro motion.
- Couple species through Poisson equation/Ampère's law.
- Flux-surface-average of the radial flux $\langle \Gamma_s \cdot \nabla r\rangle = \left\langle \int d^3v\, f_s\, \mathbf{v}\cdot\nabla r\right\rangle$.

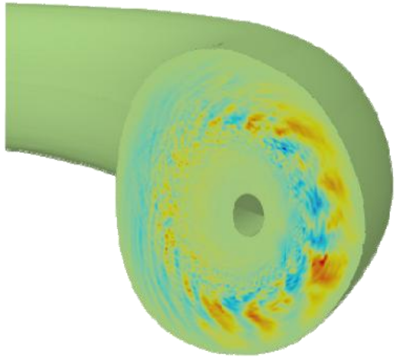
Gyrokinetic simulations

Local

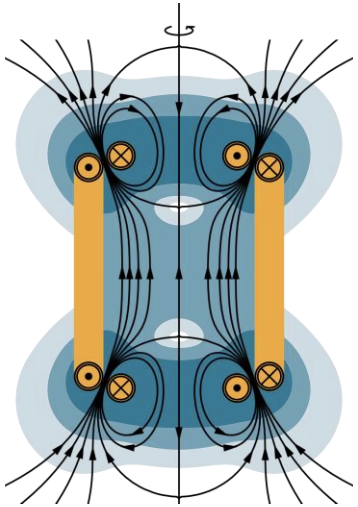


Annulus or flux-tube
$n, T, \partial n/\partial r, \partial T/\partial r$ constant
Periodic boundary conditions
Less expensive

Global



Full domain
n, T profiles
Dirichlet/Neumann b. c.
More expensive



Linear

Single mode (fastest growing)
$\delta Q \propto \exp(i\,\mathbf{k}\cdot\mathbf{r} - i\omega t)$
No absolute fluxes
Less expensive

Nonlinear

Several modes (truncated series)

$$\delta Q = \sum_{\mathbf{k},\omega} \delta\tilde{Q}_{\mathbf{k},\omega} \exp(i\,\mathbf{k}\cdot\mathbf{r} - i\omega t)$$

Mode coupling ⇒ absolute fluxes
More expensive

Planned future work: Gyrokinetic simulations in the magnetic mirror machine Novatron at KTH.