CWGM 2017 Oct. @ Kyoto ISHW
Transport modelling (Neoclassical transport part)
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- Recent research activities in CWGM

1. Phi1 effect on impurity neoclassical transport
2. Comparison among local drift-kinetic models
3. Bootstrap current calculation V&V

1. Phi1 effect on impurity neoclassical transport

- Variation of electrostatic potential on flux surface → impact on impurity transport
  - J.M. García-Regaña PPCF (2013) 074008 , Nucl. Fusion (2017) 056004

Assuming adiabatic response of electron and trace impurity : $\Phi_1 \cong \frac{T_e}{e}\left(n_{0e} + n_{0i}\frac{T_e}{T_i}\right)^{-1} n_{1i}$

n_{1i} : density anisotropy of bulk ions on flux surface evaluated from δf drift-kinetic simulation

Effect of Φ_1 on drift velocity and mirror force :

$\frac{v_{\nabla\Phi_1 \times B}}{v_d} \sim \frac{Ze\Phi_1}{T}\frac{R}{a}, \frac{Ze\mathbf{b}\cdot\nabla\Phi_1}{\mu\mathbf{b}\cdot\nabla\mathrm{B}} \sim \frac{Ze\Phi_1}{T}\frac{B}{\Delta B}$ → more significant for Z>>1 ion species

In CWGM, many Phi1 studies were presented.

J.M. García-Regaña (EUTERPE) : Configuration dependence (TJ-II, W7-X, LHD)
A. Mollén (SFINCS) : Multi-ion species collision term & self-consistent ambipolar $\Phi_0 + \Phi_1$
J.L. Velasco (KNOSOS) : Bounce-average calculation with both Phi1 and tangential magnetic drift

Comparisons with experimental observations are ongoing.

Further steps :

- Comparison (or coupling) with gyrokinetic turbulent transport (Nunami and Mollén)
- Global calculation [Satake (FORTEC-3D), Matsuoka (GT5D), García-Regaña (EUTERPE)]

2. Comparison among local drift-kinetic models

Approximations in radially-local drift-kinetic modelling and its effects in evaluating neoclassical transport

$$\left\{\frac{\partial}{\partial t} + \left(\mathbf{v}_{\parallel} + \mathbf{v}_{\mathrm{E}\times B} + \mathbf{v}_{\mathrm{B}}^{\wedge} + \mathbf{v}_{\mathrm{B}}^{\perp}\right)\cdot\nabla + \dot{v}\frac{\partial}{\partial v} + \dot{\xi}\frac{\partial}{\partial \xi}\right\}\delta f(\boldsymbol{x}, v, \xi) = S_0 + C(\delta f) + S_1$$

$\mathbf{v}_{\mathrm{B}}^{\perp}$: Global (finite-orbit-width) effect

$\mathbf{v}_{\mathrm{B}}^{\wedge}$: Tangential magnetic drift

$\mathbf{v}_{\mathrm{E}\times B} \rightarrow \langle \mathbf{v}_{\mathrm{E}\times B}\rangle = \frac{\boldsymbol{E}\times\boldsymbol{B}}{\langle B^2\rangle}$: incompressible-ExB approx., $\dot{v}\frac{\partial}{\partial v} \rightarrow 0$: mono-energy approx.

Tangential magnetic drift : important for $\mathbf{v}_{\mathrm{E}\times B} \ll \mathbf{v}_{\mathrm{B}}^{\wedge}$, ions, low-collisionality, non-optimized configuration

ExB compressibility : important for $\mathbf{v}_{\mathrm{E}\times B} \sim \frac{B_p}{B} v_{th}$ [heavy impurity ions or $T_e/T_i \gg 1$ CERC plasma (like HSX)]

[B. Huang PoP 2017 and her doctor thesis]

Further steps:

- Including the magnetic-shear effect in local DKE (bounce-average formulation) : KNOSOS
  - Benchmark with global codes (FORTEC-3D & GT5D, Matsuoka's paper will appear in PoP) ,application for NTV in perturbed tokamak

$$\omega_B = \langle v_B \cdot \nabla\theta\rangle_{bounce} = -\frac{c\mu B_0 \epsilon'}{e\chi'}\left[\frac{2E(\kappa)}{K(\kappa)} - 1 + 4s\left(\frac{E(\kappa)}{K(\kappa)} + \kappa^2 - 1\right)\right],\ s \equiv \frac{r}{q}\frac{dq}{dr} \text{ and } \kappa^2 \equiv \frac{mv^2/2 - \mu B_0(1-\epsilon)}{2\mu B_0 \epsilon} \text{ (tokamak case)}$$

- Another Zero-orbit-width (ZOW) model in conserved form (Sugama PoP 2016)
- Application of the "modern" local DKE for neoclassical optimization studies (STELLOPT for example)

3. Bootstrap current calculation V&V (1/2)

- W7-X is designed to reduce bootstrap current effect on MHD equilibrium.
- Small BSC is important for the island-divertor concept of W7-X as intended.
  - → V&V studies of bootstrap current calculation are proposed for
  - ▪ W7-X OP1.2a (comparison b/w std. and hi-mirror configurations)
    - ✓ Observation of plasma current evolution and comparison with expected BSC(A. Dinklage ISHW2017)
    - ✓ Hope to carry out cross-benchmark of NCT codes as we have done for CERC discharges in OP1.1. (N. Pablant submitted a paper)
  - ▪ LHD (difference in e-root and i-root phases)
    - ✓ Analysis are going on (Satake ISHW2017 and ITC2017).
    - ✓ Non-negligible effect of perpendicular NBI-driven current is found.
    - ✓ BSC was too small to see the effect on iota profile (MSE diagnostics).

- Basic simulation study on the isotope effect
  - ▪ Using PENTA, artificially changing the D/H ratio
    - ✓ Small change in ambipolar-Er in e-root → finite but small difference in BSC
    - ✓ D/H ratio of radial particle and energy transport shows large variation in e-root case

- Direct $U_{\|}$ measurement (and its poloidal variation of a flux surface) in HSX and its application for neoclassical transport analysis is reported in ISHW2017 (Kumar)

3. Bootstrap current calculation V&V (2/2)

Further steps :

- More V&V of Bootstrap current calculation
  - ✓ Including tangential and perpendicular NBI and ECCD effect
    Nishioka (PoP2016) has developed a way to include the effect to DKES/PENTA and applied to Heliotron-J.
  - ✓ Consideration on the slow L/R time in high-T discharges
  - ✓ In RFX and RELAX (discussed with I. Predebon and A. Sanpei during ISHW)

- Experiment proposal for next LHD campaign
  BSC in D/H/He mixed plasmas, difference in e-root and i-root

- BSC in quasi-symmetric stellarator (Chinese First Quasi-axisymmetric Stellarator, CFQS)
  - ✓ Adopt CHS-qa design, can be large BSC effect on MHD
- Consider the possibility of parallel flow measurement by CXRS in LHD / W7-X in the same way as in HSX.
  - ✓ Comparisons only from the integrated total BSC with observation is not satisfactory for the validation of NCT codes.
  - ✓ Ion parallel flow measurement → faster saturation than electron is expected (?).