TOKAM-3D: 3D full torus modelling of edge plasma
Study of parallel Mach number asymmetries

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Flux driven transport + turbulence code

TOKAM-3D: a new tool for edge transport and turbulence studies

- 3D fluid drift equations [B. Scott, IPP 5/92, 2001]
- Bohm boundary conditions in the SOL
- T=cst in current version
3D fluid drift equations

\[ \partial_t N_e + B \nabla \parallel \frac{N_e M}{B} - B \nabla \parallel \frac{J_\parallel}{B} + \frac{1}{B} [\Phi, N_e] = -B N_e \left( \frac{1}{B^2} \nabla \perp - \nabla \parallel \frac{N_e T_e}{B^2} \right) + S_{N_e} + \nabla \perp \cdot (D_{\perp N_e} \nabla \perp N_e) \]

\[ \partial_t W + M \nabla \parallel W + \frac{1}{B} [\Phi, W] = \frac{B^3}{N_e} \left[ N_e (T_i + Z T_e), \frac{1}{B^2} \right] + \frac{Z B^3}{N_e} \nabla \parallel \frac{J_\parallel}{B} + \nabla \perp \cdot (D_{\perp W} \nabla \perp W) \]

\[ W = \nabla^2 \Phi + \frac{\nabla^2 (N_e T_i)}{Z N_e} \]

\[ \partial_t M + M \nabla \parallel M + \frac{1}{B} [\Phi, M] = - \nabla \parallel \left( \frac{N_e (T_i + Z T_e)}{N_e} \right) + \frac{Z}{N_e} \nabla \cdot (D_M \nabla M) + \frac{Z}{N_e} S_M - \frac{S_{N_e}}{N_e} M + D_{\perp N_e} \frac{\nabla \perp N_e}{N_e} \nabla \perp M \]

\[ \eta \parallel N_e J_\parallel = T_e \nabla \parallel N_e + 1.71 N_e \nabla \parallel T_e - N_e \nabla \parallel \Phi \]

- ExB advection
- curvature
- parallel dynamics
- diffusive transport

vorticity definition
parallel momentum
parallel current

ITPA, Garching, May 7-10 2007
Association EURATOM-CEA
presented by A. Grosman
From Diffusive to Turbulent Transport

- searching for a relevant equilibrium with high $D_\perp$

- decrease of $D_\perp$ to reach turbulent regime

$D_\perp / D_{\text{Bohm}} \sim \nu^*$

$t$

$8 \times 10^{-2}$
“Neoclassical” poloidal asymmetries

Spontaneous growth of poloidal asymmetries even without turbulence

- high diffusion: $D_\perp / D_{\text{Bohm}} = 0.1$
  => neoclassical equilibrium with consistent ExB drifts

- enhanced parallel Mach number at the top: $M \sim 0.3$

- uniform $D_\perp$ ⇒ not linked to poloidal distribution of radial transport
Link with experimental results?

Reminiscent of poloidal asymmetries measured in most machines

- $M \approx 0.5$ measured at the top where $M \approx 0$ expected
- universal phenomenon (X-point and limiter)
- non-uniform poloidal distribution of transport?

*Courtesy Gunn & al., JNM (2007).*
2D modelling with TECXY fluid code

Strong imposed transport asymmetry necessary to recover experimental results

- reproduces some dependence with limiter position
  ⇒ role of ExB drift

- strongly ballooned radial transport needed to recover all experimental results:
  \[ \frac{D_{\perp \text{LFS}}}{D_{\perp \text{HFS}}} \approx 200 \]

Geometric dependences

Impact of toroidal field inversion and limiter position

- 3 cases at $D_{⊥}/D_{\text{Bohm}}=0.2$: shifting limiter position and reversing toroidal field direction (ion $\nabla B$ drift side)

- Bottom, normal $\nabla B$
- Bottom, reverse $\nabla B$
- Equatorial, normal $\nabla B$
Edge turbulent transport (no SOL)

3D edge turbulent simulations exhibit large poloidal asymmetries on M

- low diffusion: $D_{\perp}/D_{\text{Bohm}}=0.02$
- $\Rightarrow$ turbulent transport

poloidal up/down ($m=1, n=0$) asymmetry in spite of strongly aligned structures
Edge turbulent transport (no SOL)

3D edge turbulent simulations exhibit large poloidal asymmetries on M

- low diffusion: $D_\perp/D_{Bohm}=0.02$
  => turbulent transport

\[ <\Gamma_{r \text{ turb}}>_t,\theta,\phi \]
\[ <\Gamma_{r \text{ diff}}>_t,\theta,\phi \]
Towards turbulent transport (2)

Asymmetry enhanced by strongly ballooned turbulent flux

- large amplitude parallel flow asymmetry: $M_{\text{top}} \sim 0.5$
- asymmetry due to enhanced radial turbulent transport at LFS
SUMMARY

➢ TOKAM-3D:
  ✓ new generation of edge codes: 3D transport & turbulence across LCFS
  ✓ coherent treatment of drifts at all scales in diffusive/turbulent transport regime
  ✓ ongoing collaborations for numerical aspects and applied mathematics: MSNM-GP (Marseille), IRMA (Strasbourg)

➢ First results: poloidal asymmetries, qualitative agreement with experimental trends
  - in “neoclassical” transport regime => coupling between ExB drift and curvature
  - in turbulent regime => ballooning of radial transport
Complementary slides...
Model and boundary conditions

Fluid modelling with Bohm-like boundary conditions

- **fluid** balance equations: matter, charge, parallel momentum, parallel current (generalized Ohm’s law)
- current version: isothermal closure
- electric and diamagnetic **drifts** + polarization for ions

![Diagram showing fluid modelling with Bohm-like boundary conditions](image)
Origin of the Mach number asymmetry

ExB drift + curvature plays a major role

» step 1: establishment of large poloidal ExB drift at LCFS

\[ \partial_r \Phi \text{ sign changes } \Rightarrow \text{drift direction does not change with field direction}\]
Origin of the Mach number asymmetry

ExB drift + curvature plays a major role

- step 1: establishment of large poloidal ExB drift at LCFS
- step 2: curvature effects trigger symmetric inhomogeneities

No curvature effect at equatorial plane

Bottom, normal $\nabla B$

Bottom, reverse $\nabla B$

Equatorial, normal $\nabla B$
Origin of the Mach number asymmetry

ExB drift + curvature plays a major role

- step 1: establishment of large **poloidal ExB drift** at LCFS
- step 2: **curvature** effects trigger **symmetric inhomogeneities**
- step 3: ExB drift advects the density and **breaks the symmetry**

--- top --- LFS

**ExB**

**Bottom, normal** \(\nabla B\)

**Bottom, reverse** \(\nabla B\)

**Equatorial, normal** \(\nabla B\)
Successful Validation Steps

**Numerical validations**
- ✓ conservation laws
- ✓ parallel dynamics
- ✓ growth rates

**Physical validations**
- ✓ TOKAM-2D physics
  \( \subset \) TOKAM-3D
- ✓ plasma polarization and Pfirsch-Schlüter current
- ✓ flows, simple analytical behaviors…

\[ \Phi \]

\[ B \]

\[ t = 600 / \omega_c = 3 \ \mu s \]
3D fluid drift equations

\[
\partial_t N_e + BN_e \frac{N_e M}{B} - BN_e \frac{J}{B} + \frac{1}{B} [\Phi, N_e] = \\
-BN_e \left[ \Phi, \frac{1}{B^2} \right] + B \left[ N_e T_e, \frac{1}{B^2} \right] + S_{N_e} + \nabla_\perp \cdot \left( D_{\perp N_e} \nabla_\perp N_e \right)
\]

\[
\partial_t W + M \nabla_\parallel W + \frac{1}{B} [\Phi, W] = \\
\frac{B^3}{N_e} \left[ N_e (T_i + Z T_e), \frac{1}{B^2} \right] + Z \frac{B^3}{N_e} \nabla_\parallel \frac{J}{B} + \nabla_\perp \cdot \left( D_{\perp W} \nabla_\perp W \right)
\]

\[
W = \nabla_\perp^2 \Phi + \frac{\nabla_\perp^2 (N_e T_i)}{ZN_e}
\]

\[
\partial_t M + M \nabla_\parallel M + \frac{1}{B} [\Phi, M] = \\
-\nabla_\parallel \left( N_e (T_i + Z T_e) \right) \frac{1}{N_e} + \frac{Z}{N_e} \nabla_\perp \cdot \left( D_M \nabla_\perp M \right) + \frac{Z}{N_e} S_M
\]

\[
-\frac{S_{N_e} M}{N_e} + D_{\perp N_e} \frac{\nabla_\perp N_e}{N_e} \cdot \nabla_\perp M
\]

\[
\eta_\parallel N_e J_\parallel = T_e \nabla_\parallel N_e + 1.71 N_e \nabla_\parallel T_e - N_e \nabla_\parallel \Phi
\]