Max-Planck-Institut für Plasmaphysik

Interpretative and predictive transport modeling of ASDEX Upgrade L-mode plasmas

I. Erofeev[1,2]*, E. Fable[1] and the ASDEX Upgrade Team
Acknowledgements: C. Angioni[1] and R.M. McDermott[1]

[1]Max-Planck-Institut für Plasmaphysik, 85748 Garching, Germany
[2]Technische Universität München, 80333 München, Germany

Motivation

General:

- Correct reconstruction of plasma transport coefficients from experimental data
- Plasma profiles prediction for arbitrary tokamak parameters
- Understanding of physics behind intrinsic toroidal rotation

Specific:

- Validation of TGLF (trapped-gyro-Landau-fluid) module for ASTRA
- Assessment of the importance of accounting for main species and impurity rotation velocity difference (differential rotation)
- Analysis of plasma rotation variations with collisionality using TGLF results

Interpretative: profiles

In order to reconstruct radial profiles of transport coefficients (electron/ion heat conductivity) a simple power balance (PB) consideration is usually applied:

$$q_a = -\frac{\partial V}{\partial \rho}\langle|\nabla\rho|^2\rangle \chi_a n_a \frac{\partial T_a}{\partial \rho},$$ where a may denote electron or ion species.

- Represents a phenomenological approach, a diagnostic mean
- No microscopic description
- Can be used to benchmark sophisticated models

Here the PB results are shown in comparison with TGLF

Interpretative: intrinsic rotation

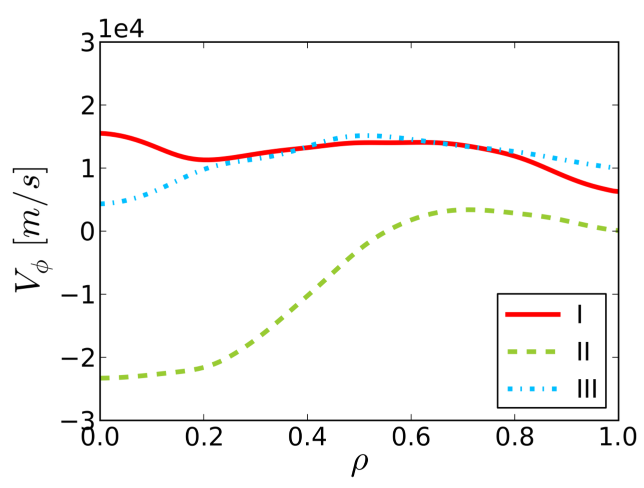
- Observation: plasma finite toroidal rotation without any external torque in some tokamaks – "intrinsic rotation"
- Feature: as plasma collisionality grows the rotation direction switches from co-current to counter-current and back again at even higher values
- Possible reason: component of the stress tensor neither proportional to viscosity nor pinch – "residual stress"
- Explanation: there exist several hypotheses on the residual stress origin: electric field shear [1], deviations from maxwellian distribution [2], breaking of up-down symmetry [3], turbulent modes interplay [4]…
- Has been done: ASTRA simulation using a model that implies turbulent origin of the residual stress, based on the data from AUG dedicated shot database [5] where the collisionality has been gradually increased. Three different typical cases are chosen:

Case I
#27000, t = 2.1s
$\nu_e = 0.025$

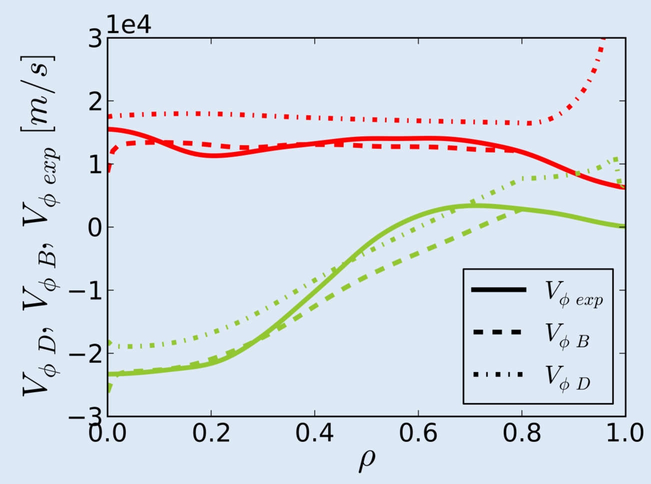
→ **Case II**
#27000, t = 4.1s
$\nu_e = 0.114$

→ **Case III**
#27001, t = 2.5s
$\nu_e = 0.272$

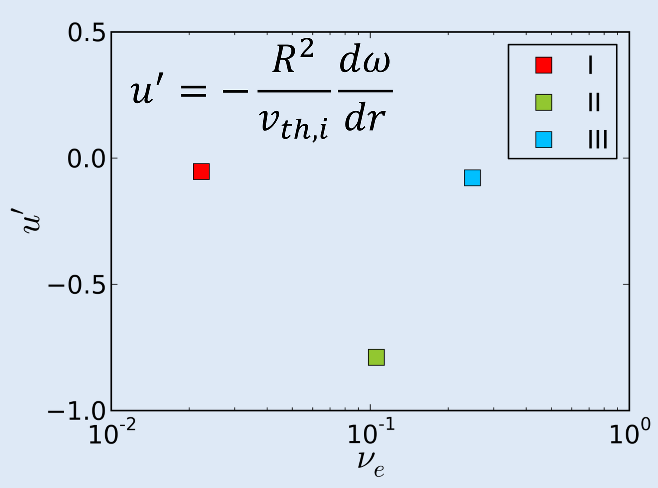
Toroidal rotation profiles for the chosen cases:

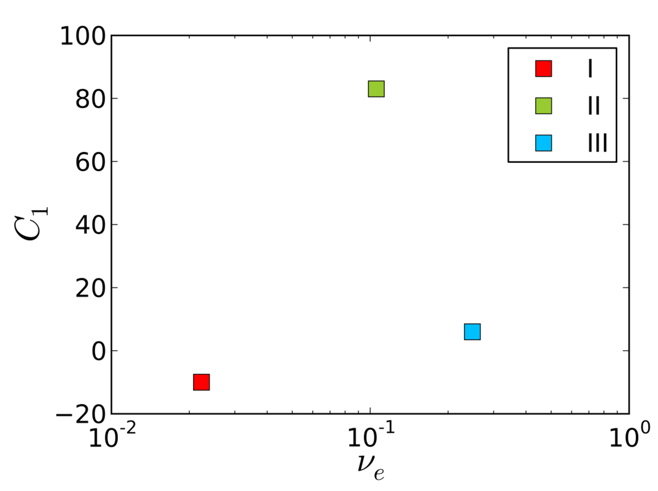


Velocity measurements with charge exchange (CXRS) on NBI boron: a difference in rotation between B and D is notable though rather constant, no significant effect on the gradient



Normalized toroidal velocity gradient – a basic rotation profile characteristic:





ASTRA model: ρ_i -linear turbulent driven residual stress:

$$\Pi_{R_\phi} = C_1 \rho_m \chi_i c_s \frac{\rho_i}{R}\left(C_2 \frac{R}{L_{n_e}} + C_3 \frac{R}{L_{T_i}}\right)$$

- ∇n_e and ∇T_i drives relation is given with the coefficients $C_2 = 1.0$ and $C_3 = 0.5$.
- C_1 has to be varied in a very wide range [-10, 80], as the effect of normalized logarithmic gradient scale lengths R/L_{n_e} and R/L_{T_i} is not enough
- A regression of u' proposed in [5] is linear in $\ln(\nu_e)$, though a momentum transport equation does not include ν_e – it has to appear via turbulence properties

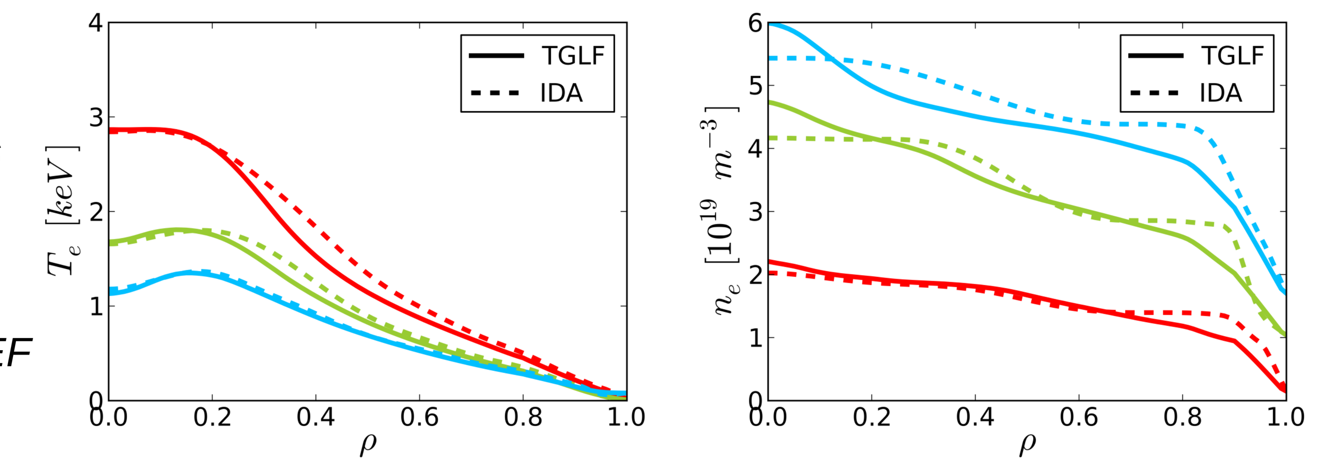
Another model with $\rho_i^{1/3}$- dependence [6] was also put under investigation and showed similar weakness.

Predictive

ASTRA system provides an interface to include various transport codes as modules. One of those is the TGLF, it involves trapping, general toroidal geometry, electron-ion collisions, impurity ions and is fully electromagnetic [8].

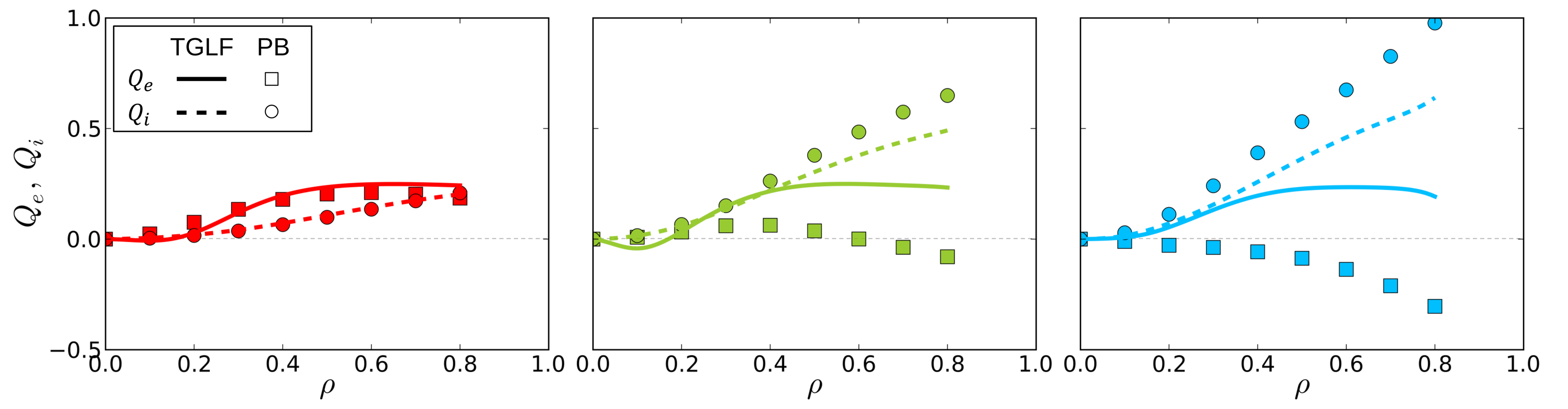
Plasma profiles: validation vs experiment

IDA – Integrated Data Analysis tool, combines measurements with many available diagnostics:
LiB, DCN, ECE, TS, REF



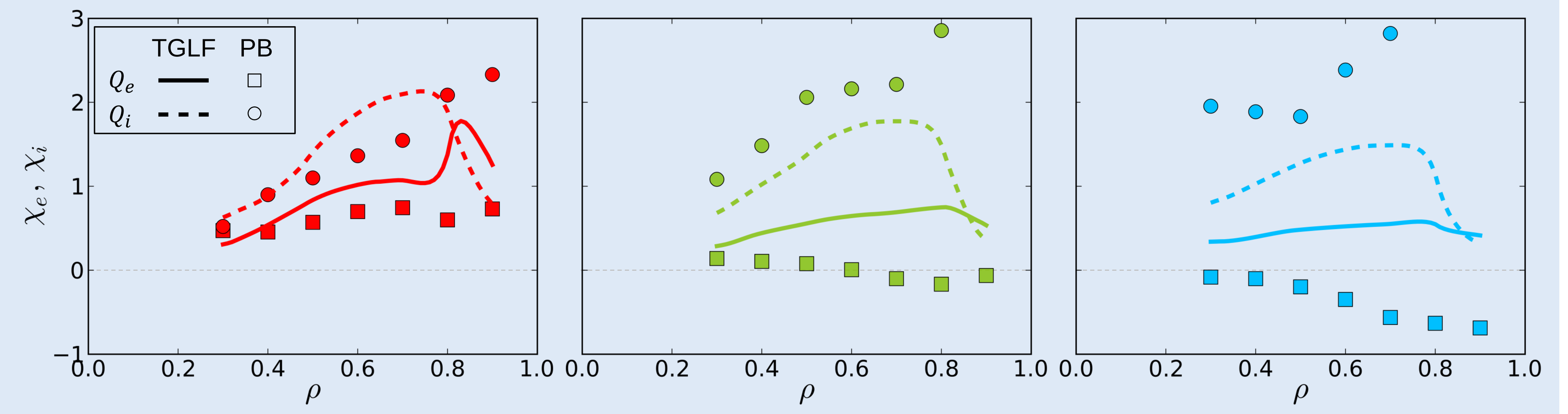
Transport coefficients: comparison to power balance

Electron/ion heat flux



The sum $Q_e + Q_i$ approximately matches in the two models, but each quantity separately does not, because of equipartition sensitivity on $T_e - T_i$.

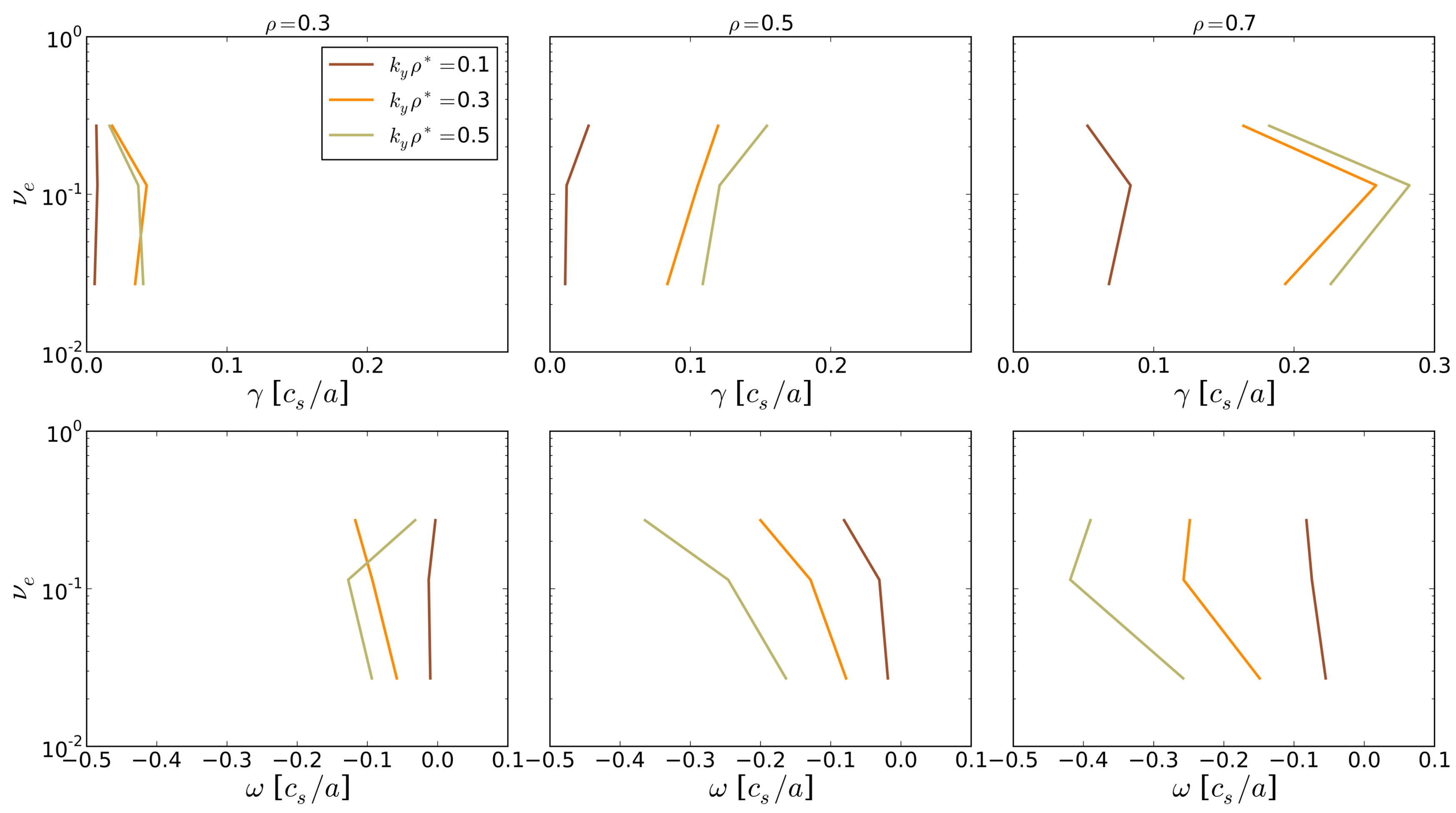
Electron/ion heat transport coefficients



\+ The coefficients from TGLF are always positive
– The profile structure requires complex explanation

Mode spectra:

ITG turbulence occurs at scales $L > \rho_i \rightarrow k_y\rho^* < 1$; radial coordinate $\rho = \frac{r}{a}$



Mode frequencies and growth rates for ion turbulence only weakly depend on the collisionality regime and cannot lead to mode dominance change.

Conclusions

- TGLF vs PB: good ion heat conductivity agreement, unaccounted effects for electrons
- D-B differential rotation is important to consider when getting the rotation absolute value, though the gradient is almost unaffected
- Intrinsic rotation reversal: no ITG/TEM mode dominance change confirmed
- Turbulence-driven intrinsic rotation model: constant proportionality to R/L_{n_e}, R/L_{T_i} is not enough, dependence on collisionality or other factors would be necessary

Outlook

- TGLF simulations for other rotation models verification ([7] at first)
- Π_{R_φ} from GK: bring two approaches together
- Extend the database with JET and TCV shots with rotation reversal
- Investigate ECRH effect on the rotation behaviour

Citations

[1] Ö. Gürcan et al., PoP **14** (2007)
[2] M. Barnes et al., PRL **111** (2013)
[3] Y. Camenen et al., PRL **111** (2009)
[4] P.H. Diamond et al., NF **49** (2009)
[5] R.M. McDermott et al., NF **54** (2014)
[6] Y. Camenen et al., NF **51** (2011)
[7] E. Fable, PPCF **57** (2015)
[8] G.M. Staebler et al., PoP **14** (2007)

*Corresponding author:
ivan.erofeev@ipp.mpg.de

'This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Prague, November 2015