Remote ISM meeting, June 8 2011

WP11-ITM-ISM-ACT2/ISM-P2-2011-02: Modelling of plasma rotation in Hybrid Scenario

Report on benchmarking of GLF23 model for toroidal velocity in ASTRA, CRONOS, FASTRAN, JETTO and ONETWO

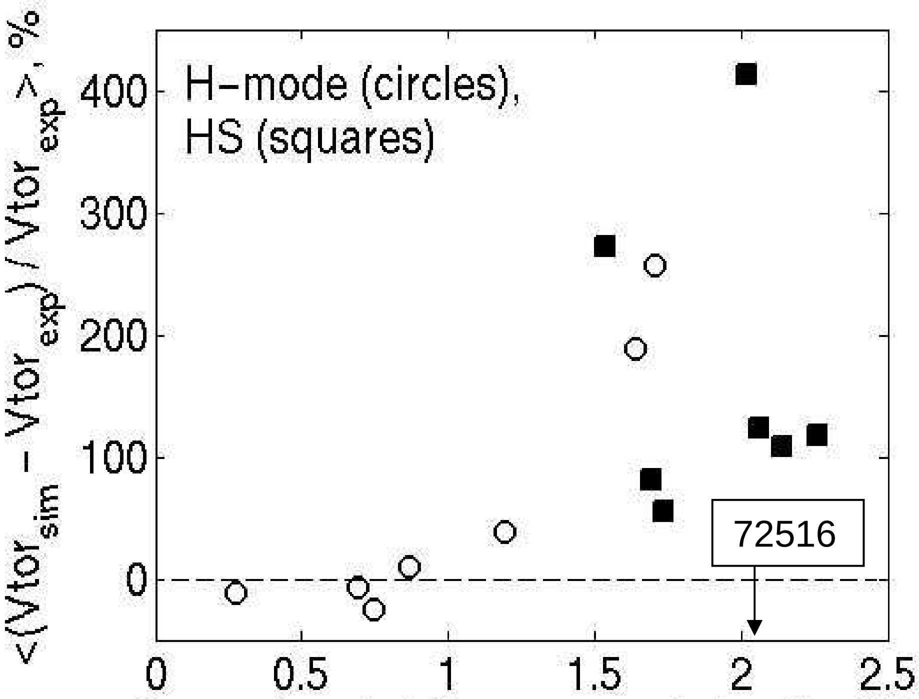
J. Garcia, J. Ferreira, D. Kalupin, X. Litaudon, J.M. Park, G. Pereverzev, I. Voitsekhovitch

This work has been performed mainly during the ISM mini-WS (JET, April 15-20). Supported by Euratom mobility (J. Garcia, J. Ferreira, D. Kalupin) and EU-US bilateral collaboration (J.M. Park)

JET discharge 72516 has been selected for benchmarking

- *current ramp up discharges submitted to the ITPA Profile Database –> same data are available for all five codes*
- *NBI heating (4 MW), L-mode*
- *time at the end of current ramp up (8 s) is selected for benchmarking*
- *comparison with previously analysed discharges: integrated torque/nl ~ 2.e-19 Nt/m2*
- *#72516 is used for benchmarking purpose only - rotation is unlikely affects the confinement during this phase*

The discrepancy with GLF23 model at r/a=0.5 averaged over 1 s during the stationary phase of discharge and plotted as a function of NBI torque per particle. [I. Voitsekhovitch et al, EPS 2006]



Volume integrated torque/central line averaged density*1.e19, Nt/m^2

Equation for toroidal rotation in various codes:

TRANSP [R J Goldston]:

m =<R²>ωΣ$_j$n$_j$*M$_j$, ω(√Φ) = Vφ/R (sum over thermal ion species)

$$\frac{\partial m}{\partial t} = Torque - losses + \frac{1}{V'}\frac{\partial}{\partial \rho}\left(V'\left\langle R^2\left|\nabla\rho\right|^2\right\rangle\left(\chi_\varphi \sum_j n_j M_j \frac{\partial \omega}{\partial \rho} - \sum_j n_j M_j \omega\left(\frac{V_\rho}{\nabla\rho}\right)\right)\right)$$

ONETWO and FASTRAN:

$$\frac{\partial m}{\partial t} = Torque - losses - \frac{1}{V'}\frac{\partial}{\partial \rho}\left(V'\left\langle\left|\nabla\rho\right|^2\right\rangle\left(-\chi_\varphi \frac{\partial m}{\partial \rho} - \left\langle R^2\right\rangle \omega \sum_j \Gamma_j M_j\right)\right)$$

CRONOS [J F Artaud et al, NF 2010]:

$$\frac{\partial R}{\partial t} = Torque - losses - \frac{1}{V'}\frac{\partial}{\partial \rho}\left(V'\left\langle\left|\nabla\rho\right|^2\right\rangle\left(-\chi_\varphi \frac{\partial R}{\partial \rho} - V_\rho R\right)\right)$$

of the total toroidal momentum $\Re = \sum_k m_k n_k \langle R V_{k,\varphi}\rangle$, where the sum is over all plasma species (ions and electrons), m_k is the mass of species k, n_k the density, R the major radius and $V_{k,\varphi}$ the toroidal velocity. The notation $\langle\ \rangle$ indicates a magnetic

ASTRA [G Pereverzev, P Yushmanov, IPP-2002]:

$$\frac{\partial F}{\partial t} = Torque - losses - \frac{1}{V'}\frac{\partial}{\partial \rho}\left(V'\left\langle\left|\nabla\rho\right|^2\right\rangle\left(-\chi_\varphi \frac{\partial F}{\partial \rho} - V_\rho F\right)\right)$$

where ***F*** is specified by user. Torque and losses should correspond to the choice of ***F***

JETTO solves the equation for Vtor

GLF23 equations for rotation
[R. E. Waltz et al, Phys. Plasmas 4 (1997), 2482]

$$M_i n_i \, \partial V_\phi / \partial t = -1/V' \; \partial/\partial\rho \; V' \langle |\nabla \rho| \rangle \times [(d\rho/dr) M_i n_i \eta_{\text{eff}}^{\phi} \, \partial V_\phi / \partial\rho + M_i v_\phi \Gamma],$$

Γ is the ion particle flux

- torque from TRANSP to be recalculated to rotation source

- $\chi\varphi$ → $(d\rho/dr) n_i \eta^{\phi}_{eff}$

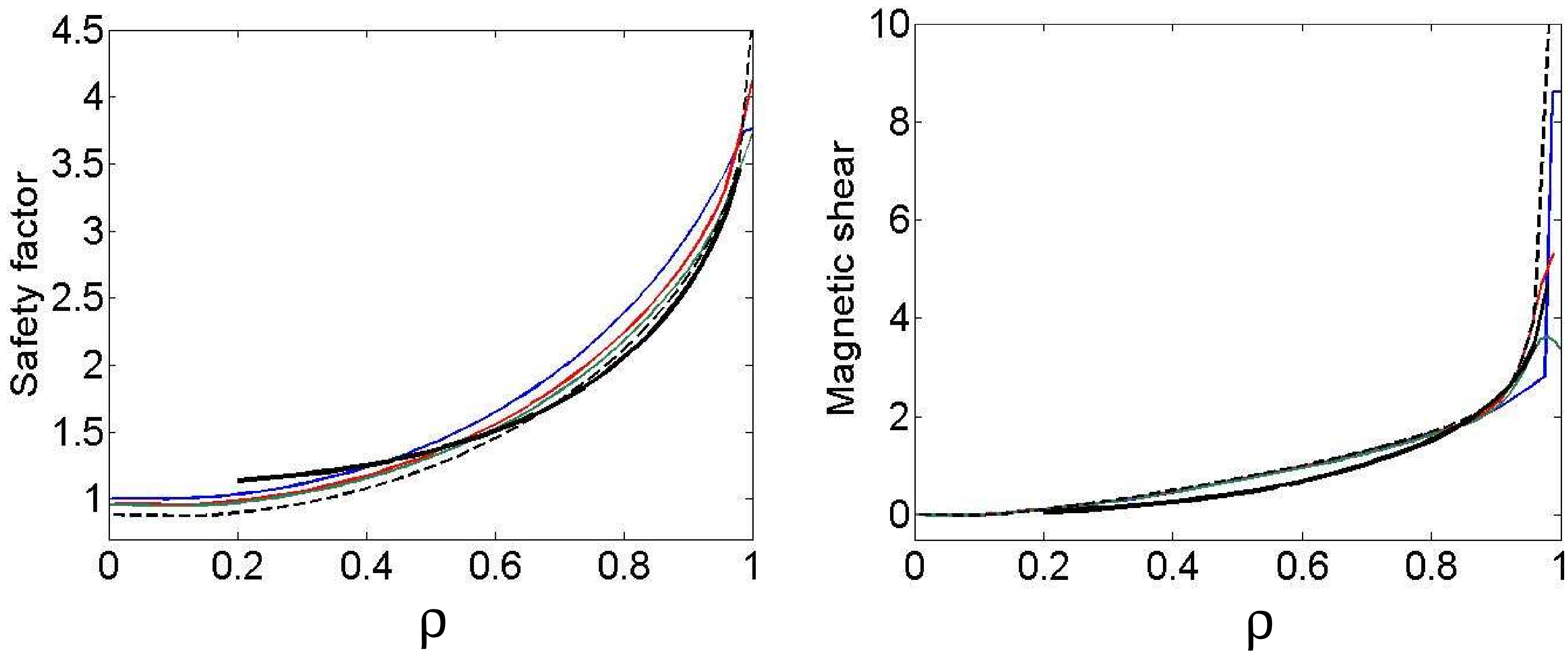
- modification of equations for momentum implemented in transport codes may be needed for simulations of the scenarios with time evolving ion density $n_i(t,\rho)$

Simulation assumptions:

- **Input data for JET 72516 at 8 s:**
  - Te, Ti, ne, Zeff, nD, q (or j);
  - global parameters;
  - torque and beam density are simulated by TRANSP
- **Equilibrium: EFIT (CRONOS, JETTO), eqdsk (FASTRAN, ONETWO), 3 moment (ASTRA)**
- **q-profile: calculated q using j(r) from TRANSP normalised to total current (ASTRA), eqdsk and TRANSP (FASTRAN), eqdsk (ONETWO, JETTO), TRANSP (CRONOS)**
- **Zero momentum losses**
- **Boundary condition at ρ=1 is taken from measurements (ITPA DB input files)**
- **Transport model: $\chi_\varphi = \chi_{\varphi}$_GLF23 + 0.1 m2/s (0.1 m2/s is added to provide the non-zero diffusivity in the GLF23 stable region)**
- **ExB shear calculated by GLF23**
- **GLF23 settings are documented in Appendix 1**

Input data: q and magnetic shear

ASTRA/CRONOS/FASTRAN(dashed)/JETTO/ONETWO(solid)

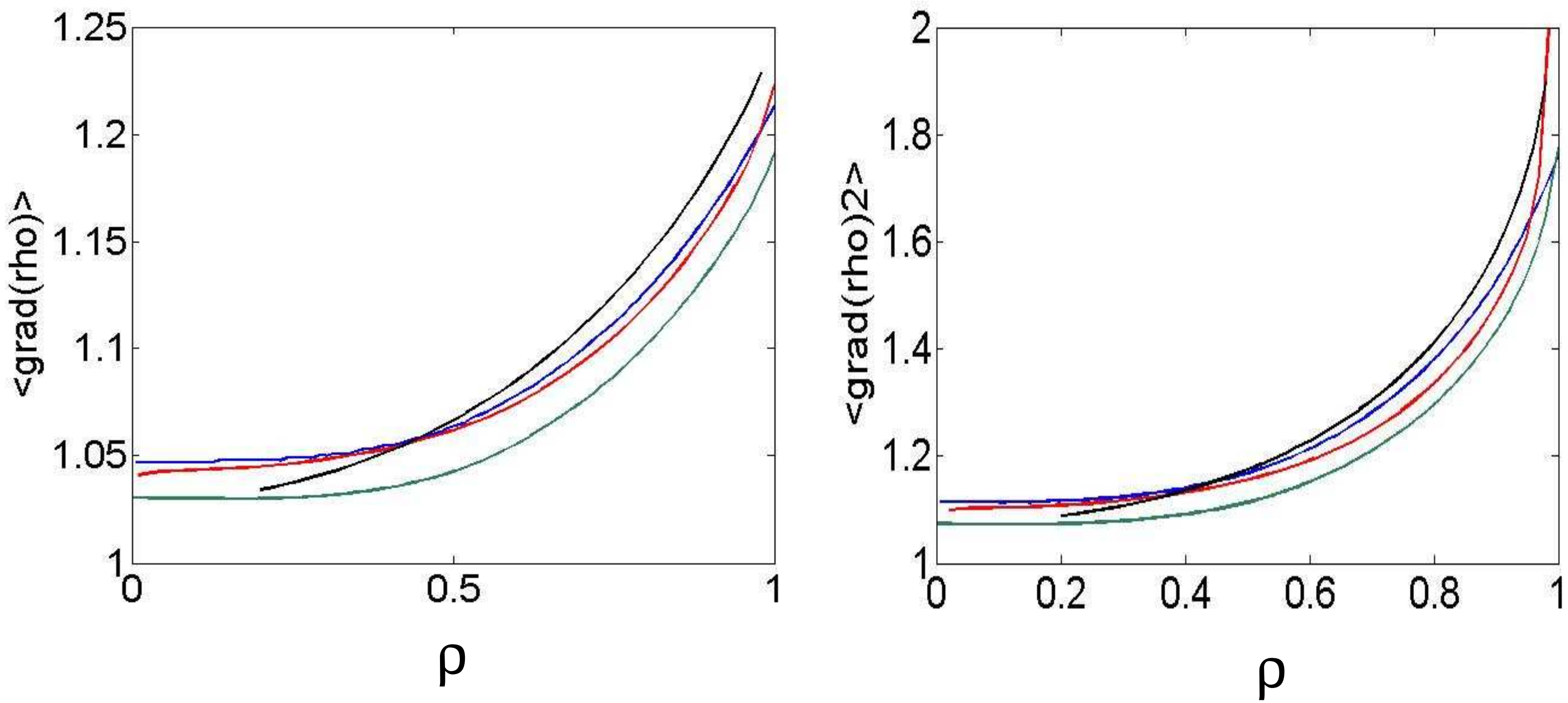


- difference in q(r) is within 20%

- difference in magnetic shear between ONETWO and other codes in the core, ASTRA and other codes at the edge

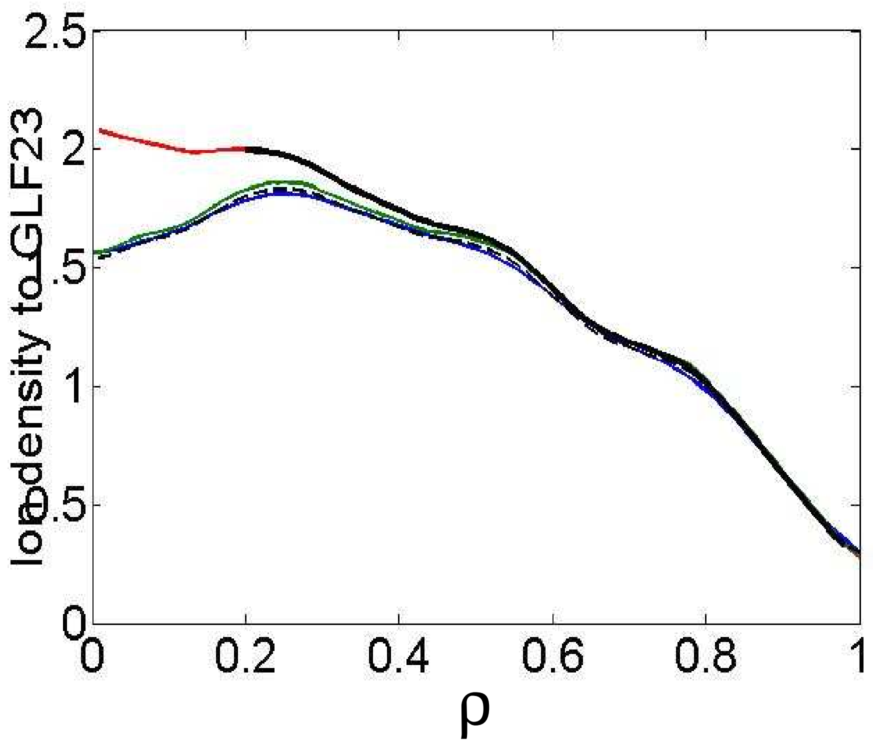
Input data: metric coefficients

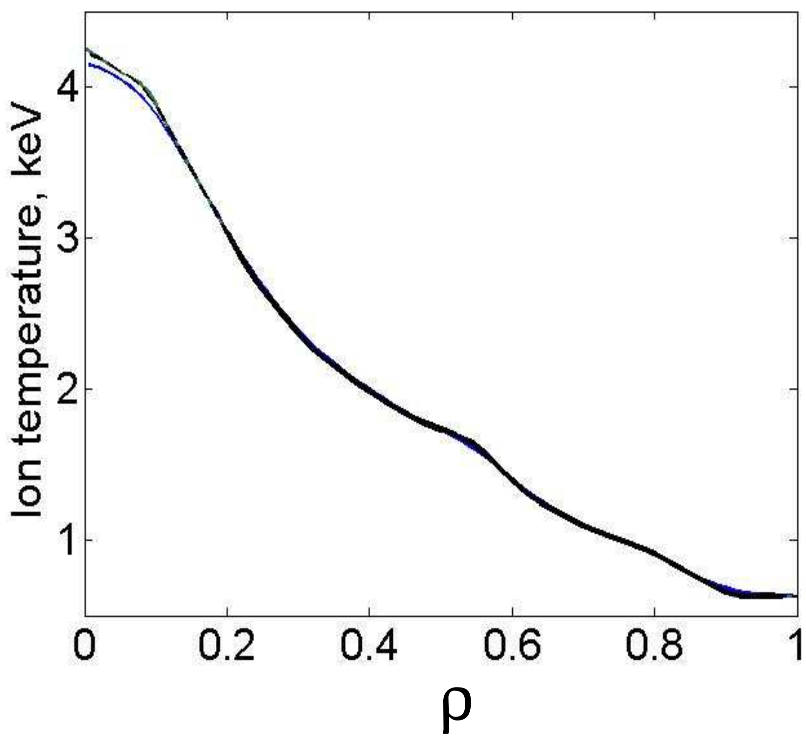
ASTRA/CRONOS/JETTO/ONETWO(solid)



Input data: ion density and temperature

ASTRA/CRONOS/FASTRAN(dashed)/JETTO/ONETWO(solid)





- Total ion density passed to GLF23 includes the thermal ions only (ASTRA, CRONOS, FASTRAN) and thermal + fast ions (JETTO and ONETWO)

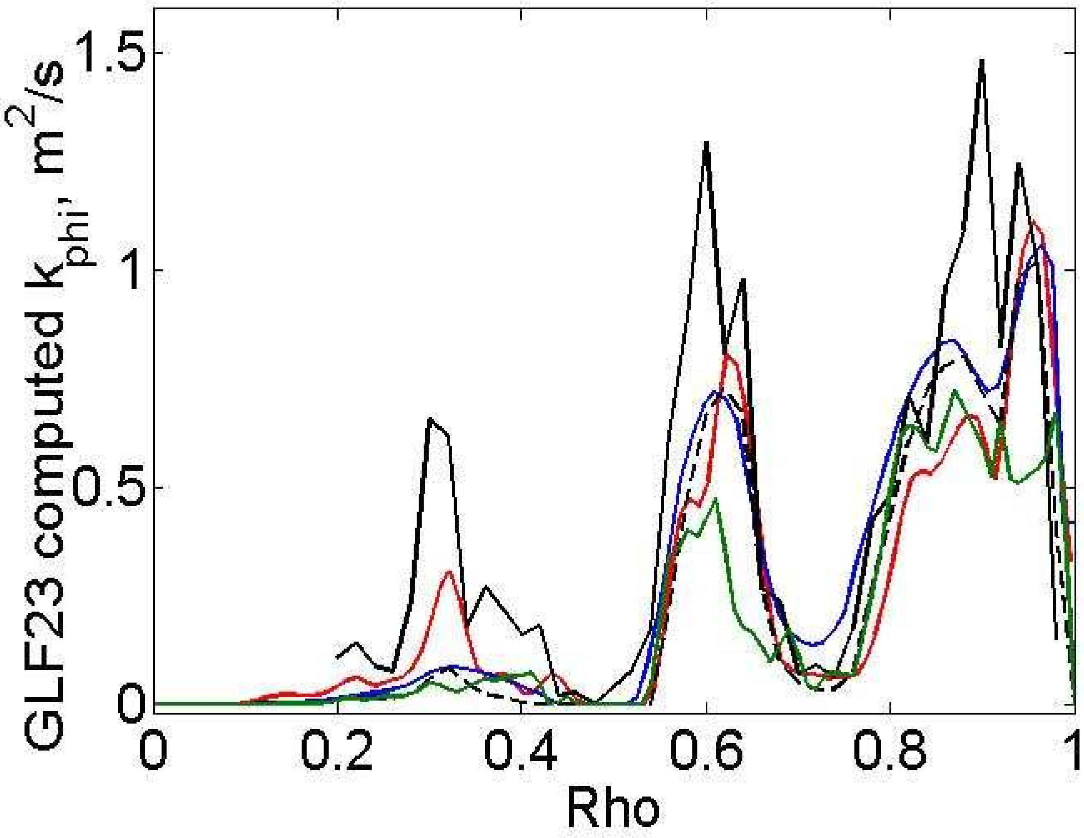
-Te, Ti and ni profiles are very similar

Benchmarking cases
(steady-state based on the measured profiles at 8 s)

- **Case 1: χφ is computed using prescribed plasma profiles (ne, ni, Ti, Te, q, Zeff)**
- **Case 2: simulated Vφ assuming zero particle flux**
- **Case 3: same as case 2 but with prescribed radially dependent particle flux from TRANSP**
- **Case 4: self-consistent ni & Vtor simulations**

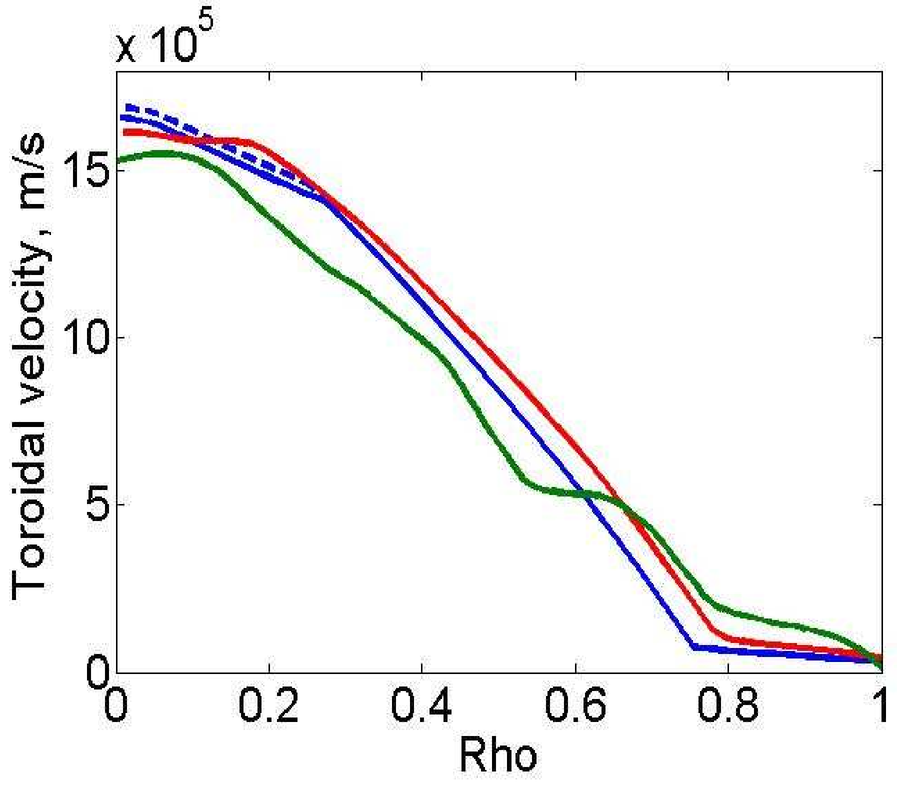
Case 1: computed momentum diffusivity with fixed profiles

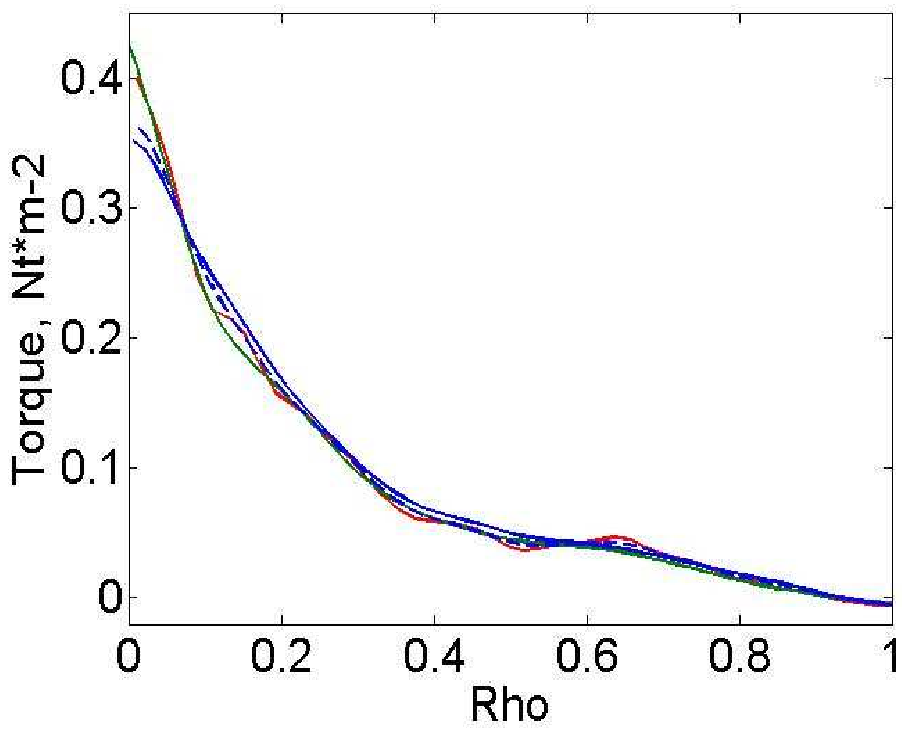
ASTRA/CRONOS/FASTRAN(dashed)/JETTO/ONETWO(solid)



Case 2: predicted toroidal velocity in ASTRA, CRONOS and JETTO

JETTO (red, jmsfer seq.201), ASTRA with different choice of numerical scheme control parameters (blue), CRONOS (green). Stationary profiles are shown.



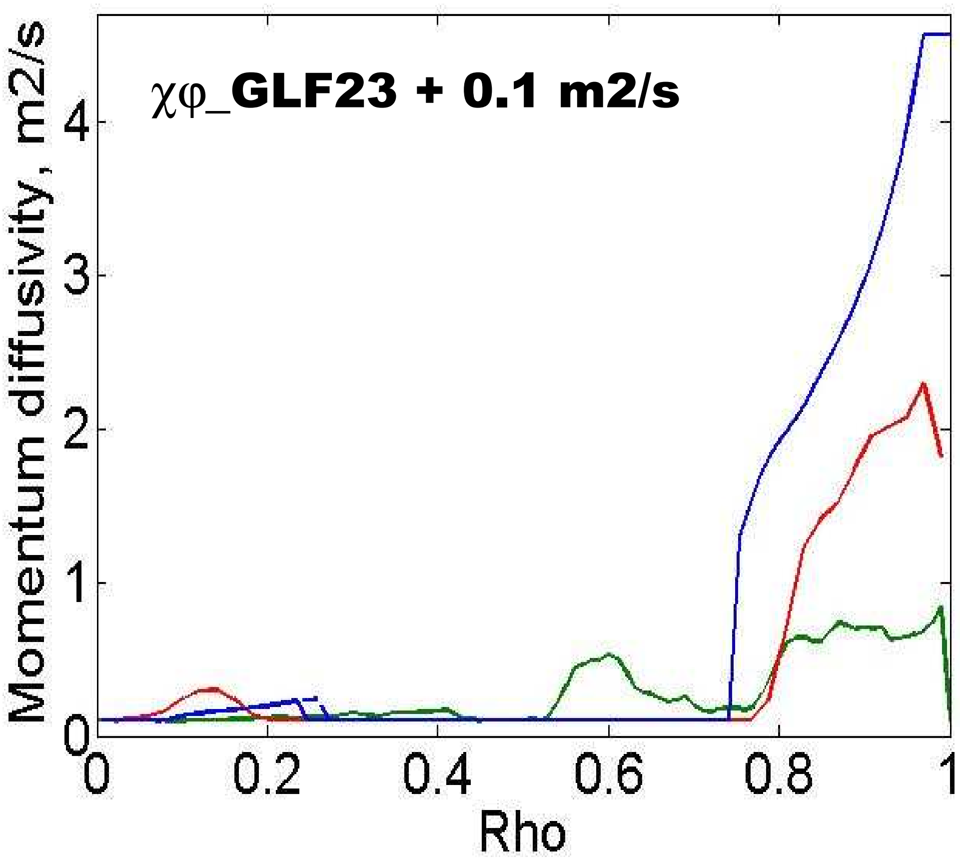


JETTO run is performed with IDENGRAD=3, the difference in $\chi\varphi$ computed with IDENGRAD=2 and 3 is small (page 20)

Torque profiles are very similar in three codes

EFDA Task Force
EUROPEAN FUSION DEVELOPMENT AGREEMENT
INTEGRATED TOKAMAK MODELLING

Case 2: momentum diffusivity computed in ASTRA (blue), CRONOS (green) and JETTO (red)



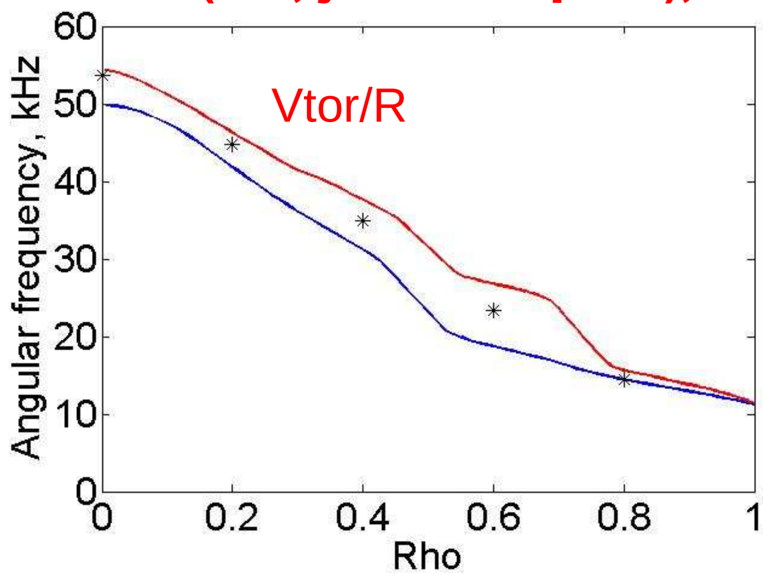
- $\chi\varphi$s are very different at the edge, different stability regions

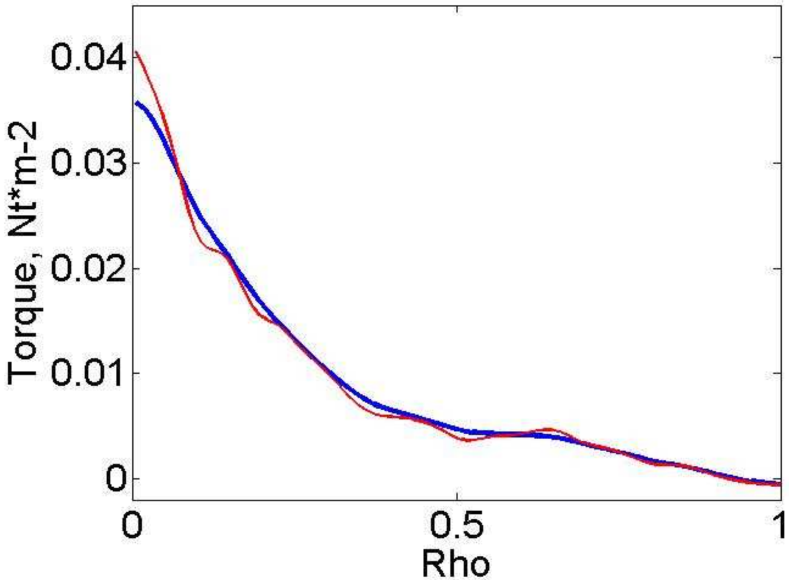
- ASTRA: the choice of control parameters for fast numerical scheme affects the boundary of stable region, but not the unstable $\chi\varphi$ values

EFDA Task Force
EUROPEAN FUSION DEVELOPMENT AGREEMENT
INTEGRATED TOKAMAK MODELLING

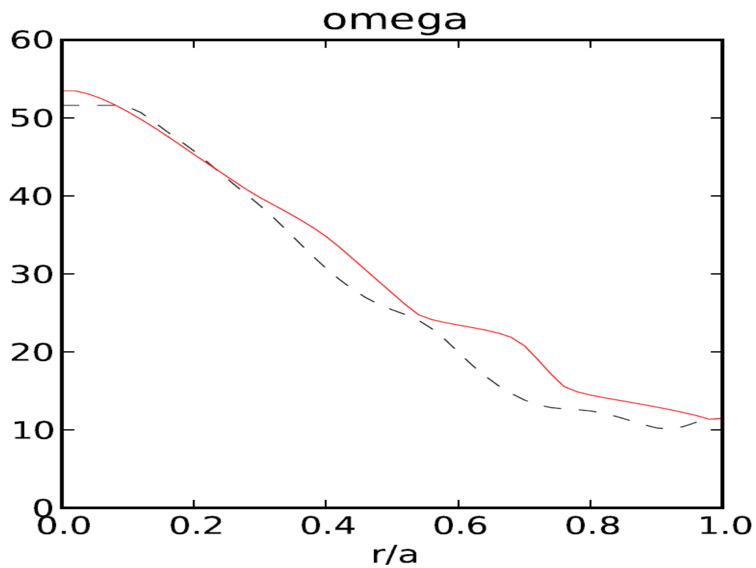
Case 2 (reduced torque): predicted angular frequency in ASTRA, JETTO and FASTRAN

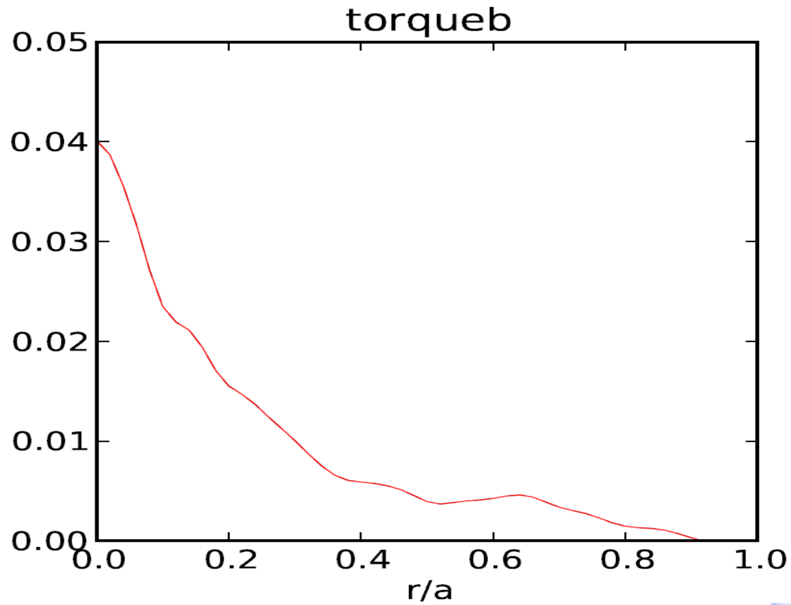
JETTO (red, jmsfer seq.211), ASTRA





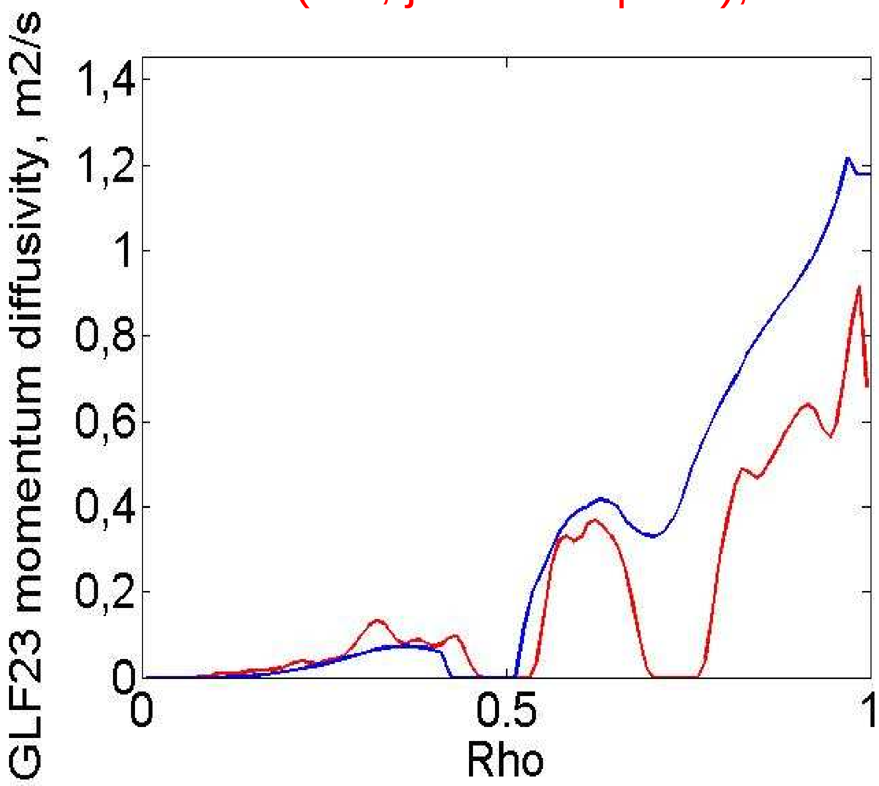
FASTRAN: black (initial), red (steady-sate)





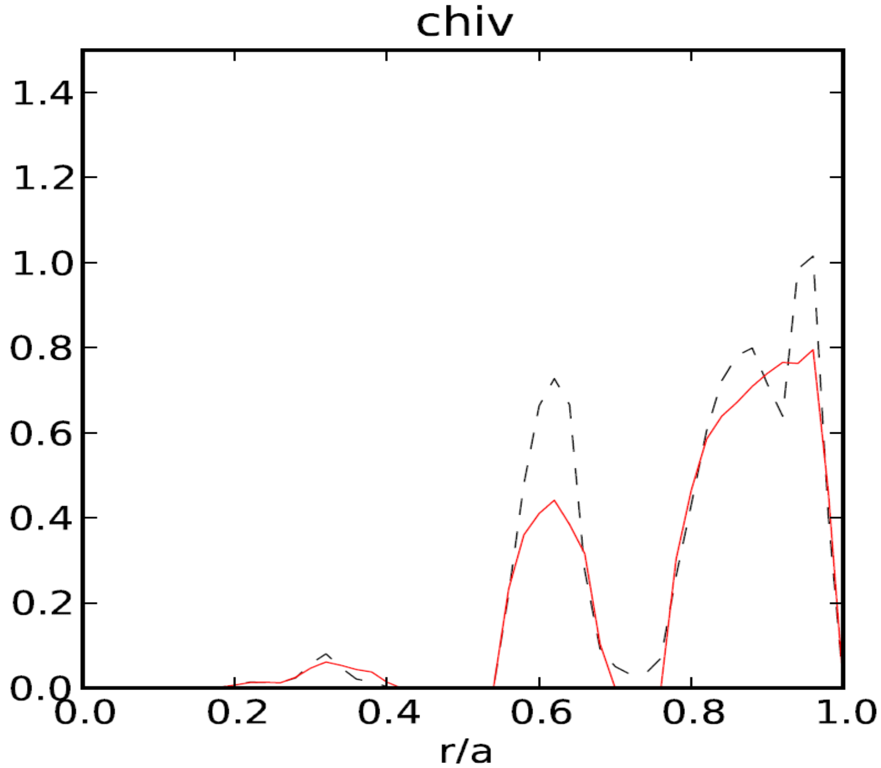
Case 2 (reduced torque): momentum diffusivity

JETTO (red, jmsfer seq.211), ASTRA



χφ_GLF23/FASTRAN

(black – initial, red-steady-state)

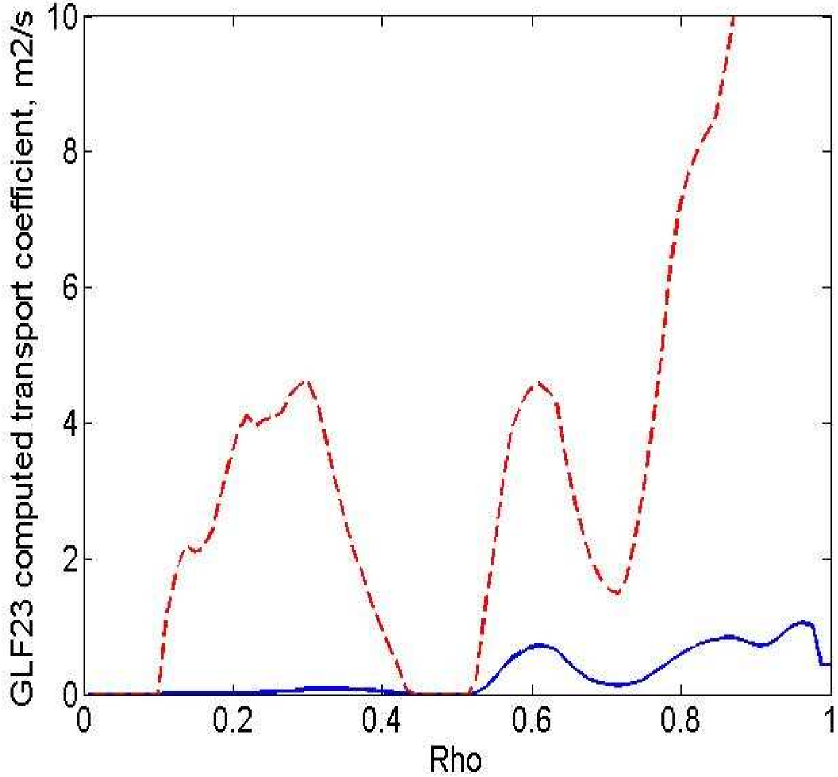


JETTO and FASTRAN results are relatively close, ASTRA gives larger diffusivity

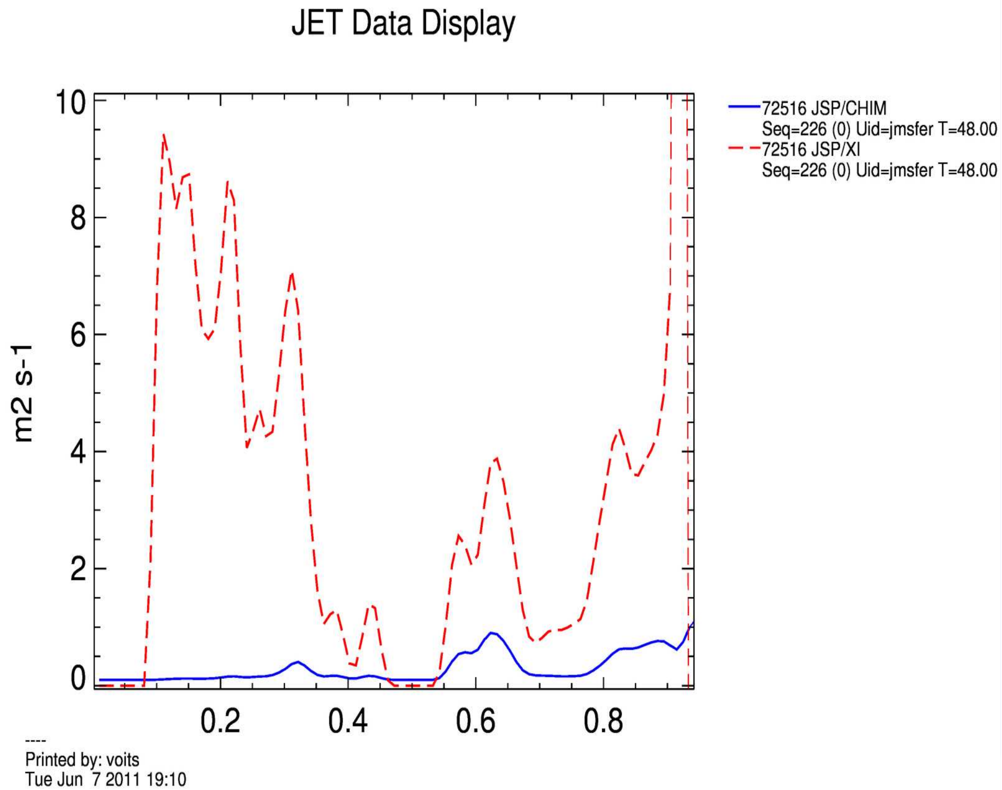
EFDA Task Force
EUROPEAN FUSION DEVELOPMENT AGREEMENT
INTEGRATED TOKAMAK MODELLING

Case 1: comparison of GLF23 computed $\chi\varphi$ and χi

ASTRA



JETTO



Summary:

- **Benchmarking difficulties: different equilibrium, q profile, different GLF23 implementation in different codes (for example, the calculation of gradients)**

- **Comparison of computed $\chi\varphi$ with prescribed profiles: $\chi\varphi$ shapes are close, but not exactly the same**

- **Predictive modelling of toroidal velocity:**
  - relatively close Vtor in ASTRA&JETTO at high torque
  - good agreement between JETTO and FASTRAN at low torque, lower Vtor in ASTRA

- **Fast numerical scheme for GLF23 (ASTRA):**
  - $\chi\varphi$ does not depend on the control parameters in the ITG/TEM unstable region
  - the boundary between stable and unstable region is affected by the choice of control parameters leading to slightly different toroidal velocity

Discussion of further steps:

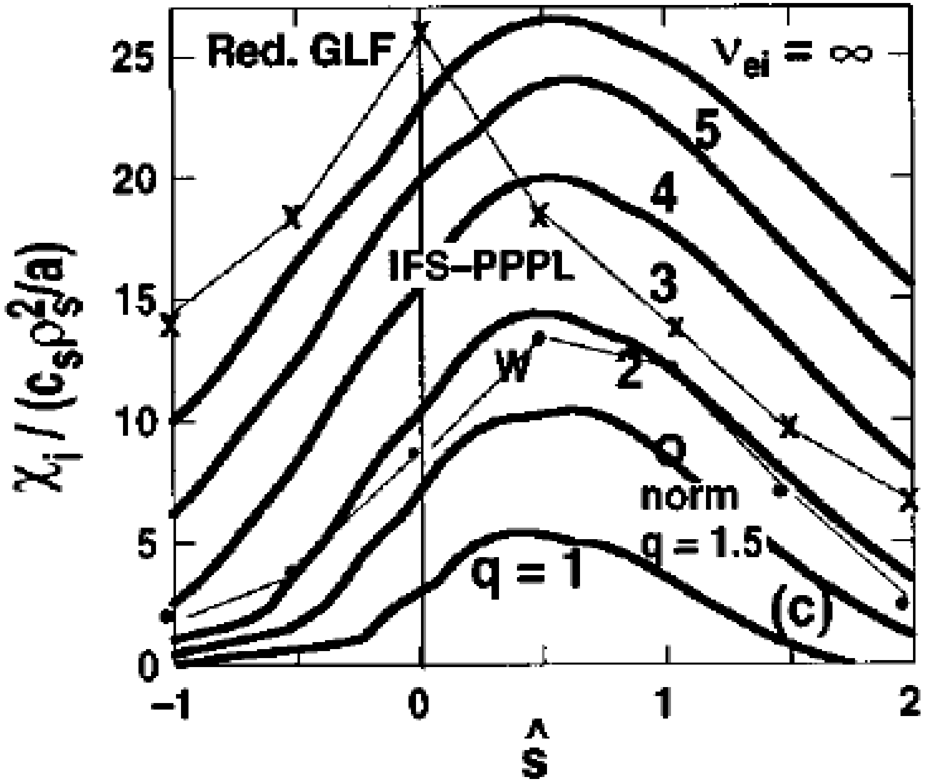
- **Efforts for using the same equilibrium in all codes?**
- **Benchmarking of momentum equation with radially constant $\chi\varphi$? FASTRAN simulations with $\chi\varphi$=0.1 m2/s are available.**
- **Benchmarking with $\chi\varphi = \chi i\_GLF23$?**
- **Should we move to Case 3 (non-zero $M_i V_\varphi \Gamma$)?**
- **Modelling of rotation in HS (stationary flat-top phase)?**

Appendix 1. GLF23 settings used for benchmarking

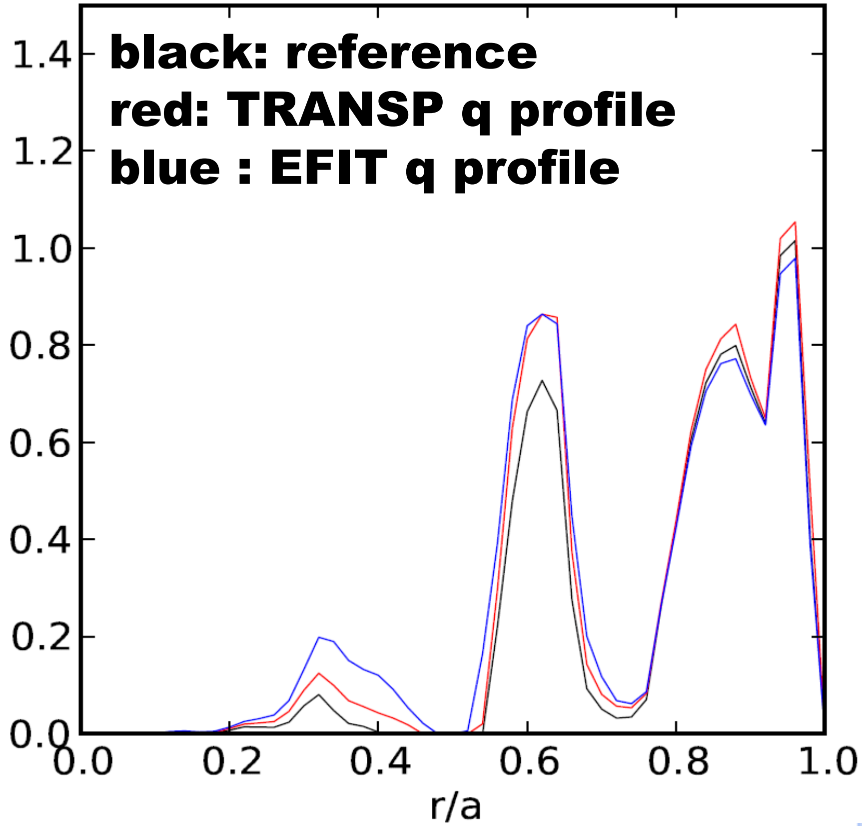
```
nroot    = 12          ! n. of roots in eigenvalue solver (12 impurity dynamics)
igrad    = 0           ! 1 input gradients, 0 compute gradients
idengrad = 2           ! simple dilution, 2
itport_pt(1) = 1       ! 1 particle transport on, 0 off
itport_pt(2) = 1       ! 1 electron heat transport on, 0 off
itport_pt(3) = 1       ! 1 ion heat transport on, 0 off
itport_pt(4) = 1       ! 1/0/-1 v_phi transport on/off/use egamma_exp
itport_pt(5) = 0       ! 1/0/- v_theta transport on/off/use gamma_p_exp
irotstab    = 1        ! 1 use internally computed wExB, 0 for prescribed
bt_flag     = 1        ! 0 do not use effective B-field
alpha_e   = 1.0        ! 1/0 ExB shear stabilization on/off
x_alpha     = -1.0     ! 1/0/-1 alpha stabilization on/off/self-cons
ns_m(j-1) = 0.0        ! impurity density, 10^19 m^-3
          shat_exp(j-1)   = SHEAR(j)              !astra variable
          alpha_exp(j-1)  = ALMHD                 !astra variable
          gradrho_exp(j-1) = GRADRO(j)            ! <|grad rho|>
          gradrhosq_exp(j-1) = G11(j)/VRS(j)      ! <|grad rho|**2>
          angrotp_exp(j-1) = VTOR(j)/RTOR         ! if itport_pt(4) = 0
egamma_exp(j-1)  = ROTSH*ROC/(CS+0.0001) ! prescribed ExB shear (cs/rho units), used
if(itport_pt(4).eq.-1) only
gamma_p_exp(j-1) = 0.0 ! par. velocity,shear rate, used if(itport_pt(4).eq.-1) only
  vphi_m(j-1)      = VTOR(j) ! calculated if itport_pt(4)*itport_pt(5)=0
```

Appendix II: sensitivity of GLF23 $\chi\varphi$ to q-profile

R. E. Waltz et al, Phys. Plasmas 4 (1997), 2482



J.M.Park: FASTRAN computation of $\chi\varphi$GLF23 with different q-profile



EFDA Task Force
EUROPEAN FUSION DEVELOPMENT AGREEMENT
INTEGRATED TOKAMAK MODELLING

Case 1: JETTO runs with IDENGRAD=2 (solid) and 3 (dashed)