Report on IOS-JA4

by
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Presented at the
7th ITPA-IOS Topical Group Meeting
Kyoto Univ, Kyoto, Japan

Oct 18–21, 2011

ITER Steady-State Scenario Code-to-Code Benchmark

- **Published in Nuclear Fusion (M. Murakami *et al,* 2011 Nucl. Fusion 51 103006)**
- **Participating codes trough ITPA-IOS JA-4**
  - FASTRAN/ONETWO, TRANSP, CRONOS, TOPICS-IB, ASTRAi, ASTRAk (ACCOME, TASK, …)
- **Generally, excellent agreement among the codes**
- **But, also identified a number of small(?) differences, especially in**
  - He transport
  - Rotation
  - H&CD modules (NB, EC, FW)

Weak Magnetic Shear Scenario

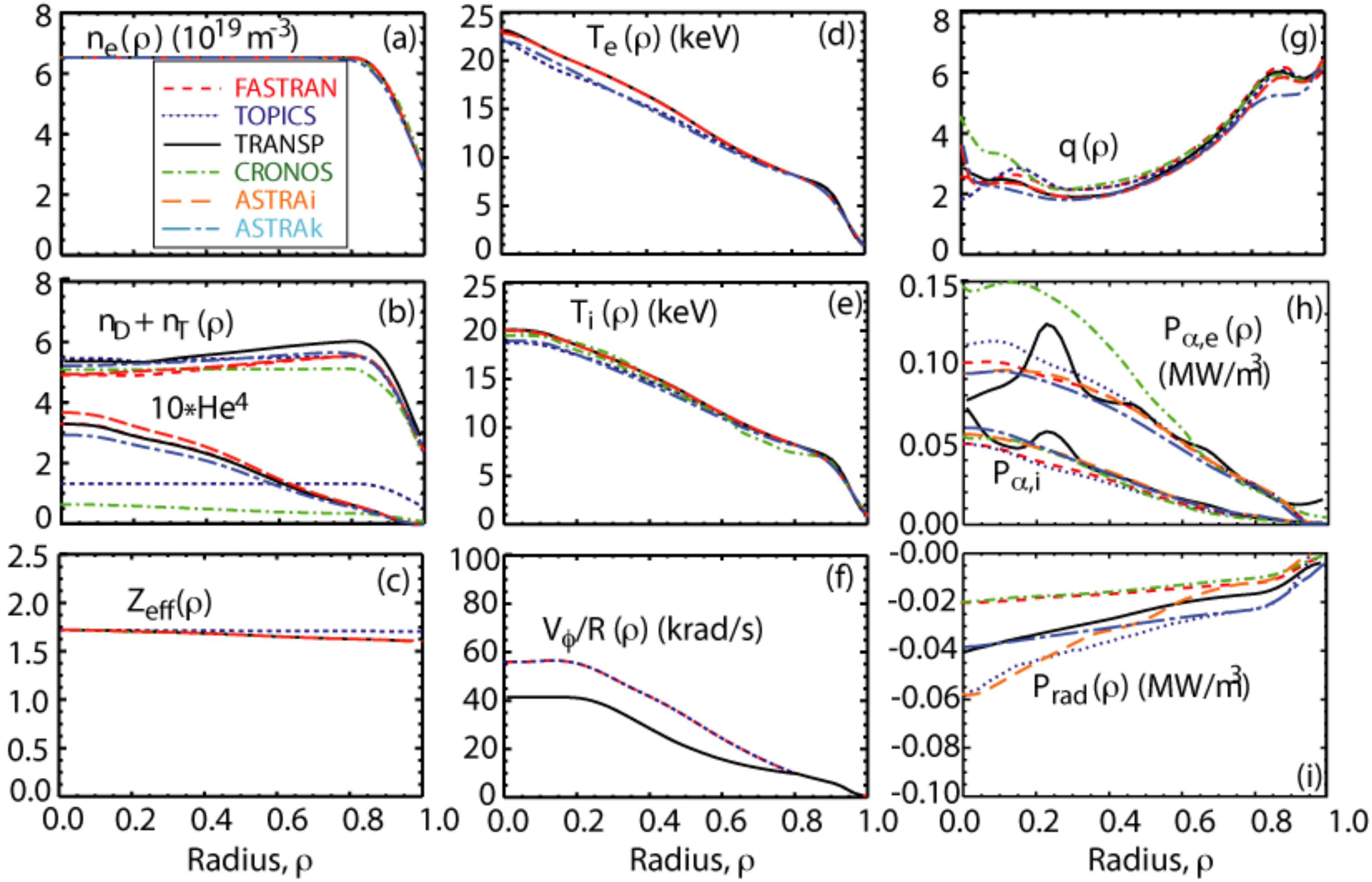

Figure 1. Results of code-to-code benchmarking for the ITER weak-shear SS scenario. Profiles calculated by different codes are compared for (a) electron density, (b) ion and helium-4 density, (c) effective charge, (d) electron and (e) ion temperature, (f) toroidal angular velocity, (g) safety factor, (h) alpha power to electrons and ions and (i) total radiation power (electrons and ions, and total radiation power). FASTRAN/ONETWO denoted as FASTRAN, ASTRA implemented in ITER as ASTRAi [9] and ASTRA implemented in KSTAR as ASTRAk [10].

Plan for 2011 WAS to Resolve Differences We Found

- **He transport**
  - Previous guideline: $\tau_p^*/\tau_E = 5$
  - ⇒ benchmark with more specific He transport model (D, V, recycling, …)
- **Rotation**
  - Most codes fixed the rotation profile (Ω_ϕ=0)
  - No boundary condition provided yet
  - ⇒ a) Check momentum balance equation, GLF23 implementation
    b) Check beam-driven torque
- **EC**
  - Benchmkark for ECH upgrade (wider range of steering angle)
  - Impact of momentum conservation, especially for $\rho_{EC} > 0.5$
- **FW**
  - Most codes imported the guideline profile ⇒ need self-consistent modeling

✓ **No much progress yet!!**

Equation for toroidal rotation in various codes:

TRANSP [R J Goldston]:

$m = \langle R^2\rangle \omega \Sigma_j n_j^* M_j$, $\omega(\sqrt{\Phi}) = V\varphi/R$ (sum over thermal ion species)

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

ONETWO and FASTRAN:

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

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

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

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]:

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

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

JETTO solves the equation for Vtor

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GLF23 equations for rotation

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

$$M_i n_i \, \partial V_\phi / \partial t = -1/V' \;\; \partial/\partial\rho \;\; V' \langle |\nabla \rho| \rangle$$

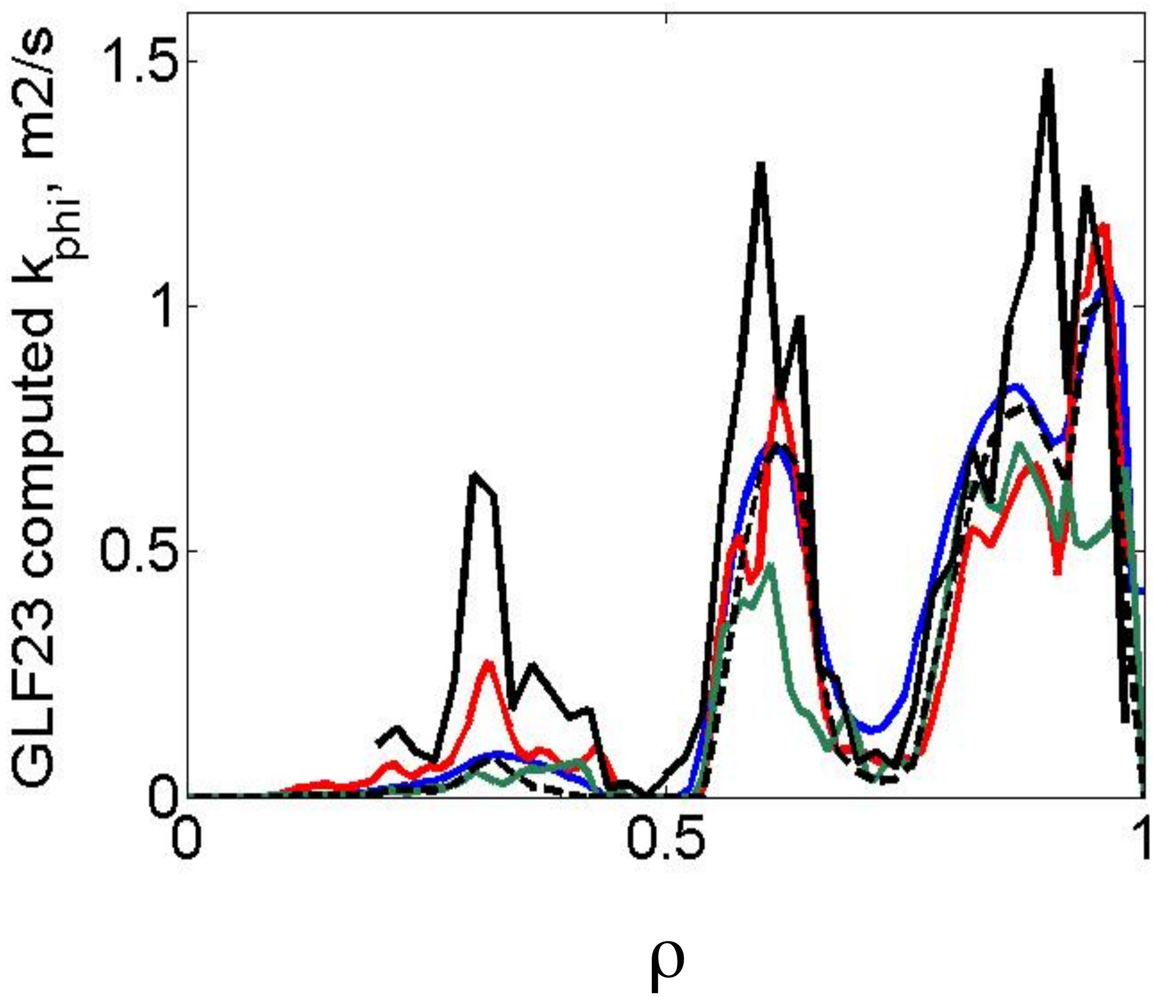
$$\times [(d\rho/dr) M_i n_i \eta_{\mathrm{eff}}^{\phi} \, \partial V_\phi / \partial \rho + M_i v_\phi \Gamma],$$

Γ is the ion particle flux

- torque from TRANSP to be recalculated to rotation source
- $\chi\varphi \rightarrow (d\rho/dr) n_i \eta^{\phi}_{eff}$
- scenario with time evolving ion density $n_i(t,\rho)$ requires the changes of equation for momentum implemented in transport codes

Case 1: computed momentum diffusivity with fixed profiles

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



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Benchmark between Full-wave AORSA and Ray-tracing CURRAY codes

Table 3. Benchmark between full-wave AORSA and ray-tracing CURRAY codes. CURRAY-1 includes beam and alpha absorption, while CURRAY-2 does not.

	AORSA	CURRAY-1	CURRAY-2
P (electron) (%)	64.3	71.6	79.3
P (D-thermal) (%)	0.4	1.3	0.2
P (T-thermal) (%)	32.8	19.5	20.3
P (D-beam) (%)	1.0	7.4	0.2
P (Alpha) (%)	1.5	0.2	0
P (He^4) (%)	0.0	0.0	0
P (impurity) (%)	0.0	0	0
I (FWCD) (kA)	603	645	654

ITB Scenario

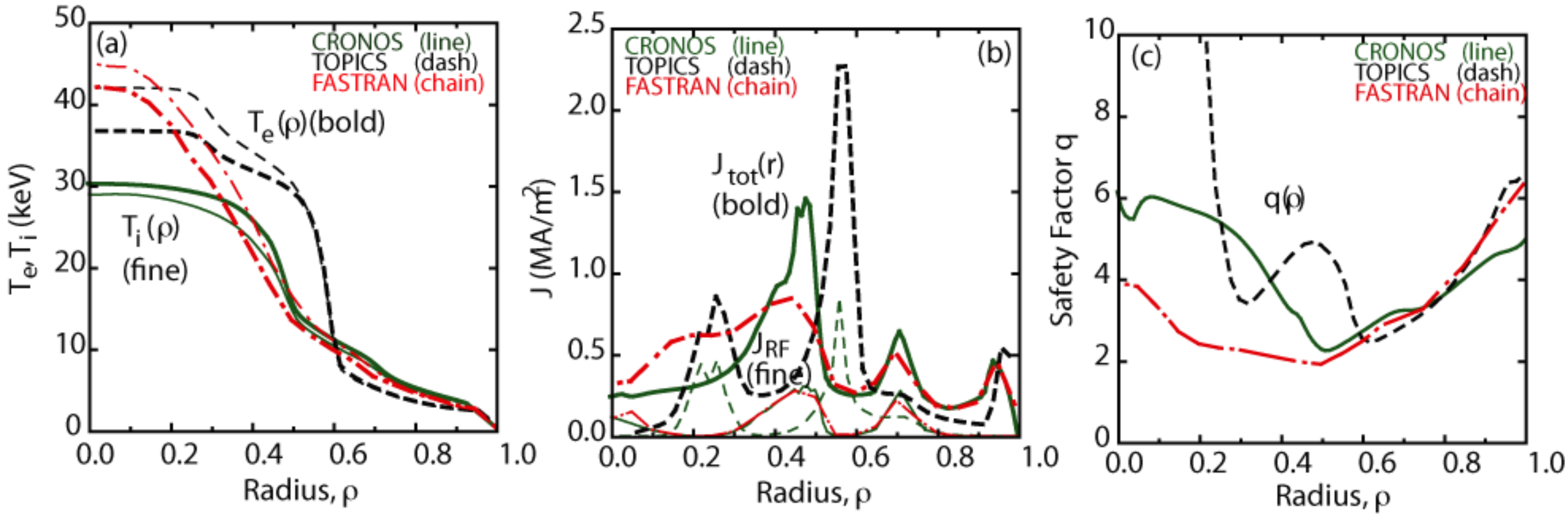

Figure 3. Results of benchmarking for ITER SS ITB scenarios. Profiles calculated by three codes are compared for profiles of (a) electron and ion temperature, (b) total current density and external CD sources from RF (fast wave, EC and lower hybrid CD) and (c) safety factor.

Plan for 2011 WAS to Resolve Differences We Found

- **More participating codes/modelers (ASTRA, TRANSP,…)**
- **Simplify the guideline for quick convergence**
- **Employ theory-based transport model**

✓ **No much progress yet!!**

Next Step?

- **Close out JA-4?**
  - Mission completed??
  - Documented well (Masanori's NF paper)
  - Need to archive simulation data
    - ITER Profile database format
    - Simply upload data files to the ITER ITPA homepage
- **Further utilize the guideline scenario to explore steady-state optimization?**
  - Now we have a good starting point
    - Well benchmarked in terms of numerics and modeling protocols
  - Sensitivities to the transport and pedestal models, density peaking (particle transport), …
  - Optimization of SS scenario towards the steady-state Q=5 mission
    - Heating/CD upgrade study