EFDA
EUROPEAN FUSION DEVELOPMENT AGREEMENT

Task Force
INTEGRATED TOKAMAK MODELLING

P2-25 The EU ITM-TF effort –Achievements & First Physics Results

Presented by G. Falchetto

P2-01 The European Transport Solver (ETS): an integrated approach for transport simulations in the plasma core

Presented by D. Kalupin

on behalf ITM-TF members

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https://www.efda-itm.eu/

ITM workflows in a glance

The EU ITM-TF is developing a new modular transport simulator: the ETS (European Transport Simulator)

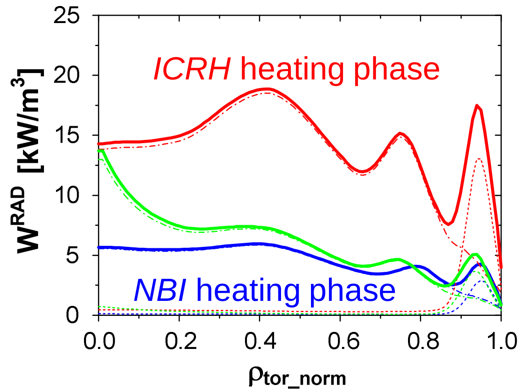
ETS workflows presently incorporate a large number of physics modules for equilibrium (BDSEQ, EMEQ, SPIDER, EQUAL, HELENA, CHEASE, EQUIFAST), pellets, impurities, neutrals, sawteeth and NTM, a variety of neoclassical (NCLASS, NEOWES, NEOS) and turbulence transport modules of different complexity (Bohm-GyroBohm, Coppi-Tang, ETAIGB, GLF23, Weiland, GEM) as well as particle sources and a sophisticated module allowing to account for synergy effects between heating schemes.
Synthetics diagnostics are being integrated, tested (neutron and NPA diagnostics, reflectometry) and validated (MSE).

Some IM workflows produced physics results (MHD chain, NTM, impurity), some provided rigorous code benchmarking (equilibrium, EC codes), some proofs-of-principle are given (FBE-ETS, turbulence-transport, core-edge coupling…)

ITM-TF recent achievements-1

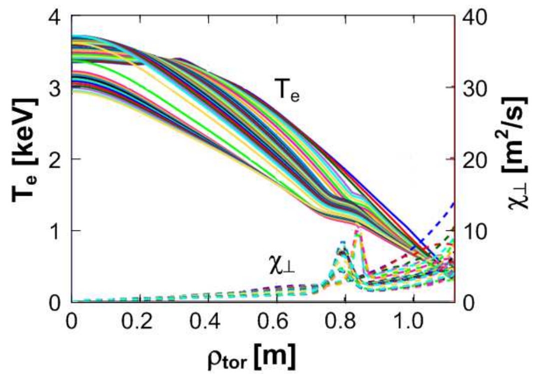
Physics results obtained with ITM workflows

✓Impurity simulations within ETS workflow performed for JET conditions allow to infer that the increased radiation during the ICRH phase as compared to the NBI phase can be explained by an increased W source.



Radiative power density profiles JET shot #81856 conditions

✓ETS workflow simulations including NTM module show a modification of temperature profile as a consequence of increased radial transport due to 2/1 magnetic island growing over resistive time scale.



Modification of the heat transport coefficient due to 2/1 magnetic island and its effect on the temperature profile (JET shot #77922)

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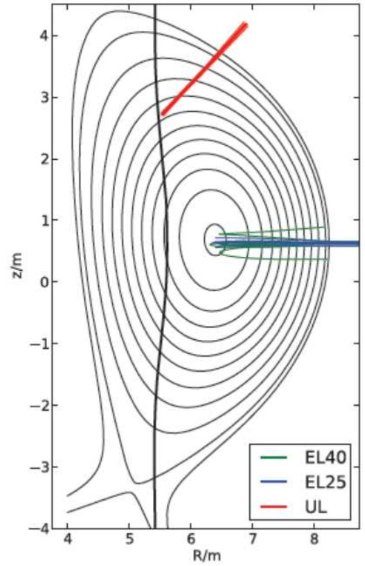
ITM-TF recent achievements-2

Cross-verification of codes within the ITM framework

✓Successful benchmark between 5 EU EC beam/ray-tracing codes interchanged as modules of the same ITM workflow for an ITER standard inductive H-mode scenario ("Scenario 2") for different launching conditions both from the Equatorial (EL) and Upper Launcher (UL) FIGINI, EPJ Web of Conferences, proc. EC-17, 2012



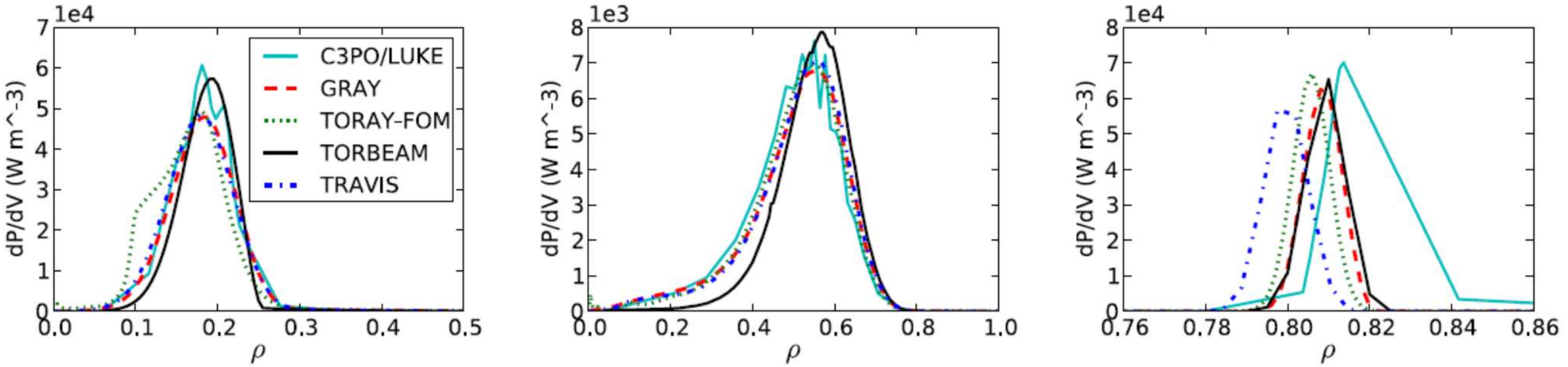
ITER scenario 2 (Gribov)

$B_T(0)$ = -5.3 T @ R_0 = 6.2 m
I_p = -15 MA
q = 3/2 @ r_p = 0.8
→ (*Equilibrium* CPO)

$n_e(0) = 10^{20}$ m^{-3}
$T_e(0)$ = 25 keV
Z_{eff} = 1.7
→ (*Coreprof* CPO)

r_p: square root of normalized poloidal flux

Good agreement in all the 3 cases:
$|\delta I_{CD} / I_{CD}|$< 15%,
$\delta(dP/dV)/ dP/dV \sim |\delta J_{CD} / J_{CD}| \sim$ 10%,
peaking positions match within $\delta\rho \sim 0.02$

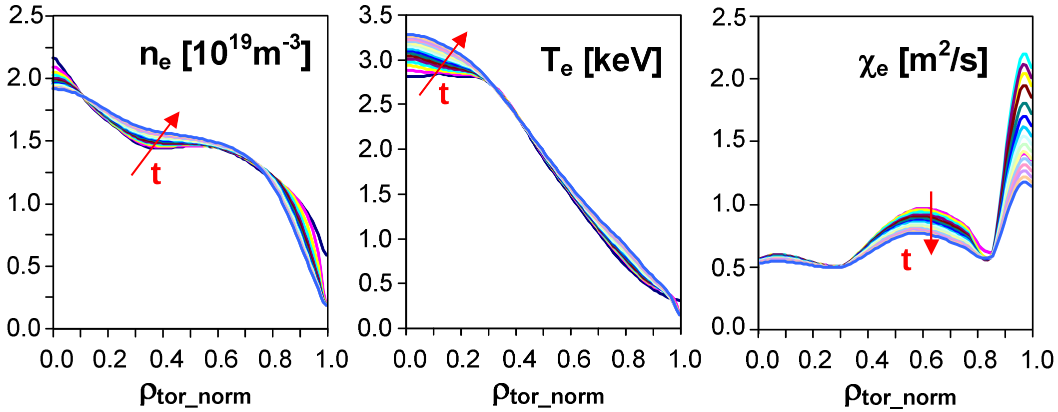


ITM-TF present capabilities -1

- ✓ Interoperability of the ITM cluster with HPC-FF confirmed for high CPUs demanding turbulence simulations

  ! Interoperability with IFERC to be addressed ➔ higher challenges expected

  - ✓ **proof of principle** of **turbulence-transport coupling**: GEM fluid core turbulence code run in a time-dependent ETS workflow



Relaxation of plasma profiles due to turbulence transport coefficients from GEM code, run remotely on HPC-FF on 256 cores while the main ETS workflow, which is serial, is run on the ITM computing cluster

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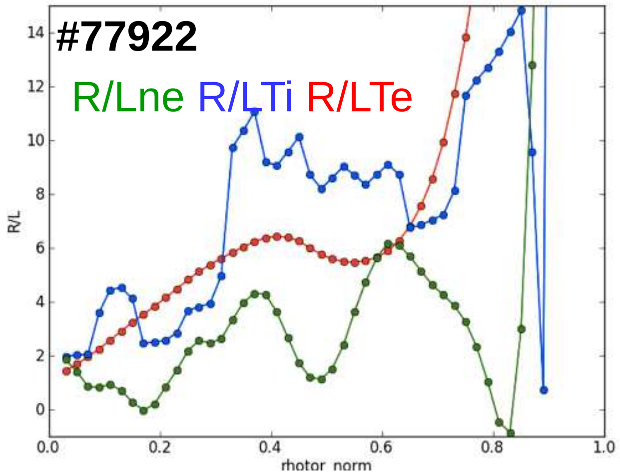
ITM-TF present capabilities -2

Turbulence simulations for JET hybrid discharge #77922 were performed with the electromagnetic non-linear gyrofluid GEM code [10] executed in batch on the HPC-FF within an ITM workflow.
Experimental profiles at 47.7s (Te,i,ne,i,toroidal current) and basic MHD equilibrium geometry were given and s-α model assumed.
GEM actor runs in parallel 8 independent fluxtube cases, at given reference points on the profile producing particle and heat fluxes profiles for both species. The **experimental case was found to be ITG stable** for most of the profile except for the edge point at r/a=0.96.



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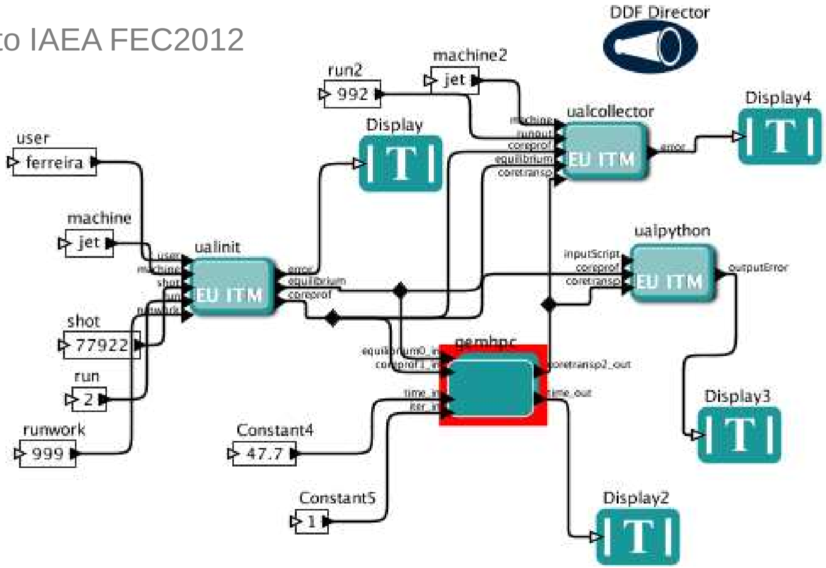
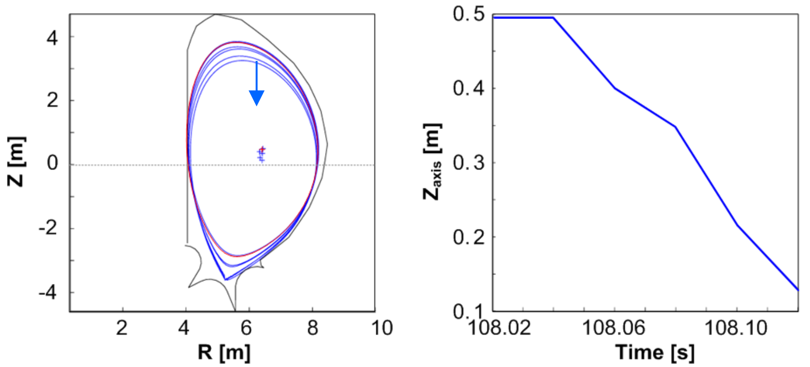


! interpretative runs with turbulence codes starting from experimental data profiles remain challenging, e.g. when exp. conditions near to stability thresholds

ITM-TF present capabilities-3

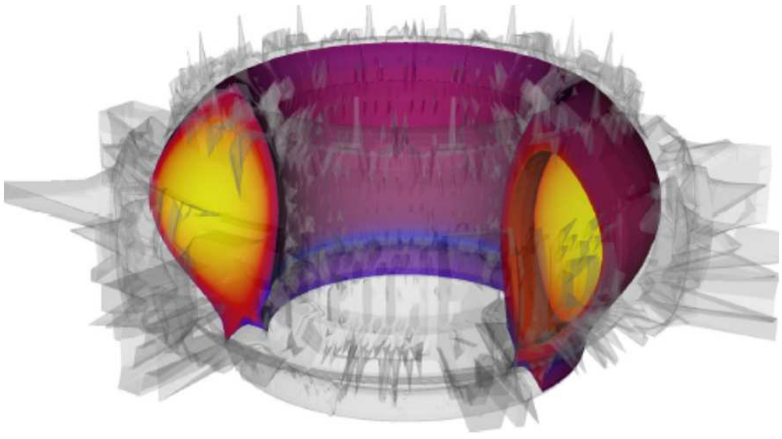
- ✓Demonstration of coupling of ETS with a free-boundary equilibrium code, CEDRES++
  - ✓first test simulation of an imposed VDE for ITER plasma conditions finds a VDE timescale of 100ms, consistently to other studies



Imposed VDE: evolution of the last closed magnetic flux surface and of magnetic axis height

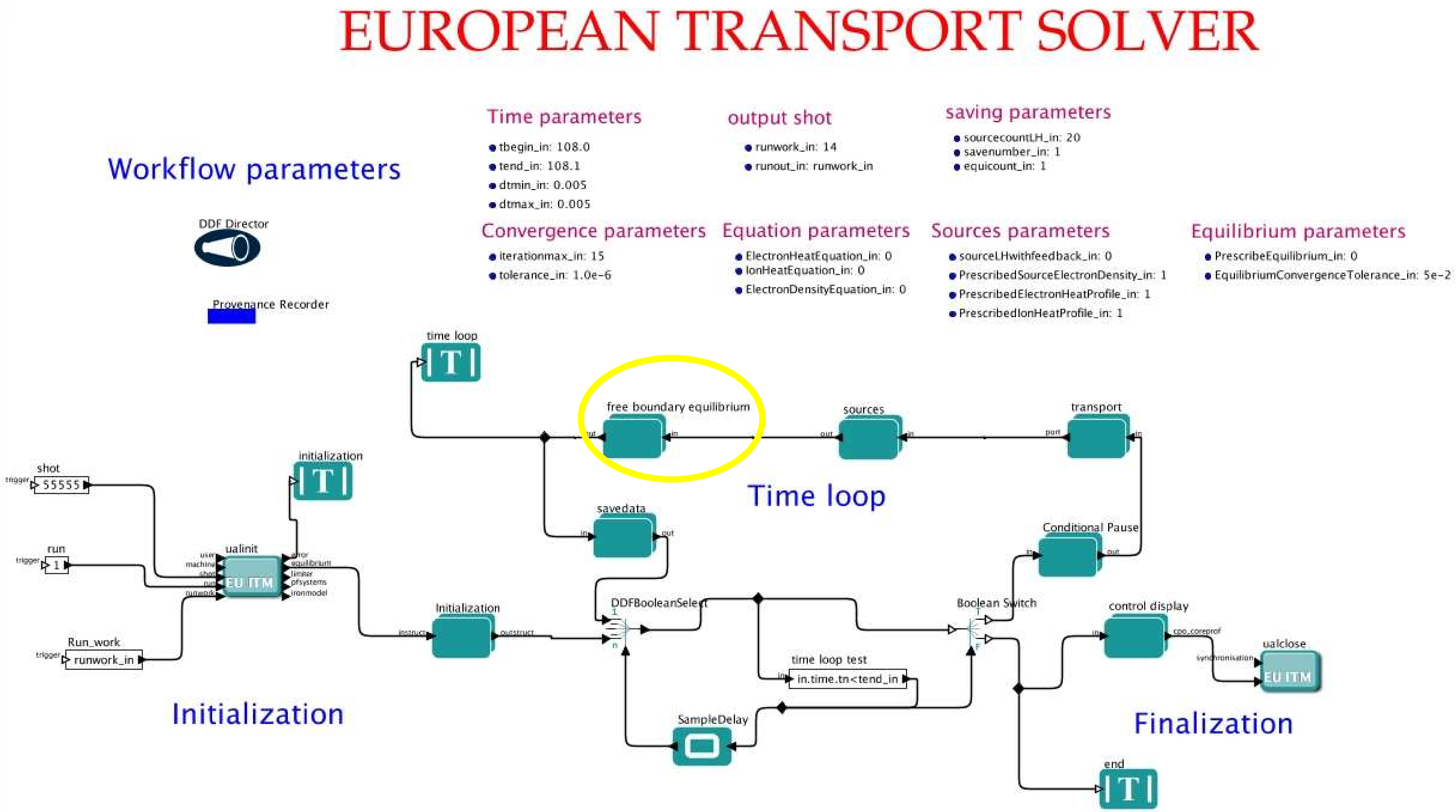
- ✓Automated direct core/edge coupling between 1D core ETS transport solver and 2D edge SOLPS, successfully demonstrated for the particular case of steady state and multiple impurities (Fortran workflow)

COSTER 39th EPS 2012



Visualization of electron temperature from the core-edge coupled simulation within the 3D defeatured first wall of ASDEX Upgrade (all data in CPOs, Visit plotting tool).

ETS - FBE workflow

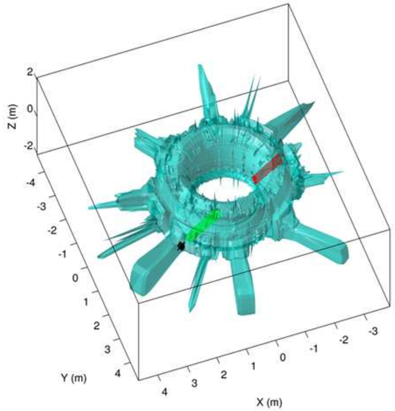


Integration & validation of Synthetic Diagnostics

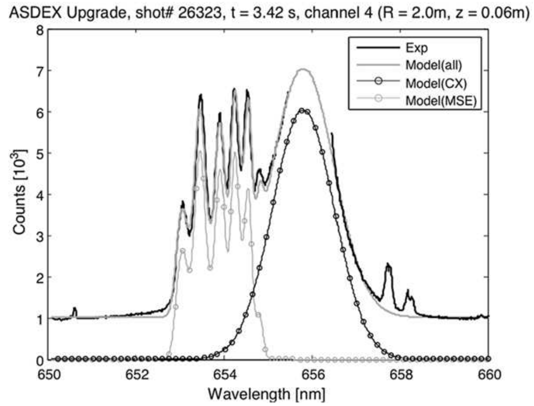
- SD integration on the ITM platform & testing is ongoing :
  3D reflectometry (ERC3D), neutron and NPA diagnostics, MSE
  – spectral MSE forward model is being validated on ASDEX Upgrade data

Neutral Particle Analyser (born neutrals from ASCOT + pitch velocity in collimator domain)

ASDEX Upgrade 3D wall and collimator domain

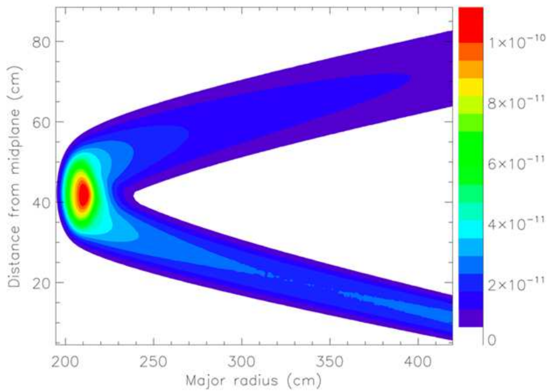


MSE emissivity wavelength spectra (full, ½ and 1/3 beam components included ***for ASDEX Upgrade shot #26323***

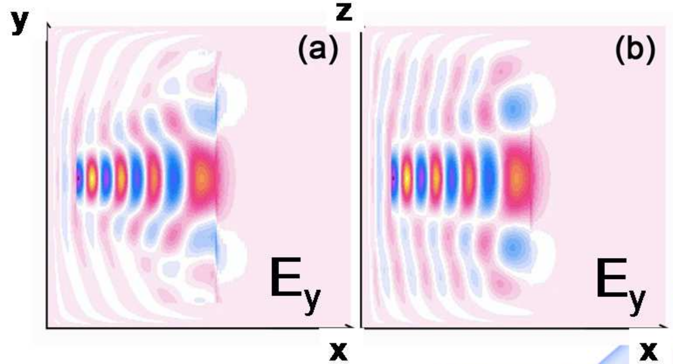


A generic framework for neutron synthetic diagnostics has been integrated (domain voxelization + neutron source rate/spectra + diagnostic response)

JET neutron MPR "solid angle" contribution



Synthetic reflectometry:
full-wave 3D code (ERC3d) valid for both O and X-mode polarizations



Undertakings and caveats

The ITM-TF framework proved to be a valuable environment to benchmark codes addressing th same physics, which can be interchanged as modules within the same workflow thus minimizing the sources of discrepancy

Benchmark of equilibrium codes used within the ETS workflow

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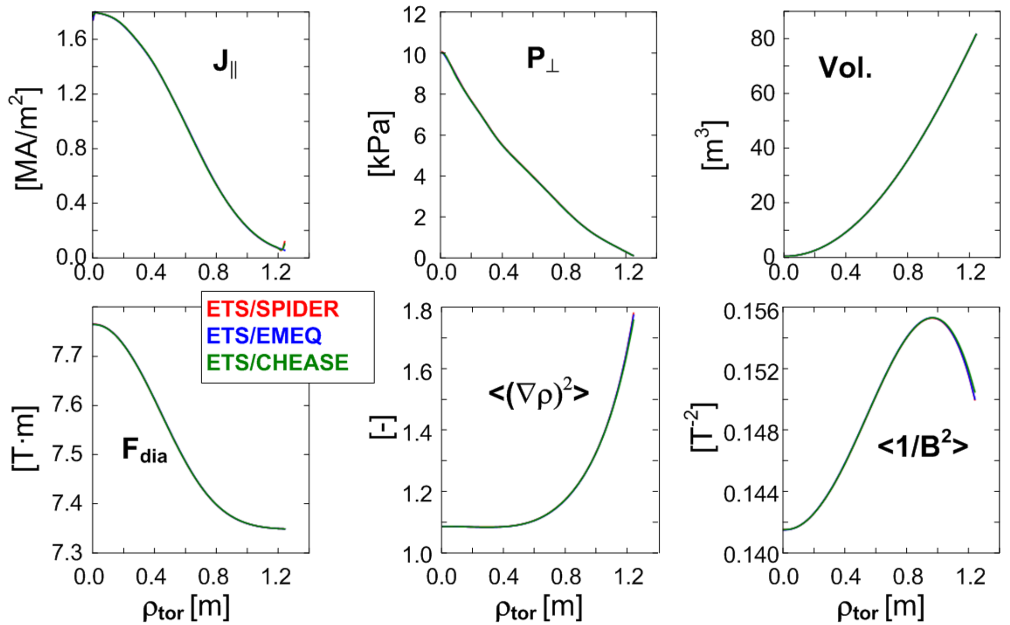
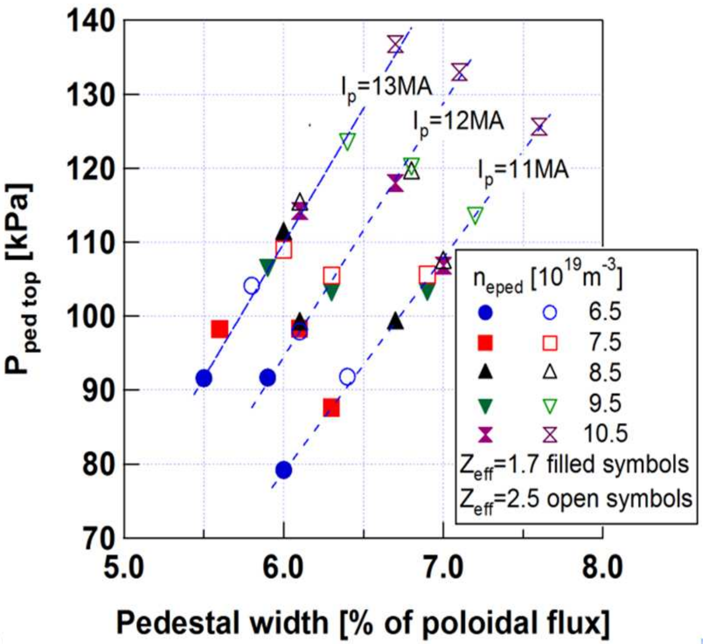


! The benchmarking work revealed the need, for any IM framework, to clearly and unambiguously define all the physical quantities and coordinate conventions on top of a standardized interface (cfr. COCOS O. Sauter and S. Y Medvedev, to appear in Comput. Phys. Commun. (2012))

ITER Scenario Modelling group: Modelling of Hybrid Scenario

- Integrated modeling of ASDEX-Upgrade and JET hybrid scenario
  - ✓ Current diffusion, importance of s/q on core transport, validation of GLF23 with self-consistent density, temperatures & momentum
- Predictive integrated modeling of ITER hybrid scenario
  - ✓ Access of hybrid current profile with ITER H&CD mix
  - ✓ Develop model-based magnetic & kinetic real time burn control
  - ✓ Simulate core & pedestal properties with first principle modelling

Pedestal prediction (EPED): Ip & density scan



Prescribed density profile scan at fixed n_l =8.8x10^{19}m^{-3} n_{eo}/n_l=1,1.25,1.5

consistent core & edge simulations n_{eo}/n_l ↑ at n_l=cst:
- Edge confinement ↓
- Core confinement ↑

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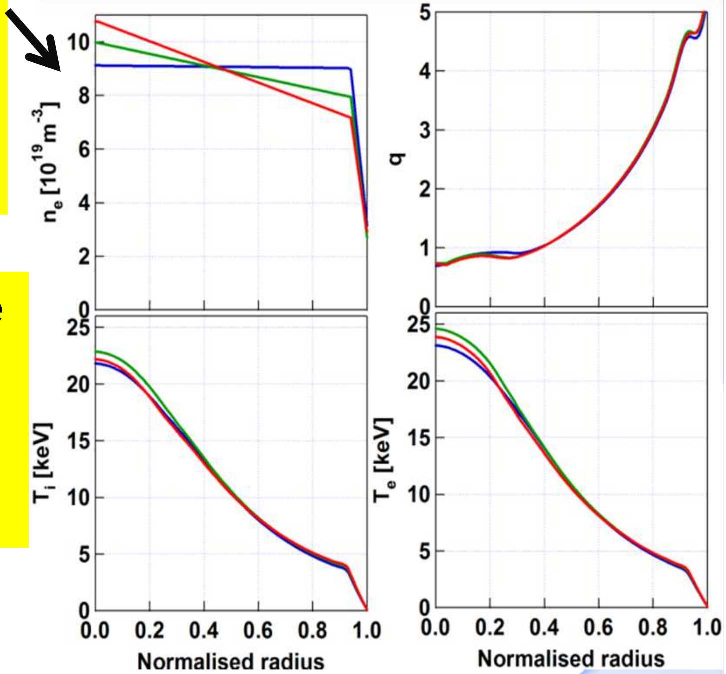
CRONOS simulation: GLF23 (core) with EPED constrains



ITM-TF 2013 WP

Increased focus on validation and application of the available workflows on physics problems of relevance to the ITER Scenario Modelling activity and ITPA and/or for regular interpretative/predictive modelling of present devices.

Physics milestones for 2013:

I. Integrated modelling of ITER hybrid scenarios with ITM ETS workflows, based on the existing scenario developed with CRONOS, JETTO and ASTRA – Calculation of edge MHD stability and core turbulence.

II. Impurity modelling for JET and ASDEX Upgrade - address the core impurity transport (Be and W) in L mode and baseline ELMy scenario for JET with the new ILW and AUG with W wall.

III. VDEs in present experiments (e.g. JET, TCV) and ITER

IV. First exploitation of a system code for DEMO reactor modelling, using ITM framework

Technical milestones: development of workflows providing for the following capabilities

1. First-principle based core/edge transport simulations using HPC resources.
2. Local analysis of the bulk plasma - interpretative simulations including: equilibrium reconstruction, the use of measured profiles, calculation of H&CD deposition profiles (accounting for synergy effects) and calculation of transport coefficients (possibly including turbulence modules).
3. Full scale simulation involving feedback control and H&CD.
4. SYCOMORE system code, workflow for reactor design, self-consistently simulating Plasma, Divertor, Breeding Blanket and Bio-Shields, TF and CS coils