Physics model development and extensive validation of predictive integrated modelling within the new EU framework programme 2021-2027 (TSVV11 activity)

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"a strong theory and modelling programme is essential because empirically based predictions are uncertain in unexplored environments like ITER and particularly DEMO, and this will be a stronger focus than foreseen earlier" [Statement from the 2018 Fusion Roadmap]

In the EUROfusion Work Package Advanced Computing, among the 14 'Theory, Simulation, Verification and Validation ' activities one is devoted to such effort.

The TSVV11 team plan to significantly extend the state-of-the-art in predictive integrated tokamak simulation, and validation methodologies thereof, **combining both technical framework and physics-module advances.**

All the physics that we master in 2021 has to be available from ITER control room in 2027.

Therefore the TSVV11 guiding principles are:

- **Align with ITER technical choices** in terms of integrated modelling workflow and database management (WP1)
- **Improve and validate advanced physics modules** focusing on high priority modelling extensions that will be needed for multi-physics full predictive modelling, with the help of other TSVV activities (WP2)
- **Demonstrate validation of full pulse predictive modelling** from breakdown to termination, including a realistic assessment of operational limits (WP3)
- Support extended validation against EU operating tokamaks by providing to users outside this TSVV yearly training on the integrated modelling workflow, a detailed and clear documentation on the workflow and the embedded physics modules, a user friendly interface and **automated validation tools.** (WP4)

Aligning with ITER choices for Integrated modelling means:

Start from a Python-based integrated modelling framework building on principles developed in past EUROfusion programmes: ITM and subsequently WPCD, namely independent and heterogeneous modules communicating physical data only via IMAS Data Structure arguments. A functional template for this framework has been developed and demonstrated by ITER and the CCFE team (under contract to ITER) with modules developed by WPCD for the HCD workflow, and with the JETTO and Edge2D-EIRENE transport modules [Pinches AAPPS 2020]. This High Fidelity Pulse Simulator (HFPS) presently allows core-edge-SOL coupled simulations for multi-channel transport, including multiple ions and radiation (from low Z to W). We will further develop this framework under the name of HFPSeu. The HFPSeu will use EUROfusion software standards, it will couple all previously developed under EUROfusion IMAS-adapted modules as well as new modules provided by this TSVV and other TSVVVs activities, and will use run management tools for efficient validation pipelines and simulation workflows.

Physics module development involves:

development and validation of reduced turbulence models in L-mode up to LCFS, and including isotope effects and all ions; reduced neoclassical models, including poloidal asymmetries most relevant for W impurities; MHD modules adequate for ramp-up and ramp-down; reduced pedestal and SOL models accounting for the fueling impact; breakdown and burn-through modules with self-consistent equilibrium and plasma evolution**.**

Automated validation means :

Focus is placed on systematic and automated validation, verification, and uncertainty quantification (VVUQ) pipelines. Integrated modelling advanced preparation pipelines including automated fitting procedures will be generated. Automated simulation execution, validation workflows including UQ, and database storage, will be developed. Consistency checks in 0D, 1D, and 2D synthetic diagnostics will be implemented for a hierarchy of modelling use-cases.

The HFPSeu framework will also be demonstrated for ITER First Plasma scenarios and the pre-fusion-power-operation (PFPO) phase. The physics-based full pulse predictive capability validated within TSVV11 will be an **input to the plasma model needed in the flight (or pulse design) simulator** which is developed in parallel to design DEMO.

2021 integrated modelling state-of-the-art

Some very nice success stories

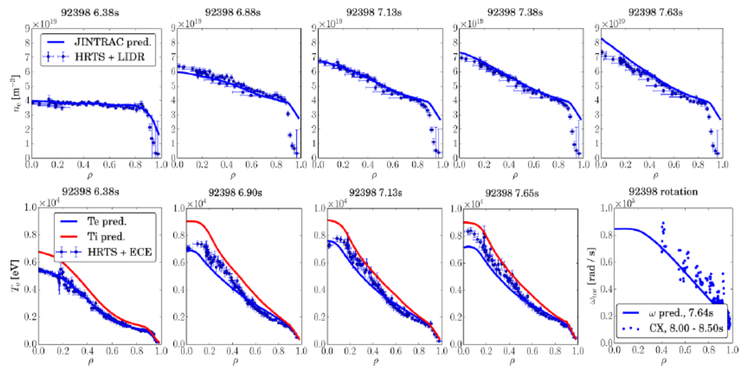
Using JINTRAC on JET for **multi channel prediction incl. multiple impurities**

[Casson et al NF 2020]

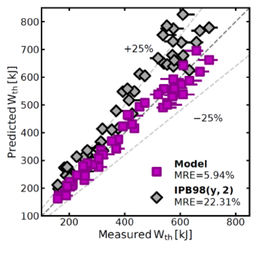
[Citrin @ IAEA]

[Manas @IAEA] on AUG

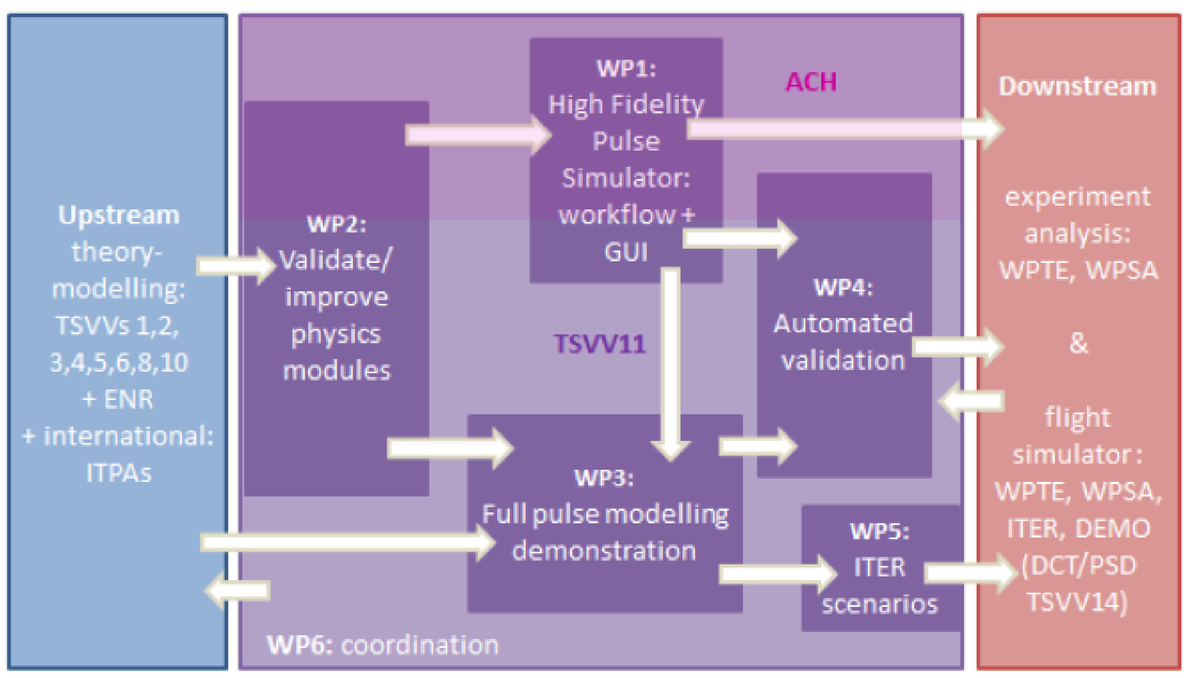
And much more…



Also very successfull SOL-core integration on:
50 AUG H modes: better than empirical scaling laws, qualitatively of course but also quantitatively!
[Luda NF 2020 and this conference]
28 JET-ILW H modes [Saarelma PPCF2018]
And much more…



State-of-the-art extended to prepare ITER operation within the TSVV11 project, supported by the Advanced Computing Hub @Poznan



TSVV11 project structure (PI C. Bourdelle)
WP1: HFPSeu Workflow orchestration and module coupling framework
(coordinator: F.J. Casson, 2.5 ppy incl. 1.5 ACH)
WP2: HFPSeu key physics modules validation (3.5 ppy incl. 1 from ACH)
WP2-D1 Turbulent transport reduced models targeted validation (coordinator: Y. Camenen)
WP2-D2 Core-edge-SOL coupling targeted validation (coordinator : C. Bourdelle)
WP2-D3: Impurity transport, development of reduced models, verification and targeted validation (coordinator: C. Angioni)
WP2-D4: MHD modules targeted validation (coordinator: P. Maget)
WP2-D5: Plasma initiation (Breakdown and burn-through and MHD equilibrium) integration and validation (coordinator: J-F Artaud)
WP3-HFPSeu full pulse modelling capability demonstration (coordinator: E. Fable, 2 ppy)
WP4-HFPSeu systematic validation (coordinator: A. Ho, 1ppy incl. 0.5 from ACH)
WP5- HFPSeu initial ITER phase modelling (coordinator: J. Citrin, total effort 0.5 ppy)

Updated info here https://wiki.euro-fusion.org/wiki/TSVV-11
Do not hesitate to contact clarisse.bourdelle@cea.fr for any questions/suggestions.

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