IP:xxx

Progress in edge plasma turbulence modelling – hierarchy of models from 2D transport applications to 3D fluid simulations in realistic tokamak geometry

H. Bufferand[a], S. Baschetti[a], J. Bucalossi[a], G. Ciraolo[a], G. Falchetto[a], N. Fedorczak[a], A. Gallo[a], Ph. Ghendrih[a], G. Giorgiani[b], Y. Marandet[c], M. Raghunathan[c], F. Schwander[b], M. Scotto d'Abusco[b], E. Serre[b], P. Tamain[a], H. Yang[a], the WEST team & the JET contributors

a. CEA, IRFM, France ; b. M2P2, Aix-Marseille Université, CNRS, Centrale Marseille, France ; c. PIIM, Aix-Marseille Université, CNRS, France

hugo.bufferand@cea.fr

ABSTRACT

- SOLEDGE3X : new versatile 2D/3D fluid code for edge plasma simulation
- In transport mode, a reduced model for turbulence transport intensity prediction is proposed based on "k-epsilon" like formalism
- Full 3D turbulent simulations have also been performed to test the ability of the code to simulate turbulent plasma including realistic wall geometry and plasma-wall interaction
- Simulation results applied to JET and WEST are presented as illustration

BACKGROUND and METHODS

- From former codes SOLEDGE2D and TOKAM3X, the new drift-fluid 2D/3D code SOLEDGE3X have been developed at CEA-IRFM and French Federation for Fusion
- Immersed boundary conditions are used to address complex wall geometry and enable simulation of the edge plasma up to the first wall
- Zhdanov multi-component closure is implemented to simulate impurities and hydrogen isotopes mixture without trace impurity assumption
- SOLEDGE3X is coupled to EIRENE for neutrals modelling
- Method of manufactured solution has been used to verify operators implementation

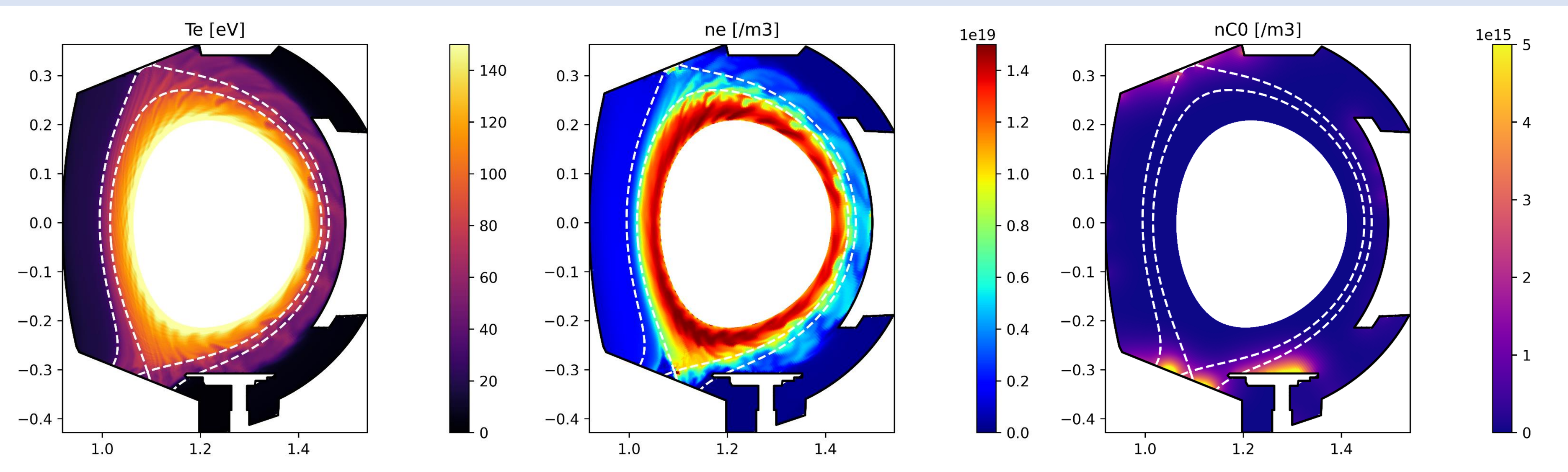
TURBULENCE MODELS

FIRST PRINCIPLE

Full 3D simulations of the edge plasma can be performed with the SOLEDGE3X code. Turbulent structures spontaneously appears as the edge plasma instabilities grow. Only electrostatic turbulence is model for the moment in SOLEDGE3X. An example of full 3D turbulent simulation for WEST is illustrated below. This kind of simulation is similar to the "Large Eddy Simulations" in the fluid neutral community. These "high fidelity" simulations are predictive but remain numerically expensive.

REDUCED MODELS

For experiment analysis and interpretation, 2D transport simulations remain the workhorse since they are relatively fast to run. The main drawback is their poor description of turbulence, the latter being emulated by diffusion empirically tuned. To add some information about turbulence in transport simulation and to make a step towards predictability, SOLEDGE3X implements a reduced model for turbulence based on the "k-epsilon" approach widely used in the neutral fluid community.



SOLEDGE3X simulation results for a 3D WEST case including recycling and Carbon sputtering. Left: electron temperature. Middle: electron density. Right: Carbon neutral density.

REDUCED MODEL FOR TURBULENCE

K-EPSILON like models

One or two equations for the turbulence intensity "k" and for the turbulence dissipation "epsilon" (optional) are added to the mass, momentum, energy and current balance. The cross-field diffusivities are linked to turbulence intensity by the relation $D = \tau k = Rk/c_s$.

The equation for the turbulence intensity "k" takes the form

$$\partial_t k + \vec{\nabla}\cdot(k\vec{v}) = S - P + \vec{\nabla}\cdot\left(D\vec{\nabla}_\perp k\right)$$

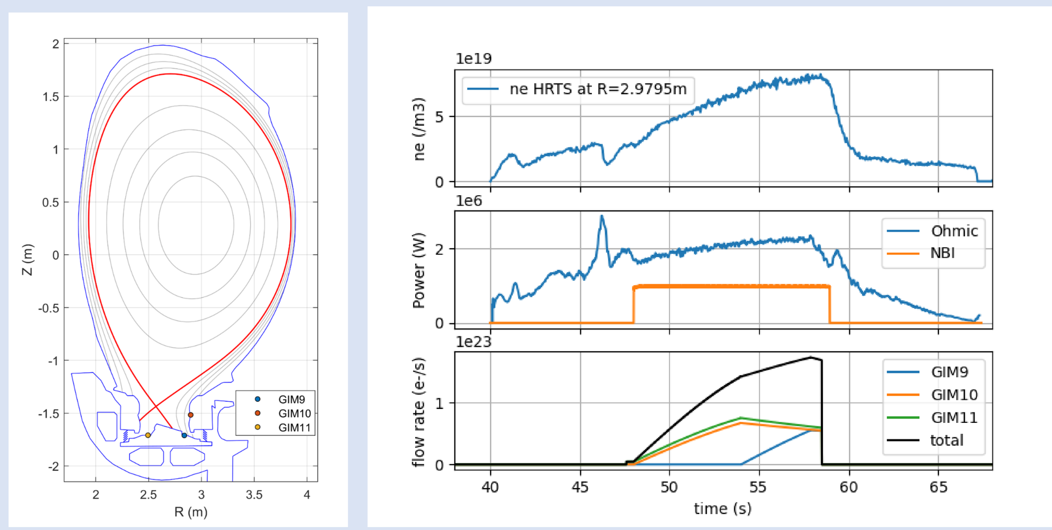
- **Turbulence drive (S)**: interchange linear growth rate is used leading to a source of turbulence at the interchange unstable low field side.

$$S = \gamma_I k = c_s\sqrt{\frac{\vec{\nabla}p}{p}\cdot\frac{\vec{\nabla}B}{B}}\,k$$

- **Turbulence saturation (P)**: the saturation of turbulence follows empirical consideration. In particular, an L-mode scaling law for the SOL width is used to control the level at which turbulence saturates

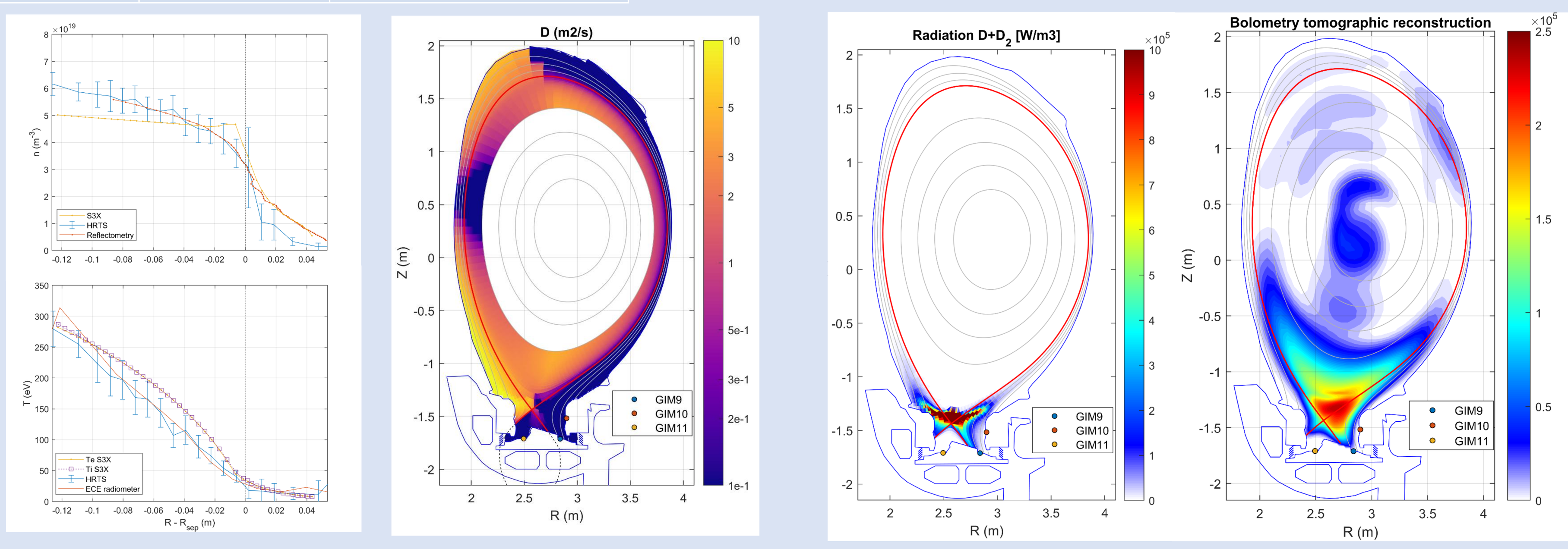
$$P = \alpha k^2 = \gamma_I\left(\frac{2\pi q_{cyl}R^2}{\lambda_{scaling}^2}\right)\frac{k^2}{c_s^2}$$

JET shot #95235 used as an example for the k-model: L-mode density ramp. Simulation parameters are adjusted to plasma conditions at $t = 54s$.



Simulation parameters:

Power	Transport coefficients	Gas puff
3MW	K-model	Feedback for $n_{sep} = 3.5\cdot10^{19}m^{-3}$



SOLEDGE3X simulation results vs experimental measurements: Left: midplane density and temperature profiles. Middle: Diffusion coefficient map computed buy the k-model. Right: comparison between radiation map from SOLEDGE3X and from bolometry tomographic reconstruction.

CONCLUSION

- New SOLEDGE3X 2D/3D code enables transport and first principle turbulent simulation in realistic geometry
- Reduced turbulent models have been implemented for transport simulations, inspired from the "k-epsilon" model widely used in the neutral fluids community
- Validation by confrontation to experiments is ongoing

ACKNOWLEDGEMENTS

- This work was granted access to the HPC resources of CINES, under the allocation 2020-A0080510482 made by GENCI and to the HPC resources of Aix-Marseille University financed by the project Equip@Meso (ANR-10-EQPX-29-01). This work was supported by the EoCoE-II project, grant agreement 824158, funded within the EU's H2020 program. This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission