White paper :

'developing a reduced turbulent transport model

to prepare ITER operation and optimize reactor design'

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Context:

Within high fidelity integrated modeling, turbulent transport is modeled using the quasi-linear models QuaLiKiz or TGLF [Casson NF 2020, Angioni NF 2022, Dudding NF 2022]. For faster pulse design tools, a Neural Network version of QuaLiKiz is used [Maget NF 2022, Ho NF 2023]. QuaLiKiz has been developed in the EU [Bourdelle PoP 2007, Citrin PPCF 2017], it models electrostatic, circular geometry turbulent transport. Since 2017, no further improvements took place. TGLF is still being developed by Gary Staebler, formerly at General Atomics, now at Oak Ridge, USA, until his upcoming retirement. It is electromagnetic and includes a shaped equilibrium. Both the linear dispersion relation and the saturation model are tuned with free parameters against nonlinear gyrokinetic simulations valid over given parameter sets. Neither QuaLiKiz nor TGLF are adequate for all plasma phases, in particular not for high beta phases obtained on JET and AUG, on which ad-hoc tricks have been added to QuaLiKiz [Casson NF 2020] or TGLF [Reisner NF 2020]. They are hence inadequate for high beta JT60-SA operation, and furthermore, being local, they are not suited to describe global energetic particles interplay [Chen, Zonca RMP 2016, Citrin, Mantica PPCF 2023] in burning plasmas of ITER and beyond. Independent activities are taking place within Europe which address this gap from different angles. They would benefit from a joined framework and additional resources to develop an electromagnetic transport model adequate in high beta plasma and in presence of energetic particles.

On one hand, the impact of Energetic Particles on MHD and turbulence modeling progresses are made under the auspices of TSVV10 activities https://wiki.euro-fusion.org/wiki/TSVV-10. In the ENR project ATEP https://wiki.euro-fusion.org/wiki/Project_No10 reduced global model for Energetic Particle driven MHD and turbulence has been developed based on Phase Space Zonal Structure transport theory. This project expired May 2024.

On the other hand, a French initiative has been granted (ANR FASTER 2022-2026) to support the development of a local turbulent transport model using 1/ for the linear response: ML techniques applied on a database of local high fidelity gyrokinetic codes such as GKW, GENE 2/ for the saturation existing rules available in the community at the moment. Synergy is being seeked with effort ongoing in understanding the role of self-generated zonal flows, and their implementation into existing quasi-linear transport formulations, in particular based on the knowledge in the Geophysical Fluid Dynamics community.

In order to develop a new electromagnetic transport model adequate also in presence of energetic particles, a framework in which the Energetic Particle and the turbulent transport communities could join forces is timely. Such a framework would maximize the synergy among theoreticians and modelers: extending the linear response towards global effects, exploring the saturation mechanisms of the turbulence in presence of Zonal Flows as well of Energetic Particle driven modes.

Deliverable:

Provide an advanced turbulent transport model (heat, particle and momentum) applicable in all the plasma phases, including high beta burning plasmas. The CPU or GPU time scale of such a model should be compatible with its usage within High Fidelity Integrated modeling as well as Pulse Design Tools.

Milestones:

M.1 Understand the frontier between local and global effects in presence of Energetic Particles both on the linear response as well as on non-linear interplays between turbulence, Zonal Flows and EP driven modes.

M.2 Extend the IMAS gyrokinetics data dictionary from local to global codes. Extend the linear dataset to high beta, high fraction of alphas cases. Maintain the gyrokinetic database. Learn how to integrate and parallelise the models within IMAS, e.g. using the emerging persistent actor framework (PAF).

M.3 Use ML techniques to speed up the linear response calculation, including high beta plasmas and plasmas with a significant contribution of Energetic Particles.

M.4 Develop saturation rules robust to all plasma phases, ion heated vs electron heated, various collisionality regimes, various beta, and Energetic Particle contribution.

M.5 Supervise the validation within integrated modeling framework against high beta experimental data on JET, AUG and JT60-SA.

M.6 Supervise the implementation and test in Pulse Design Tools to predict burning plasma phases (Q>5) of ITER and DEMO. Collaborate with other international projects such as BEST, STEP, CFEDR etc.

Ressources needed:

In terms of manpower, to achieve the above milestones, an effort of ~8 ppy is needed over a 4-5 years window.

More detailed estimates in terms of manpower for each milestone is given below, assuming in all cases a time frame of at least 4 years:

M.1 This work requires numerical global gyrokinetic nonlinear modeling and analytical understanding to diagnose, 2-3 ppy

M.2 This task needs to be manned on the long term, it needs to be interfaced with a future long Term Storage Facility and adequate softwares. 0.5 ppy

M.3 This work requires active exchange between experts and students, tests of various ML techniques, starting from the on-going effort on local gyrokinetics simulations within the French granted ENR FASTER project running until 2026. 2 ppy

M.4 This is a theoretical work, testing understanding of the non-linear saturation physics on simpler non-linear models before extending the tests on state of the art global nonlinear simulations in collaboration with TSVV10. It requires dedicated efforts and training of PhD students. The Phase Space Zonal Structure model (ENR ATEP M. Falessi NJP 2023) will be continued and merged with other on-going work at Ecole Polytechnique France by O. Gürcan et al. 3 ppy.

M.5 This task will be done in collaboration with TSVV11. Some dedicated ppy is required on both sides to discuss in detail the 1st validation.

M.6 This task will be done in collaboration with TSVV15. Some dedicated ppy is required on both sides to discuss in detail the 1st implementation.