Updates on DTT Theory activities

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On behalf of DTT Theory & Simulation group

TCM 48 June 2025

Theory and simulations research topics

Within the theory and simulations area 4 topics are actively pursued:

- Integration of Theory, Simulation and Experiments: IMAS database and workflows for equilibrium, MHD stability and transport studies;
- Global and Hybrid Gyrokinetic simulations;
- Particle losses due to Ripple and Alfvénic fluctuations;
- EP distribution function modelling;

Integration of Theory, Simulation and Experiments

- Critical for the scientific exploitation of the machine and for predictive capability in reactor relevant plasmas;
- Requires comparison of simulations, experiments and reduced models;
- Accurate modelling of magnetic geometry, kinetic profiles, fluctuation modes structures and EP distribution functions are required;

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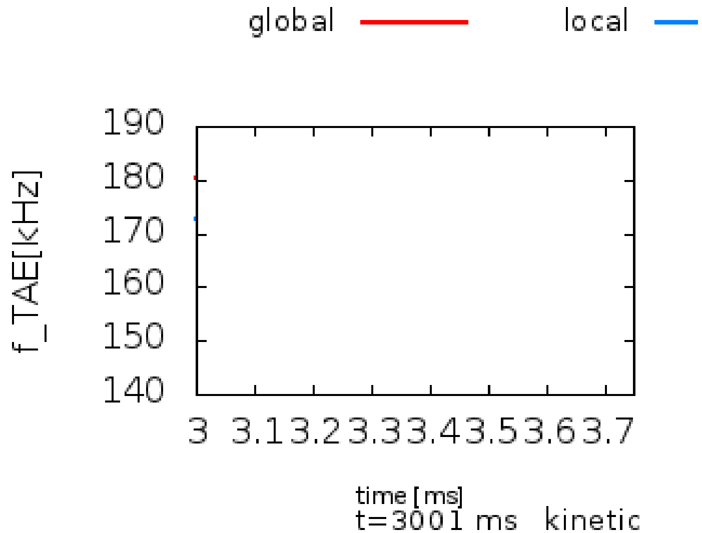
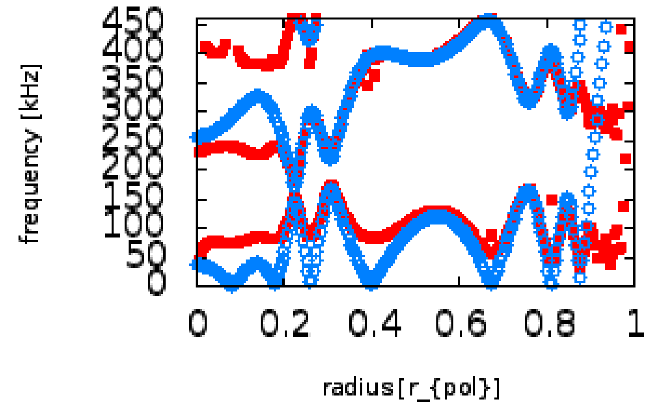
- Critical for the scientific exploitation of the machine and for predictive capability in reactor relevant plasmas;
- Requires comparison of simulations, experiments and reduced models;
- Accurate modelling of magnetic geometry, kinetic profiles, fluctuation modes structures and EP distribution functions are required;
- Only a centralized IMAS database can ensures integration and consistency;
- Automated IMAS workflows operate directly on the database.





DTT Research plan

Headline number	Headline contents	Priority (+,++, +++)	ITER	DEMO
Construction Phase 2022-2029				
C.8.1	Verification of Phase 1 scenarios and extended/kinetic MHD modelling with high fidelity theory-based tools. Predict and prepare Phase 1 Experimental programme.	++	*	*
C.8.2	Set up IMAS infrastructure and workflows, e.g. ATEP code	+++		

IMAS equilibria for DTT

- No IMAS equilibria were available at the start of this activity;
- Also no agreement between ENEA and ITER on the usage/development of IMAS;
- A database entry has been created for the DTT full power scenario using the kinetic profiles by the T&M group and a new magnetic equilibrium;
- The ITER cluster has been used to store data and maintain numerical workflows;
- Both Theory and Simulation and T&M groups have dedicated accounts on the cluster;
- Collaboration with ITER allow to have always updated libraries and workflows;

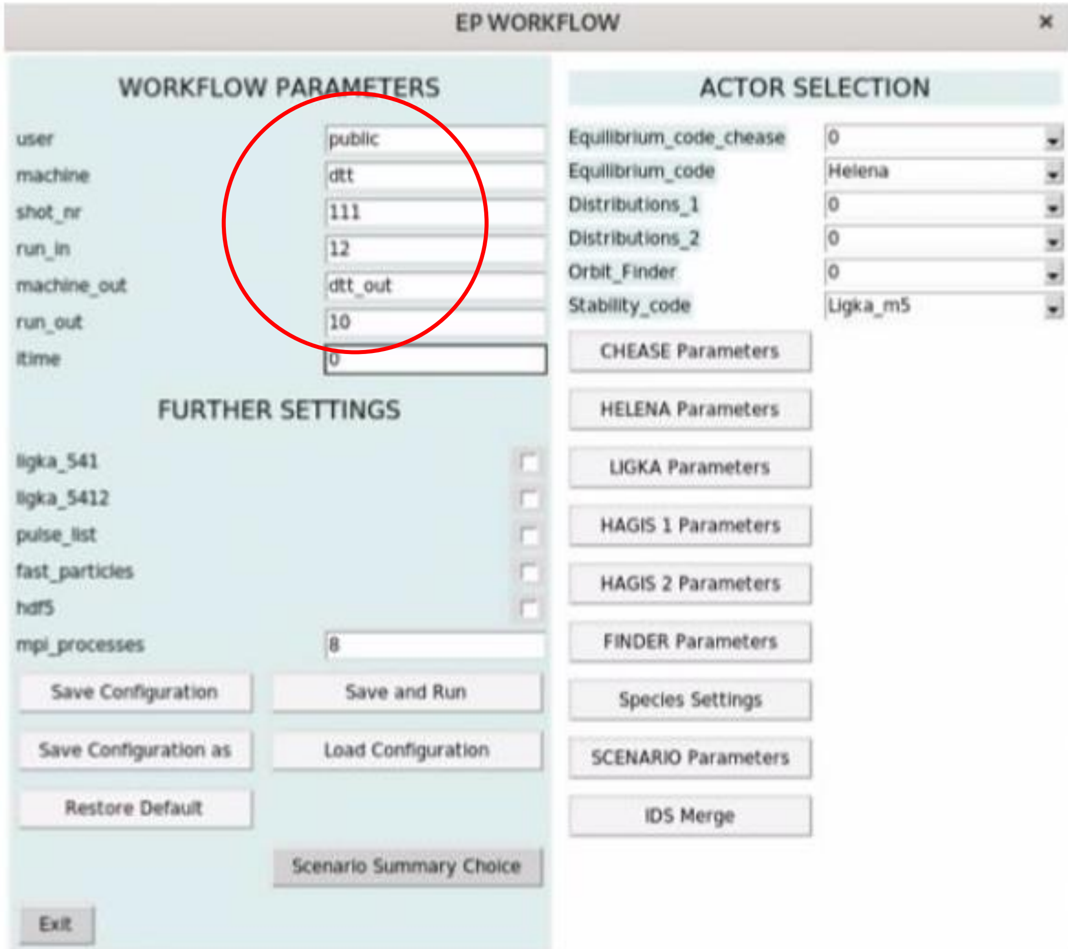
HYMAGYC workflow

HYMAGYC has been modified to:

- Read equilibrium from an IMAS database and compute a high resolution version suitable for MHD and EP studies;
- Read EP (model) distribution function and kinetic profiles;
- submit a parallel batch job executing HYMAGYC;

It is possible, **but not yet tested,** to use the same workflow substituting HYMAGYC with MARS for MHD stability studies

IMAS equilibria for DTT

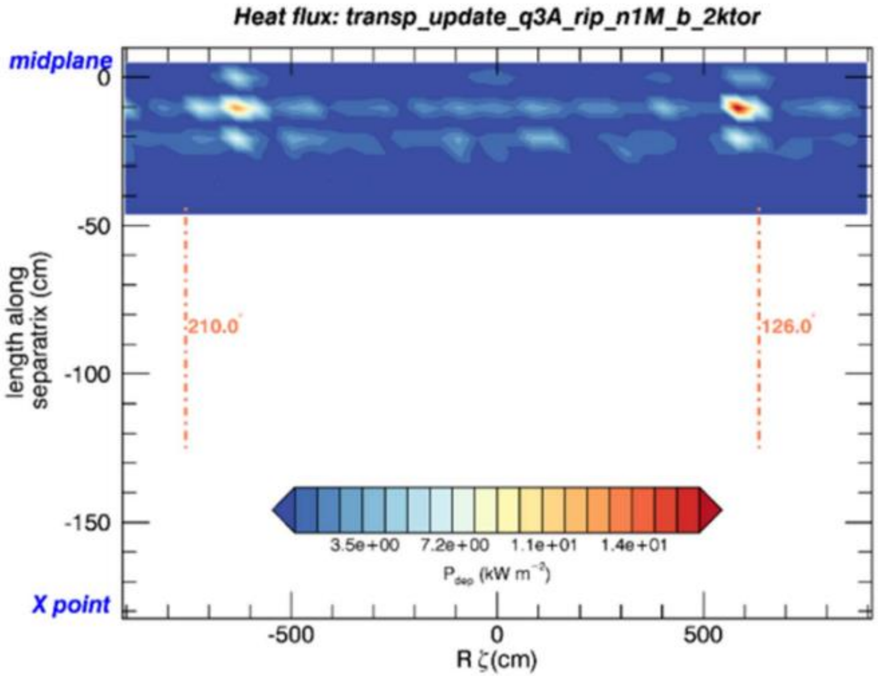


Next steps

- The JINTRAC transport code can now write directly to IMAS databases;
- A collaboration with Paola and the T&M group is underway to generate a set of database entries for various DTT scenarios;
- Development of a MAXFEA interface to IMAS;
- In the future, IMAS database and workflows should be migrated to a dedicated DTT HPC facility

Losses due to Ripple and Alfvénic fluctuations

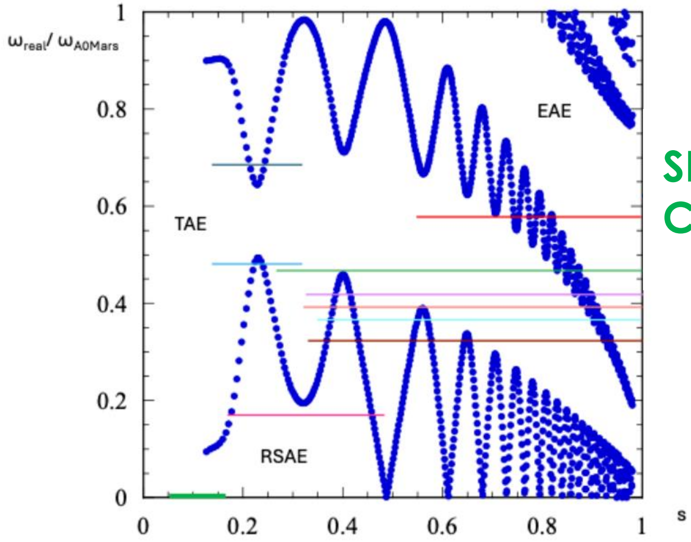
- Preliminary analysis show low EP particle losses though poloidally localized;
- TAEs and other modes may significantly enhance EP losses;
- A general workflow has been developed to compute fluctuation induced fast ion losses in DTT, using MARS results as input for the ORBIT code;



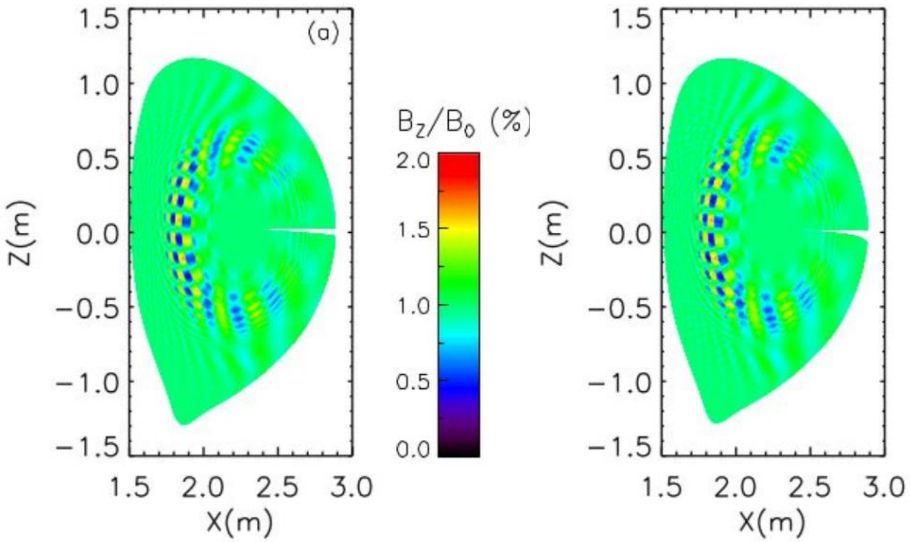
Losses due to Ripple and Alfvénic fluctuations

Spectrum and radial profiles of TAE determined by DAEPS/FALCON, MARS and HYMAGYC codes (**n=10**)

remapping the perturbed TAE fields from MARS into the guiding center code **ORBIT** Boozer coordinates

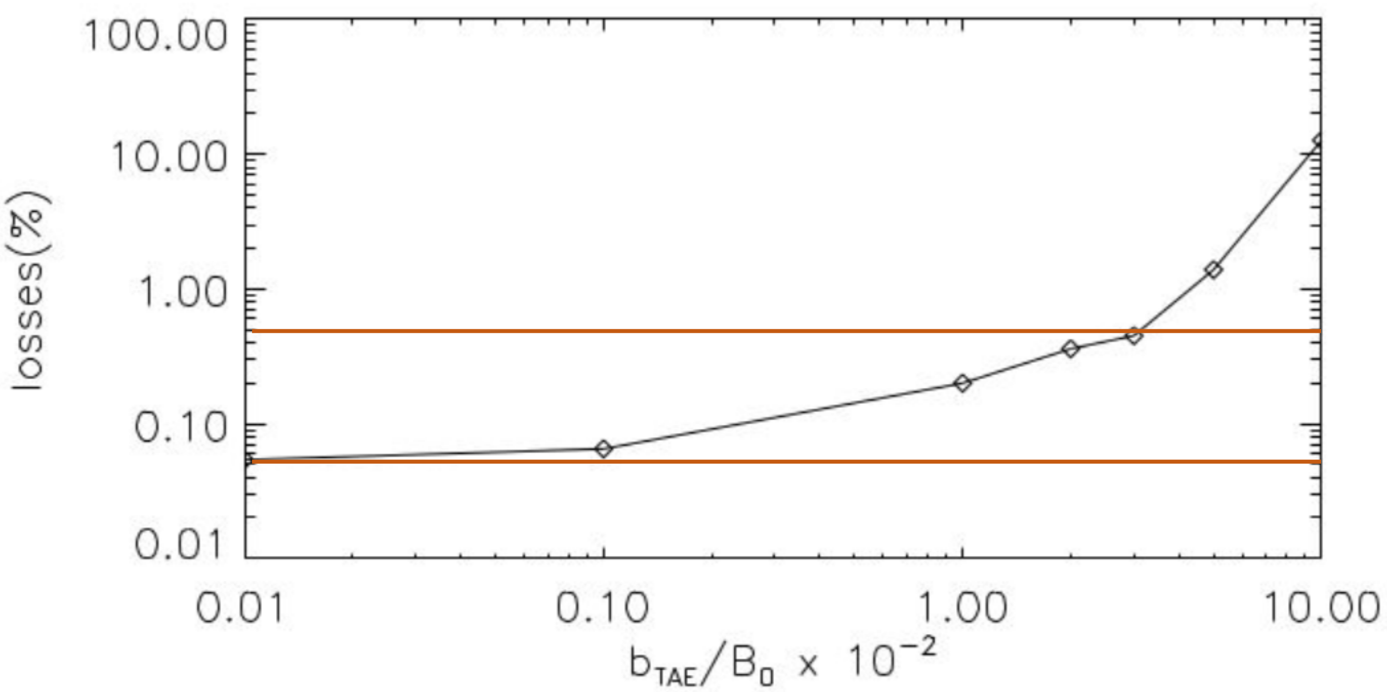


SELECTED CASE



Losses due to Ripple and Alfvénic fluctuations

- Equilibrium with R0 = 2.19 m (JETTO PPF=1184)
- NNBI parameters : E = 510 keV, 1 beam@10MW
- 3D TRANSP distribution with 10k test particles



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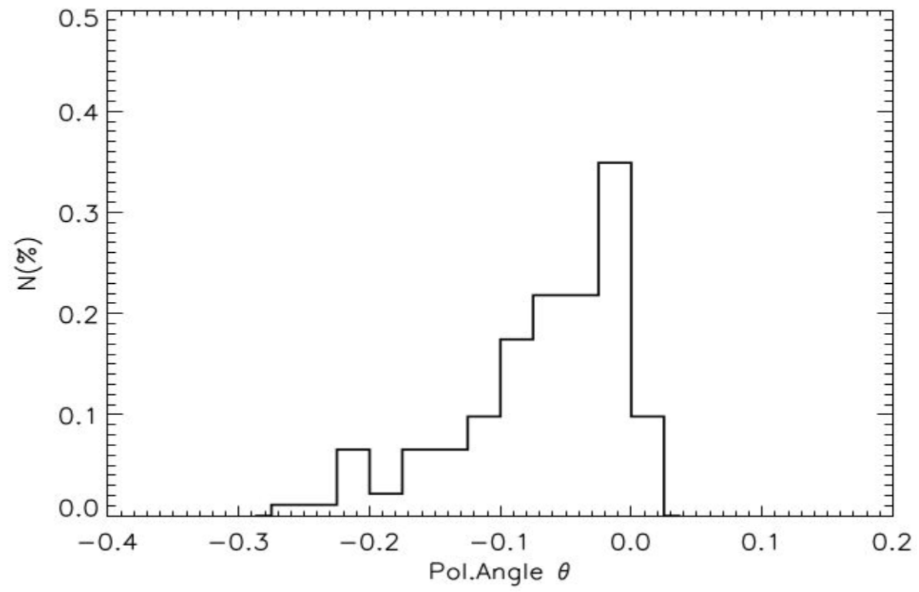
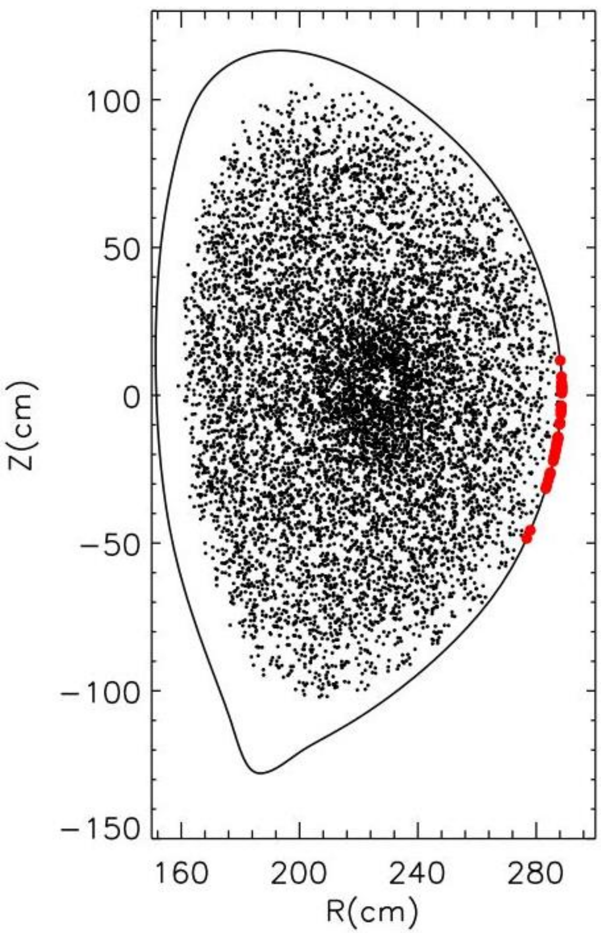




- losses mainly close to $\theta = 0$ in the bottom half of device (LFS);

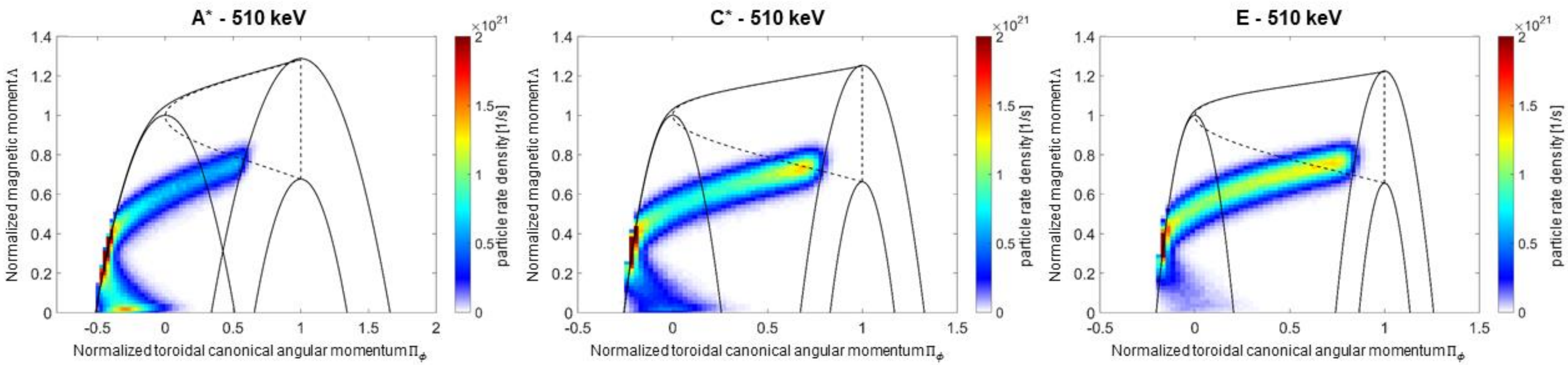
Next steps

- High-statistics simulations with 1 million test fast ions are underway to evaluate the heat power deposition map
- Inclusion of multiple TAEs as calculated by MARS is in progress
- Apply this workflow to the latest version of the E scenario;

Equilibrium EP distribution function modelling

Study of beam NBI EP distribution functions in various DTT plasmas:

- different I_p/B_t values
- NBI simulated on plasmas of scenarios A, C, E
- Steady-state beam EP distribution functions is given as input for nonlinear GK simulations, i.e. HYMAGYC
- EP distribution analysis in COM space (DTT Research Plan)

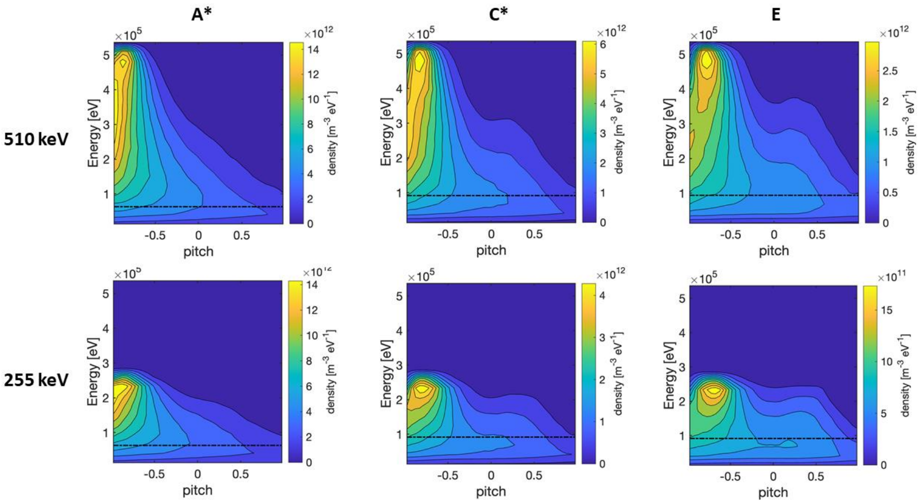


A, C scenarios do not foresee NBI, though NBI will be used in similar plasmas during DTT operation phases

Next steps

- Provide, upon request, fast ion distribution functions to other groups (e.g., to HYMAGIC, for MHD studies, and for diagnostics studies – e.g., Collective Thomson Scattering)
- Depending on the advances with ASCOT-RFOF and DTT IMAS implementation, preliminary ICRH+NBI simulations can be set
- Investigate the importance of using first wall as a boundary condition for EP losses and not the LCFS to correctly estimate the fraction of EP prompt losses

Thank you for your attention!



- Collisional slowing down simulated with ASCOT:
  - Steady-state beam EP distribution functions
  - Collisional losses
  - Absorbed power, current-drive, torque

Take-home messages for DTT:

- Collisionless beam EP analysis:
  - Passing orbits dominate ref. scenario E
  - Passing/trapped orbit ratio varies with plasma density and NBI energy
  - Small fraction of stagnating orbits
  - Importance of using the first wall as a boundary condition for EP losses (ASCOT) and not the LCFS (CoM) to correctly estimate the fraction of EP prompt losses
- Collisional slowing down of beam EPs:
  - Efficient beam coupling, slightly reduced at high NBI energy at low plasma density
  - NBI current drive of 0.24 MA in ref. scenario E
  - NBI provides torque to the plasma of some Nm
  - Off-axis beam power deposition due to vertically shifted injection geometry
  - Relevant ion heating between 40% and 55% of the absorbed power, depending on NBI energy and plasma kinetic profiles
- This work contributed to the DTT research plan and constitutes an input for other DTT studies (e.g. MHD)

De Piccoli C et al., Front. Phys. 12:1492095, 2024, doi: 10.3389/fphy.2024.1492095

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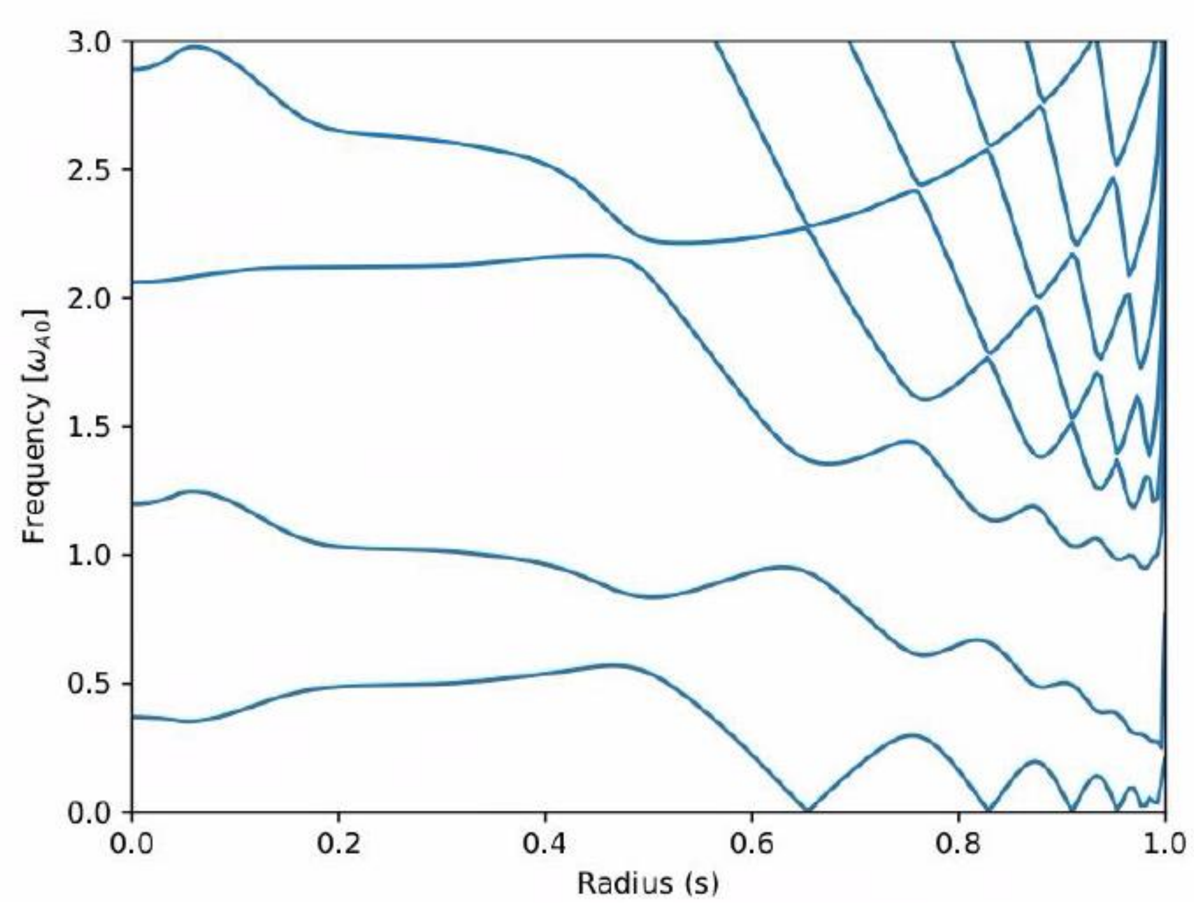

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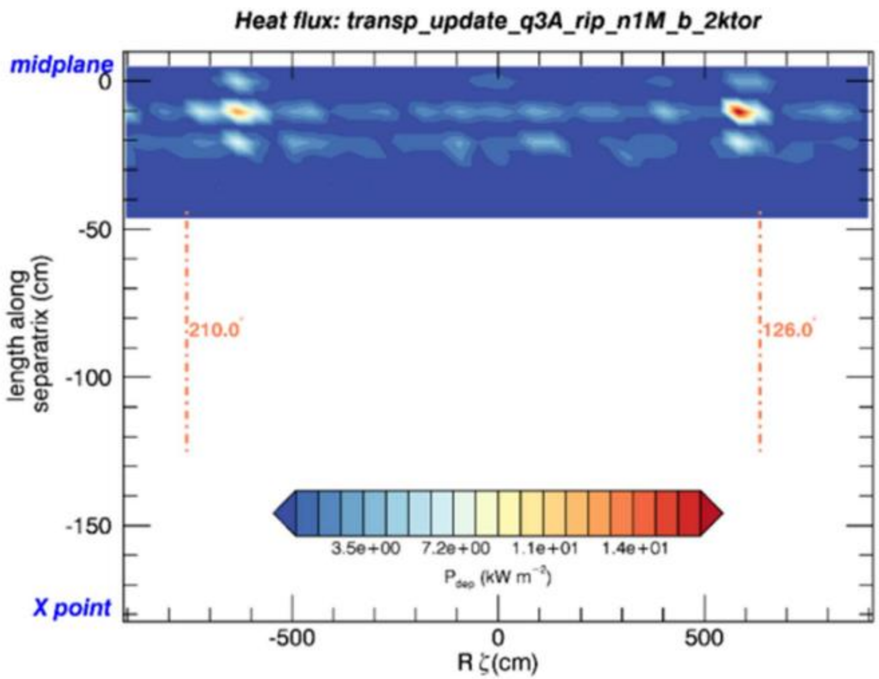

IMAS equilibria for DTT

HYMAGYC has been modified to:

- No IMAS equilibria when this activity studied;
- A database entry for the DTT full power has been created and the workflow has been sucesfully tested;
- JINTRACK transport code is now capable of writing directly IMAS databases. A collaboration with Paola and the T&M is taking place to create a set of databases for different DTT scenarios;
- ITER cluster is used to store data and maintain numerical workflows.

3 main issues tackled recently:

- Develop a full power Hybrid scenario with q>1 to avoid large sawtooth crashes (two upcoming conference presentations EPS and TTF)
- Revise flux consumption by including two elements previously neglected (L-H threshold scaling for metallic machines and use of EC current drive)
- Revision of EM equilibria with v16-v17
- Continue studies of negative triangularity scenarios (one invited talk at TTF)