Chapter 8

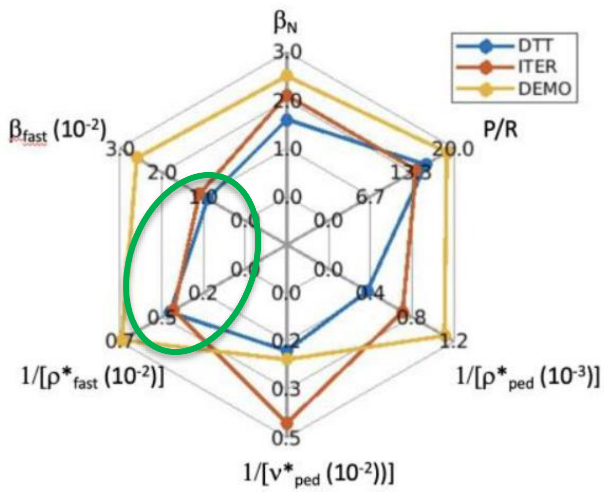
THEORY AND SIMULATION

M. Falessi, G. Vlad, E. Nardon,
G. Brochard, C. De Piccoli, G. Falchetto, M. Gobbin, Y. Kominis, P. Lauber, M. Nocente, M. Salewski,
G. Spizzo, P. Vincenzi, F. Zonca, M. Zuin

Outline

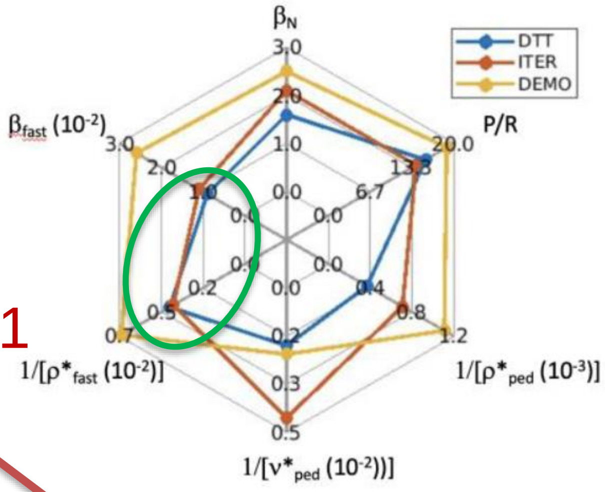
- Rationale
- Main additions to the chapter
- Scientific Headlines
- Suggestions for next versions of Chapter 8
- Ideas for follow-up of the DTT-RP activity

Rationale of Chap 8



- DTT has been designed to describe the physics of reactor-relevant fusion plasmas;
- reactor-relevant plasmas are a complex system;
- as a result, it gives rise to challenges in the theoretical description of the physics processes;

Rationale of Chap 8



Interest from TSVVs 10-11 and DEMO

- DTT has been designed to describe the physics of reactor-relevant fusion plasmas;
- reactor-relevant plasmas are a complex system;
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What makes DTT unique?

– 8.1 Weak similarity scaling & DTT;
– 8.2 Plasma as a complex system: nonlinear equilibria and self organization;
– 8.3 Gyrokinetic transport theory: general approach & reduced models;
– 8.4 Integration of theory, simulation and experiments;
– 8.5 Novel approaches and open problems

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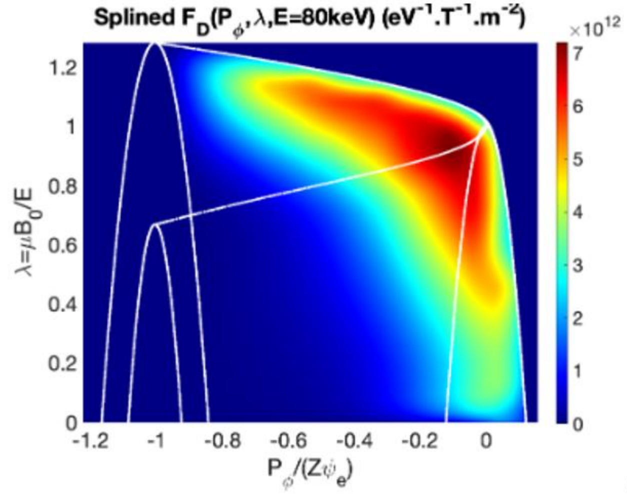
Theoretical challenges in describing the physics of DTT

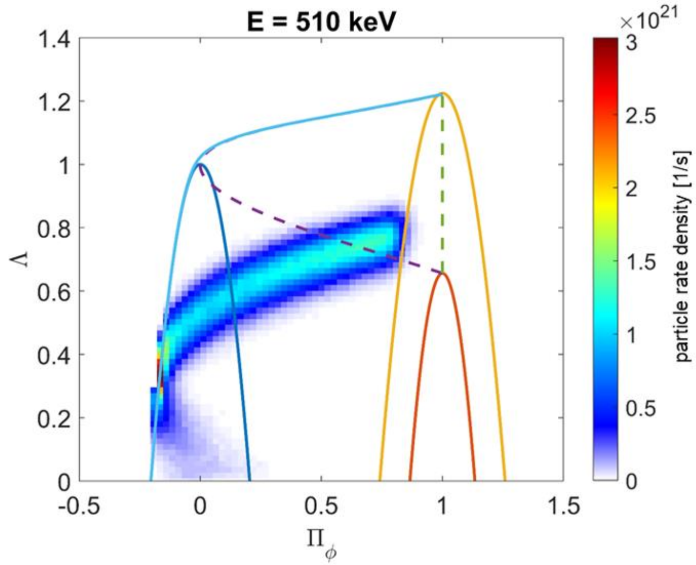
Suggestions received

- Give more emphasis to ITER collaborations;
- give inputs and collaborate with the diagnostics team;
- IMAS infrastructure maintenance and workflows should be included within Chap. 8
- include a set of headlines relatives to the different construction phases;

DTT & ITER collaborations

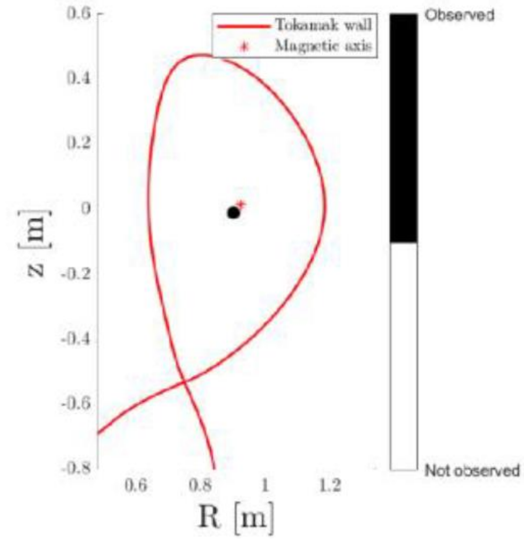
- We established an important collaboration regarding the representation of the kinetic equilibrium;
- Crucially important for δf and Full-f gyrokinetic simulations of reactor relevant plasmas;
- New sub-sections written with G. Brochard, P. Vincenzi, C. de Piccoli

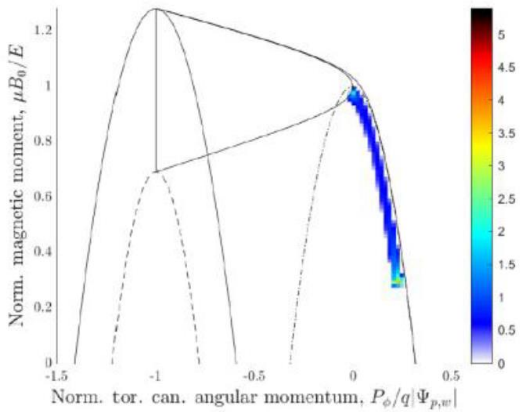




Phase Space diagnostics

- Collaborations with the diagnostics team started;
- Crucial importance of IMAS infrastructure;
- Collaborations with M. Nocente and M. Salewski on phase space diagnostics for validation of models, e.g. FIDA diagnostics;
- New sub-section on experimental techniques for the reconstruction of 3D phase-space distribution functions;





(e) $\varphi = 26.4°$, $E = 95keV$

Headlines

- A set of headlines has been added;
- we emphasized the importance of early/intermediate phases;

C.1	Verification of Phase 1 scenarios and extended/kinetic MHD modelling with high fidelity theory-based tools. Predict and prepare Phase 1 Experimental programme.	++	**Construction**	2022-2029	*	*
C.2	Set up IMAS infrastructure and workflows, e.g. ATEP code	+++				

Headlines

1.1	Verification of Phase 1 scenarios and extended/kinetic MHD modelling with high fidelity theory-based tools. Predict and prepare Phase 2 Experimental programme.	++	**Phase 1**	2029-2034	*	*	
1.2	Validation of IMAS workflows under Low EP (ICRH) Pressures and Currents and scenario optimization	++					

Headlines

1.1	Verification of Phase 1 scenarios and extended/kinetic MHD modelling with high fidelity theory-based tools. Predict and prepare Phase 2 Experimental programme.	++	**Phase 1**	2029-2034	*	*
1.2	Validation of IMAS workflows under Low EP (ICRH) Pressures and Currents and scenario optimization	++				
2.1	Verification of Phase 2 scenarios and extended/kinetic MHD modelling with high fidelity theory-based tools. Predict and prepare Phase 3 Experimental programme	+++	**Phase 2**	2034-2038	*	*
2.2	Validation of IMAS workflows description of new EP transport regimes with NNBI and high current and scenario optimization	++			*	*
2.3	Development of reduced models for describing DTT's full power EP transport	++			*	*

Headlines

3.1	Verification of Phase 3 scenarios and extended/kinetic MHD modelling with high fidelity theory-based tools. Predict and prepare Phase 3 Experimental programme	+++	**Phase 3**	2038-...	*	*
3.2	Validation of IMAS workflows with full power plasmas and scenario optimization	++			*	*
3.3	Development of reduced models for describing DTT's EP transport	++			*	*

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- The advanced transport descriptions introduced should be applied to DTT Phase 1, Phase 2 and Phase 3 plasmas;

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- Edge physics paragraph should be expanded and should become a separate section;
- Global gyrokinetic simulations of DTT plasmas should be included and compared to reduced descriptions;
- The advanced transport descriptions introduced should be applied to DTT Phase 1, Phase 2 and Phase 3 plasmas;
- More interaction with the diagnostic team is required. This section should be expanded;

Follow up of DTT-RP activities

– First collaborations have been made on voluntary basis. We need to find a way to pay for PMs coming from institutions outside the SCARL;

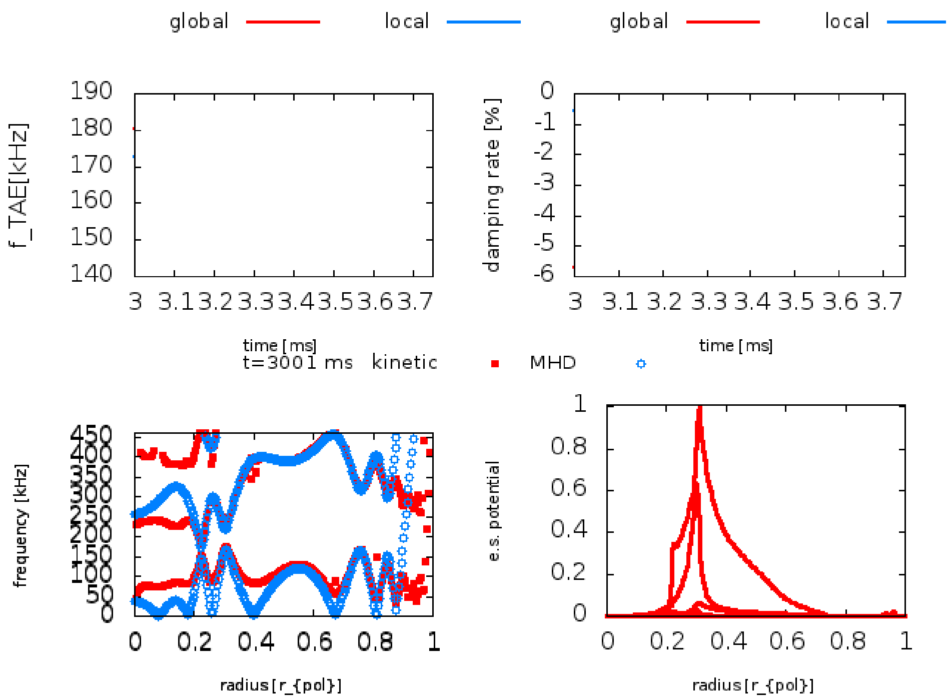
Follow up of DTT-RP activities

- First collaborations have been made on voluntary basis. We need to find a way to pay for PMs coming from institutions outside the SCARL;
- Chapter 8 should be more interlinked with other chapters;
- A set of topics where important theory developments and/or understanding is required should be mentioned throughout in the RP;

Thank you for your attention!

8.4 Integration of theory, simulation and experiments

- Importance of building an infrastructure to verify and validate reduced models on DTT;
- role of IMAS infrastructure;
- Ligka-Hagis EP workflow, synthetic diagnostics;



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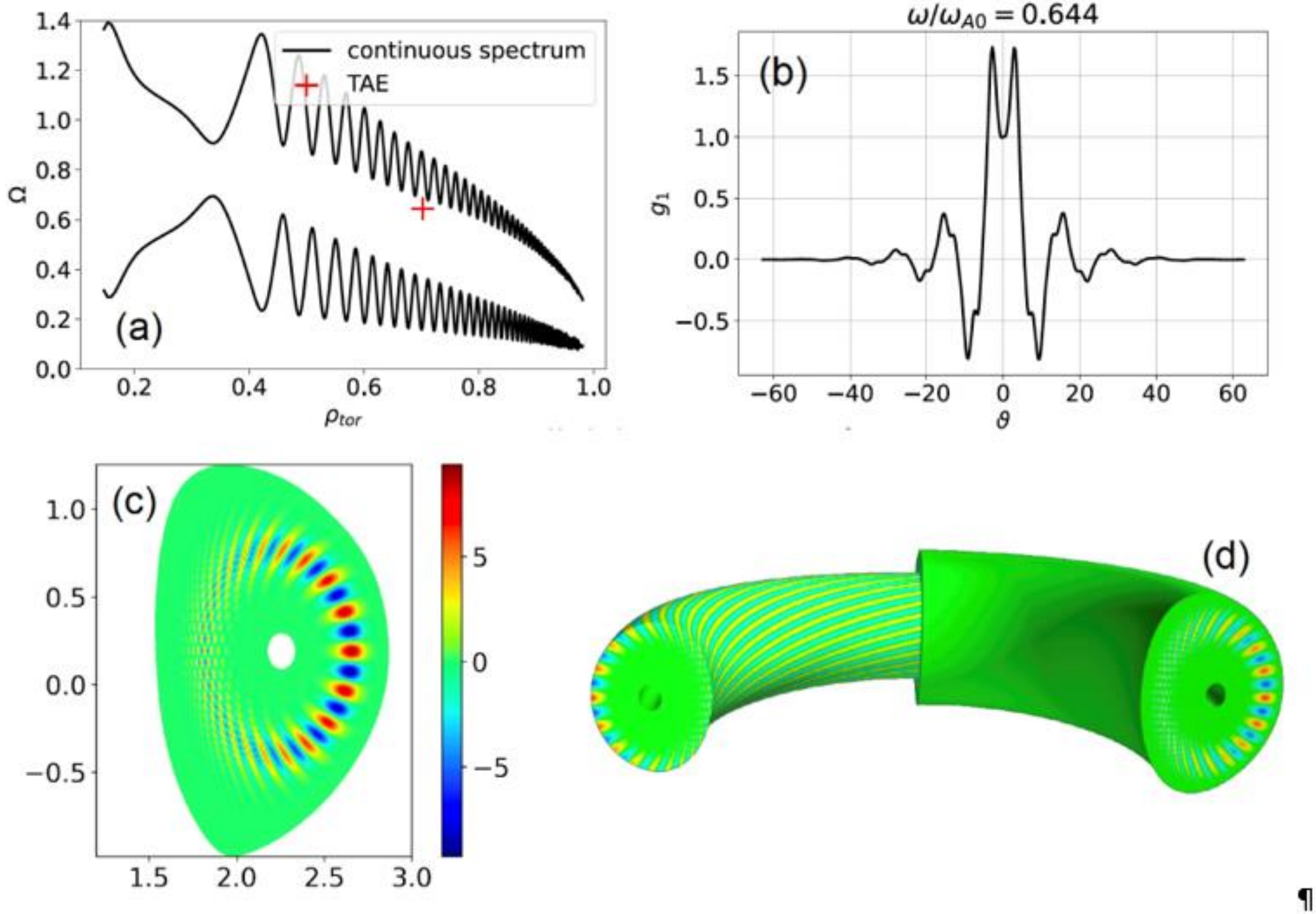
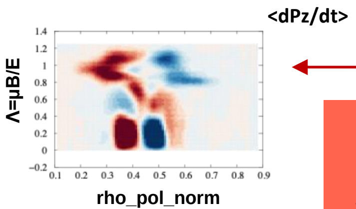


Figure 3 (a) Continuous spectrum (n=20) and location of TAE in DTT; (b) normalized parallel mode structure of the magnetic stream function at ρ_{tor}=0.702; 2D (d) 3D mode structure (n=20) obtained with an ad-hoc radial envelope. Courtesy of G. Wei [G. Wei 2024]. ¶

8.4 Integration of theory, simulation and experiments

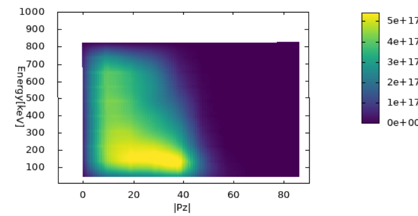
ATEP code: solve transport equation for PSZS with sources and collisions, Lauber 2022

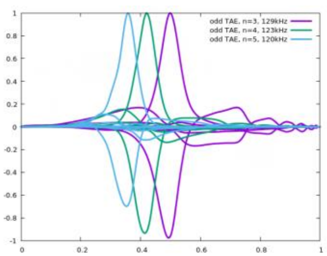
$$\frac{\partial}{\partial t}\overline{F_{z0}} + \frac{1}{\tau_b}\left[\frac{\partial}{\partial P_\phi}\overline{\left(\tau_b\delta\dot{P}_\phi\delta F\right)}_z + \frac{\partial}{\partial \mathcal{E}}\overline{\left(\tau_b\delta\dot{\mathcal{E}}\delta F\right)}_z\right]_S = \overline{\left(\sum_b C_b^g\left[F,F_b\right]+\mathcal{S}\right)}_{z\,S}$$



calculate PSZS fluxes with prescribed amplitude

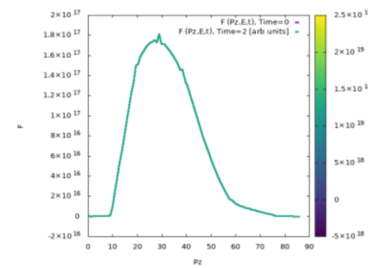
advance F_{EP} and return updated F_{EP} into IDS, or its moments

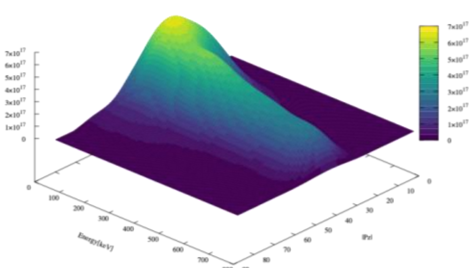




calculate linear mode spectrum

DAEPS and LIGKA Are interchangeable Thanks to IMAS

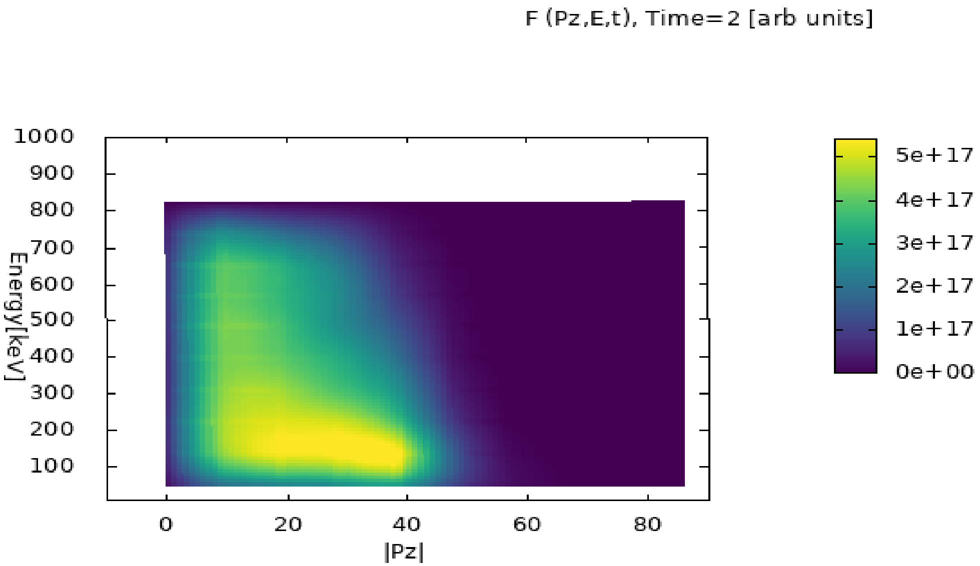


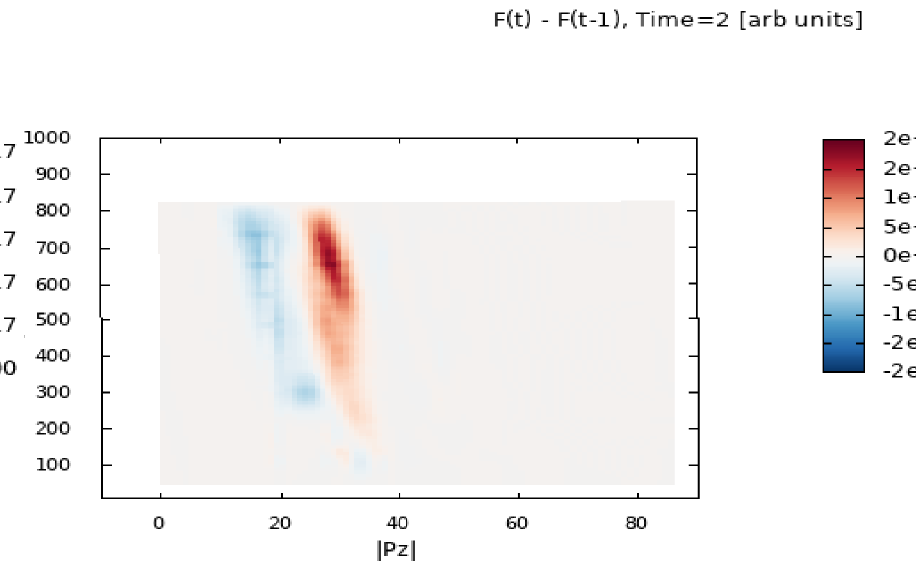


core_transport
equilibrium
mhd_linear
distributions

time

8.4 Integration of theory, simulation and experiments

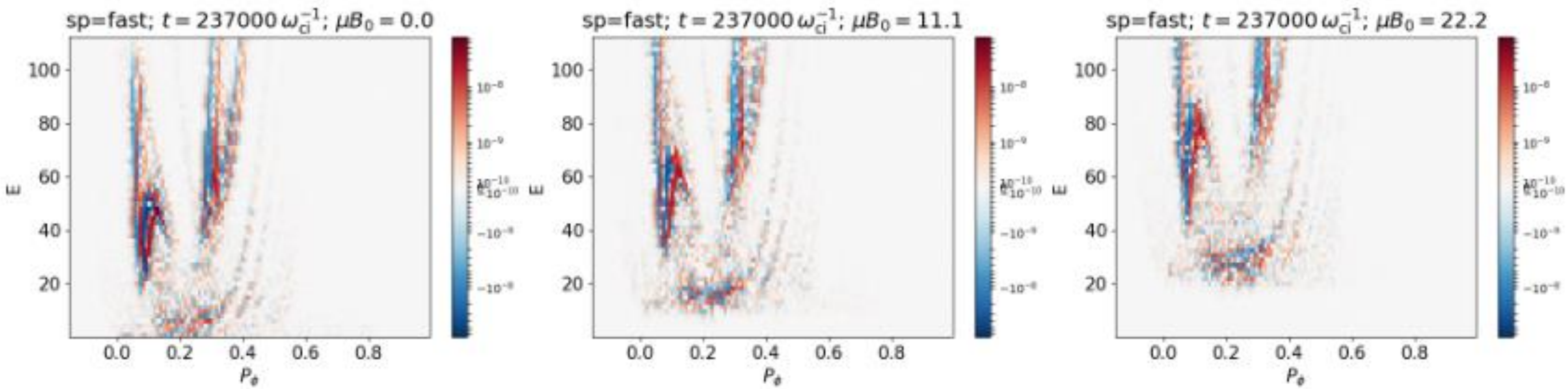




$$\frac{\partial}{\partial t}\overline{F_{z0}} + \frac{1}{\tau_b}\left[\frac{\partial}{\partial P_\phi}\overline{\left(\tau_b\delta\dot{P}_\phi\delta F\right)_z} + \frac{\partial}{\partial \mathcal{E}}\overline{\left(\tau_b\delta\dot{\mathcal{E}}\delta F\right)_z}\right]_S = 0$$

8.3 Gyrokinetic transport theory: general approach & reduced models

Courtesy of Thomas Hayward-Schneider



$$\frac{\partial}{\partial t}\overline{F_{z0}} + \frac{1}{\tau_b}\left[\frac{\partial}{\partial P_\phi}\overline{\left(\tau_b\delta\dot{P}_\phi\delta F\right)_z} + \frac{\partial}{\partial \mathcal{E}}\overline{\left(\tau_b\delta\dot{\mathcal{E}}\delta F\right)_z}\right]_S = 0$$

Backup

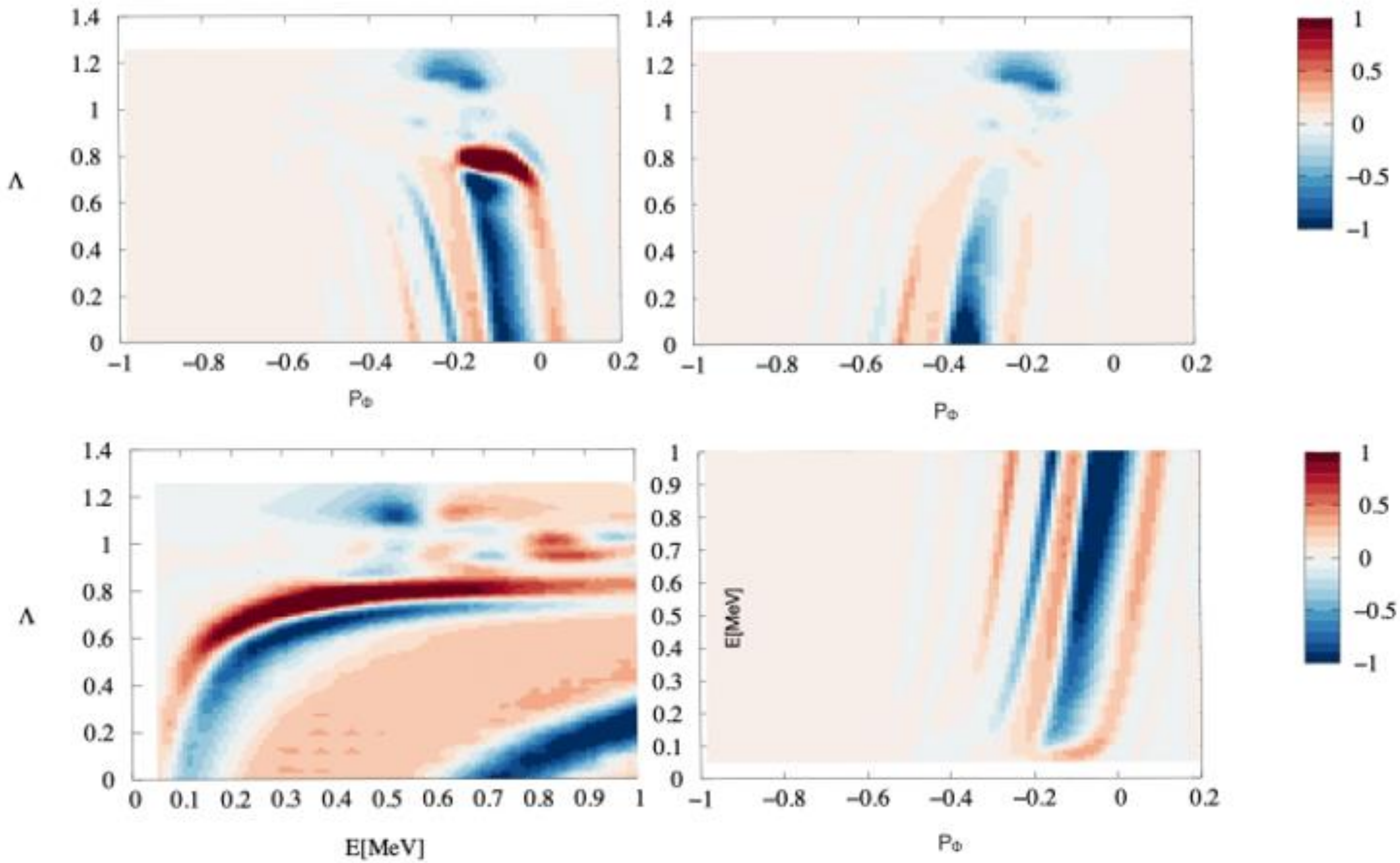


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Figure 4 Calculation of the orbit average of $\delta\dot{P}_{\phi}$ produced by a single $n = 13$ TAE mode for an ITER pre-fusion scenario. The plots on top left describes for fixed energy E (500 KeV) co-passing and trapped particles, on the top right counter-passing and trapped particles while plots at the bottom show the structure of the $E - \Lambda$ space for fixed $P_{\phi} = -0.2$ (left) and in $P_{\phi} - E$ space for fixed $\Lambda = 0.12$. Courtesy of P. Lauber [32]¶