EUROfusion

ENR ATEP mid-term review

ATEP team:

Philipp Lauber (PI), Matteo Falessi (Co-PI), Alessandro Biancalani, Sergio Briguglio, Alessandro Cardinali, Nakia Carlevaro , Valeria Fusco, Thomas Hayward-Schneider, Florian Holderied, Axel Könies, Yang Li, Yueyan Li, Guo Meng, Alexander Milovanov, V.-Alin Popa, Stefan Possanner, Gregorio Vlad, Xin Wang, Markus Weiland, Alessandro Zocco, Fulvio Zonca

MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

ENEA ITALIAN NATIONAL AGENCY FOR NEW TECHNOLOGIES, ENERGY AND SUSTAINABLE ECONOMIC DEVELOPMENT

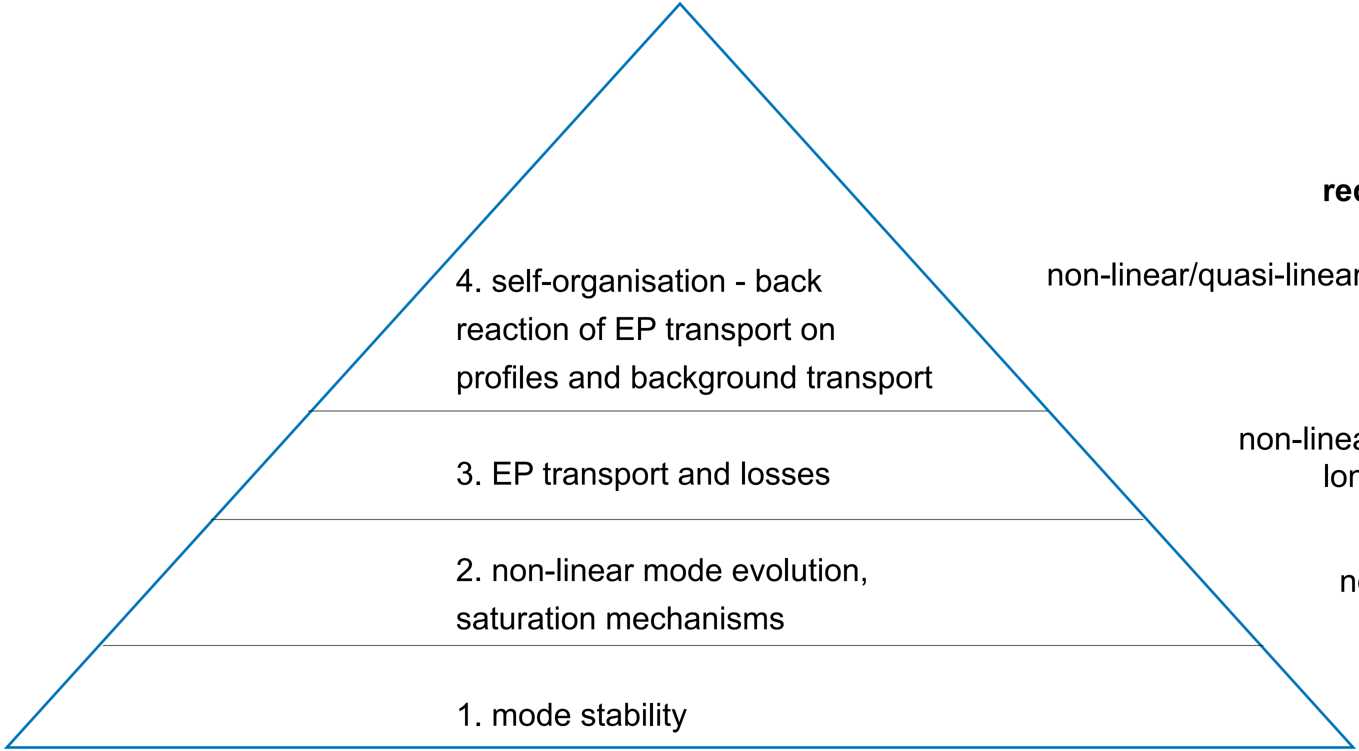
CNPS Center for Nonlinear Plasma Science Since 2020

iter china eu india japan korea russia usa

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

ATEP’s goal: add reduced EP transport models to presently available tools:

needed for scaling from TCV-AUG-JET, W7X… to JT-60SA-DTT-ITER-DEMO, in particular burning plasmas



required models:

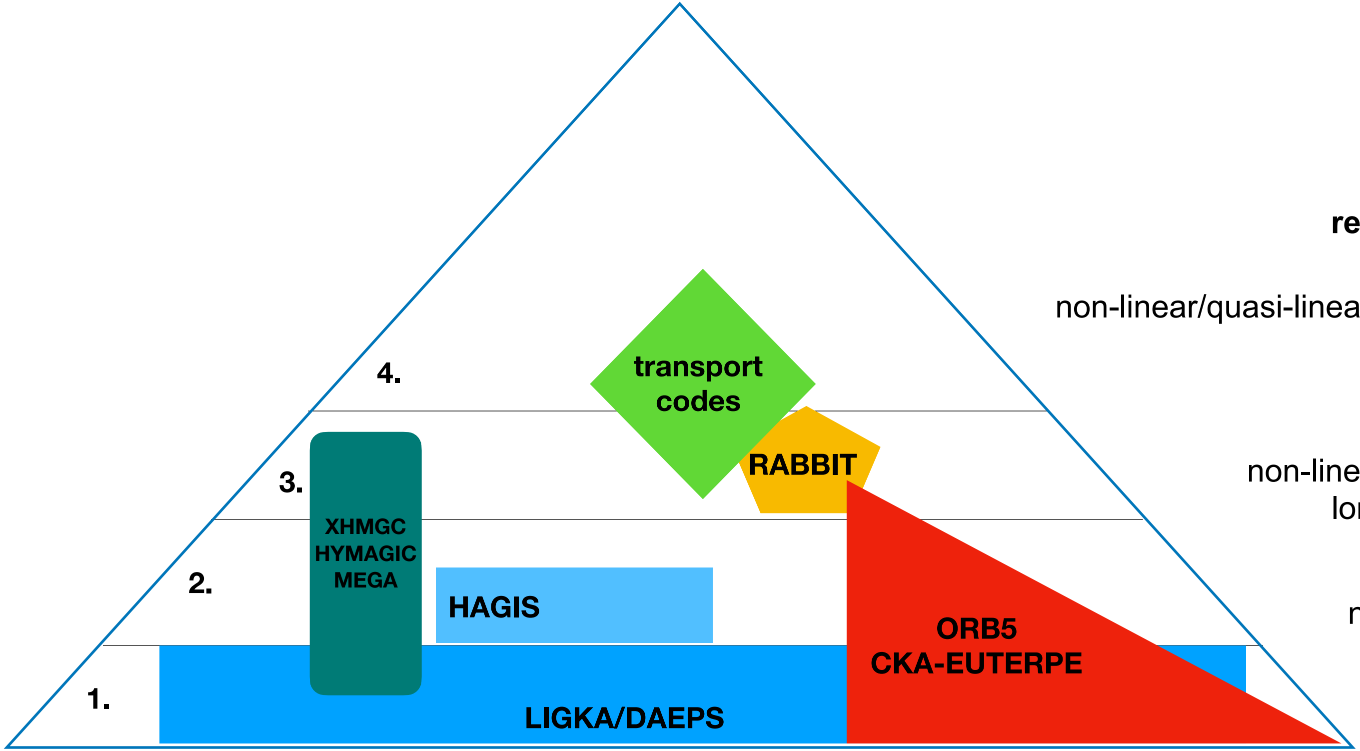
non-linear/quasi-linear global kinetic e.m.+ background transport

non-linear/quasi-linear global kinetic e.m. + long time scales (source +sink)

non-linear global kinetic e.m.

linear global kinetic e.m.

modelling hierarchy for plasmas with significant energetic particle pressure



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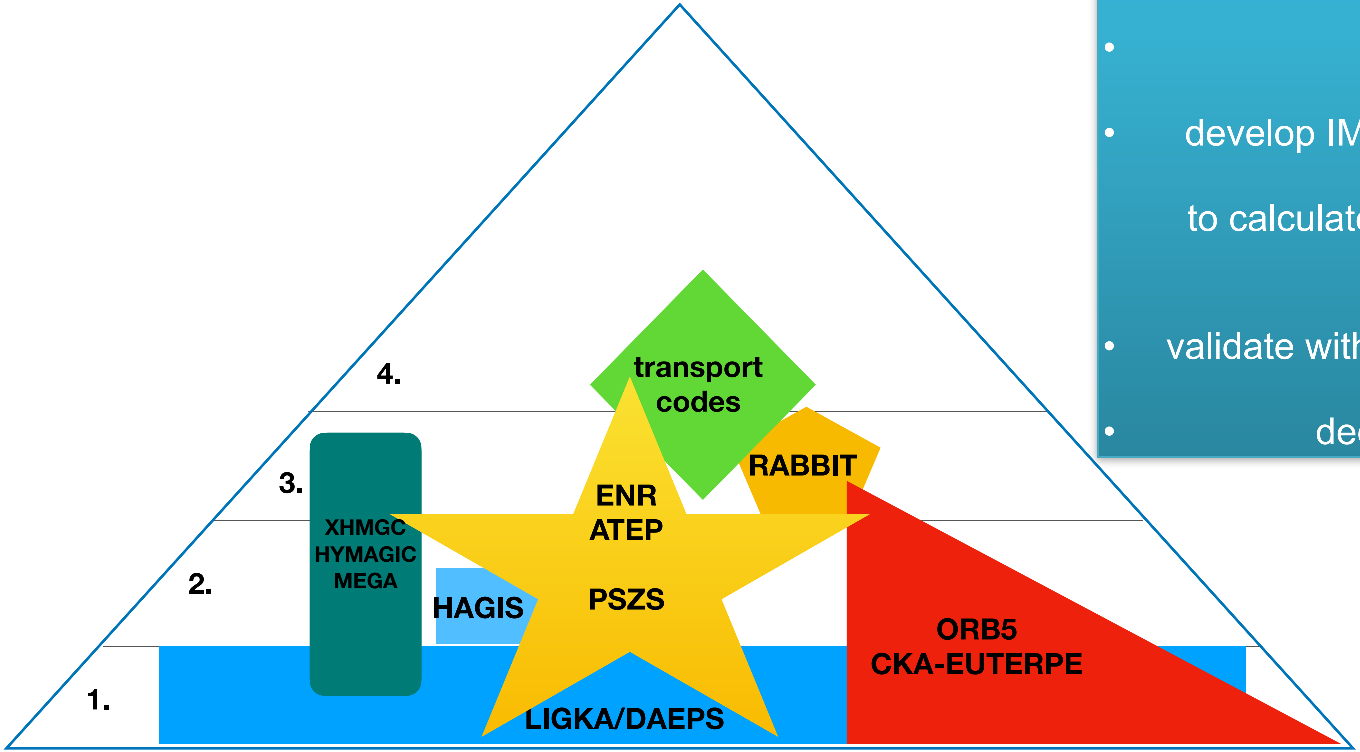

ENR ATEP aim:

- advance theory
  &
- develop IMAS based models of various fidelity and cost
  to calculate electromagnetic, global EP transport
  &
- validate with more comprehensive codes
  &
- dedicated experiments

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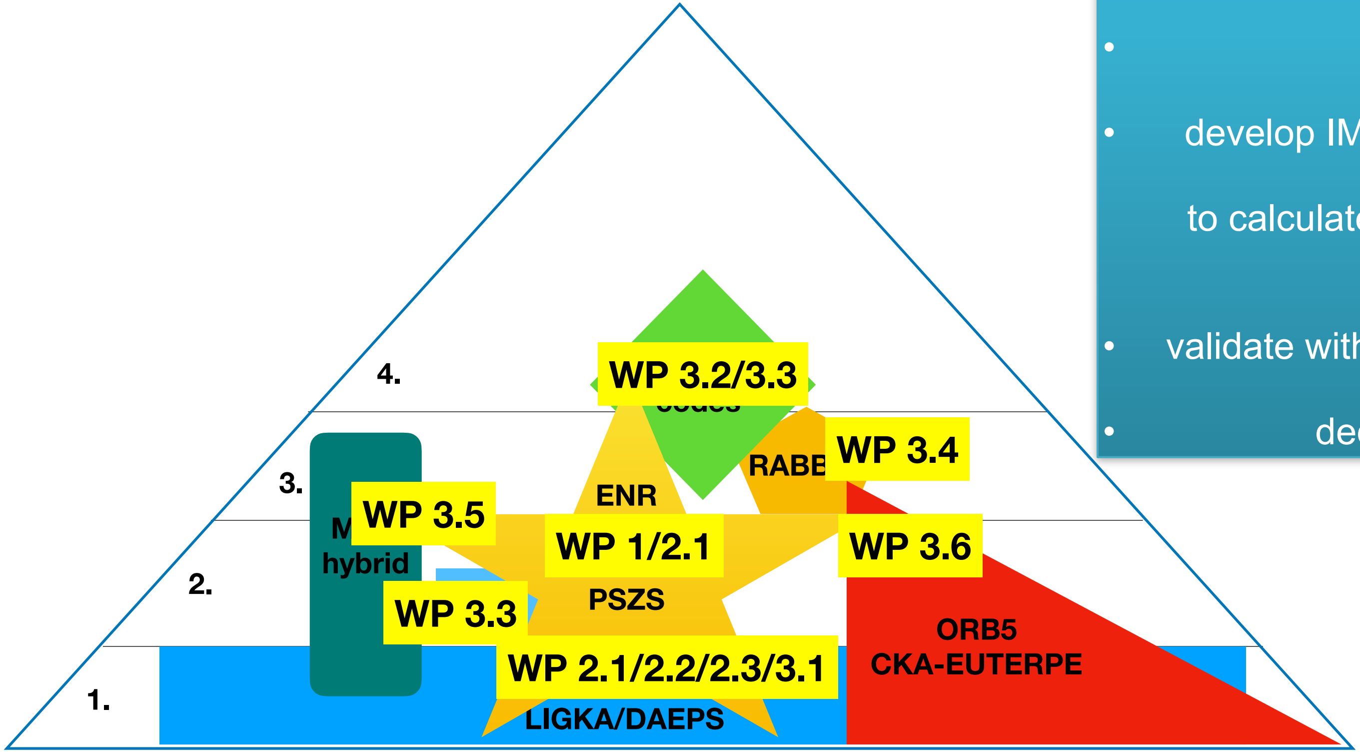


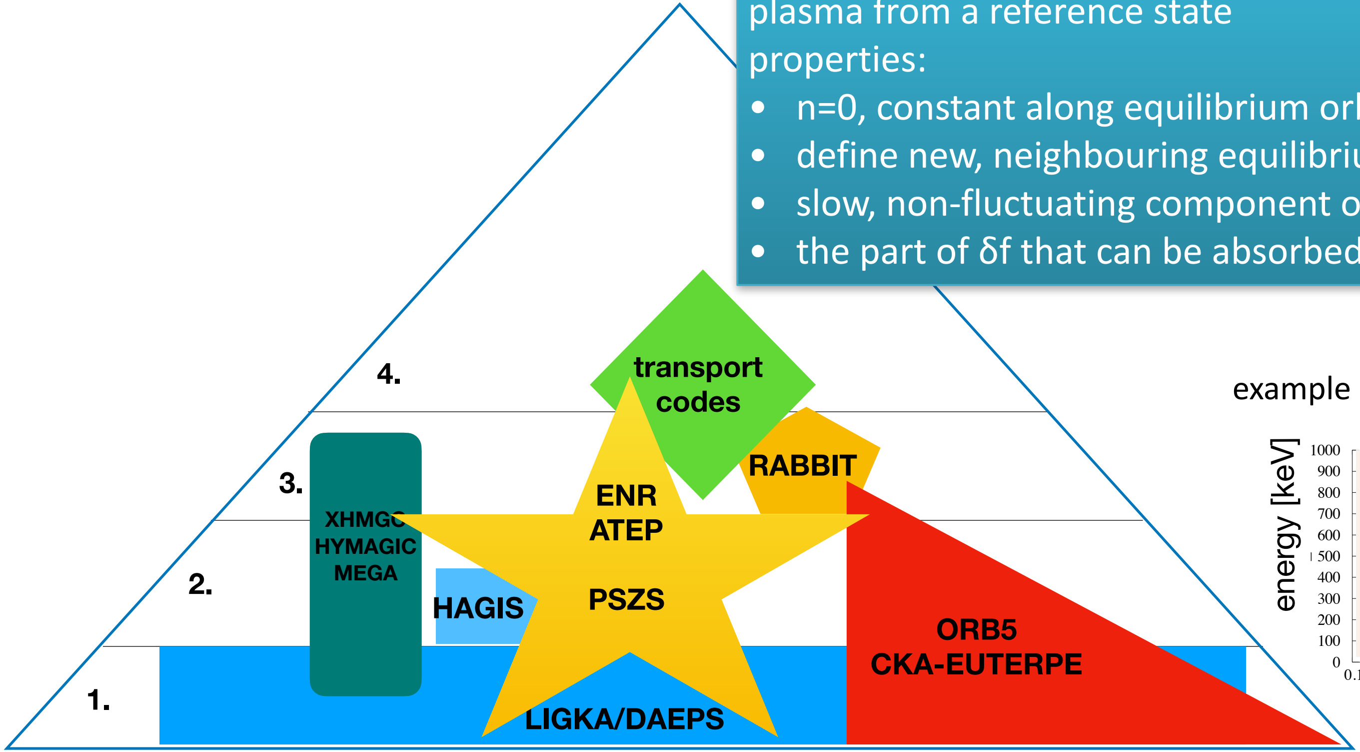
ENR ATEP aim:

- advance theory **WP 1**
  &
- develop IMAS based models of various fidelity and cost **WP 2**
  to calculate electromagnetic, global EP transport
  & **WP 3**
- validate with more comprehensive codes
  &
- dedicated experiments **WP4**

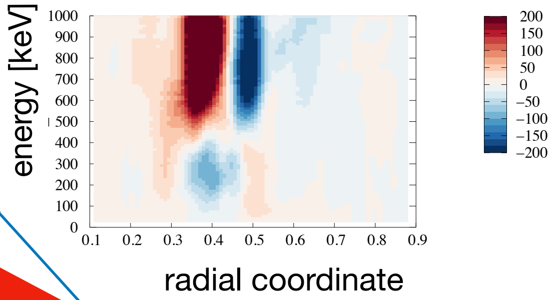
phase space zonal structures (PSZS) are
collision-less undamped, long-lived nonlinear deviations of the plasma from a reference state

properties:

- n=0, constant along equilibrium orbits
- define new, neighbouring equilibrium reference state
- slow, non-fluctuating component of F_{EP} evolution
- the part of δf that can be absorbed in new F_0



example in COM space representation:



modelling hierarchy for plasmas with significant energetic particle pressure

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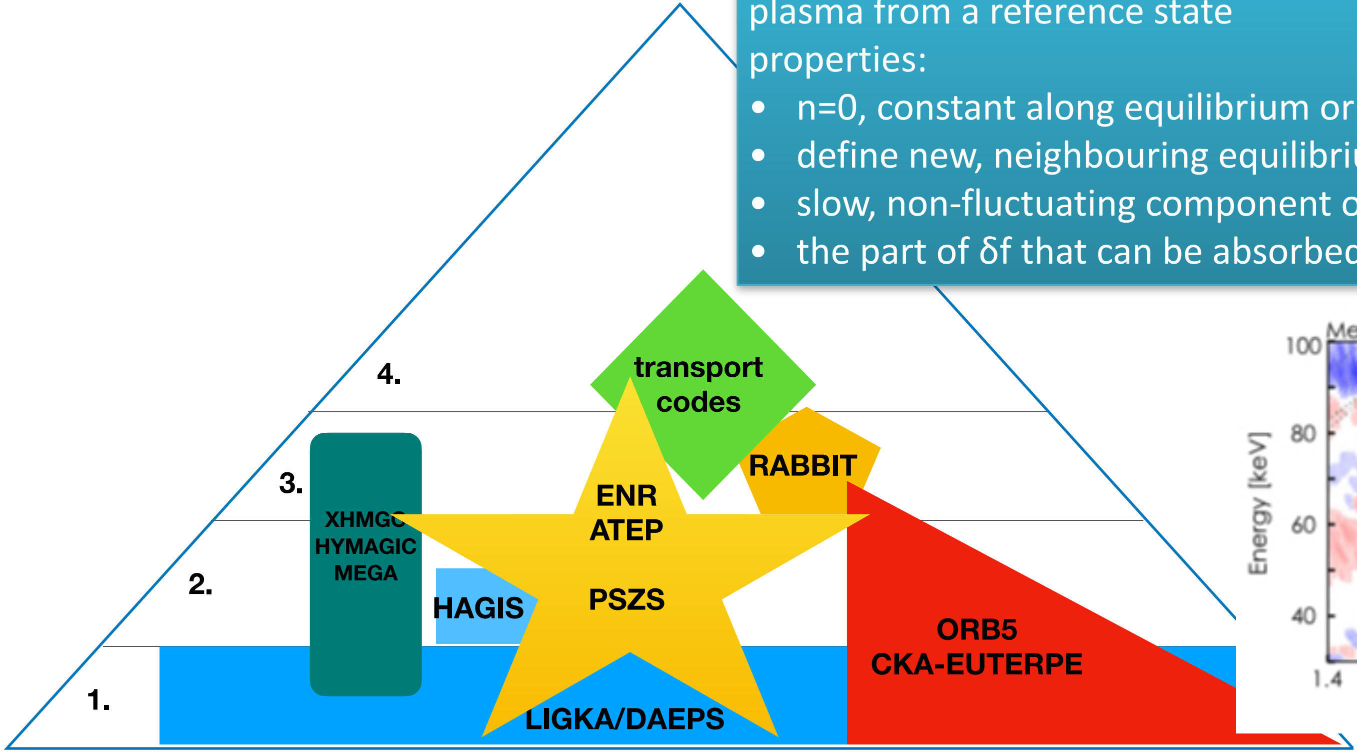
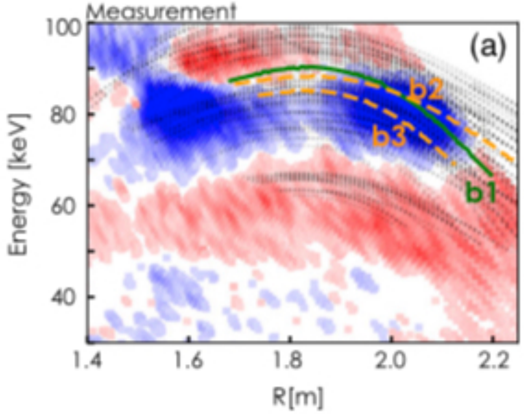




DIII-D, INPA [Du et al PRL 2021]

- Y.Y. Li left ATEP project by 1st July 2022 - duties within ATEP have been taken over by newly hired PostDoc: Yang Li
  project resources unchanged (ENEA)

- A. Biancalani moved from IPP to Léonard de Vinci Pôle Universitaire, Paris
  reduced manpower; ESILV into the federation of research for magnetic confinement fusion (Fr-FCM) has been accepted (Jan 2022)

- G. Meng - parental leave till mid Sept 2022, reduced manpower in 2021 and 2022

- T. Hayward-Schneider took over responsibilities
  project resources unchanged (MPG-IPP)

WP1

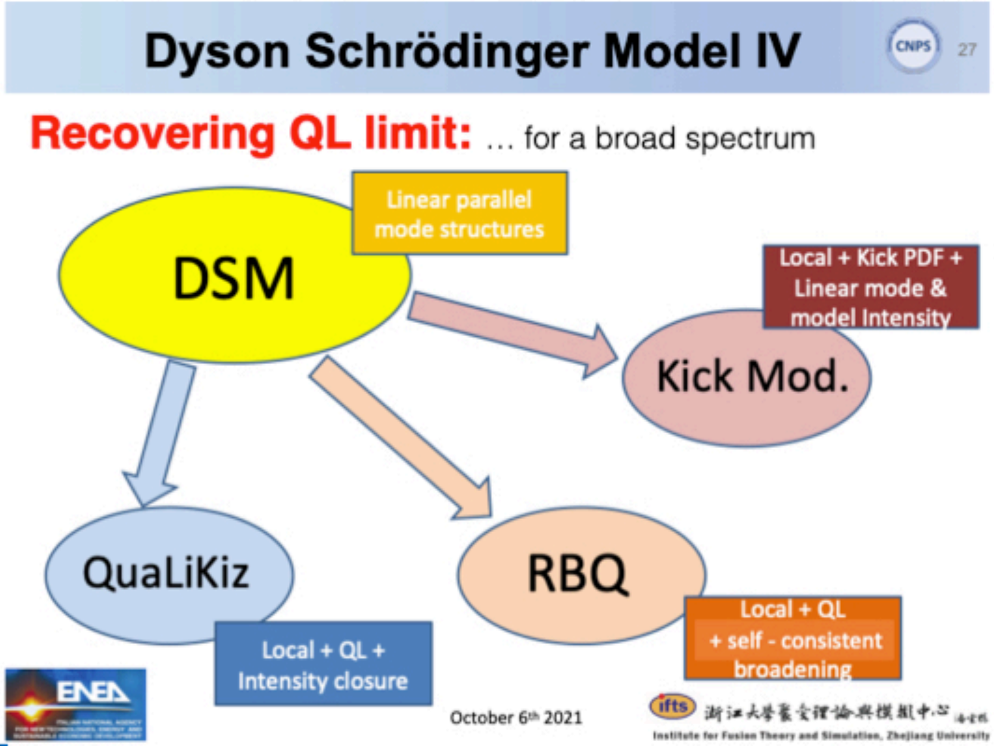
WP1:
theoretical framework

WP 2:
Advancing various building blocks according to WP1

WP3:
Implementation, application and verification of reduced EP transport models

WP4:
Preparation of time-dependent reference cases

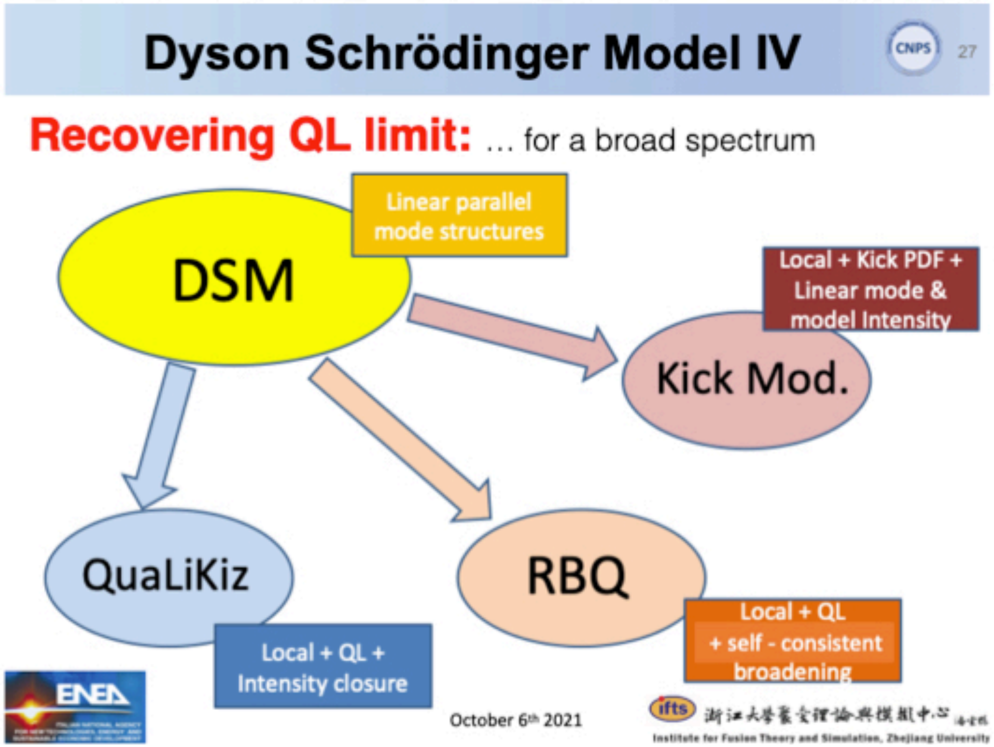
WP1: theoretical framework



[Zonca & Chen, NJP15 Zonca & Chen et al. NJP 17, Zonca et al, JPCS 2021, M-V. Falessi, PoP 2018, PoP 2019, Zonca et al JPCS2021, NJP 2021]
outreach astrophysical problems - Chorus wave excitation

- Nonlinear envelope equations for the self-consistent evolution of the SAW fluctuation spectrum driven by EPs and the PSZS transport equations can be cast in form of a Dyson-Schrödinger equation (='DSM')
- DSM is superset of various models presently used in community
- describes EP dynamics on transport time scales with general GK transport theory
- applicability beyond QL and intensity closure models
- crucial new element: introduce concept of long-lived formations in the particle phase space (PSZS); separate from fast fluctuating contributions
- accounting in particular for meso-scales introduced by EPs

WP1: theoretical framework



in particular for this project, it has been shown:

- how to evolve renormalised dist. function consistent with finite level of fluctuations
- how to connect to corresponding CGL equilibrium
- how to use a multipole expansion to obtain an anisotropic CGL pressure tensor

in addition to 2021 report references:
[M Falessi, invited talk AAPPS-DPP 2022,
M. Falessi, NJP paper, in preparation]

(WP1-D1 fully)

WP1: theoretical framework

derived explicit analytical expressions for fluxes:

$$\partial_t \left(\overline{e^{iQ_z} \bar{F}_0} + \overline{e^{iQ_z} \delta F_z} \right) = - \frac{1}{\tau_b} \frac{\partial}{\partial \psi} \left[\tau_b \overline{e^{iQ_z} \delta \dot{\psi} \delta F} \right]_z - \frac{1}{\tau_b} \frac{\partial}{\partial \mathcal{E}} \left[\tau_b \overline{e^{iQ_z} \delta \dot{\mathcal{E}} \delta F} \right]_z$$

phase space flux

$$\begin{aligned}
\tau_t \overline{\delta \dot{\bar{r}} \delta F} = & \frac{\pi |A|^2}{\omega_{Ts} \bar{x}} F_s \mathrm{Re}\left(i\omega_{ds}^T\right) \int d\vartheta \frac{\mathfrak{r}^{3/2}}{\sqrt{\mathfrak{r}-\lambda}} e^{inq2\pi l} J_{0s}(\vartheta)\, \bar{\phi}^\star(\vartheta)\, \bar{\phi}(\vartheta - 2\pi l) \\
+ & \frac{\pi |A|^2}{\omega_{Ts} \bar{x}} F_s \mathrm{Re} \frac{\hat{\sigma} \bar{x} \omega_{ds}^T}{\bar{\omega}^\star} \int d\vartheta e^{inq2\pi l} J_{0s}(\vartheta)\, \partial_\vartheta \bar{\psi}^\star(\vartheta)\, \bar{\phi}(\vartheta - 2\pi l) \\
+ & \frac{\pi |A|^2}{\omega_{Ts} \bar{x}} \mathrm{Re}\left(i\omega_{ds}^T\right) \left(-1 + \frac{\omega_{*ns}^T}{\omega} - \frac{3}{2}\frac{\omega_{*Ts}^T}{\omega} + \frac{\omega_{*Ts}^T}{\omega}\bar{\mathcal{E}}\right) F_s \int d\vartheta \frac{\mathfrak{r}^{3/2}}{\sqrt{\mathfrak{r}-\lambda}} e^{inq2\pi l} J_{0s}(\vartheta)\, \bar{\phi}^\star(\vartheta)\, \bar{\psi}(\vartheta - 2\pi l) \\
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\end{aligned}$$

[Y.Y. Li et al, invited talk Varenna Theory meeting 2022, PPCF paper, in preparation]

(WP1-D2 fully)

+ 3D version of PSZS equation [A. Zocco et al, draft Aug 2022, DTT Seminar Oct 2021]

WP 2

WP1:

theoretical framework

WP 2:

Advancing various building blocks according to WP1

WP3:

Implementation, application and verification of reduced EP transport models

WP4:

Preparation of time-dependent reference cases

WP 2.1/2.2/3.1 DAEPS, LIGKA and 1d-map model as building blocks for reduced transport models

‘more analytical’

DAEPS

- use mode decomposition methodology to separate radial envelope and parallel mode structures
- solve general fishbone-like dispersion relation
- calculate non-linear fluxes (see explicit expressions above)

benchmarks, shared repositories

‘more numerical’

LIGKA-HAGIS

- local and global solver
- solve linear GK equations
- use IMAS-coupled EP stability WF (HAGIS/ LIGKA) to calculate orbit+zonal averaged fluxes

‘fastest’

1d reduced model

- 1d beam-plasma system: bump on tail
- partition phase space in slides of maximal power exchange
- use LIGKA linear mode information
- can directly run on long time scales

- use sources from models or ITER H&CD and/or RABBIT
- trapped particle model
- evolve transport equations

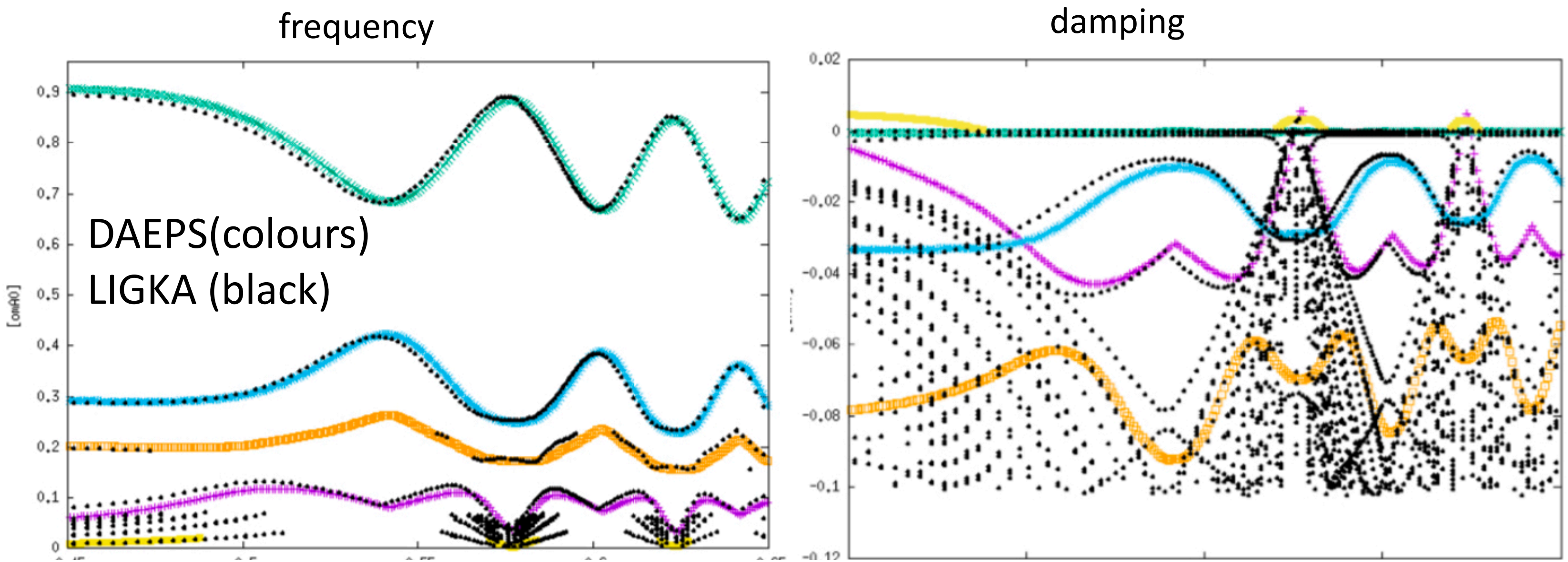
[Y. Li, PoP 2020, EPS 2022 ID: 31816, Invited talk at Varenna Theory meeting 2022]

[Ph. Lauber, EPS 2022,(ID 31591),Ph. Lauber: AAPPS-DPP 2021 (ID 30323)]

[N. Carlevaro et al PPCF 2022 (ID 30899)]

WP 2.1/2.2 extend and benchmark DAEPS and LIGKA

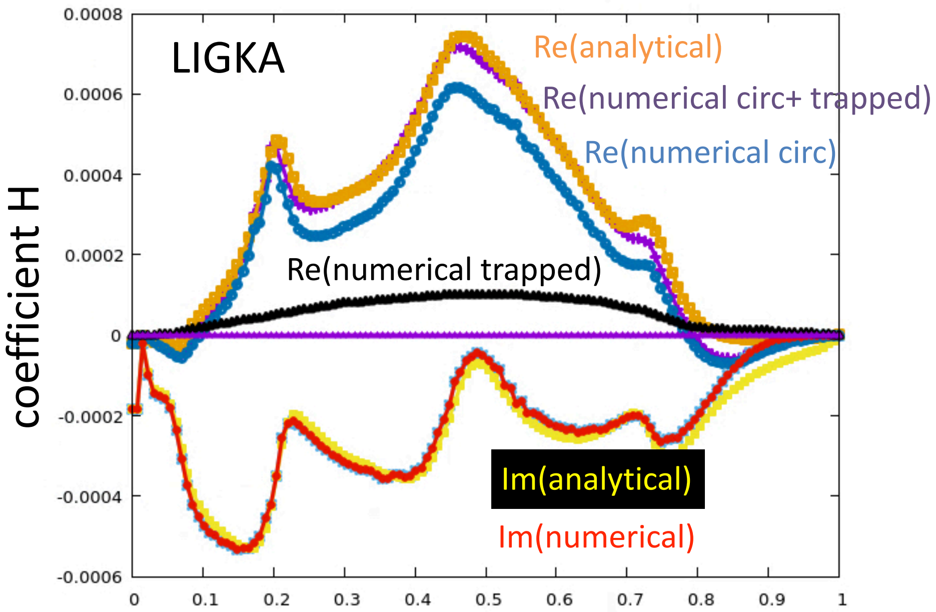
- End 2021: WP2.1-D1 DAEPS in general tokamak geometry (fully)
- End 2022: WP2.1-M1 Benchmark of DAEPS in general toroidal geometry against reduced local LIGKA analysis for trapped particles (partly)



[Y. Li, EPS 2022 ID: 31816]

WP 2.1/2.2 extend and benchmark DAEPS and LIGKA

- End 2022 WP2.2-D1 Fast analytical LIGKA version including trapped particles (ongoing)
- Mid 2022 :WP2.2-M1 Develop (semi-)analytical trapped particle model for LIGKA (ongoing, slightly delayed)
- End 2022: WP2.1-M1 Benchmark of DAEPS in general toroidal geometry against reduced local LIGKA analysis for trapped particles (partly)



- after extension of distribution IDS, kinetic HAGIS data for LIGKA phase space integrals is now also processed via IMAS
- successful validation finished
- investigation of circ/trapped contribution on TAE-KAW damping for JET-like case
- trapped particle model from Chavdarovski 2009 and implementation on D. Curran 2011 under discussion/ common strategy with DAEPS

presentations/paper

Ph. Lauber: plenary topical talk AAPPS-DPP 2021 (ID 30323)

Ph. Lauber: presentation at JET TF meeting, 5.10.2021

Ph. Lauber: invited presentation at ISEP meeting, 17.11.2021

Ph. Lauber: chapter 7/8 NF EP chapter update (ITPA group)

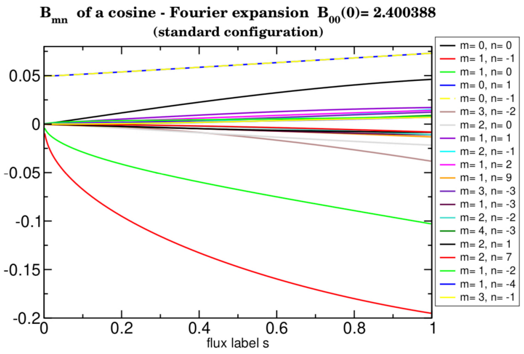
WP 2.3 Extend to 3d geometry

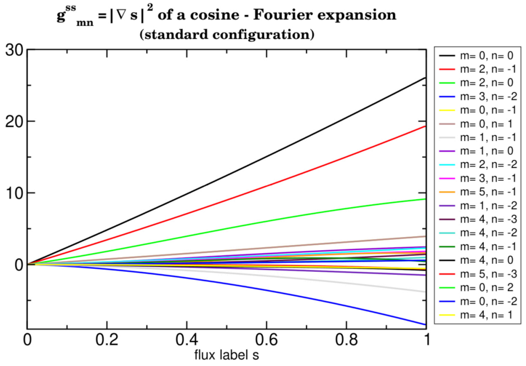
Mid 2022 WP2.3-D1 Explicit expressions for local eigenvalue code in 3D (ongoing, end October 2022)

WP2.3-M1   Derive equations for local LIGKA-like version in 3D Mid 2022 (slightly delayed - end 2022)

WP2.3-M2 Local eigenvalue code in 3D (LIGKA) including passing particles   End 2023

- in analogy to the local version two-dimensional gyro-kinetic code LIGKA, develop a three-dimensional extension -> stellarator equilibria calculated with VMEC.
- kinetic part: drift kinetic code CAS3D-K, benchmark against analytical model of Kolesnichenko et al. and EUTERPE/ STAE-K code.





Stellarator specific modifications

$$B(r,\vartheta,\varphi) = B_0\left(\epsilon_{00}(r) + \epsilon_t(r)\cos\vartheta + \epsilon_h(r)\cos(m_h\vartheta + n_h\varphi) + \epsilon_m(r) cos\varphi\right)$$

$$g^{ss}(r,\vartheta,\varphi) = \sum_{i=1}^{n_g} \epsilon_i^g(r)\cos(m_i\vartheta + n_i\varphi)$$

- ☑ large aspect ratio in Boozer coordinates to keep the integrals tractable
- ☑ decomposition of the particle motion
- ☑ quasi-neutrality, Ampère's law
- ☑ kinetic equation
- ☐ compose terms (tedious, but straight-forward)
- ☐ decide upon approximation on the left hand side of Eq. (1)
  (MHD coupling in W7-X is strong ⇒ n_g must have a certain size
  otherwise the quantitative agreement in the MHD limit is not sufficient)

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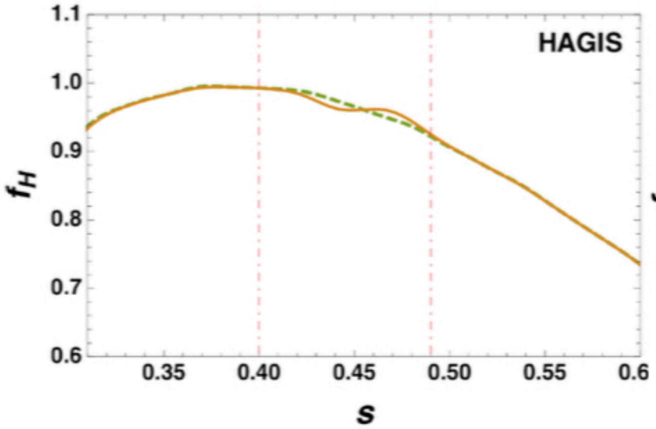
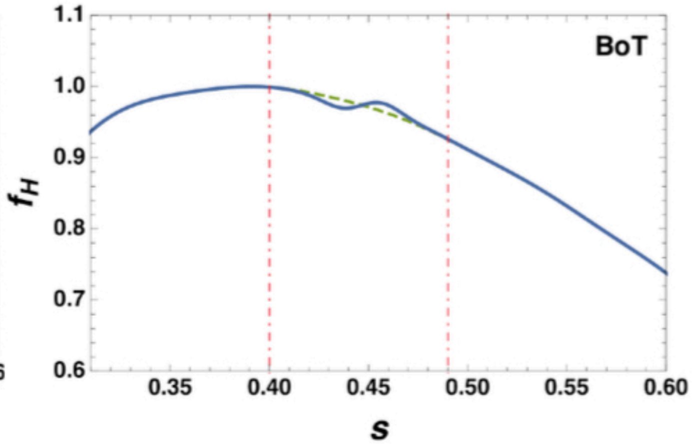
[N. Carlevaro et al PPCF 2022 (ID 30899)]

WP 3.1: benchmark: 1d reduced model-HAGIS

successful benchmark with HAGIS:

[N. Carlevaro et al PPCF 2022 (ID 30899)]

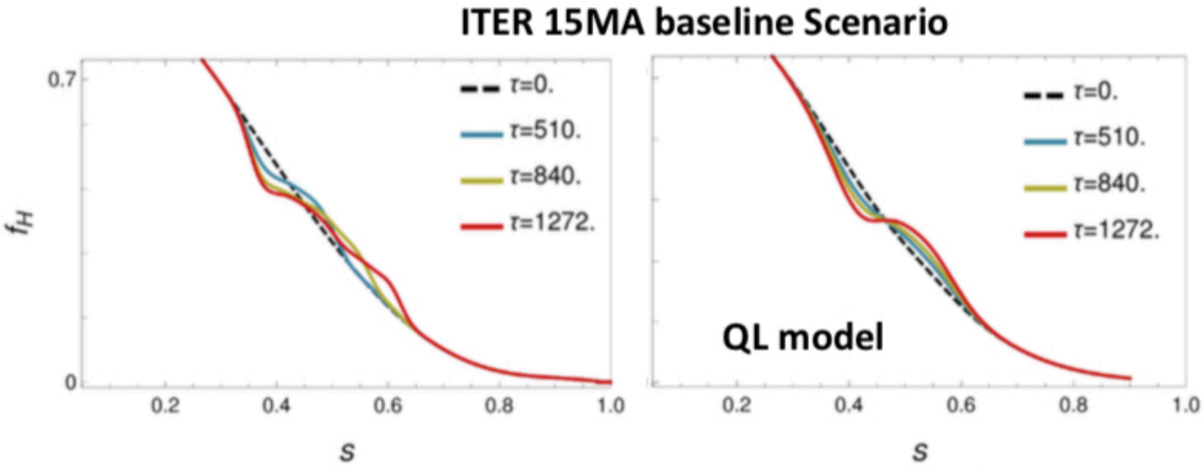




WP3.1-M2: Interface of the 1D “mapping” in the ITER/IMAS workflow [end 2022, planned fall 2022]

Investigation of the influence of turbulence on the 1D mapping [end 2022, ongoing] model is able to go beyond QL theory:

[N. Carlevaro et al PPCF 2022 (ID 30899)]



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Investigation of the influence of turbulence on the 1D mapping [end 2022, ongoing]

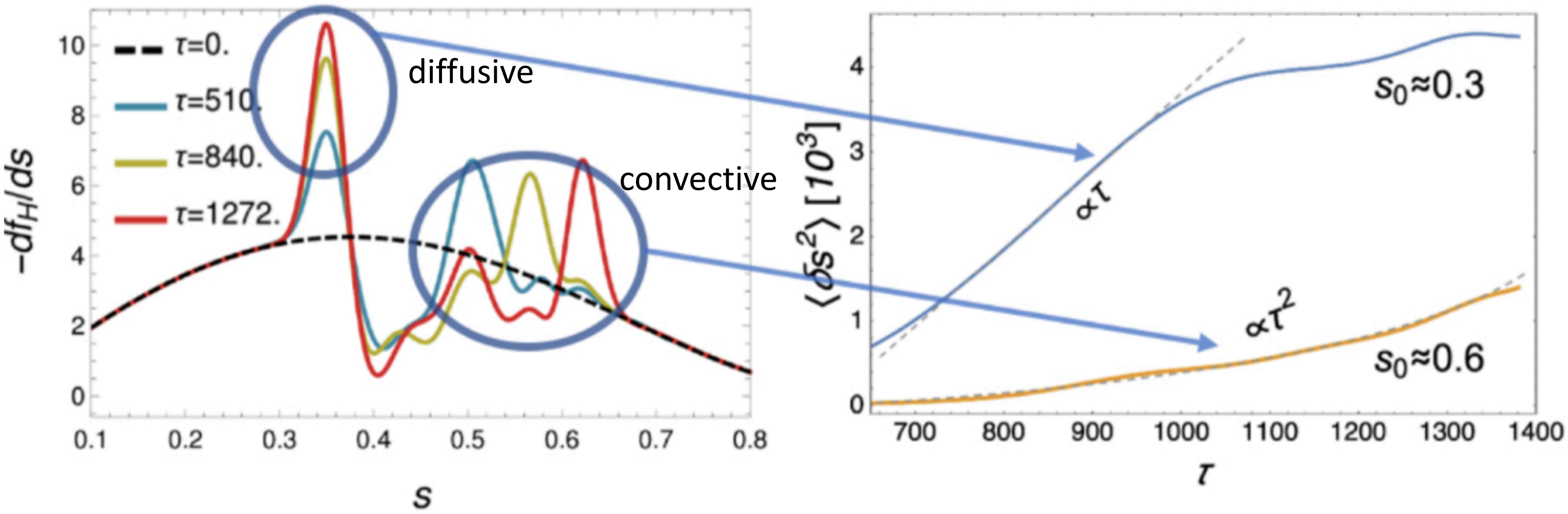
1. slice decomposition - run and mix several BoT simulations to find maximal wave-particle power exchange in multi-mode system

2. tune reduced model using QL theory (use scalar turbulence ansatz for AEs)

WP3.1 1d reduced model - investigate nature of EP transport

add tracers to system an determine diffusive (τ) vs. convective (τ2) scaling:

N. Carlevaro et al, EPS22, P5a.113 ID : 32056



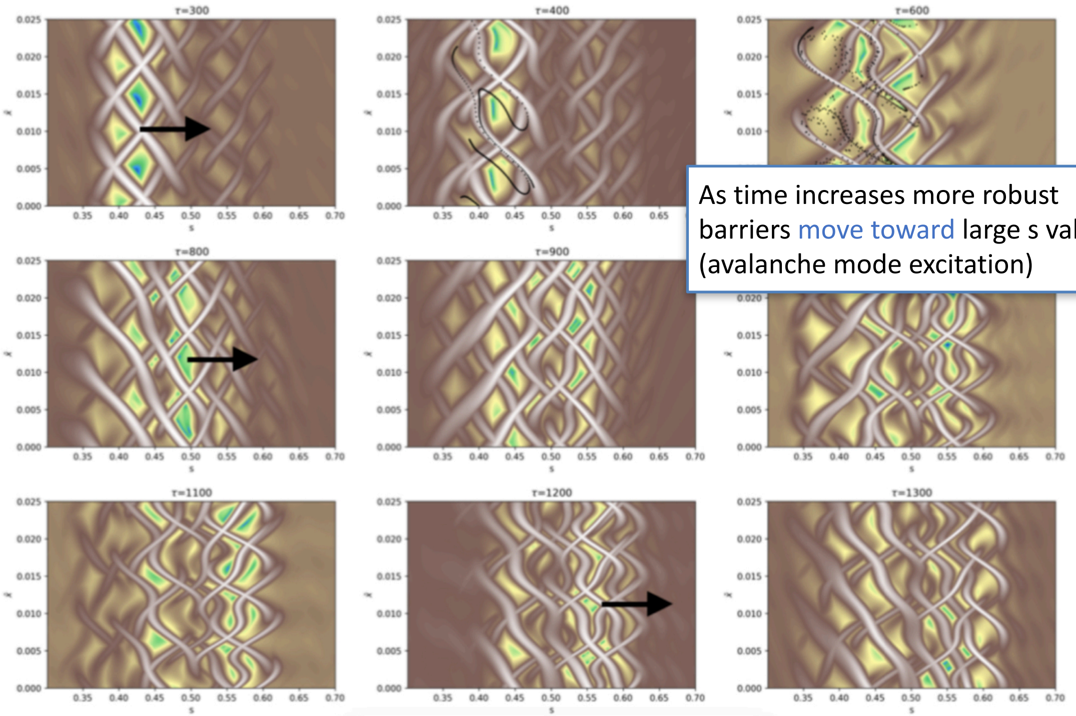
WP3.1-D2: Systematic statistical analysis of test particle transport and assessment of diffusive vs. non diffusive behaviours [**End 2023**]

WP 3.1/3.2/3.5 Analysis of transport properties

WP3.1-D2: Systematic statistical analysis of test particle transport and assessment of diffusive vs. non diffusive behaviours [**End 2023**]
WP3.2-D1: Insights into short- and long-time relaxation dynamics of a non-thermal jointly with WP3.2 plasma with intense energetic particle component [**End 2022**]
WP3.2-M1: Probability density function of the radial displacements of tracer particles deduced from EP transport models [**Mid 2022**]

N. Carlevaro et al, EPS22, P5a.113 **ID : 32056**

- Tracers dynamics studied with Lagrangian Coherent structures: relevant structures/barriers change during non-linear evolution: from inner to outer radial transport peak (see ITER case above):
- investigate convective EPM transport analytically: in force-free limit it was confirmed that Lévy flights do not influence the dynamics of EPMs [A. Milovanov et al PHYSICAL REVIEW E (2021)]
- No “heavy” power-law tails with regard to the long-time distribution of EPs have been found in simulations. explanation: dissipative nonlinearity and continuum damping of EPM can effectively stabilise the nonlocal features typical of Lévy flights (Milovanov 2022, in preparation).



As time increases more robust barriers move toward large s values (avalanche mode excitation)

WP 3.5 Hamiltonian-mapping diagnostics

continuous trapping/de-trapping for single-n chirping mode (XHMGC)

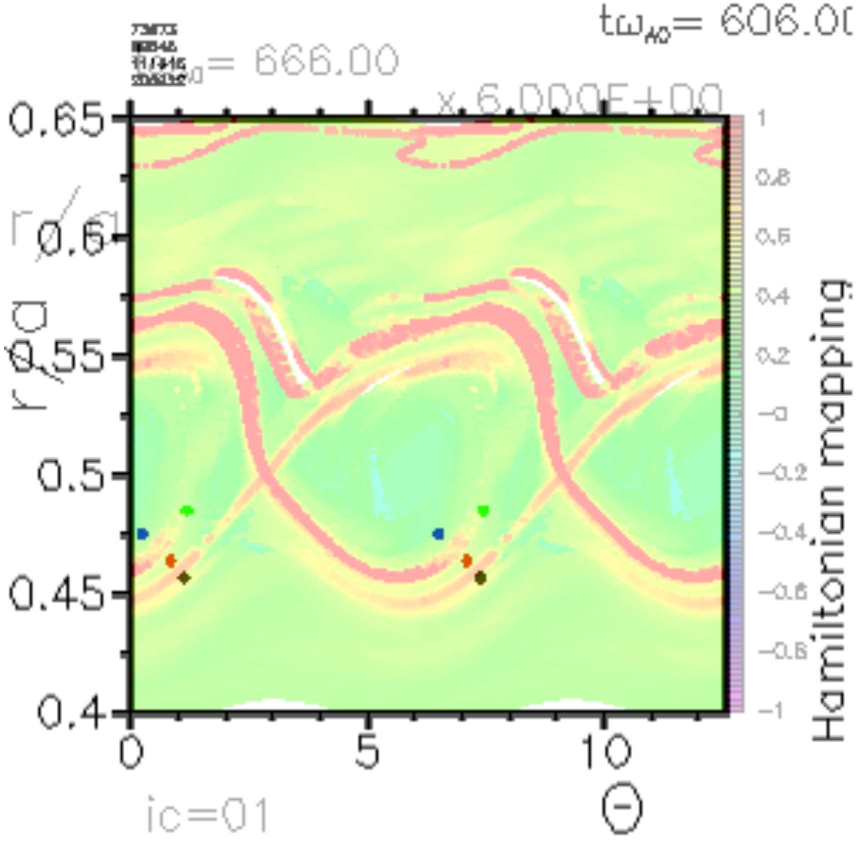
Lagrangian coherent structures (repulsive and actractive lines superimposed) also studied with MHD-kinetic hybrid code XHMGC

4 initially passing particles:

- blue and green get and remain trapped in the wave
- red gets trapped and, then, untrapped
- **black** remains passing

important diagnostics for understanding fundamental transport properties in various regimes:
adiabatic vs non-adiabatic chirping [X. Wang, Varenna Theory 2022, PoP 2021, ID 30841]

also implemented in ORB5



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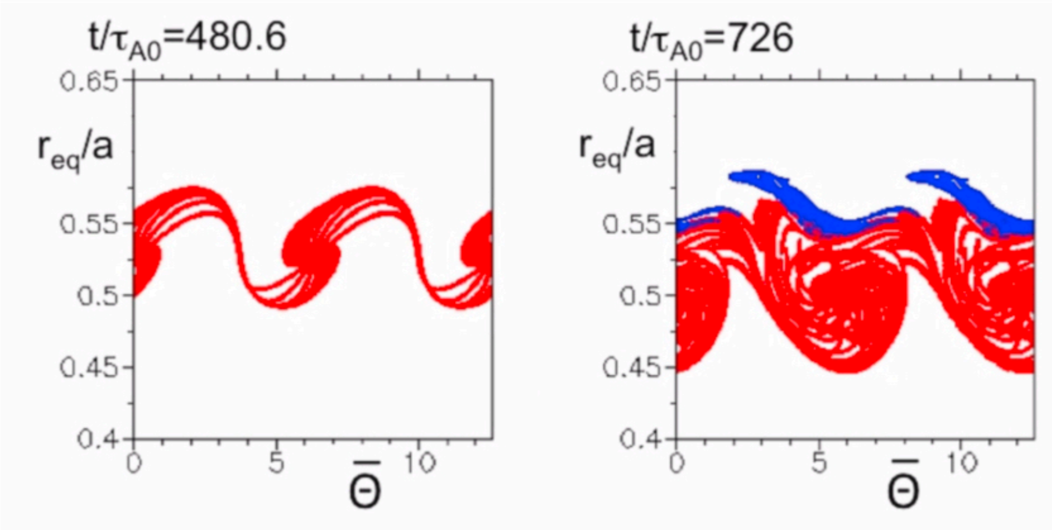
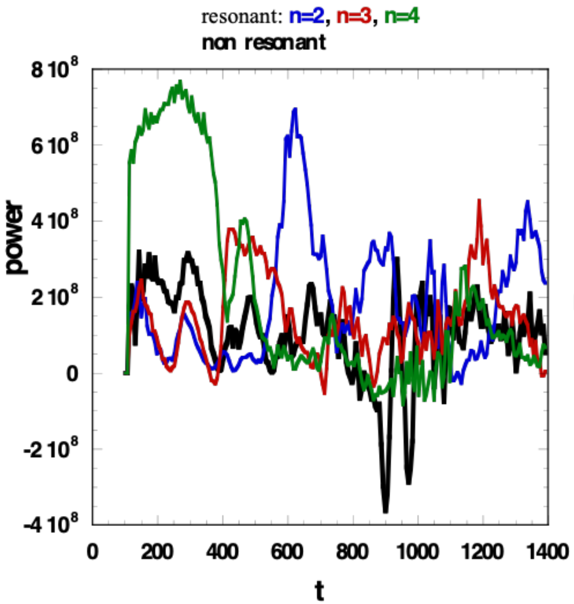
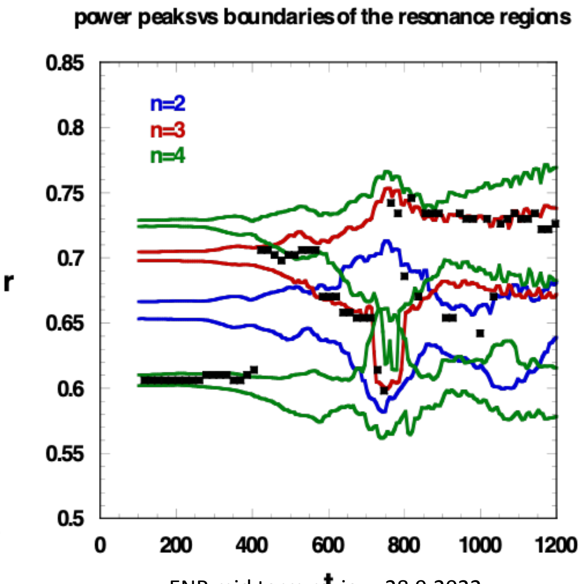
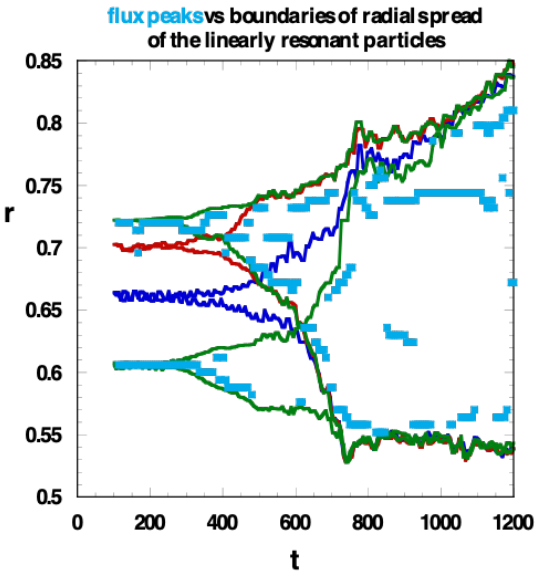


- each mode yields an "island"; islands overlap allowing for larger radial excursion of linearly resonant particles
- density-gradient and flux peaks are tightly related to the radial boundaries of such overlapping region; power peaks are not
- power peaks are instead related to the boundaries of the resonance regions
- thus, power transfer is mainly resonant







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'more analytical' 'more numerical' 'fastest'

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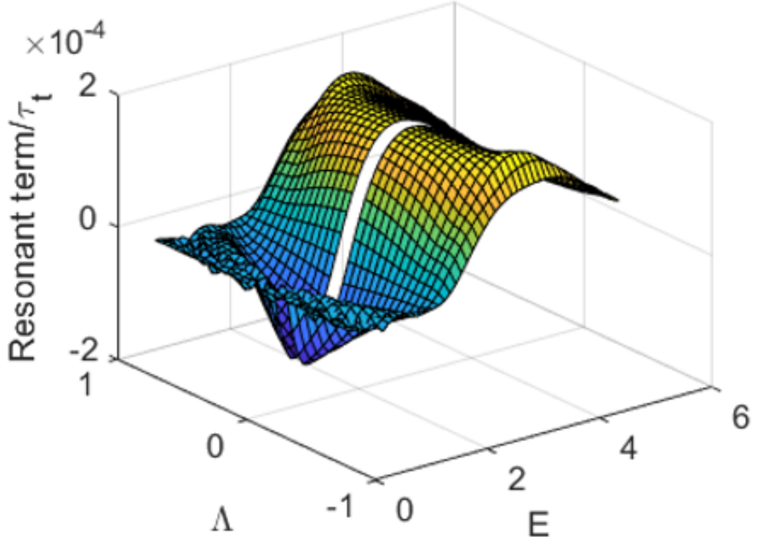
[N. Carlevaro et al PPCF 2022 (ID 30899)]

WP2.1, WP3.3 explicit calculation of PSZSs

DAEPS

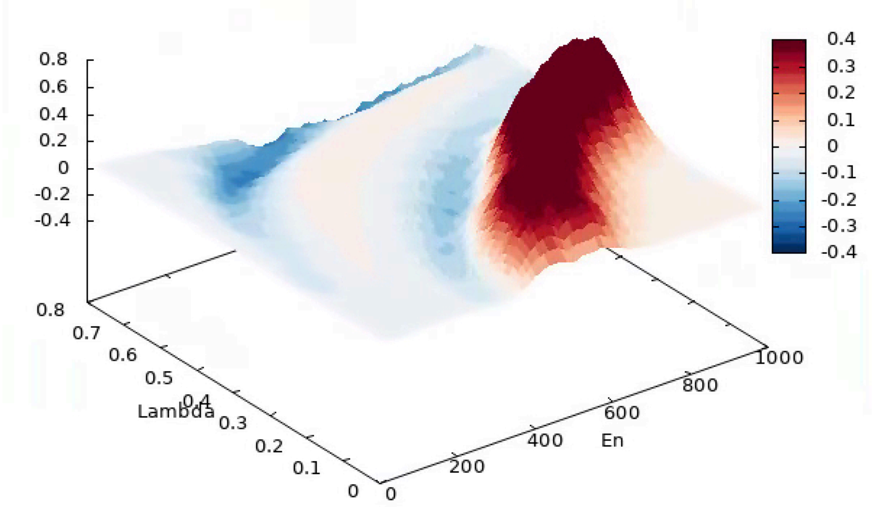
$$\left[\overline{\tau_b e^{iQ_z} \delta\dot{\psi}\delta F}\right]_z$$



DTT, TAE

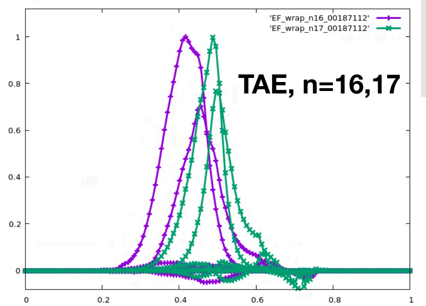
LIGKA/HAGIS

$$\left[\overline{\tau_b e^{iQ_z} \delta\dot{\psi}\delta F}\right]_z$$



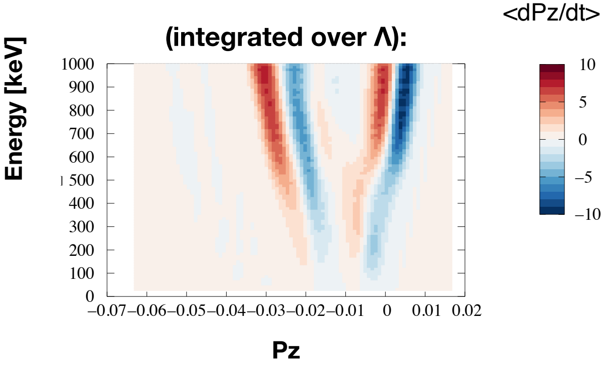
ITER, TAE

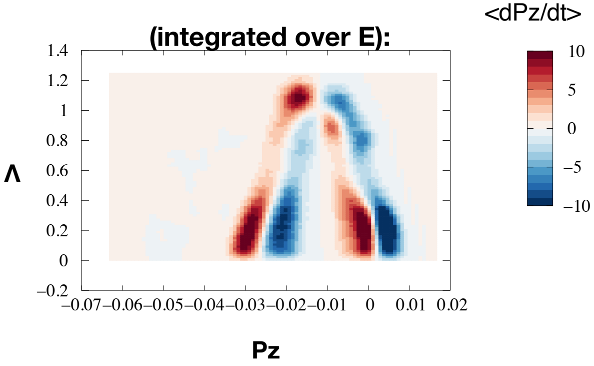
WP 3.3 Extend HAGIS/LIGKA framework to calculate EP fluxes

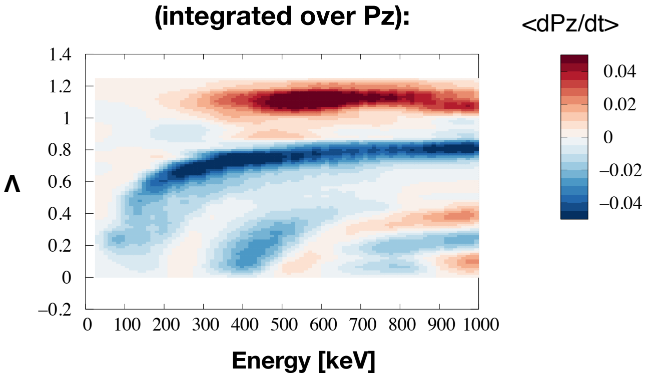


WP3.3-M1 Extend unperturbed orbit integration routines and averaging procedures in order to calculate phase space fluxes in HAGIS mid 2022 (fully)

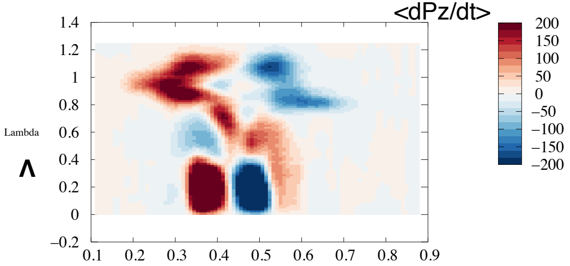
by zonal averaging of a representative particle ensemble, calculate <dPz/dt>, i.e. radial transport for given set of fixed mode structures at fixed amplitudes, write as IDS object in COM Pz,E,Λ [Lauber DTT seminar, 5/2022, Bierwage et al, ID: 30554]

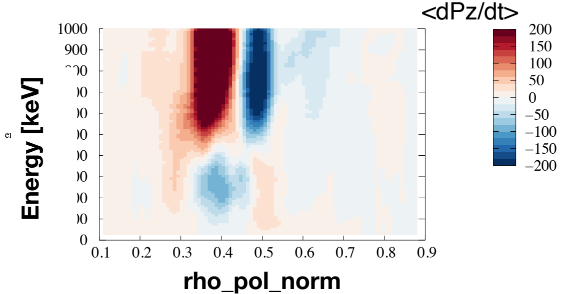






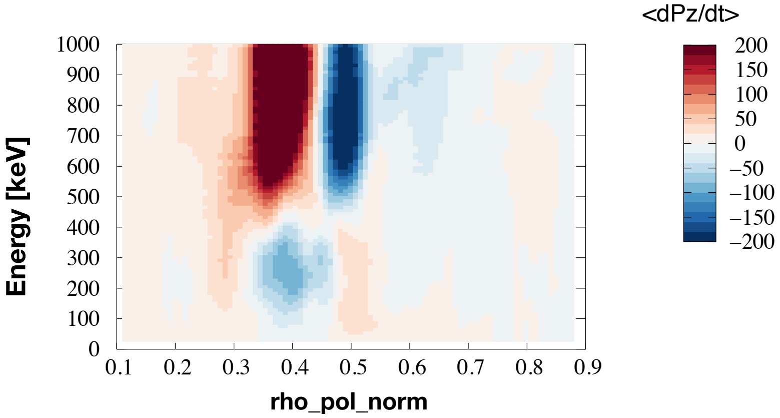
can be easily mapped to <s>:



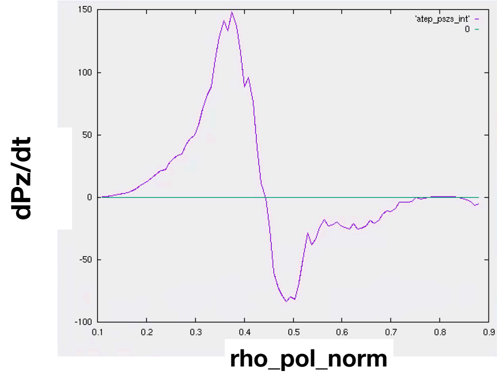


WP 3.3 Extend HAGIS/LIGKA framework to calculate EP fluxes

calculation of diffusions coefficients: D(s,E) and D(s)



E integration →



to be done: transform from<dPz>²/<dt> to D(s,E)=<ds>²/<dt>

and feed back to transport code

WP 3.3 ATEP code: advance transport equation

Mid 2024 WP3.3-D1 Availability of validated reduced phase space transport model based on LIGKA/HAGIS/RABBIT within IMAS framework (partly)

simple finite difference scheme to start with (final scheme to be decided when sources/collisions are implemented):

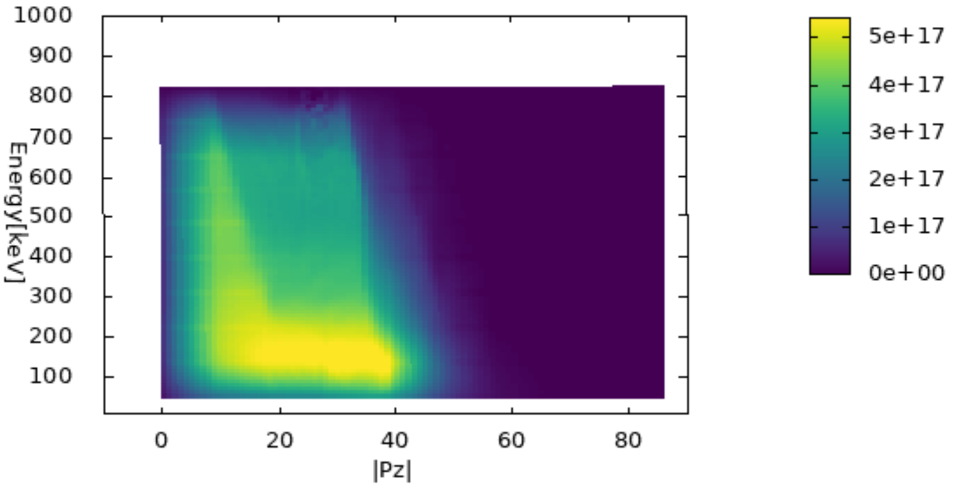
$$\frac{\partial F_{EP}}{\partial t} = \frac{\partial Pz}{\partial t}\frac{\partial F_{EP}}{\partial P_z} + \frac{\partial E}{\partial t}\frac{\partial F_{EP}}{\partial E}$$

note: $\frac{\partial^2 Pz}{\partial t \partial P_z} F_{EP}$ **term excluded so far: dPz/dt assumed constant -> kick model limit**

runtime: several seconds

F (Pz,E,t), Time=199 [arb units]

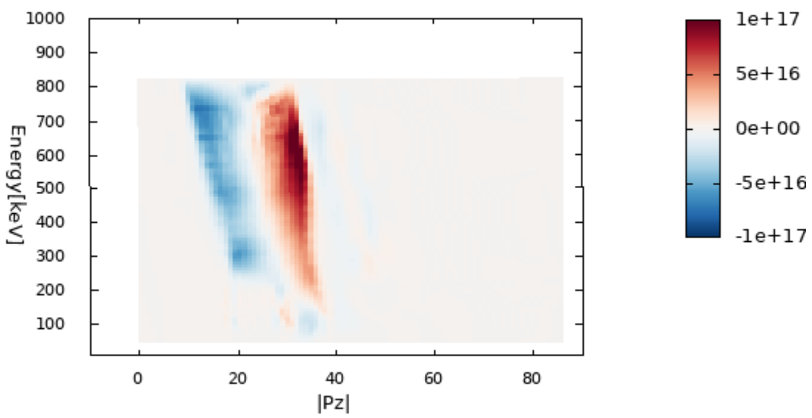
full F:



radial coordinate

F(t) - F(t=0), Time=147 [arb units]

delta F:



radial coordinate

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

WP 3.3 ATEP code: advance transport equation

Mid 2024 WP3.3-D1 Availability of validated reduced phase space transport model based on LIGKA/HAGIS/RABBIT within IMAS framework (partly)

simple finite difference scheme to start with (final scheme to be decided when sources/collisions are implemented):

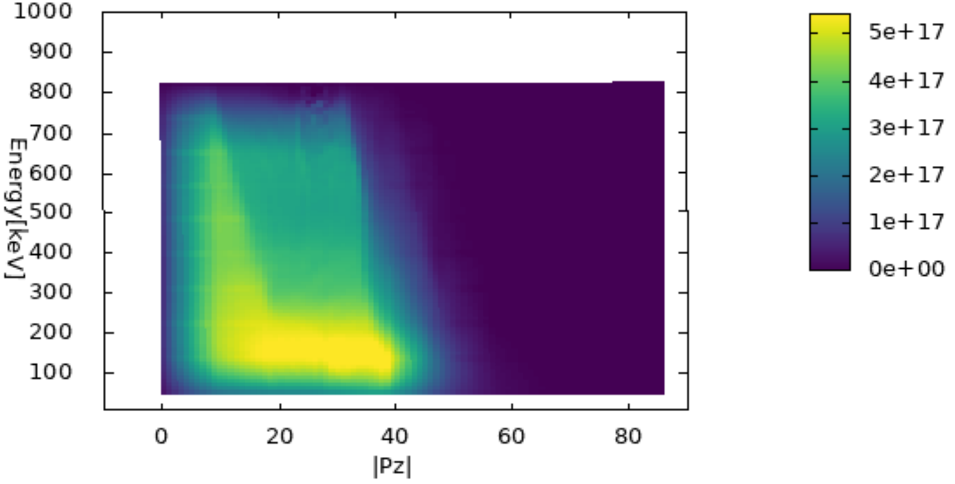
$$\frac{\partial F_{EP}}{\partial t} = \frac{\partial Pz}{\partial t}\frac{\partial F_{EP}}{\partial P_z} + \frac{\partial E}{\partial t}\frac{\partial F_{EP}}{\partial E}$$

note: $\frac{\partial^2 Pz}{\partial t \partial P_z} F_{EP}$ **term excluded so far: dPz/dt assumed constant -> kick model limit**

runtime: several seconds

F (Pz,E,t), Time=199 [arb units]

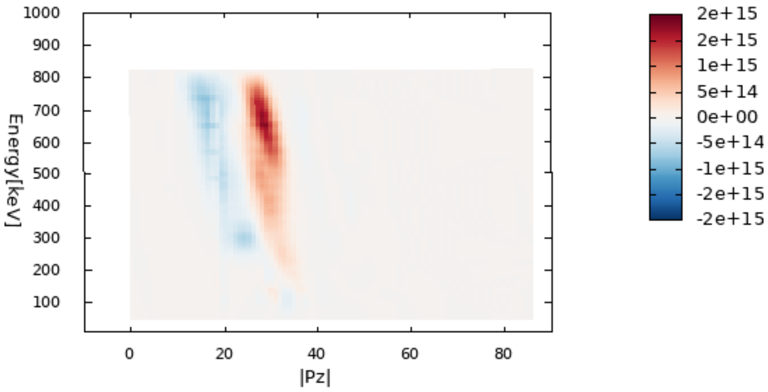
full F:



radial coordinate

F(t) - F(t-1), Time=2 [arb units]

dF/dt: maximal transport at resonance boundaries:

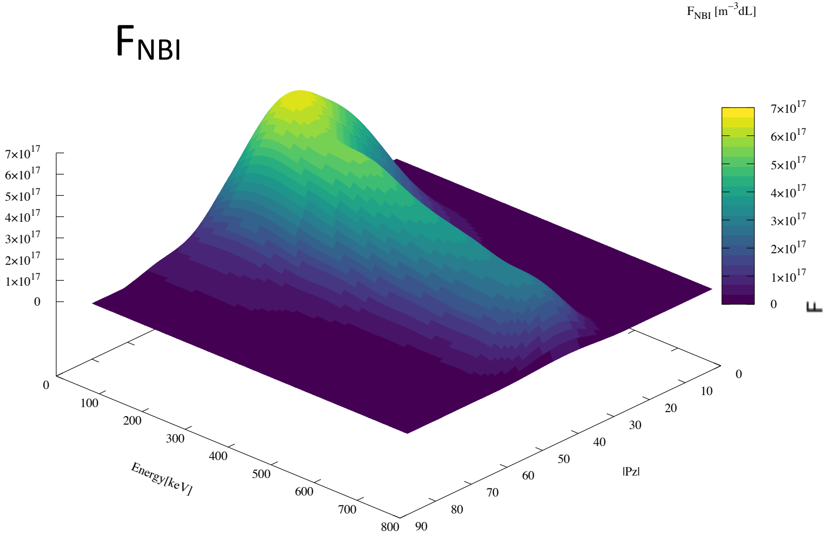


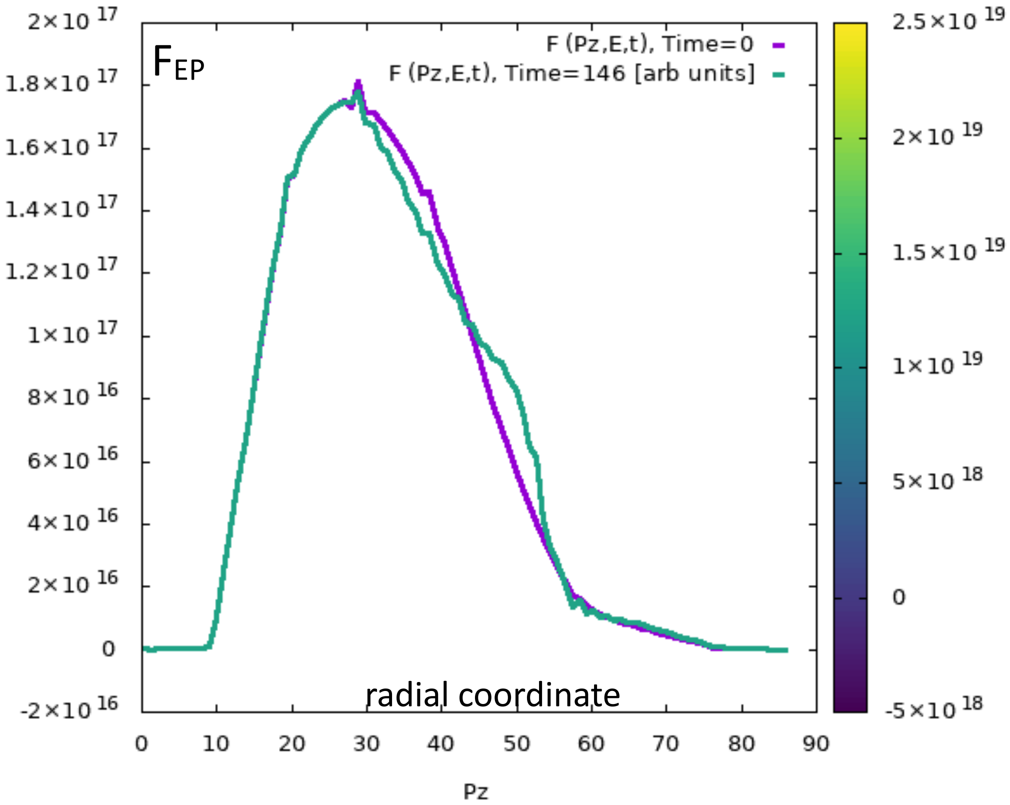
radial coordinate

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

WP 3.3/3.4 Extend HAGIS/LIGKA framework to calculate EP fluxes

Mid 2024 WP3.3-D1 Availability of validated reduced phase space transport model based on LIGKA/HAGIS/RABBIT within IMAS framework (partly)





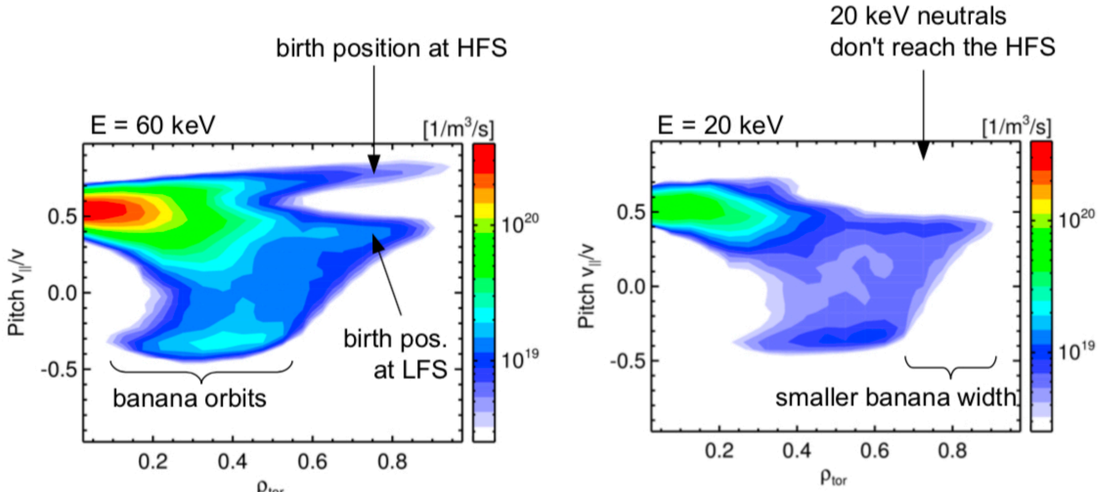
using ITER NBI off-off axis configuration

WP 3.4 RABBIT as particle source for ATEP code

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

- focus first on: Mid 2024 WP3.3-D1 Availability of validated reduced phase space transport model based on LIGKA/HAGIS/RABBIT within IMAS framework (partly)
- End 2022:WP3.4-M1 Develop and implement radial diffusion model to RABBIT (delayed)

- RABBIT is optimised for fast evolution of moments while keeping reasonable v-space resolution
- direct evolution in RABBIT possible, but ‘ATEP part’ part still too slow for RABBIT
  present plan:
- use average over first orbit of all Monte Carlo birth position markers as source (see plot) - use orbit data-base for mapping
- use Langevin type equations in HAGIS to describe collisional slowing down processes



[M Weiland]

WP 3.5/3.6

WP1:

theoretical framework

WP 2:

Advancing various building blocks according to WP1

WP3:

Implementation, application and verification of reduced EP transport models

WP4:

Preparation of time-dependent reference cases

WP3.5 Generalised distribution functions

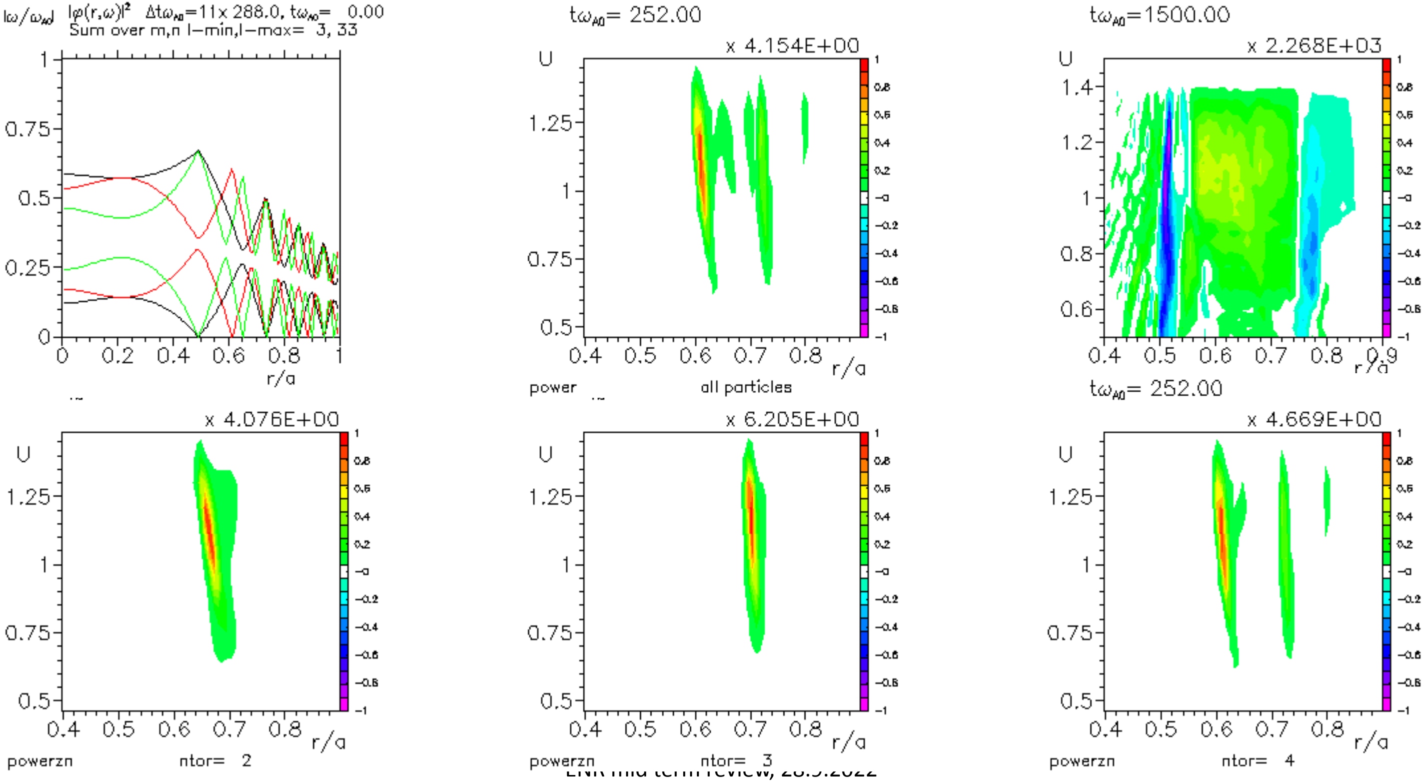
21 2023 WP3.5-M2 Implementation of generic EP distributions into XHMGC, HYMAGYK and MEGA (partly)

- Apart from several analytical initial distribution functions (Maxwellian, Slowing down, Bump-on-tail, Claudio's functions, etc.), a numerical $F_0(P_\phi,\mu,E)$ on a grid can be adopted (only for full-F evolution) by MEGA and XHMGC
- ORB5:
  - numerical $F_0(\psi,v_{||},E)$ given by Rabbit, implemented
  - numerical $F_0(P_\phi,\mu,E)$ will be implemented as well
- Numerical $F_0(P_\phi,\mu,E)$ is being implemented in HYMAGYC

power exchange and radial flux for multi-n chirping modes

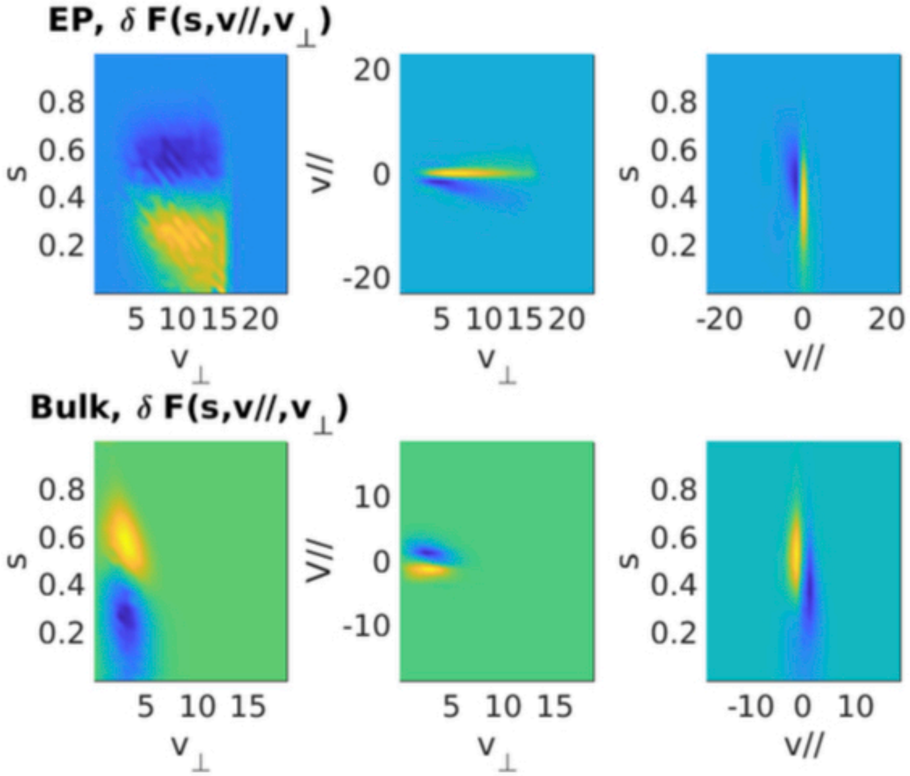
n=2, 3, 4

μ-average of power, flux and power(n)

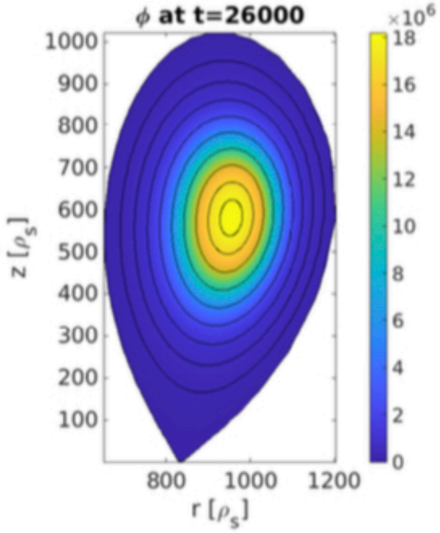


WP 3.6: PSZS diagnostics has been implemented in ORB5

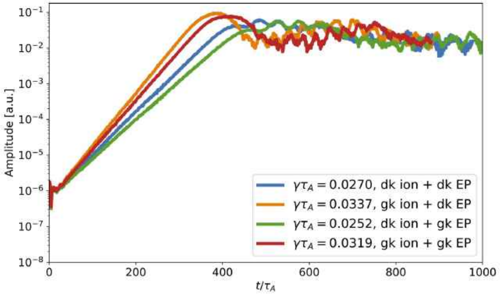
- **PSZS are a very useful quantity when comparing the results of non-linear codes and transport models**
- **possibility to restart simulations consistently**

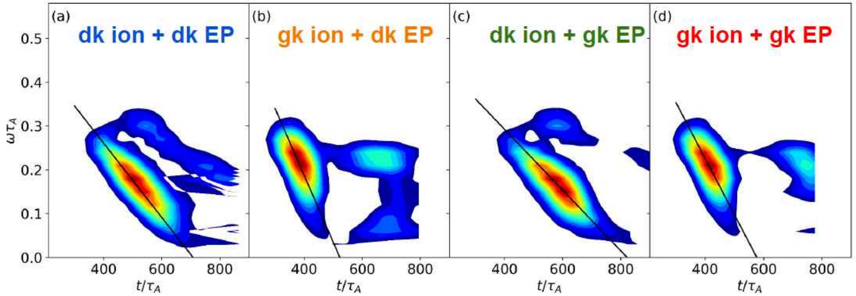


EGAM ORB5, A Bottino, Varenna 2022



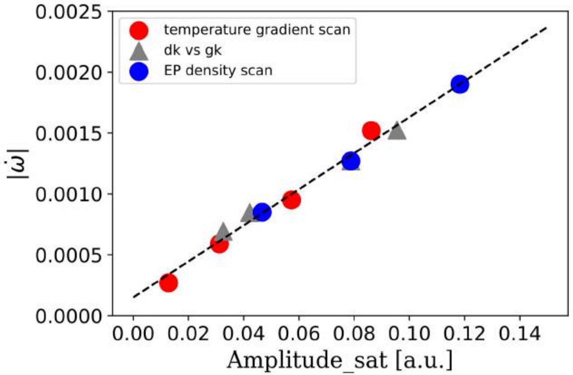
- Single-n chirping-mode dynamics carefully analysed by XHMGC (X. Wang et al., Phys. Plasmas 29, 032512, 2022) and ORB5 (X. Wang, Varenna 2022)





ORB5 results obtained

- with and without FLR effects
- different EP densities
- different bulk-plasma temperature gradient



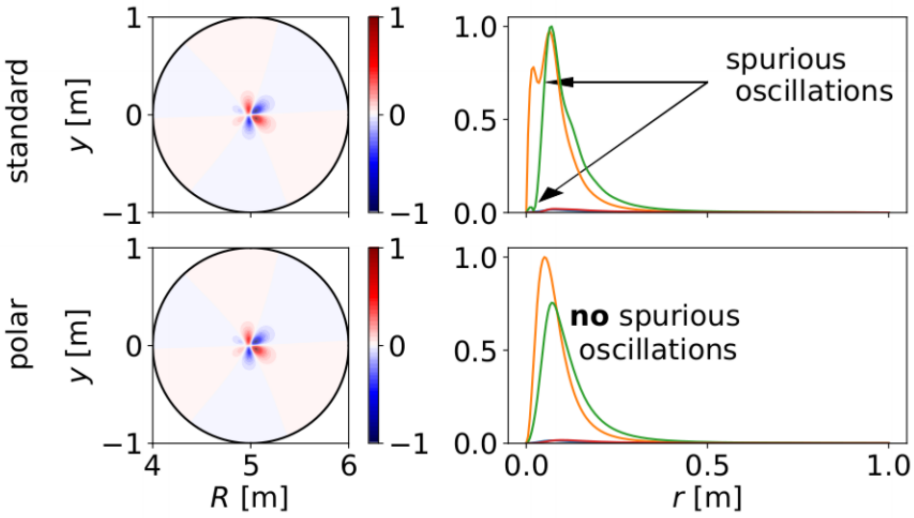
⇒ chirping rate scales linearly with the saturation amplitude
same ORB5 runs are available also in presence of turbulence

WP 3.5: STRUPHY MHD-kinetic hybrid code for long time scales

20 WP3.5-M1 add magnetic axis to STRUPHY End 2021

21 WP3.5-M2 add drift-kinetic model to STRUPHY; couple to GVEC 3D equilibrium solver for application to tokamaks and stellarators, end 2022 (ongoing master thesis)

- follows stringent mathematical formulation: geometric finite elements + PIC ⇒ **improved non-linear stability**
- modular python package, contains a collection of mappings, equilibria, initial conditions, dispersion relations
- presently ongoing: MPI-OpenMP hybrid parallelization, **scalability of field/fluid part - crucial for long time simulations**
- several successful benchmarks (ITPA TAE)



F. Holderied, PhD thesis 2022, JCP 2021 & 2022

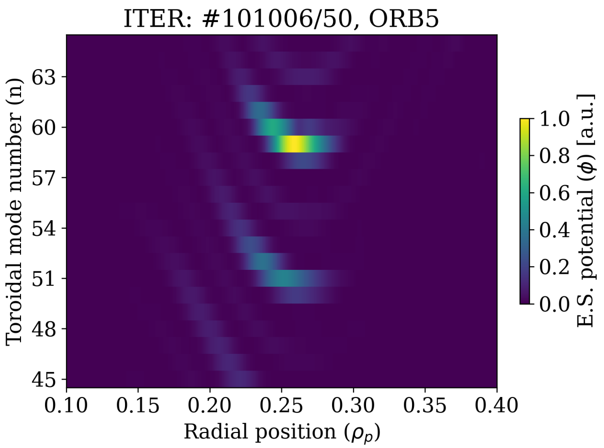
WP 3.6: ORB5 to provide high-fidelity results for validation

- ITER 15MA Q=10 low-shear scenario (cf. HAGIS: Schneller 2015-6, H-S 2017; N. Carlevaro WP 3.1)
  • EP redistribution, enhancement with multi-modes à la Schneller. • Hayward-Schneider+ NF 2021.

- ITER Pre-Fusion-Power-Operation (PFPO-2) case: H-plasma, 1⁄2 field, 1⁄2 current, NBI.
  • (T)AEs n~[10-20]; AITGs n~[50-100]; ITG n~[180-200] • Hayward-Schneider+ NF 2022.

- ASDEX Upgrade (NLED-AUG): high β / β ratio. Anisotopic EPs.
  • EGAM anisotopy: B. Rettino+ NF 2022
  • EGAM/Alfven mode interaction: Vannini+ Varenna2022 (Pinboard #32625)

- effect of Alfvén modes on turbulence [Biancalani EPS 2022 (ID 31903)]:
  - modification of equilibrium profiles due to AMs observed
  - effect of profile modification on turbulence studied with e.s. ITGs: turbulence reduced with AM-modified profiles



WP 4

WP1:

theoretical framework

WP 2:

Advancing various building blocks according to WP1

WP3:

Implementation, application and verification of reduced EP transport models

WP4:

Preparation of time-dependent reference cases

WP 4 - reference cases based on experimental scenarios

End 2021/22 WP4-M1 Plan and conduct AUG experiments in the view of clear and well-diagnosed transitions between EP transport regimes

End 2022 WP4-D1 Availability of reference scenarios (ITER, AUG, DTT) for application of transport models

presently the following scenarios are available on ITER/Gateway (IMAS) and have been investigated with the EP stability WF:

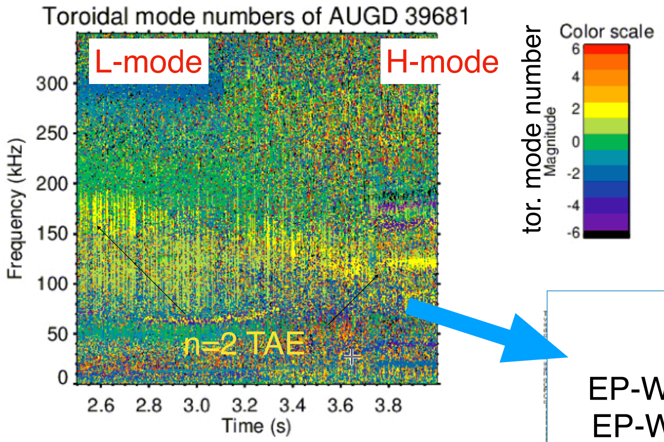
AUG*
TCV* [M. Vallar, subm NF, ID 33003]
JT-60SA
DTT (updated scenarios soon)*
ITER*: 15MA (various), PFPO2

*time dependent

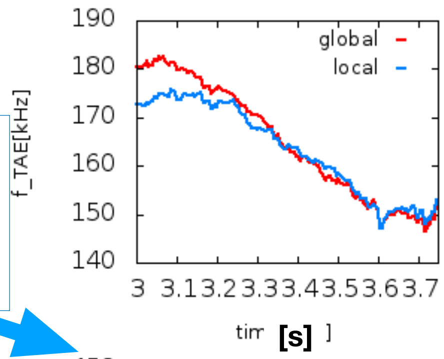
further needs: location for publicly available IMAS database for sharing on gateway, with standard for 'mandatory fields' in IDS

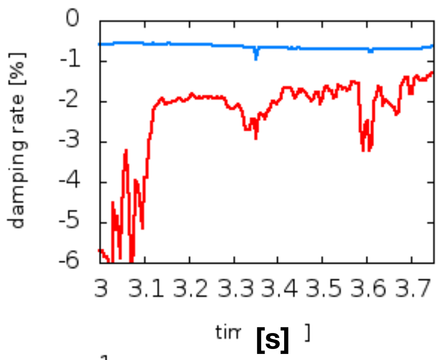
WP 4: AUG reference case: L-H transition in presence of TAEs

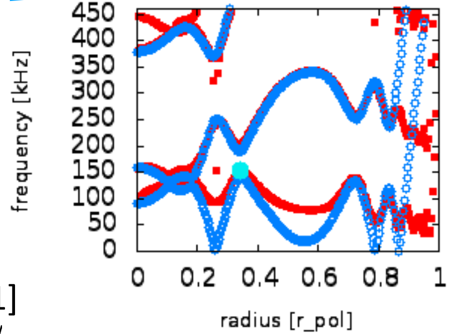
AUG EP 'supershot' scenarios: D NBI into D plasmas, D -> H and H-> H

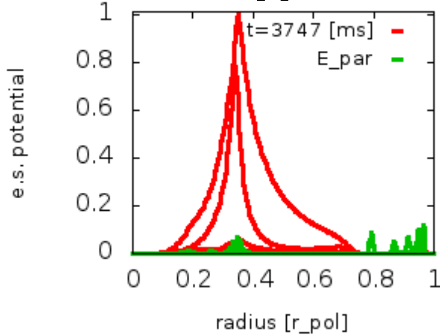


IDA +
TRVIEW +
EP-WF: LIGKA local +
EP-WF: LIGKA global







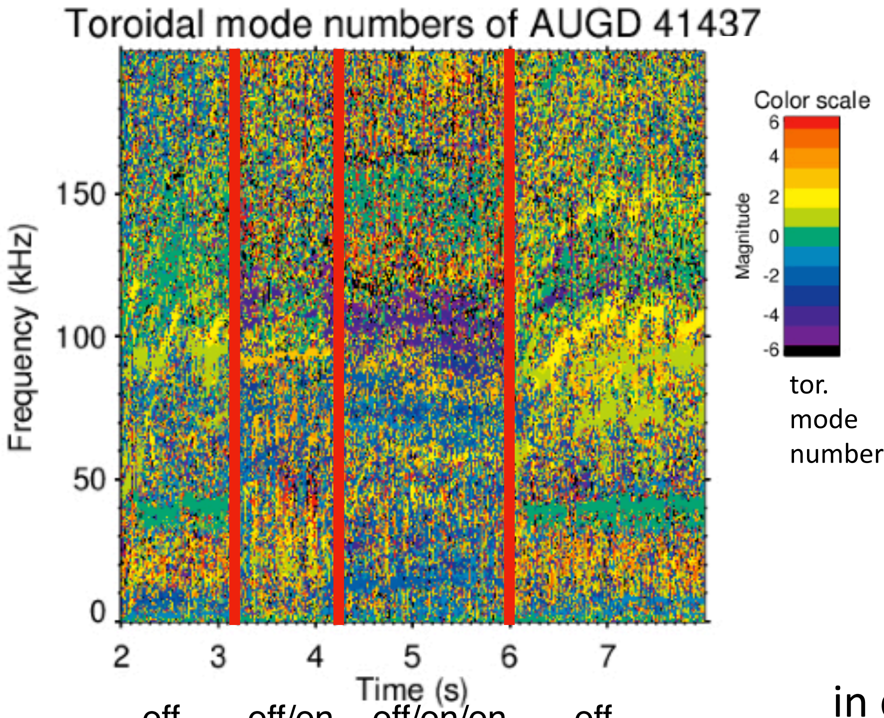


- analyse L-mode,H-mode and transition phase using
- systematic uncertainty quantification feasible
- bursty and steady-state phases visible, in agreement with damping analysis and drive - EP transport?
- speed up WF using ML methods [V.-A. Popa]

[Lauber, EPS 2022,ID 31591]

WP 4 - isotope scans

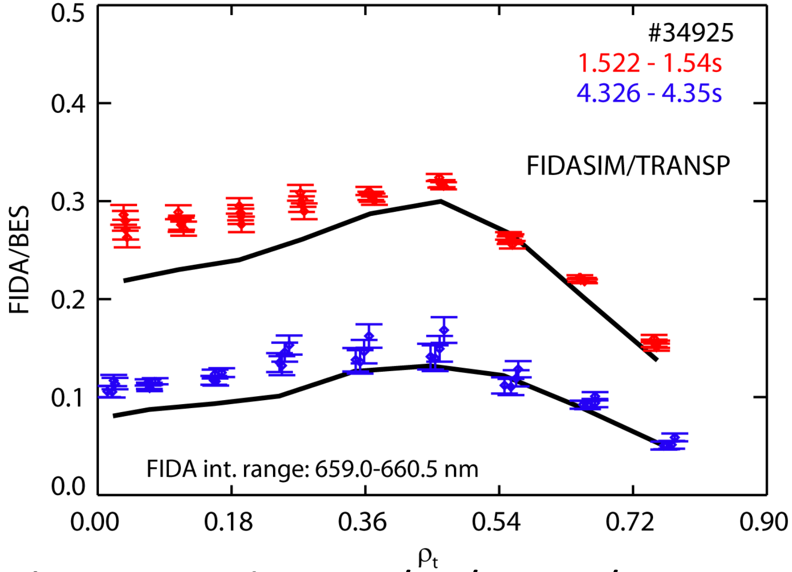
- July 2022: D NBI in He plasmas - ideal for numerical isotope studies, stability FOW/ FLR effects and EP transport under stationary conditions



tor. mode numbers

off off/on off/on/on off

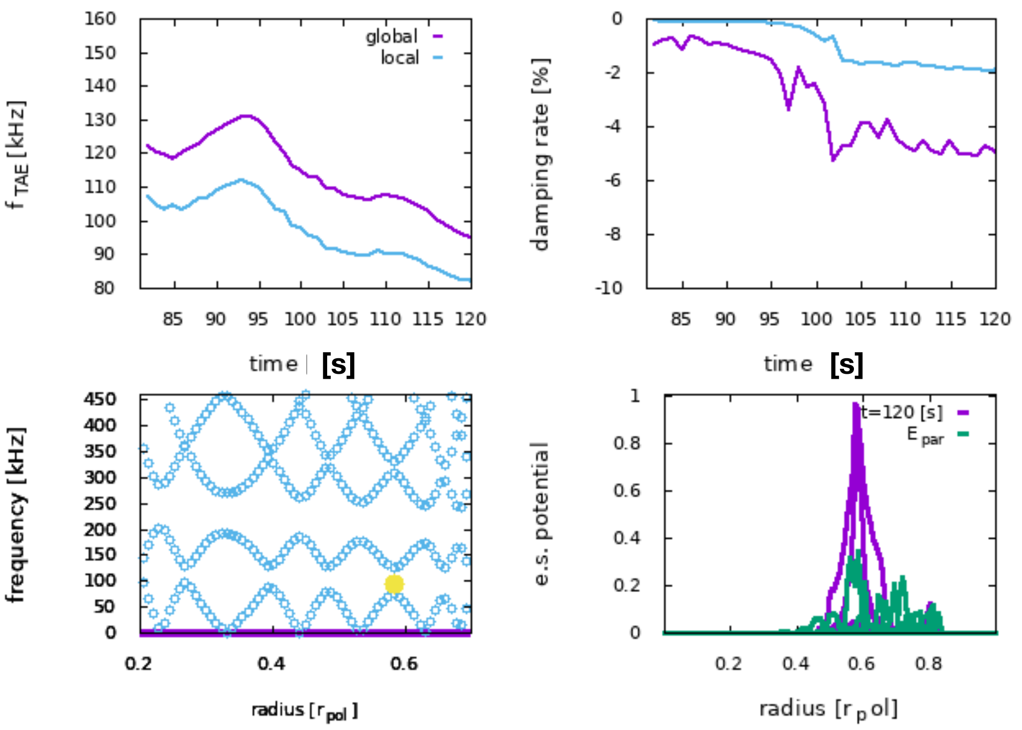
for some shots: FIDA data available

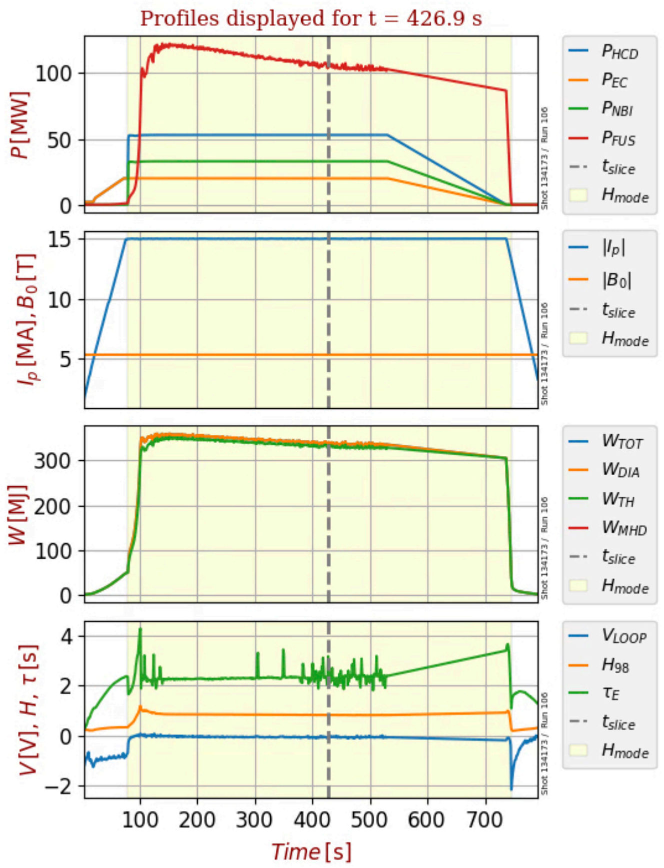


in depth analysis started 34924/25/39681/41437

WP 4 projected ITER scenarios (HFPS): #134173, 106
[S.D. Pinches, plenary EPS 2022]

TAE n=18





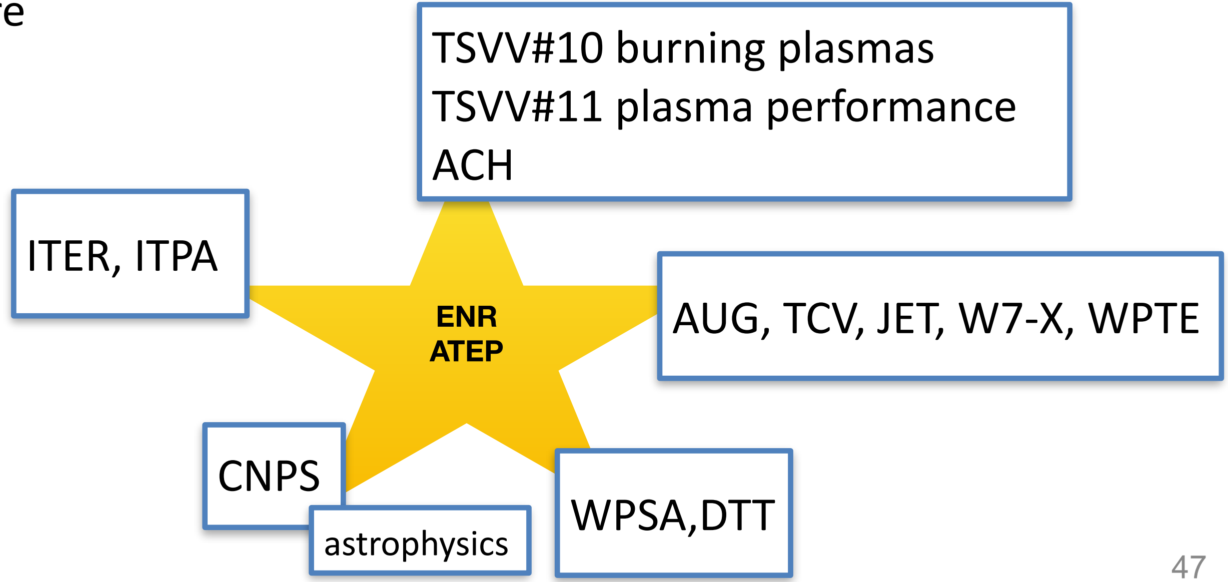
identified end of power ramp-up phases as most critical time points
for in-depth EP transport analyses

summary, outlook, dissemination of results

ATEP aims to ‘enable’ new routes to EP transport analysis and prediction via:

- new theoretical framework
- new common concept of connecting non-linear code results to reduced models (PSZS)
- new common EP (transport) code developments - explore speed up possibilities
- new analysis methods
- new IMAS based infrastructure

established and growing connections to other WPs:



Deliverables 1

- End 2021 WP1-D1 Complete transport theory of Phase Space Zonal Structures and Zonal State separating its microscale structures from macro-/meso- scale components (last report)
- End 2022 WP1-D2 Explicit expressions of phase space fluxes as input for WP2
- End 2021 WP2.1-D1 DAEPS in general tokamak geometry
- mid 2023 WP2.1-D2 Reduced EP transport model in tokamaks
- End 2022 WP2.2-D1 Fast analytical LIGKA version including trapped particles
- Mid 2022 WP2.3-D1 Explicit expressions for local eigenvalue code in 3D (ongoing, end October 2022)
- End 2022 WP3.1-D1 Validated 1D reduced model for EP transport in ITER/DTT
- End 2022 WP3.2-D1 Insights into short- and long-time relaxation dynamics of a non- thermal plasma with intense energetic particle component)
- Mid 2024 WP3.3-D1 Availability of validated reduced phase space transport model based on LIGKA/HAGIS/RABBIT within IMAS framework
- End 2022 WP3.4-D1 Validated version of RABBIT including model for fluctuation-induced radial transport of EPs (postponed to 2023)
- End 2022/23 WP3.5-D1 Hybrid kinetic-MHD results for V&V of transport models: with generalized distributions functions and collisions for AUG, ITER, DDT.
- End 2022/23 WP3.6-D1 Deliver quantitative criteria for transitions between different transport regimes w/o turbulence and ZF/ZSs in experimentally
- End 2022 WP4-D1 Availability of reference scenarios (ITER, AUG, DTT) for application of transport models

fully
partly
not started

Deliverables 2

- End 2023 WP1-D3 Self-consistent description of EPM repeated burst dynamics using the PSZS theoretical framework
- End 2023 WP3.2-D2 Practical basic understanding of convective radial transport of energetic particles versus the possible non-local transport regimes
- End 2023 WP2.3-D2 Local eigenvalue code in 3D (LIGKA) including passing particles
- End 2023 WP2.1-D3 DAEPS in general stellarator geometry
- End 2023 WP3.1-D2 Systematic statistical analysis of test particle transport and assessment of diffusive vs. non diffusive behaviours - jointly with WP3.2
- End 2023 WP2.2-D2 Fast analytical LIGKA model including guesses for global mode structures and non-Maxwellian distribution functions
- End 2023 WP3.5-D2 STRUPHY will deliver long time-scale simulations for V&V purposes (demonstrating conservation properties of advanced coupling scheme) based on the same equilibria as XHMGC, HYMAGYK, MEGA and ORB5

fully
partly
not started

Milestones 1

1 WP1-M1 2D and 3D formulation of Phase Space Zonal Structures transport equations, and definition of Zonal State with corresponding equations for Zonal Field Structures governing equations with separated dependences from nonlinear radial envelope and parallel mode structures, end 2021

2 WP1-M2 study of EPM dynamics in the presence of linearized collision integral and source terms, end 2022

3 WP2.1-M1 Benchmark of DAEPS in general toroidal geometry against reduced local LIGKA analysis for trapped particles, mid 2022

4 WP2.1-M2 Computation of nonlinear coupling coefficients in the nonlinear envelope equation and of EP fluxes in phase space, end 2022

5 WP2.1-M3 Benchmark of DAEPS in general stellarator geometry (jointly with WP2.3), end 2023

6 WP2.2-M1 Develop (semi-)analytical trapped particle model for LIGKA, mid 2022

7 WP2.2-M2 Test and tune analytical global mode structure model for LIGKA/HAGIS, end 2022

fully
partly
not started

Milestones 2

8 WP2.2-M3 Generalize fast analytical LIGKA version to non-Maxwellian distribution functions, in particular slowing down End 2023

9 WP2.3-M1 Derive equations for local LIGKA-like version in 3D Mid 2022 (slightly delayed - end 2022)

10 WP2.3-M2 Local eigenvalue code in 3D (LIGKA) including passing particles End 2023

fully
partly
not started

11 WP3.1-M1 Implementation of the 1D "mapping" in general geometry End 2021

12 WP3.1-M2 Interface of the 1D "mapping" in the ITER/IMAS workflow; Investigation of the influence of turbulence on the 1D "mapping" End 2022

13 WP3.2-M1 Probability density function of the radial displacements of tracer particles deduced from EP transport models Mid 2022

14 WP3.2-M2 The hypothesis of super-diffusive spreading of tracer particles on Lévy flights tested in simulations, hybrid flight- convective model complete mid 2023

Milestones 3

15 WP3.3-M1 Extend unperturbed orbit integration routines and averaging procedures in order to calculate phase space fluxes in HAGIS mid 2022 (fully)

16 WP3.3-M2 Explore methodology and possibly implement RABBIT as EP source into HAGIS End 2023 (ongoing)

17 WP3.3-M3 Finish reduced EP transport workflow based in LIGKA/HAGIS within IMAS mid 2024 (ongoing)

18 WP3.4-M1 Develop and implement radial diffusion model to RABBIT End 2022 (postponed to 2023)

19 WP3.4-M1 Apply extended RABBIT model to transient events, e.g. EP evolution during sawtooth cycles End 2023

fully
partly
not started

Milestones 4

20 WP3.5-M1 Flux calculations for frequency-chirping modes, compared to fixed frequency modes; add magnetic axis to STRUPHY End 2021

21 WP3.5-M2 Implementation of generic EP distributions into XHMGC, HYMAGYK and MEGA; add drift-kinetic model to STRUPHY; couple to GVEC 3D equilibrium solver for application to tokamaks and stellarators

22 WP3.6-M1 Calculate zonal structures in the presence of turbulence with ORB5 for validation of the reduced models End 2021

23 WP3.6-M2 Calculate particle and heat transport in the presence of turbulence with ORB5 for validation of the reduced models End 2022

24 WP4-M1 Plan and conduct AUG experiments in the view of clear and well-diagnosed transitions between EP transport regimes End 2021/22

fully
partly
not started