WP 3.1

1D reduced models

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

- Largely based on the results of WP1 and WP2, WP3 contains the detailed description of the plans for implementation, verification and validation of the advanced transport models.

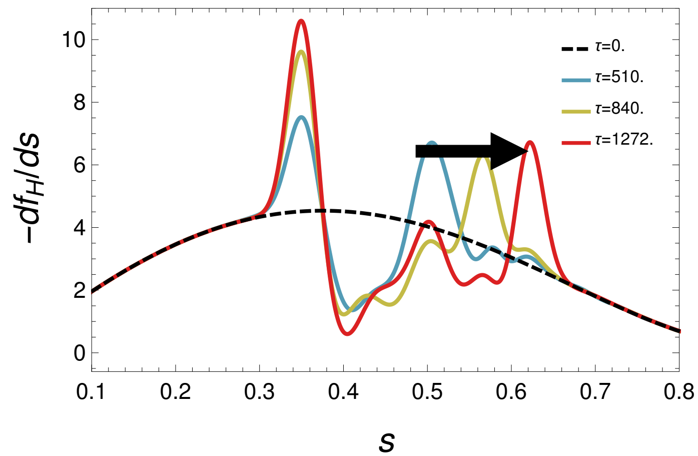
- **Key Persons**: N. Carlevaro, M.V. Falessi, A. Biancalani
- **Collaboration:** P. Lauber, G. Meng, X. Wang, F. Zonca

Main objective: optimize and validate the mapping procedure partially developed in MET (details in the next slides) to situations of practical interest.

- Analysis/prediction of avalanches (non-diffusive transport) triggered by EPs.

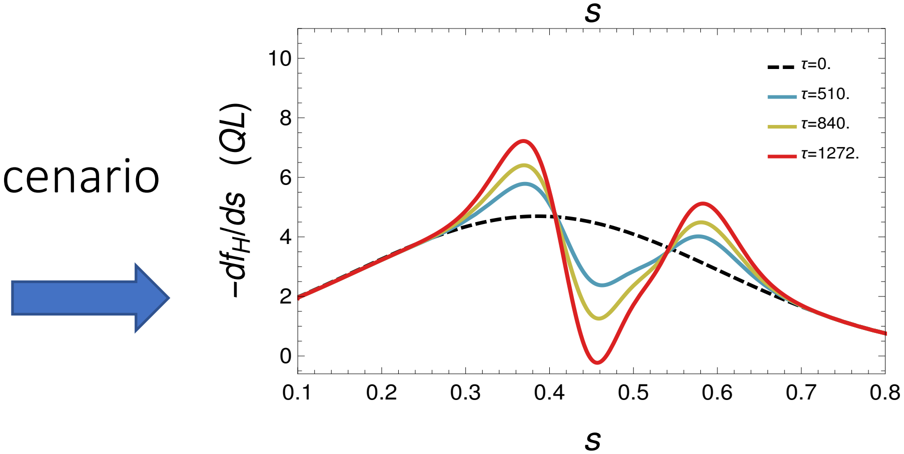
Mapping Procedure

- Aim: **reproduce radial transport of EP using a reduced 1D model** (bump-on-tail)
  - low computational effort
  - predict relevant phenomena beyond QL



- Local mapping: $\boldsymbol{u} = (\mathbf{1} - \boldsymbol{s})\ell$.

- Application to the ITER 15MA baseline scenario (PPCF 58, 014019 (2016)) w/ 27 TAEs
  - Relevance of **convective transport** (breakdown of diffusive paradigm).

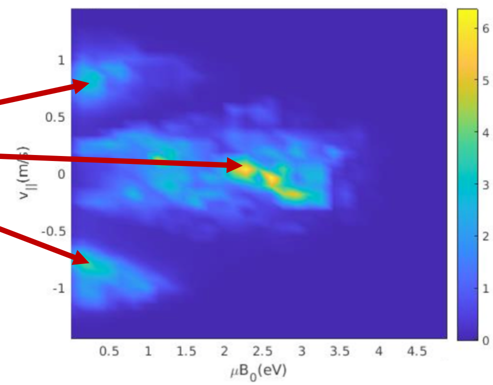


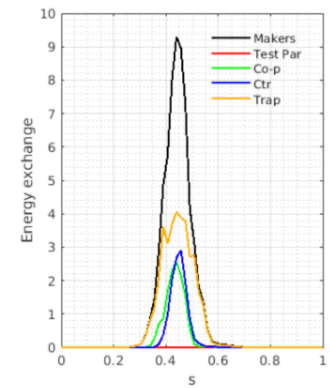
- **1D transport more efficient transport:** realistic redistribution averaged on the whole EP addressing the detailed **modulation of wave-particle power transfer**.
  - drive reduction $\gamma_D/\omega_0 = \alpha\ \gamma_D^{AE}/\omega_{AE}$ with $\alpha \leq 1$

- Redistribution of a set of EP tracers which **maximize the power exchange** can be proper described with $\alpha = 1$ (CNPS Talk, paper to be submitted).

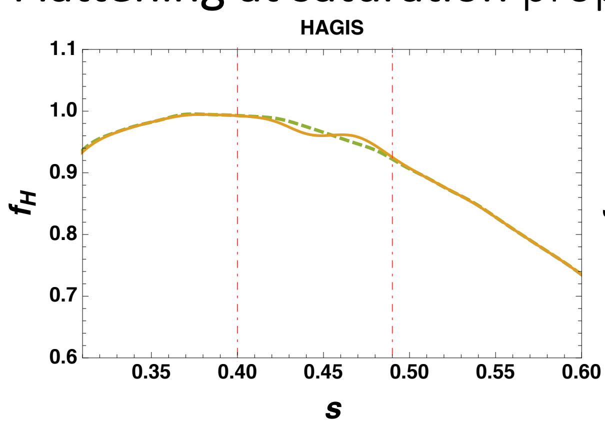
- Single toroidal mode number: cut the phase space into **infinitesimal/ independent slices** by fixing two constants of motion μ and $K = E - \omega_{AE} P_\phi / n$

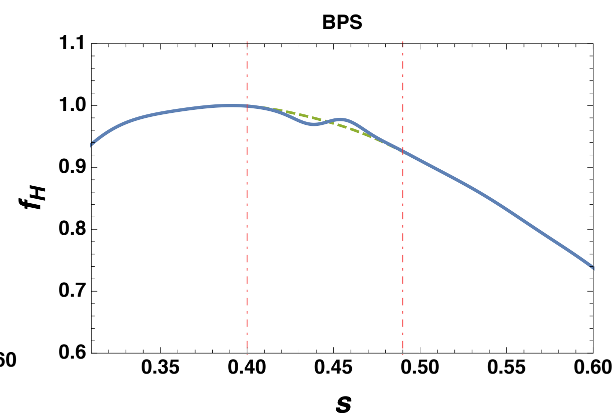
- Test case: $n = 25$
  - Dynamics driven by the three distinct populations.
  - Fraction of power exchange: Trap = 0.59; Co-p=0.2014; Ctr-p=0.2.





- **Co-p tracers: most resonant slice** $K = 1.5\, MeV$ and $\mu = 164\, keV$.
- **Flattening at saturation** properly reproduced for $\alpha = 1$:





Modeling beyond the QL approach

- MET results (EPS 2021): **hierarchical description** of the 1D VP system

$$\partial_t f_k = -ikv\, f_k + \frac{e}{m}\sum_{k'} E_{k'}\partial_v f_{k-k'}$$

$$\partial_t E_k = -i\omega_p E_k + \frac{2\pi e\omega_p}{k}\int_{-\infty}^{\infty} dv f_k$$

Spatial homogeneous initial conditions: dynamics of $k = 0$

$$\partial_t f_0 = \frac{e}{m}\sum_{k'} E_{k'}\partial_v f_{-k'}$$

- **Diagonal reduction**: f_k is assumed to receive mainly contribution from the correspondent harmonics ($k' = k$) (no mode-mode interaction):

$$\partial_t f_k = -ikv\, f_k + \frac{e}{m}E_k\partial_v f_0 \;\longrightarrow\; f_k(t,v) = \frac{e}{m}\int_0^t dt' E_k(t')e^{ikv(t'-t)}\partial_v f_0(t',v)$$

- Dynamics of EP distribution function:

$$\partial_t f_0(t,v) - \frac{e^2}{m^2}\sum_k \left[E_k\,\partial_v\left(\int_0^t dt' E_k^*(t')e^{ikv(t'-t)}\partial_v f_0(t',v)\right) + c.c.\right] = 0$$

  - Using external spectrum: well **prediction until saturation.**

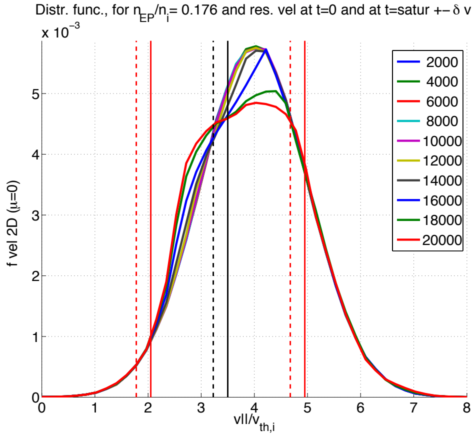
- In the mapping framework: diagonal VP system implemented to describe realistic **temporal mesoscales**.

GK Simulations (details in A. Biancalani talk)

- GK PIC **code ORB5 sims** are in plan to provide a further test-bed for reduced models.

- EP transport carried by Alfvén modes studied with ORB5 in **simplified configurations** [e.g. Biancalani-PPCF-2017, Cole-PoP-2017] and **experimental configurations** [Hayward-Schneider-NuFu-2021].

- **EP transport carried by EGAM** also studied with ORB5 [Biancalani-JPP-2018, Novikau-PoP-2020] and compared with 1D reduced models [Biancalani-JPP-2018] --> good estimation of the **nonlinear width** of the EP distr. funct. modified by the EGAM in velocity space (see figure).



- EP-turbulence direct or indirect interaction has raised interest of our community.

- In this project: EP transport carried by Alfvén modes and EGAMs in the presence of turbulence with **ORB5 simulations and comparison with reduced models**.

Workplan details

- Define mapping procedure moving to **global dynamics** implementing coherent **summation over different slices**: estimation of the corresponding weight invoking the global/reduced wave-particle power exchange.

  Systematic implementation to study reference cases and w/ possible QL upgrading: DTT and ITER inductive scenarios; AUG cases for validation with the experiment.

  Extension of the 1D reduced models to cases with ZS and turbulence: benchmark w/ fully gyrokinetic simulations using ORB5 (see WP 3.6). Discrimination for relevance of ZS and turbulence.

- **Milestones (**no updates/changes)
  2021 - M1: Implementation of the 1D “mapping” in general geometry.
  2022 - M2: Interface of the 1D “mapping” in the ITER/IMAS workflow;
  Investigation of the influence of turbulence on the 1D “mapping”.

- **Deliverables** (no updates/changes)
  2022 - D1: Validated 1D reduced model for EP transport in ITER/DTT.
  2023 - D2: Systematic statistical analysis of test particle transport and assessment of diffusive vs. non diffusive behaviors (WP3.2).

- **Manpower allocation** (tentative)
  - N. Carlevaro, M.V. Falessi, F. Zonca:
    BPS simulations, mapping extension (global description and slices).
  - P. Lauber, G. Meng, X. Wang:
    LIGKA/HAGIS simulations, reference case selection/analysis.
  - A. Biancalani:
    fully GK simulation (ORB5) benchmark (ZS/turbulence).

- **Exchange of data**
  - IMAS compatibility for the “mapping” planned in M2 (2022).
  - Quantities needed for reduced model: drives/damping for spectrum (linear theory), mode structure (resonance width).

- **Diagnostics**
  - Mapping initial step: slice identification (G. Meng); details of power exchange.
  - ZS/turbulence.

- **Simplified benchmark case**
  - First step (M1 – end 2021): single reference case (one population drive, high saturation) for moving to global mapping representation.
  - Specific WP workshops.

- No travel needed for this initial stage.