

# IMAS - INTEGRATED WORKFLOW FOR ENERGETIC PARTICLE STABILITY

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<sup>1</sup>IPP <sup>2</sup>ITER

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# Motivation and Structure

- **All EP transport models rely on linear properties of instabilities.**
- **In the past:**
  - Damping/drive assessment difficult because global – electromagnetic problem
  - Local – global analysis not connected
  - Problems with centralization of data from different codes
- **Now:**
  - Development of the Integrated Modelling & Analysis Suite (IMAS)
  - Equilibrium and stability codes (HELENA, LIGKA) were further developed and adapted to work with IMAS.
- **This work:**
  - Using IMAS as a centralized database tool
  - Adaptation of HELENA and LIGKA
  - Python time-dependent workflow
  - Impact of Toroidal Alfvén Eigenmodes (TAEs) on various ITER scenarios:
    - ITER baseline DT - METIS<sup>1</sup> -130012
    - pre-fusion plasma - 101006
    - steady state scenario (ITER > 2038)
    - experimental data AUG - 39681
  - Fundamental first step to automated analysis of time-dependent scenarios.

# Numerical Tools: Overview

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- **IMAS:**

- Integrated Modelling & Analysis Suite

- **LIGKA<sup>1</sup>:**

- Linear gyrokinetic eigenvalue code

- **HELENA<sup>2</sup>:**

- MHD equilibrium solver

- **EP - WF<sup>3</sup>:**

- Energetic Particle Stability Workflow (Python)

- **Models form hierarchy of fidelity, complexity:**

- Use local solvers to have an overview of the scenario before attempting global, more expensive runs.
- Use global solver to validate the results obtained by the local, faster runs.

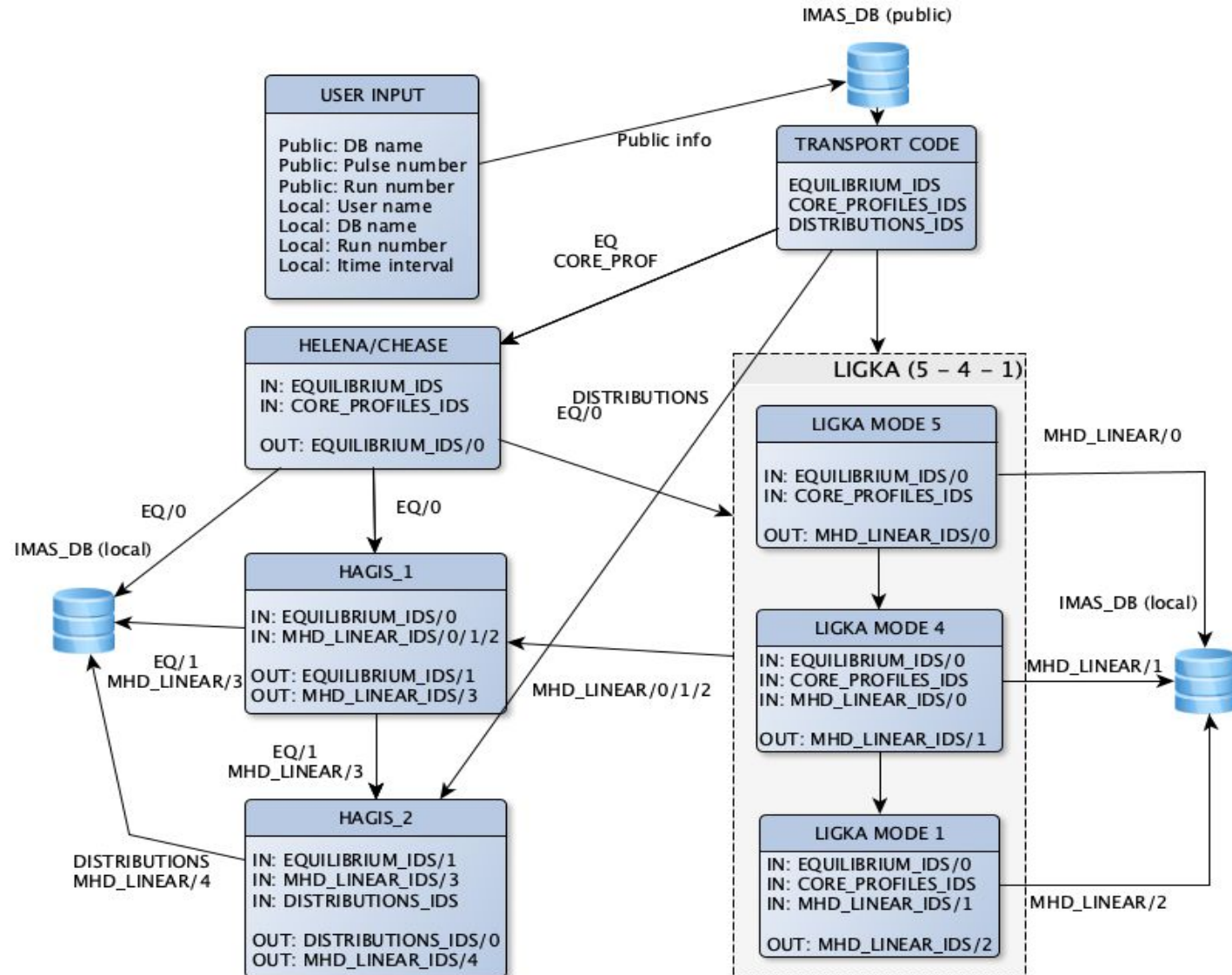
1) Lauber JCP (2007); 2) CP90 Conference on Computational Physics. (1991)  
3) V.-A. Popa Master Thesis (2020)

- **LIGKA:**

- Solves the linearized gyrokinetic equations -> eigenvalues and eigenfunctions (frequency, damping, mode structure).
- Different physics in the data structure need to be studied, thus mapping to the underlined data management in order to derive the uncertainty quantification for each model is necessary.
- Subprograms of LIGKA used in this work are:
  - ~ 1 s • Model 5: local analytical estimates of various basic AEs properties: frequency, estimated mode structure, rational surface, next and previous gap informations.
  - ~ 10 s • Model 4: based on model 5 results, the local analytical dispersion relation for each mode is calculated. Determines the starting point for global calculations.
  - ~ 1 h • Model 1: performs a frequency scan throughout the gap to find global linear properties of the modes.

# Numerical Tools: Energetic Particles Stability Workflow

- First time - dependent workflow which makes use of the IMAS infrastructure and various codes.
- **Scope:**
  - Connect the numerical tools with the data infrastructure (IMAS).
  - Facilitates retrieving/saving data from the DB through XML files.
  - Fast configuration of numerical tools.
  - Complete data analysis suite integrated in the interface.



# Numerical Tools: EP - WF - GUI



WORKFLOW PARAMETERS

userpublic  
machineITER  
shot\_nr130012  
run\_in2  
machine\_outtest\_DB  
run\_out10  
itbegin15  
itend16

FURTHER SETTINGS

ligka\_541  
pulse\_list  
fast\_particles  
mpi\_processes8

Save ConfigurationSave and Run  
Save Configuration asLoad Configuration  
Restore DefaultLIGKA Analysis (Testing)  
Scenario Summary Choice  
Exit

ACTOR SELECTION

Equilibrium\_codeHelena  
Distributions\_1Hagis\_1  
Distributions\_2Hagis\_2 (testing now)  
Orbit\_FinderFinder (testing now)  
Stability\_codeLigka\_m5

HELENA Parameters  
LIGKA Parameters  
HAGIS 1 Parameters  
HAGIS 2 Parameters  
FINDER Parameters  
Species Settings  
SCENARIO Parameters

EP Analysis

Analysis Settings

shot\_number130012  
run19  
userpopaa  
machineligka\_modes  
n\_min10  
n\_max10  
m\_min10  
m\_max20  
r\_TAE\_min0.2  
r\_TAE\_max0.9  
itbegin1  
itend1  
mode4  
compare\_modes

Frequency  
Damping  
Radial Position  
Mode Structure  
Mode Structure 2D  
Radial Position for all modes

Export Data  
Save Analysis Configuration

LIGKA PARAMETERS

LIGKA PARAMETERS

modus1  
min\_n\_tor10  
max\_n\_tor10  
min\_m10  
max\_m11  
sidebands4  
sidebands\_asy0  
mode\_type1  
even0  
start\_pos1  
force\_mfalse  
offset\_d0.0  
npsi\_out256  
kr\_read0.0

Save LIGKA Configuration

SPECIES SETTINGS

SPECIES SETTINGS

H0.02  
D0.02  
T0.02  
Be0.02  
Ne0.02  
He4\_ash0.02  
C0.02

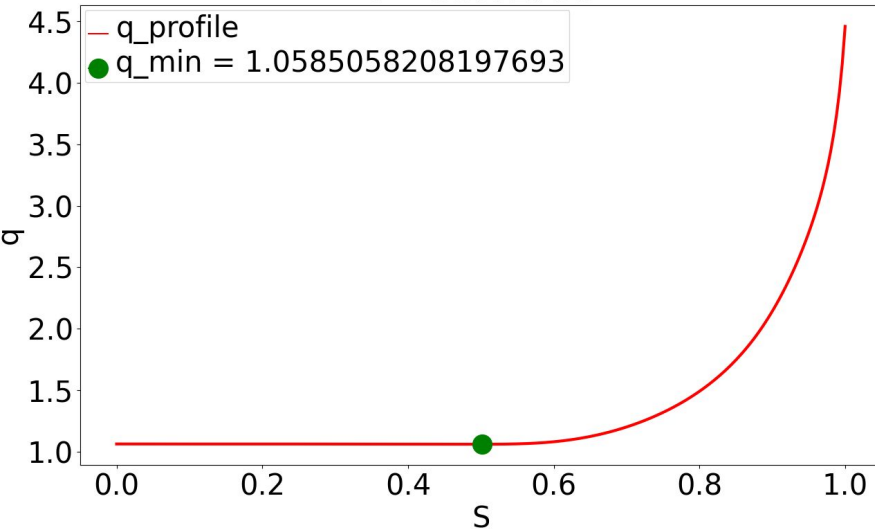
Scenario Selector

Pulse	Run	Database	Reference	Ip[MA]	B0[T]	Fuelling	Confinem	Workflow
100002	1	ITER	ITER-half-field-H	-7.5	-2.65	H	L-mode	METIS
100001	2	ITER	ITER-full-field-H	-15.0	-5.3	H	L-mode	METIS
100003	1	ITER	ITER-third-field-H	-5.0	-1.8	H	L-H-L	METIS
100007	1	ITER	ITER-intermediate-3T-H	-8.5	-3.0	H	L-H-L	METIS
100008	1	ITER	ITER-intermediate-3.3T-H	-9.5	-3.3	H	L-H-L	METIS
100009	1	ITER	ITER-intermediate-4.5T-H	-12.5	-4.5	H	L-mode	METIS
100013	1	ITER	ITER-PFPO1-1.8T-H	-5.0	-1.8	H	L-H-L	METIS
100015	1	ITER	ITER-PFPO2-1.8T-H-0.9*n	-5.0	-1.8	H	L-H-L	METIS
100014	2	ITER	ITER-PFPO2-1.8T-H-0.5*n	-5.0	-1.8	H	L-H-L	METIS
100501	3	ITER	ITER-nonactive-H	-7.5	-2.65	H	L-H-L	CORSICA

Close

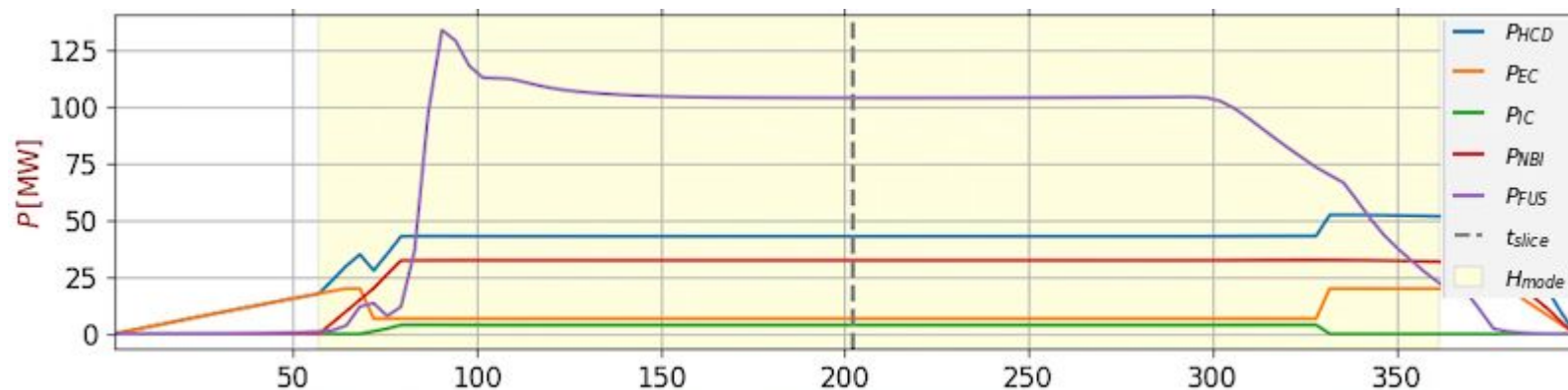
# Results: METIS case 130012/2 (ITER DB)

t = 98.01798



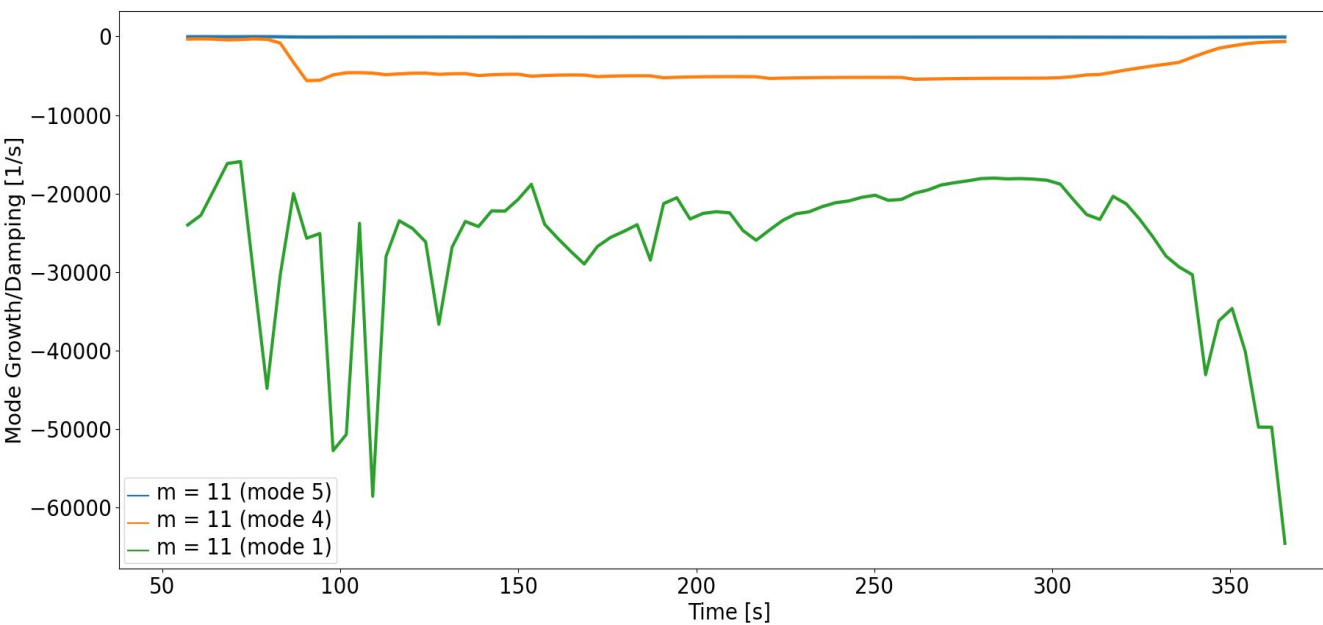
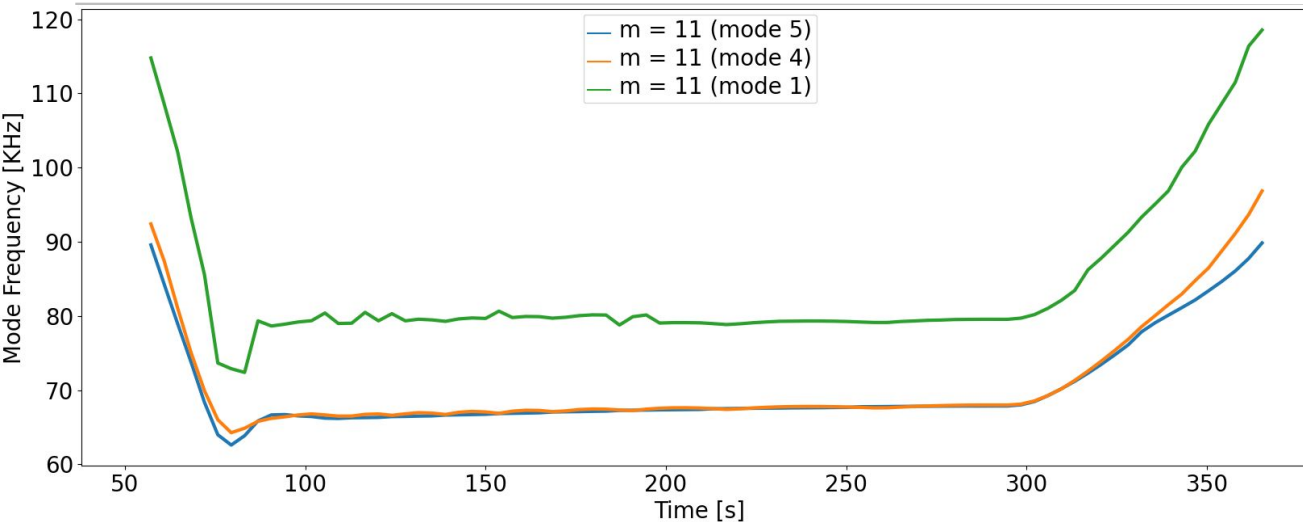
- Time – dependent scenario (METIS)
- ITER baseline DT scenario
- confinement regime: H-L-H
- magnetic field: -5.30 [T]
- main species: D-T
- plasma current: -15 [MA]
- central electron density:  $1.01e+20[m^{-3}]$

species:	H	D	T	He3	He4	Be	O	W
a:	1.0	2.0	3.0	3.0	4.0	9.0	16.0	183.0
z:	1.0	1.0	1.0	2.0	2.0	4.0	8.0	74.0
n_over_ntot:	1.17e-20	0.468	0.469	0.045	1.43e-03	0.016	1.63e-04	3.81e-06
n_over_ne:	1.07e-20	0.428	0.429	0.041	1.30e-03	0.015	1.49e-04	3.48e-06
n_over_n_maj:	2.50e-20	0.997	1.000	0.096	3.04e-03	0.035	3.48e-04	8.11e-06





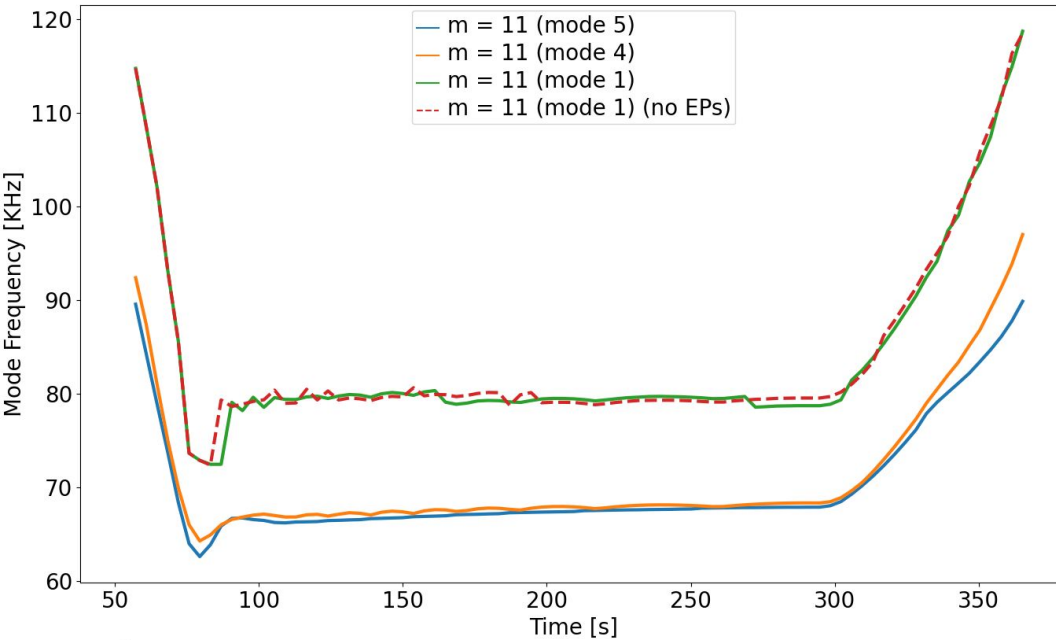
# Results: METIS case 130012/2 (ITER DB)



- **n = 10, m = 11:**
- No alpha particles are considered for now.
- A correlation in frequency between local solver and global one with a 10% expected difference.
- Local solvers (mode 5 and 4) do not consider the continuum damping and radiative damping (i.e. coupling to KAW) contributions.



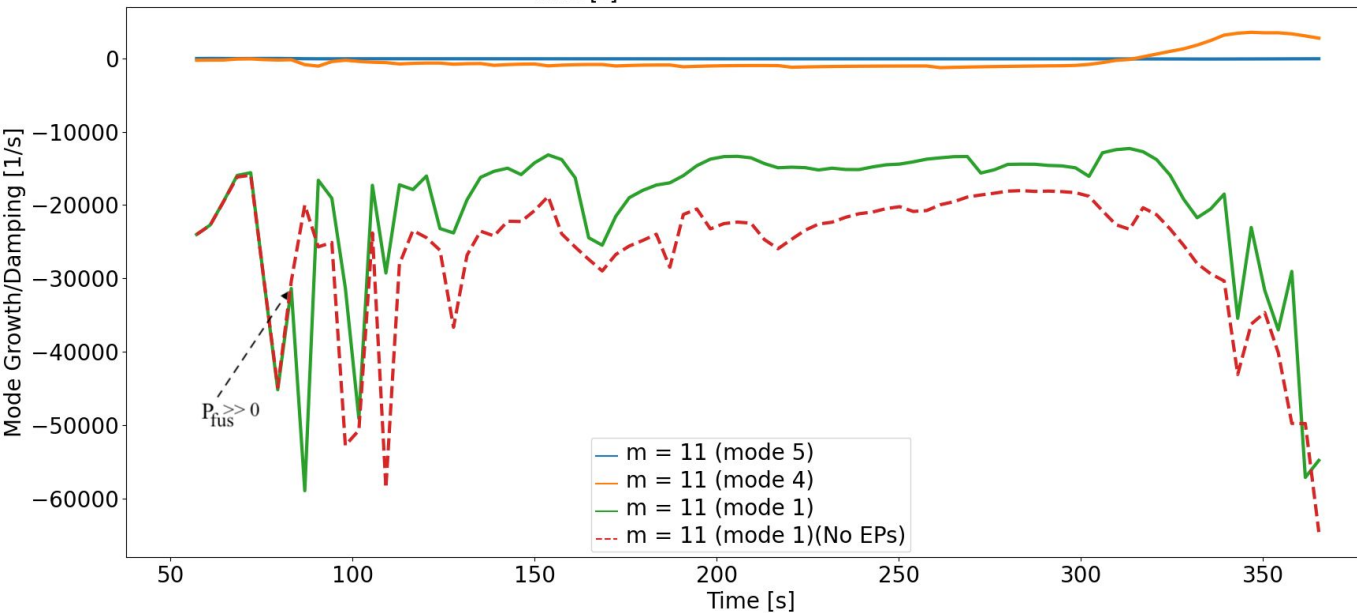
# Results: METIS case 130012/2 (ITER DB)



- **n = 10, m = 11:**

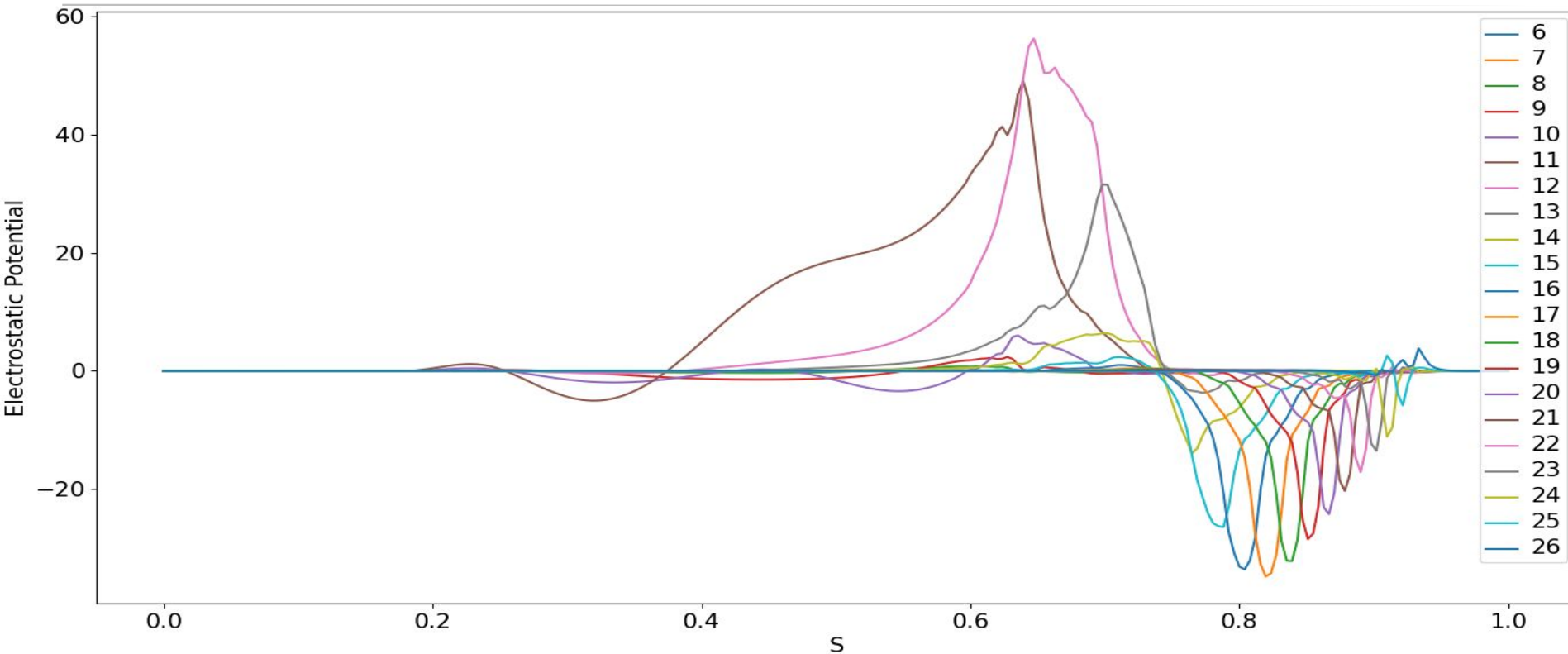
- Alpha particles are considered.
- As expected, the frequency did not shift by a semnificative margin.
- In mode 4 (local solver) one can see a growth in the modes once EPs are included.

- In mode 1 (global solver) a better view towards the growth of the mode can be observed.



- Until  $P_{fus}$  is significant, the modes follow the exact same path. The modes are less damped once  $P_{fus}$  is large enough.
- In this case, the EPs drive is not sufficient to drive the modes unstable.

# Results: METIS case 130012/2 (ITER DB)



- **Mode structure  $n = 10$ ,  $m = 11$ ,  $t = 201.96s$ :**
- Due to the extremely flat  $q$  - profile (if steep  $q$ , poloidal harmonics become smaller and more narrow towards the edge)
- **This case, stable for all modes investigated ( $n=5-30$  TAEs) so far more realistic  $q$  leads to more unstable situations (papers [1],[2],[3]).**

[1] S.D.Pinches et al. 2015

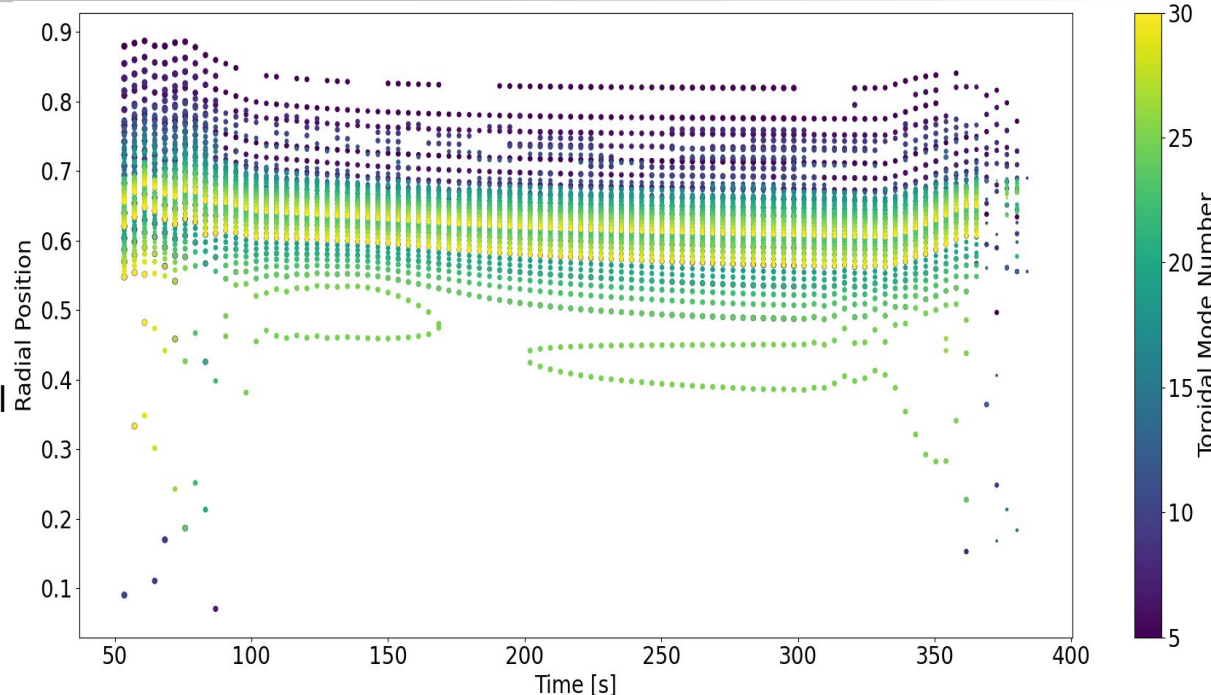
[2] Ph.Lauber et al. 2015

[3] T.Hayward-Schneider et al., NF (2021)

# Outlook - this work has unlocked possibilities

## • The next steps are:

- Consolidation and removal of remaining problems (porting to gateway complete).
- Mode 5 analytical mode structure improvement, in the future , it will decide when to run mode 1 (global solver) or not.
- Include and test other AEs (EAE,BAE,RSAE,...)
- NBI distribution function to be added (Interface to ITER H&CD wf already developed)
- Non – linear hybrid model ( HAGIS 2) to predict saturation level of modes (already imported in IMAS).
- Build transport models from the results obtained in the stability analysis (pursued within Eurofusion Enabling Research Project ATEP).



- Other scenarios tested with the WF:
  - pre-fusion plasma - 101006
  - steady state scenario (ITER > 2038)
  - experimental data TCV (M. Vallar - EPFL)
  - experimental data AUG - 39681