MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

# Overview of the Stability workflow

## Virgil – Alin Popa

## EP-Stability-WF, July 2023

Collaborators: Ph. Lauber, T. Hayward-Schneider,
S. Pinches, M. Schneider, O. Hoenen

*Integrated Modeling and
Analysis Suite@ITER.org

EUROfusion

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# Numerical tools: Overview

- **IMAS:**
  - Integrated Modelling & Analysis Suite
- **LIGKA[1]:**
  - Linear gyrokinetic eigenvalue code
- **HELENA/CHEASE[2]:**
  - MHD equilibrium solver
- **EP-Stability-WF:**
  - Energetic Particle Stability Workflow (Python)

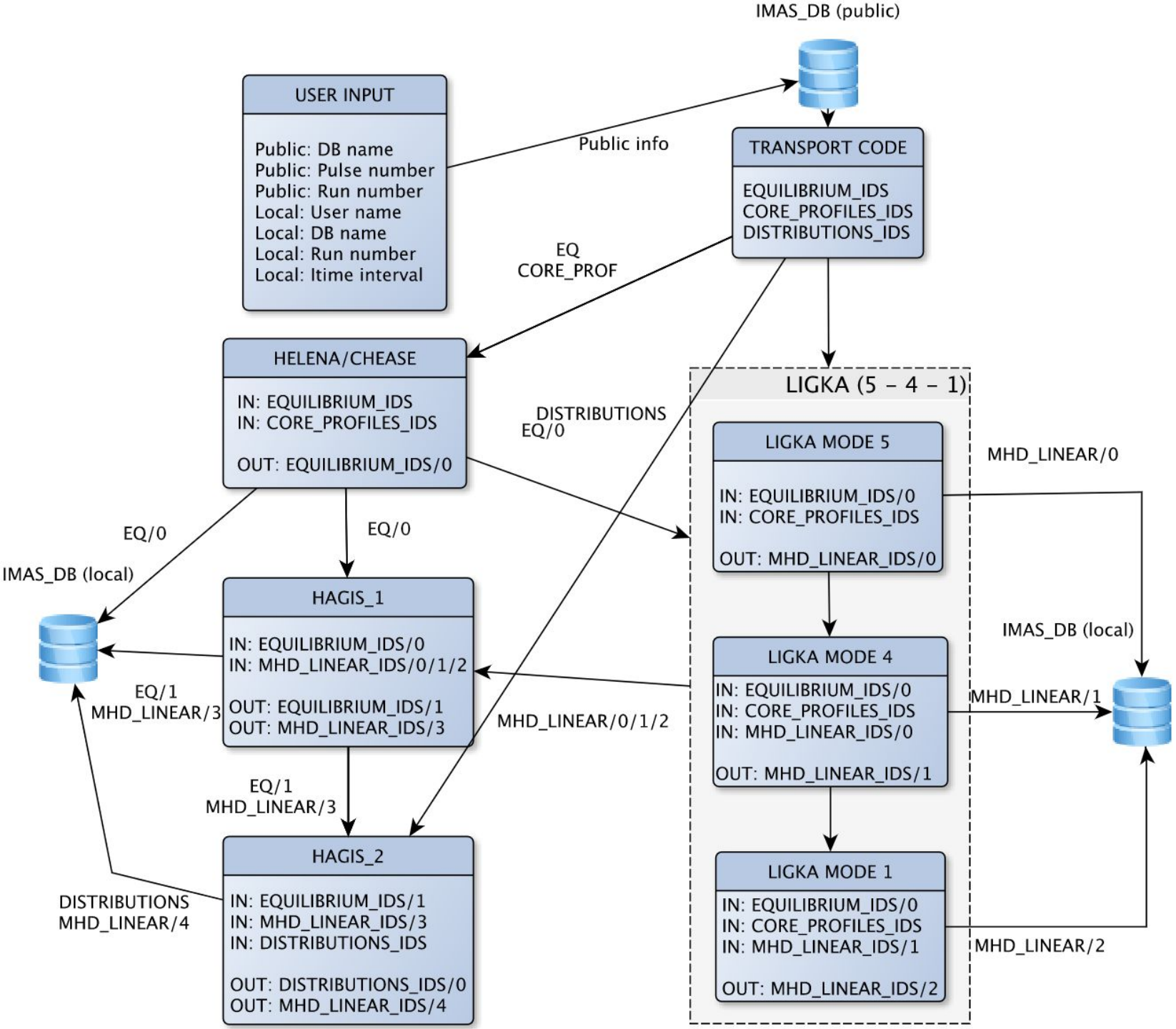
- **Models form hierarchy of fidelity, complexity:**
  - Use local solvers to have an overview of the scenario before attempting global, more expensive runs.
  - Use global solver to validate the results obtained by the local, faster runs.

1) Lauber JCP (2007); 2) CP90 Conference on Computational Physics. (1991)

# Numerical tools: LIGKA

- **LIGKA:**
  - Solves the linearized gyrokinetic equations -> eigenvalues and eigenfunctions (frequency, damping, mode structure).
  - Models used in this work are (among others):

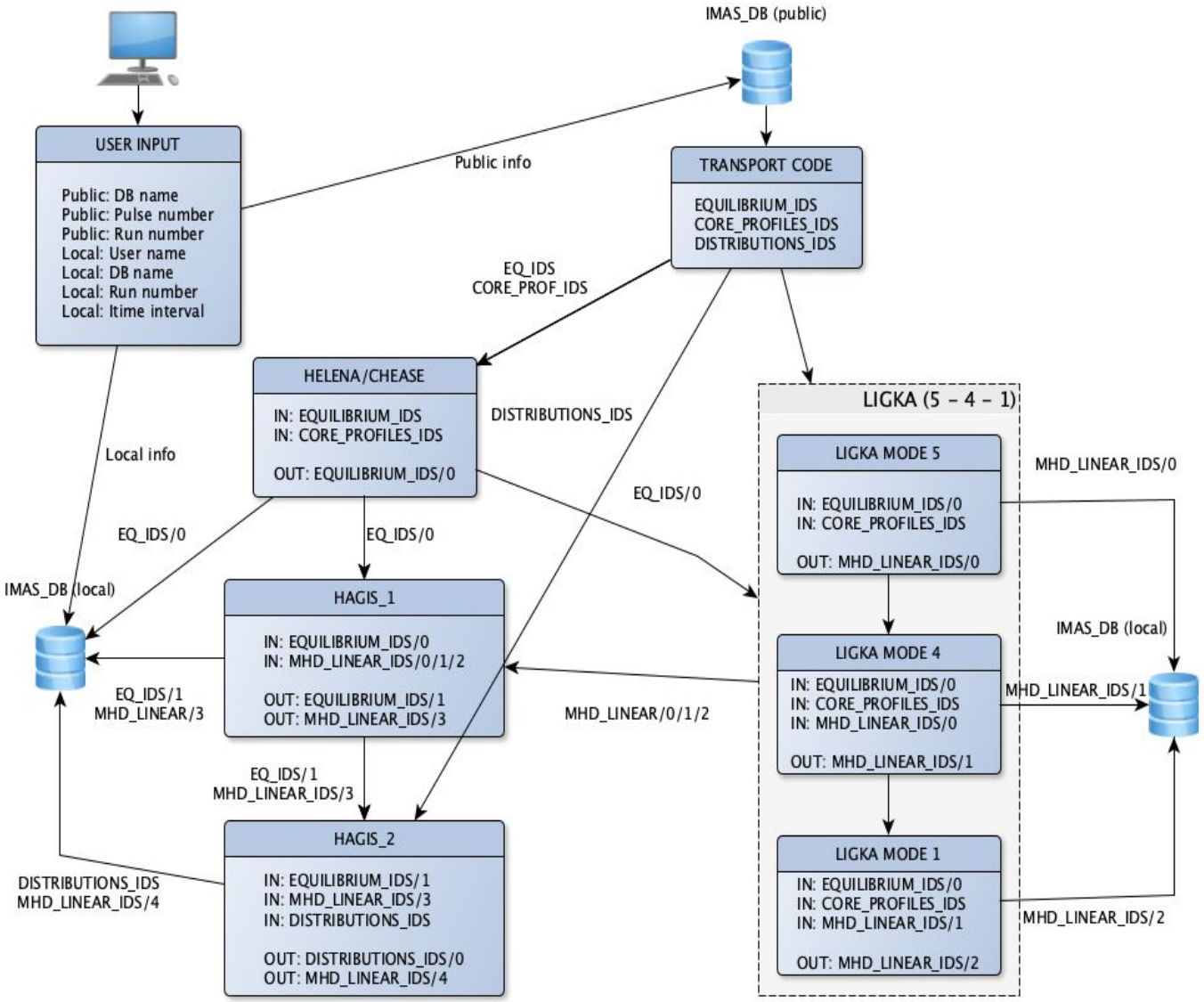
| | |
|---|---|
| >1 s/mode | • Model 5: local analytical estimates of various basic AEs properties: frequency, estimated mode structure, rational surface, next and previous gap informations. |
| ~ 10 s/mode | • Model 4: based on model 5 results, the local analytical dispersion relation for each mode is calculated. Determines the starting point for global calculations. |
| ~ 30 min/mode | • Model 1: performs a frequency scan throughout the gap to find global linear properties of the modes. |


IMAS_DB (public)
USER INPUT
Public: DB name
Public: Pulse number
Public: Run number
Local: User name
Local: DB name
Local: Run number
Local: Itime interval
Public info
TRANSPORT CODE
EQUILIBRIUM_IDS
CORE_PROFILES_IDS
DISTRIBUTIONS_IDS
EQ
CORE_PROF
HELENA/CHEASE
IN: EQUILIBRIUM_IDS
IN: CORE_PROFILES_IDS
OUT: EQUILIBRIUM_IDS/0
DISTRIBUTIONS
EQ/0
LIGKA (5 – 4 – 1)
LIGKA MODE 5
IN: EQUILIBRIUM_IDS/0
IN: CORE_PROFILES_IDS
OUT: MHD_LINEAR_IDS/0
MHD_LINEAR/0
EQ/0
EQ/0
IMAS_DB (local)
HAGIS_1
IN: EQUILIBRIUM_IDS/0
IN: MHD_LINEAR_IDS/0/1/2
OUT: EQUILIBRIUM_IDS/1
OUT: MHD_LINEAR_IDS/3
IMAS_DB (local)
LIGKA MODE 4
IN: EQUILIBRIUM_IDS/0
IN: CORE_PROFILES_IDS
IN: MHD_LINEAR_IDS/0
OUT: MHD_LINEAR_IDS/1
MHD_LINEAR/1
EQ/1
MHD_LINEAR/3
MHD_LINEAR/0/1/2
EQ/1
MHD_LINEAR/3
HAGIS_2
IN: EQUILIBRIUM_IDS/1
IN: MHD_LINEAR_IDS/3
IN: DISTRIBUTIONS_IDS
OUT: DISTRIBUTIONS_IDS/0
OUT: MHD_LINEAR_IDS/4
DISTRIBUTIONS
MHD_LINEAR/4
LIGKA MODE 1
IN: EQUILIBRIUM_IDS/0
IN: CORE_PROFILES_IDS
IN: MHD_LINEAR_IDS/1
OUT: MHD_LINEAR_IDS/2
MHD_LINEAR/2

# Numerical tools: Energetic Particles Stability Workflow

- The aim of the WF is to perform an automated linear stability analysis on different time slices of a projected scenario or reconstructed experimental equilibrium.
- 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. (to be completed)



# Flow of FC2K actors in the WF

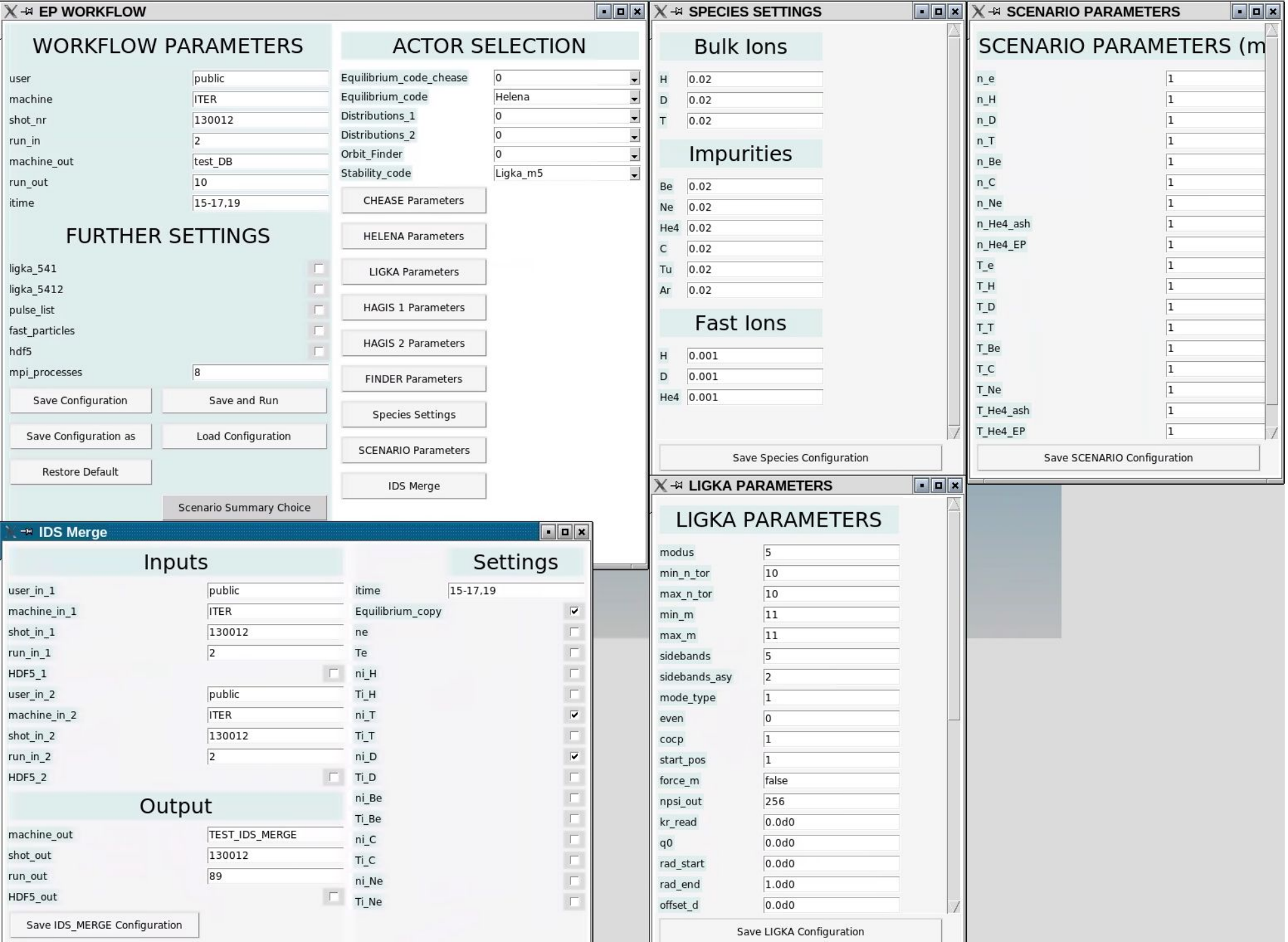
```python
def actor_settings(actor):
    actor_params = {}
    input_ids = {}
    output_ids = {}
    if actor == "Chease":
        actor_params["entrypoint_actor"] = True
        actor_params["wrapper"] = chease_actor_wf_wrapper
        actor_params["config_file_name"] = "chease_input_choices.xml"
        input_ids = {"equilibrium": 0, "core_profiles": 0}
        output_ids = {"equilibrium": 2, "core_profiles": 0}
    if actor == "Helena":
        actor_params["entrypoint_actor"] = True
        actor_params["wrapper"] = helena_actor_wf_wrapper
        actor_params["config_file_name"] = "helena.xml"
        input_ids = {"equilibrium": 0, "core_profiles": 0}
        output_ids = {"equilibrium": 0, "core_profiles": 0}
    if actor == "Ligka_m5":
        actor_params["entrypoint_actor"] = False
        actor_params["wrapper"] = ligka_actor_wf_wrapper
        actor_params["config_file_name"] = "z_ligka.xml"
        input_ids = {"equilibrium": 0, "core_profiles": 0}
        output_ids = {"mhd_linear": 0}
    if actor == "Ligka_m4":
        actor_params["entrypoint_actor"] = False
        actor_params["wrapper"] = ligka_actor_wf_wrapper
        actor_params["config_file_name"] = "z_ligka.xml"
        input_ids = {"equilibrium": 0, "core_profiles": 0, "mhd_linear": 0}
        output_ids = {"mhd_linear": 1}
    if actor == "Ligka_m1":
        actor_params["entrypoint_actor"] = False
        actor_params["wrapper"] = ligka_actor_wf_wrapper
        actor_params["config_file_name"] = "z_ligka.xml"
        input_ids = {"equilibrium": 0, "core_profiles": 0, "mhd_linear": 1}
        output_ids = {"mhd_linear": 2}
    if actor == "Ligka_m6":      Popa Alin, 22 months ago • Code cleanup and im
        actor_params["entrypoint_actor"] = False
        actor_params["wrapper"] = ligka_actor_wf_wrapper
        actor_params["config_file_name"] = "z_ligka.xml"
        input_ids = {"equilibrium": 0, "core_profiles": 0, "mhd_linear": 0}
        output_ids = {"mhd_linear": 5}
    if actor == "Ligka_m2":
        actor_params["entrypoint_actor"] = False
        actor_params["wrapper"] = ligka_actor_wf_wrapper
        actor_params["config_file_name"] = "z_ligka.xml"
        input_ids = {"equilibrium": 0, "core_profiles": 0, "mhd_linear": 2}
        output_ids = {"mhd_linear": 6}
    if actor == "Ligka_m3":
        actor_params["entrypoint_actor"] = False
        actor_params["wrapper"] = ligka_actor_wf_wrapper
        actor_params["config_file_name"] = "z_ligka.xml"
        input_ids = {"equilibrium": 0, "core_profiles": 0, "mhd_linear": 0}
        output_ids = {"mhd_linear": 7}
    if actor == "Hagis_1":
        actor_params["entrypoint_actor"] = False
        actor_params["wrapper"] = hagis1_actor_wf_wrapper
        actor_params["config_file_name"] = "hagis1.xml"
        input_ids = {"equilibrium": 0, "mhd_linear": 0}
        output_ids = {"equilibrium": 1, "mhd_linear": 3}
    if actor == "Hagis_2":
        actor_params["entrypoint_actor"] = False
        actor_params["wrapper"] = hagis2_actor_wf_wrapper
        actor_params["config_file_name"] = "hagis2.xml"
        input_ids = {"equilibrium": 1, "mhd_linear": 3, "core_profiles": 0}
        output_ids = {"distributions": 0, "mhd_linear": 4}
    if actor == "Finder":
        actor_params["entrypoint_actor"] = False
        actor_params["wrapper"] = finder_actor_wf_wrapper
        actor_params["config_file_name"] = "finder_input.xml"
        input_ids = {"equilibrium": 1}
        output_ids = {"distributions": 1}
    if actor == "Falcon":
        actor_params["entrypoint_actor"] = False
        actor_params["wrapper"] = falcon_actor_wf_wrapper
        actor_params["config_file_name"] = "falcon_input.xml"
        input_ids = {"equilibrium": 2}
        output_ids = {"mhd_linear": 5}

    actor_params["input_ids"] = input_ids
    actor_params["output_ids"] = output_ids

    return actor_params
```

Fc2k actors:

1) Have callable functions (wrappers to the fortran, or python code (Falcon)
2) Input only IDSs
3) Output only IDSs
4) Easier to manage input/output and decide order of execution


EP WORKFLOW
WORKFLOW PARAMETERS
user
public
machine
ITER
shot_nr
130012
run_in
2
machine_out
test_DB
run_out
10
itime
15-17,19
FURTHER SETTINGS
ligka_541
ligka_5412
pulse_list
fast_particles
hdf5
mpi_processes
8
Save Configuration
Save and Run
Save Configuration as
Load Configuration
Restore Default
Scenario Summary Choice
ACTOR SELECTION
Equilibrium_code_chease
0
Equilibrium_code
Helena
Distributions_1
0
Distributions_2
0
Orbit_Finder
0
Stability_code
Ligka_m5
CHEASE Parameters
HELENA Parameters
LIGKA Parameters
HAGIS 1 Parameters
HAGIS 2 Parameters
FINDER Parameters
Species Settings
SCENARIO Parameters
IDS Merge
IDS Merge
Inputs
user_in_1
public
machine_in_1
ITER
shot_in_1
130012
run_in_1
2
HDF5_1
user_in_2
public
machine_in_2
ITER
shot_in_2
130012
run_in_2
2
HDF5_2
Output
machine_out
TEST_IDS_MERGE
shot_out
130012
run_out
89
HDF5_out
Save IDS_MERGE Configuration
Settings
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15-17,19
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Ti_H
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Ti_T
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ni_Be
Ti_Be
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Ti_C
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Bulk Ions
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T
0.02
Impurities
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Ne
0.02
He4
0.02
C
0.02
Tu
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Ar
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Fast Ions
H
0.001
D
0.001
He4
0.001
Save Species Configuration
LIGKA PARAMETERS
LIGKA PARAMETERS
modus
5
min_n_tor
10
max_n_tor
10
min_m
11
max_m
11
sidebands
5
sidebands_asy
2
mode_type
1
even
0
cocp
1
start_pos
1
force_m
false
npsi_out
256
kr_read
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q0
0.0d0
rad_start
0.0d0
rad_end
1.0d0
offset_d
0.0d0
Save LIGKA Configuration
SCENARIO PARAMETERS
SCENARIO PARAMETERS (m
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n_H
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n_D
1
n_T
1
n_Be
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n_C
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n_Ne
1
n_He4_ash
1
n_He4_EP
1
T_e
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T_H
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T_D
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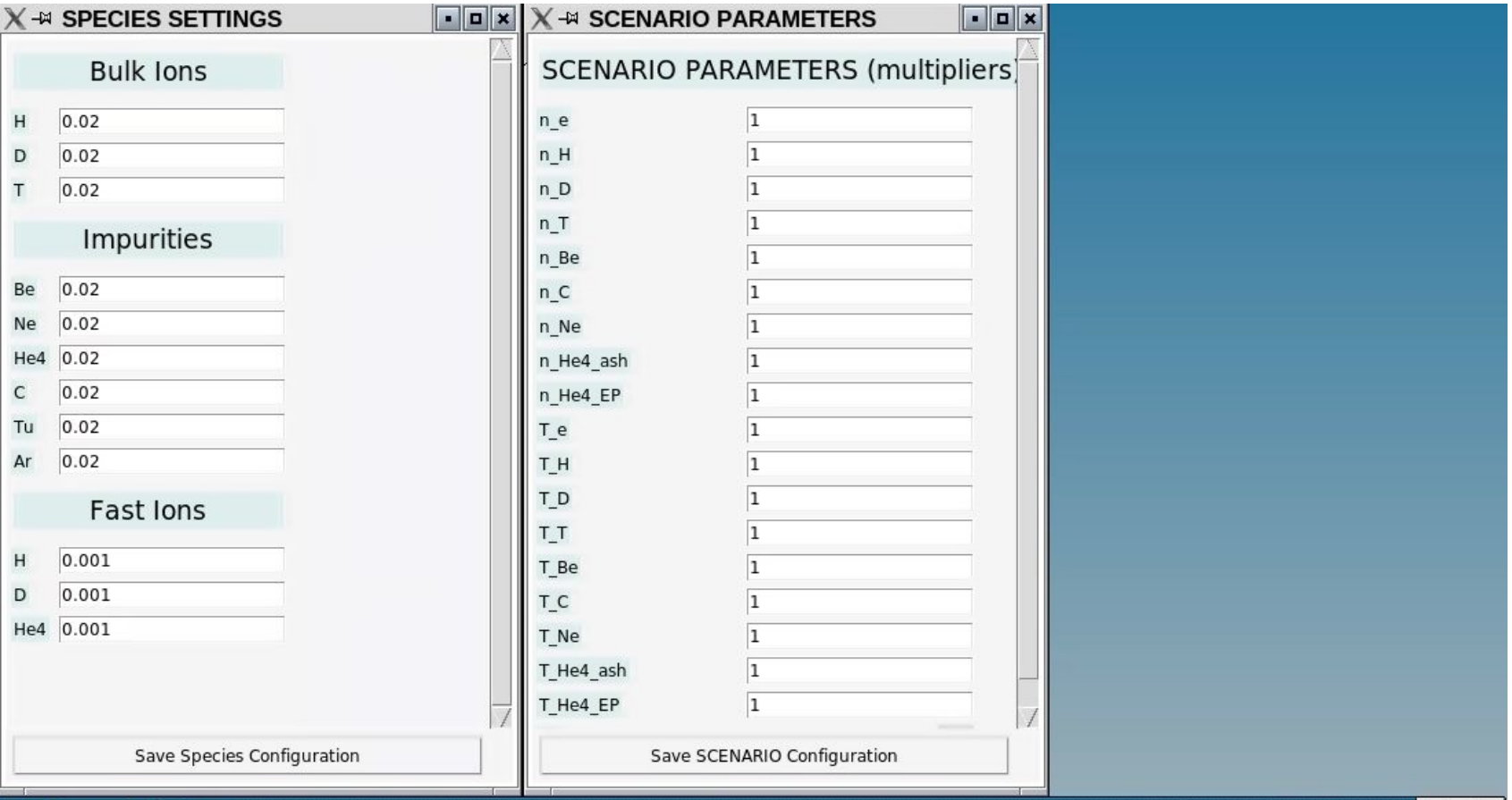
T_T
1
T_Be
1
T_C
1
T_Ne
1
T_He4_ash
1
T_He4_EP
1
Save SCENARIO Configuration

# Extra features







Scenario Selector

| ulse | Run | Database | Reference | Ip[MA] | B0[T] | Fuelling | Confinement | 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_GW-NBI_745keV_22.3I | -5.0 | -1.8 | H | L-H-L | METIS |
| 100014 | 2 | ITER | ITER-PFPO2-1.8T-H-0.5*n_GW-NBI_530keV_9.4M | -5.0 | -1.8 | H | L-H-L | METIS |
| 100016 | 1 | ITER | ITER-10MA-5.3T-Hydrogen | -10.0 | -5.3 | H | L-mode | METIS |

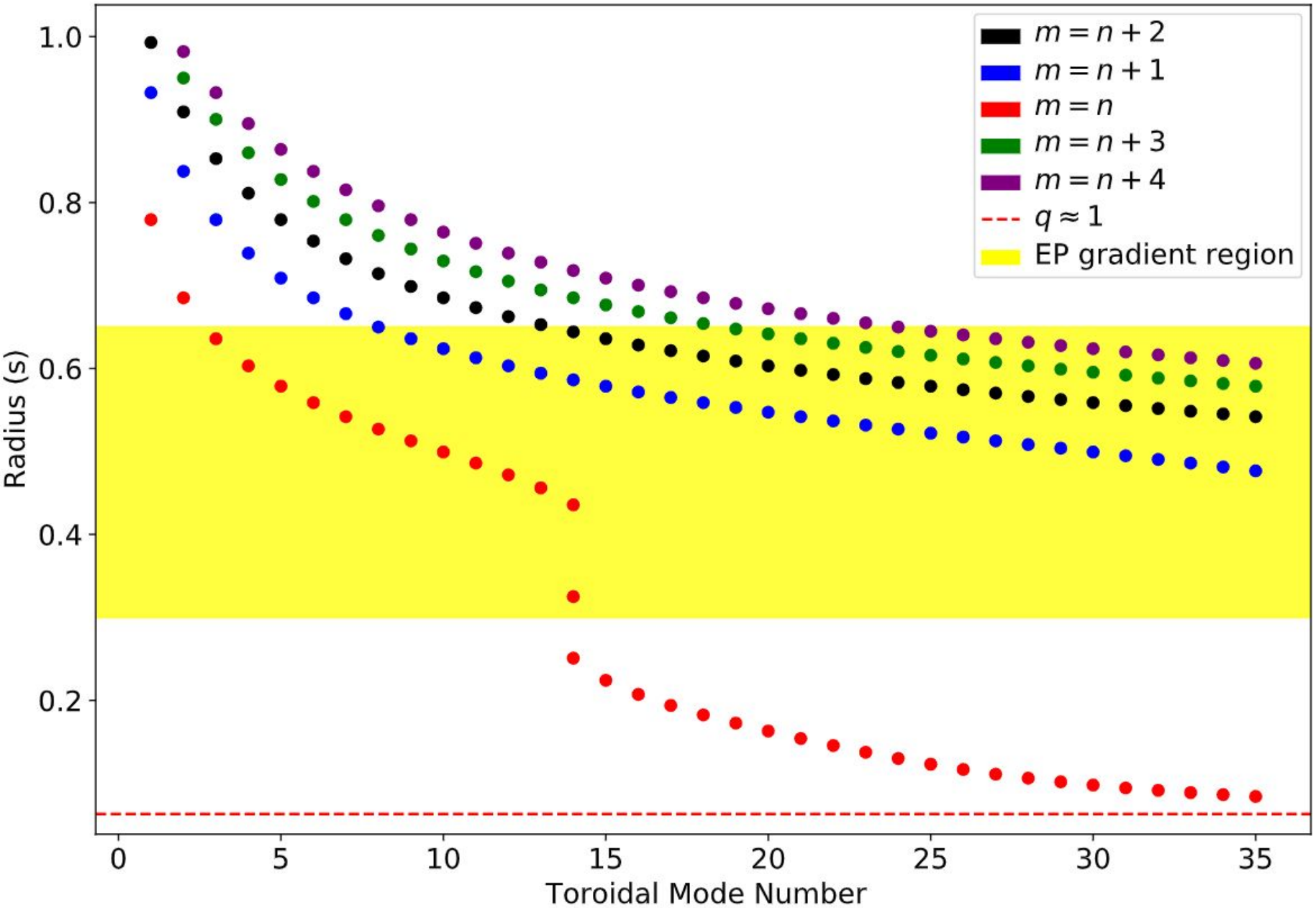
# Development/testing cycle, current and previous versions

- **Maintenance cycle of actors + WF:**
  - Actors are self contained codes that can act independently or as part of a workflow.
  - They are continuously tested and maintained via versions (different modules in sdcc/gw)
  - On top of that we have the EP-Stability-WF integrated testing.
  - When testing the wf, we also test the integration of LIGKA + HELENA/CHEASE inside the WF (2x testing for actors)
  - Testing happens automatically at every push of every piece of code (via automated bamboo tests)

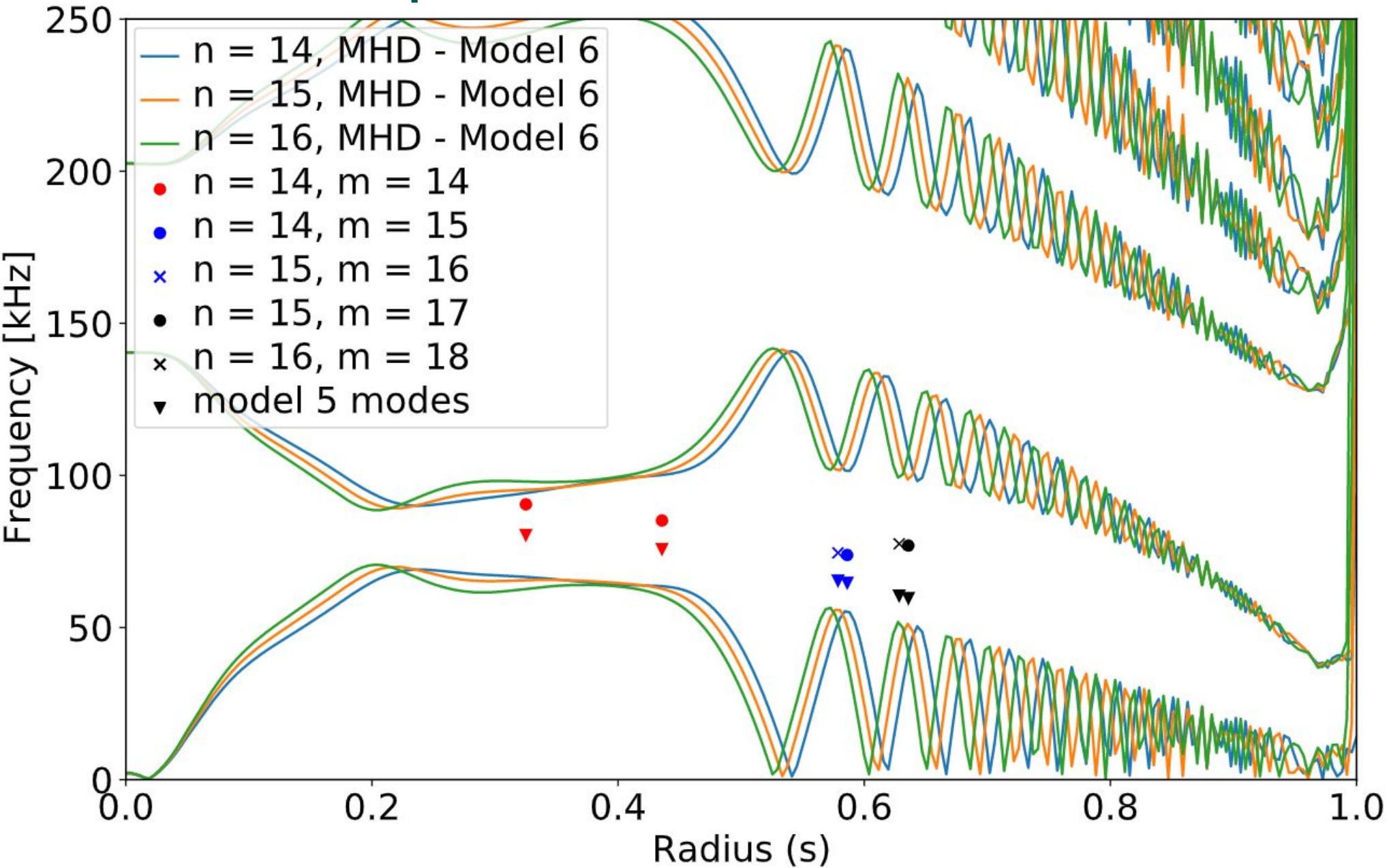
- **Following runs were performed with:**
  - HELENA: 2.0.1-intel-2020b-DD-3.35.0
  - LIGKA: 1.0.1-intel-2020b-DD-3.35.0
  - CHEASE: 1.0.9-intel-2020b-DD-3.35.0
  - EP-WF: 1.0.2-intel-2020b-DD-3.35.0
- **Current status of codes:**
  - HELENA: 2.0.1-intel-2020b-DD-3.37.0
  - LIGKA: 1.0.5-intel-2020b-DD-3.37.0
  - CHEASE: 13.1.2-intel-2020b-DD-3.37.0
  - EP-WF: 1.0.4-intel-2020b-DD-3.37.0

***Things are moving fast!!***

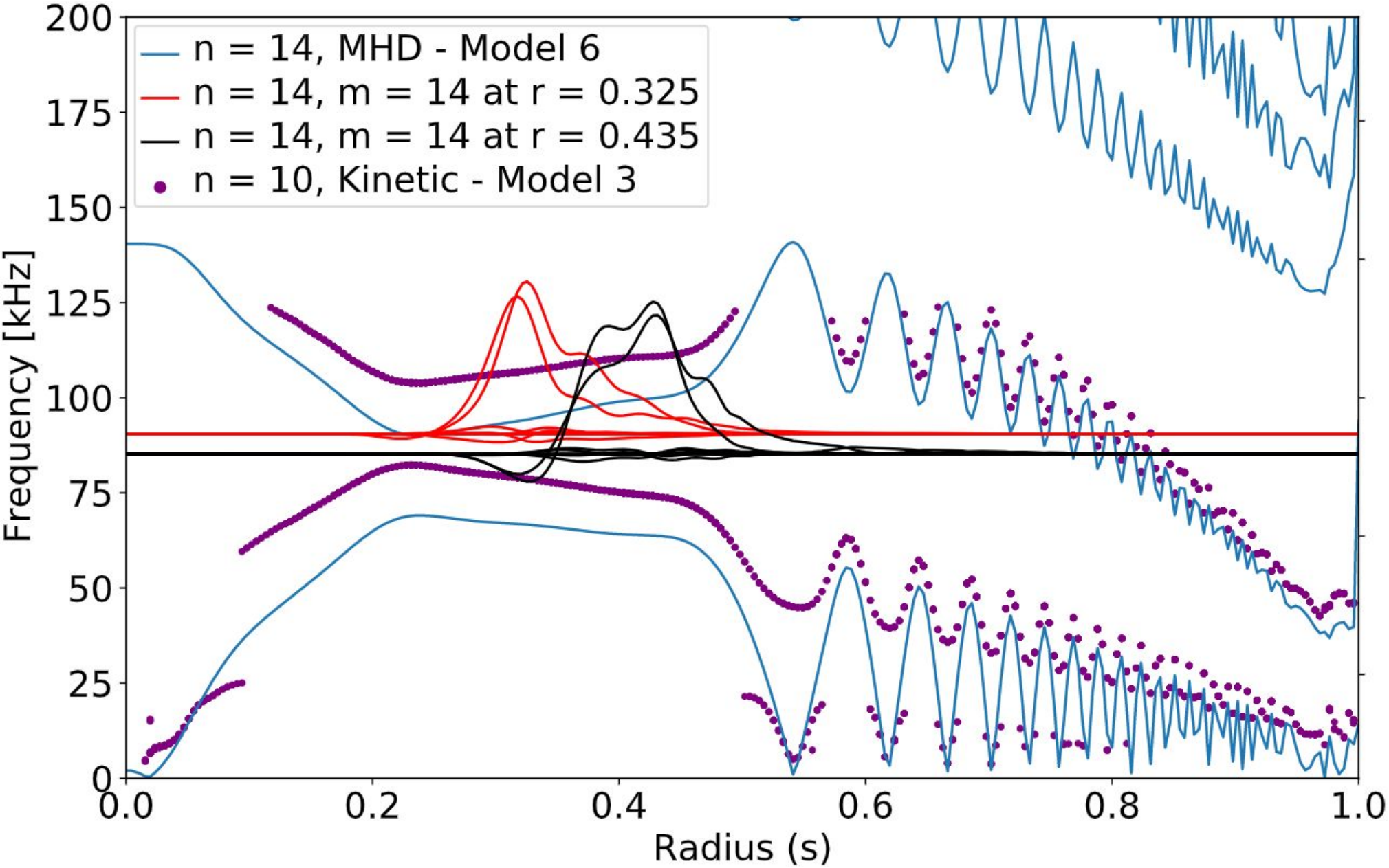
# Scenario 1: ASTRA - 131025/34 ITER DB - model 5



# Model 6 + comparison between model 5-4-1

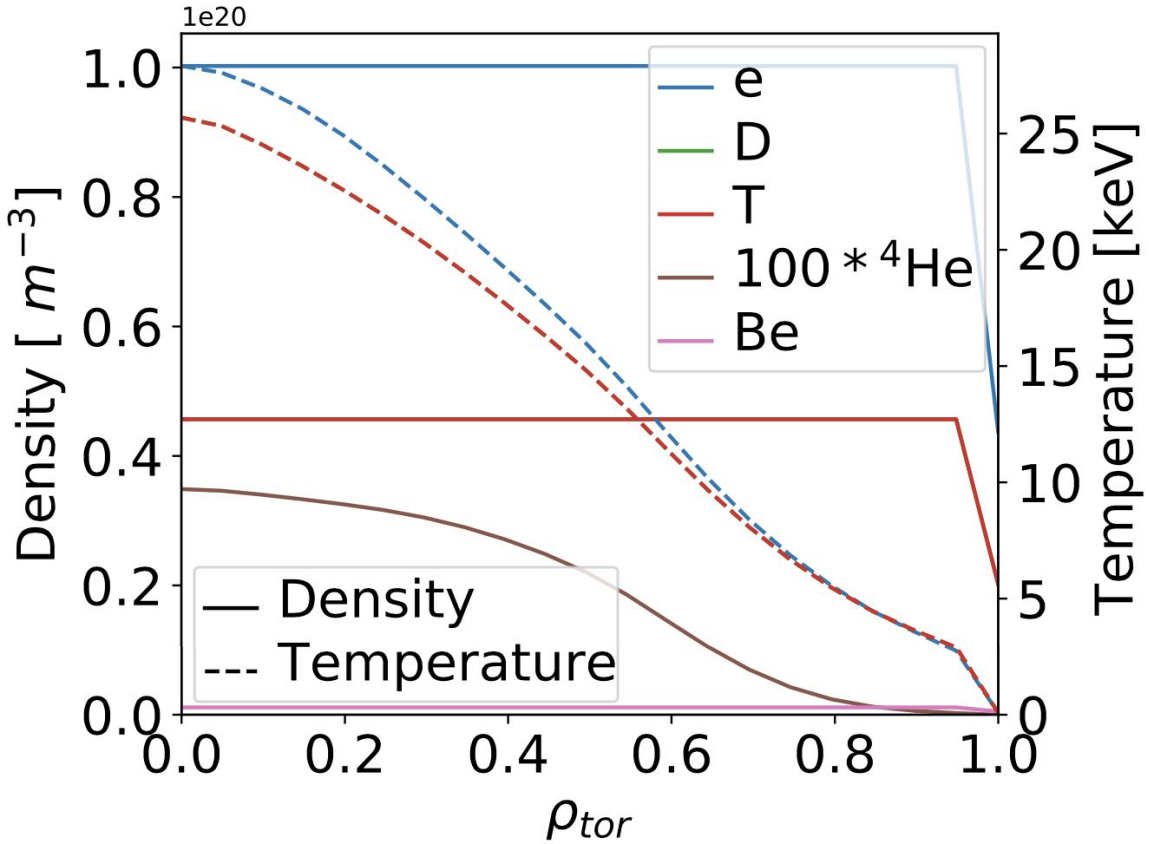


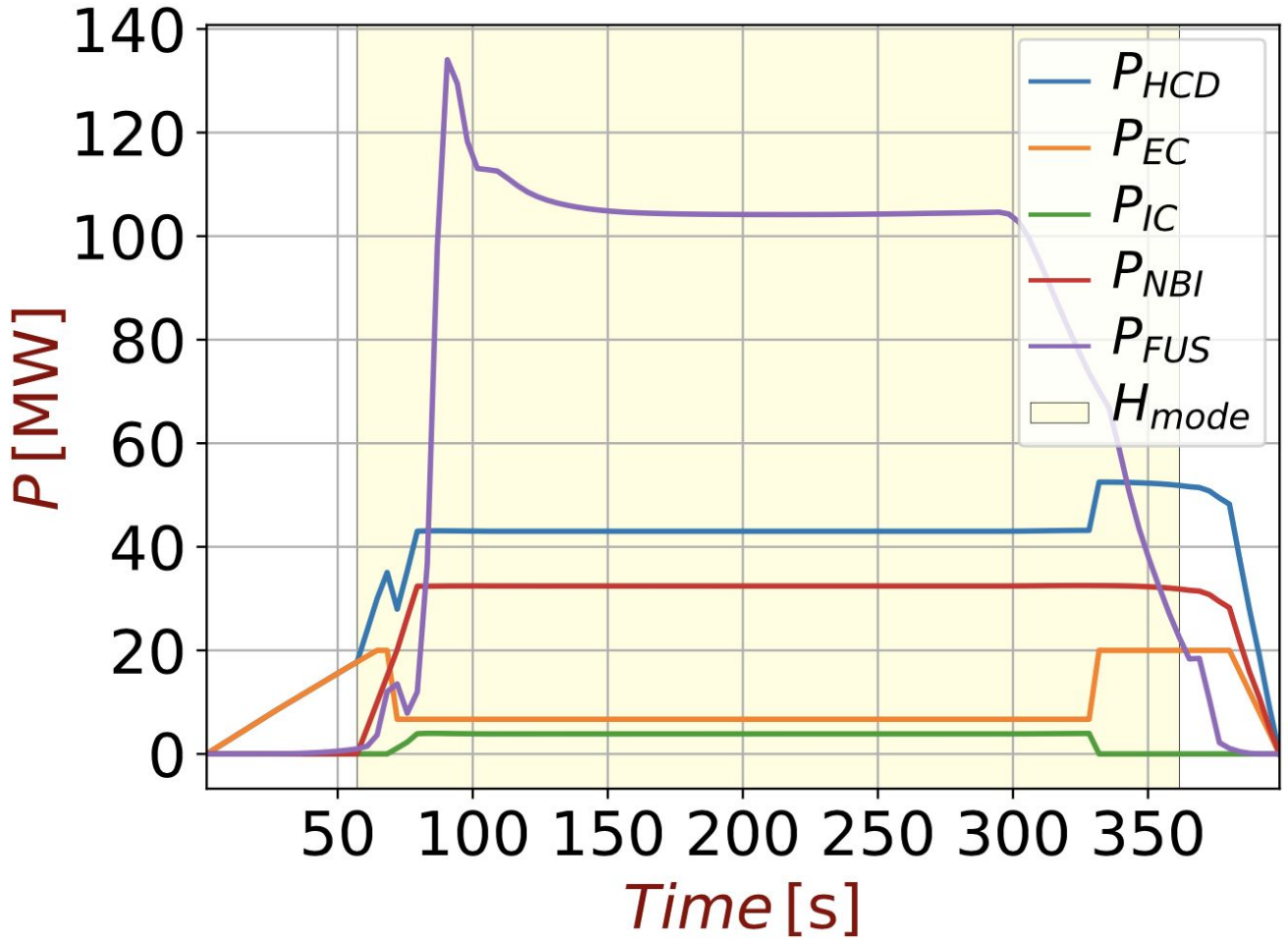
# Model 6 + 3 + model 1 global EFs.



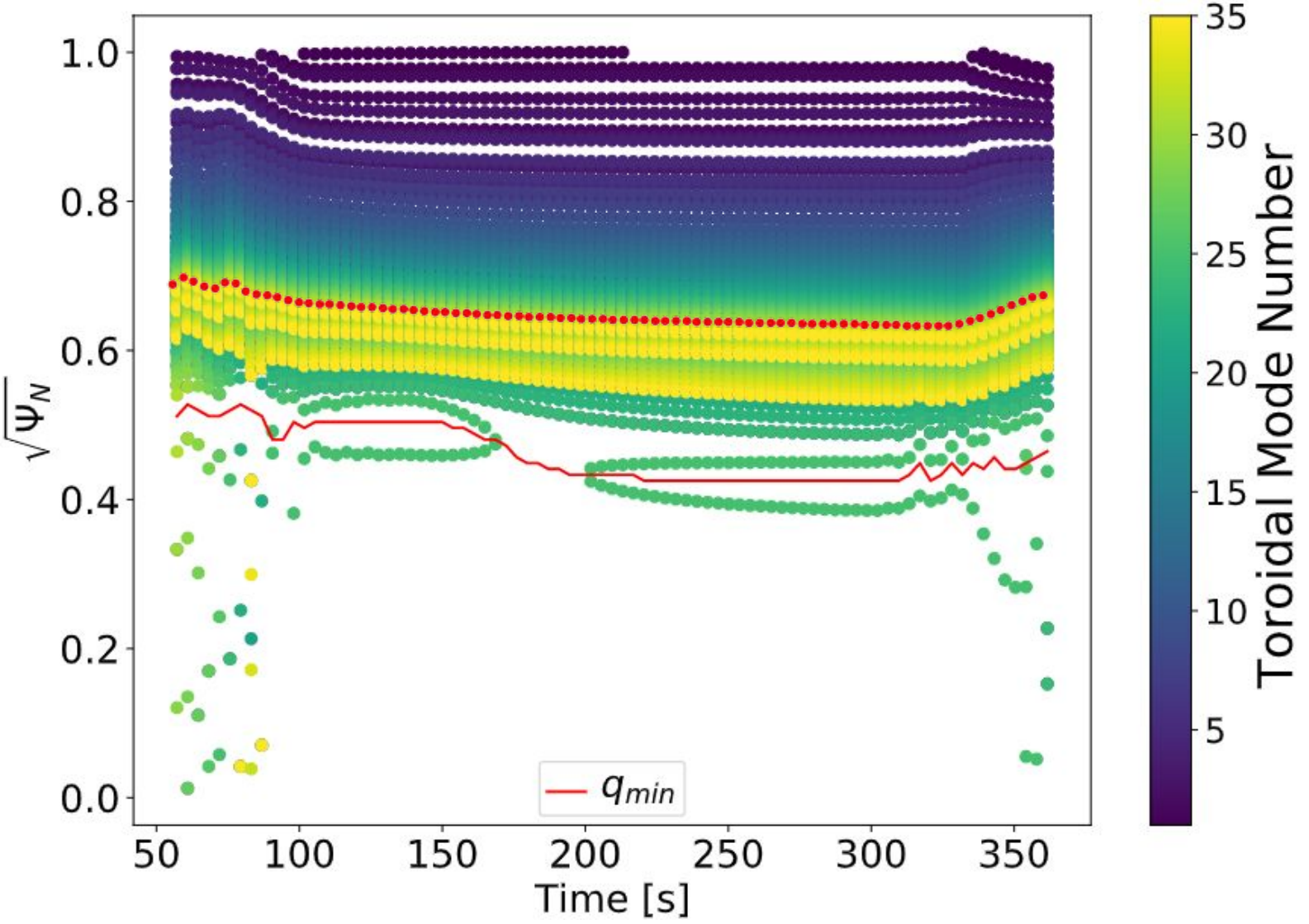
# Scenario: METIS time-dependant Q=10 ITER baseline

- D-T plasma, Q = 10, 15 MA
- Peak axis $T_{e,0} \cong 27$ keV, 4 keV pedestal top
- $T_{D/T,0} \cong 25$ keV
- $n_{e,0} \cong 10^{20} m^{-3}$, $n_{D/T,0} \cong 0.45 \times 10^{20}\ m^{-3}$



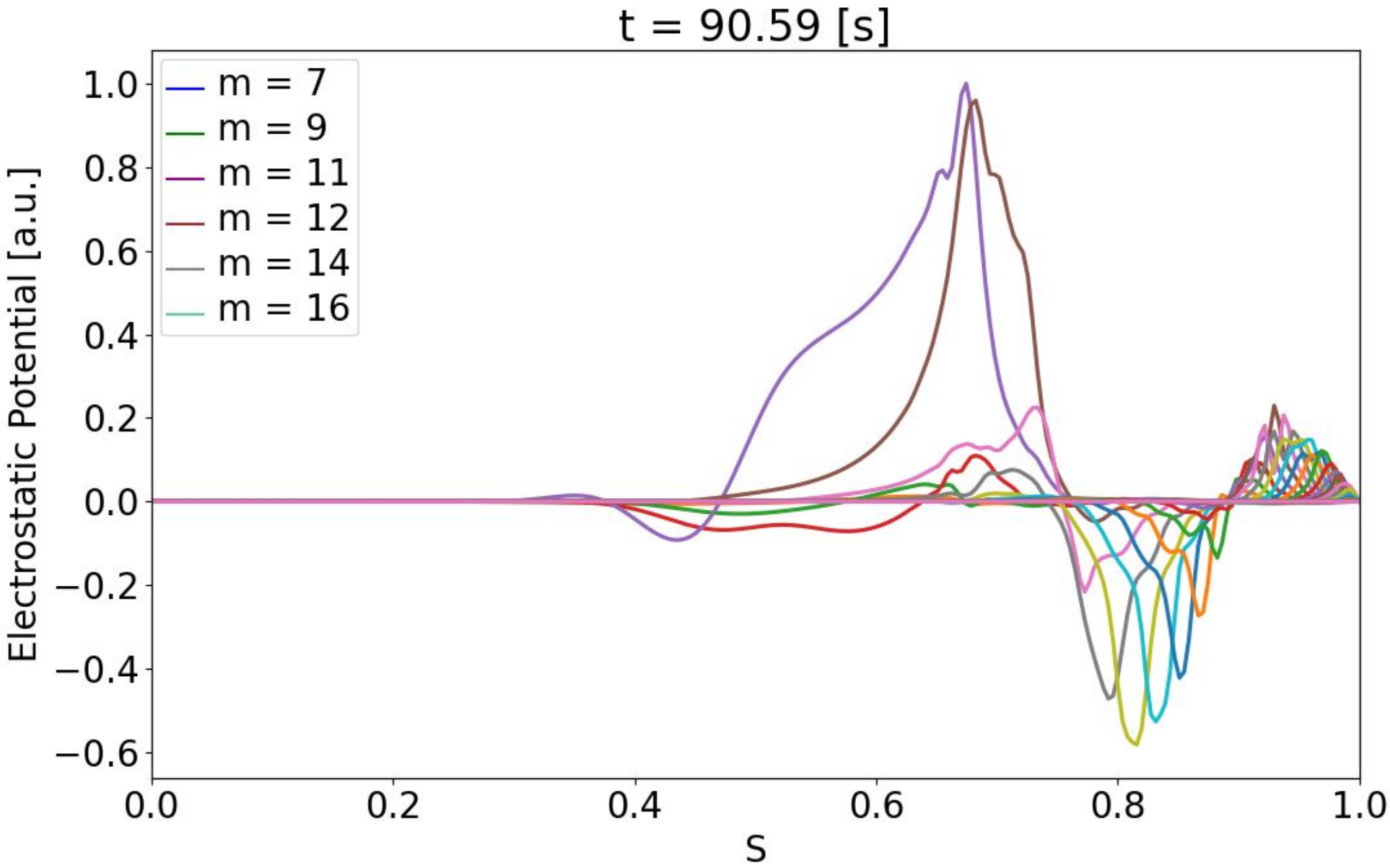



# Results: Scan over the entire Radial/Temporal domain

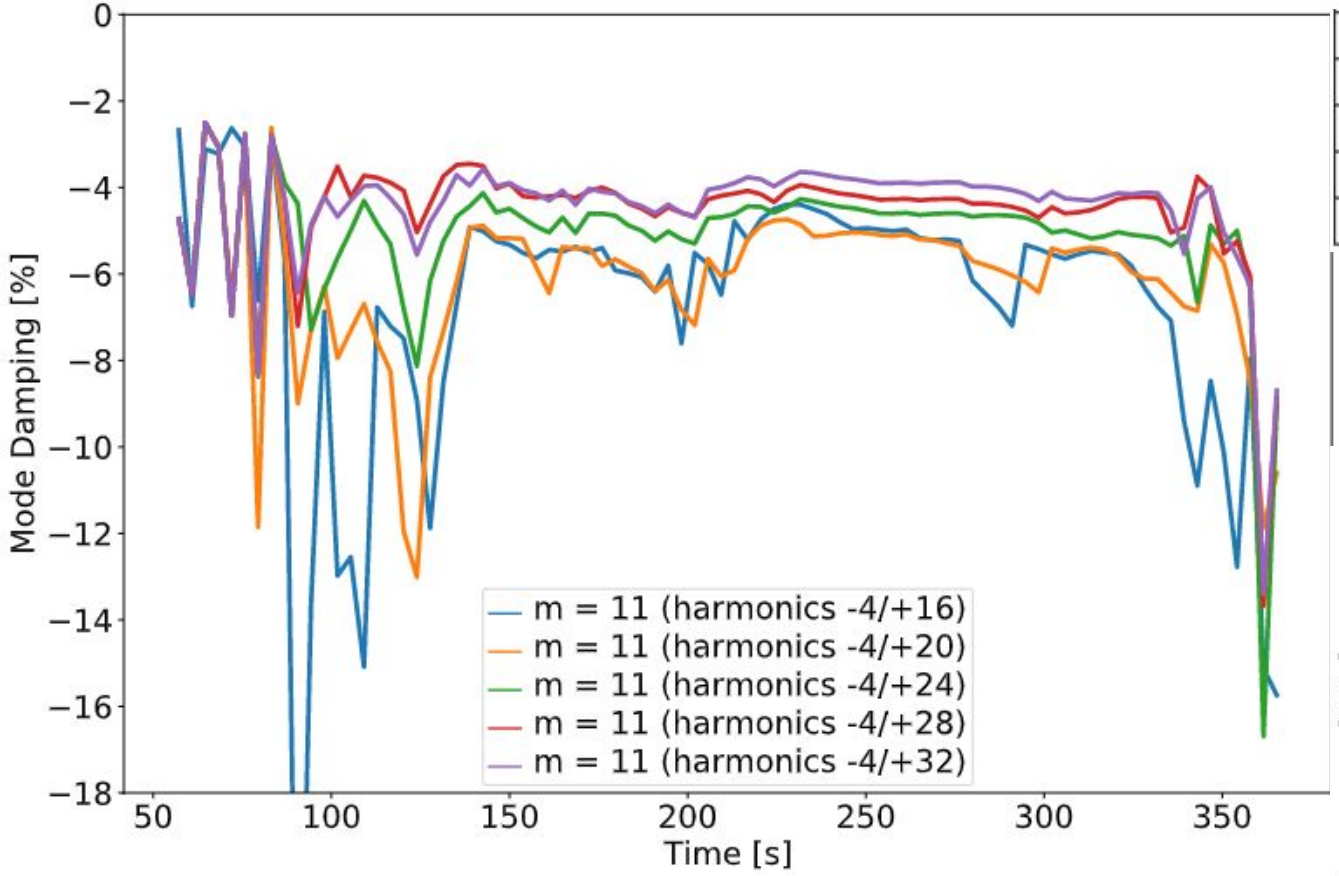



- n = 1…35
- m = n + 1…m = n + 5
- 12014 total number of modes, 137/time-point
- With red n = 10, m = 11 mode
- Slightly inverted q-profile around s = 0.5 leads to two different TAE branches with the same mode numbers.
- After 90s no more TAEs are found in the core, due to small magnetic shear in the core assumed by the METIS-given equilibrium.

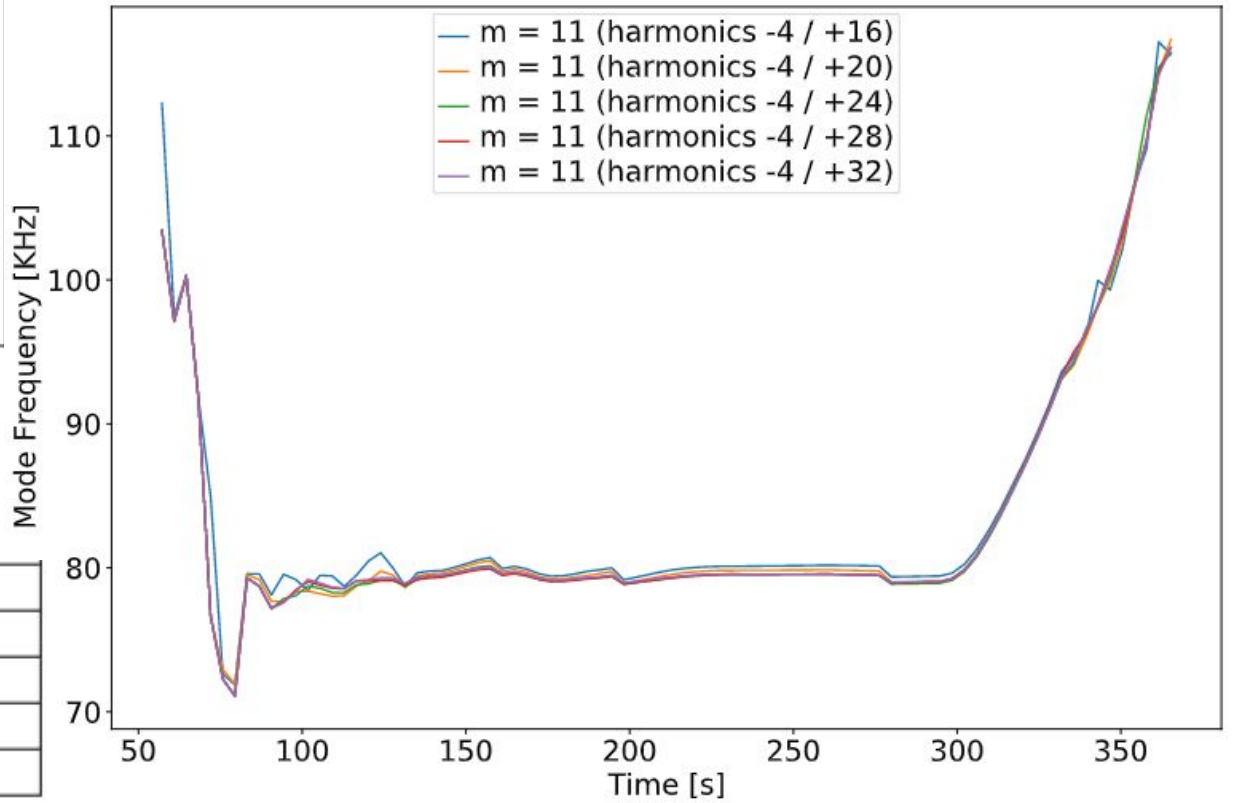
# Results: TAE n = 10, m = (11,12) global mode structure



# Results: Convergence test (n = 10)

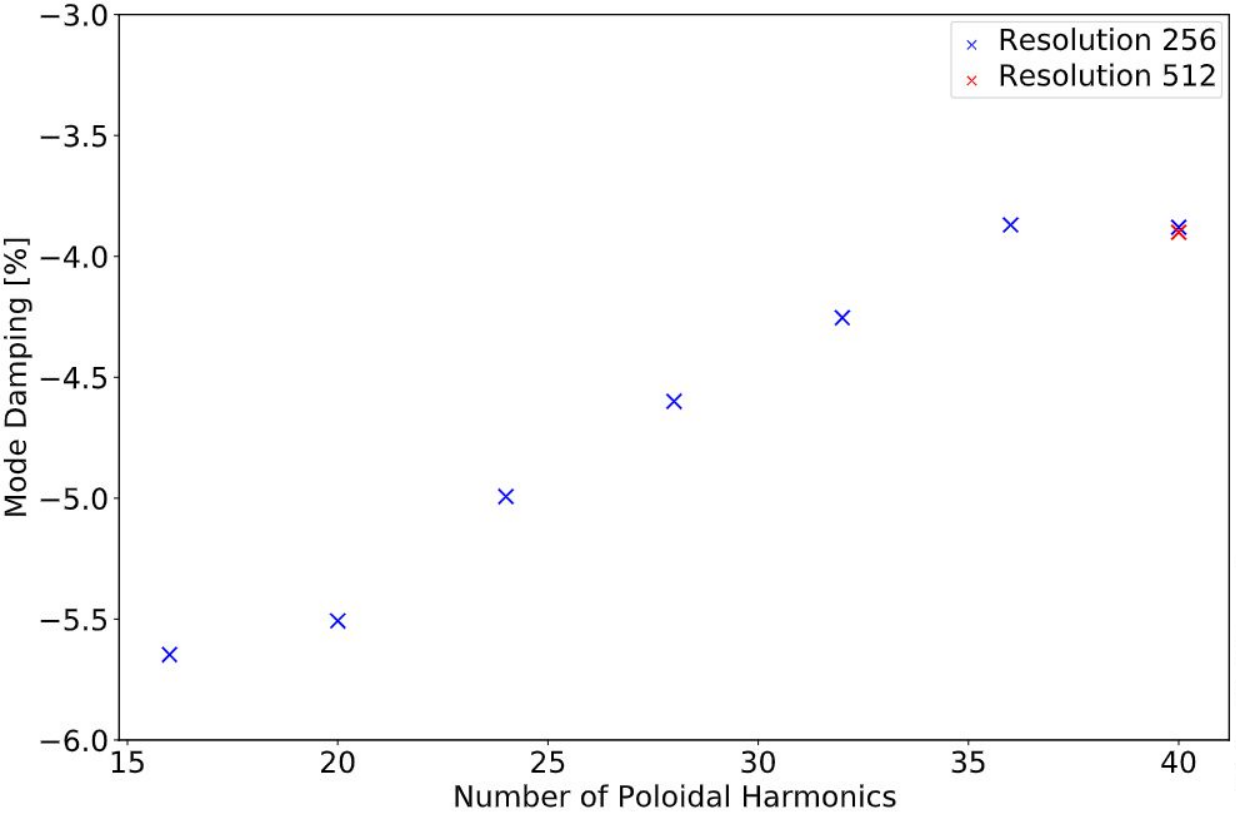


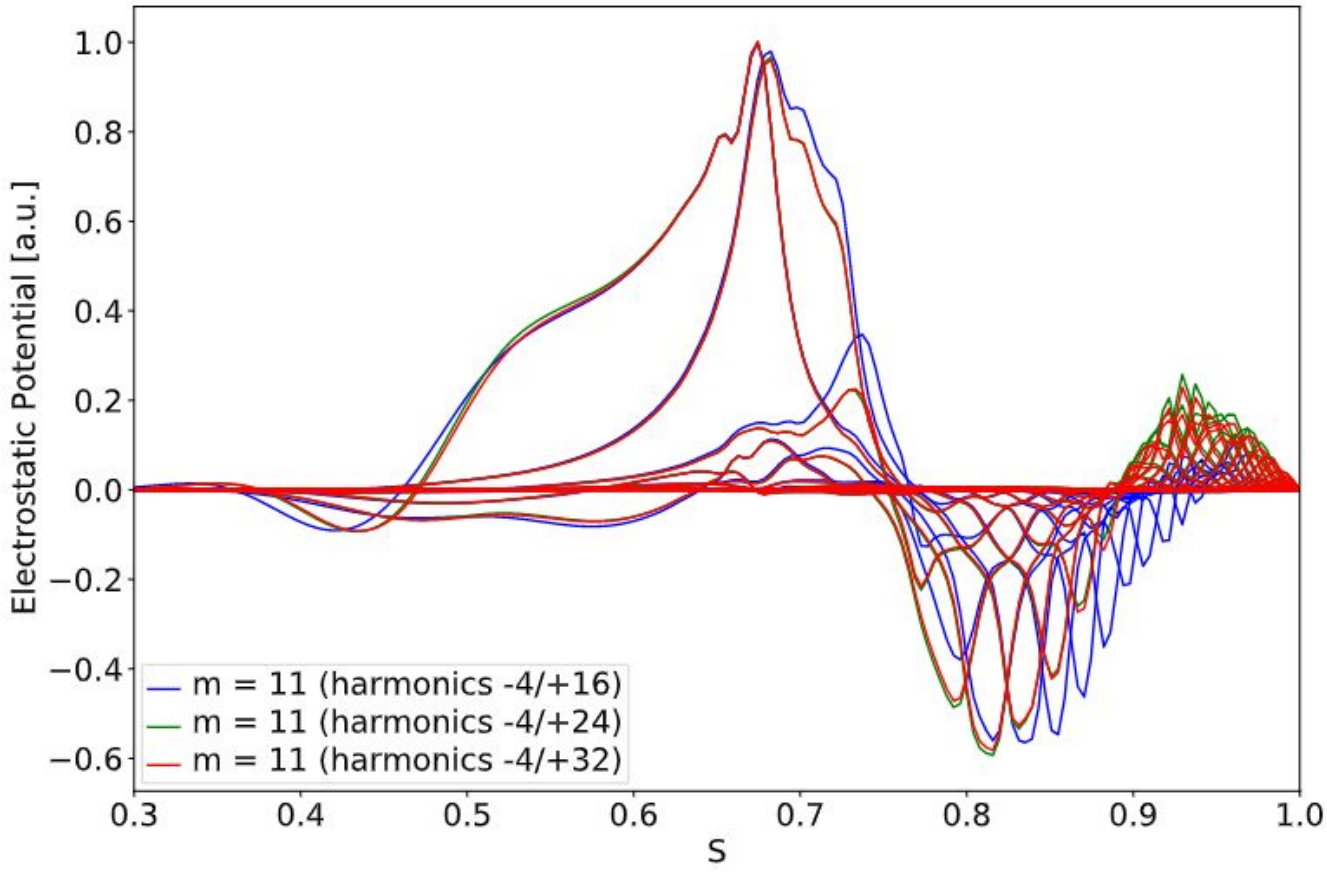

| | | | | |
|---|---|---|---|---|
| METIS | local scan | 106 | 12014 | 1 |
| METIS | local + global (-4/+16) | 106 | 1 | local = 1, global = 8 |
| METIS | local + global (-4/+20) | 106 | 1 | local = 1, global = 8 |
| METIS | local + global (-4/+28) | 106 | 1 | local = 1, global = 8 |
| METIS | local + global (-4/+32) | 106 | 1 | local = 1, global = 8 |




| | | | | |
|---|---|---|---|---|
| METIS | local scan | 01:00:24 | 00:00:34 | <1s |
| METIS | local + global (-4/+16) | 04:36:41 | 00:02:36 | - |
| METIS | local + global (-4/+20) | 06:20:02 | 00:03:35 | - |
| METIS | local + global (-4/+28) | 10:31:06 | 00:05:56 | - |
| METIS | local + global (-4/+32) | 13:00:35 | 00:07:23 | - |

# Results: Convergence test - mode structure/extra points



# Results: EP influence on TAE, n = 10 mode