PRINCETON PLASMA PHYSICS LABORATORY

Feasibility of MHD stability analysis in time-dependent simulations and applications to scenario design

presented by Francesca M. Poli

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Many thanks to

J. Breslau, M. Podestà (PPPL), D. Spong, Y. Ghai (ORNL), M. A. Van Zeeland (General Atomics),
L. Garcia, J. Varela (Univ. Carlos III, Madrid)
the FAR3D team, the ISEP project and the TRANSP team

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Outline

- Why are we doing this?
- How are we doing this?
- Do we see what we expect to see?
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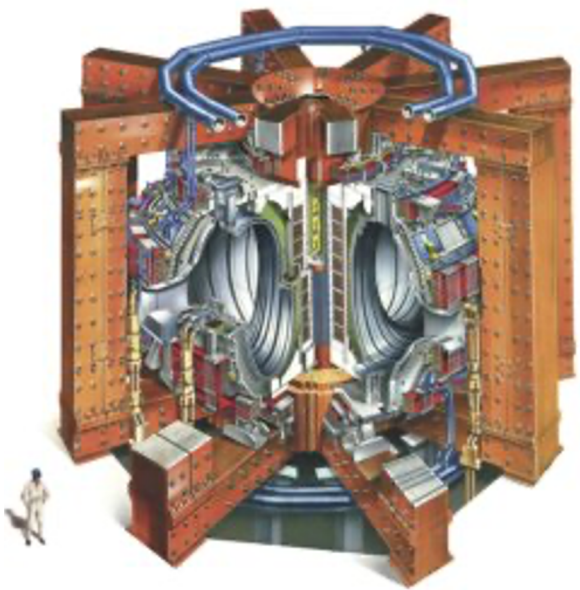
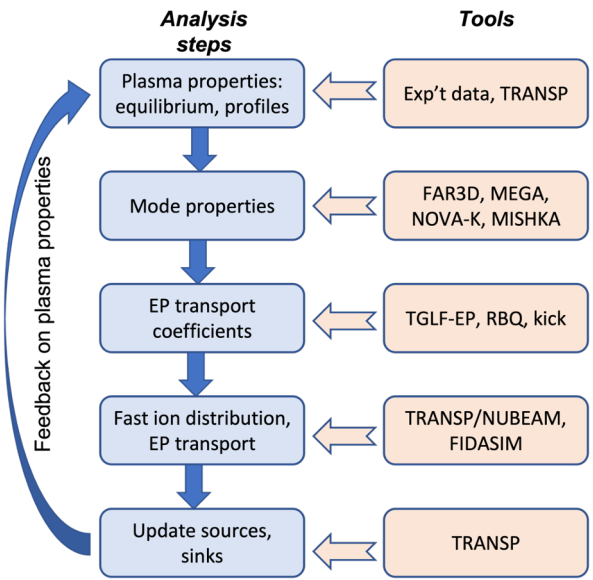
Self-consistent EP transport calculations critical for scenario optimization and control (ITER and beyond)

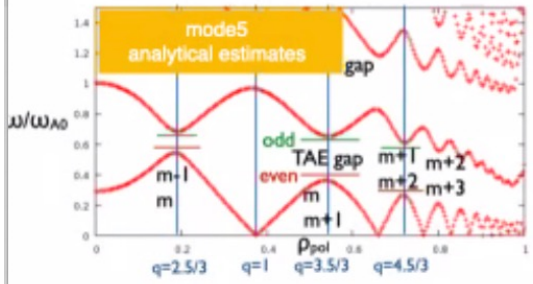


How can discharge parameters be optimized based on mission goals?

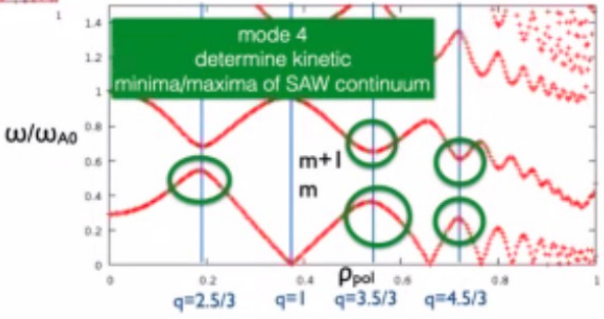
Do experimental results agree with model's predictions? E.g. EP transport, losses

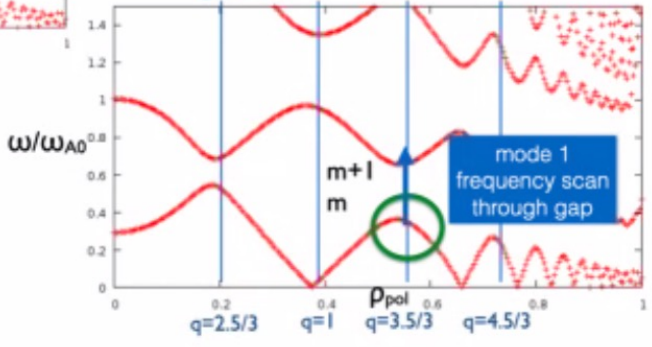


combination of models lead to a staged approach for automated analysis



Example: ITER/IMAS workflow
Slide courtesy of P. Lauber
Work presented at ITPA-EP fall meeting (2021), by P. Lauber
Also talk by T. Hayward-Schneider on Monday





mode5:
- [Fesenyuk 2014]
- [S.D. Pinches et al PPCF 2015)]
- suggestions for useful formulae can be easily implemented, e.g. trapped el. coll. damping [Gorelenkov]

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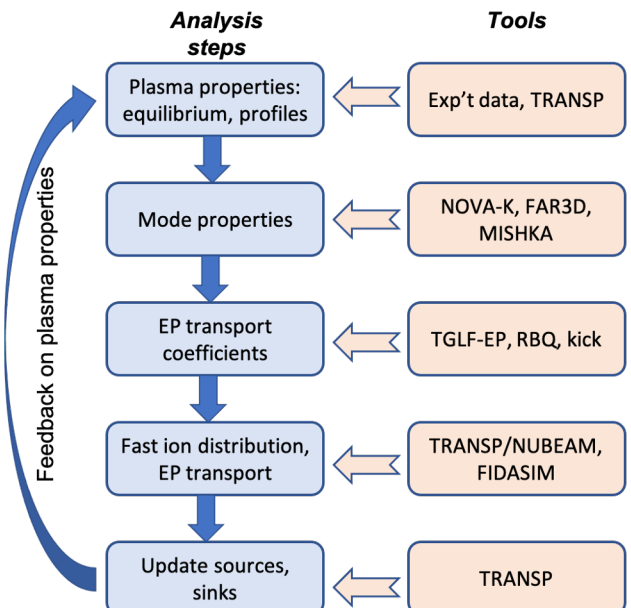
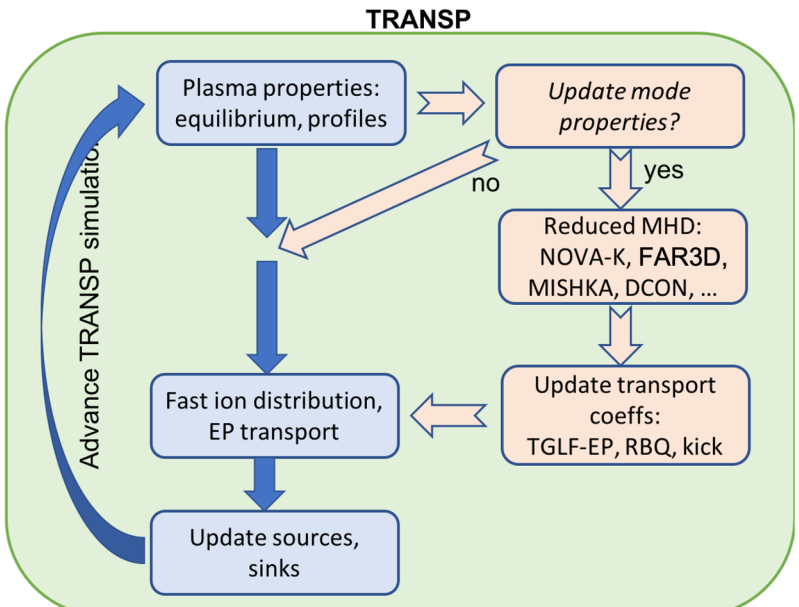
Apply EP transport models in time-dependent integrated simulations => path for scenario optimization

Combine scenario development, interpretation of exp't data and EP modeling

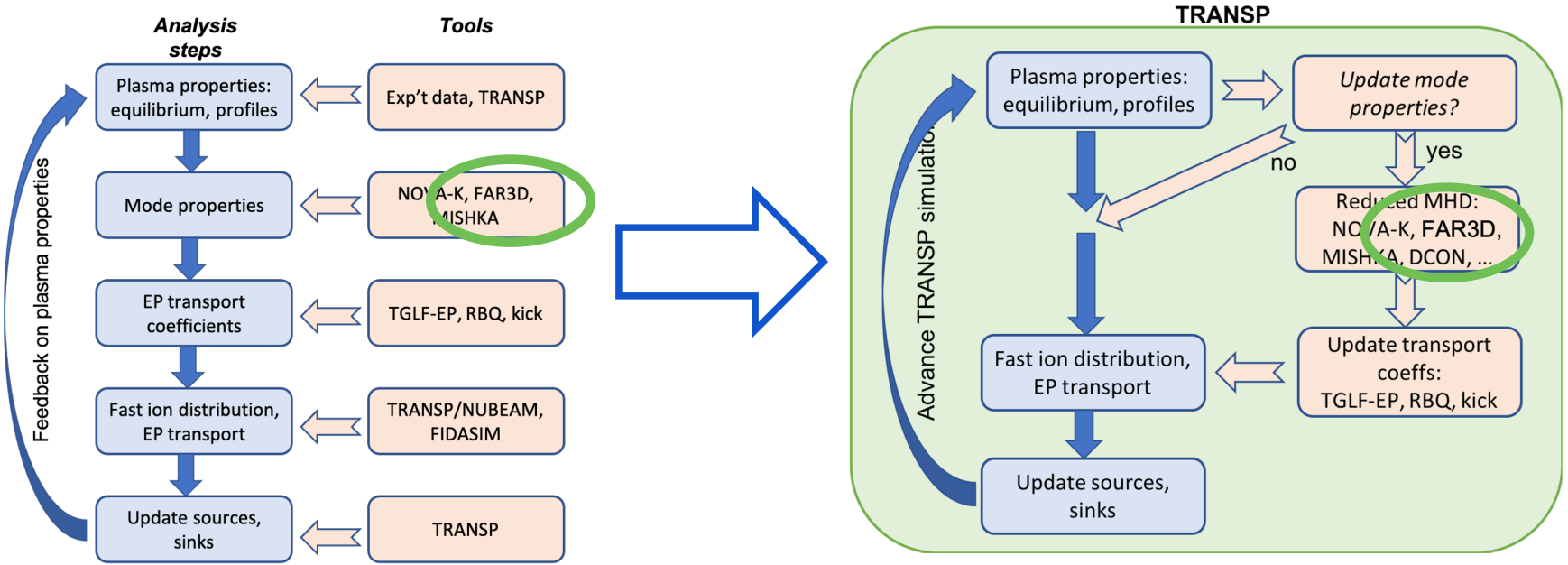
Add transport loop to previous work by ITER/IMAS/IPP team => enables use of multiple tools





Apply EP transport models in time-dependent integrated simulations => path for scenario optimization

Take a first step by implementing in TRANSP stability calculations currently done offline and in a loop.



Running an MHD stability code in a time-dependent simulation has its own challenges

- You cannot tweak on the fly equilibrium, profiles, parameters
  - Time-dependent solvers use coarse grids (larger error in Grad-Shafranov solution)
  - Stability codes usually need more refined magnetic equilibrium mapping
    - Need balance between robust stability and fast calculations
  - Measured spectra are the result of the “real world plasma”
    - Experimental uncertainties in the equilibrium reconstruction
    - Experimental uncertainties in the kinetic profile mapping
  - Simulated spectra are the result of the “plasma model”
    - Limits and assumptions in the stability calculaitons
    - Approximations and assumptions in the neutral beam model
    - Experimental uncertainties in the input profiles

⇒ Should not expect to reproduce the experimental spectrogram

Our case study tests the feasibility of TRANSP/FAR3D

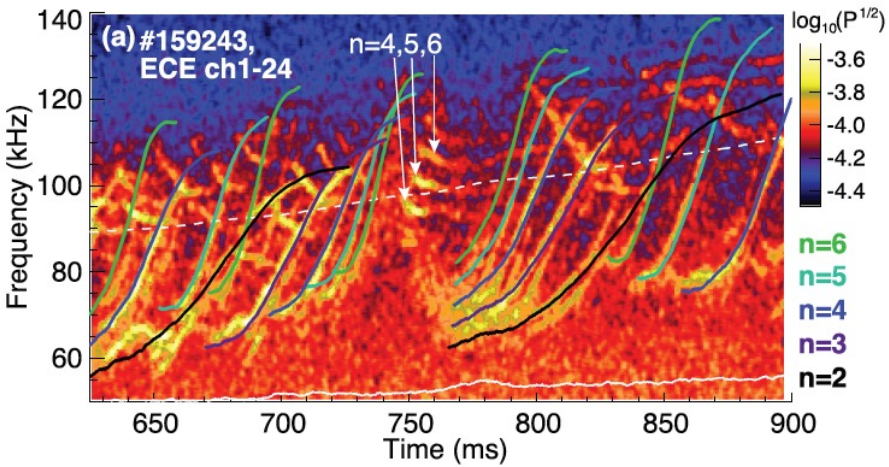
- FAR3d is a gyro-Landau fluid model used for energetic particle instabilities in tokamaks and stellarators.
- In initial value mode, it iteratively searches a provided equilibrium for unstable Alfvén eigenmodes at specified toroidal mode numbers, returning growth rates and real frequencies.
- In eigensolver mode, it computes the mode structures of unstable eigenmodes.

[see talks by Yashika Ghai and Donald Spong]

Use a discharge widely studies by the EP community and used for benchmarking of codes within ISEP

- L-mode current ramp-up scenario.
- Previously used for ISEP benchmark.
- Search for unstable TAE and RSAE modes with n=3.

*S. Taimourzadeh, et al., Nucl. Fusion **59** 066006 (2019).*

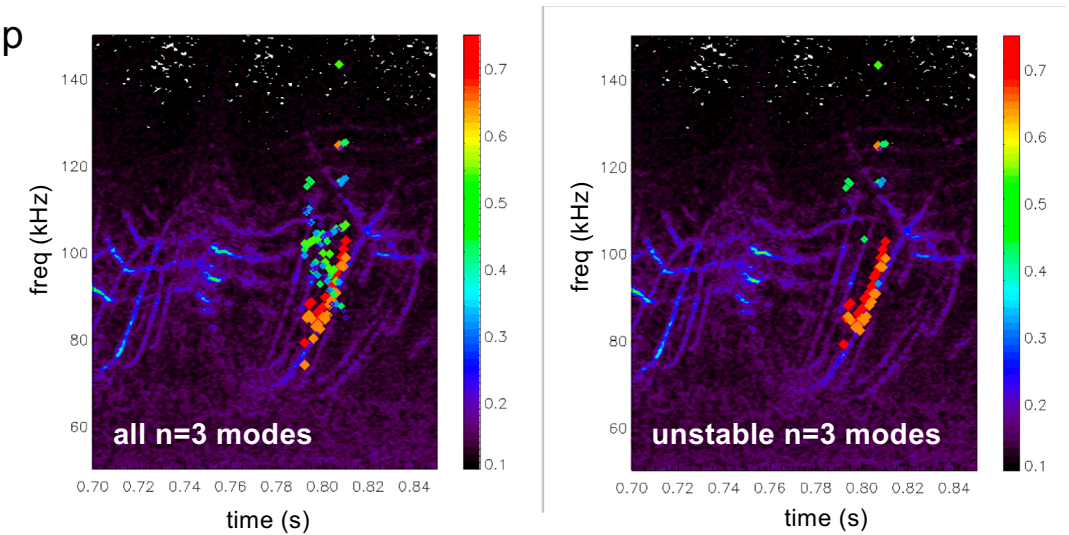


The parameters chosen for the previous benchmarking still work in a reduced time window

- TRANSP/FAR3D interface
  - Runs FAR3D @ each time step
  - automatic selection of m/n
- Working with ORNL on
  - IMAS compatibility (ITER)
- Capabilities are under test
  - Not available to users yet

DIII-D #159243, SciDAC-EP validation case [Taimourzadeh, NF 2019]

Turn on FAR3D in TRANSP for 0.79-0.81 s, look for most unstable n=3 modes



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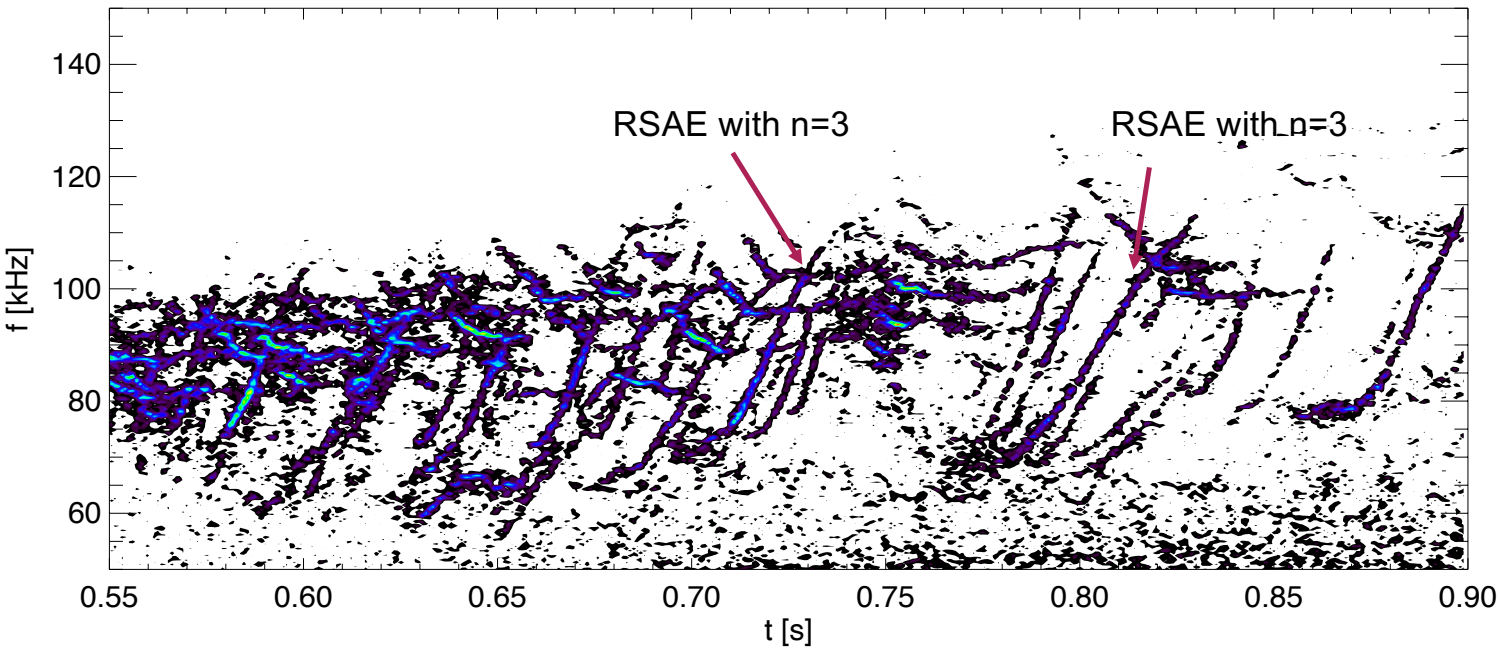
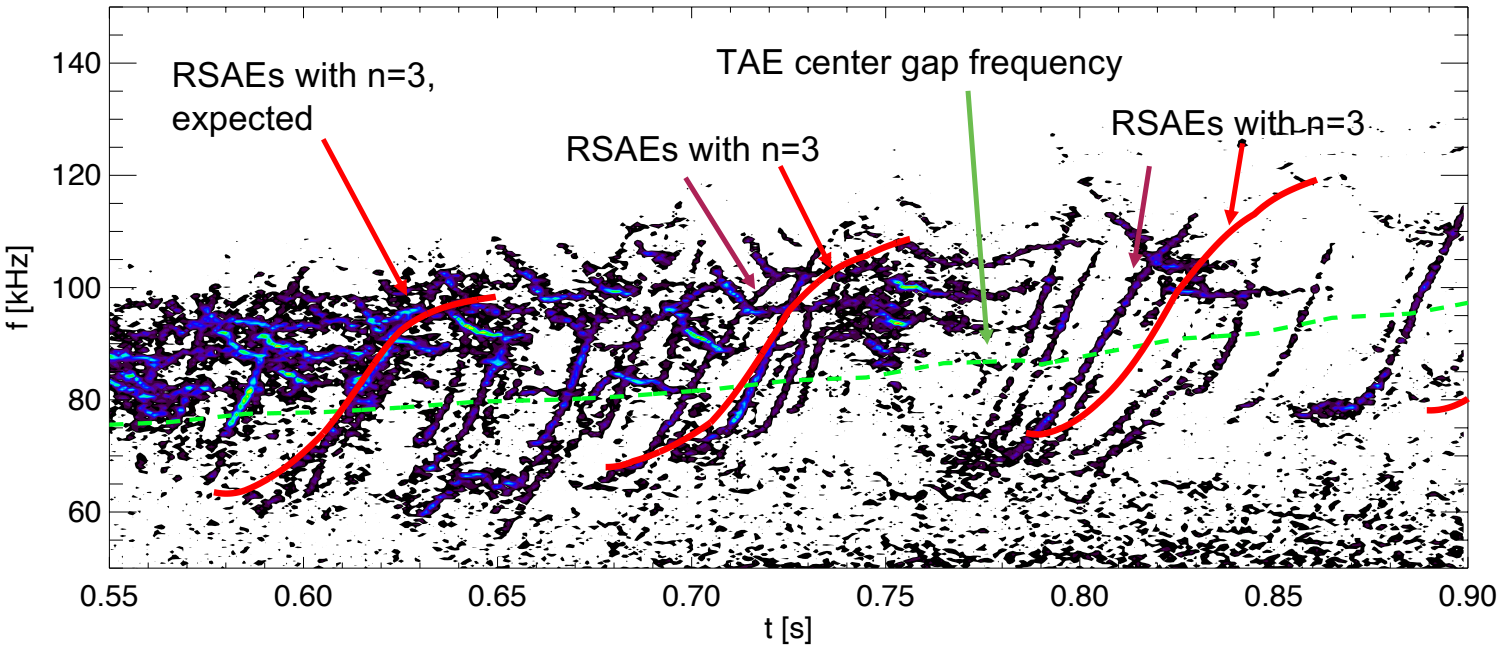
We focus on RSAEs with n=3 (well known dependence on q)

*[M.A. van Zeeland, Nucl. Fusion **56** (2016) 112007]*

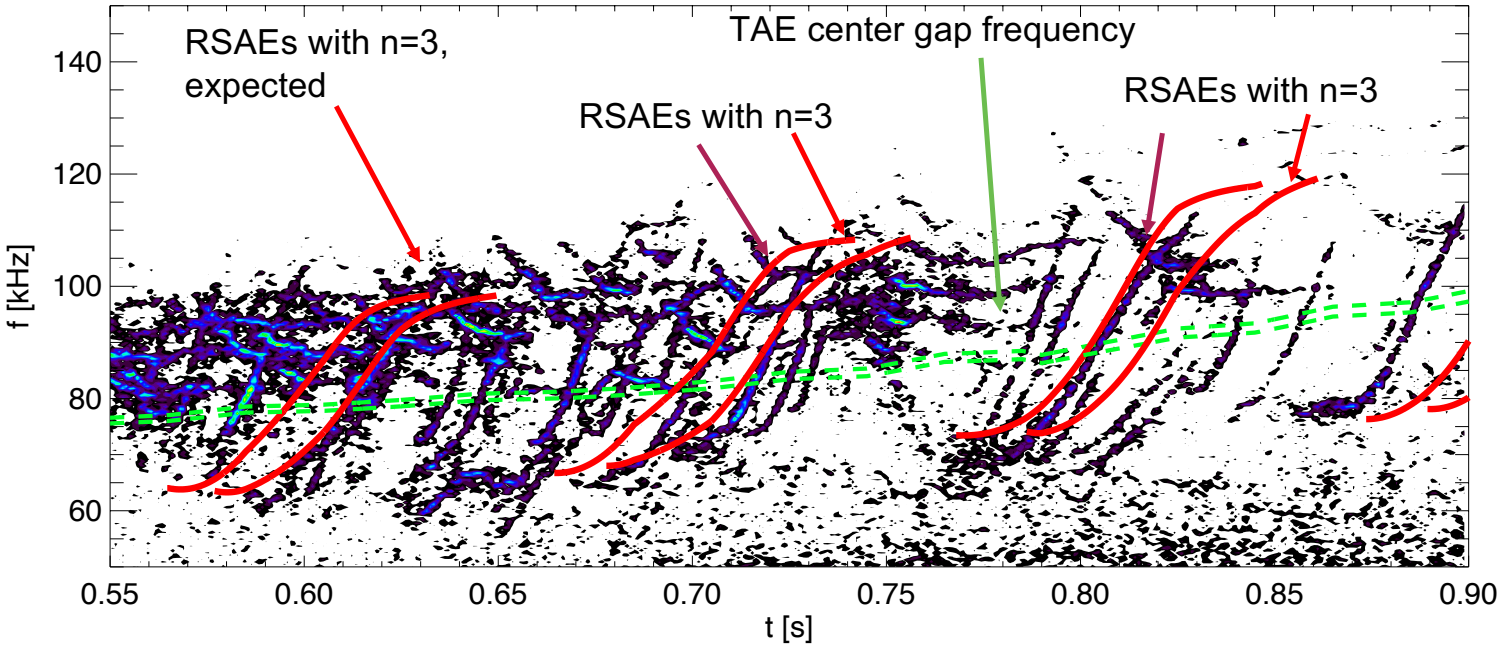


RSAEs could be used to provide a very precise reconstruction of the safety factor profile

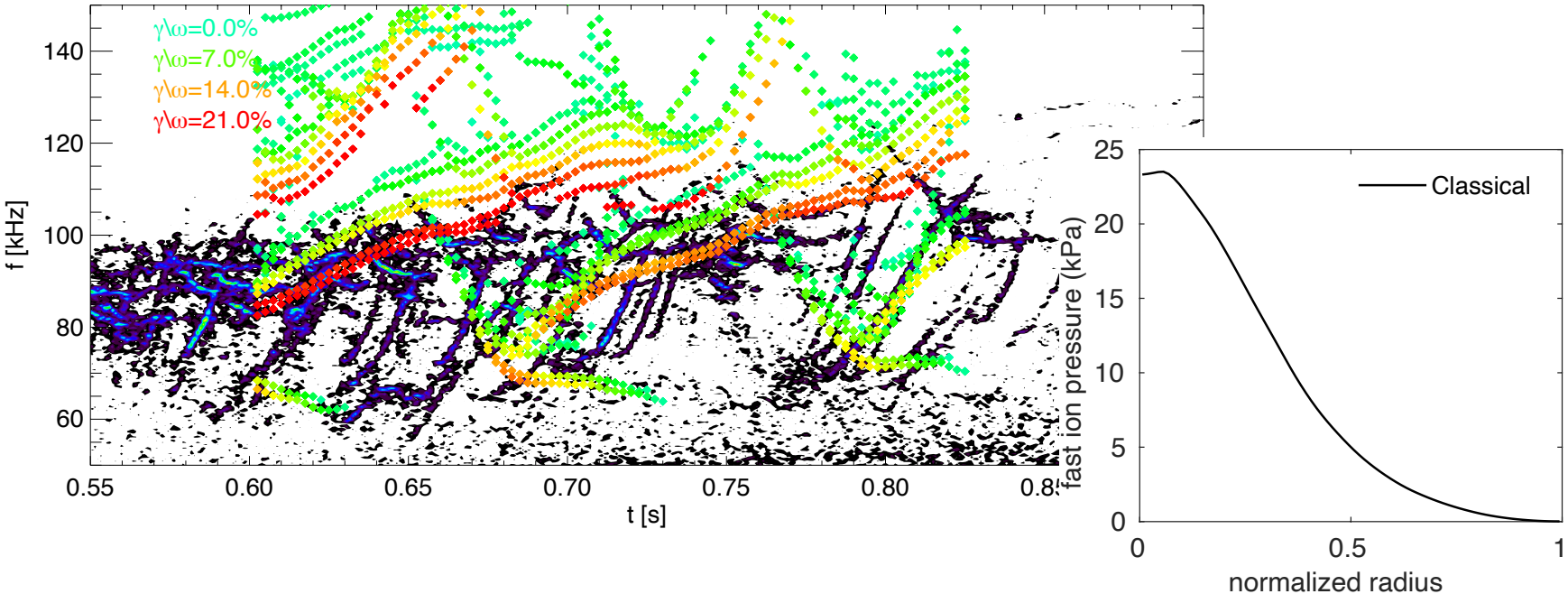
Based on TRANSP (input) profiles, there is a time shift between the expected and the measured n=3 RSAEs



A rigid downshift of only 0.05 on the q profile can substantially modify the expected frequency evolution

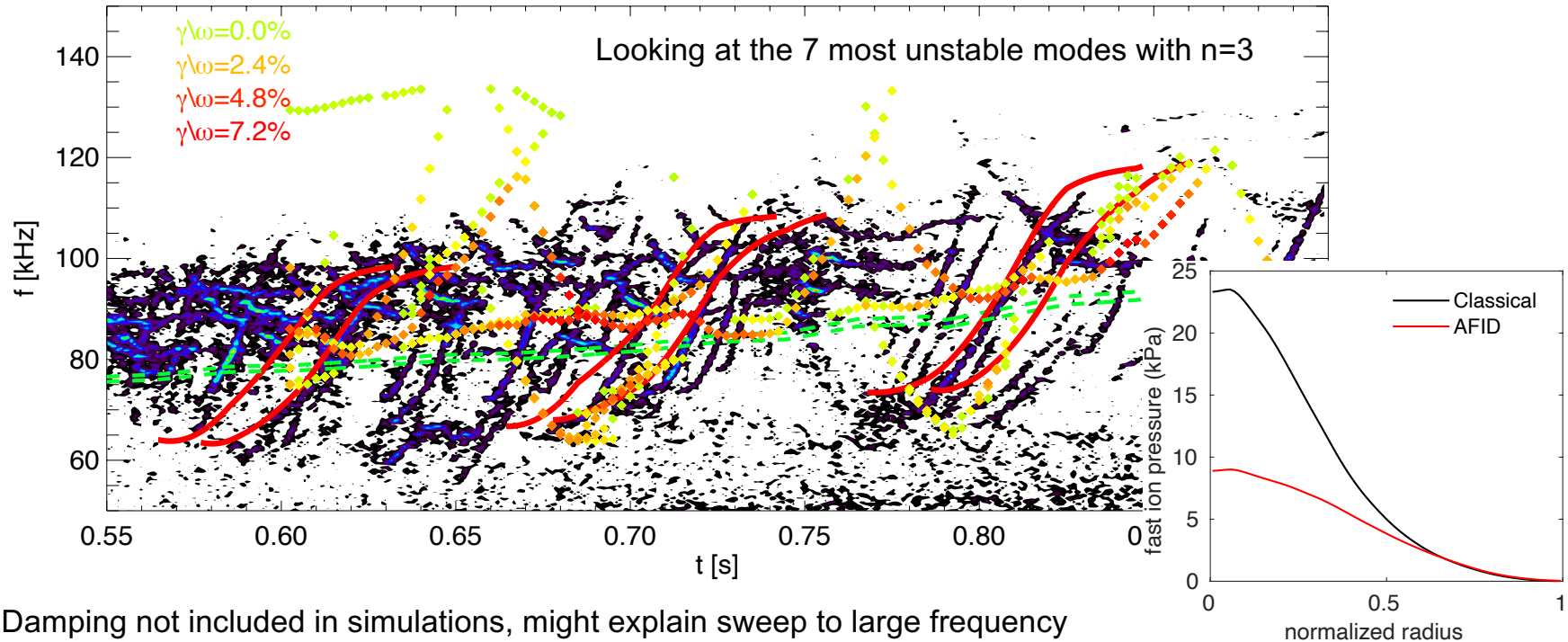


Unphysical growth rate obtained when a classical model for fast ion transport is assumed



Looking at the 7 most unstable modes with n=3

More realistic results obtained when fast ion transport is artificially increased by matching simulated/measured neutron rate in TRANSP



Damping not included in simulations, might explain sweep to large frequency

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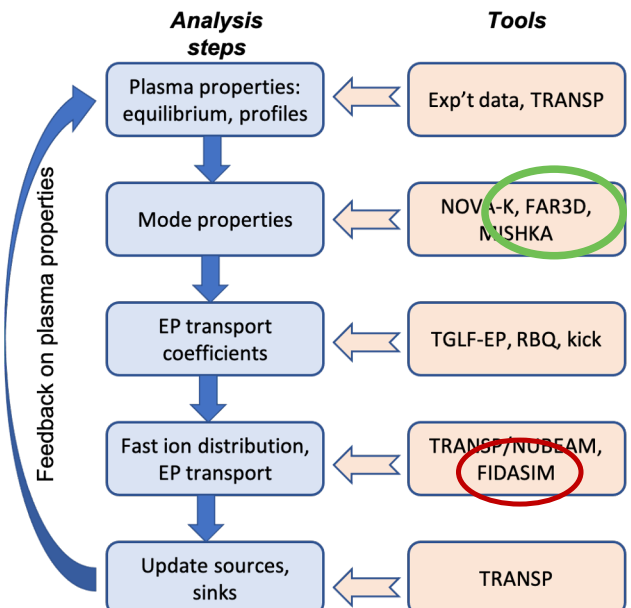
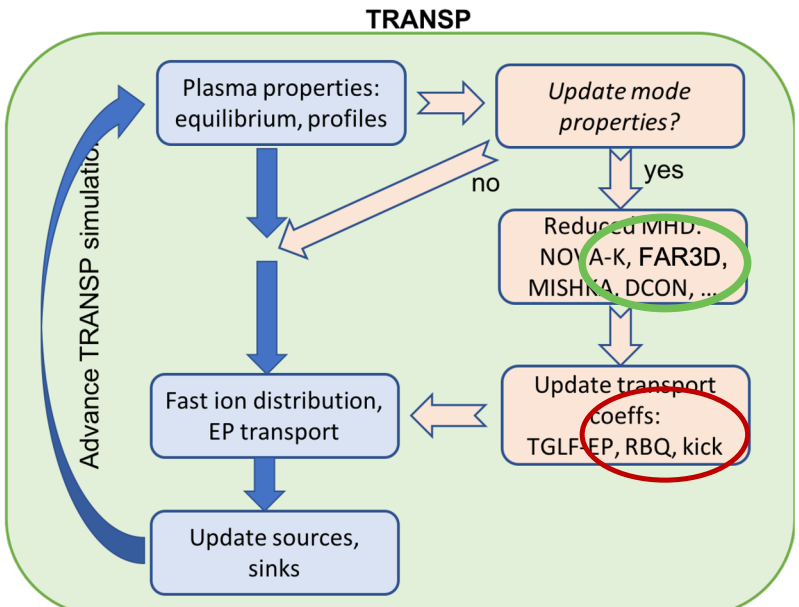
Close the loop with transport and with diagnostics, to improve/constrain simulations

Spectroscopic measurements to provide constraints on magnetic equilibrium reconstruction, rotation and beam model

FIDASIM for constraints on beam model





Summary and outlook

- AE stability module being implemented in TRANSP
  - In-line calls to FAR3d code to infer properties of unstable AEs
  - Reasonable results from initial tests with n=3 RSAE for DIII-D #159243

- Initial tests promising, but much more work to do!
  - Using reduced set of damping terms in FAR3d for initial tests
  - Plan to improve initial guess for frequencies of interest
  - Need to implements “selection rules” to down-select AEs for transport models
  - Need to interface *reduced* transport model for in-line simulations in TRANSP
    - FAR3d (transport), kick, RBQ, …

Input and help from the EP community is more than welcome!