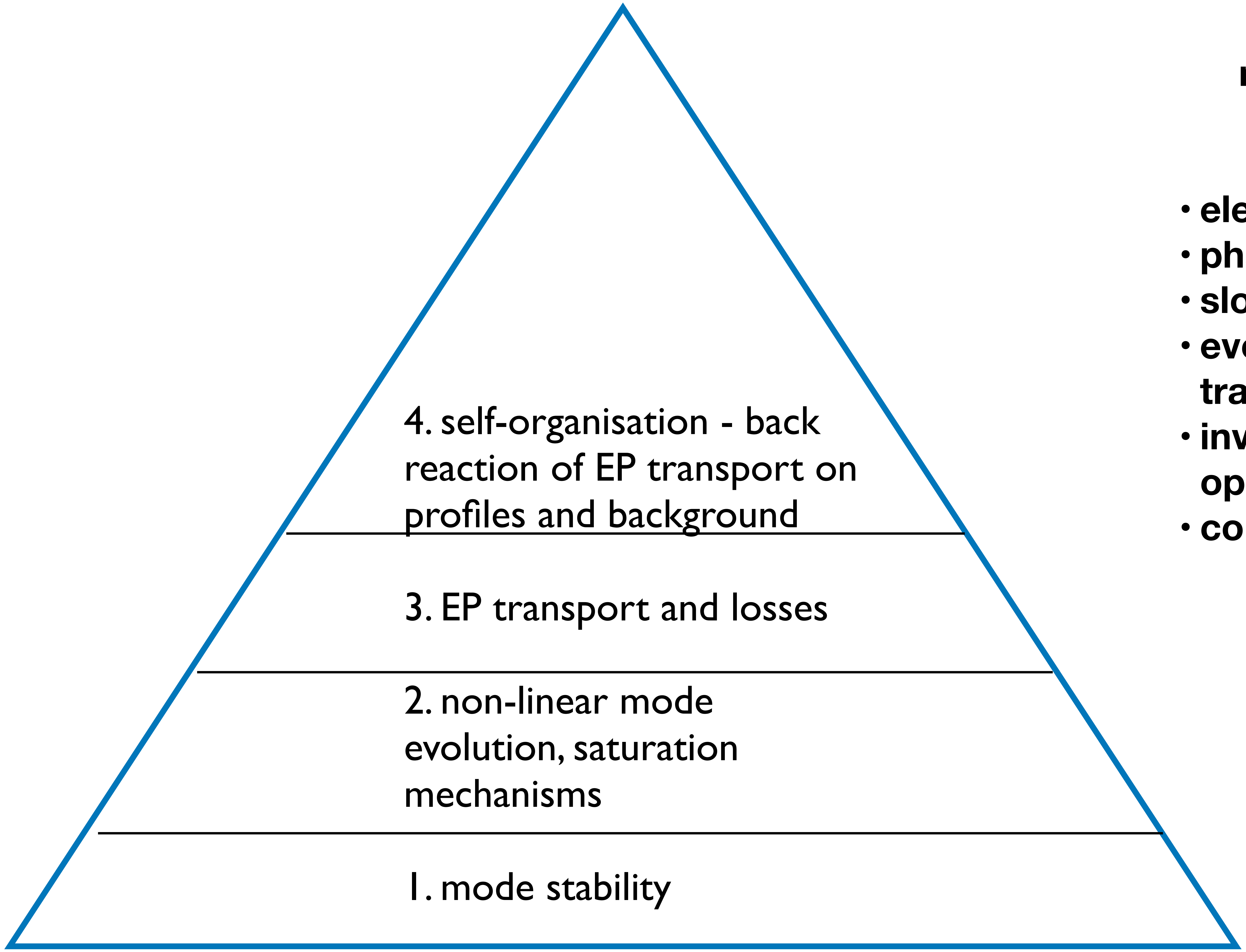
Update on ITER modelling using the EP-Stability WF and the ATEP code

Ph. Lauber acknowledgements: ATEP ENR team, TSVV#10 team, C. Bourdelle

ENR ATEP: https://wiki.euro-fusion.org/wiki/Project_No10

https://indico.euro-fusion.org/category/309/

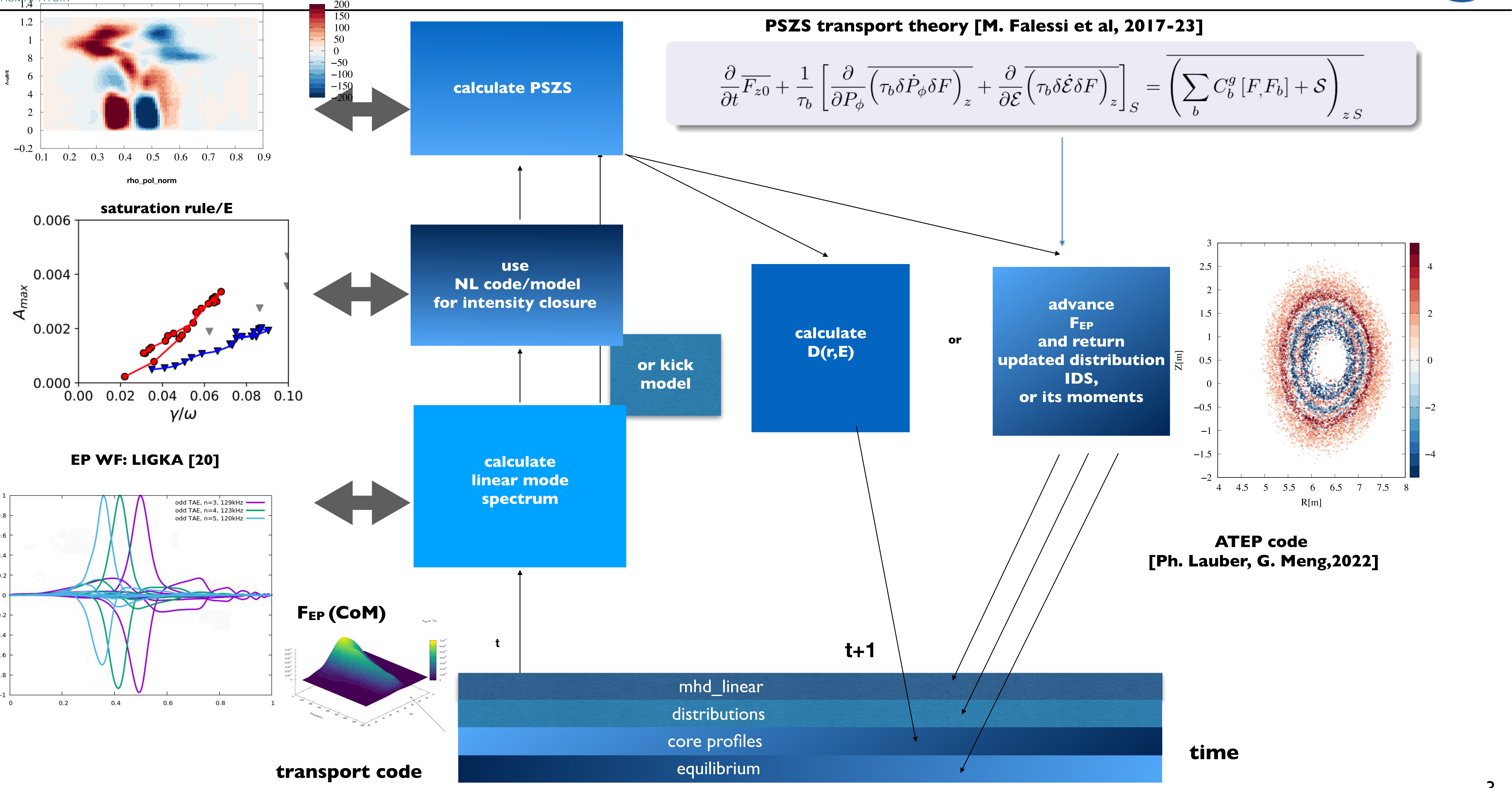
towards DEMO plasmas



needed to assess EP transport aspects in burning plasmas:

- **electromagnetic global gyro-kinetics**
- **phase-space resolved**
- **slowing down time scales**
- **evolve non-linear equilibrium, as F_{EP} can be - at least transiently - far from neoclassical state**
- **investigate ramp-up - how can we reach the envisaged operating point?**
- **consistent reduced/fast models needed**

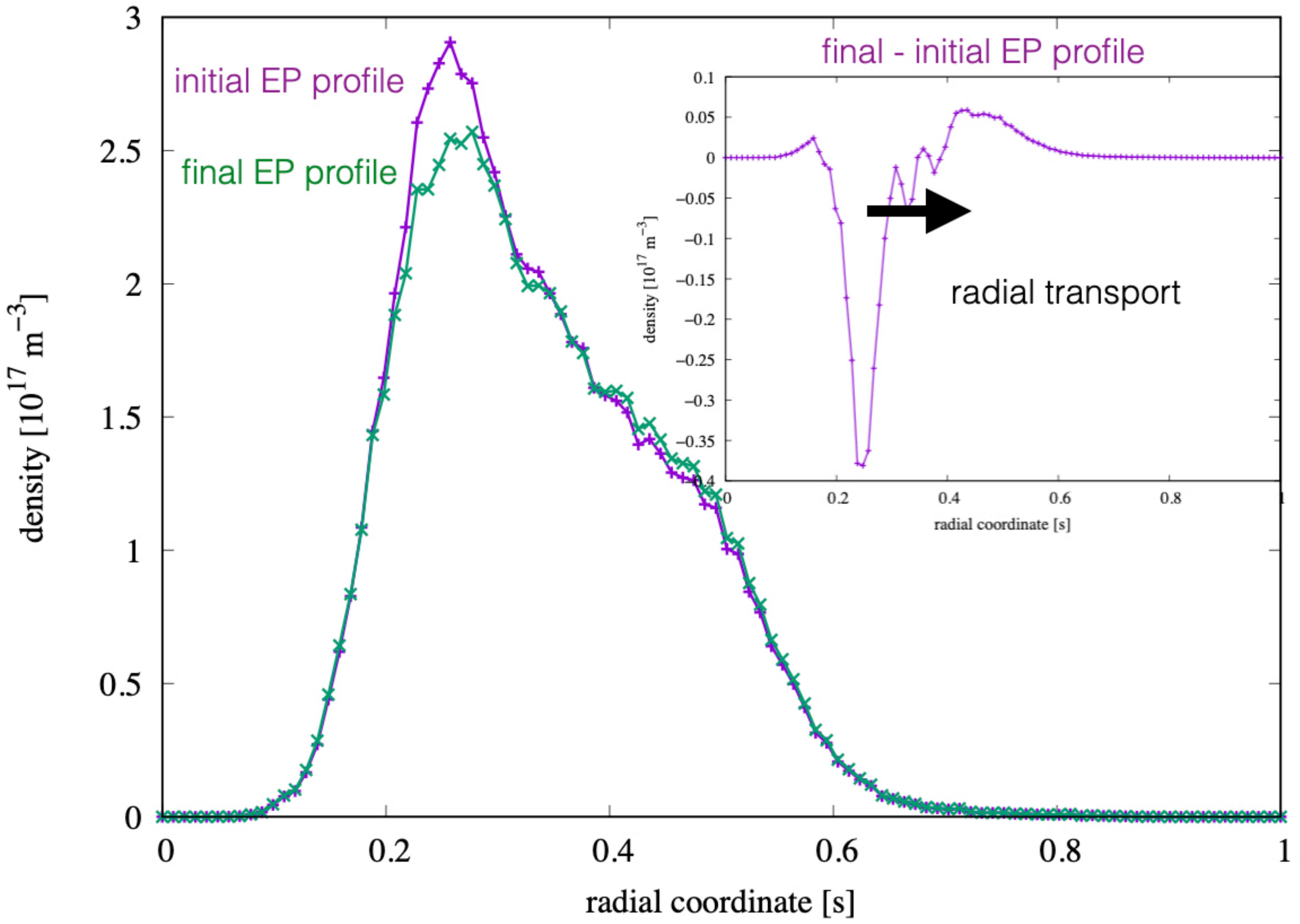
ATEP code: physics and structure

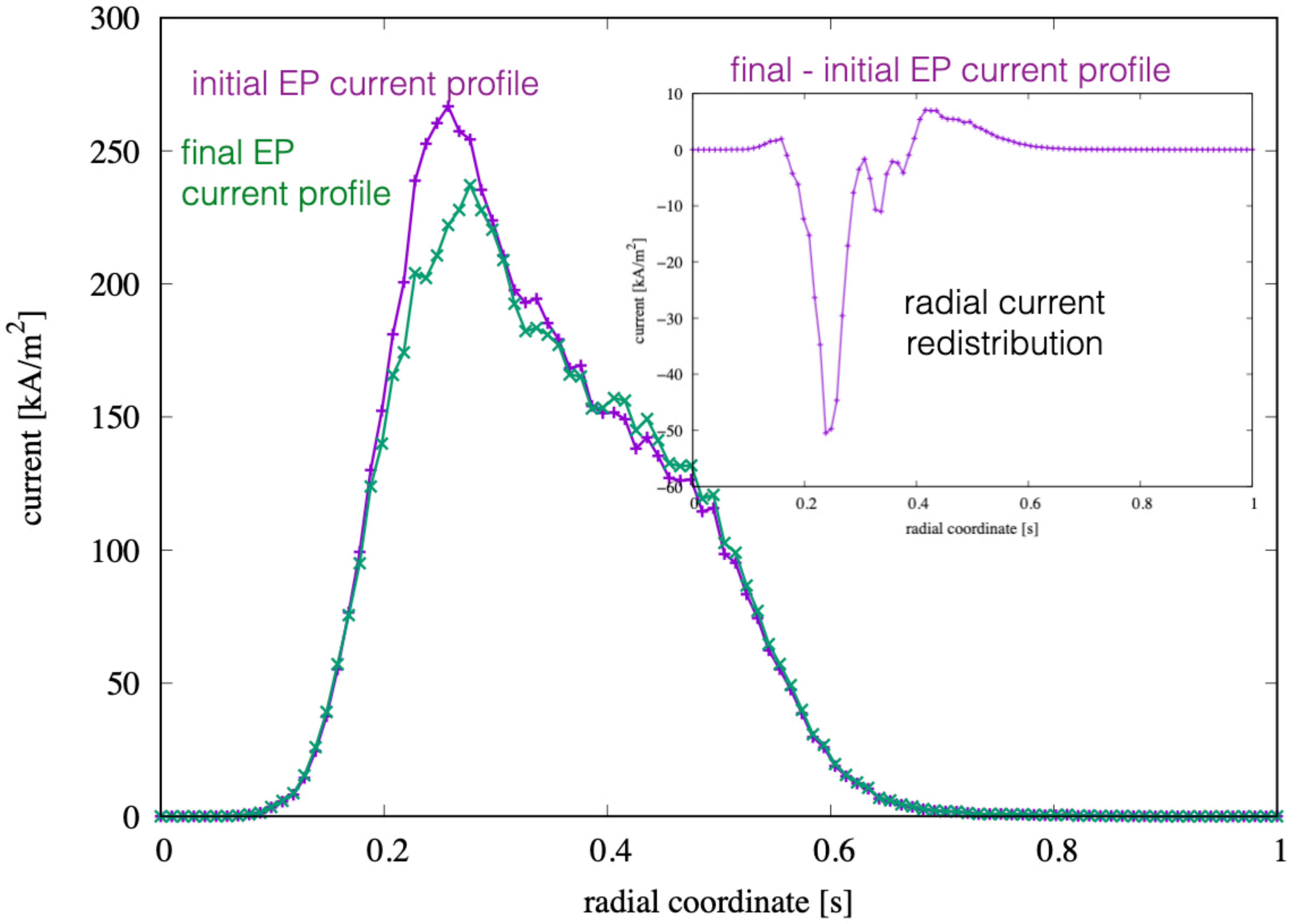


$$\frac{\partial}{\partial t}\overline{F_{z0}} + \frac{1}{\tau_b}\left[\frac{\partial}{\partial P_\phi}\overline{\left(\tau_b\delta\dot{P}_\phi\delta F\right)_z} + \frac{\partial}{\partial \mathcal{E}}\overline{\left(\tau_b\delta\dot{\mathcal{E}}\delta F\right)_z}\right]_S = \overline{\left(\sum_b C_b^g\left[F,F_b\right]+\mathcal{S}\right)_{zS}}$$

ATEP code: calculate moments of F_{EP} as ingredients to new, non-linear equilibrium

back-mapping and calculating moments given EP transport in physical units: example NBI at ITER



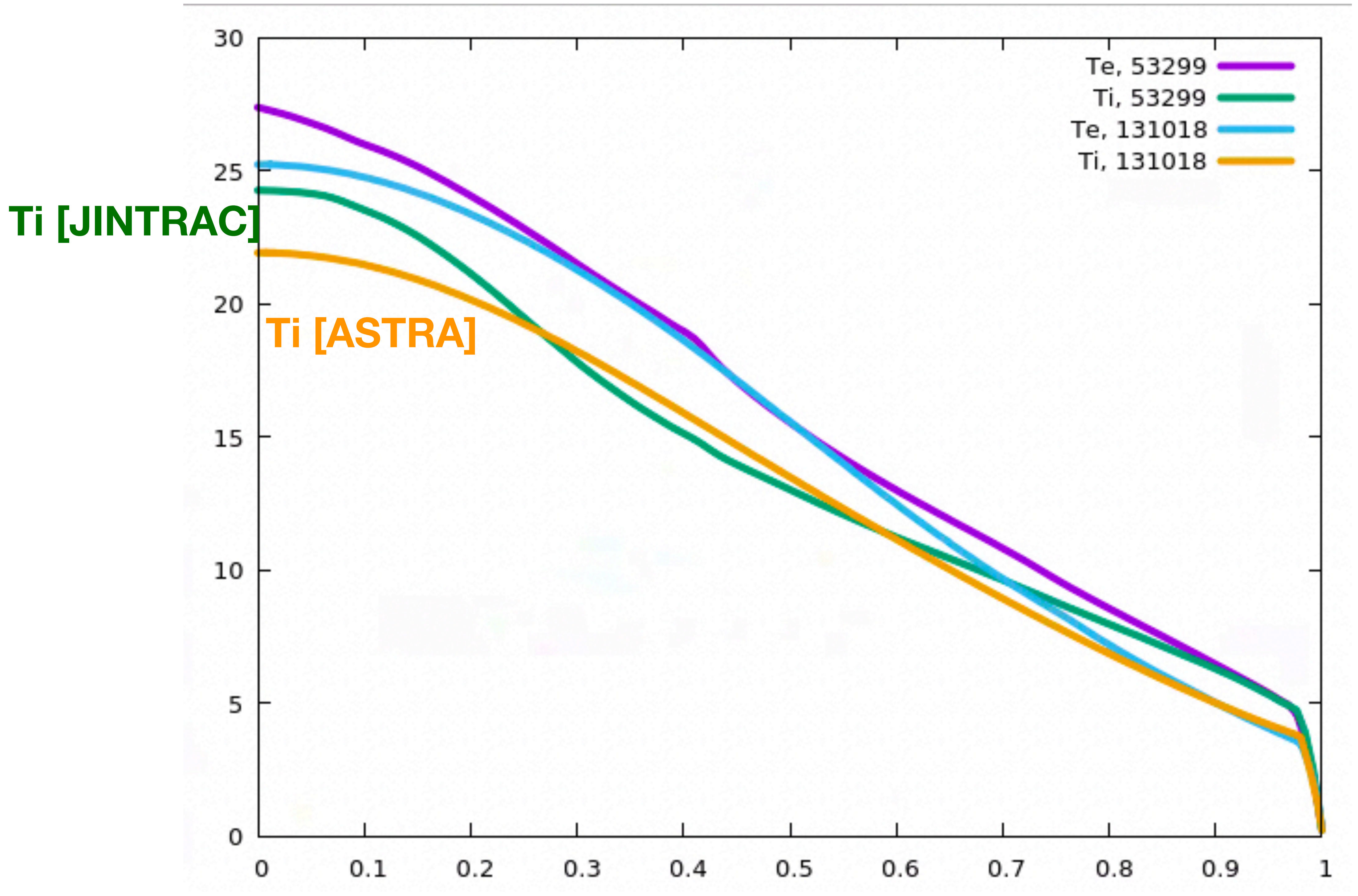


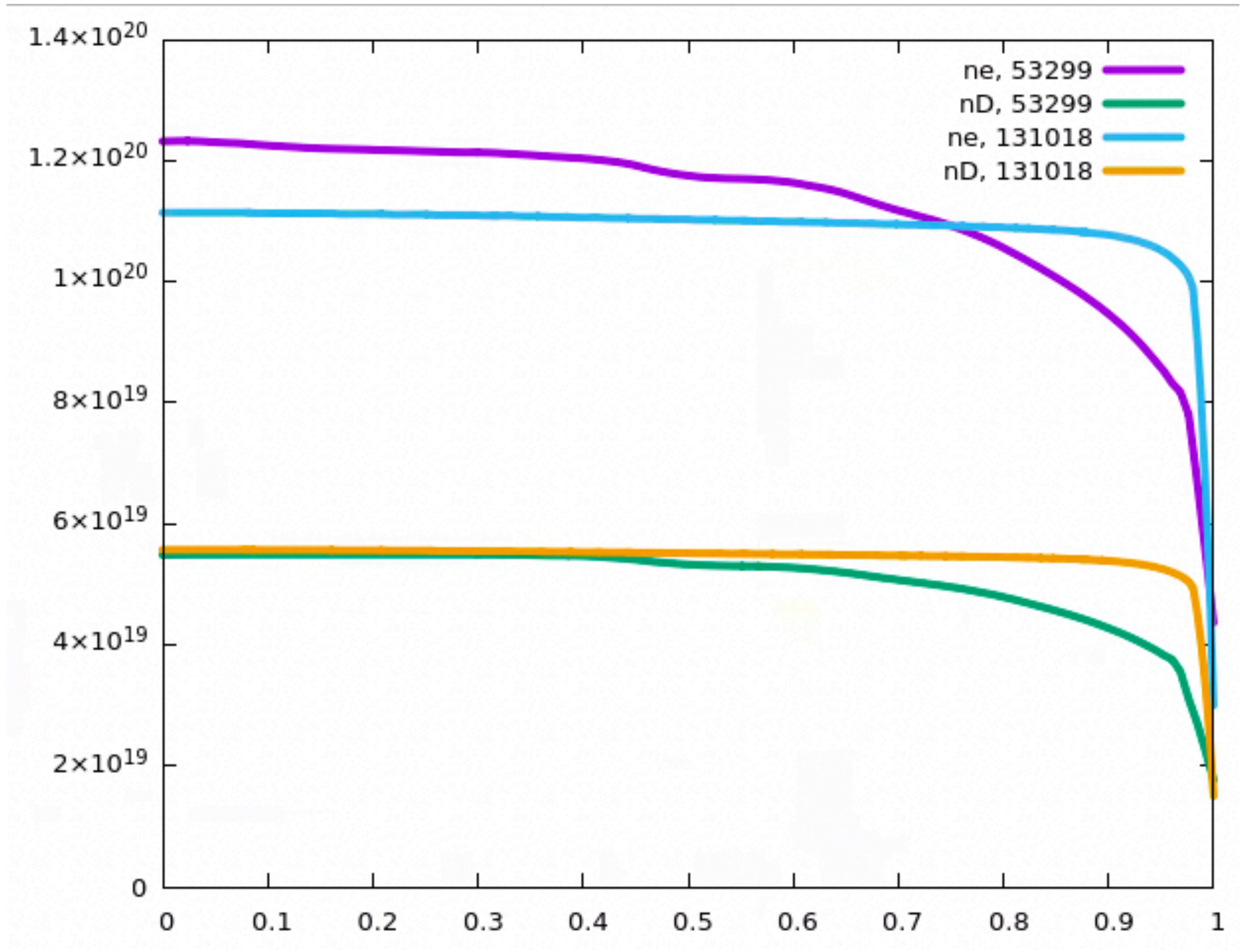
can be passed to transport/equilibrium code

[Lauber, FEC 2023]

new vs old ITER 15 MA projections - expectations EP stability

comparison: Polevoi 2002 (ASTRA, #131018), #53299,2 (JINTRAC) steepened Ti [Bourdelle]

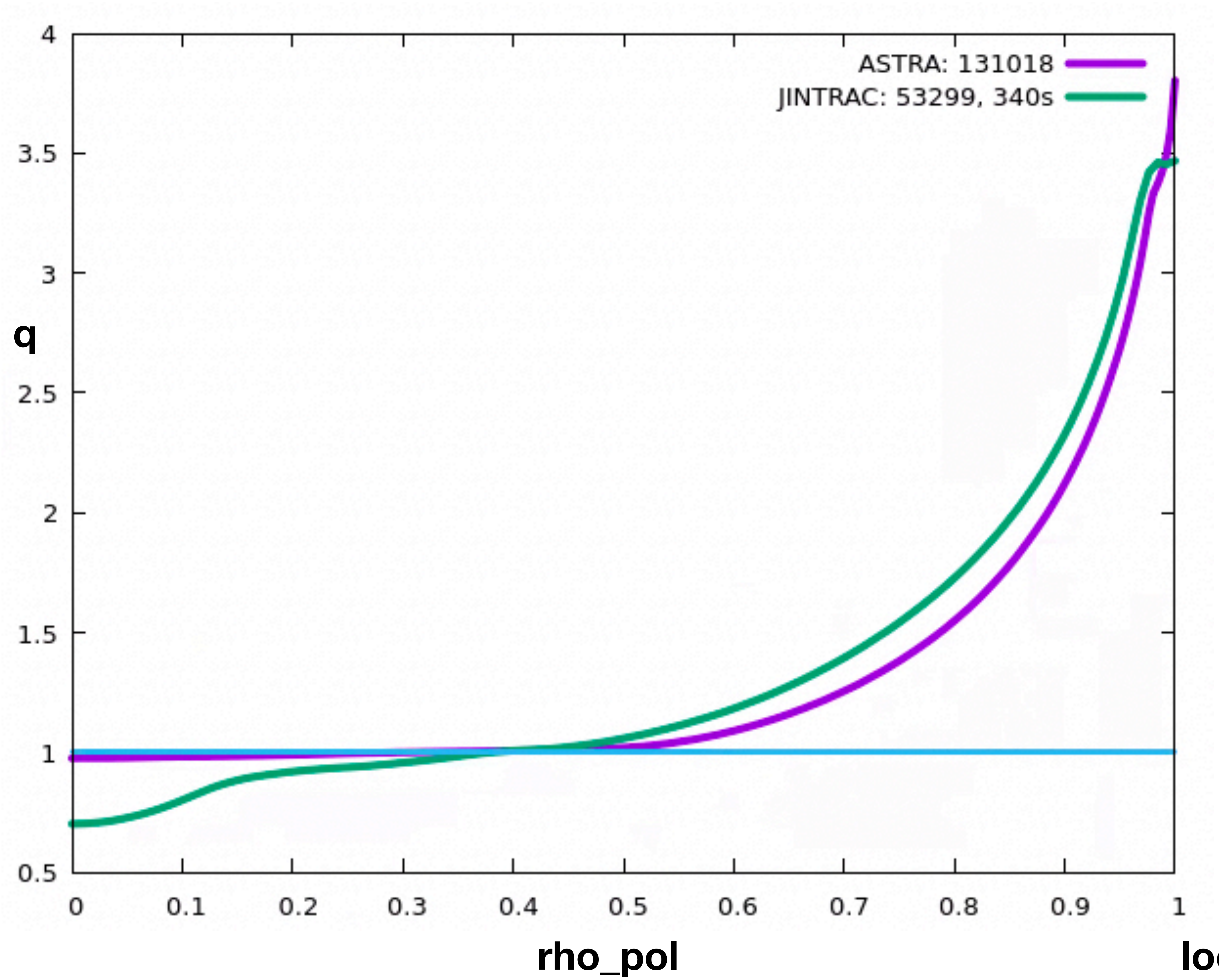




- **#131018 is known to have slightly unstable TAEs with small EP transport [Pinches 2015, Lauber 2015, Schneller 2015] - threshold for significant transport was found at $n_\alpha = 1.8\ n_{\alpha,nom}$**

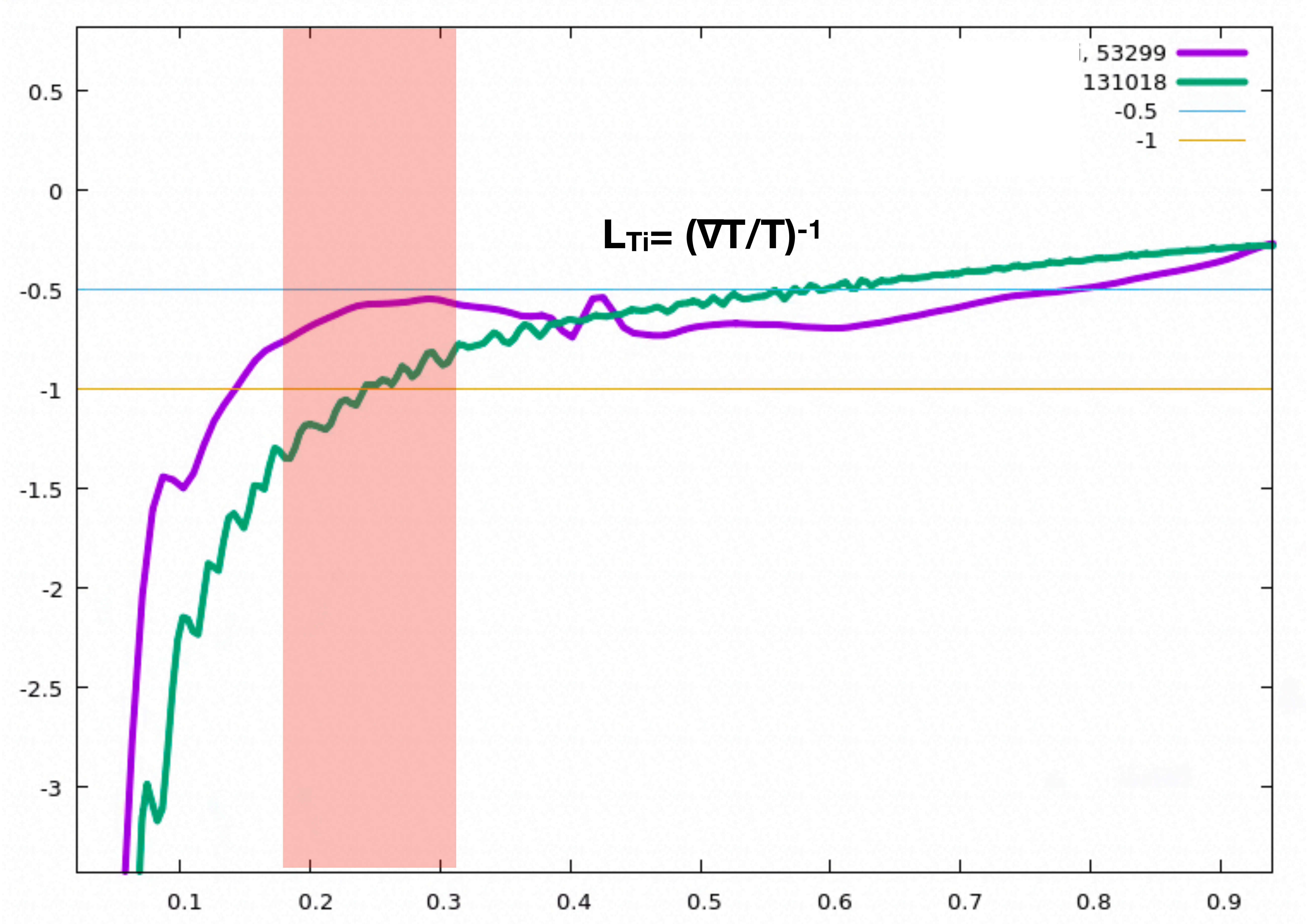
comparison: Polevoi 2002 (ASTRA, #131018), #53299,2 (JINTRAC) steepened Ti [Bourdelle]

- like most Ti-steepened AUG and JET cases with q~1, this scenario has probably fishbones (G. Brochard, FEC 2023)
- sawteeth - considerable stabilisation due to EPs - need to investigate cycle assuming different ST models



location of q=1 one of the crucial parameters

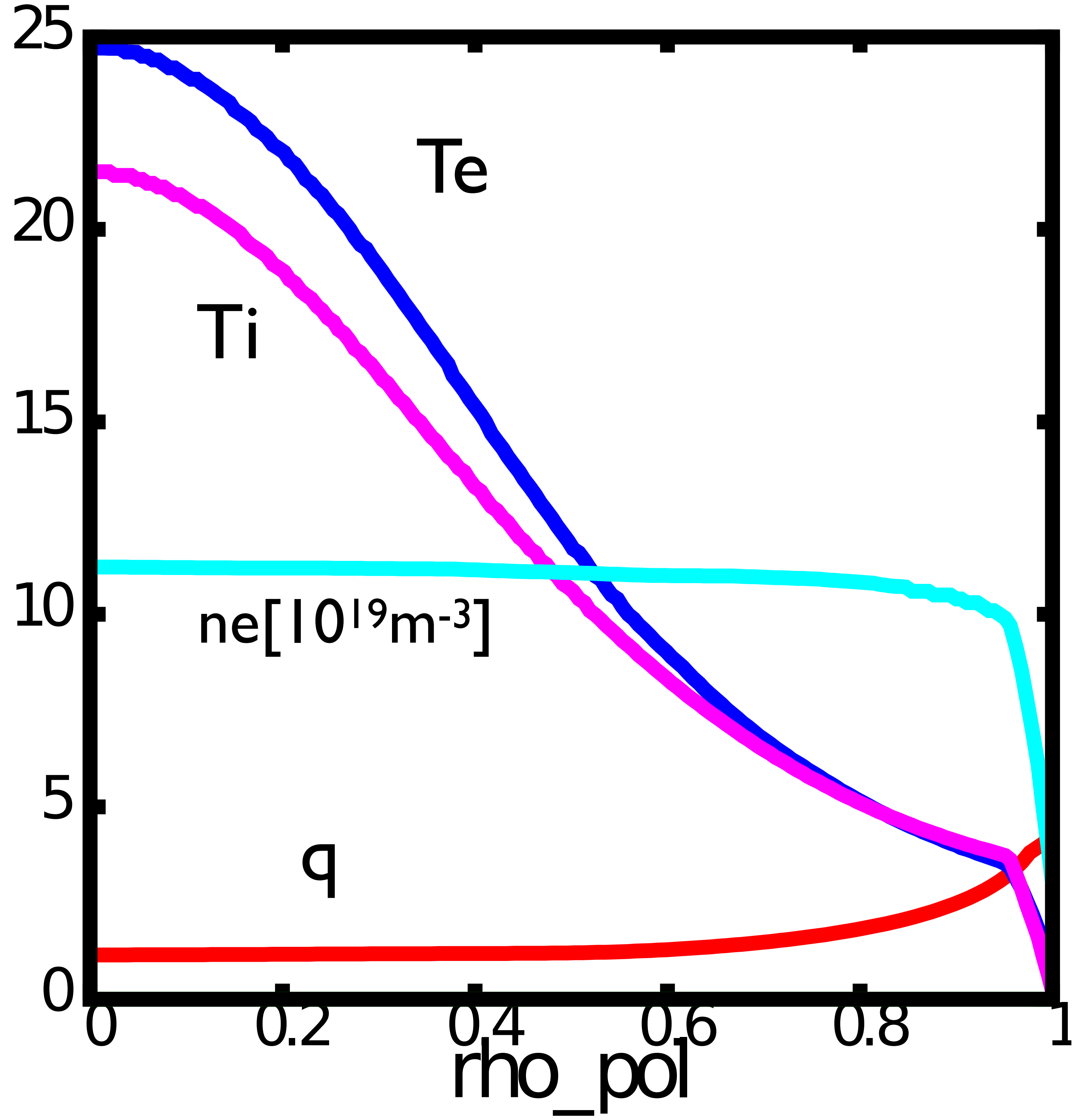
T_i - comparison: Polevoi 2002 (ASTRA, #131018), #53299,2 (JINTRAC)

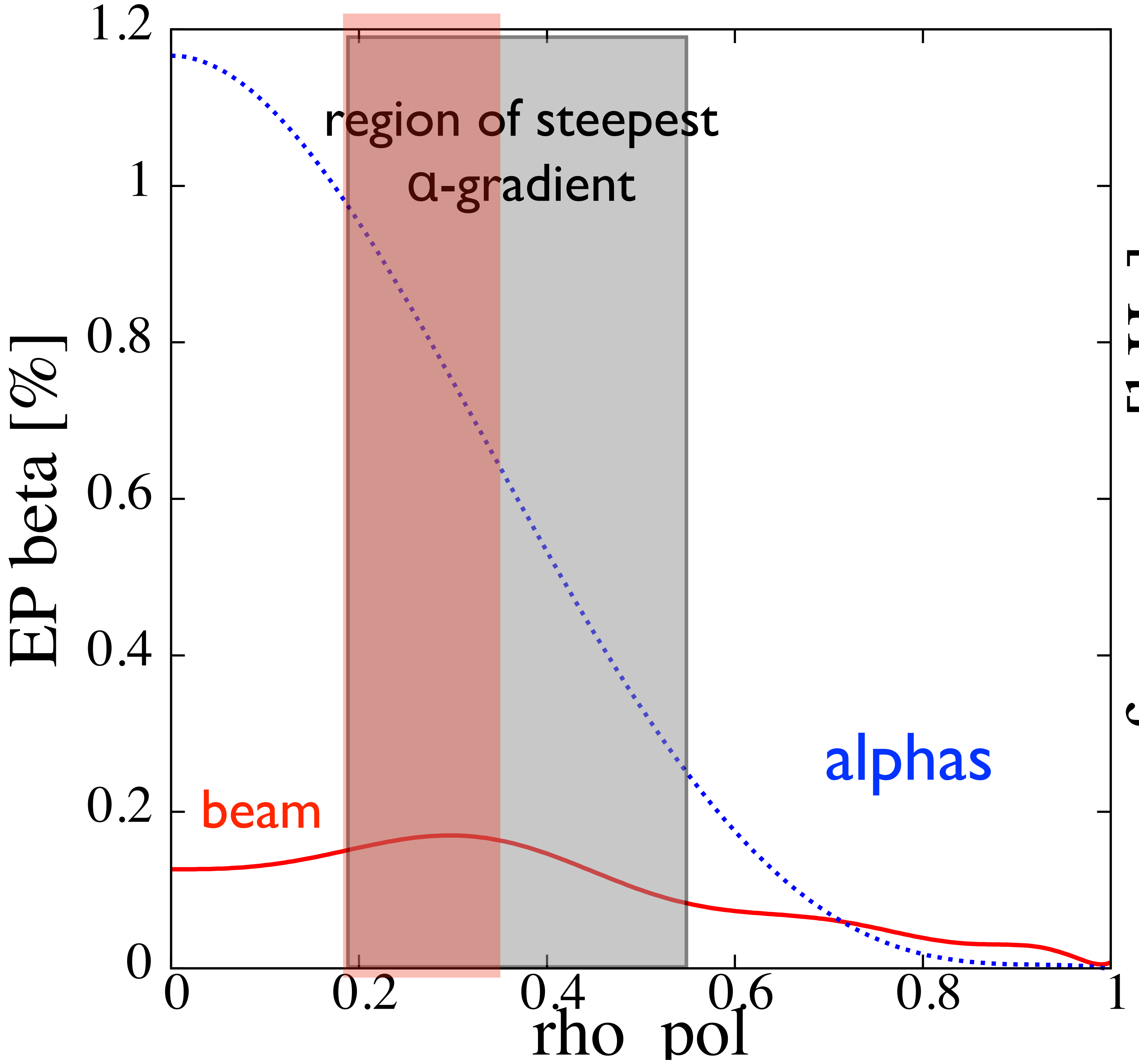


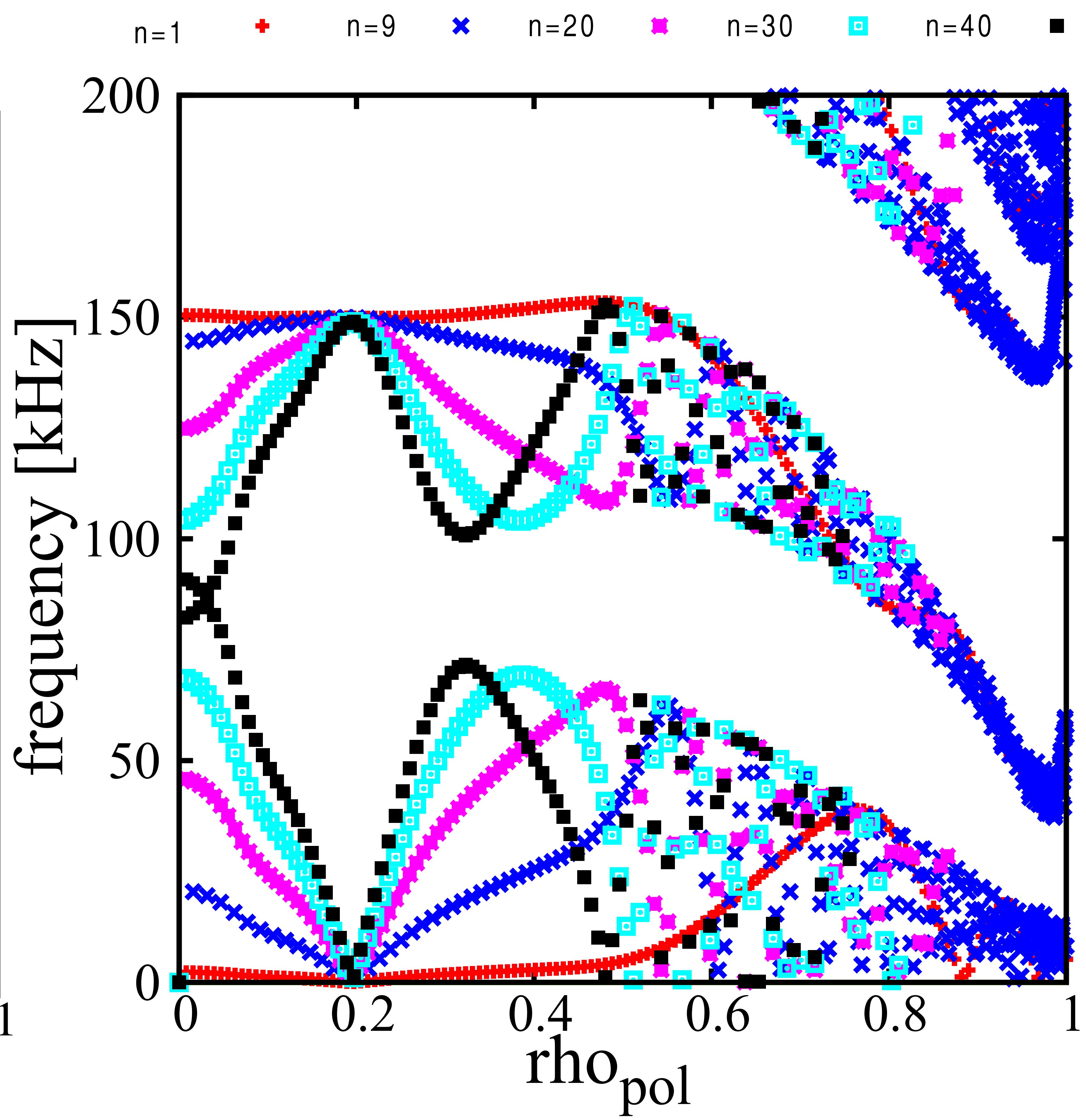
- L_{Ti} ~2* L_{Ti} (131018) at s=0.2…0.3
- $n_\alpha \sim T_{D,T}^{(2-\varepsilon)}$ - more peaked alpha particle profile expected (unfortunately not available in IDS)

α-particle profile: ASTRA, #131018

[A. R. POLEVOI ET AL. J. Plasma Fusion Res., 5 (2002)]







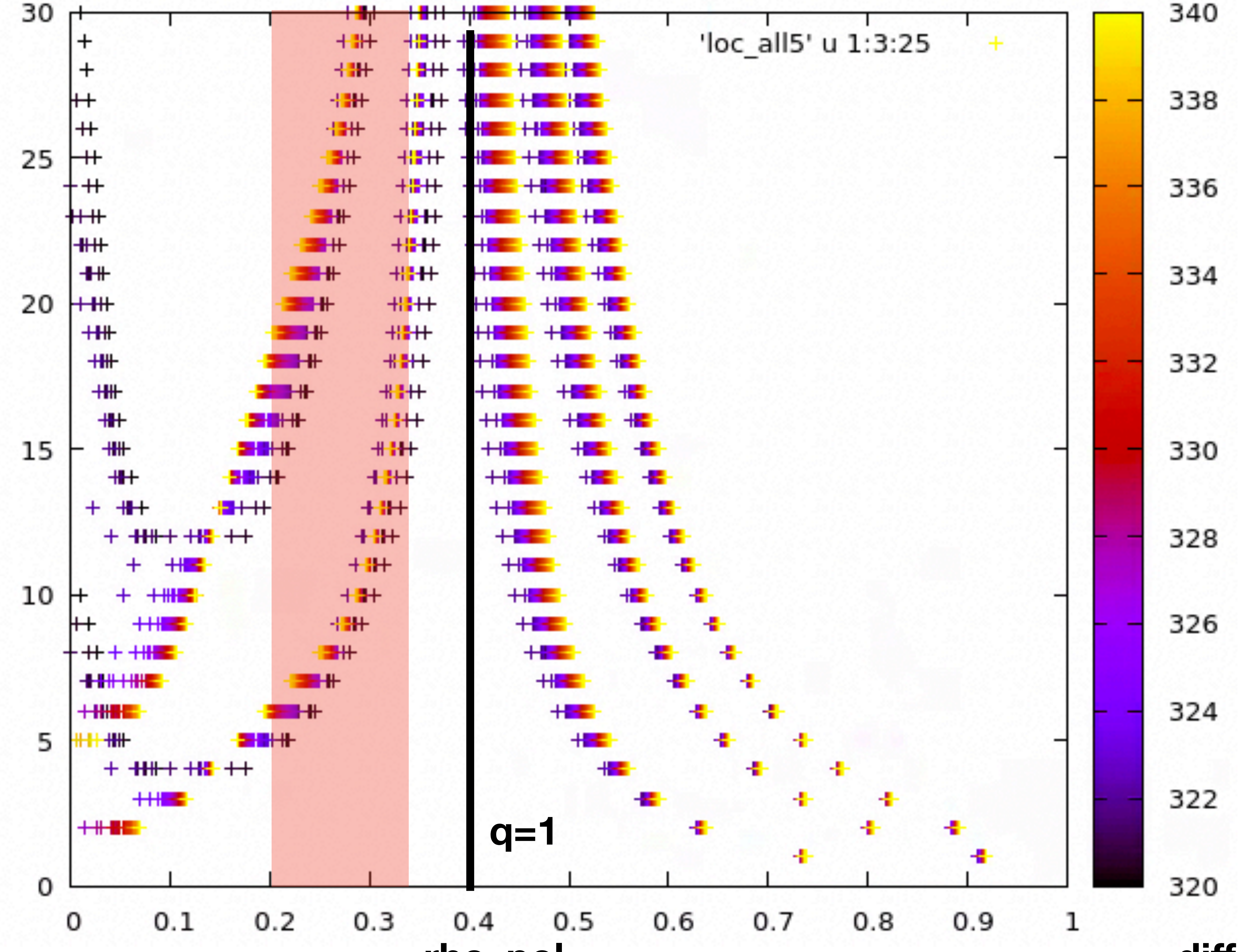
B0=5.3T, R0=6.2m, D,T,He-ash, Be,α,NNBI-D

[S.D. Pinches et al PoP , 2015
Ph. Lauber PPCF 2015]

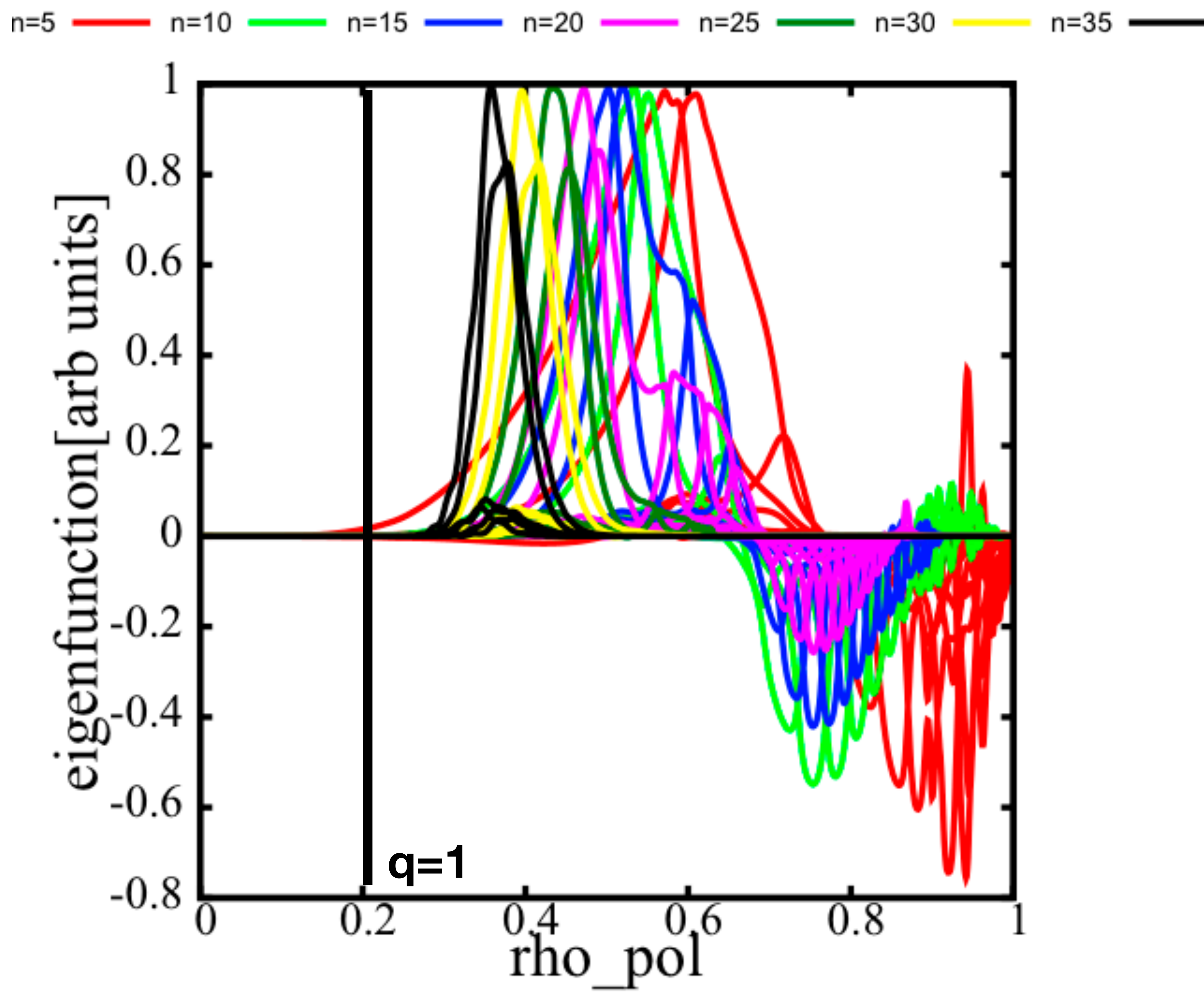
#53299,2 (JINTRAC) vs 131018 (ASTRA): TAE locations

#53299,2 (JINTRAC)

toroidal mode numbers of TAEs



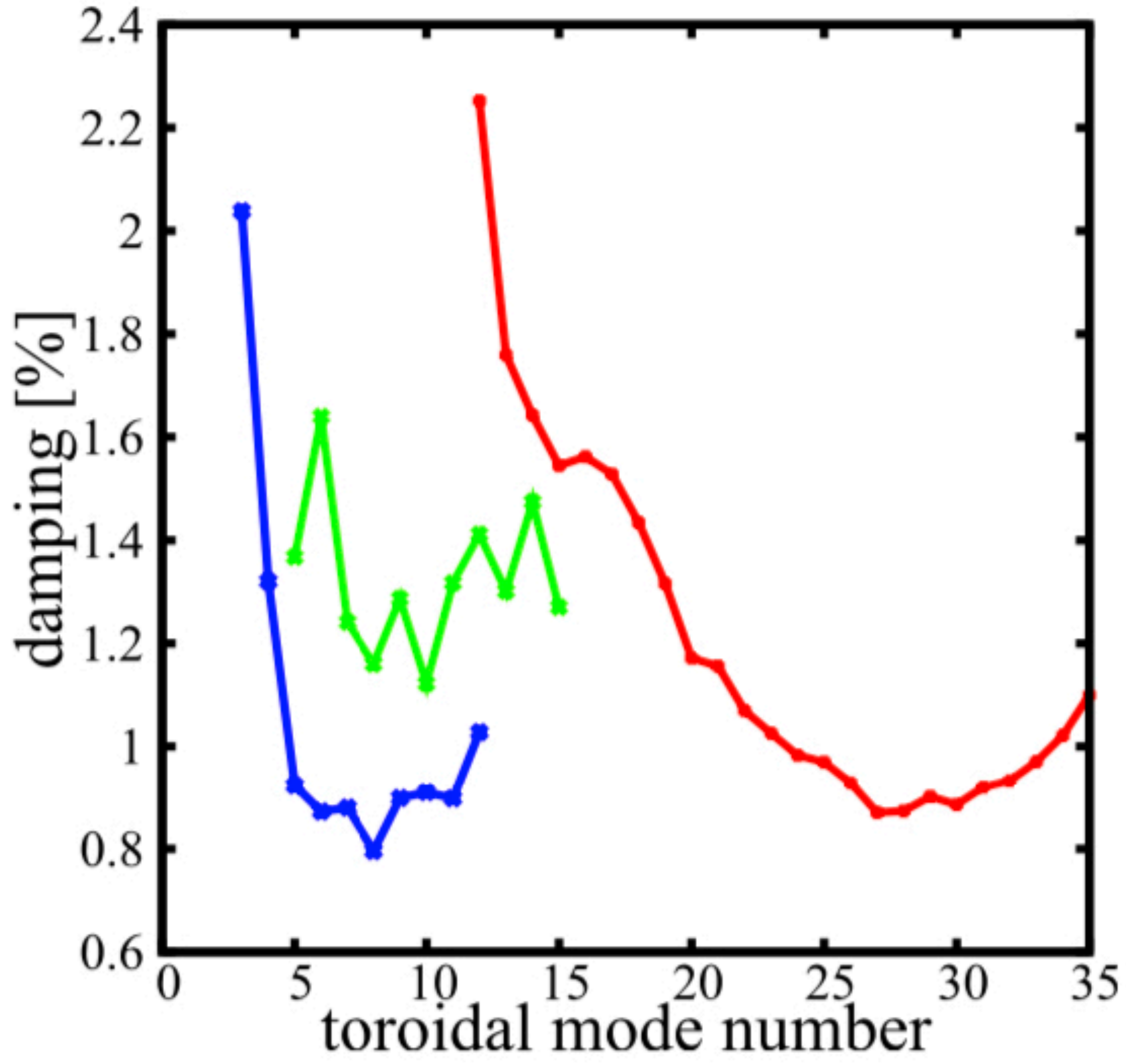
131018 (ASTRA)

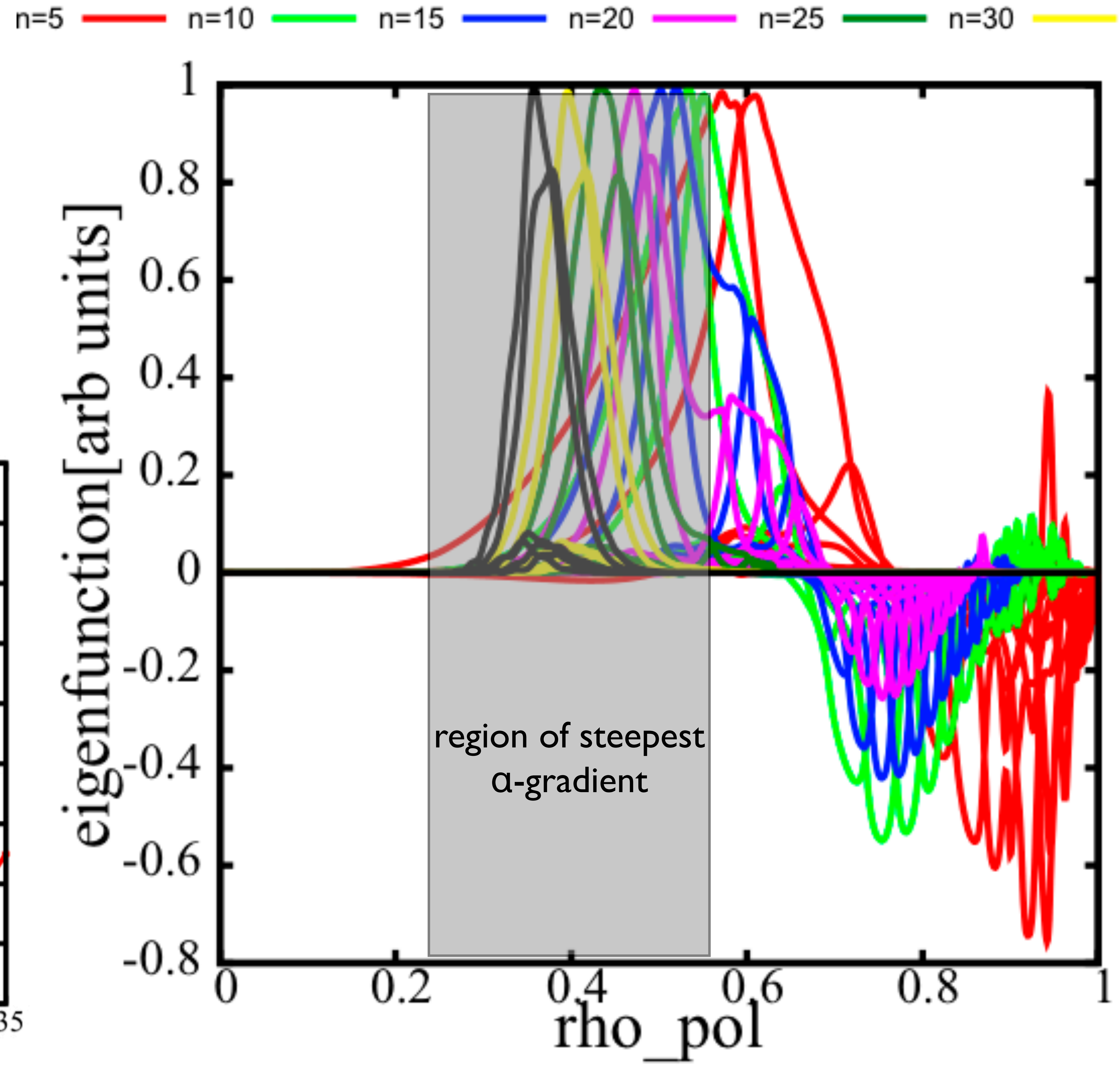


difference: core-localised TAEs with larger drive in 53299

131018 (ASTRA): global TAE stability

damping > ~1%
various TAE branches with same n due to alignment of SAW gaps





[Ph. Lauber PPCF 2015]

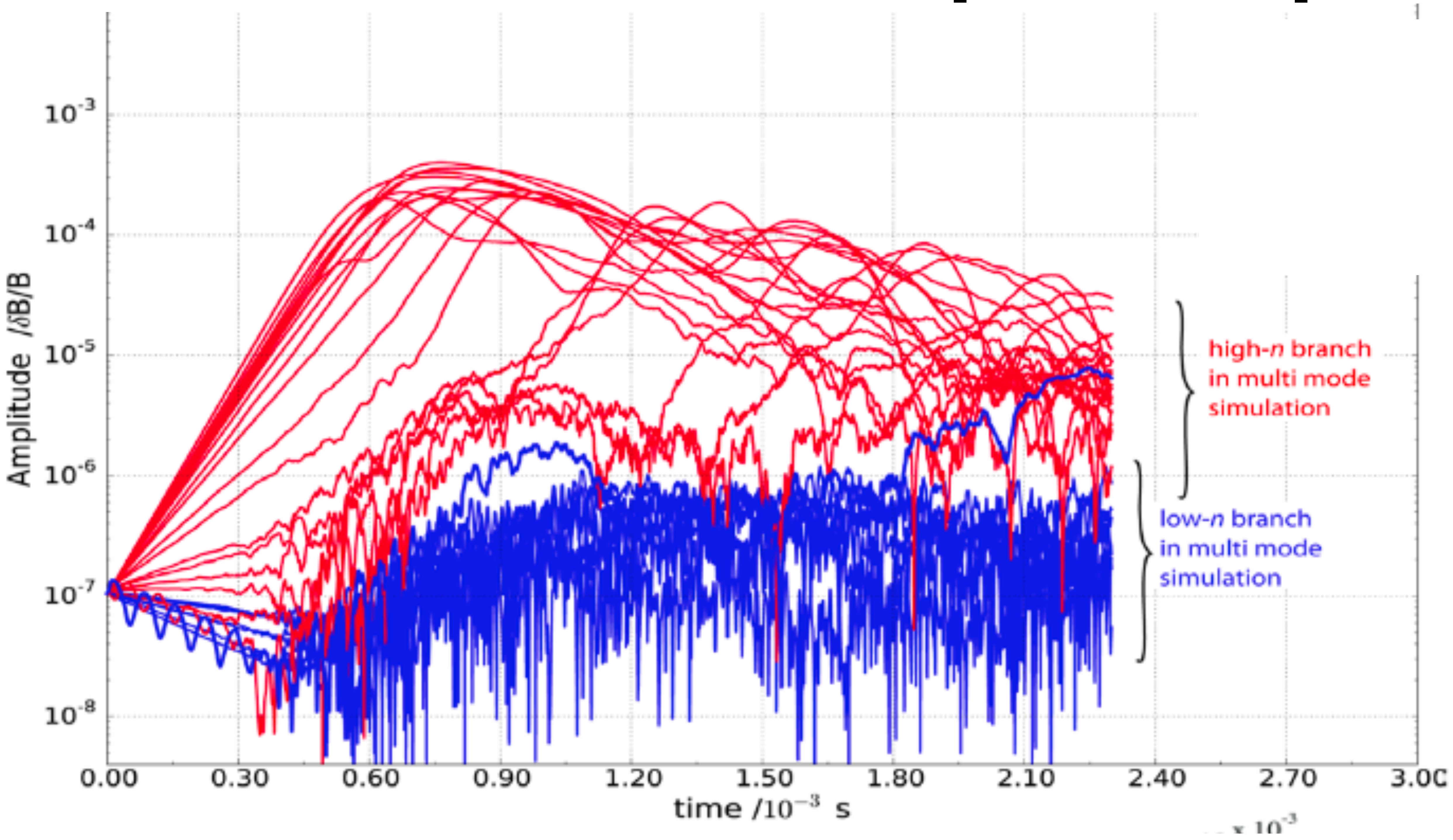
qualitatively new situation compared to present-day experiments:

cluster of most unstable modes 15<n<25

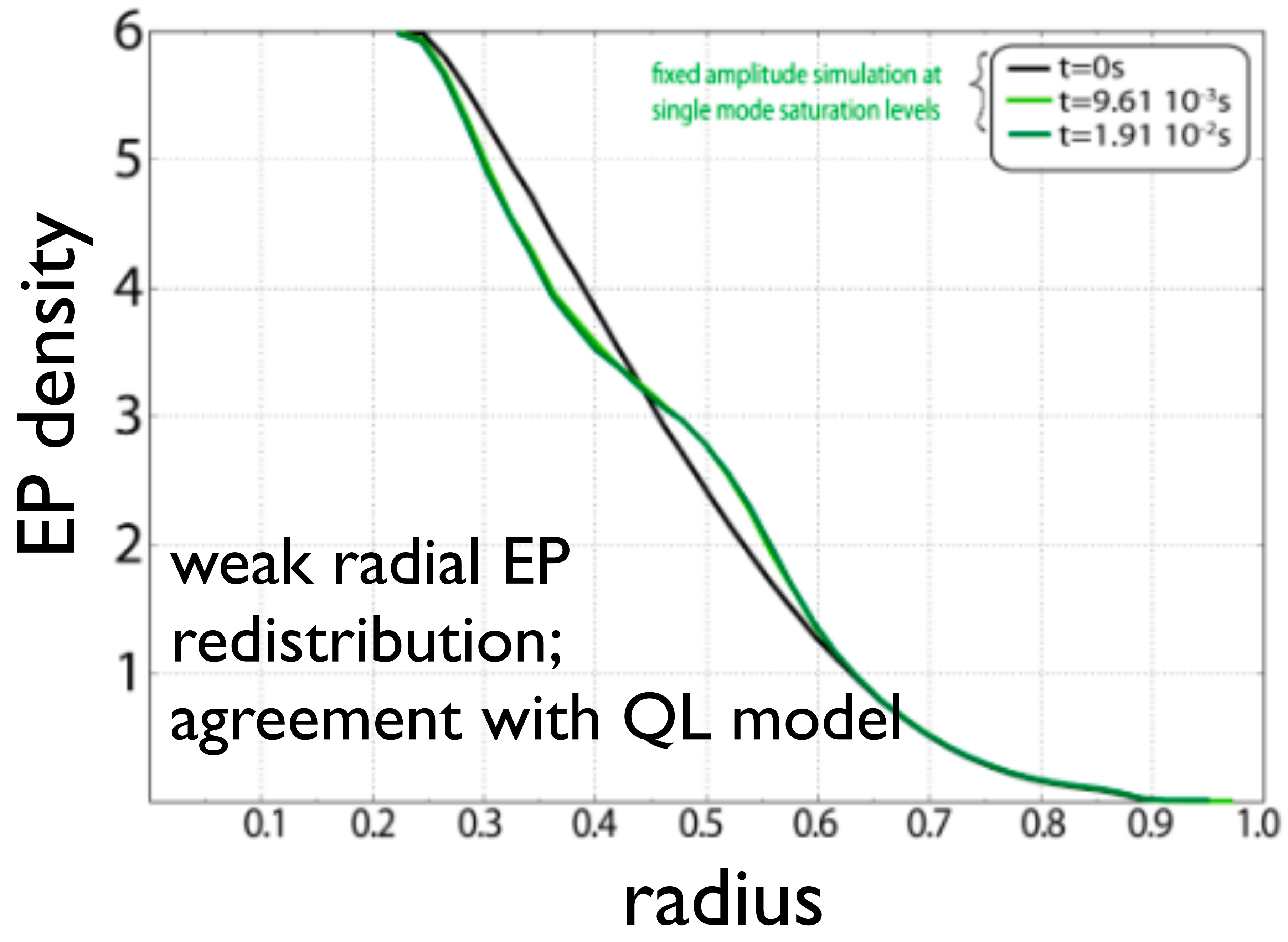
may destabilise subdominant modes with lower n in outer core

131018 (ASTRA): non-linear perturbative runs: add energetic ions, calculate wave-particle power transfer until non-linear saturation

HAGIS/LIGKA model, ITER 15 MA TAEs [Schneller, 2015]



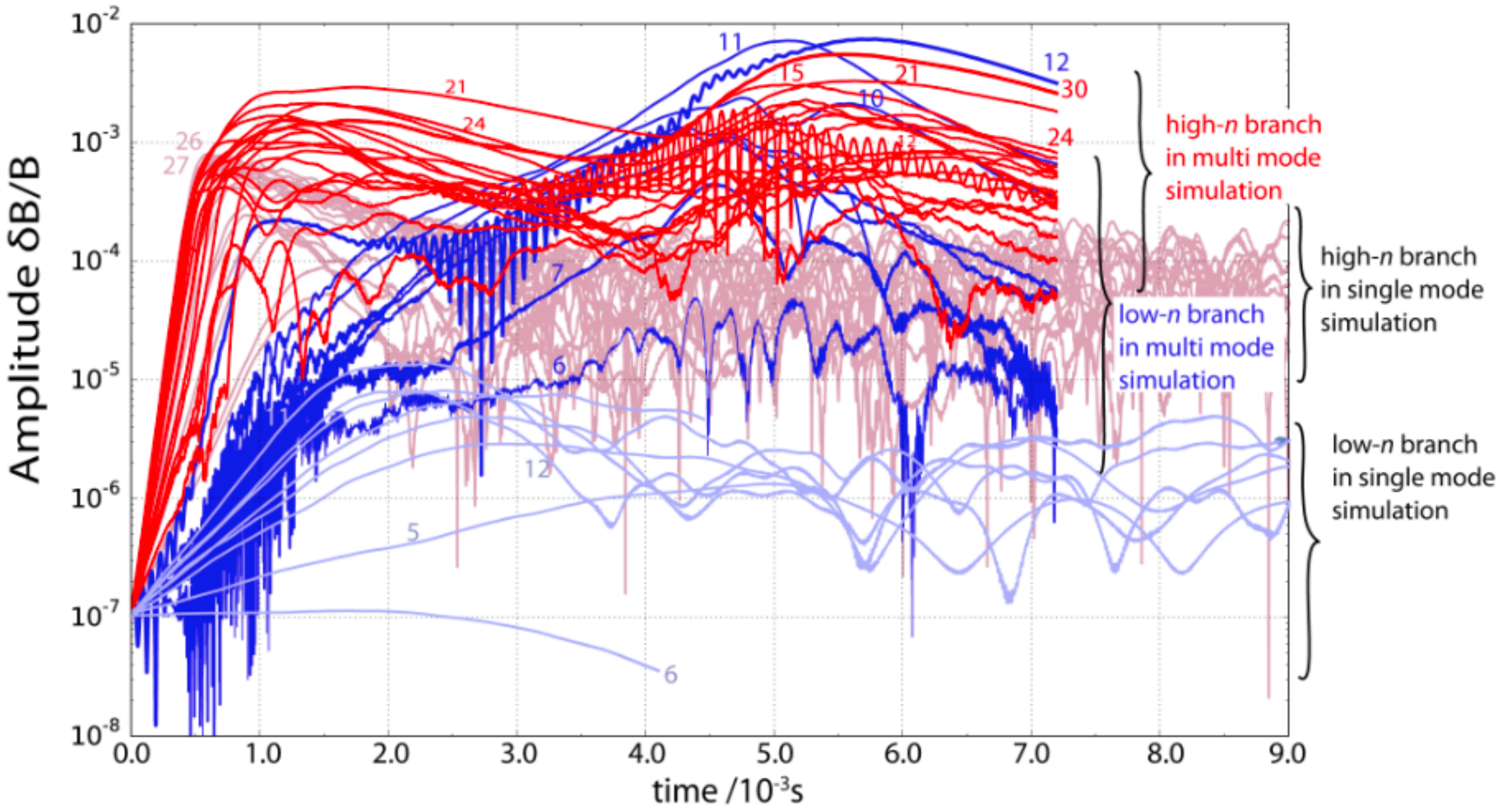
'sea' of weakly unstable TAEs expected with small EP transport;
agreement with QL estimates

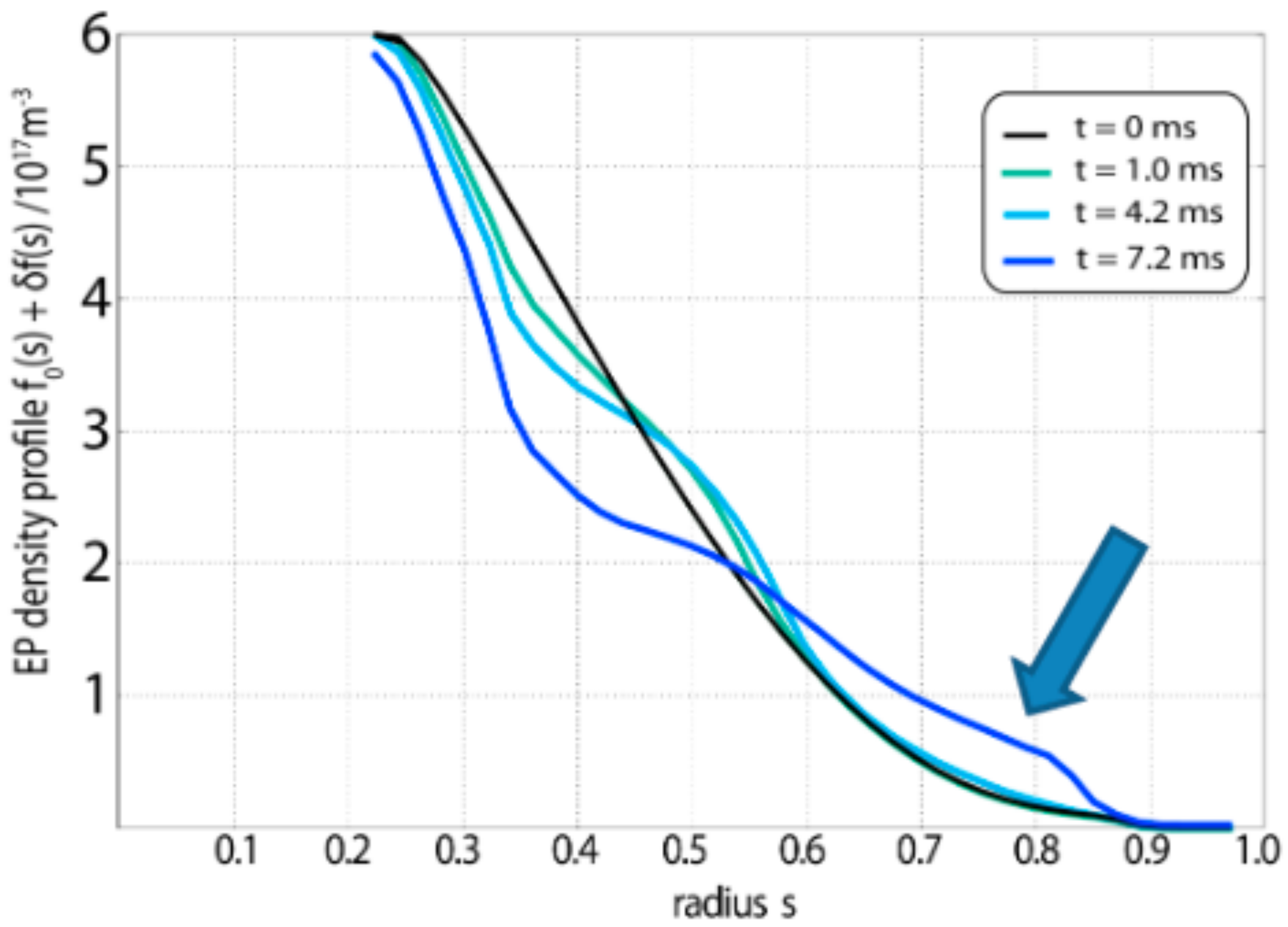


QL boundaries? for artificially higher EP pressure (~2 times), energetic particle avalanches are found

MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

HAGIS/LIGKA model, ITER 15 MA TAEs [Schneller, 2015]

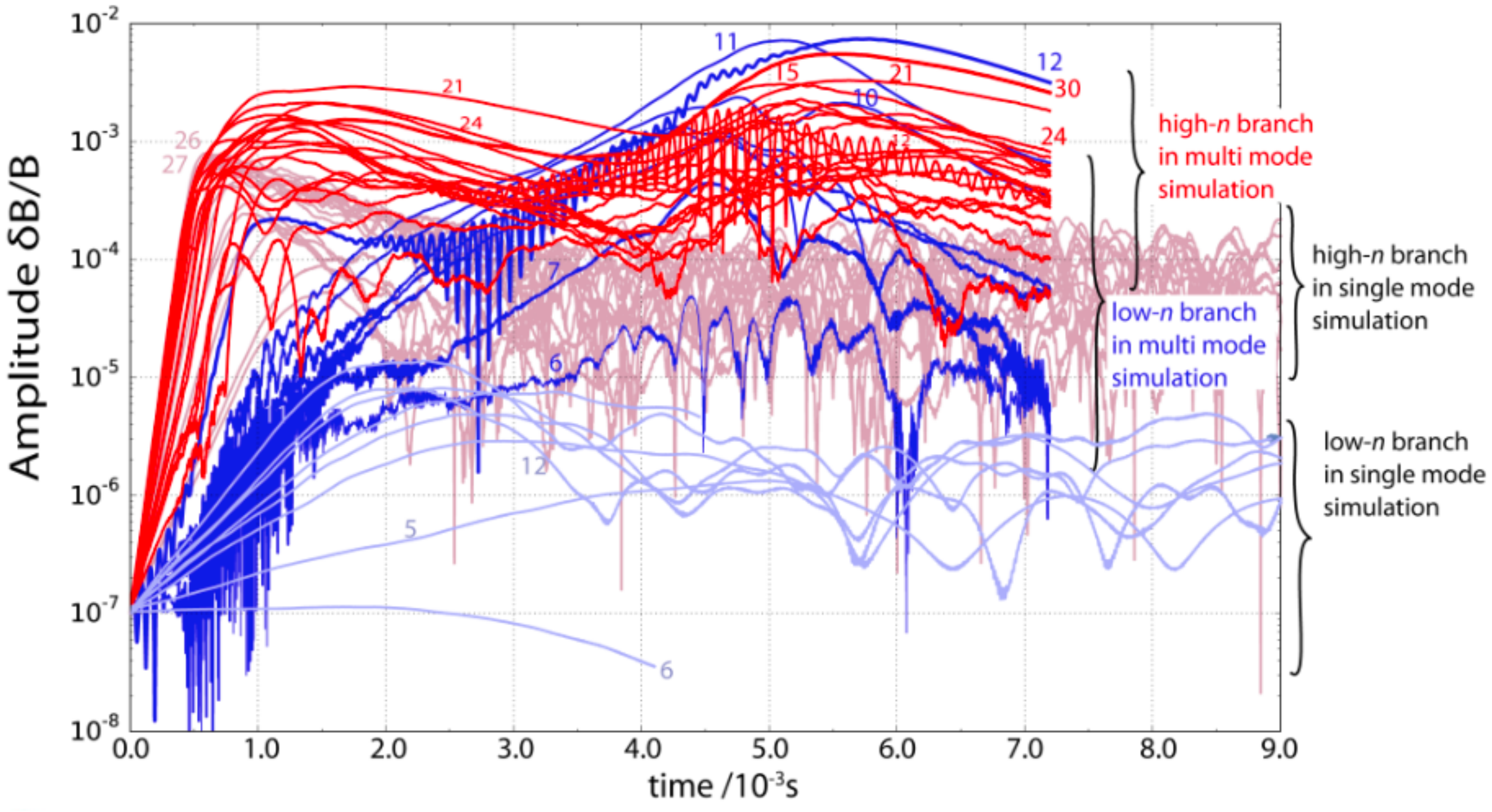




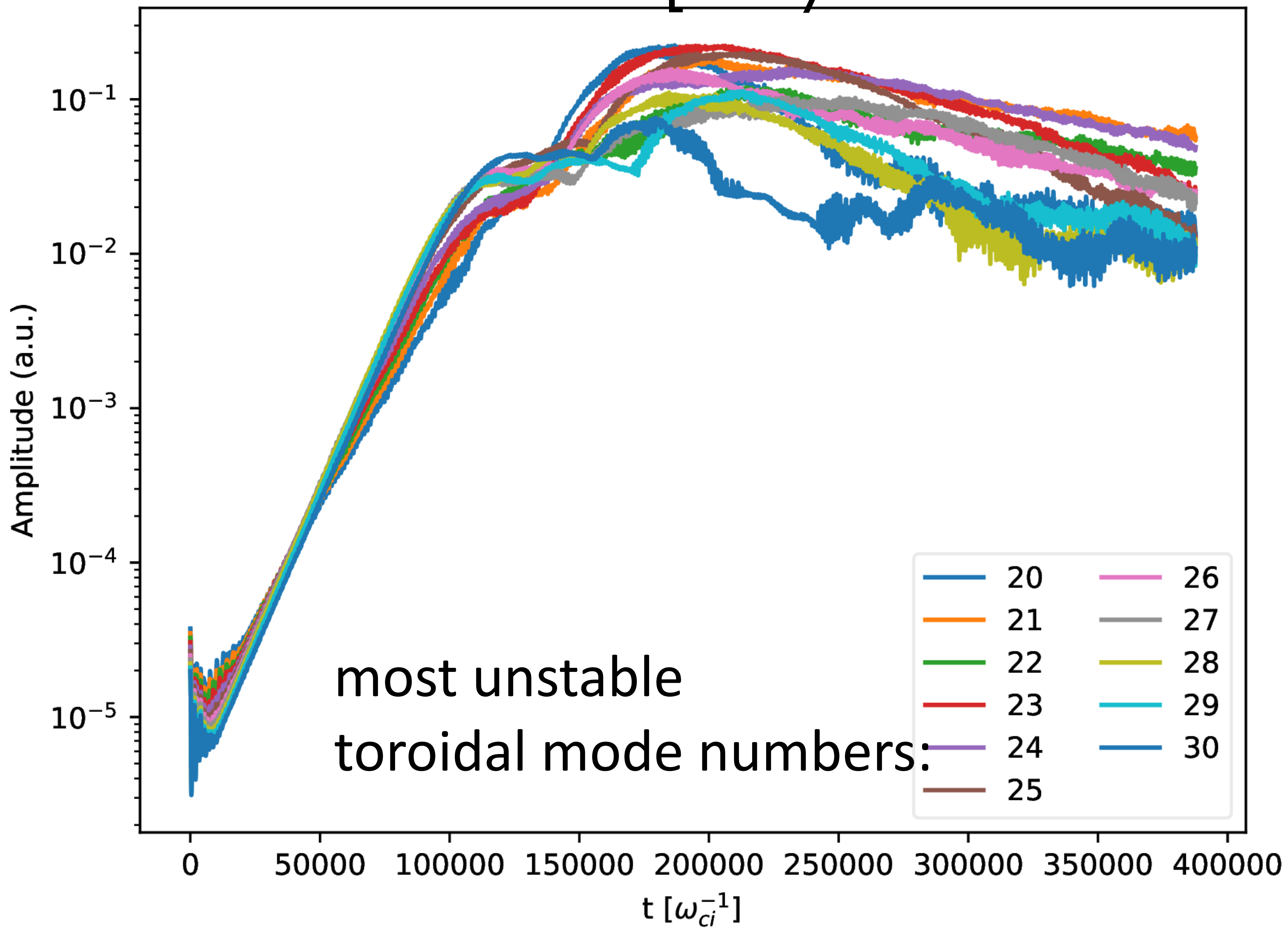
- also found in reduced descriptions: 1d beam plasma model [Carlevaro, 2015-17,2021]
- above simulations do not consider wave-ZF/wave-wave non-linearities
- collisions influence saturation level [C Slaby 2020]
- interplay with fishbones/ BAEs need to be investigated: hierarchical approach within ATEP code: diffusion model [R.Lake], PSZS theory [F. Zonca, FEC, AAPPS-DPP 2023]

successful comparison with global non-linear GK code ORB5

HAGIS/LIGKA model, ITER 15 MA TAEs [Schneller, 2015]



ITER 15 MA case - ORB5 [T Hayward-Schneider NF 2021]



- compare LIGKA/HAGIS model to ORB5: global electromagnetic gyrokinetic code using the PIC approach in toroidal geometry [Lanti CPC 2020, for EP physics: Biancalani, Bottino, Hayward-Schneider, Vannini,… 2012-21]
- very similar linear and non-linear properties of ITER 15 MA case were found [T Hayward-Schneider 2021, AAPPS-DPP 2020]

stabilisation of sawteeth, interaction with core-localised AEs

AUG
ICRH

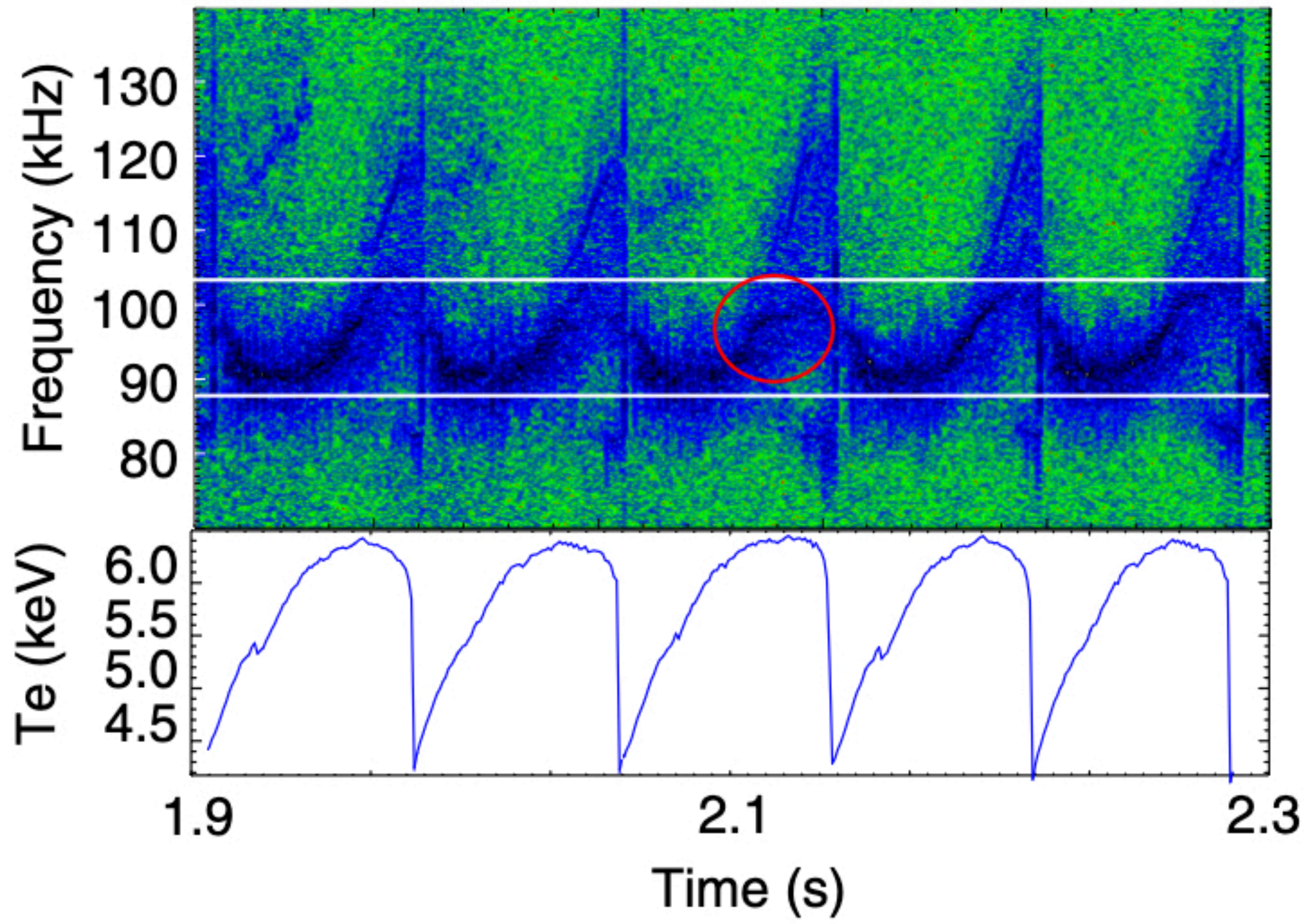
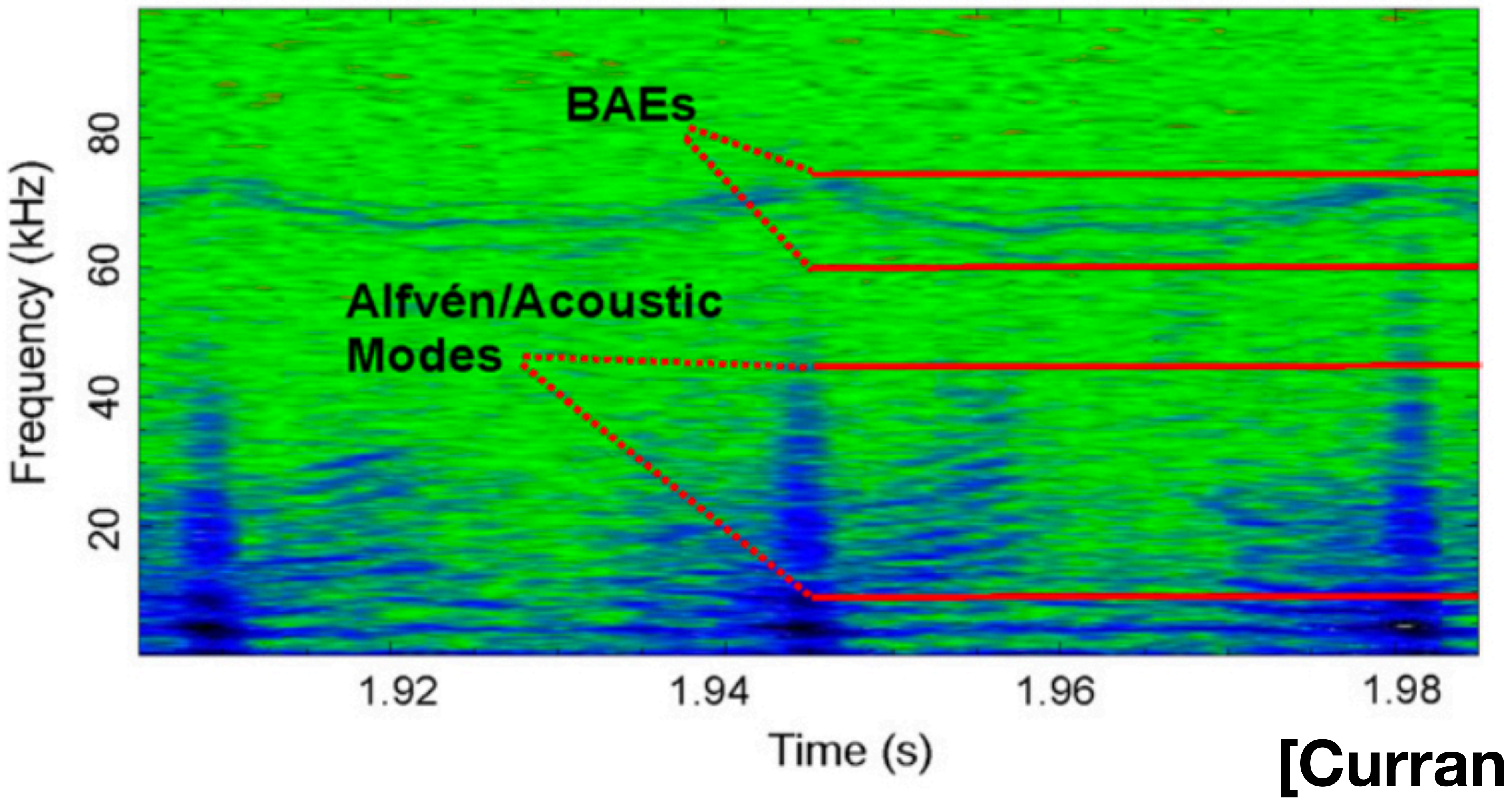
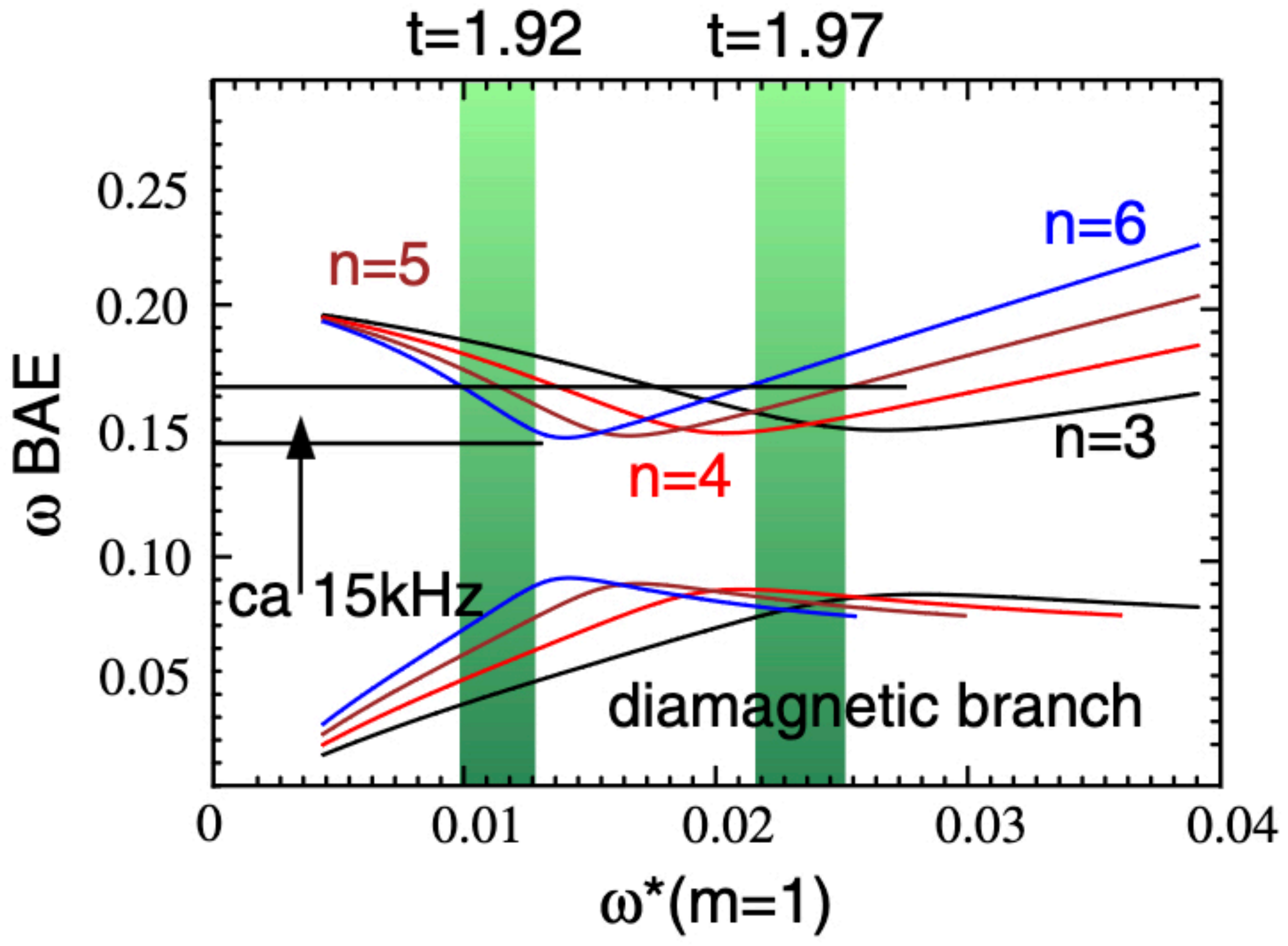


Figure 5. Spectrogram (Mirnov coils) and central electron temperature evolution for #20488.



[Curran 2012]

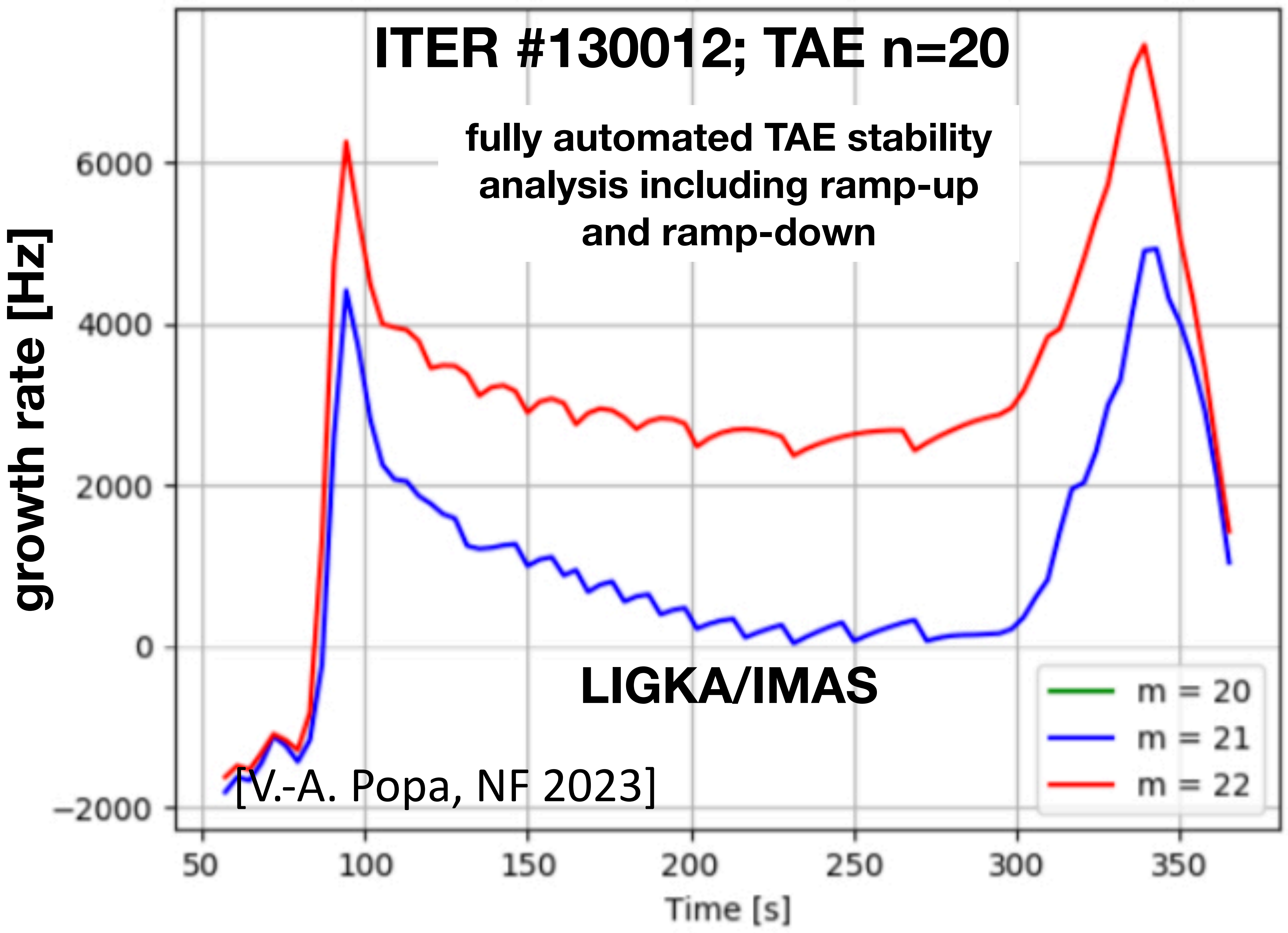


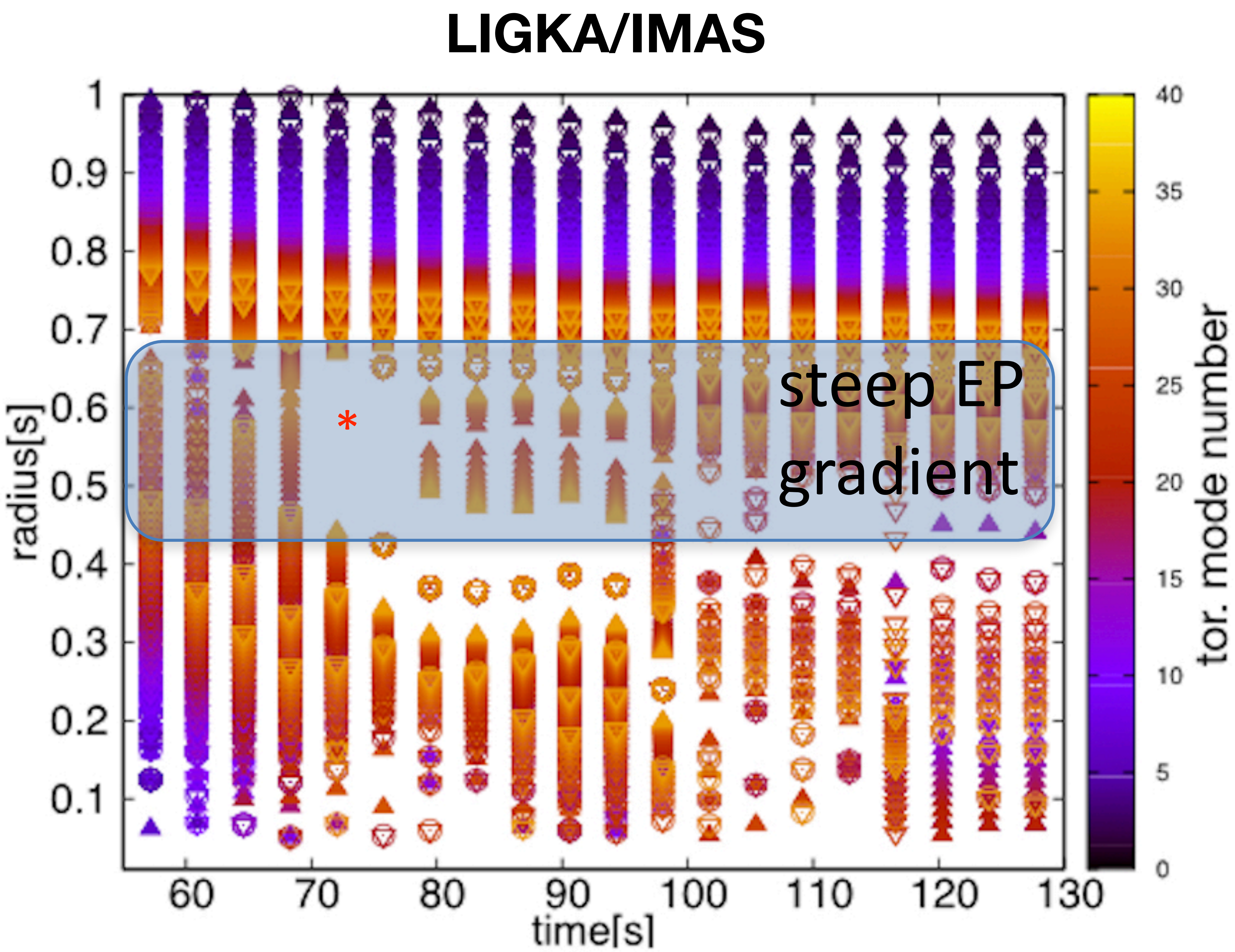
[Lauber 2009]

details of distribution function determines FB/BAE/LFAM activity

time-dependent, automated runs possible based on experimental/transport code output

(here: ITER DT plasma based on METIS transport run)





- identification of optimal scenarios with respect to AE locations and EP gradients: e.g. hybrid scenario with flat q≳1 has no AE resonances in steep EP gradient region - how does the plasma self-organise? *

time-dependent, automated runs possible based on experimental/transport code output

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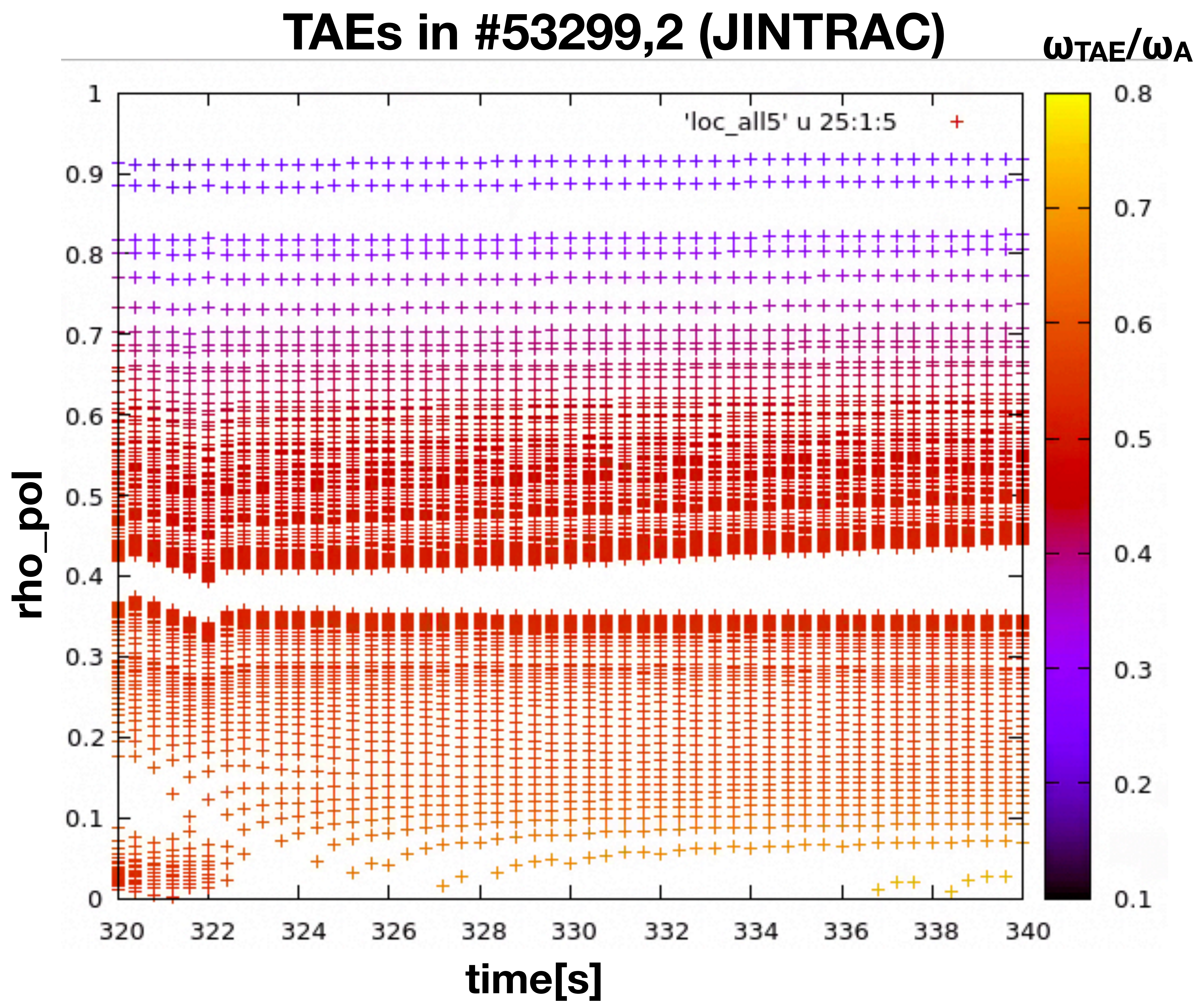

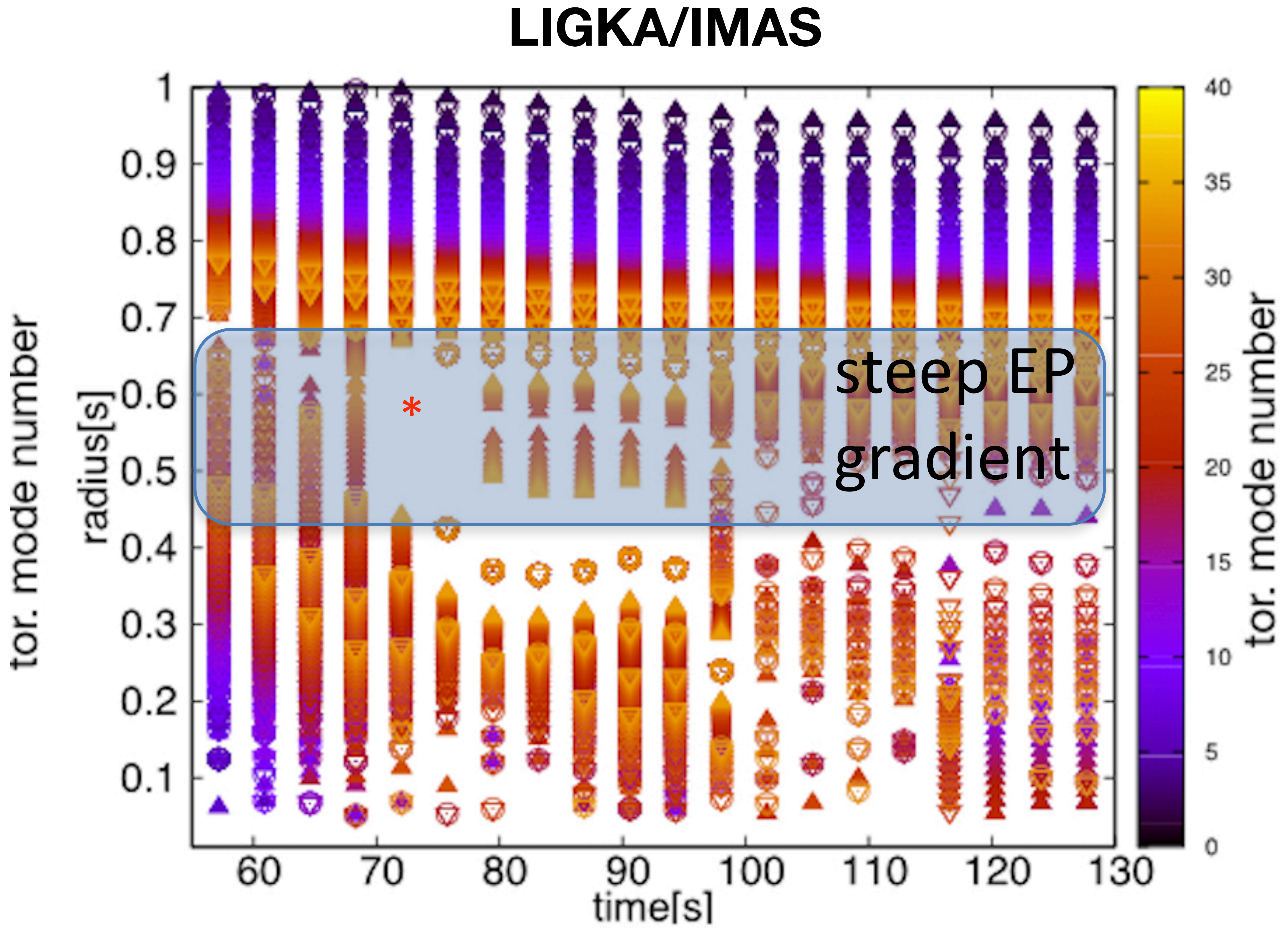

- identification of optimal scenarios with respect to AE locations and EP gradients: e.g. hybrid scenario with flat q≳1 has no AE resonances in steep EP gradient region *

needs & outlook

- consistently filled IDS - in the best case time-dependent data
- in particular, at least n_{fast} and p_{fast} are needed
- uncertainties/error in the profiles are highly welcome - automated modelling chain allows to asses UQ
- working interface to heating code H&CD WF, ASCOT in case anisotropic distributions are to be assessed

outlook

- use ATEP code to asses importance of steeper α-particle profiles
- close feedback-loop to JINTRAC
- interplay of AEs and fishbones needs to be assessed (non-linear FB (PSZS) theory: Zonca FEC 2023, R. Lake 2013)
- self-organisation of current (‚flux pumping‘) may play role