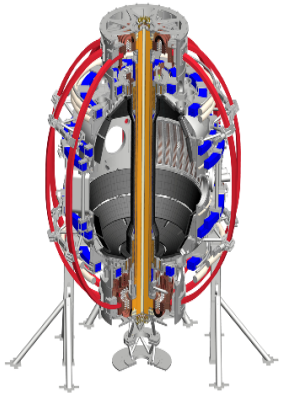
NSTX-U

NSTX-U is sponsored by the
U.S. Department of Energy Office of Science
Fusion Energy Sciences

Advancing understanding and predictive capability for fast-ion driven instabilities and associated anomalous transport in NSTX-U

Neal A. Crocker (UCLA) and Zhihong Lin (UCI)

NSTX-U External Collaborators Meeting – Feb. 15, 2021



UCLA/UCI grant supports Expt.+Theory effort focused on fast-ion physics and transport

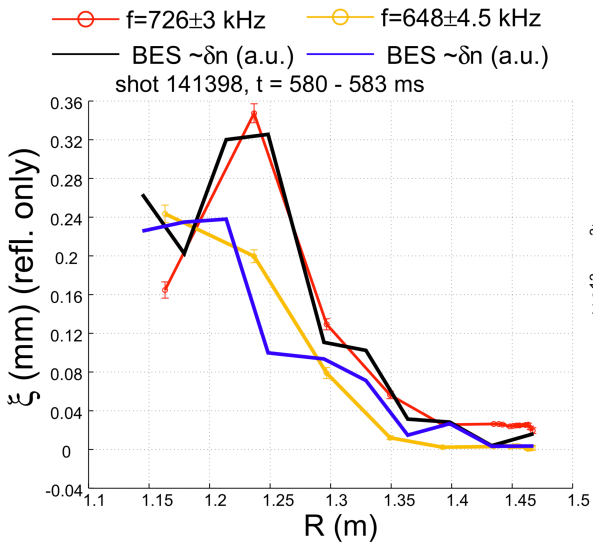
- **Collaboration between UCLA and UCI**
- **Research goals support NSTX-U Objective 1:**
  - *Experimental investigation of anomalous fast-ion & energy transport from broad range of modes (from BAE to CAE/GAE) in new NSTX-U regime (higher IP, B_T, β, P_{NB}, more tangential injection) (UCLA)*
  - *Validation of physics models in GTC and HYM for simulating fast-ion modes and their fast-ion and energy transport (UCLA/UCI)*
    - *GTC: BAE/RSAE/TAE, CAE/GAE, potentially ICE*
    - *HYM: CAE/GAE*
  - *Verification of GTC with HYM and linear theory for CAE/GAE (UCI)*
- **Indirect support for NSTX-U Objective 2:**
  - *investigation of anomalous fast-ion transport in noninductive scenarios*
- **UCLA + UCI currently collaborate on MAST-U under separate funding**

UCLA/UCI collaboration organization and key needs

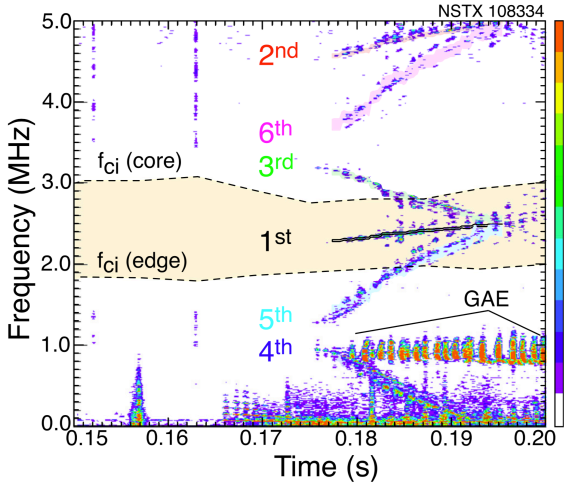
- UCLA effort:
  - Starts July 2022 (~ end of recovery); minimal funding before
  - Off site: Neal Crocker (1/4 time), Clive Michael (1/3 time)
  - On site: staff scientist (full time), graduate student (full time)
- UCI effort:
  - Started 9/2021
  - Off site: Zhihong Lin and graduate student
- Need office space for UCLA scientist + student
- Need support for verification and validation of PPPL code HYM (author: Elena Belova)

NSTX-U will feature powerful diagnostics for AEs

- Arrays of internal fluctuation diagnostics probe structure & amplitude up to CAE/GAE frequencies
  - BES
  - Reflectometry
    - 1st harmonic ICE may also be possible
- External Magnetics broadband sensitivity up to low ICE harmonic frequencies



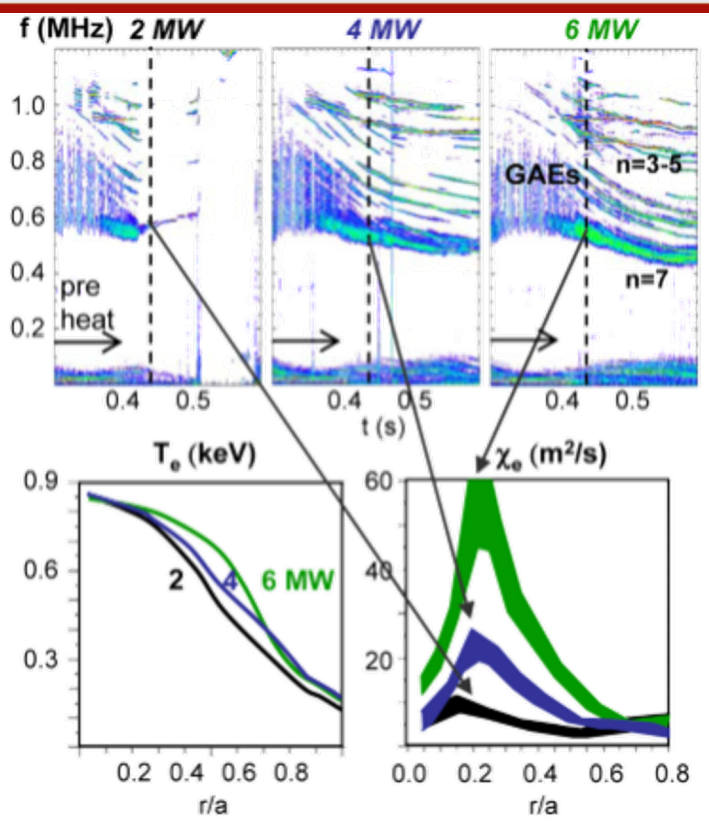
[K. Tritz APS DPP Invited 2010]



[E. D. Fredrickon PoP 2019

CAEs & GAEs candidates for core energy transport in NSTX ⇒ what about NSTX-U (higher P_{NB}, …)

- CAEs & GAEs excited by Doppler-shifted cyclotron resonance with beam ions
  [N. N. Gorelenkov, NF 2003]
- CAE & GAE activity correlates with enhanced χ_e in core
  [D. Stutman, PRL 2009; K. Tritz, APS 2010 Invited Talk; N. A. Crocker, PPCF 2011]
  - T_e profile flattens as P_{NB} increases
  - χ_e from TRANSP modeling
- Two leading hypotheses:
  - Stochastization of e^- guiding center orbits enhance χ_e [NN Gorelenkov, NF 2010]
  - Coupling to KAWs = missing transport channel ⇒ TRANSP χ_e wrong [Ya.I. Kolesnichenko, PRL 2010, E.V. Belova, PRL 2015]

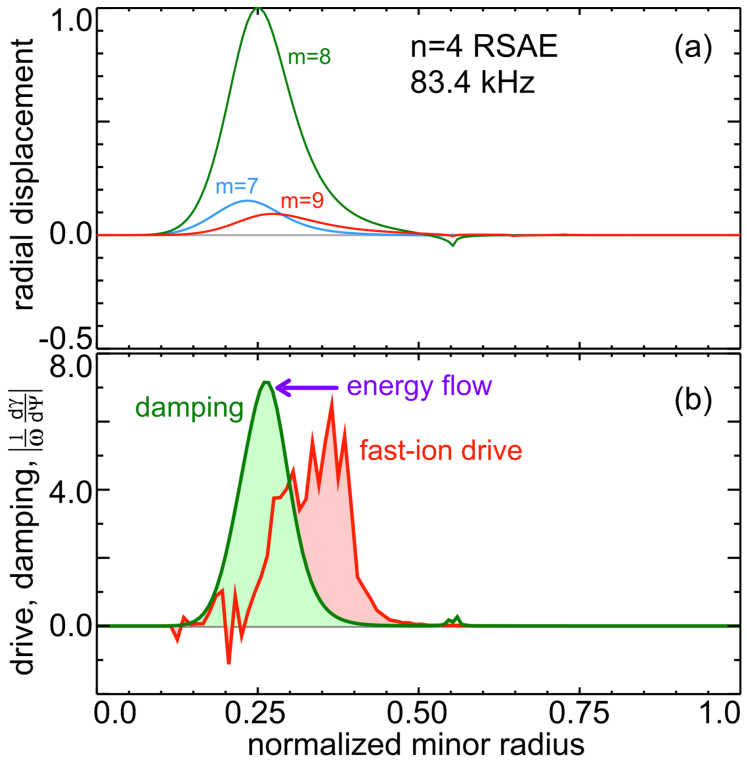


[D. Stutman et al., PRL 102 115002 (2009)]

BAE/RSAE/TAE potentially transfer/transport energy from fast-ions to thermal plasma ⇒ power balance impact?

- modeling/simulation shows energy transfer from fast-ions to thermal plasma via multiple mechanisms, sometimes across space (i.e. transport)
- NOVA-K adapted to evaluate energy transport [GJ Kramer NF 2019]
- GTC self-consistently simulates a broad range of mechanism [W Deng NF 2012, Y Liu NF 2017]

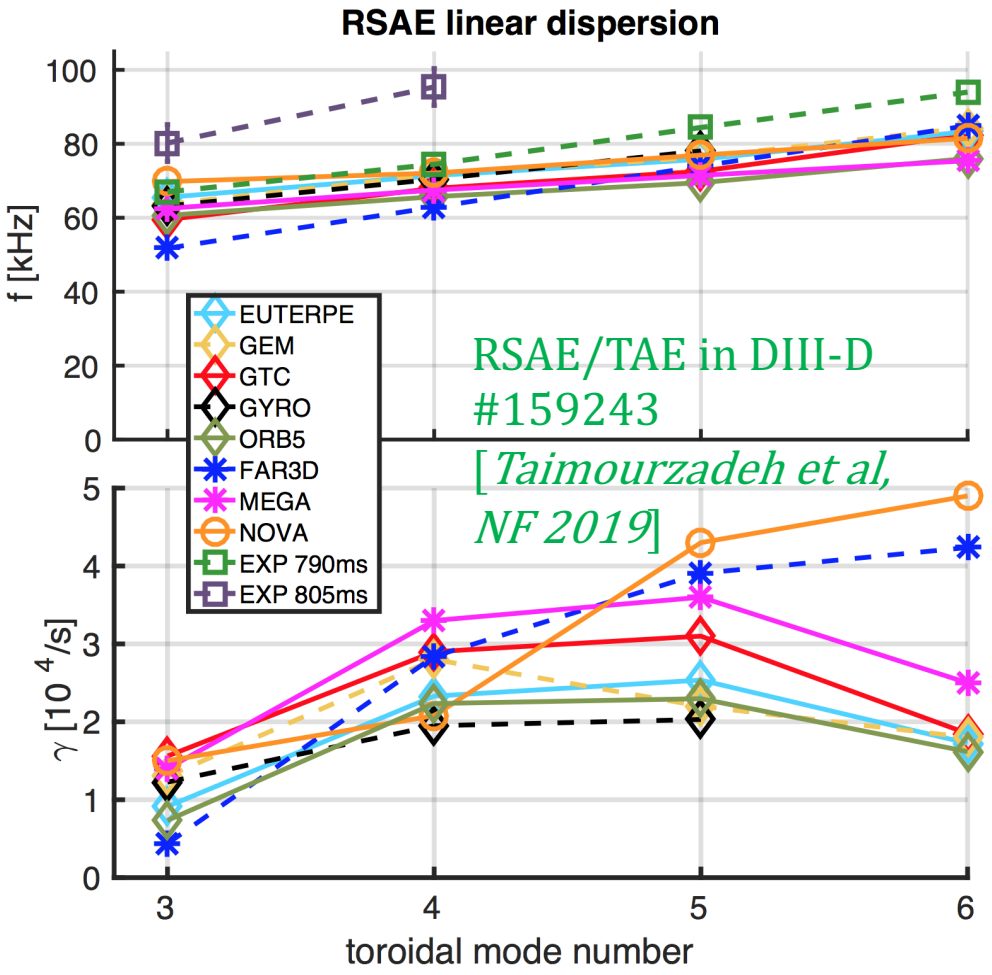
Modeling with adapted NOVA simulation results



[G.J. Kramer NF 2019]

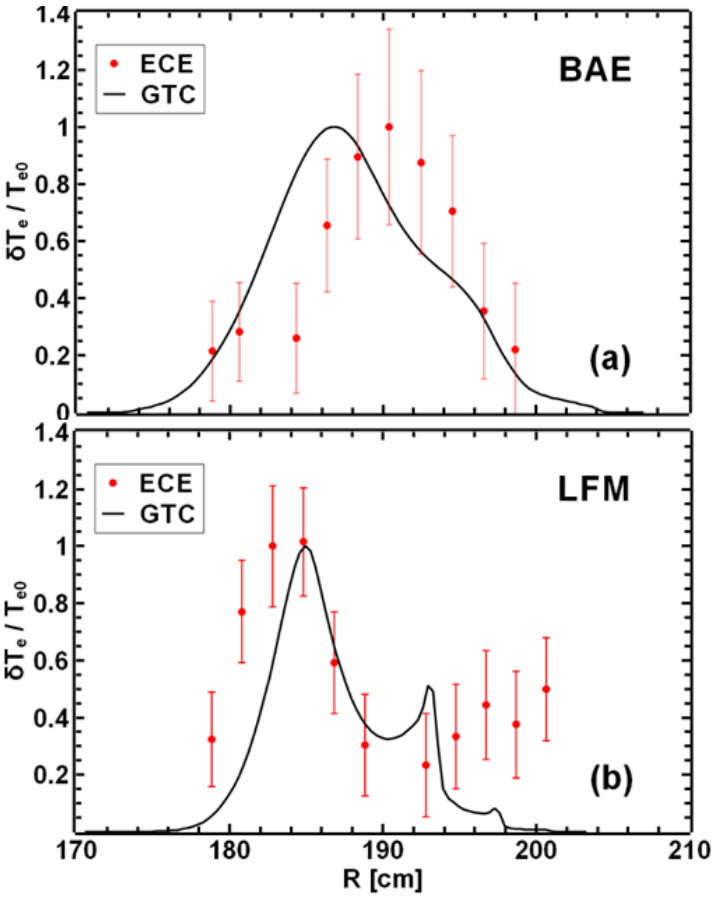
Recent V&V of GTC simulations of RSAE/TAE in DIII-D show good agreement ⇒ Extend to NSTX-U

- Good agreement in frequency f: 5% variations
- Growth rate γ: 17% variations for n=4 & 5
- Frequency f agrees better with experiment at 790ms
- Simulations use profiles at 805ms



GTC simulations of BAE/LFM undergoing validation for structure predictions in DIII-D

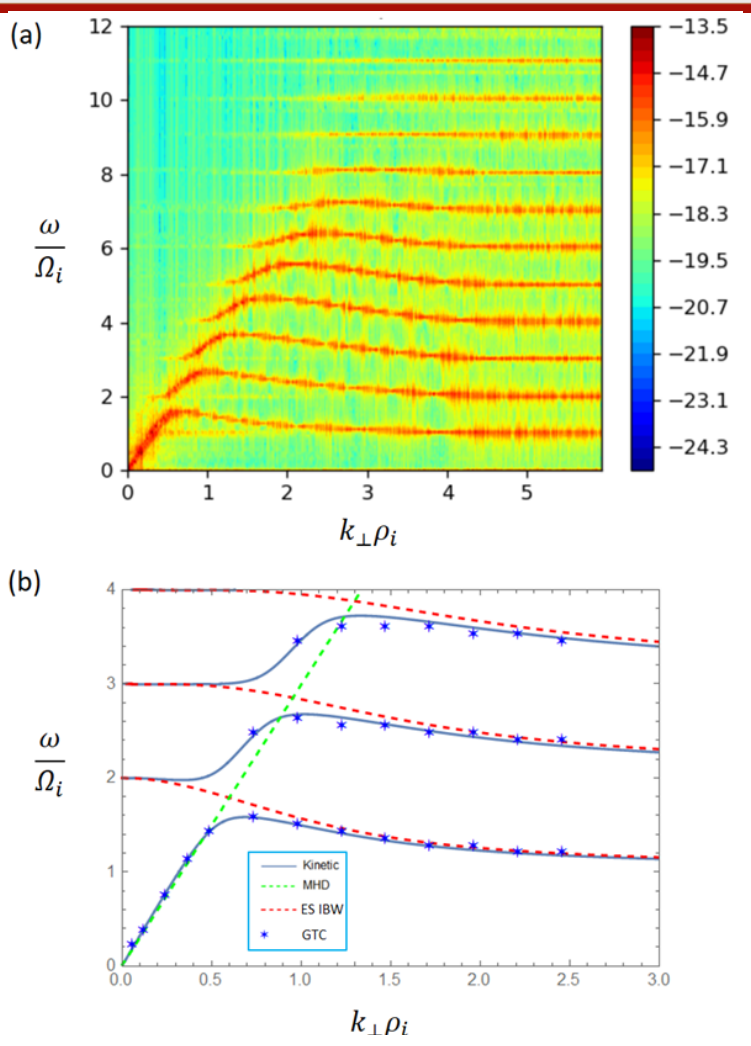
- LFM: low frequency mode (interchange-like), sometime identified as "BAAE" in DIII-D.
- radial structures from simulations show reasonable agreement with measurement
- frequencies show significant differences
  - simulation & measurement make approximations on plasma flows – relatively significant for low frequency of BAE/LFM



BAE/LFM in DIII-D #178631 [*Choi et al, NF 2021*]

Verification of GTC simulation of CAE/ICE

- Simulation model
  - Fully kinetic (6D) Vlasov equation for ions (FKi)
  - Drift kinetic equation for electrons (DKe)
  - Poisson equation for electrostatic potential ($\delta\phi$)
  - Parallel Ampere's law for parallel vector potential ($\delta A_\parallel$)
  - Perpendicular electron force balance for compressible magnetic perturbation ($\delta B_\parallel$)
- Verification of linear simulation of CAE/ICE
  - Massless electron, perpendicular propagation ($k_\parallel = 0$)
  - Simulation with all $k_\perp$ exhibits CAE/ICE (upper panel)
  - Simulations with a single $k_\perp$ agree with dispersion relation from kinetic theory (lower panel)



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UCLA – Planned research activities for 5 Year Period

Y1–Y2:
- Initial planning/scoping for experiments
- Collaborate with UCI and NSTX-U researchers to develop GTC BES synthetics diagnostics.

Y3:
- Collaborate to validate analytic theory (Lestz 2020) and HYM for GAE/CAE
  - Extend measured scaling of GAE/CAE properties & energy transport to **BT <= 0.85, higher P_{NB} & β**
  - Measure CAE/GAE mode structure; Compare with HYM
  - Experiment to investigate **more tangential NBI** on CAE/GAE
- Experiments to validate for BAE/TAE/RSAE stability and frequency
- Collaborate to with UCI to develop GTC reflectometer synthetics diagnostics

Y4:
- Collaborate to validate analytic theory, HYM and GTC for GAE/CAE
  - Extend measured scaling of GAE/CAE properties & energy transport to **BT <= 1 T, full beam power, even higher P_{NB} & β**
  - Measure CAE/GAE mode structure; compare with HYM and GTC
- Experiments to investigate to BAE/TAE/RSAE energy transport
- Collaborate to validate GTC for BAE/TAE/RSAE stability and frequency and fast-ion transport

Y5:
- Collaborate to validate GTC and HYM for CAE/GAE energy transport
- Collaborate to validate GTC for BAE/TAE/RSAE for energy transport
- Experiments to investigate interaction of AEs with turbulence

UCLA

UCI – Planned research activities for 5 Year Period

Y1:

- Verify GTC FKi/fluid electron simulation of GAE/CAE in simple tokamak geometry using analytic theory and HYM

Y2:

- Benchmark GTC/HYM simulation of GAE/CAE in NSTX
- Develop GTC BES synthetics diagnostics

Y3:

- Benchmark GTC/HYM simulation of GAE/CAE in NSTX-U
- Assist UCLA on GTC GKi/DKe simulation with $\delta B_{\parallel}$ of BAE/TAE/RSAE in NSTX-U
- Develop GTC reflectometer synthetics diagnostics

Y4:

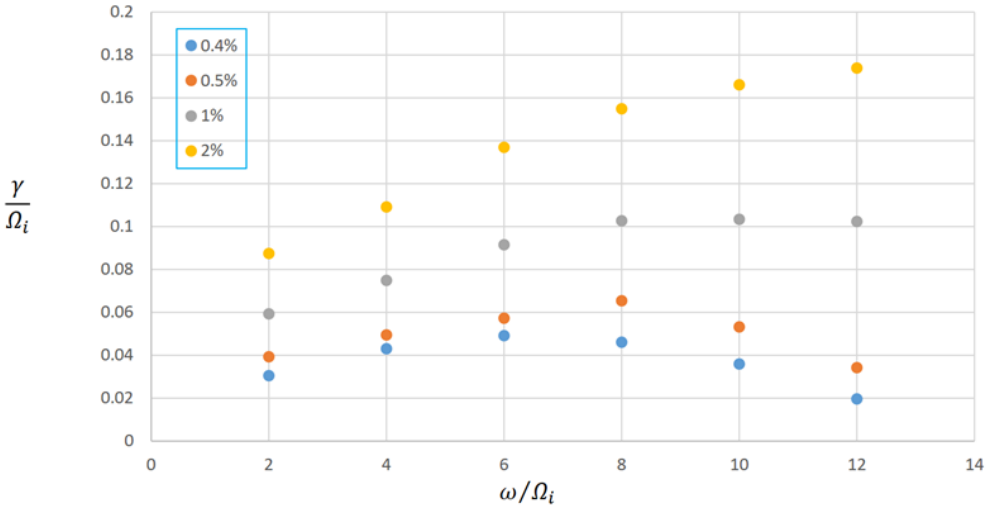
- Validate FKi/DKe simulation of GAE/CAE in NSTX-U using BES/reflectometer data
- Assist UCLA on validating GKi/DKe simulation of BAE/TAE/RSAE in NSTX-U
- Study fast-ion transport by AEs

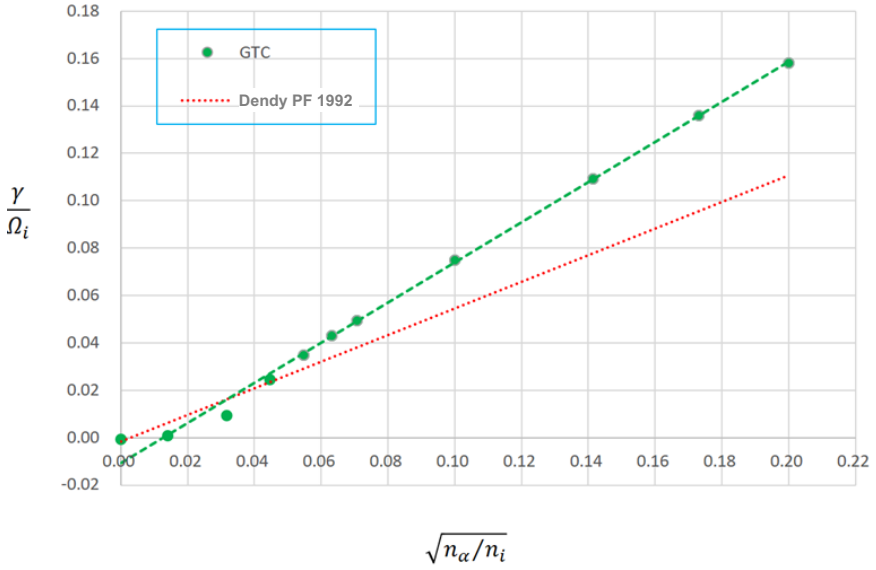
Y5:

- Study electron heat transport by GAE/CAE in NSTX-U
- Assist UCLA on studying electron heat transport by TAE/RSAE in NSTX-U
- Simulate AEs and microturbulence interaction in NSTX-U

UCI – Progress since funding: GTC simulation of ICE excitation by α-particles

- Magnetoacoustic cyclotron instability (MCI) driven by α-particles with population inversion
- Higher harmonics excited by higher α-particle density n_α (left panel)
- Growth rate $\gamma \propto \sqrt{n_\alpha}$: qualitative agreement with Dendy PF 1992 (right panel)
- Near term plan: verification of GAE/CAE with $k_{||} \neq 0$; benchmark with HYM for GAE/CAE conventional tokamak





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