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Gyrokinetic GENE simulations for the JT-60SA reference scenario

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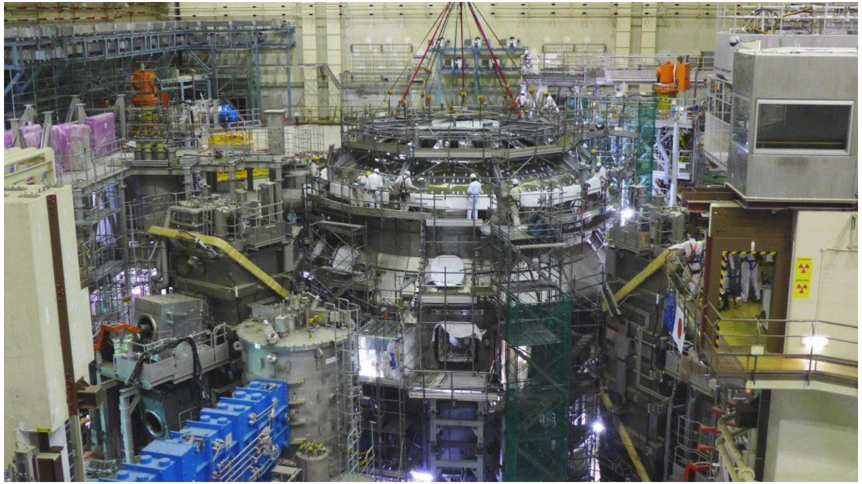
Background

JT-60SA tokamak:

- High β
- Long pulse operation
- 41 MW of heating
- **First plasma last year!**



Modelling of JT-60SA turbulence (including core) is one of the current tasks

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Reference scenarios

B_t	2.25 T
I_p	5.5 MA
R/a	2.96/1.18 m
A	2.5
κ/δ	1.93/0.5
V_p	133 m^3
t (flat-top)	100 s
H&CD power	41 MW
N-NBI (500 keV)	10 MW
P-NBI (85 keV)	24 MW
ECRH (82, 110, 138 GHz)	7 MW

	#1 Inductive	#2 Inductive
Configuration	DN	SN
I_p (MA)	5.5	5.5
B_T (T)	2.25	2.25
q_{95}	3.2	3
P_{add} (MW)	41	41
$P_{NNB}/P_{PNB}/P_{EC}$	10/24/7	10/24/7
$\bar{n}_e$ (10^{19} m^{-3}) $/f_G$	6.3/0.5	6.3/0.5
β_N	3.1	3.1

[G Giruzzi et al 2020 Plasma Phys. Control. Fusion 62 014009]

GENE code

- Gyrokinetic delta-f simulations with multiple kinetic species
- Global or local (flux-tube modelling)
- Linear and nonlinear simulations
- Electric and magnetic field fluctuations
- Field aligned geometry – radial (**x**), binormal (**y**) and parallel (**z**) grid

[Jenko F., et al. 2000 Phys. Plasmas 7]

- Will provide us with heat fluxes which can be compared to expected values (heating power)

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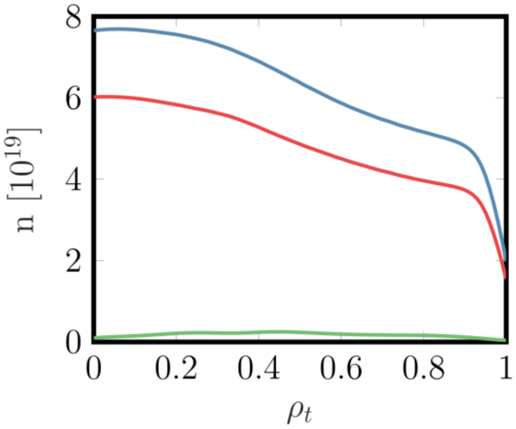
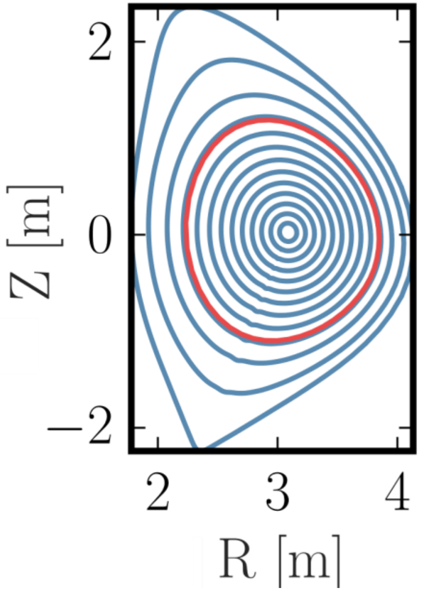
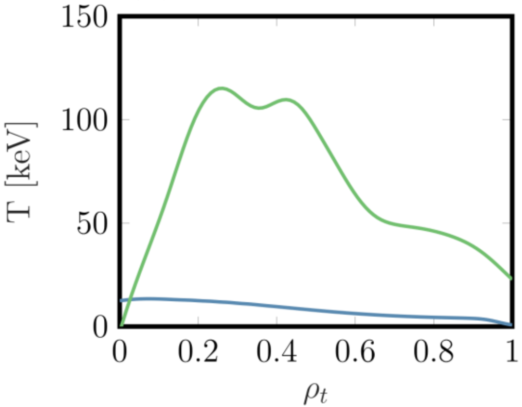
S1 reference profiles

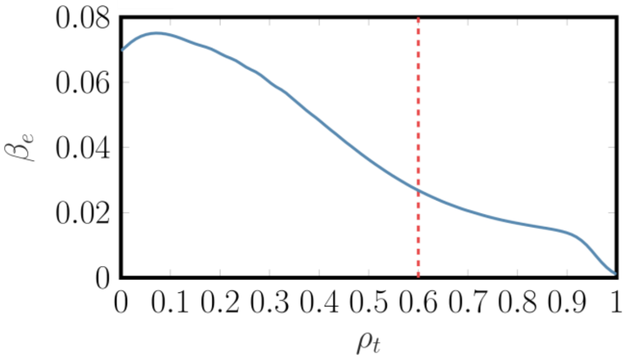
- GENE modelling carried out at $\rho_{toroidal}$=0.6
- Same electron and ion temperature
- 4 kinetic species (electrons, ions, carbon, fast ions)
- Fast ions temperature is about 10 times higher
- Results published in :

[A. Iantchenko et al 2024 Nucl. Fusion 64 026005]





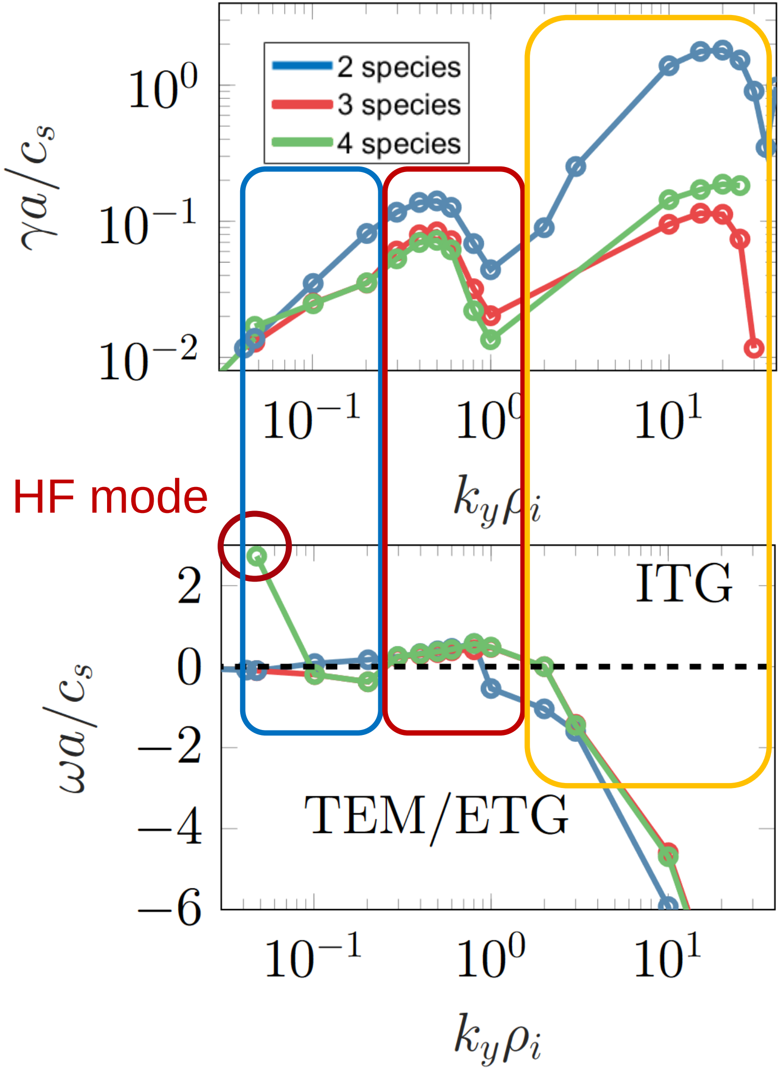




S1 linear modelling

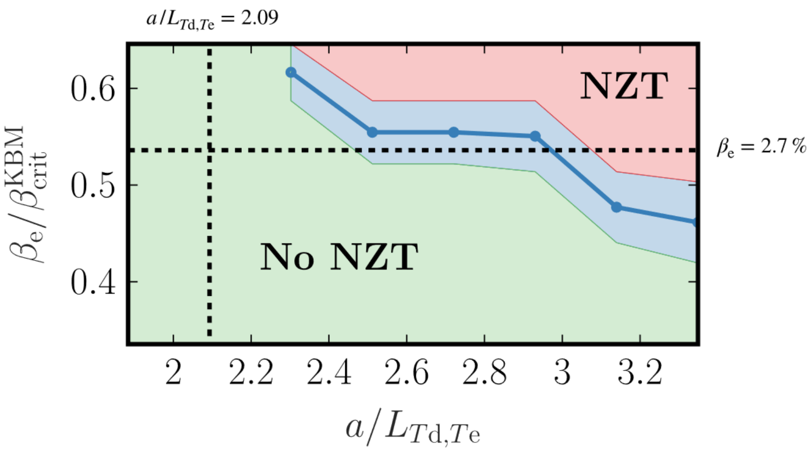
Linear GENE modelling:

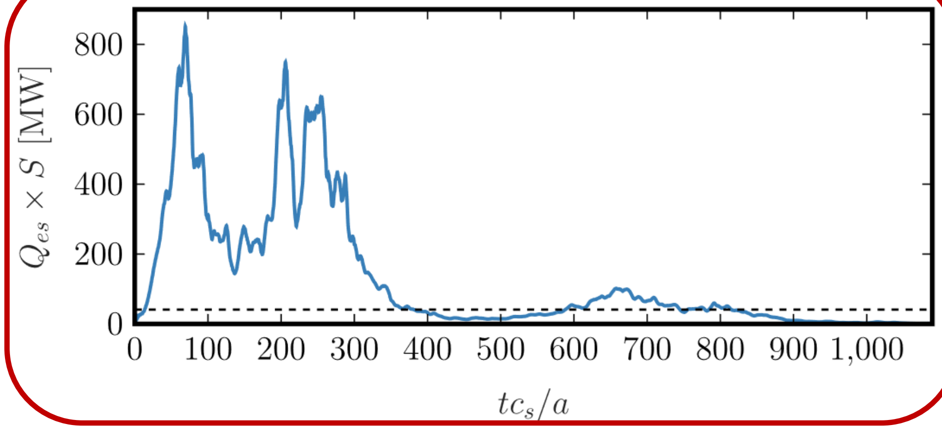
- MTM -> ITG –> ETG
- ETG growth rate not significant
- Growth rate goes down with additional species
- High frequency mode in 4 sp. case

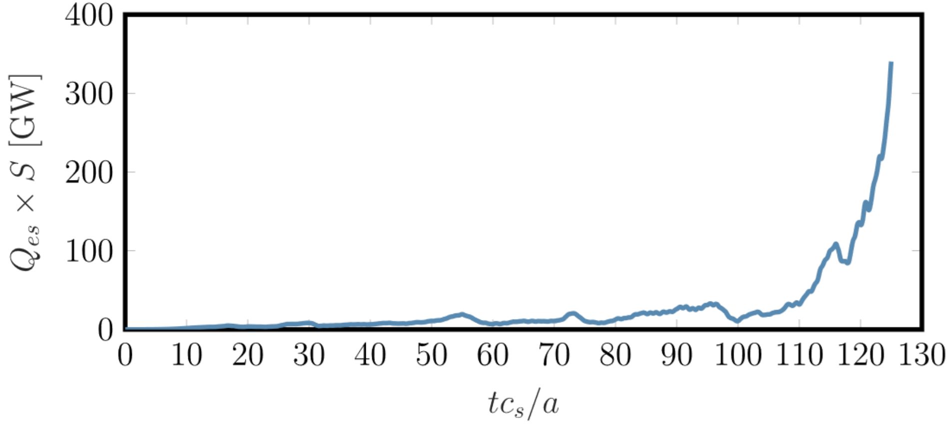


S1 two species modelling

- Default heat flux too low
- Increasing gradients causes runaway of heat flux due to non-zonal transition (NZT)







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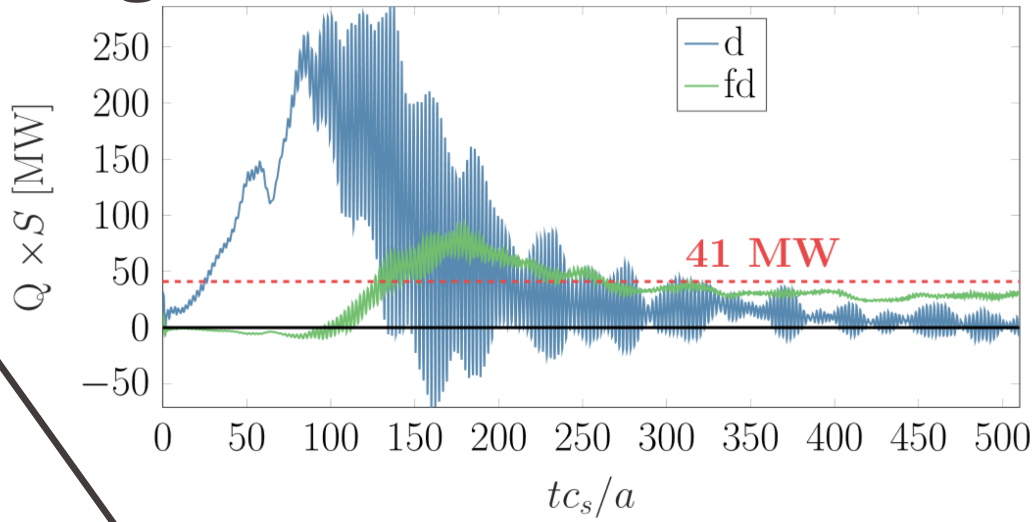
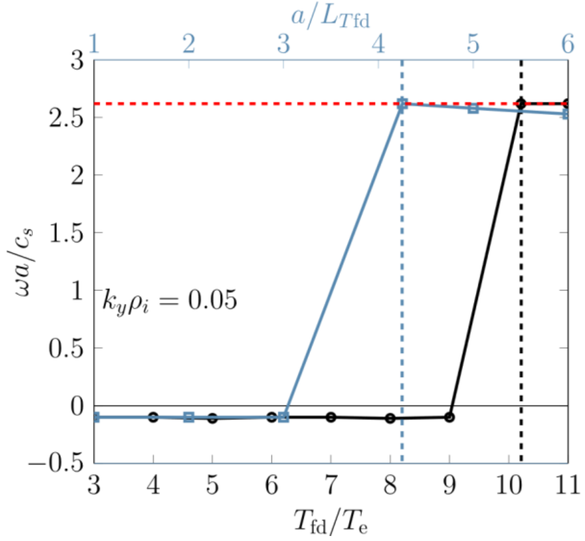
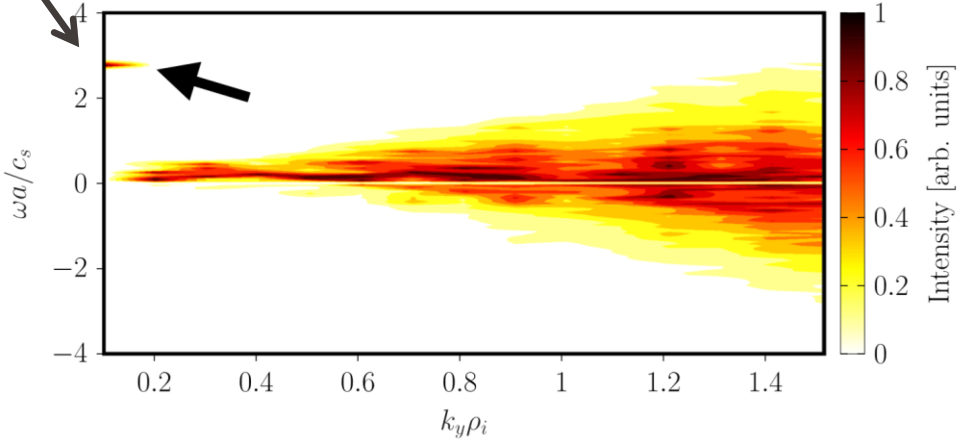
S1 four species modelling

- Heat flux too low again
- **High frequency mode** dominating the heat flux
- Mode goes away at lower T_{fd} linearly.

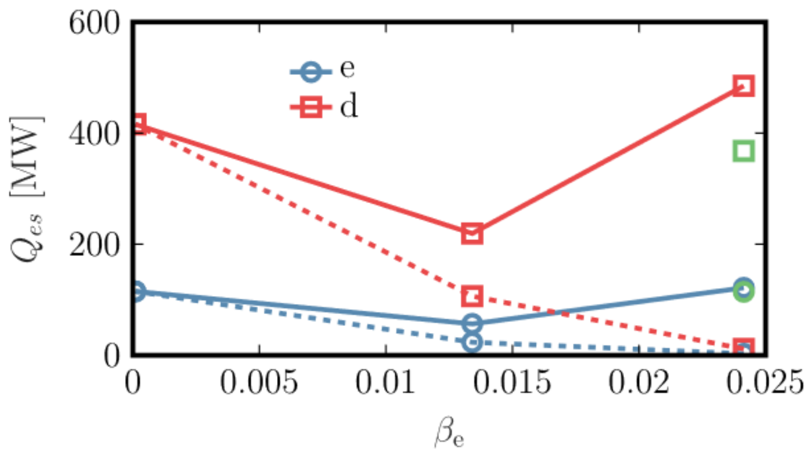


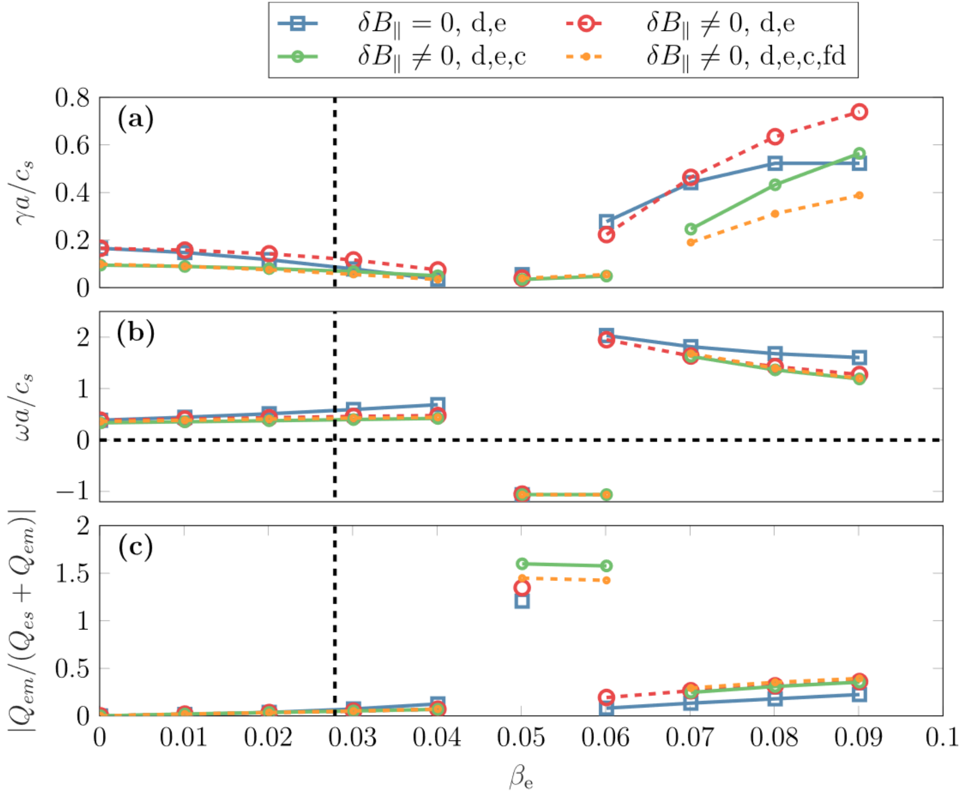




Bpar fluctuations

- Inclusion of parallel magnetic field fluctuation is crucial





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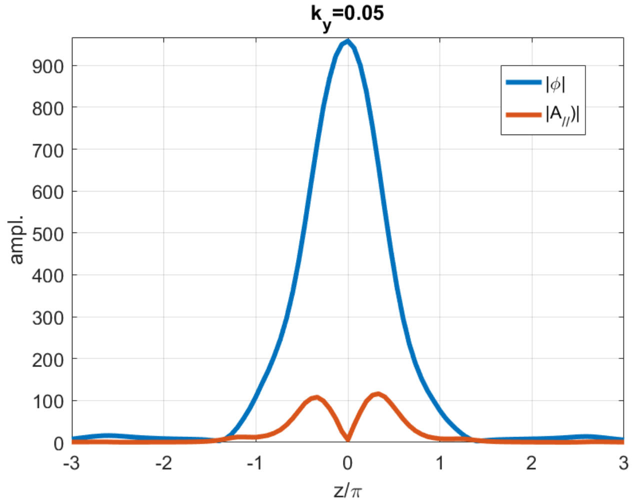
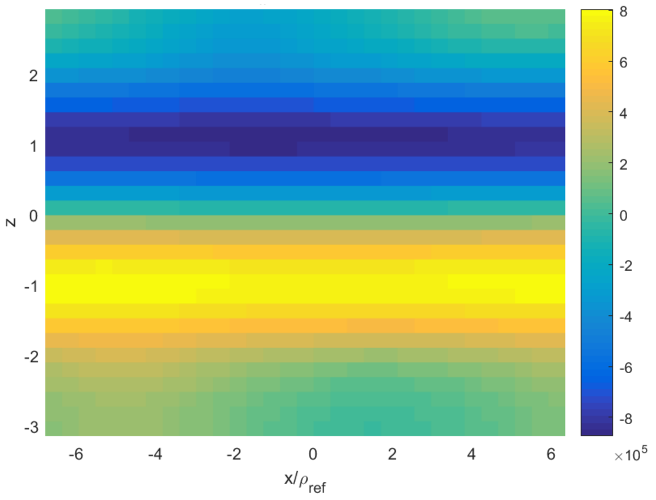
HF mode

- Not a tearing mode
- Not peaking at the center of flux tube
- Frequency comparable to Alfven frequency (144 kHz vs 105 kHz)

The HF frequency mode connected to TAE beating?

[Ajay C. 2024 arXiv:2404.18910]





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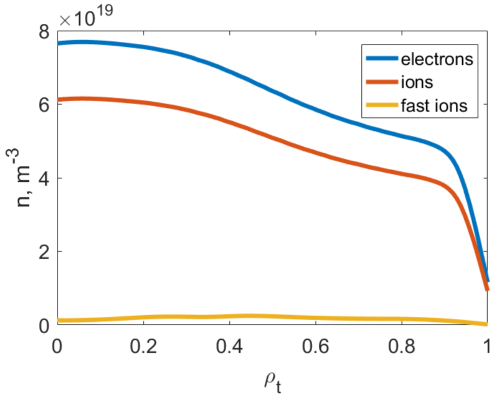
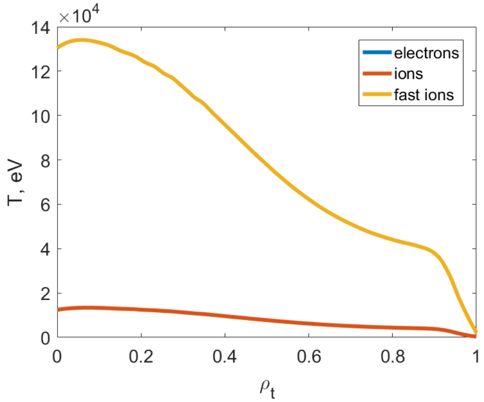
Scenario 1 summary

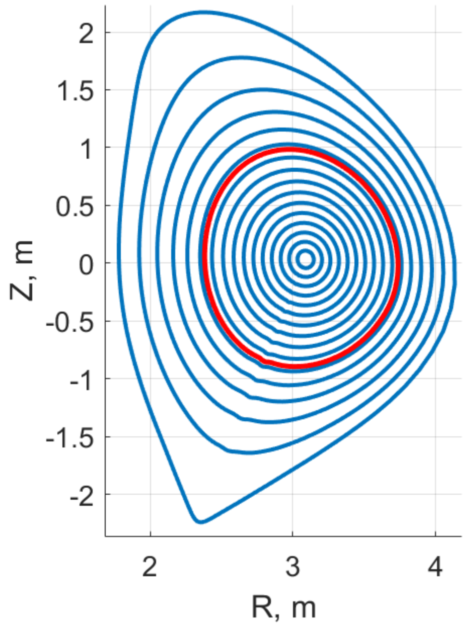
- Nominal heat fluxes are too low to account for the heating power.
- Small increase of the profile gradients results in NZT, sensitive also to β_e.
- Modelling with fast ions is complicated by a high frequency mode (possibly TAE?)
- Correct inclusion of the electromagnetic effects is important

S2 reference profiles

- GENE modelling carried out at ρ_t=0.5
- Similar profiles to the previous case
- Simulations carried out at 10x and 20x background temperature for fast ions
- **GENE simulations are still underway**



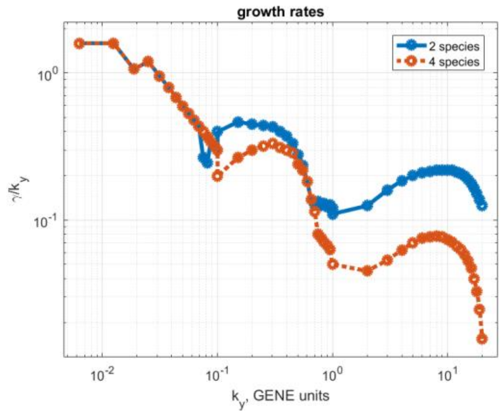


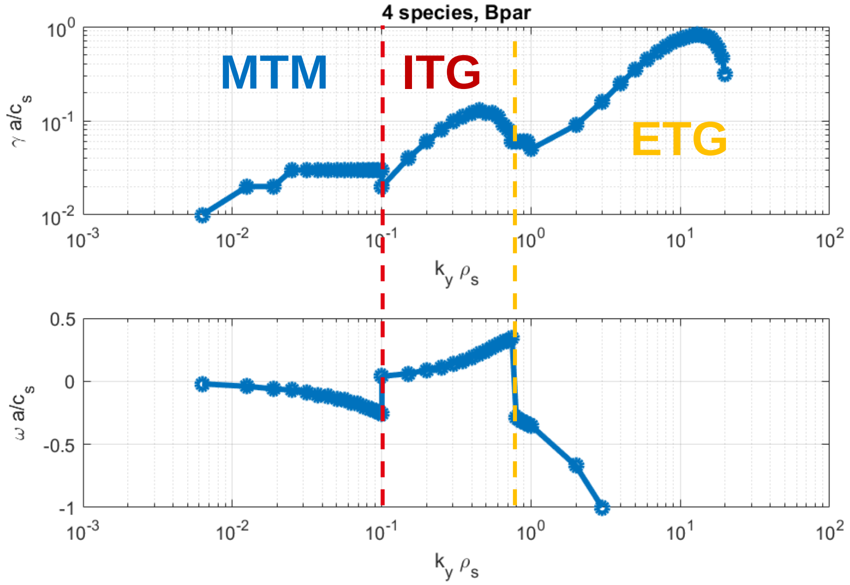


S2 linear modelling

Linear GENE modelling:

- MTM -> ITG –> ETG
- ETG growth rate not significant
- Growth rate goes down with additional species
- No high frequency mode

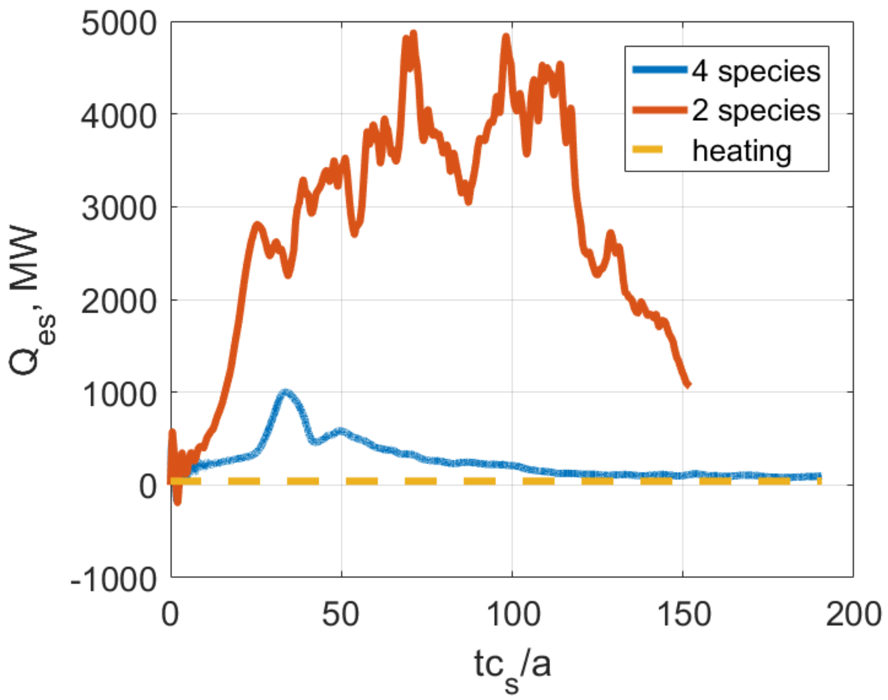




S2 nonlinear modelling

ITG scale modelling

- Heat flux about 200% of expected
- NZT still present at higher gradients
- No strong HF mode
- **2 species case still in progress, but much larger heat flux**

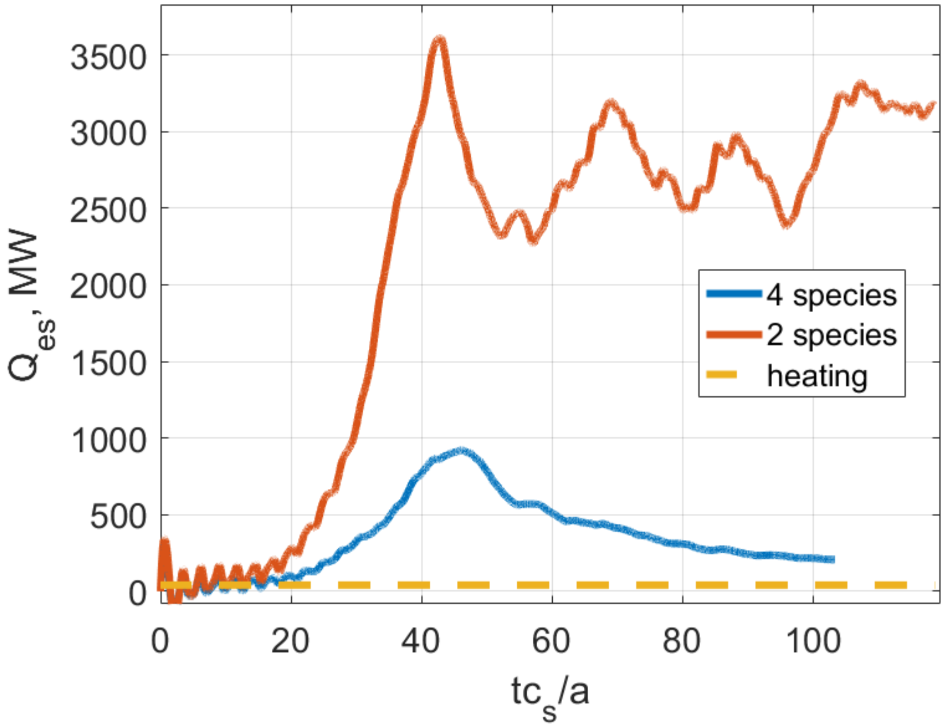


S2 nonlinear MTM modelling

Resolving MTMs:

- Challenging to resolve
- Heat flux still decreases with additional species
- No HF mode

Still a work in progress!



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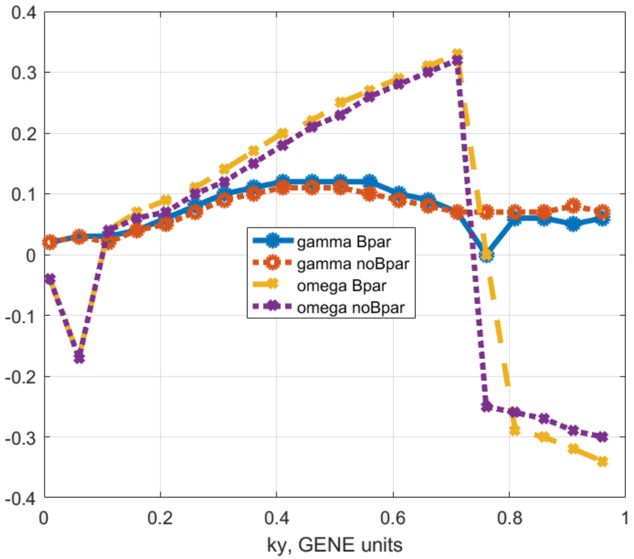
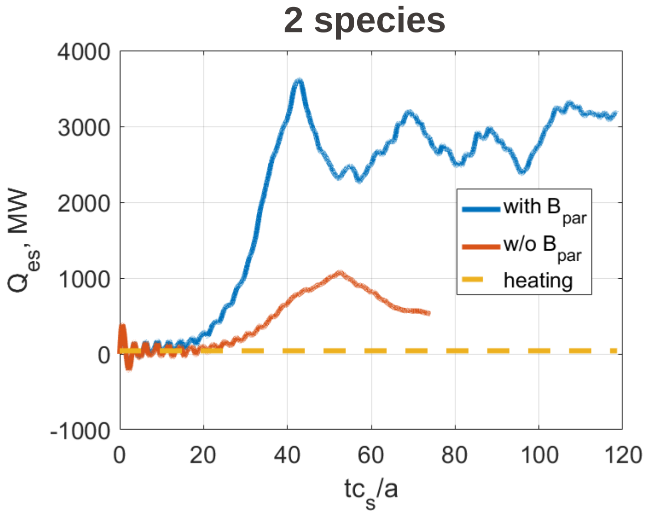
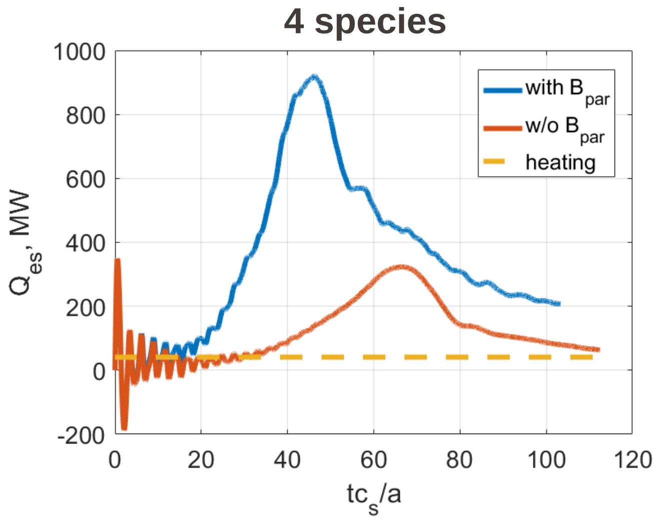
B_{par} fluctuations

- No strong linear effect of B_{par} linearly
- Still a strong nonlinear effect
- Consistent with S1 case







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S2 summary

- ~~Nominal heat fluxes are too low to account for the heating power.~~ Heat flux is overestimated in the simulations
- Small increase of the profile gradients results in NZT, sensitive also to β_e.
- ~~Modelling with fast ions is complicated by a high frequency mode (possibly TAE?)~~ HF mode has no significant impact
- Correct inclusion of the electromagnetic effects is important

Conclusions

- Gyrokinetic GENE simulations were carried out for the reference scenarios of JT-60SA
- Unique parameters of the tokamak make electromagnetic modes play an important role in the core region
- Electromagnetic effects need to be accounted for correctly (including δB_{par})
- Order of magnitude of expected heat fluxes was recovered for some cases, but strong sensitivity to profile gradients and the equilibrium was observed

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Next steps

- Confirming the nature of the HF mode
- Converging S2 simulations
- Analysis of additional radial positions
- Simulations with three species to confirm the role of fast ions

Thank you for your attention!

Extra

T_d/T_e	1	a/L_{nc}	0.72
a/L_{Te}	2.09, 2.3 (2.51)	a/L_{nfd}	1.72
n_d/n_e	0.77	a/L_{Td}	2.09, 2.3 (2.93)
$\epsilon = a/R$	0.51	n_c/n_e	0.03
Z_{eff}	2	n_{fd}/n_e	0.03
β_e	2.7% (2.4%)	a/L_{Tfd}	4.25
n_e $[10^{19}]$	5.87 (5.28)	T_e [keV]	6.27

q_0	1.16
$\hat{s}$	1.55
T_{fd}/T_e	10.22 (8)
a/L_{ne}	0.72, 0.8 (0.87)
a/L_{nd}	0.68, 0.77 (0.87)
$\nu_{ei} c_s/a$	0.045 (0.04)
B_0 [T]	2.35