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Flux-driven multi-channel simulations with the quasilinear gyrokinetic transport model QuaLiKiz

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Executive summary:

- Successful transport model validation vs a JET hybrid and baseline discharge
- First-principle-based heat, particle, impurity and momentum transport
- 1s of JET plasma evolution modelled in ~10h with 10 cores

1. The need for fast turbulent transport models

Resolving dynamics of tokamak discharge evolution demands reduced turbulence models

Hierarchy of model reduction for calculation of flux at one radial point

Full Maxwell-Vlasov → local nonlinear gyrokinetic (~10^4 - 10^5 CPU.h)

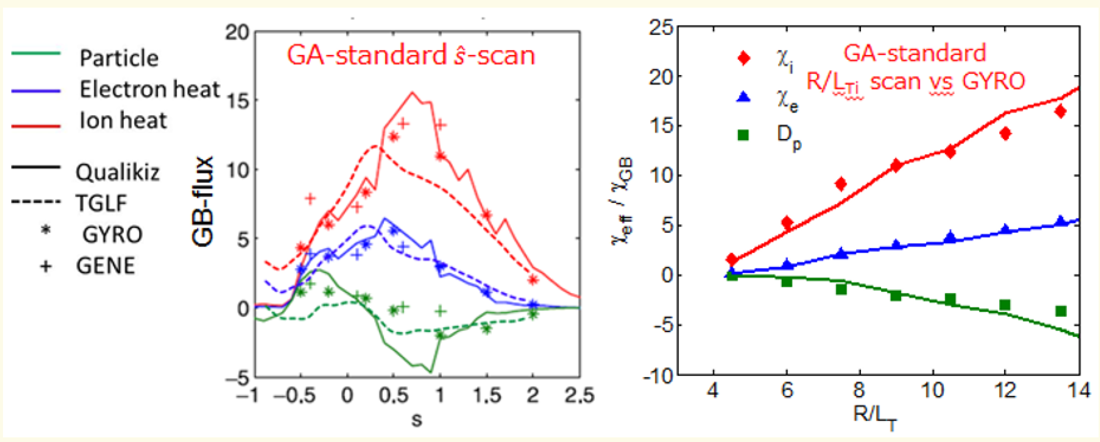
Nonlinear gyrokinetic → quasilinear gyrofluid/gyrokinetic (~10 CPU.s)

Quasilinear models allow tractable simulations of profile evolution ~10h with 10 CPUs for 1s for JET plasma

Quasilinear assumptions valid when $\frac{\delta n}{n} \sim O(\%)$, as in the confined region [1]

We apply the QuaLiKiz gyrokinetic quasilinear transport model [2,3]

Validation of QuaLiKiz fluxes by nonlinear simulations



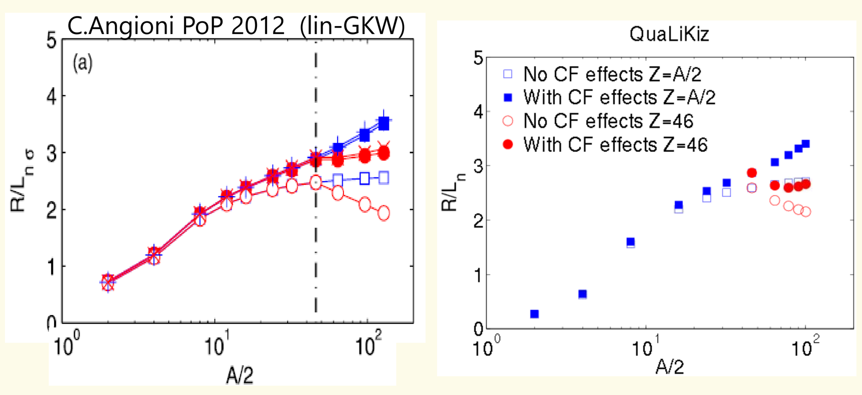
2. Recent QuaLiKiz upgrades: factor ~50 speedup, ready for extensive use in integrated modelling

- Arbitrary number of ion species
- Impact of heavy impurity poloidal asymmetries. Necessary for W-transport integrated modelling [4,5]
- ETG saturation rule based on recent (single scale) JET nonlinear gyrokinetic simulations [6])
- Optimization of dispersion relation root finder: speedup of factor ~10-30!
- Plasma dispersion functions with Weideman method (Gürcan JCP 2014). Speedup factor ~2
- Ready for extensive integrated modelling: Coupled to CRONOS [7], and to JETTO-SANCO [8,9] through TCI interface.

Test of poloidal asymmetry modification of trace heavy impurity transport

Test zero-flux R/Ln versus ITG test case published in Angioni PoP 2012

$k_y \rho_s = 0.3, q = 1.4, \hat{s} = 0.8, \frac{R}{L_{Ti}} = 9, \frac{R}{L_{Te}} = 6, \frac{R}{L_n} = 2, \epsilon = \frac{1}{6}, M = 0.1, \frac{R}{L_u} = 5$



Correspondence generally within ~10%

1 CPU.s computation time in QuaLiKiz

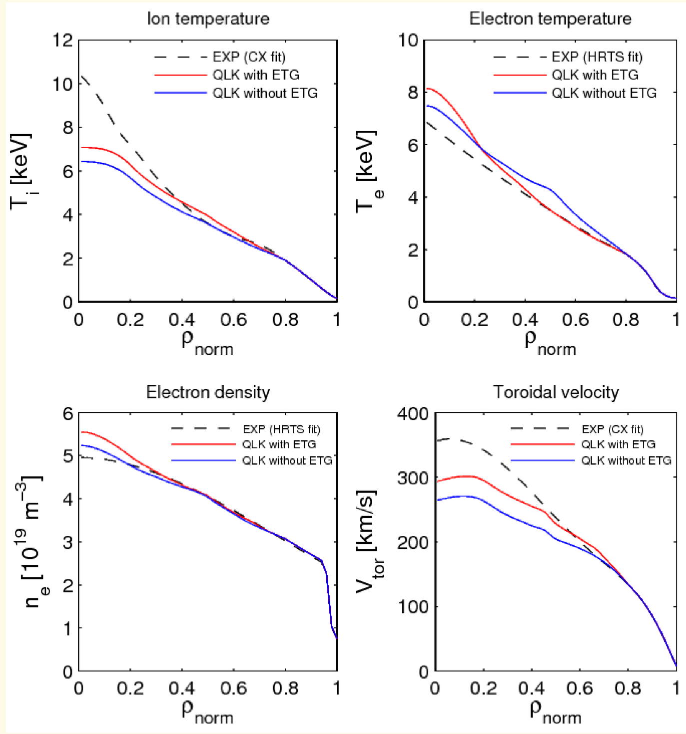
3. Hybrid scenario modelling with QuaLiKiz in JETTO-SANCO: heat, particle, impurity, and momentum transport

QuaLiKiz dynamic modelling with rotation and momentum transport [10]

C-wall hybrid scenario JET 75225 (1.7MA/2T)

Comparison with and without ETG-scales

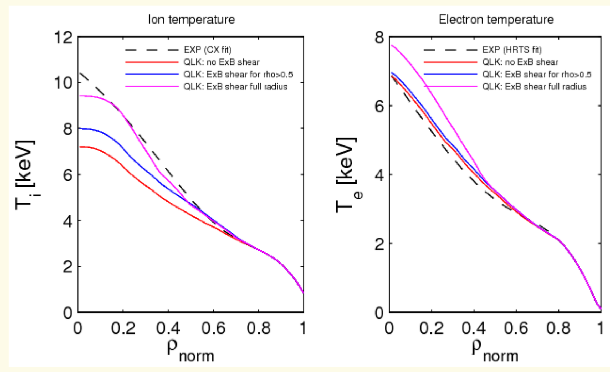
Time window averaged between 6-7s



- Multi-channel agreement at $\rho > 0.5$
- For $\rho < 0.5$, T_i underprediction due to lack of EM effects in QLK [11]
- ETG scales important for agreement

- Boundary condition at $\rho = 0.8$
- Stable for $\rho < 0.2$. No patch inserted
- Includes impact of rotation ($\rho > 0.5$)

Sensitivity to rotation settings



Caveats:

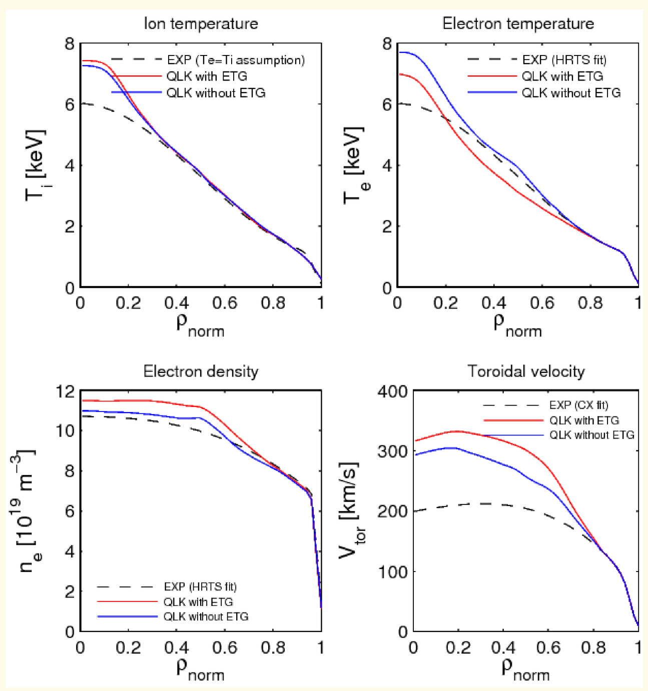
- α-stabilization not kept for $\rho < 0.5$. QLK overpredicts stabilization compared to linear-GENE
- ExB shearing not kept for $\rho < 0.5$. Shown to have weak impact in inner core [11]. Also, QLK likely underestimates parallel velocity gradient destabilization

4. Baseline scenario modelling with JETTO-SANCO

Comparison with and without ETG-scales

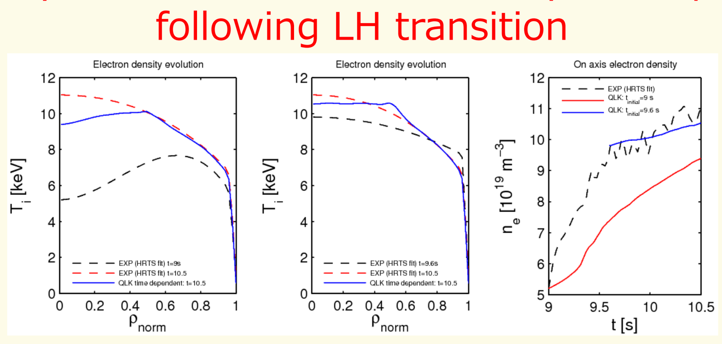
Time window averaged between 10-10.5s

ILW baseline scenario JET 87412 (3.5MA/3.35T)



- Boundary condition at $\rho = 0.85$
- Stable for $\rho < 0.2$. No sawtooth model
- For comparison, T_i=T_e assumed due to poor inner core CX.
- Good agreement apart from V_{tor}. NTV torque due to NTMs flatten profile?
- ETG scales worsen agreement. ITG-ETG multiscale effects may be in different regime [12]. Need multiscale model in QuaLiKiz

Dynamic simulation of density buildup following LH transition

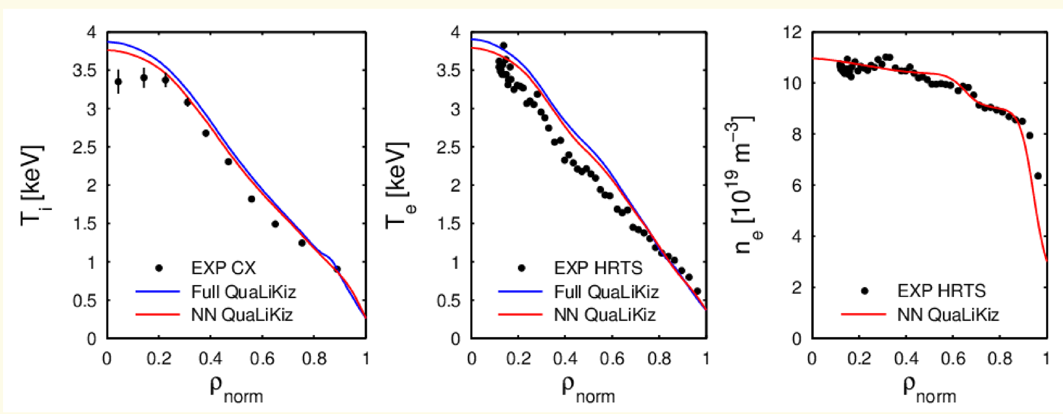


- Anomaly in early phase 9-9.6s
- General trend well captured

5. Neural network emulation of QuaLiKiz: faster than realtime

Integrated transport modelling accelerated to realtime. Neural network nonlinear regression of a QuaLiKiz output database. Proof-of-principle 4D input network [13]

JET 73342 at t~20s [14]. Integrated modelling within CRONOS



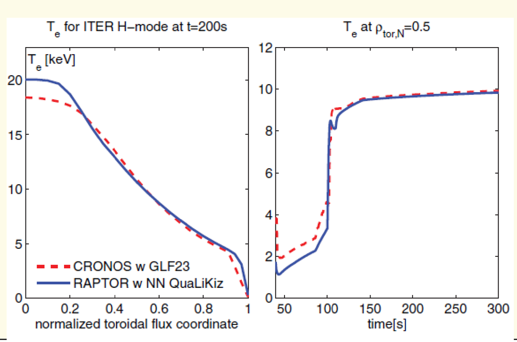
QuaLiKiz NN operational within $0.3 < \rho_N < 0.9$

Prescribed χ_i, χ_e, D, V outside this range (pedestal and saweeth)

Successful QuaLiKiz emulation, even for only a 4D input NN.

~0.5 CPU.h (NN) vs ~500 CPU.h (full QLK) for an energy confinement time

ITER scenario modelling with the QuaLiKiz NN in the realtime capable RAPTOR code [15] is 50 times faster than realtime!



6. Conclusions and perspectives

- QuaLiKiz quasilinear transport model significantly upgraded. Numerical optimization, additional physics, coupling to integrated modelling In JETTO-SANCO, models 1s of JET plasma in ~10h with 10 cores
- Successful validation vs 2 JET hybrid and baseline discharges Simultaneous heat, particle, impurity and momentum transport. Next step - integrated W-transport modelling
- Best agreement with physically motivated choices regarding α –stabilization and ExB shear settings. Improvements necessary for robustness
- ETG scales can be important. Multiscale model needed in saturation rule
- Realtime capable neural network emulation of QuaLiKiz developed. Validated proof-of-principle. Working on increased input dimensionality

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