First-principle-based integrated modelling of multiple isotope pellet cycles at JET

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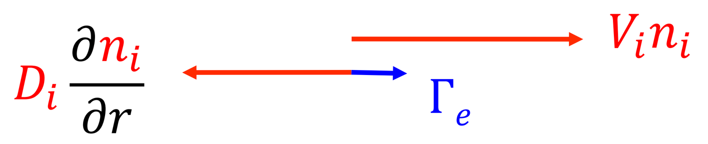
ABSTRACT

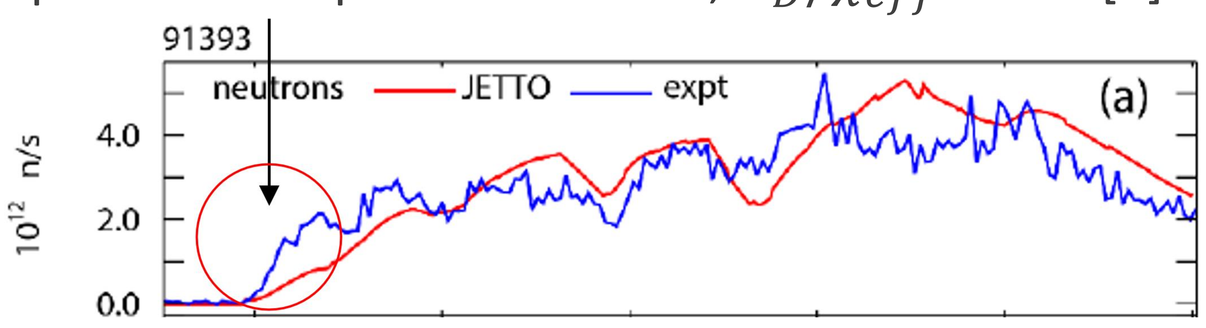
- Measurements of the isotope ratio profile inferred a fast deuterium penetration time, comparable to the energy confinement time.
- The pellet cycle of a mixed isotope tokamak plasma is successfully reproduced by integrated modelling.
- The modelling recovered the fast deuterium penetration time scale.

BACKGROUND

- $\boldsymbol{D_i \sim D_e}$ and $\boldsymbol{V_i \sim V_e}$ is often assumed in the modelling
- $\boldsymbol{D_i \gg D_e}$ and $\boldsymbol{V_i \gg V_e}$ is suggested by previous experimental observation [1]
- The theory predicts large ion transport coefficients for Ion Temperature Gradient (ITG) dominated plasma [2]
- A large diffusion can be balanced by a large pinch. Ambipolarity is maintained, but fast mixing is possible



- Interpretive modelling on experiment using pellets at JET suggested "large" ion particle transport coefficients, $D_D/\chi_{eff} \approx 0.4$ [3]



METHODS

INTEGRATED MODELLING

- Gaussian Process Regression (GPR) [4] was used to fit the profiles
- 8-channels first-principles modelling of pellet cycle performed for the first time

QuaLiKiz for Turbulent transport — ESCO — PION — HPI2

$\boldsymbol{j, T_e, T_i, \Omega, n_e, n_H, n_D, n_{Be}}$, Equilibrium, NBI, ICRH, Neutral source, Pellets

NCLASS for Neoclassical transport — SANCO — PENCIL — FRANTIC

FITTING THE PEDESTAL

- The pedestal was tuned to match experimental interferometer data on pedestal channel
- The transport predicted by QuaLiKiz automatically matched the remaining channels

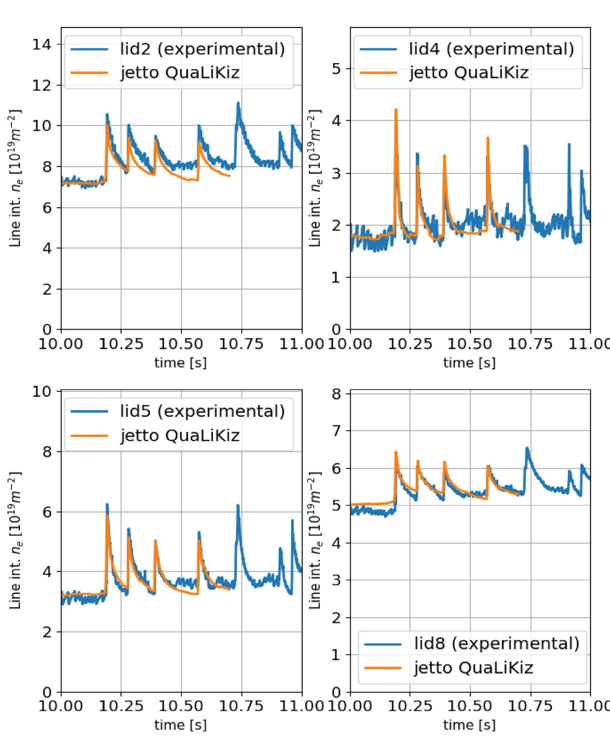
GYROKINETIC ANALYSIS

- Linear and nonlinear GENE [5] simulations were performed to validate the QuaLiKiz predictions

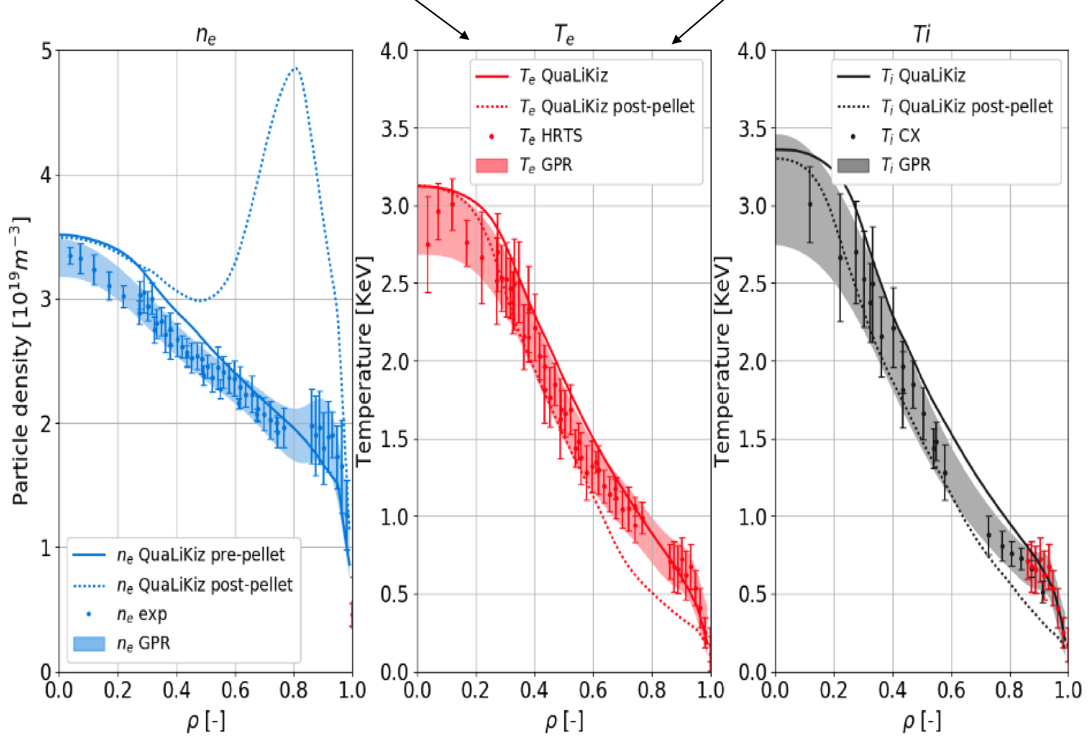
Artificially added transport $\rho < 0.2$

Self consistently evolved $0.2 < \rho < 0.94$

Pedestal evolution matched to experiment $\rho > 0.94$



Interferometer lines



Pre – pellet experiment VS model

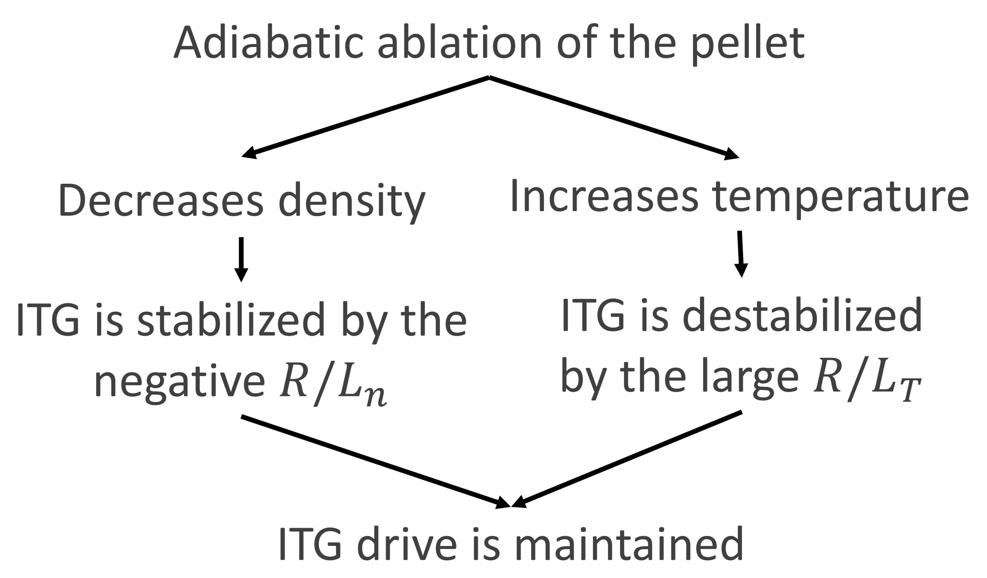
OUTCOME

FAST MIXING

- The evolution of the neutron rate is in good agreement with the experimental data
- The fast timescale immediately after the first pellet is correctly captured
- Electron profile relaxes while D and H mix at a faster timescale

INSTABILITIES ANALYSIS

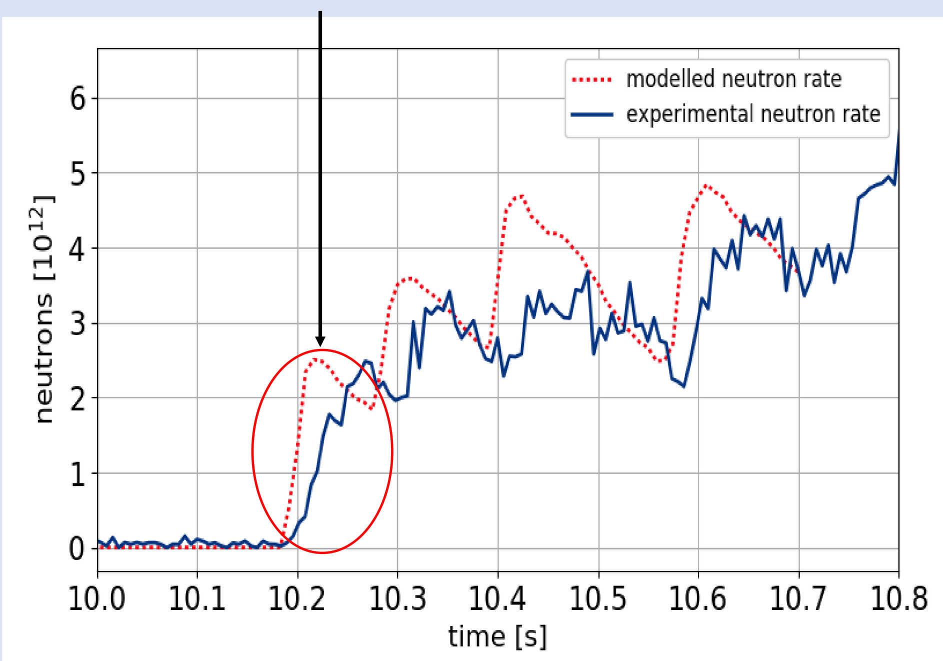
- Outer positive $\boldsymbol{R/L_n}$ region TEM drive caused by large R/L_n results in strong outward particle flux, as in [6]
- Inner negative $\boldsymbol{R/L_n}$ region ITG drive caused by large concomitant R/L_{Ti} increase.



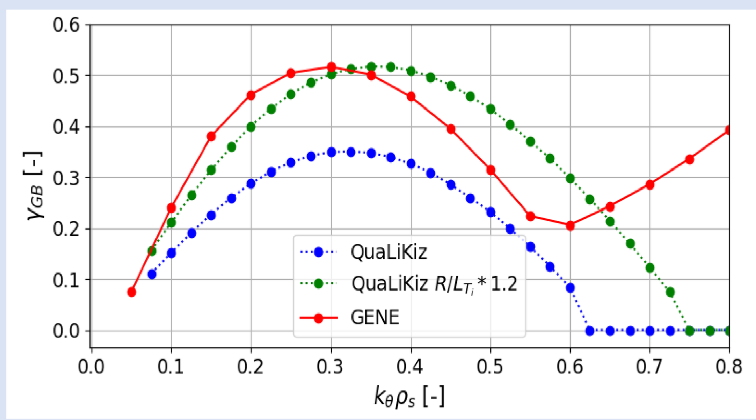
Temperature and density gradients before and after the first pellet

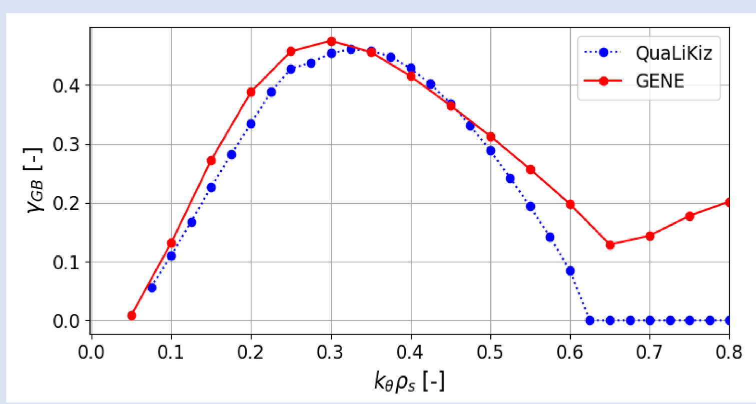
	Pre pellet			Post pellet		
Gradient	R/L_{T_i}	R/L_{T_e}	R/L_{n_e}	R/L_{T_i}	R/L_{T_e}	R/L_{n_e}
$\rho = 0.68$	7.4	7.7	2.8	14.4	18.1	-11.4
$\rho = 0.85$	11.1	12.2	5.6	9.5	8.8	14.4

Comparison of experimental and modelled neutron rates



Comparison between GENE and QuaLiKiz before and after the firs pellet





CONCLUSION

- Fast timescale for isotope mixing, validated by first principle modelling
- Extensive sensitivity tests confirmed timescales robust against modelling assumptions
- Successful comparison with GENE on linear spectra and nonlinear fluxes confirmed crucial ITG stabilization
- The results are encouraging with regard to reactor fuelling capability and burn control
- Positive ramifications for ITER Helium ash removal

REFERENCES

[1] M. Maslov et al. 2018 *Nucl. Fusion* **58** 076022

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[5] F. Jenko et al. 2000 *Phys. Plasma* **7** 1904

[6] C. Angioni et al 2017 Nucl. Fusion **57** 116053

* See the author list of 'Overview of JET results for optimising ITER operation' by J. Mailloux et al. to be published in Nuclear Fusion Special issue: Overview and Summary Papers from the 28th Fusion Energy Conference (Nice, France, 10-15 May 2021)