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Nonlinear gyrokinetic simulations of boron density peaking: experimental comparisons and reduced transport model validation References

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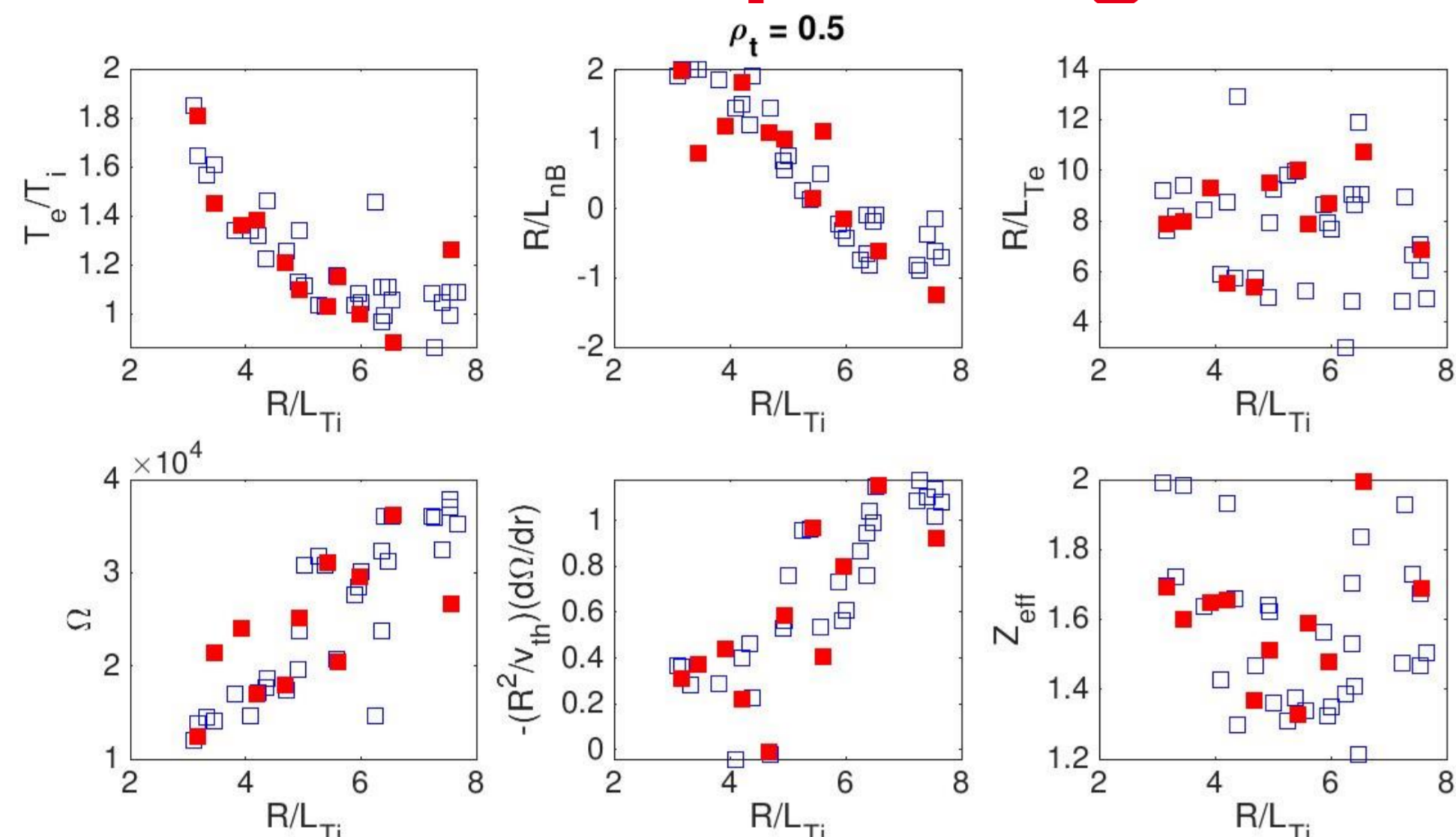
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Introduction

Accurately predicting turbulent light impurity transport in tokamaks has been a challenge for gyrokinetic codes, e.g. [1,2,3] and remains as such, in some regimes where the impurity profiles are hollow [3]. Furthermore, impurity transport modelling using reduced transport models is becoming an important ingredient in integrated modelling frameworks due to additional nonlinearities involved via light and heavy impurity profiles evolution and is well illustrated e.g. in current ramp-up modelling [4,5]. In this context, a set of nonlinear gyrokinetic simulations with GWK [6] have been performed to investigate existing discrepancies with experimental data and possible discrepancies with the quasilinear reduced model QuaLiKiz [7].

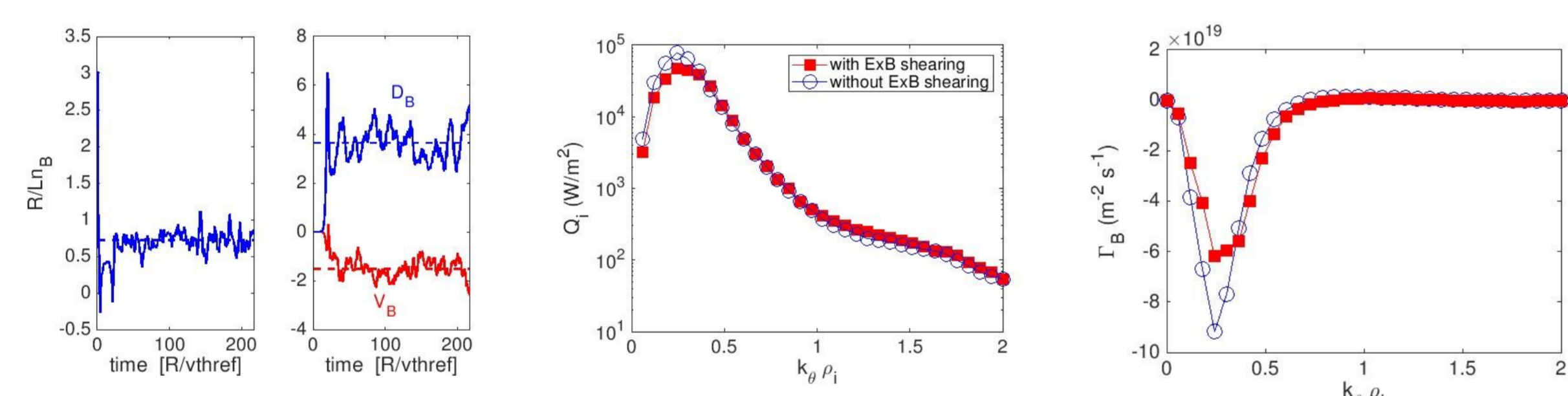
AUG experimental database of boron peaking



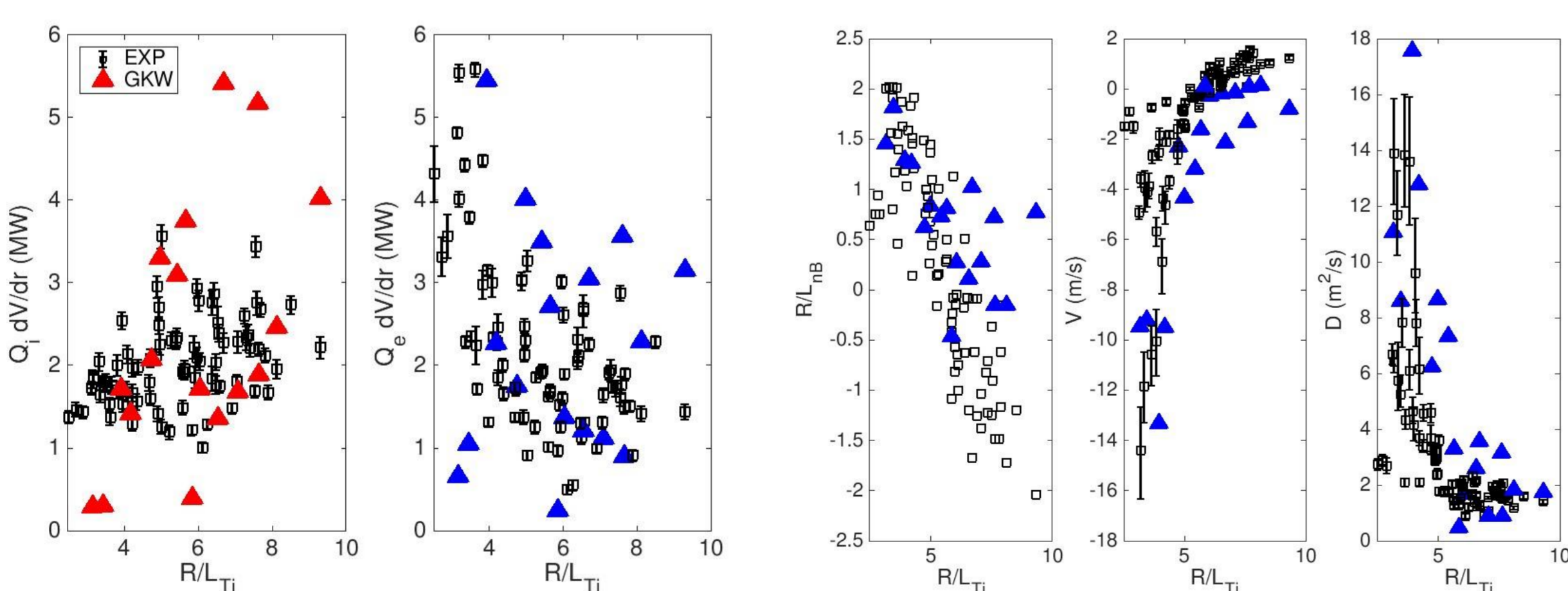
- Database of measured boron diffusion and convection coefficients described in [3]
- Strong correlation of the boron density peaking with normalized ion temperature gradient
 - From dominant ECRH heating to dominant NBI heating
 - Similar trends at $\rho = 0.5$ and $\rho = 0.4$
 - Choice for nonlinear simulations based on R/L_{Ti}
- Outward convection not reproduced with neoclassical and gyrokinetic (quasilinear) simulations using GWK [6] and NEO [8] including fast ions [9]

Can we reproduce these hollow boron profiles with nonlinear gyrokinetic simulations?
 How nonlinear compares to quasilinear and the reduced turbulent transport model QuaLiKiz? In particular in mixed ITG/TEM turbulence

Nonlinear gyrokinetic results vs measurements and power balance



- Nonlinear gyrokinetic simulation settings (GWK)
 - 6 gyrokinetic species: D, e, 2 boron species with half measured densities to disentangle diffusion and convection, C to match Z_{eff} , fast D from neutral beams
 - $k_r \rho_i^{min} = 0.067$, $k_r \rho_i^{max} = 11.3$, $k_\theta \rho_i^{min} = 0.06$, $k_\theta \rho_i^{max} = 2$
 - General geometry with CHEASE, collisions, toroidal rotation [10], ExB shearing
 - Electromagnetic: $A_{||}$, $B_{||}$

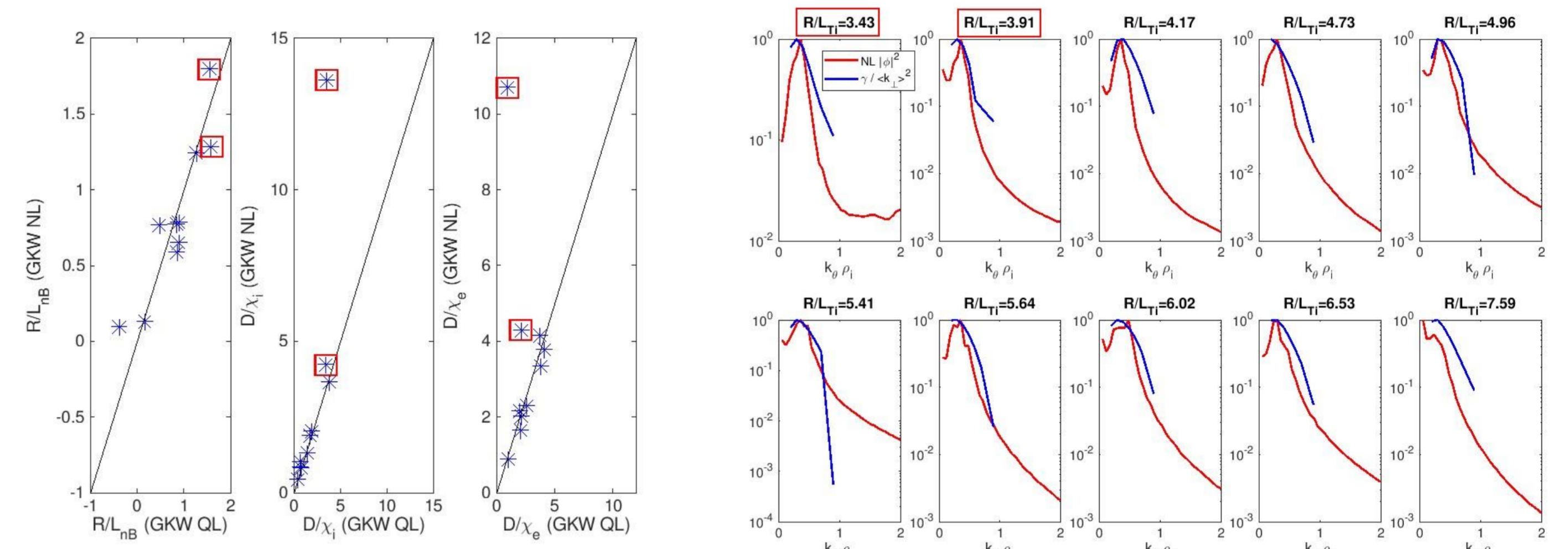


- Comparison of heat fluxes with power balance analysis for $\rho = 0.4$ and $\rho = 0.5$
 - Electron heat flux quantitatively well reproduced
 - Ion heat flux underestimated at low R/L_{Ti} and overestimated at larger R/L_{Ti} in particular at $\rho = 0.4$ (larger impact of fast ion stabilisation sensitive to fast ions pressure)
- Comparison of boron fluxes with experimental data for $\rho = 0.4$ and $\rho = 0.5$
 - Good predictions of density peaking but fails to reproduce hollow profiles
 - Outlier at largest R/L_{Ti} , off-axis ECRH heating + NBI
 - Range of variation of diffusion and convection coefficients reproduced except for outward convection
 - Underprediction of convection and overprediction of diffusion
 - Nonlinear simulations does not help recovering outward fluxes even in presence of fast ions

Nonlinear vs quasilinear GWK simulations

- Comparison of nonlinear GWK simulations with quasilinear estimate using:

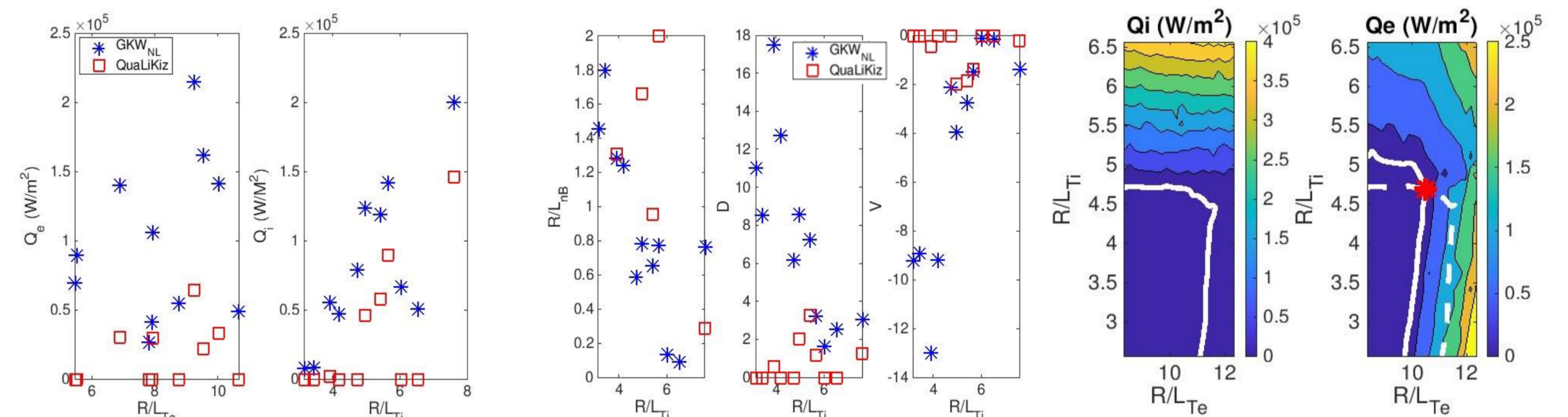
- Linear simulations at $k_r \rho_i = 0$ and $k_\theta \rho_i = 0.2$ to 0.9 using the mixing length rule: $\frac{\gamma}{\langle k_{||} \rangle^2}$
- Good agreement for cases at $\rho = 0.5$ on density peaking, D/χ_i and D/χ_e
- Lowest R/L_{Ti} cases disagreement D/χ
- Maximum of $|\phi|^2$ well reproduced with quasilinear rule but overestimation of small scale contributions



Reduced transport model validation: QuaLiKiz vs GWK

- Interest in reduced model for turbulent heat and particle transport (including impurities) within integrated modelling frameworks

- The quasilinear gyrokinetic code QuaLiKiz routinely used in such frameworks, e.g. [11, 12]
- Applied to $\rho = 0.5$ and fluxes directly compared to nonlinear GWK simulations
- Boron density peaking and ion heat fluxes in relatively good agreement BUT most of cases are found stable in particular at low R/L_{Ti}



- QuaLiKiz input parameters modified varying R/L_{Ti} and R/L_{Te} to match GWK NL fluxes

- GWK NL ion and electron heat fluxes reproduced except for lowest R/L_{Ti} cases
- Significantly higher R/L_{Te} required (lack of electron heat transport [13])
- Higher R/L_{Ti} needed close to ITG stability threshold
- Lower R/L_{Ti} needed at higher values consistent with fast ion simulations (outlier from off-axis ECRH)

- When flux matched (with GWK NL fluxes), reasonable agreement on boron convection (underestimated) and diffusion coefficients

- Boron density peaking higher in QuaLiKiz compared to GWK (also see D. Fajardo talk)

- Electrostatic potential spectra shapes in overall good agreement

- Maximum and small scale contributions follows GWK nonlinear spectra
- Amplitude 3 to 5 times larger in QuaLiKiz despite flux matched simulations

Conclusion

- Nonlinear gyrokinetic simulations in good agreement with experimental transport coefficients for boron similarly to the quasilinear simulations of [3]
- Electron and ion heat transport in reasonable agreement (fast ion stabilization included)
- Outward boron convection still missing even in nonlinear simulations
- Comparison to the reduced turbulent transport model QuaLiKiz
 - Lack of electron heat transport
 - For flux matched simulations (with GWK NL) good predictions of boron convective and diffusive coefficients
 - Electrostatic potential amplitude spectra shapes well reproduced but overestimation of the amplitude
- Difficulties in predicting heat and impurity transport simultaneously with QuaLiKiz