Kinetic modelling of parallel transport in tokamak edge plasmas

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1. Introduction

A kinetic treatment of parallel transport in the tokamak scrape-off layer (SOL) may be required to accurately capture certain transport properties [1,2]. In particular, electron kinetics (e.g. non-local heat flow) may result in reduced target temperatures, modified response to ELMs and different plasma-neutral reaction rates compared to a fluid approximation. Here, we have investigated ion-electron energy flux in equilibrium and transient SOL conditions using the 1D kinetic electron code SOL-KiT [3].

2. Model

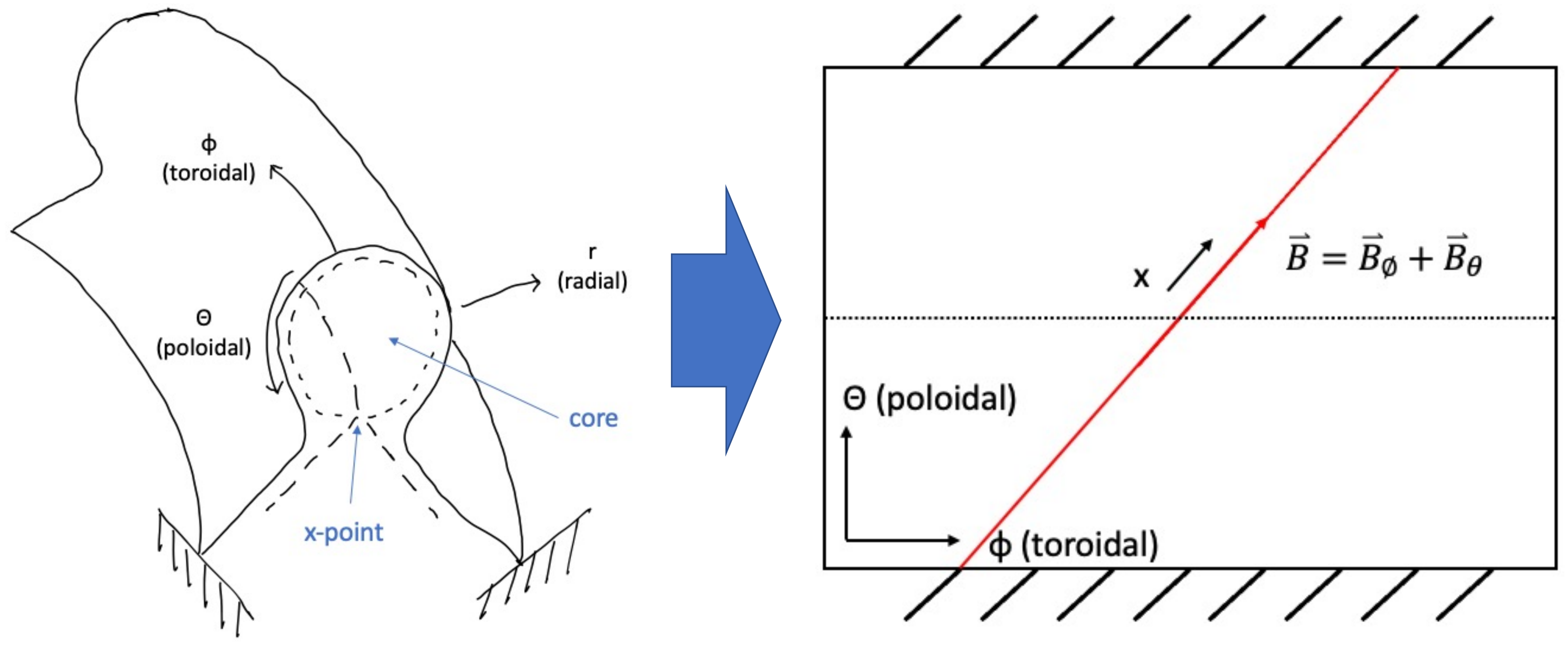

Fig 1. The scrape-off layer (SOL) of a divertor tokamak is modelled as a 1D flux tube, parallel to the magnetic field lines

- **Three-species model** for electrons, ions and neutrals, using the code SOL-KiT [3]
- The electron kinetics is described by the **Vlasov equation** with **Boltzmann** (e-n) and **Fokker-Planck** (e-i & e-e) collisions

$$\frac{\partial f(x,\boldsymbol{v},t)}{\partial t} + v_x \frac{\partial f(x,\boldsymbol{v},t)}{\partial x} - \frac{e}{m_e}E\frac{\partial f(x,\boldsymbol{v},t)}{\partial v_x} = \sum_\alpha C_{e\text{-}\alpha}$$

- We can **compare to a Braginskii-like fluid model** for the electrons
- And similar for the ions and neutrals, including important **transfer channels** (ionization, recombination, charge exchange, etc)

3. Results – ion-electron energy transfer

- Launch an ELM-like burst of energy into the SOL and observe the plasma response in the kinetic and fluid models

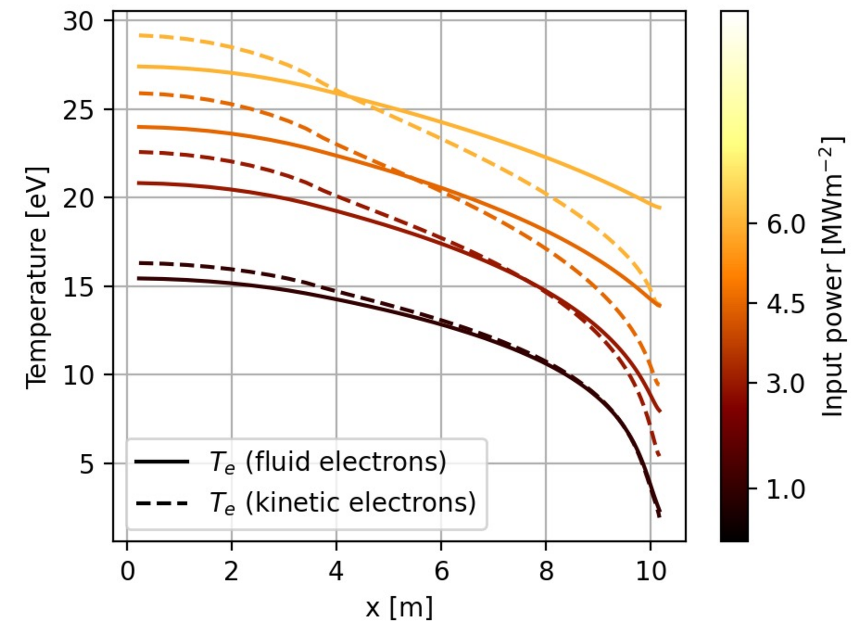

Fig 2. Equilibrated temperature profiles, fluid vs. kinetic

- We see **up to 55% higher energy transfer between ions and electrons with the kinetic model**

Fluid: $Q_{ei}^{fl} \propto (T_i - T_e)/\tau_{ei}$

Kinetic: $Q_{ei}^{kin} \propto \int d\vec{v}\,\frac{1}{2} m_e v^2 C_{ei}$

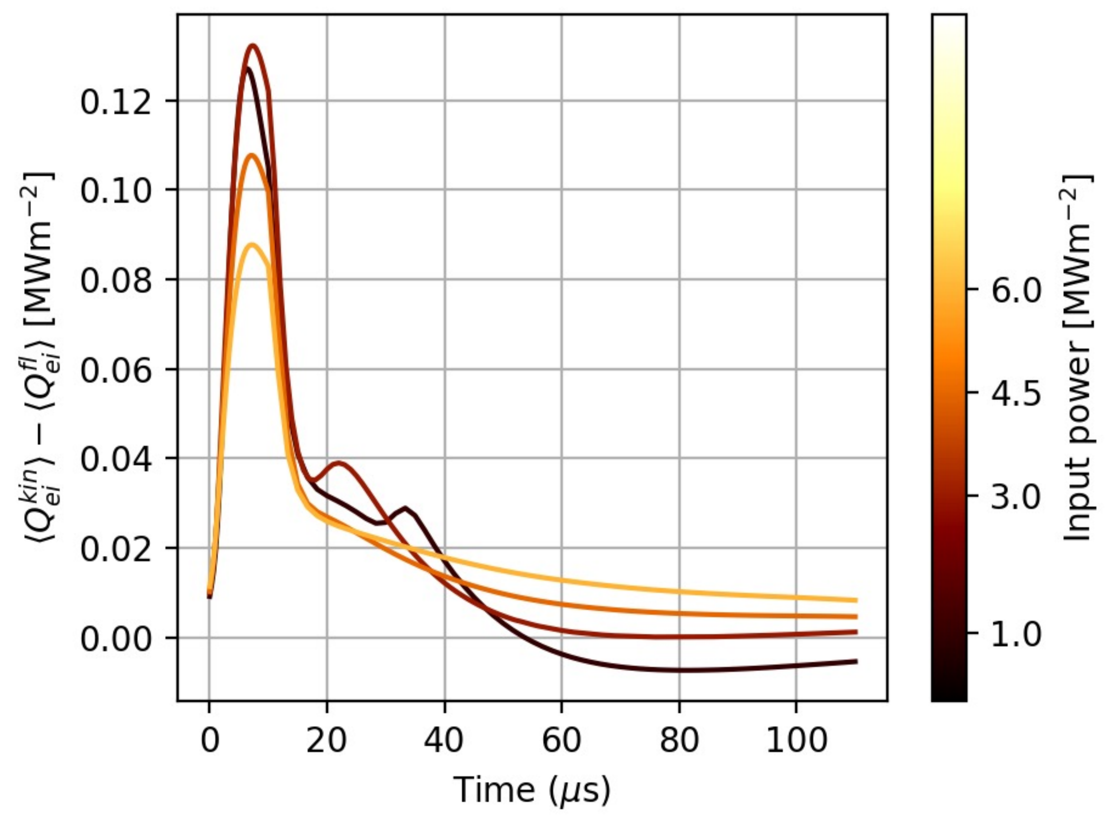

Fig 3. Differences in line-integrated electron-ion energy transfer for kinetic vs. fluid model during an ELM-like energy burst into the SOL

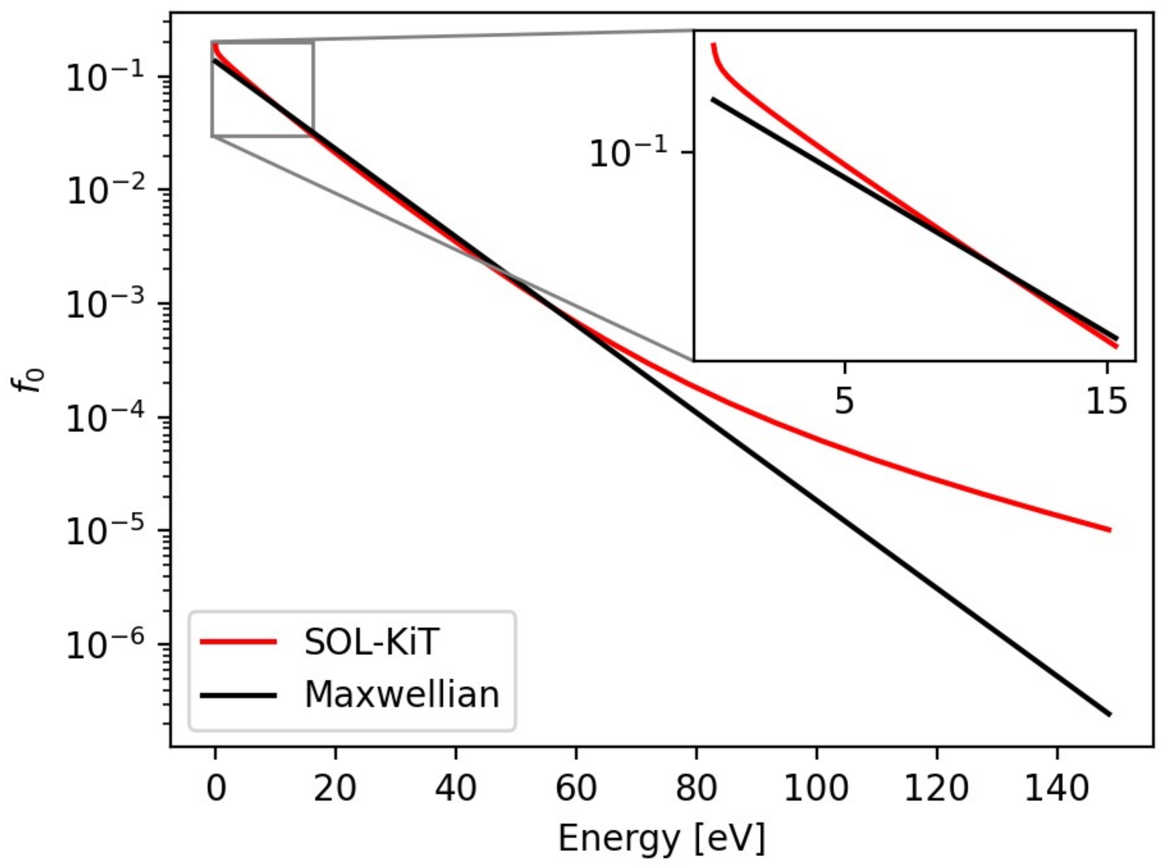

Fig 4. Non-Maxwellian electron distributions result in modified energy transfer between electrons and ions

4. Conclusions

- Non-Maxwellian electron distributions, especially close to the solid targets, result in enhanced ion-electron energy transfer

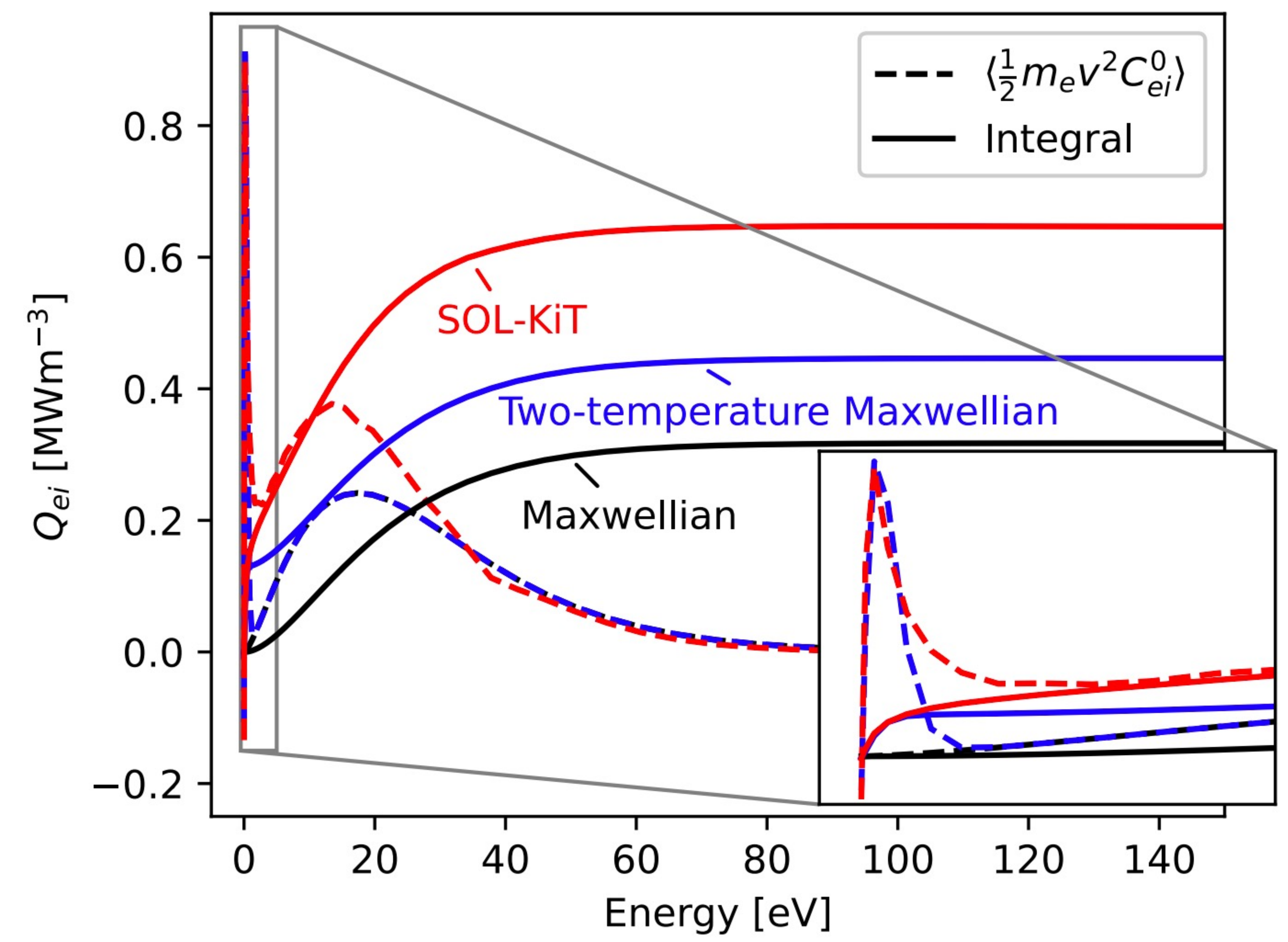

Fig 5. Contribution to Q_{ei}^{kin} as a function of electron energy. The integrand (dashed) is shown alongside its contribution to the integral (solid). A fitted two-temperature Maxwellian is also shown, which does not fully account for the observed kinetic enhancement in Q_{ei}

- This effect is most prominent in cooler background plasmas, where the magnitude of Q_{ei} is naturally smaller, **so actual impact on target conditions in likely to be small**
- Kinetics plays a role in SOL transport processes, particularly during transient regimes [3,4]
- Paper pending.

References

[1] Chankin, A. V. & Coster D. P., *J. Nucl. Mater.* 489-501, 463 (2015)
[2] Churchill, R. M. et al, *Nuclear Materials and Energy.* 978-983, 12 (2017)
[3] S. Mijin, et al., *Computer Physics Communications.* 107600, 258 *(2021)*
[4] S. Mijin, et al., *Plasma Physics and Controlled Fusion.* 125009, 62 *(2020)*