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ReMKiT1D Workshop January 2024
Electron Kinetics in ReMKiT1D

Imperial College London

Engineering and Physical Sciences Research Council

CCFE
CULHAM CENTRE FOR FUSION ENERGY

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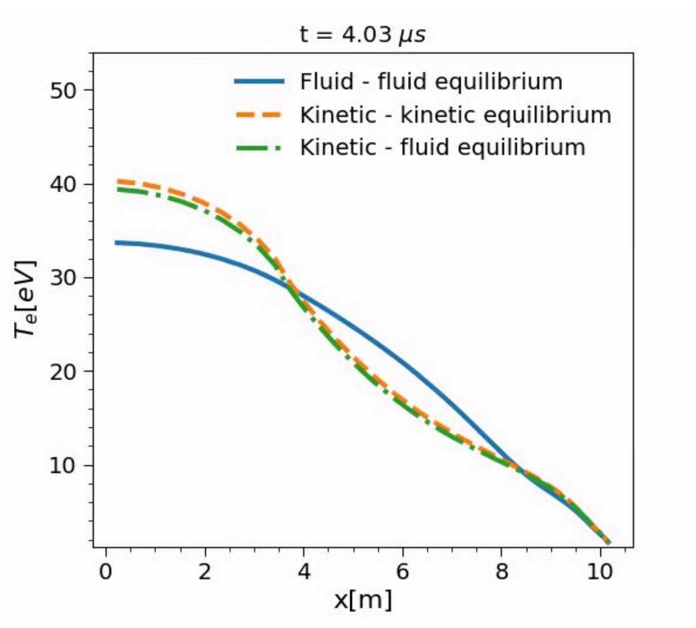
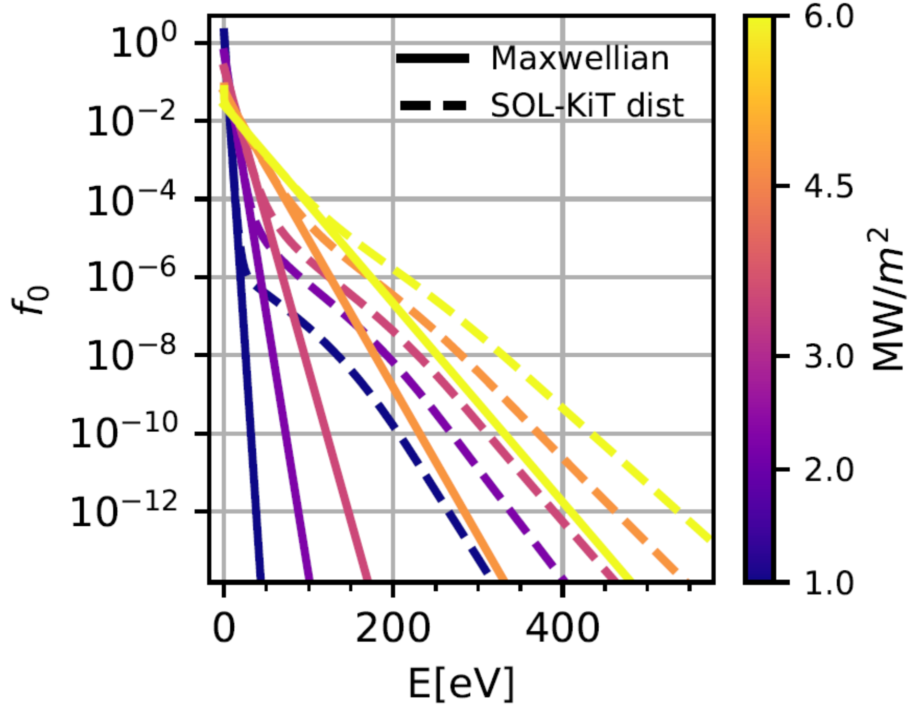
Background – Electron kinetics in the SOL

Due to large gradients in collisionality the electron distribution function in the SOL can depart from a Maxwellian in non-trivial ways

This can be seen in both transient and equilibrium simulations

Results from the SOL-KiT model:





*Mijin et al, PPCF **62** 095004 (2020)*

Background – Electron kinetics in the SOL

Part of the motivation behind ReMKiT1D was the easy creation and coupling of electron kinetic models with fluid equations

The SOL-KiT model has been implemented in the ReMKiT1D framework

Anticipating many collisional processes with heavy particles and non-trivial degrees of anisotropy → spherical harmonics

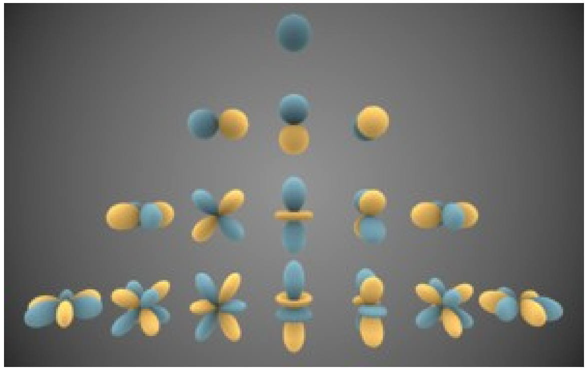
$$\varphi = \arctan(v_z/v_y)$$

$$\theta = \arccos(v_x/v)$$

$$\varphi = \arctan(v_z/v_y)$$

$$f(v,\theta,\varphi) = \sum_{l=0}^{\infty}\sum_{m=-l}^{l} f_l^m(v) P_l^{|m|}(\cos\theta) e^{im\varphi}, \quad (f_l^m)^* = f_l^{-m}$$

$f_0^m \rightarrow n, T; f_1^m \rightarrow \text{fluxes}; f_2^m \rightarrow \text{stresses (e.g. pressure tensor)}$



Ignoring magnetic fields in 1D → azimuthal symmetry → m = 0

Legendre polynomials

Electron kinetic equations in ReMKiT1D

$$\frac{\partial f}{\partial t} + v_x \frac{\partial f}{\partial x} - \frac{eE}{m_e}\frac{\partial f}{\partial v_x} = \left(\frac{\delta f}{\delta t}\right)_c$$

$$\frac{\partial f_l}{\partial t} = A_l + E_l + C_l$$

Coupling

$f_{l-1} \rightarrow f_l \leftarrow f_{l+1}$

Spatial advection

Velocity space advection due to E-field

Collisional and other source operators

The real challenge

Many electron kinetics terms and derivations available in ReMKiT1D

Electron kinetic equations in ReMKiT1D

Supporting both charged and neutral particle collisions with electrons

Coulomb Collisions
Fokker-Planck operator

Lead to Braginskii closures when strong

Both electron-electron and electron-ion collisions supported

Electron-neutral collisions
Boltzmann operator

Can implement both elastic and inelastic collisions

Can be coupled to a Collisional-Radiative Model (more on this later)

User-controlled choice of included physics through both prebuilt and custom models

Many prebuilt models handling common terms – plug and play approach

Electron kinetic equations in ReMKiT1D

Note: We now have 2 more dimensions!

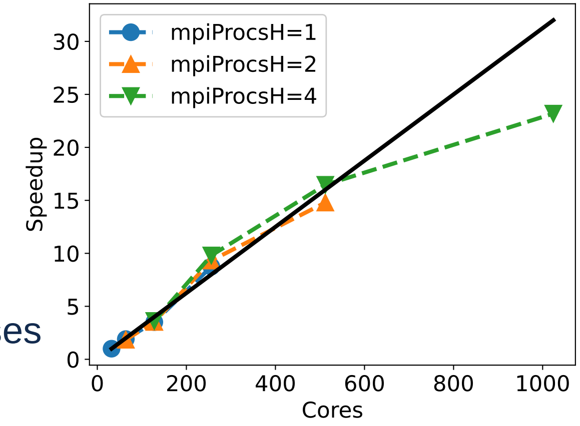
Distributions are discretised in space, velocity magnitude, and the harmonic

Kinetic terms can thus evolve one or more harmonics – recall coordinate profiles!

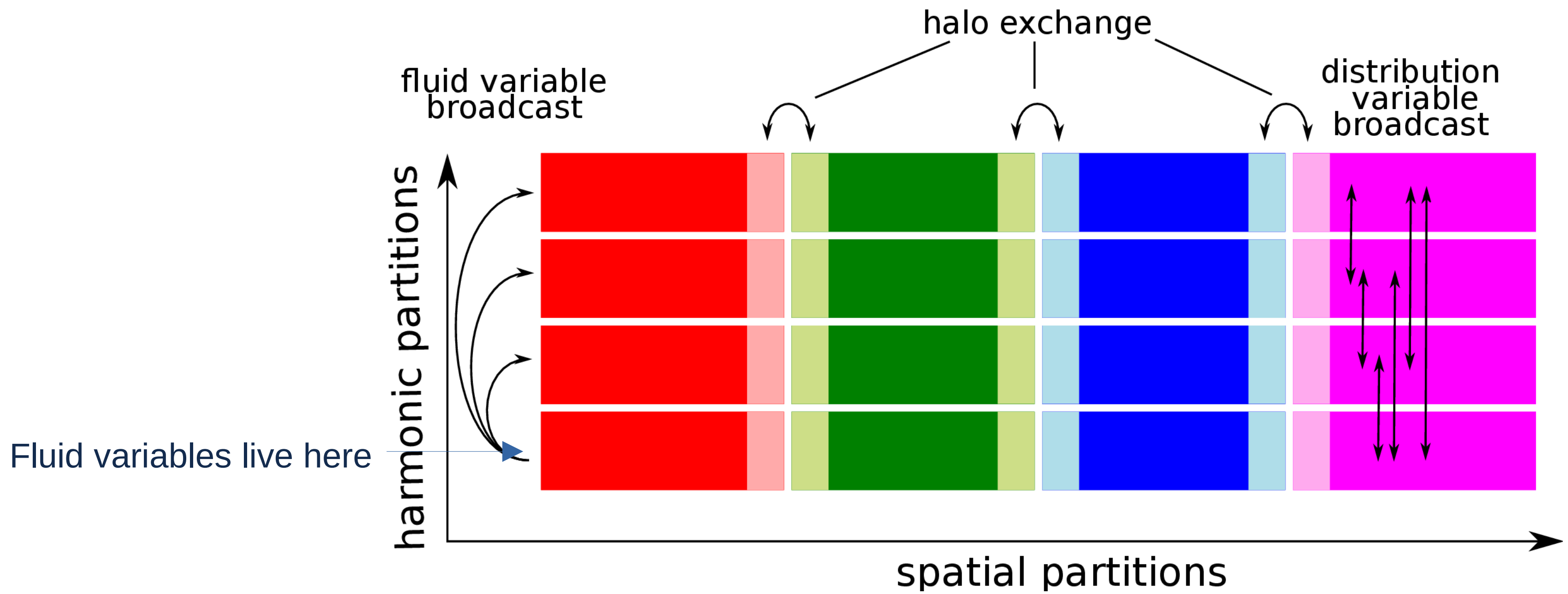
Distribution variables can be parallelised in both the spatial and harmonic directions

Improved scalability – 1024 cores on SOL-KiT-like runs on Archer2

Base case is already at 32 processes



Parallelisation revisited



Fluid variables are broadcast so that all of the distributed harmonics can access them

Individual harmonics are also broadcast so that all harmonics are known

Scalar variables (other than time) must be associated with a single parent process

Note: Not covered in this workshop – see Python examples

Coupling with fluid models

The idea:

Multifluid model with an electron species

Kinetic electrons coupled to fluid species

Seamless (or at least relatively simple!) switching between electron representations

We need ways of coupling a distribution variable with fluid variables

Solution: More stencils and derivations!

Coupling with fluid models

Going from distributions to fluid variables – taking moments

$$n = 4\pi \int_0^\infty f_0 v^2 dv$$

$$nu = \frac{4\pi}{3} \int_0^\infty f_1 v^3 dv$$

$$\frac{3}{2} nkT = 4\pi \int_0^\infty \frac{m}{2} f_0 v^4 dv$$

$$q = \frac{4\pi}{3} \int_0^\infty \frac{m}{2} f_1 v^5 dv$$

$$\langle g \rangle_{n,l} = 4\pi \int_0^\infty g(v) f_l(v) v^{2+n} dv$$

1) Distribution variable – moment derivation
2) Implicit in a matrix term – moment stencil
3) Matrix term – term moment stencil

Other velocity space stencils are also implemented

Intro to hands-on session

We will look at the Epperlein-Short problem:

- Kinetic electrons
- Stationary ions
- Decay of initial small temperature perturbation
- Electric field ensuring 0 current
- Coulomb Collisions (no e-i energy transfer)

We will look at the heat flux calculated by ReMKiT1D and compare it to Braginskii

Note: We will not construct the kinetic models we'll be using!

Hands-on session