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CHALMERS
UNIVERSITY OF TECHNOLOGY

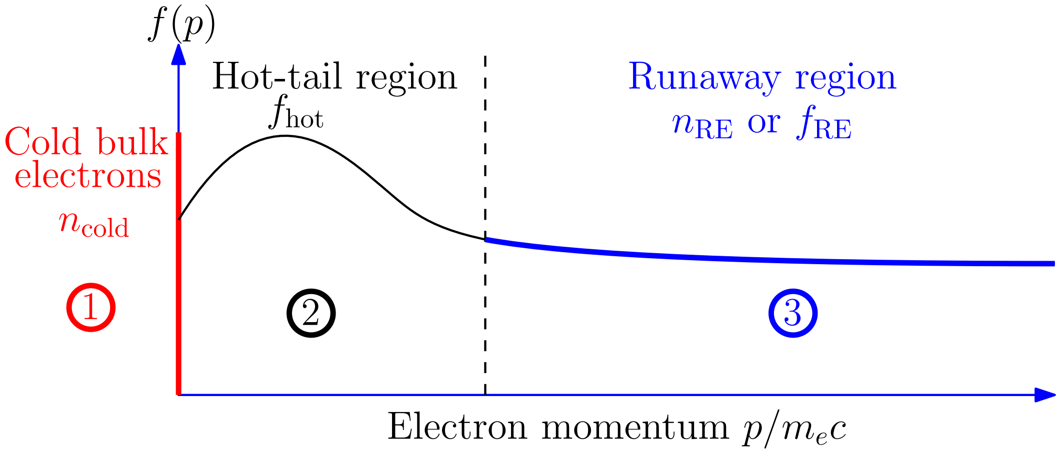
DREAM

The dreamers guide to runaway physics

O. Embreus and M. Hoppe

- Fully implicit, non-linear, self-consistent solver for runaway generation during tokamak disruptions *(time-linearized mode also available)*
- Numerical conservation of particle number and positivity
- Flux-averaged and bounce-averaged treatment of dynamics ("1.5D")
- Treating electrons as up to 4 separate populations (thermal, hot-tail, kinetic runaway, fluid runaway)
- Two-component code
  - High-performance kernel written in C++17 (with PETSc for linear algebra)
  - User-friendly frontend written in Python

Computational regions



- **Scalar quantities**
  - $I_{\mathrm{p}}(t)$: Total plasma current
  - $\psi_{\mathrm{edge}}(t)$: Poloidal magnetic flux at plasma edge
  - $V_{\mathrm{loop,wall}}(t)$: Loop voltage at the (resistive) wall
- **Fluid quantities**
  - $E_{||}(t, r)$: Parallel electric field
  - $n_{\mathrm{cold}}(t, r)$: Cold electron density
  - $n_{\mathrm{hot}}(t, r)$: Hot electron density
  - $n_{\mathrm{i}}(Z, Z_0; t, r)$: Ion (charge state) densities
  - $n_{\mathrm{RE}}(t, r)$: Runaway density
  - $j_{\mathrm{hot}}(t, r)$: Hot electron current density
  - $j_{\Omega}(t, r)$: Ohmic current density
  - $j_{\mathrm{tot}}(t, r)$: Total current density
  - $\psi_{\mathrm{p}}(t, r)$: Poloidal magnetic flux
  - $T_{\mathrm{cold}}(t, r)$: Cold electron temperature
  - $W_{\mathrm{cold}}(t, r)$: Cold electron energy content (kinetic+binding)
- **Hot-tail grid quantities**
  - $f_{\mathrm{hot}}(t, r, p, \xi)$: Hot electron distribution function
- **Runaway grid quantities**
  - $f_{\mathrm{RE}}(t, r, p, \xi)$: Runaway electron distribution function

Scalars

- $I_\mathrm{p}(t)$: Total plasma current
- $\psi_\mathrm{edge}(t)$: Poloidal magnetic flux at plasma edge

Densities

- $n_\mathrm{cold}(t, r)$: Cold electron density
- $n_\mathrm{hot}(t, r)$: Hot electron density
- $n_\mathrm{i}(Z, Z_0; t, r)$: Ion densities
- $n_\mathrm{RE}(t, r)$: Runaway density
- $n_\mathrm{tot}(t, r)$: Total electron density

Distribution functions

- $f_\mathrm{hot}(t, r, p, \xi)$: Hot electrons
- $f_\mathrm{RE}(t, r, p, \xi)$: Runaway electrons

Current densities

- $j_\mathrm{hot}(t, r)$: Hot electron current density
- $j_\Omega(t, r)$: Ohmic current density
- $j_\mathrm{tot}(t, r)$: Total current density

Other quantities

- $E_{||}(t, r)$: Parallel electric field
- $\psi_\mathrm{p}(t, r)$: Poloidal magnetic flux
- $T_\mathrm{cold}(t, r)$: Cold electron temperature

$$n_{\text{hot}} : n_{\text{hot}} = \int f_{\text{hot}}\, \mathcal{V}' \mathrm{d}p \mathrm{d}\xi, \qquad (f_{\text{hot}} \text{ density moment})$$

$$n_{\text{RE}} : \frac{\partial n_{\text{RE}}}{\partial t} = S_{\text{ava}} - \int \hat{\boldsymbol{p}} \cdot \boldsymbol{\Phi}_{\text{hot}}(p_{\max}, \xi)\, \mathcal{V}' \mathrm{d}\xi, \qquad (\text{avalanche}+f_{\text{hot}} \text{ outflux})$$

$$n_{\text{tot}} : n_{\text{tot}} = n_{\text{free}} + n_{\text{bound}}, \qquad (\text{electron conservation})$$

$$j_{\text{hot}} : j_{\text{hot}} = \int e v_{\|} f_{\text{hot}}\, \mathcal{V}' \mathrm{d}p \mathrm{d}\xi, \qquad (f_{\text{hot}} \text{ current moment})$$

$$j_{\text{tot}} : j_{\text{tot}} = j_{\Omega} + j_{\text{hot}} + e c n_{\text{RE}}, \qquad (\text{current conservation})$$

$$\psi_{\text{p}} : \mu_0 \frac{j_{\|}}{B} \langle \boldsymbol{B} \cdot \nabla \phi \rangle = \frac{1}{V'} \frac{\partial}{\partial r} \left[V' \left\langle \frac{|\nabla r|^2}{R^2} \right\rangle \frac{\partial \psi}{\partial r} \right], \qquad (\text{flux diffusion})$$

$$I_{\text{p}} : I_{\text{p}} = \frac{1}{2\pi} \int j_{\text{tot}}(r)\, V' \mathrm{d}r, \qquad (\text{definition of } I_{\text{p}})$$