CHALMERS
UNIVERSITY OF TECHNOLOGY

Validation of GO and DREAM

Oskar Vallhagen, Mathias Hoppe, and Istvan Pusztai
on behalf of the Plasma Theory group, Chalmers

EUROfusion

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1. Overview of the GO framework
2. GO validation against AUG and JET
   - Paper by K. Insulander Björk *et al* submitted to PPCF, available at `https://arxiv.org/abs/2101.02575`
3. Ongoing/planned DREAM validation efforts

The fluid modelling framework GO simulates electron dynamics in plasmas:

- 1D real space, momentum space: thermal Maxwellian + REs moving at c
- Models spatio-temporal evolution of current density, temperature and E-field
- Temperatures of free electrons and ions calculated from energy transport equations
- Densities of impurity ion charge states calculated from time-dependent rate equations
- RE generation rates including hot-tail, Dreicer and avalanche
  - Hot-tail, by an analytical model
  - Dreicer, by a neural network trained on kinetic simulation output
  - Avalanche, by a semi-analytical formula benchmarked against kinetic simulations

- Initial conditions from experimental data
- Assimilated Ar density n_{Ar} chosen to match measured max free e^{-} density
- Hot-tail loss factor f_{HT} emulating losses due to stochastic flux surfaces
- Simplest case: Prescribed temperature evolution:

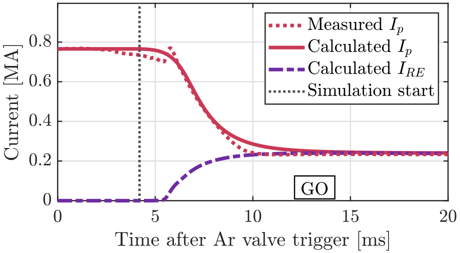
  $$T_e = T_{\mathrm{end}} + (T_{\mathrm{initial}} - T_{\mathrm{end}}) \cdot e^{-\frac{t}{t_{\mathrm{TQ}}}}$$

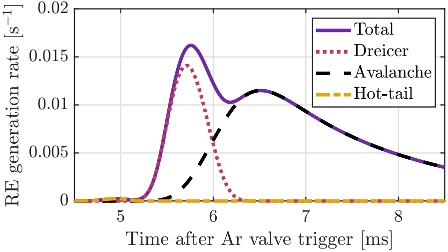
  - Parameters chosen to reproduce the I_p evolution
- Advanced case: Switch to energy transport equation when $T_e < T_{\mathrm{switch}} \approx 100$ eV
  - Exponential drop emulating transport losses due to stochastic flux surfaces
  - Assume radiation-dominated losses when $T_e < T_{\mathrm{switch}}$ due to $T_e^{5/2}$-scaling of transport losses [1]

[1] D.J. Ward and J.A. Wesson: *Nuclear Fusion*, **32** 1117, 1992

Matching I_p evolution with Prescribed T_e (AUG #34183)

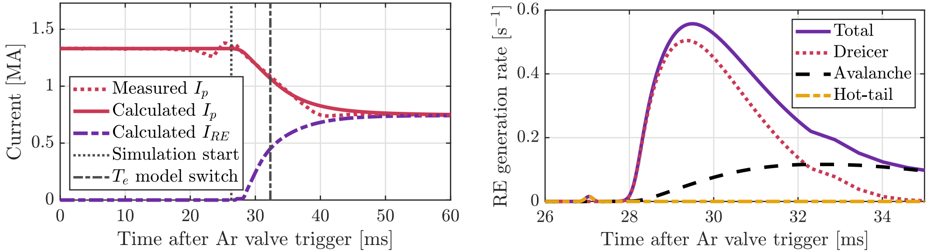
- Simplest case: Prescribed temperature evolution:
  $$T_e = T_{\text{end}} + (T_{\text{initial}} - T_{\text{end}}) \cdot e^{-\frac{t}{t_{\text{TQ}}}}$$
- Fit parameters:
  $n_{Ar} = 1.8 \cdot 10^{19}$ m^{-3}, $T_{\text{end}} = 20$ eV, $t_{\text{TQ}} = 0.35$ ms, $f_{HT} =\leq 0.1$
- >99.9% hot-tail RE loss required for I_p evolution matching in AUG



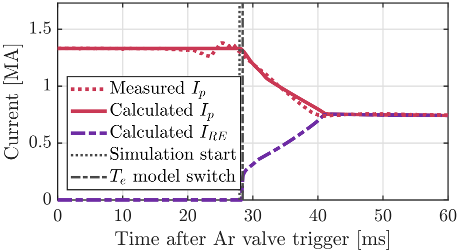


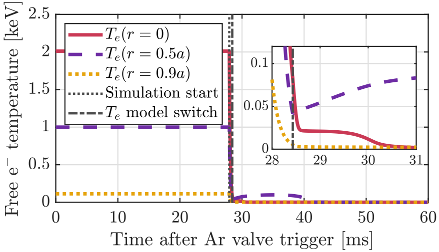
Matching I_p evolution with Prescribed T_e (JET #95125)

- Simplest case: Prescribed temperature evolution:
  $T_e = T_{\text{end}} + (T_{\text{initial}} - T_{\text{end}}) \cdot e^{-\frac{t}{t_{\text{TQ}}}}$
- Fit parameters:
  $n_{Ar} = 0.45 \cdot 10^{19}$ m^{-3}, $T_{\text{end}} = 21$ eV, $t_{\text{TQ}} = 0.2$ ms, f_{HT} unconstrained
- Hot-tail subdominant without losses in JET

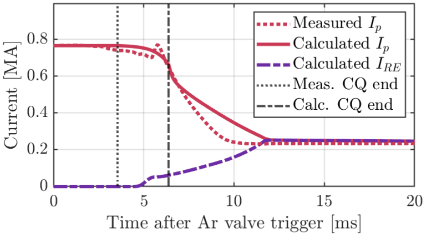


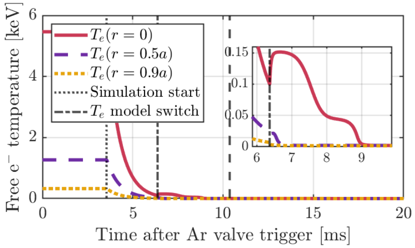
- Advanced case: Switch to energy transport equation when $T_e < T_{\text{switch}} \approx 100$ eV
- I_p matching for some shots...



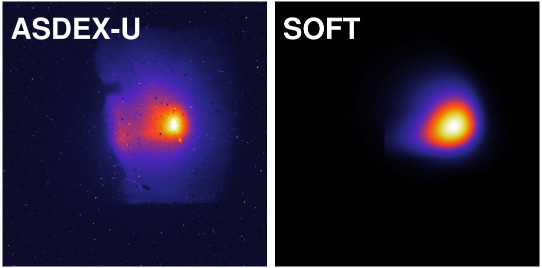


- Advanced case: Switch to energy transport equation when $T_e < T_{\text{switch}} \approx 100$ eV
- ...but T_e evolution prone to reheating
  - Additional transport or wall impurity losses might play a role
  - Current flattening during TQ re-distribute ohmic heating not modelled



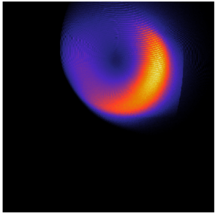


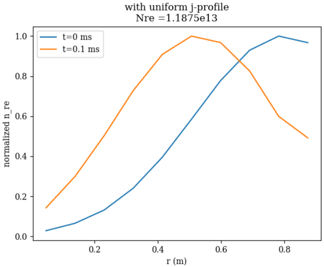
- Combined GO+CODE+SOFT simulations carried out for ASDEX-U [2]
- Answers some important questions:
  - Significant seed loss indicated
  - Suggests straightforward hot-tail + avalanche picture
  - Seed radial profile “directly” accessible
- Simplified disruption model



[2] M. Hoppe *et al*, Accepted in Journal of Plasma Physics (2021).

- Free parameters, as entire disruption modeling is not self-consistent. Goal: with free parameters chosen to match certain observables (e.g. I_p evolution), predict other features (e.g. synchrotron images) and compare them to experiments.
- DREAM+SOFT simulations of JET (fluid, hybrid, fully kinetic)
- Focus on the CQ dynamics
- MSc project ongoing; some overlap with previous GO studies (verification)
- Spoilers: Plasma shaping, finite wall time, initial current profile flattening needed to explain multiple features simultaneously





- Studied JET 95125 with DREAM. Self-consistent hot-tail in kinetic treatment.
- Similar modeling choices as in GO $\rightarrow$ results similar.
- Confirmed negligible role of hot-tail seed.

Ongoing work:

- JET 85943, previously thoroughly studied with JOREK (some GO simulations too). Part of B_T scan, with $1\,\mathrm{MA}$ RE current.
- Time resolved radiation loss measurement available.
- Can we construct diffusive electron heat transport, $\chi(r,t)$, that a self-consistent energy balance calculation reproduces radiative heat losses and temperature at the end of TQ?
- Is this $\chi(r,t)$ consistent with JOREK findings, and seed losses (if those appear constraining)?

- Studying same experimental cases with multiple tools allows cross code comparison, and help find a comprehensive picture of physics processes
- **Experimental data is not sufficient to fully constrain our simulations**
  - Ad-hoc modeling choices unavoidable.
  - Hint most problematic modeling limitations
    (e.g. need for forced temperature evolution to avoid reheating calls for accurate modeling of radial transport, including that of particles).
  - Still need to find ways to avoid being perceived a "fancy fit". Keeping some observable to be explained outside the "fitting".
  - Taking transport coefficients from MHD simulations will help on this front.
- What are the great sensitivities of ITER predictions? Is it possible to isolate these in the validation effort? (e.g. opacity).