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Validation of ASTRA and ETS

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ASTRA: An overview

What is ASTRA[1-3]?

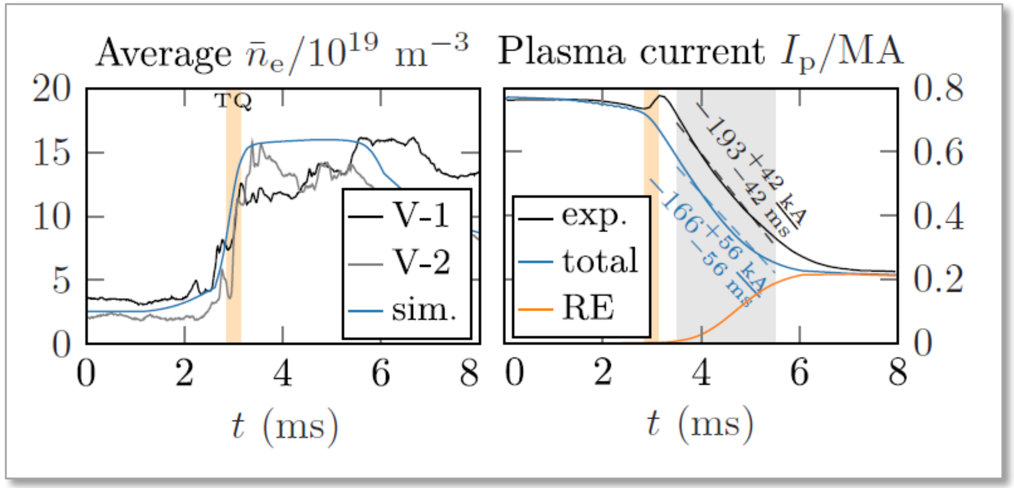
1.5D transport solver for plasma, impurities, and REs

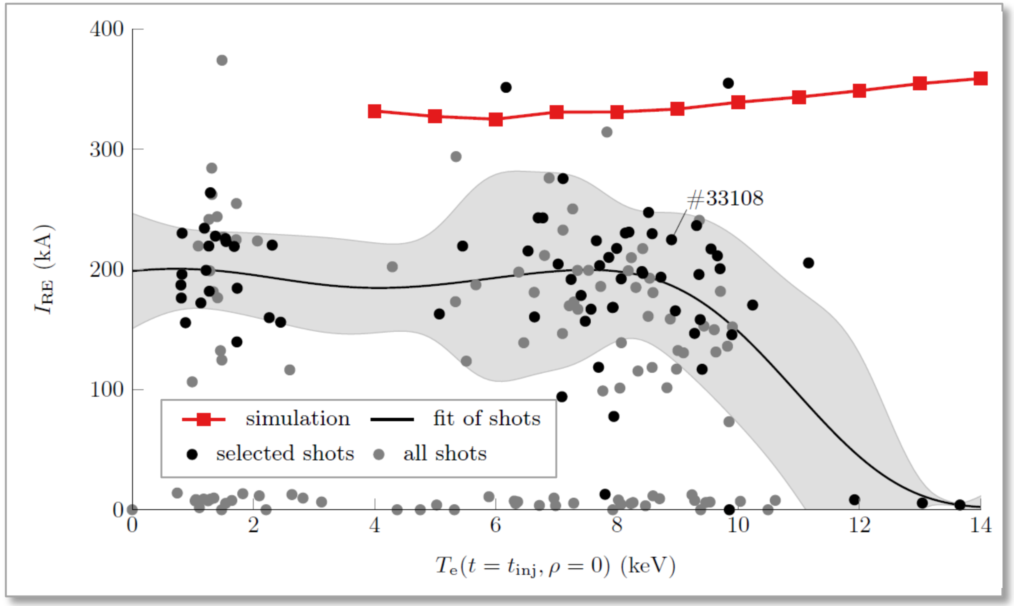
What can it do?

Simulations of disruptions induced artificially through MGI

Recent results

- Capable of reproducing experimental trends in AUG #33108[3]
- 1.5D approach for impurity deposition and propagation suitable[3]; driven by neoclassical and MHD-induced transport
- Necessity of considering high-Z effects for RE generation[3]
- RE generation in AUG avalanche dominated[4]
  (seed of secondary importance)
- RE current insensitive to temperature variation in AUG below 9 keV, but increases above 10 keV[4]
  (agreeing/disagreeing with experiment)





[1] E. Fable *et al. Plasma Phys. Control. Fusion* **55**, 074007 (2013)
[2] R. Dux *et al. Nucl. Fusion* **39**, 1509 (1999)
[3] O. Linder *et al. Nucl. Fusion* **60**, 096031 (2020)
[4] O. Linder *et al. J. Plasma Phys.*, to be submitted

Tool capabilities: RE generation

Reduced models	ASTRA[1-3,a]	ETS[4,b]
Dreicer generation:		
• Analytic[5]	Done	Done [c]
• CODE NN[6]	Done	Planed 2021
Hot-tail generation		
• Smith & Verwichte[7]	Done	Not planed
• Reduced kinetic[8]	not available yet	not available yet
Tritium decay generation[9]	Planed 2021	Planed
Compton scattering[9]	Planed 2021	Planed
Avalanche generation:		
• Rosenbluth & Putvinski[10]	Done	Done [c,d]
• Hesslow *et al* [11]	Done	Planed 2021

Kinetic models	ASTRA[1-3]	ETS[4,e]
NORSE[12]	Not planed	Ongoing
DREAM (only RE generation part)	not available yet	not available yet
LUKE[13]	Not planed	Planed

Implementation/Coupling:

Done — Ongoing — Planed — Not planed

[a] Implemented in standalone fortran module (github.com)
[b] Models inside module *Runaway Fluid* (github.com/osrep)
[c] Including toroidicity corrections[14]
[d] Including low E-field corrections[15]
[e] Models included as actors (modules)

[1] E. Fable *et al. Plasma Phys. Control. Fusion* **55**, 074007 (2013)
[2] R. Dux *et al. Nucl. Fusion* **39**, 1509 (1999)
[3] O. Linder *et al. Nucl. Fusion* **60**, 096031 (2020)
[4] G.I. Pokol *et al. Nucl. Fusion* **59**, 076024 (2019)
[5] J.W. Connor *et al. Nucl. Fusion* **15**, 415 (1975)
[6] L. Hesslow *et al. J. Plasma Phys.* **85**, 475850601 (2019)
[7] H.M. Smith *et al. Phys. Plasmas* **15**, 072502 (2008)
[8] I. Svenningsson, Chalmers University of Technology (2020)
[9] O. Vallhagen *et al. J. Plasma Phys.* **86**, 475860401 (2020)
[10] M.N. Rosenbluth *et al. Nucl. Fusion* **37**, 1355 (1997)
[11] L. Hesslow *et al. Nucl. Fusion* **59**, 084004 (2019)
[12] A. Stahl *et al. Comp. Phys. Comm.* **212**, 269 (2017)
[13] Y. Peysson *et al. Fusion Sci. Technol.* **65**, 22 (2014)
[14] E. Nilsson *et al. Plasma Phys. Control. Fusion* **57**, 095006 (2015)
[15] P. Aleynikov *et al. Phys. Rev. Lett.* **114**, 155001 (2015)

Task V1: Validation approach – the 3(+1) axes

0. Base case verification
1. Extend the set of validation cases
2. More experimental signals
3. Quantify uncertainties

Task V1: Push the validation of ASTRA, ETS and DREAM regarding RE generation during disruptions (D1&D4)

A validation effort regarding RE generation has been started for GO [10][13], ASTRA [4] and CODE [12][14]. However, validation is challenging because the models contain free parameters and experimental data has been found lacking to provide enough constraints. In order to make progress, we will focus on ASTRA, ETS and DREAM and explore 3 axes:

1) Extend the set of validation cases, in strong relation with Task V2
2) Take more experimental signals into account
3) Quantify uncertainties, i.e. assess to what degree free parameters can be varied while still matching experimental data.

Axis 0: Base case verification

Goal: Verify ASTRA and ETS through base case simulation, e.g. of AUG #33108

Approach: Bottom-up

Verification step	Kinetic profile evolution	Impurity evolution	RE generation (High-Z models)	Equilibrium evolution	Note
1	no, prescribed	no, absent	yes	no, constant	ETS 5/6
2	yes	yes	(yes) no $\Psi(t)$-coupling	no, constant	ETS 6
3	yes	yes	yes	no, constant	ETS 6
4	yes	yes	yes	yes	ETS 6

Axis 1: Extend the set of validation cases

ASDEX Upgrade

- Base case for validation: #33108
  (already used by various tools/studies)
- 2nd base case: particularly well diagnosed discharge
  (to be determined)
- Many shots and parameter scans available
  (Temperature, current, impurity amount, etc.)
- Possibility to perform further shots as needed
- Expert: Geri

JET

- Great for size scaling studies
- Expert: Cédric

COMPASS

- Many RE shots available
- Great for size scaling studies
- Conversion tool to IMAS data structure?

TCV

- Validation of atomic physics
  (multitude of different gases used)
- Application to flattop RE generation
- Application to breakdown RE generation
  (if models suitable)
- Study of plasma shape on runaway
- Possibility to perform further shots as needed
- Expert: Geri

Axis 2: More experimental signals

Needed: Fast diagnostics throughout disruption!

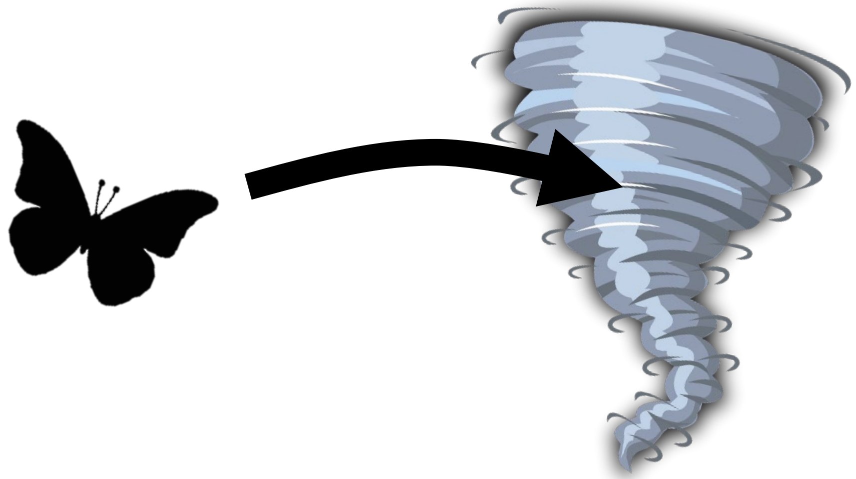
- **Magnetic diagnostics**
  $\rightarrow I(t)$
  $\rightarrow I_{\mathrm{RE}}$
  $\rightarrow \langle\eta\rangle \propto Z_{\mathrm{eff}}/T_{\mathrm{e}}^{3/2}$ from $\dot{I}$
- **Interferometry** (e.g. CO_2 at AUG)
  Impurity propagation
  $\rightarrow \bar{n}(t)$
- **Soft X-ray radiation**
  Indication for impurity propagation and onset of TQ
  $\rightarrow \propto n_{\mathrm{e}}^2 T_{\mathrm{e}} Z_{\mathrm{eff}}$
- **Hard X-ray radiation**
  Indication of highly energetic electrons

- **Fast (visible) cameras**
  Impurity & RE propagation
- **Charge state analysis/broadband spectroscopy**
  Indicate presence of ionization stages
  Impurity propagation
- **(Multiple) Narrowband imaging** (MANTIS)
  Impurity propagation (certain ionization stages)
  RE propagation
- **Synthetic diagnostics for synchrotron radiation** (SOFT)
  Forward modelling: Transport solvers →
  → distribution function → SOFT →
  → radiation measurements

→ **Design experiments (AUG, TCV) with simulations in mind!**

Axis 3: Quantify uncertainties

How sensitive are our models to variations of the input data?



Problem: Feedback loops and non-linear interactions
→ Need qualitative understanding of uncertainties

For quantification

1. Linear uncertainty quantification of representative case
2. Automated analysis of (many) simulations
3. Parameter scans of experimental trends (see axes 1 & 2)