



# Update on TSVV 9: Dynamics of Runaway Electrons in Tokamak Disruptions

Thrust 3 meeting, 29/06/23

E. Nardon and the TSVV 9 team



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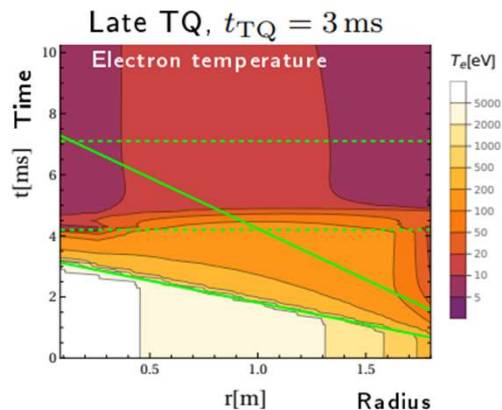
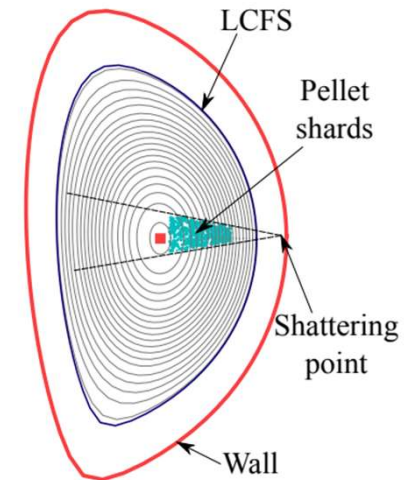
# DREAM predictions of RE generation in ITER (1/3)



## Setup:

- Considered H-mode and L-mode scenarios at 15/7.5/5 MA
- Simulated either single Ne+H SPI or 2-stage (H then Ne+H) SPI
  - Ne quantity adjusted so that  $50 \text{ ms} < \tau_{\text{CQ}} < 100 \text{ ms}$
- Ad hoc TQ
  - Tested 2 trigger conditions
    - Ne shards @  $q=2$  ('early TQ')
    - $T_e < 10 \text{ eV}$  anywhere inside  $q=2$  ('late TQ')
  - Impose  $\delta B$  such that Rechester-Rosenbluth transport corresponds to prescribed  $\tau_{\text{TQ}}$  (either 1 or 3 ms)
    - Same  $\delta B$  used to calculate RE transport
  - Fast particle (incl. Ne) mixing imposed via large D and V

Note: geometry fixed in time!

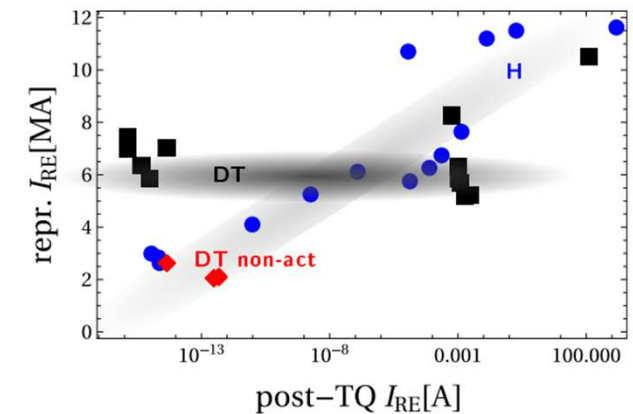
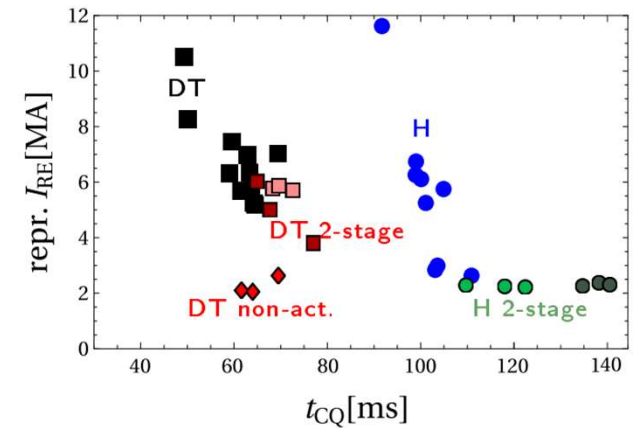


# DREAM predictions of RE generation in ITER (2/3)



- Results for 15 MA DT H-mode and H L-mode:
  - Multi-MA beam in all cases ☹
    - Caused by huge avalanche gain
  - Smallest RE currents obtained
    - in absence of activated RE seeds (T  $\beta$  decay and Compton scattering from wall-emitted  $\gamma$ 's)
    - for 2-stage SPI (~suppresses hot tail seeds)
- Activated seeds make losses during the TQ ineffective
  - Note: need to update Compton source for W first wall

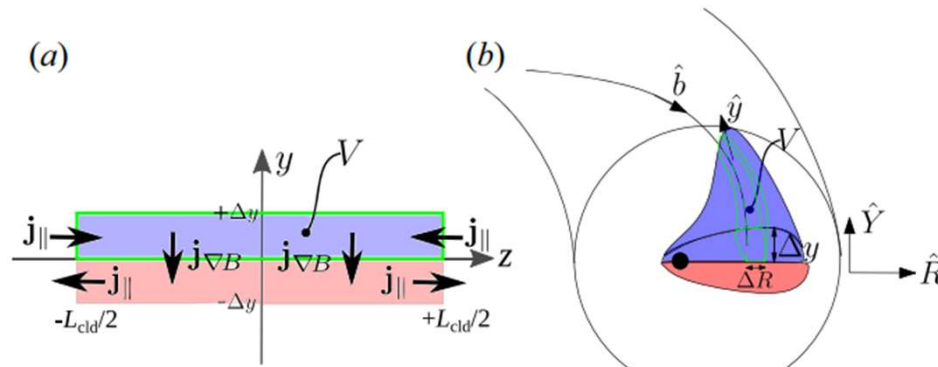
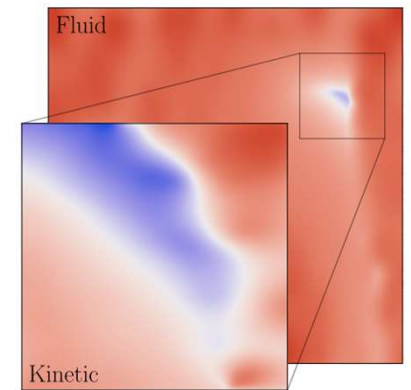
[Fülöp REM 2023]



# DREAM predictions of RE generation in ITER (3/3)



- Bayesian Optimisation with different levels of precision in DREAM [Ekmark REM 2023]
  - Fast scoping with RE fluid model, refinement with full kinetic model
  - Realized that hot tail seed is over-estimated by RE fluid model  
→ Need to revisit previous results (which used RE fluid) with improved hot tail model
- Modelling of ablation plasmoid drift [Vallhagen JPP 2023]
  - Can be important for H SPI and thus for 2-stage scheme

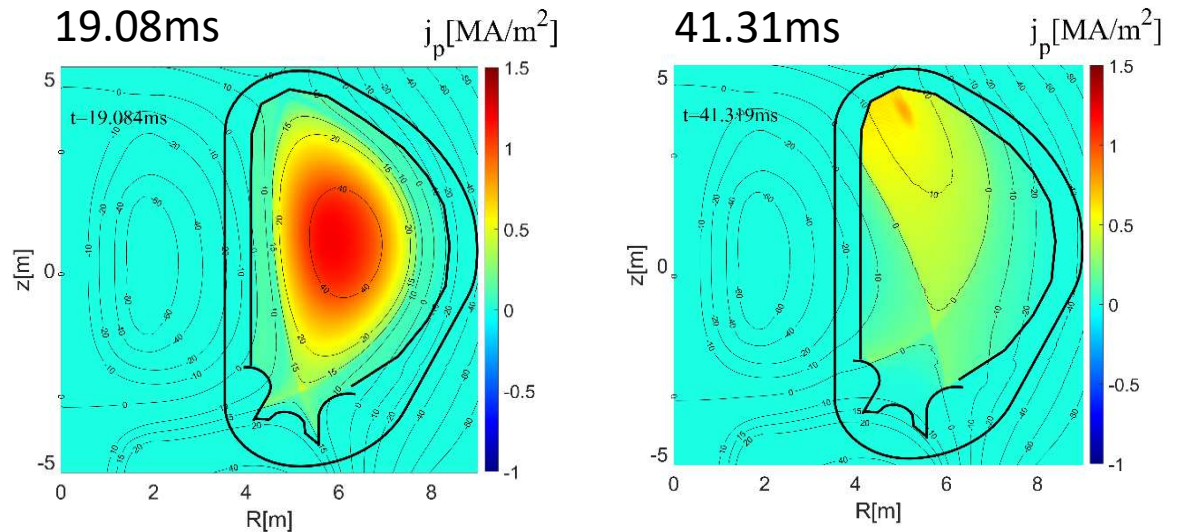
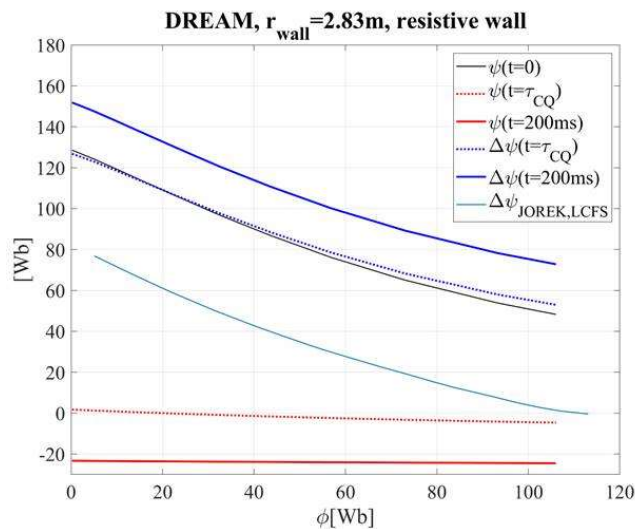


# Effect of vertical movement assessed with JOREK



- Avalanche gain exponentially sensitive to poloidal flux variation  $\Delta\psi(\Phi)$ :

$$\frac{n_{RE}}{n_{RE0}} = \exp\left(\frac{\Delta\psi(\Phi)}{\psi_C}\right)$$

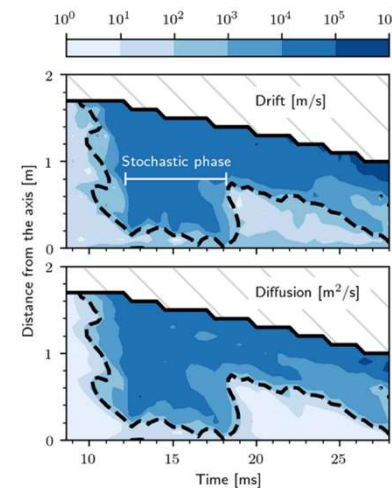
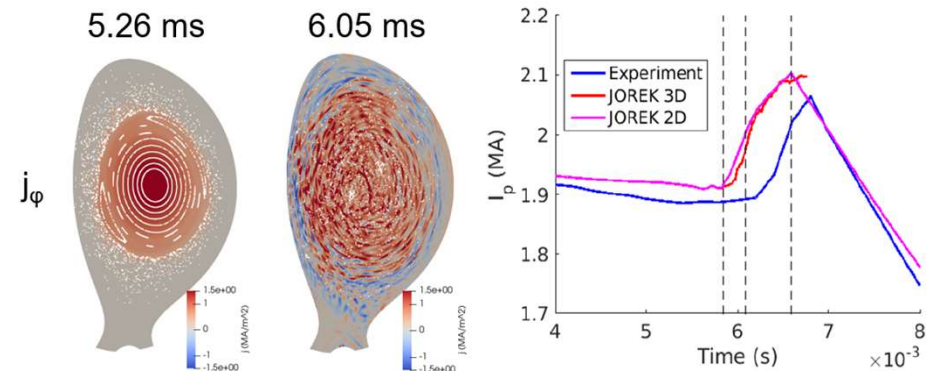


- $\Delta\psi(\Phi)$  assessed with 2D JOREK simulations
- Substantially smaller than in DREAM simulations due to vertical movement [Wang REM 2023]
- Need to revisit DREAM study

# Thermal Quench electron transport studied with JOREK



- Analysis of JOREK JET Ar MGI simulation with realistic  $I_p$  spike supports relation  $I_p$  spike  $\leftrightarrow$  level of stochasticity [Nardon NF 2023]
  - But macroscopic ExB core mixing also plays an important role
- JOREK test electron tracer developed to include collisions and applied to assess transport in ITER 3D CQ simulation [Särkimäki NF 2022]
  - (Long stochastic phase but unclear if this is realistic)
- PhD on predicting hot tail generation in ITER starting this autumn (CEA-IO co-funding)





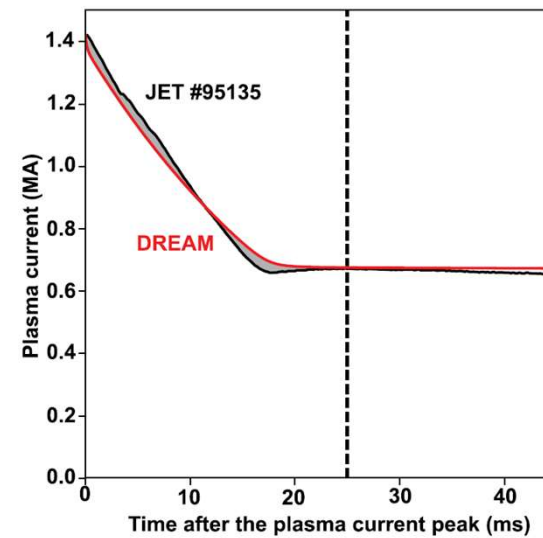
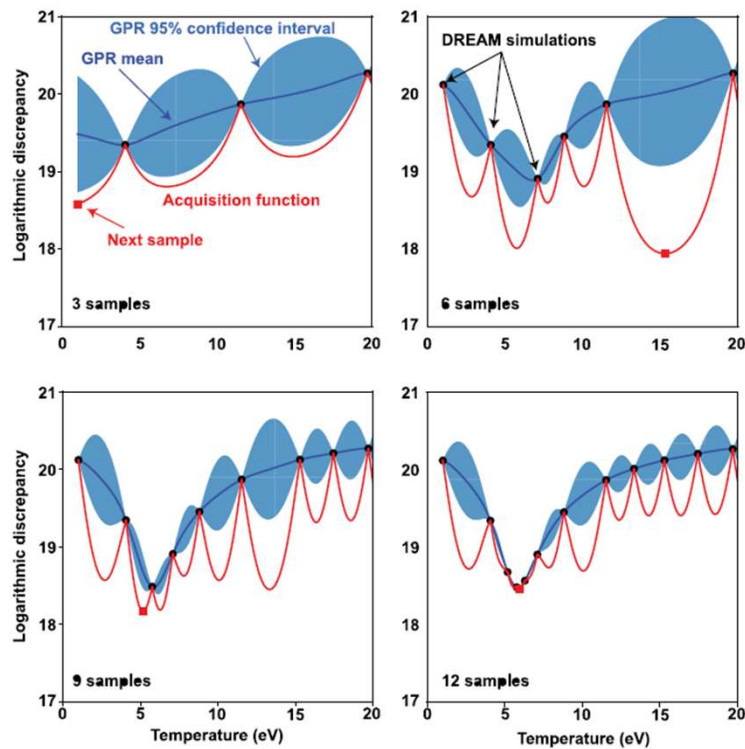
# Validation of avalanche modelling with DREAM and JOREK (1/2)



- Bayesian Optimisation framework applied to DREAM simulations of RE generation by Ar MGI in JET #95135

[Järvinen JPP 2022]

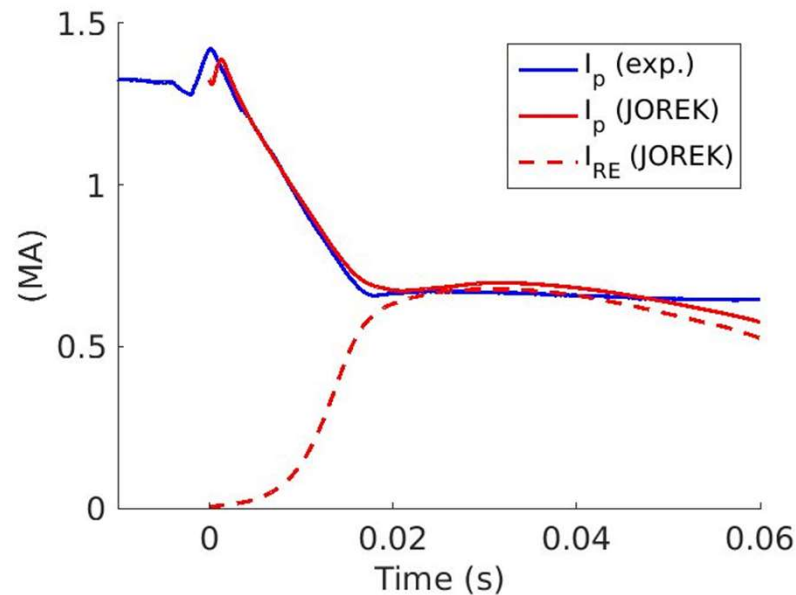
- Ad hoc RE seed → Test only avalanche model
- Now including synchrotron radiation [Järvinen REM 2023]



## Validation of avalanche modelling with DREAM and JOREK (2/2)



- Same case studied with JOREK (RE fluid model) [Nardon REM 2023]
  - Synergies with DREAM work
  - Encouraging agreement with experiment
    - Input parameters adjusted by hand
  - Real validation or fancy fit? → Plan to use BO framework for an objective assessment

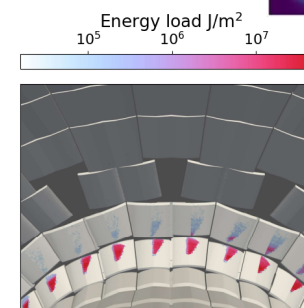
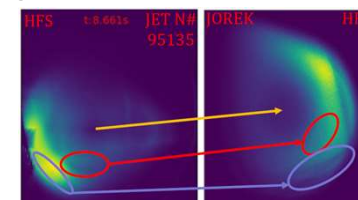
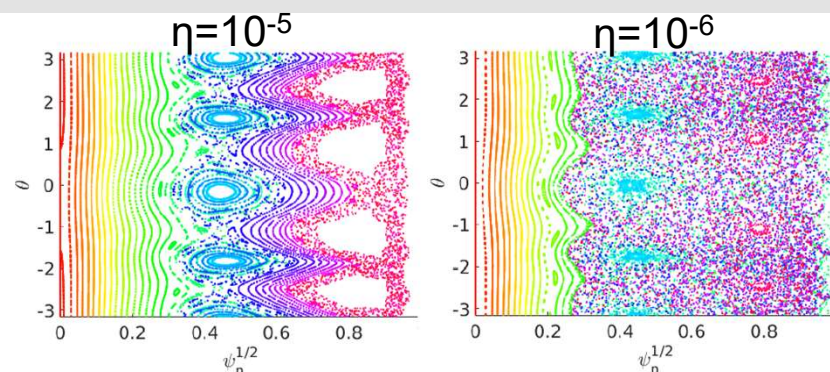




# RE beam (benign) termination modelling with JOREK



- Validation on JET #95135 (benign termination after D<sub>2</sub> SPI)
  - Building on [Bandaru PPCF 2021]
  - Improved understanding of role of resistivity in non-linear dynamics [Nardon PoP 2023 (subm.)]
    - At large  $\eta$ , main islands can grow to larger size before stochastization
  - Also begun investigating dynamics when ramping up  $I_p$  (as in exp.) instead of starting from a very unstable situation [Nardon TSVV 9 meeting April 2023]
    - Was done w/o REs in the model, but will be repeated with REs (L. Singh)
  - Synthetic synchrotron radiation diagnostic developed and applied in presence of islands in JET #95135 [Sommariva REM & EPS 2023]
- Simulations for ITER ongoing [Bandaru REM 2023]
  - Heat loads calculated with test particles and realistic 3D wall model
- Need to model recombination and impurity ‘purge’ from D<sub>2</sub>/H<sub>2</sub> SPI
  - Both in DREAM and JOREK
  - Looking for manpower



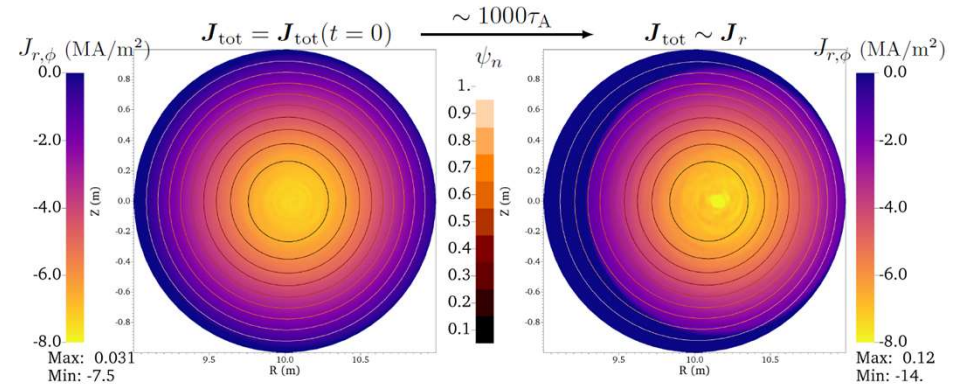
- JOREK electron pusher evolves a population of kinetic electrons
- Moments of kinetic electron population used in the fluid equations
  - 2 possible coupling schemes: via current or via pressure → Implemented both
- Now in phase test, looking at equilibrium radial shift

$$\frac{\partial \rho_b}{\partial t} + \nabla \cdot (\rho_b \mathbf{u}_b) = S_{\rho_b}$$

$$\rho_b \left( \frac{\partial \mathbf{u}_b}{\partial t} + \mathbf{u}_b \cdot \nabla \mathbf{u}_b \right) = (\mathbf{J} - \mathbf{J}_r) \times \mathbf{B} - \nabla p_b + \mathbf{S}_{u_b}$$

$$\frac{\partial p_b}{\partial t} + \mathbf{u}_b \cdot \nabla p_b + \Gamma p_b \nabla \cdot \mathbf{u}_b = (\Gamma - 1) (Q_b - \nabla \cdot \mathbf{h}_b + S_{p_b})$$

$$\mathbf{E} = -\mathbf{u}_b \times \mathbf{B} + \eta (\mathbf{J} - \mathbf{J}_r) - \frac{1}{\sigma_e} (\nabla p_e + \mathbf{S}_{u_e})$$



[Bergström REM 2023]

## Many other activities...



- Organization of the [REM meeting \(picture from last week →\)](#)
- IMASification of DREAM, participation in development of IDSs for REs and SPI
- Effect of alpha-particle-driven modes on RE generation in ITER
- Participation in DEMO meetings + DREAM and JOREK modelling
- DREAM modelling for STEP
- JOREK modelling for DTT
- DREAM modelling for RE Mitigation Coil for SPARC
- DREAM modelling of AUG SPI & Ip spike
- DREAM modelling of effect of ripple on TCV
- Development of an analytical general atomic physics model
- DREAM modelling of RE generation in W-dominated disruptions
- DREAM+SOFT study on EDICAM camera for SR measurement in JT60-SA
- JOREK modelling of effect of SPI shards on hot tail
- Coordination of ITPA Joint Activity called 'Characterization of power deposition to PFCs by runaway electrons'
- Study on start-up REs with STREAM
- ...

