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Exploration of the Equilibrium and Stability Properties of Spherical Tokamaks and Projection for MAST-U

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ABSTRACT

- The disruption event characterization and forecasting (DECAF) code is utilized to map disruptions in MAST; VDEs were not found to be common.
- Equilibrium reconstructions work well for MAST, inclusion of rotation was tested, and procedures are set up for MAST-U, including a 3D wall model.
- A machine learning algorithm for stability calculation developed for NSTX was applied to MAST plasmas; warning levels have been calculated.
- Projections of MAST-U stability indicate a region of high β operational space where new passive stabilization plates stabilize ideal kink modes.

BACKGROUND

- The MAST-U experiment, an upgrade of the MAST device, recently began plasma operations and is entering its first physics campaign.
- In preparation for MAST-U high β_N operation, research was performed on the existing database of MAST discharges on the topics listed above.
- Recent publications [1,2] outline the progress in MAST-U equilibrium and stability. This poster/paper summarizes that work, with new details.

DISRUPTION EVENT CHARACTERIZATION AND FORECASTING

THE DECAF CODE

The DECAF code identifies chains of events that lead to disruptions and the specific physics elements that comprise those chains [3]. The code can generate diagrams showing the probability of a DECAF event occurring within a given parameter space of tokamak operation.

VERTICAL DISPLACEMENT EVENTS

The DECAF code declares that a VDE event has occurred when axis position ($|Z|$), axis velocity ($|dZ/dt|$), and $Z\ dZ/dt$ pass threshold levels set by the user. The region of κ, l_i parameter space where the VDE event was detected in DECAF can be quite different from where plasmas end up at the disruption (DIS) event. One possible explanation for the relative lack of VDE events found for MAST is that MAST had (and MAST-U has) close fitting internal coils that were used for active vertical control.

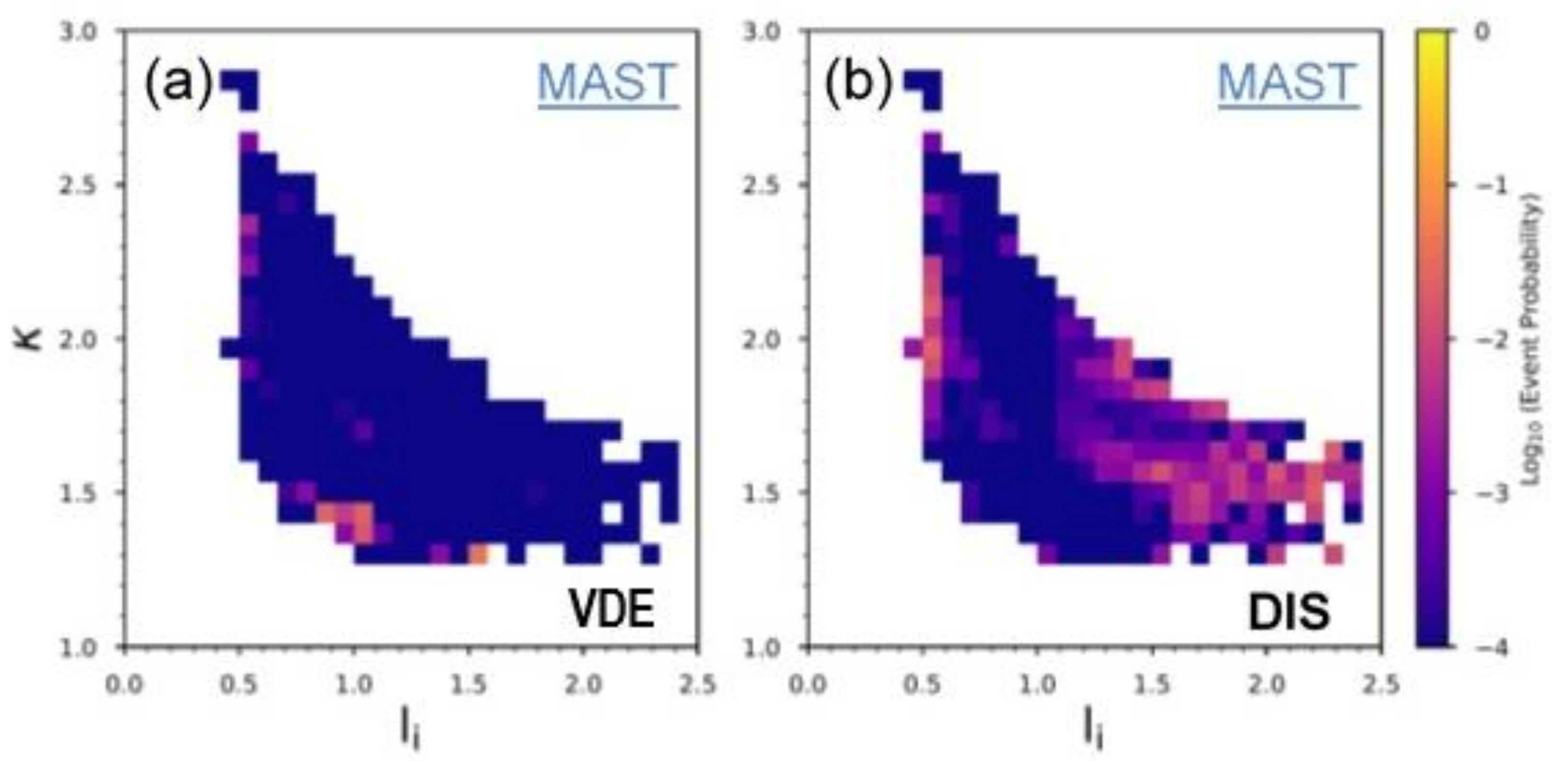

FIG 1: Diagrams of a) VDE and b) DIS in a database of MAST discharges. Colors show probability of the events in segments of κ vs. li parameter space.

EQUILIBRIUM RECONSTRUCTION

THREE LEVELS OF RECONSTRUCTION: MAGNETIC, KINETIC, KINETIC+MSE

All three levels of equilibrium reconstruction are working well for plasmas in the MAST database [2]. Time-domain calculations with the VALEN 3D conducting structure code examined the difference in the modeled induced current between vacuum and plasma shots. The toroidal current in the conducting structure is reduced when plasma current is present, and the decay of 600kA of plasma current (at ~0.3s) can induce ~60kA of additional current in the vessel.

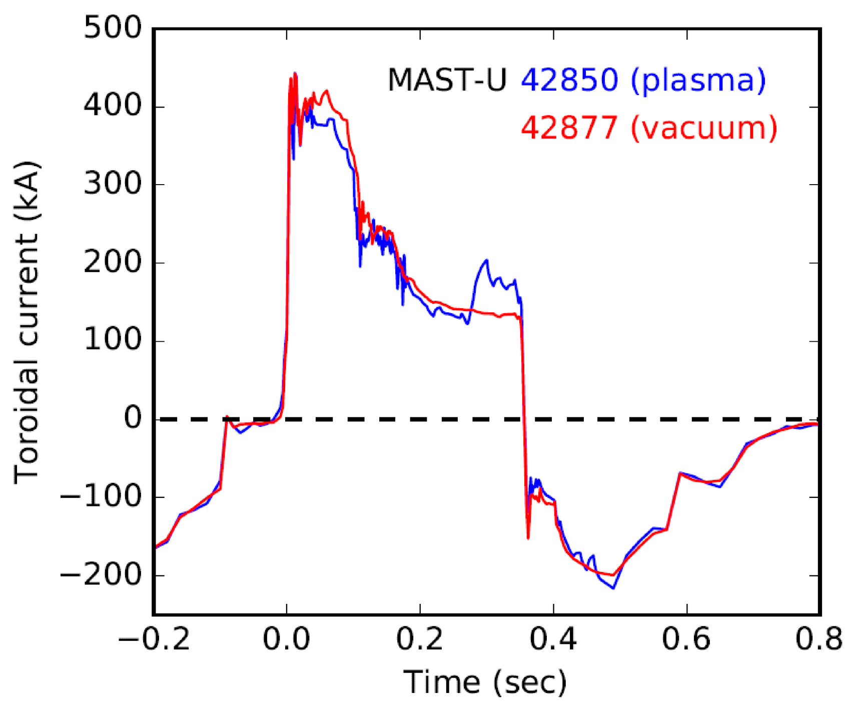

FIG 2: Total induced toroidal current MAST-U conducting structure with (blue) and without (red) plasma current, as calculated by VALEN.

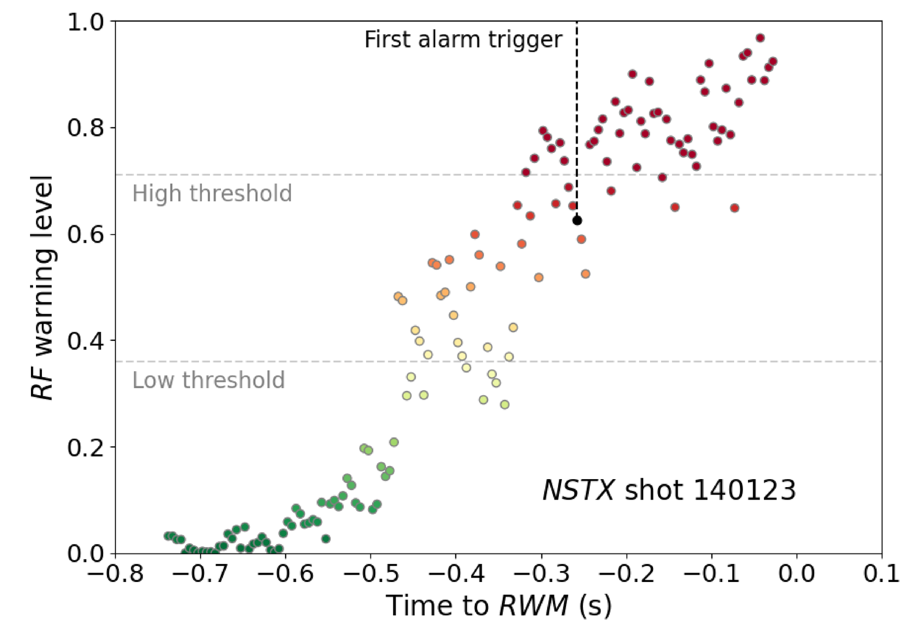

FIG 3: Random forest warning level for NSTX discharge 140123 vs. the time leading to the human-defined time of resistive wall mode instability.

STABILITY ANALYSIS AND PROJECTIONS

MACHINE LEARNING ASSISTED STABILITY CALCULATIONS

The no-wall β_N limit for MAST determined with an NSTX-trained ML algorithm was seen to perform well [4]. These techniques are now being improved, including a random forest detection algorithm for unstable RWMs and utilizing causal graph structures with Bayesian networks.

PROJECTED GLOBAL STABILITY OF HIGH BETA MAST-U ST PLASMAS

Projected MAST-U equilibria were scanned in pressure and current profiles to find the ideal MHD stability limits [1]. The operating space in between these limits is a potential region of high beta operation which is opened up by the effect of eddy currents in the structures surrounding the plasma. This region is projected to be larger in MAST-U than MAST because of newly installed passive stabilization plates in MAST-U.

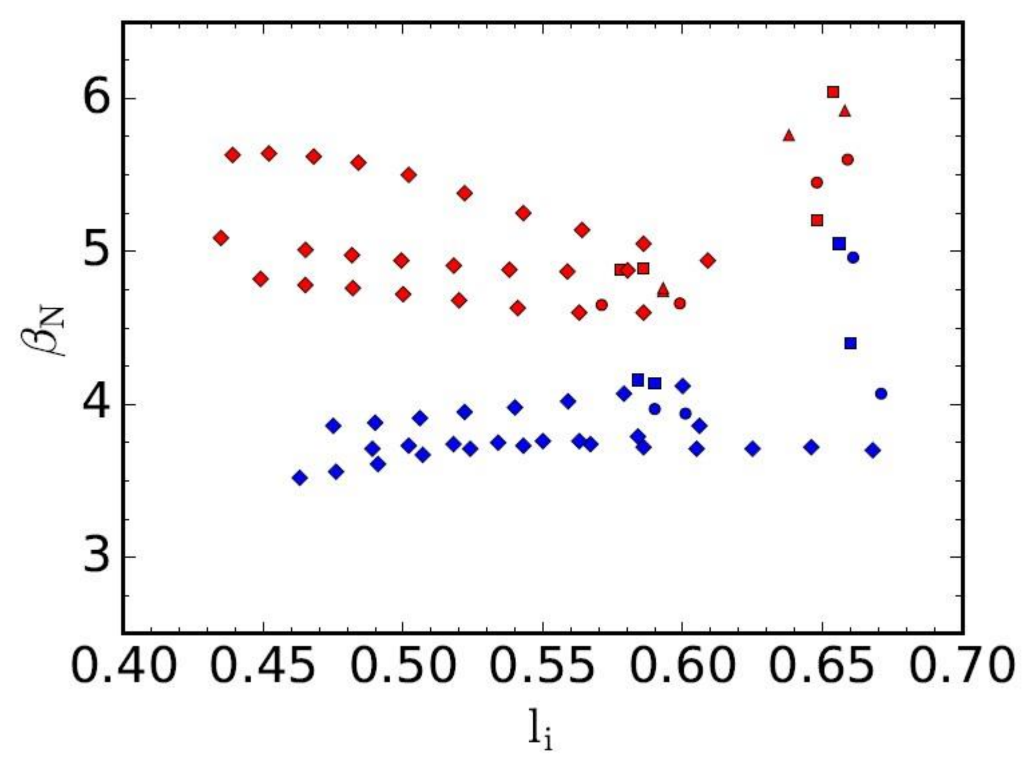

FIG 4: No-wall/with-wall (blue/red) stability limits in projected MAST-U equilibria.

CONCLUSIONS

In preparation for MAST-U, equilibrium and stability properties of plasmas in the MAST database, as well as projections for MAST-U, were explored. DECAF analysis showed low VDE levels. Equilibrium reconstruction works well for MAST and is set up for MAST-U. ML stability tools progress, and projections show a region of potential high beta stability in MAST-U.

ACKNOWLEDGEMENTS / REFERENCES

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