FES Joint Facilities Research Milestone 2015

Annual Target: Conduct experiments and analysis to quantify the impact of broadened current and pressure profiles on tokamak plasma confinement and stability. Broadened pressure profiles generally improve global stability but can also affect transport and confinement, while broadened current profiles can have both beneficial and adverse impacts on confinement and stability. This research will examine a variety of heating and current drive techniques in order to validate theoretical models of both the actuator performance and the transport and global stability response to varied heating and current drive deposition.

1st Quarter Milestone

Begin analysis of previously collected data with a goal of defining new experiments. Develop an initial plan for collaborative experiments and analysis to be conducted during the remainder of the fiscal year.

Overview of achievements during 1st Quarter

The targeted goal for the first quarter was achieved, as documented in more detail in the remainder of this report. Analysis of data from the three facilities has been performed to identify topics for which joint analyses and experiments are required. Recent results will also inform on experimental plans for the three facilities, which will be discussed at Research Forums early in 2015.

Alcator C-Mod progress

In the Alcator C-Mod, analysis of scenarios with LH injection shows that etc etc etc.

DIII-D progress

The plan for experiments in DIII-D includes 1) something; 2) something else; and 3) even more.

NSTX-U progress

Analysis of NSTX data has been performed to guide the preparation of Experimental Proposals that will be discussed at the NSTX-U Research Forum (Feb. 2015). Two main areas of research have been identified to address the overall JRT-15 goals, namely: (i) achievable performance in terms of NBI parameters for current profile control, in particular in connection with stability properties of Energetic Particle (EP) driven modes and their effects on NB ions; (ii) MHD stability properties (including disruptivity) with respect to current/pressure profile and NB injection parameters.

Advances on the first topic have been made by compiling a database of stable vs. unstable EP-driven modes on NSTX as a function of “global” plasma parameters, such as the fast ion vs. thermal beta and typical fast ion velocities compared to the Alfvén speed (Fig. 1). Based on predictive TRANSP runs, it is found that NSTX-U should be able to access parameters which were found to be quiescent on NSTX, as well as parameters where EP-driven instabilities can be expected. Analysis is progressing to include in the database q-profile and pressure peaking factors.

The assessment of the effects of instabilities on plasma performance has required the improvement of existing modeling tools and the development of new tools for more accurate predictions. The ideal MHD code NOVA-K has been improved by including finite rotation in the computation of the drive and damping rate of the modes, as required to study plasmas whose rotation is of the order of the mode frequency (this includes NSTX and NSTX-U, but also DIII-D plasmas with strong co-NB injection). Calculation of other stability terms has also been improved, for instance to compute ion Landau damping based on the actual ion thermal distribution.

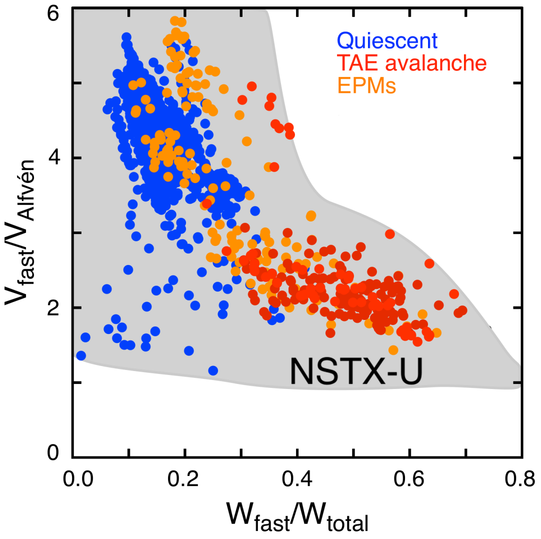

Figure 1: Fast ion parameter space for EP-driven modes and quiescent regions (from Ref. [1]).

In addition to NOVA, new tools have been developed to predict the effects of EP-driven instabilities on the fast ion population, hence on quantities such as NB-driven current profile and NB power transfer to the thermal species (through slowing down). Two complementary approaches have been pursued to compute the fast ion response to a given set of instabilities, namely: through quasi-linear theory (Fig. 2) and via a reduced, "probabilistic" model for fast ion evolution in phase space. The latter model is now implemented in the NUBEAM module of TRANSP. Along with improved predictive capability, these new models will enable more accurate interpretation of experimental data from the extensive suite of fast ion diagnostics on NSTX-U. The latter includes neutron counters, fast ion D-alpha and neutral particle analyzers, whose calibration has been successfully completed in Nov. 2014.

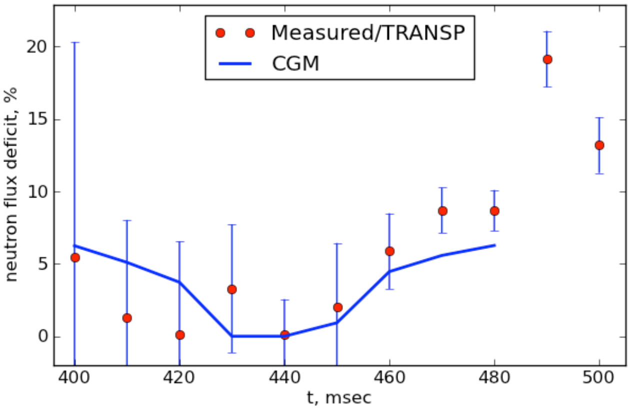

Figure 2: Comparison between measured neutron rate and predictions from CGM model [2] for NSTX #141711.

Besides the effects of EP-driven instabilities, global MHD stability is also expected to impact plasma performance depending on pressure, current and rotation profiles. Experiments on NSTX-U will target profile optimization and control to achieve and sustain stable scenarios at high beta by avoiding unstable modes eventually leading to disruptions or confinement degradation. Recent work has focused on understanding the stability of Ideal and Resistive Wall Modes (IWM, RWM) to enable predictions for NSTX-U, whose improved NB injection system will provide enhanced flexibility to control relevant quantities such as safety factor, rotation and fast ion pressure profiles.

A beneficial role of a broad fast ion pressure on IWM stability has been demonstrated through the MARS-K code. For NSTX plasmas, the predicted marginally stable β_N is higher for broader fast ion pressure profiles. Results for the marginal β_N and mode frequency are consistent with experimental observations once rotation and fast ion pressure are included in the equilibrium reconstruction from the LRDFIT code.

Kinetic effects on RWM stability have also been studied experimentally on NSTX and DIII-D, and complemented by simulations via the MISK code [3][4]. Analysis indicates a quite surprising *increase* of RWM stability at high values of β_N/l_i (here l_i is the internal inductance), see Fig. 3, which is indicative of broader current profile for similar values of β_N. The increased stability is interpreted in terms of a correlation between high β_N/l_i and kinetic stabilization of the RWM by rotational resonances [4], which will be further investigated on NSTX-U with the broader set of actuators available to modify the current profile.

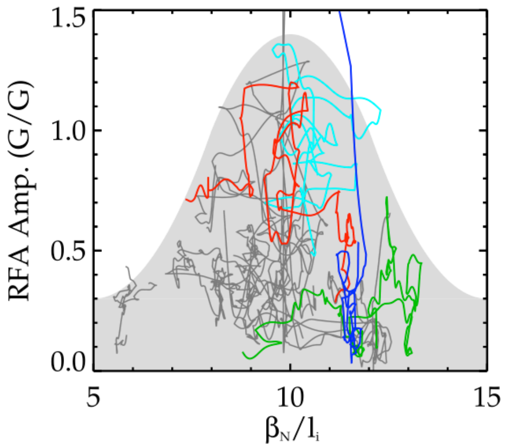

Figure 3: Resonant Field Amplification measured by active MHD spectroscopy showing increased stability (low RFA) at high β_N/l_i (from Ref. [4]).

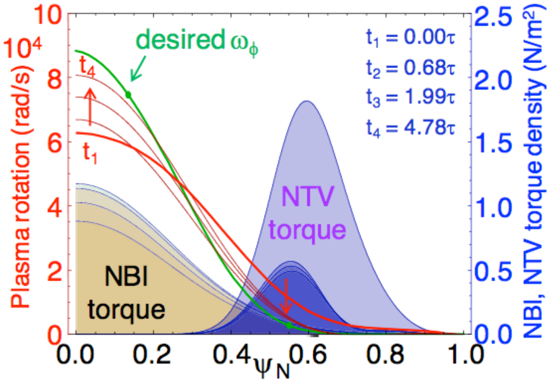

Figure 4: Test of rotation control algorithm using NB and RWM coils as actuators (from Ref. [5]).

Another long-term goal is to leverage on the increased understanding of global stability properties to develop *model-based* real-time disruption prediction algorithms as an alternative (or in combination with) real-time MHD spectroscopy data. Development of such schemes is expected to be high priority for NSTX-U experiments in FY-15, and will inform on possible schemes for disruption prediction, avoidance and mitigation on future devices such as ITER.

Another area in which improved RWM analysis and simulations will guide experiments on NSTX-U is that of rotation control, which can be used to steer the discharge away from unstable regimes and improve performance. To this end, control schemes using NBI and Neoclassical Toroidal Viscosity (NTV) as actuators in state-space rotation feedback controller are being designed for NSTX-U, cf. Fig. 4. Initial tests show promising results for rotation control in NSTX-U, and motivate further improvements to the model such as the inclusion of ion temperature variations.

Additional [recent] analysis & tools development to be considered:

- Kaye/Guttenfelder/Ren, Profile modification effects on thermal transport.
- Maingi, use of lithium for ELM-free scenarios, pedestal modification. [IAEA-14]
- Others?

Coordinated analysis and experiments

- Current profile dependence on NBI parameters. Look at data from 2013/14 to bridge the gap between DIII-D and NSTX-U (e.g. B, aspect ratio), plan new experiments.
- Validation of models for improved predictions of EP dynamics (w/ DIII-D).
- Validation of theory/codes for kinetic effects on global stability (kinks, RWM), algorithms for disruption avoidance.
- Should we include plans for *international* collaborative work? Example: SAS's work on KSTAR, DIII-D scenario development for high-qmin on KSTAR, etc.

References

[1] E. D. Fredrickson et al., Nucl. Fusion **54** (2014) 093007
[2] N. N. Gorelenkov et al., IAEA-FEC (2014); J. Lestz et al., APS-DPP (2014)
[3] S. A. Sabbagh et al., Nucl. Fusion **53** (2013) 104007
[4] J. W. Berkery et al., Phys. Plasmas **21** (2014) 056112
[5] S. A. Sabbagh et al., IAEA-FEC (2014); I. Goumiri et al., APS-DPP (2014)