Integrated Modelling of RMP-Induced ELM Suppression in NSTX-U Including Neutrals

Richard Fitzpatrick [1] Saskia Mordijck [2]

[1]University of Texas at Austin

[2]College of William and Mary

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Overview

- Aim of project to build predictive RMP-induced ELM suppression model that includes neutrals.
- Goal relevant to Thrust 1-2: *Validate role of 3D field effects in core and pedestal performance.*

Description of EPEC Code - I

- EPEC (Extended Perturbed Equilibrium Code) code implements asymptotic matching approach to modelling resistive response of toroidal tokamak plasma to RMP.[1]
- Homogeneous toroidal tearing mode dispersion relation calculated by EPEC code using high-q approximation.
- Inhomogeneous components of toroidal tearing mode dispersion relation (which pertain to ideal response of plasma to applied RMP) calculated by GPEC code.[2]
- EPEC takes both poloidal and toroidal plasma rotation into account.
- EPEC incorporates accurate neoclassical model, that includes both impurities and *neutrals*, in order to determine correct neoclassical poloidal flow damping rate, and neoclassical resistivity.

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[1] R. Fitzpatrick, and A.O. Nelson, PoP **27**, 072501 (2020); R. Fitzpatrick, PoP **27**, 102511 (2020); R. Fitzpatrick, PoP **28**, 022503 (2021).

[2] J.-K. Park, and N.C. Logan, PoP **24**, 032505 (2017).

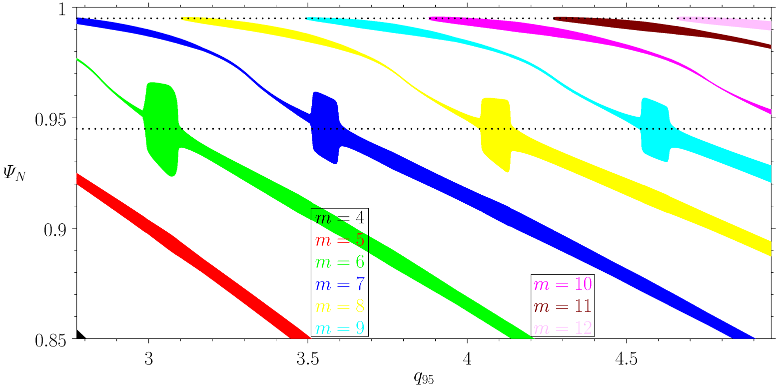
Description of EPEC Code - II

- In inner region, EPEC interpolates smoothly between linear (semi-collisional) and nonlinear (Rutherford) response regimes.
- EPEC island-induced density and temperature flattening model takes into account fact that parallel transport is *convective* rather than *diffusive* in nature.
- EPEC uses experimental plasma equilibrium (gfile), experimental profiles (pfile), and perpendicular energy/particle/momentum diffusivities determined by (e.g.) TRANSP code.
- In absence of ion poloidal rotation data, EPEC uses toroidal rotation data combined with neoclassical theory to determine ExB rotation profile.

Importance of Neutrals

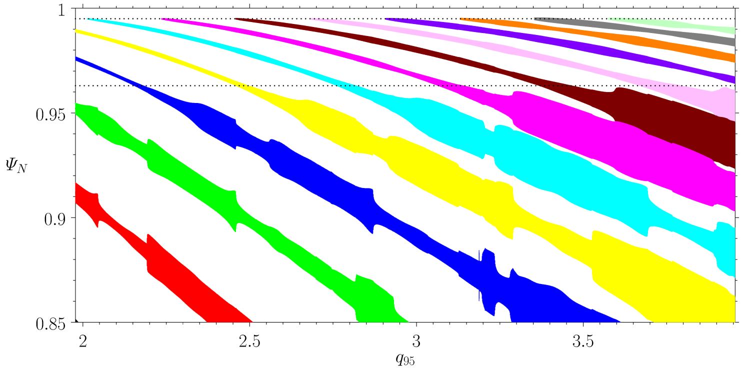
- Presence of neutrals in pedestal of H-mode tokamak plasma (in particular, poloidal variation of neutral density around flux-surfaces) *profoundly modifies* poloidal rotation profile, and also significantly affects neoclassical flow damping rate.
- Cannot accurately predict pedestal ExB rotation profile, in absence of poloidal rotation data (i.e., in NSTX-U), without knowledge of neutral distribution inside LCFS.
- Direct measurements of neutrals inside LCFS in present-day tokamaks are rare and lack spatial resolution (especially in poloidal direction).
- Only viable way forward is via *modelling* using (e.g.) SOLPS code.

KSTAR (#18594) EPEC Simulation - Driven Island Widths



- $n = 2$ RMP drives island chains at top of pedestal when q_{95} lies in certain narrow windows. Driven reconnection shielded by plasma flow elsewhere in plasma. Driven island chains in windows reduce pedestal pressure gradient by $\sim 15\%$.
- Locations of q_{95} windows predicted by EPEC match those seen experimentally.

MAST (#27205) EPEC Simulation - Driven Island Widths



- MAST plasma too cold, and has too low core rotation (because plasma shifted downward to get SND, and NBI heating missed core), for effective shielding of reconnection driven by $n = 3$ RMP. Pedestal shielding due to high diamagnetic rotation.
- According to EPEC, this discharge is a *"turkey"*!

Other Observations

- Idea that equatorial RMP coils are ineffective is a myth! Middle KSTAR coil-set 20% more effective at driving magnetic island chain at top of pedestal than upper or lower coil-sets.
- If NSTX-U can provide target H-mode plasma that is sufficiently hot (i.e., $T_e \gg 1\,\mathrm{keV}$), and has sufficiently large core rotation (i.e., $\omega_\phi \gg 100\,\mathrm{krad/s}$), and if sufficient current can be run through RMP coil (can calculate), then no reason, in principle, why RMP ELM-suppression would not work.
- Know enough about plasma energy/particle/momentum transport, and pedestal structures, to make educated guess of likely profiles in given experimental scenario. Should be possible to optimize RMP ELM-suppression scenario, *prior to performing experiment*, so as to maximize likelihood of successful outcome (or even to determine whether successful outcome is at all possible).

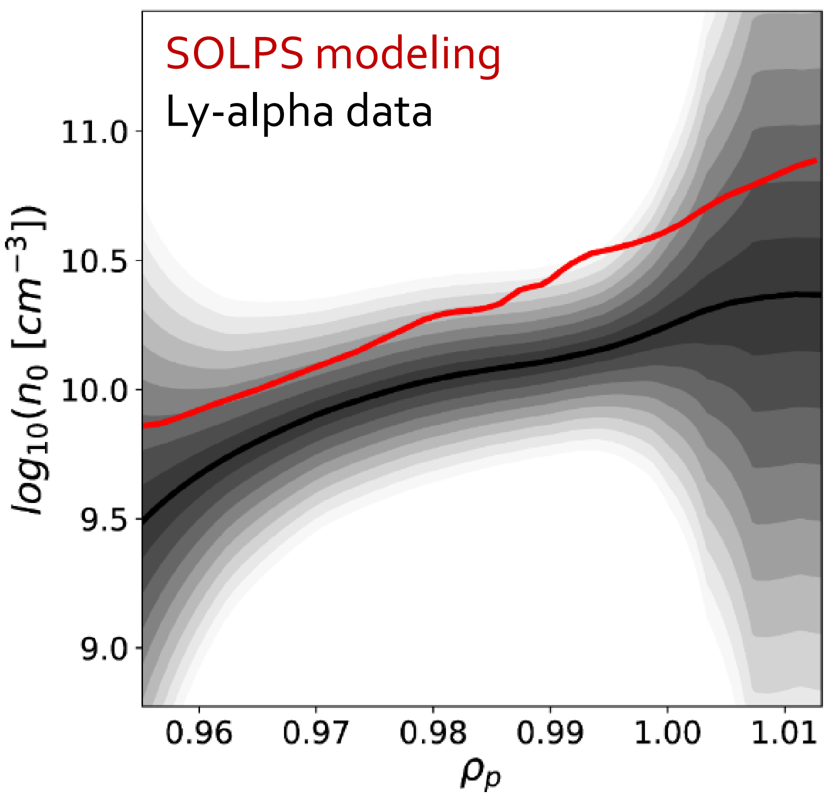
Keys Needs

- Running either EPEC or SOLPS with experimental data is currently a very labor-intensive process.
- Need to streamline process by incorporating both codes into OMFIT framework.
- Additional needs involve routine access to experimental data, smoothing of experimental profiles, generation of kinetic equilibria, TRANSP runs, etc., combined with easy transfer of data between codes involved.
- PI (RF) does not know how to do any of above-mentioned tasks! (Co-PI (SM) is very busy.) Real research need is identification of staff member at PPPL who is prepared to spend significant time guiding PI (or PI's students) through aforementioned tasks. Alternatively, PI could hire somebody who knows how to do these tasks (but who?).

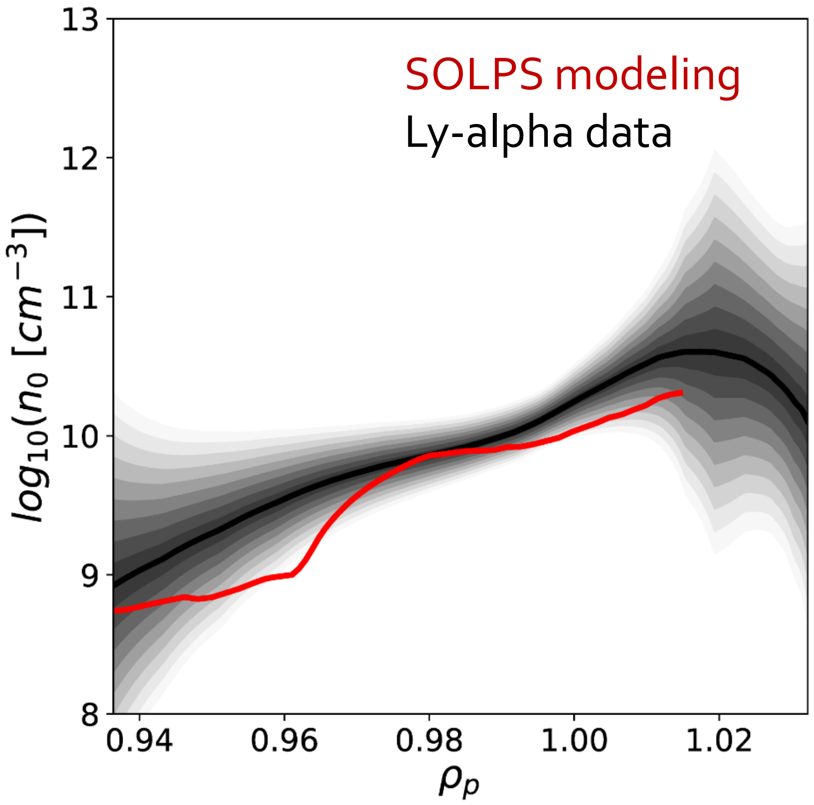
Overarching goal is to built predictive RMP ELM suppression model that includes neutrals

- Perform SOLPS modeling to get the neutral densities in the pedestal region on archived data for ST
- Built an integrated platform using OMFIT to couple neutral output back to RMP model
  - There is work in parallel with MIT to validate SOLPS modeling against measurements of neutral densities
  - Combining diagnostic input, SOLPS input and impurity transport model in Aurora
- Test the integrated model on new NSTX-U experiments and potentially use in future coil design for RMP ELM control

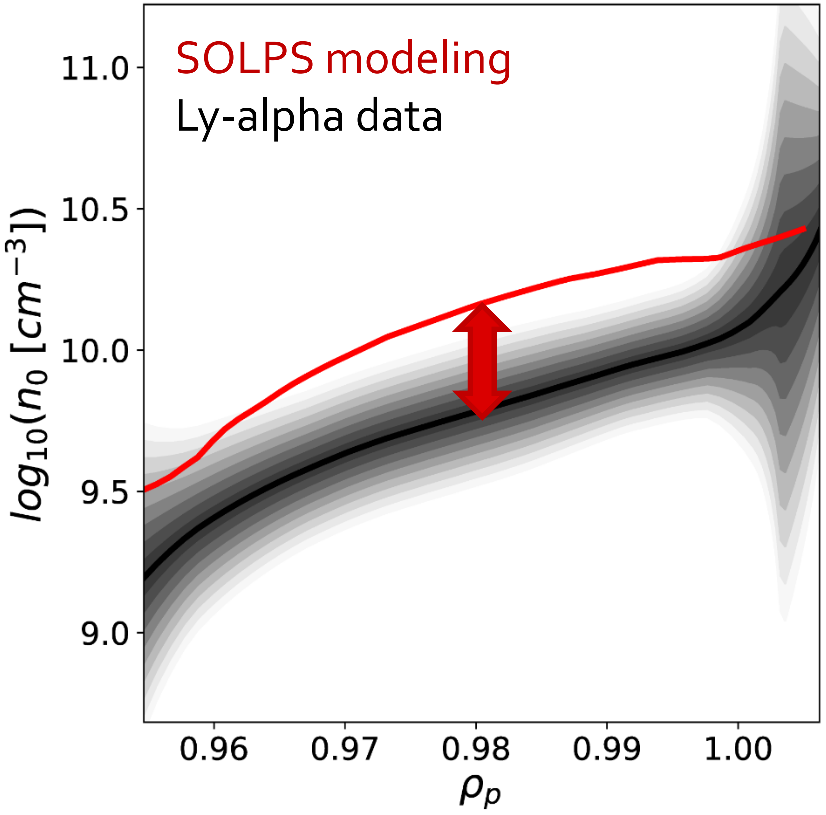
Need to validate these simulations in a range of plasma conditions to understand the validity



C-Mod L-mode



C-Mod H-mode



C-Mod I-mode

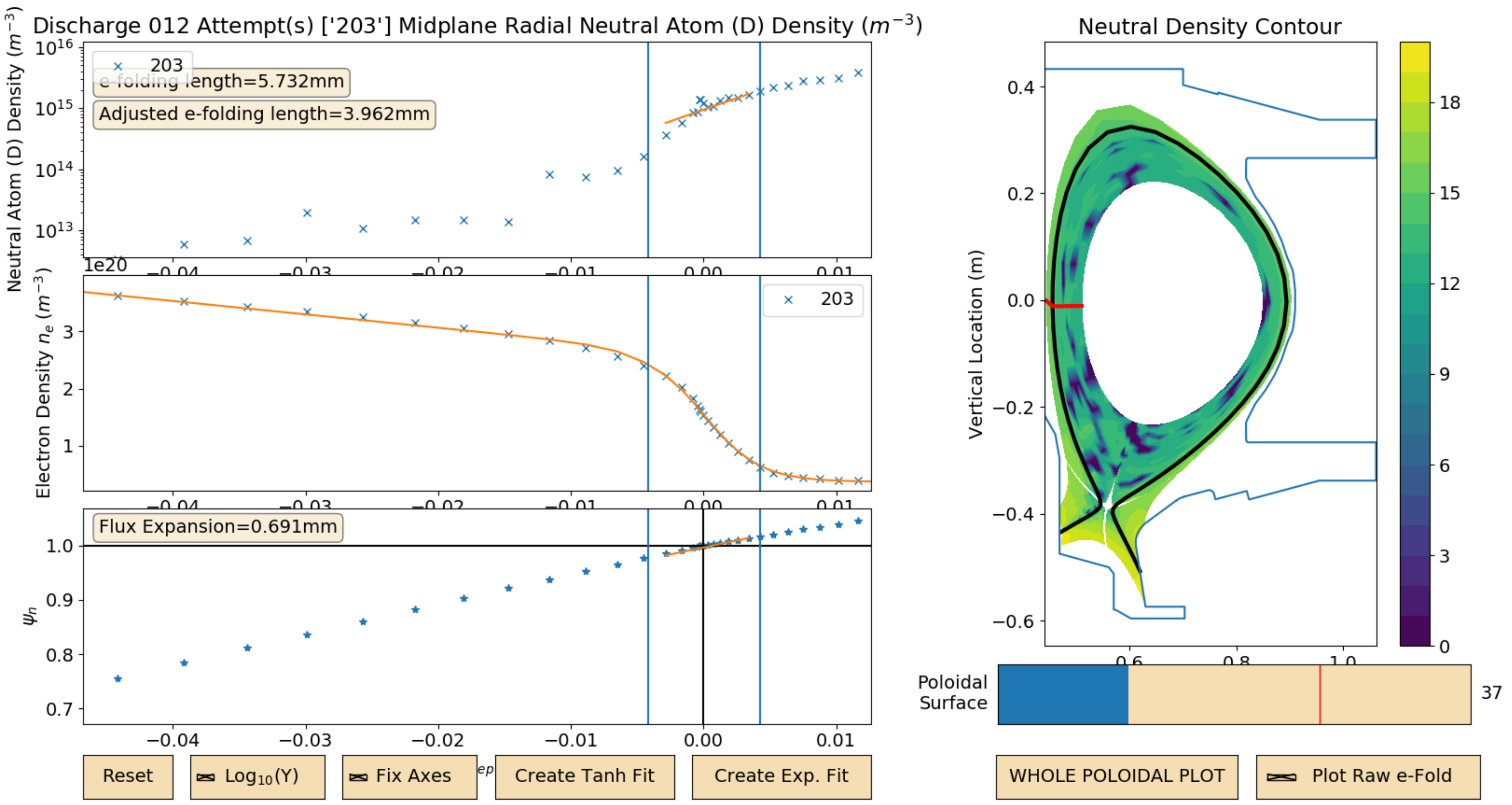
Richard Reksoatmodjo (W&M) SOLPS modeling, F. Sciortino (MIT) Ly-alpha analysis

Estimated schedule of activities

- Currently ongoing
  - Current focus is on integrating the neutral output from SOLPS into OMFIT as step stone for integrated model
  - SOLPS modeling of MAST RMP experiments
    - Training undergraduate students to run simple SOLPS simulations

- Future work
  - Couple the SOLPS/Aurora module to the MHD model
  - Perform simulations on existing ST (MAST) data
  - Model potential RMP experimental setups for NSTX-U
  - Validate SOLPS neutral results in NSTX-U against diagnostics

GUI interface to extract neutral densities at various poloidal locations – not in OMFIT



Requirements

- Recruiting 1 extra graduate student or a potential post-doc
- Access to RMP ST experiments with density pump-out and change in ELM behavior
  - Archival MAST data might be the best candidate
- New NSTX-U RMP experiments looking at changes in density and ELM behavior
- Need/Make OMFIT available for NSTX-U data