Modeling and Simulation of Pedestal Control Technique for NSTX-U

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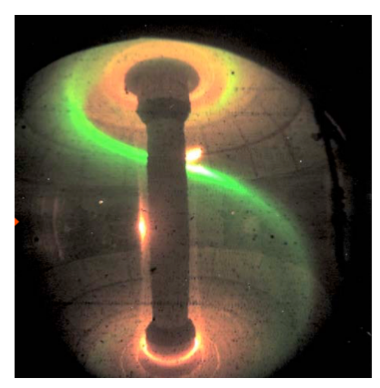
Motivations

- Lithium Granule Injections (LGI) is a new ELM control technique for tokamaks which has recently been installed on NSTX-U and DIII-D.
- Use of non-D2 pellets allows to reduce the total fuel injection rate, which is limited in ITER.
- Robust ELM-pacing on DIII-D but concern exists because of the variability of observed ELM sizes.
- Final aim: combine these methods into an adaptive and automatic pedestal control algorithm to allow one to explore new innovative scenarios such as the Super H-Mode or lithium induced ELM-free regimes.



Results

- New granule ablation model implemented and tested in M3D-C[1].
- Sub-mm granule injections simulated in NSTX plasmas.
- Maximum deposition at the pedestal top depends on the granule size, injection velocity and angle.
- A higher localized pressure increase obtained for large and slow granules.
- 3D simulations show the destabilization of high-order MHD modes during the LGI.
- Source toroidal localization has a non-negligible impact on the amplitude of the magnetic activity.

M3D-C[1] simulations of Lithium Granule Injections

$$\frac{\partial n}{\partial t} + \nabla \bullet (n\mathbf{V}) = 0 \quad + S_{density} \leftarrow \text{LGI}$$

$$\frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathbf{E} \qquad \mathbf{B} = \nabla \times \mathbf{A} \qquad \mathbf{J} = \nabla \times \mathbf{B}$$

$$nM_i\left(\frac{\partial \mathbf{V}}{\partial t} + \mathbf{V} \bullet \nabla \mathbf{V}\right) + \nabla \bullet \mathbf{P} = \mathbf{J} \times \mathbf{B} - \nabla \bullet \mathbf{\Pi}_{GV} + \mu \nabla^2 \mathbf{V}$$

$$\mathbf{E} + \mathbf{V} \times \mathbf{B} = \mathbf{R}_c + \frac{1}{ne}(\mathbf{J} \times \mathbf{B} - \nabla \bullet \mathbf{P}_e) - \lambda_H \nabla^2 \mathbf{J}$$

$$\frac{3}{2}\frac{\partial p_e}{\partial t} + \nabla \bullet \left(\frac{3}{2} p_e \mathbf{V}\right) = -p_e \nabla \bullet \mathbf{V} + \eta J^2 + \frac{\mathbf{J}}{ne} \bullet \left[\frac{3}{2}\nabla p_e - \frac{5}{2}\frac{p_e}{n}\nabla n\right] - \nabla \bullet \mathbf{q}_e + Q_\Delta$$

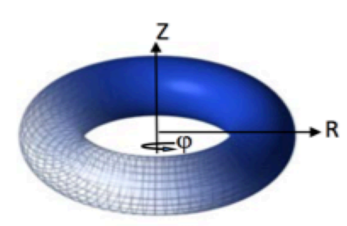
$$\frac{3}{2}\frac{\partial p_i}{\partial t} + \nabla \bullet \left(\frac{3}{2} p_i \mathbf{V}\right) = -p_i \nabla \bullet \mathbf{V} + \mu |\nabla V|^2 - \nabla \bullet \mathbf{q}_i - Q_\Delta$$

Resistive MHD: $\nabla \bullet \mathbf{P} = \nabla p$, $\mathbf{R}_c = \eta \mathbf{J}$

2-fluid terms

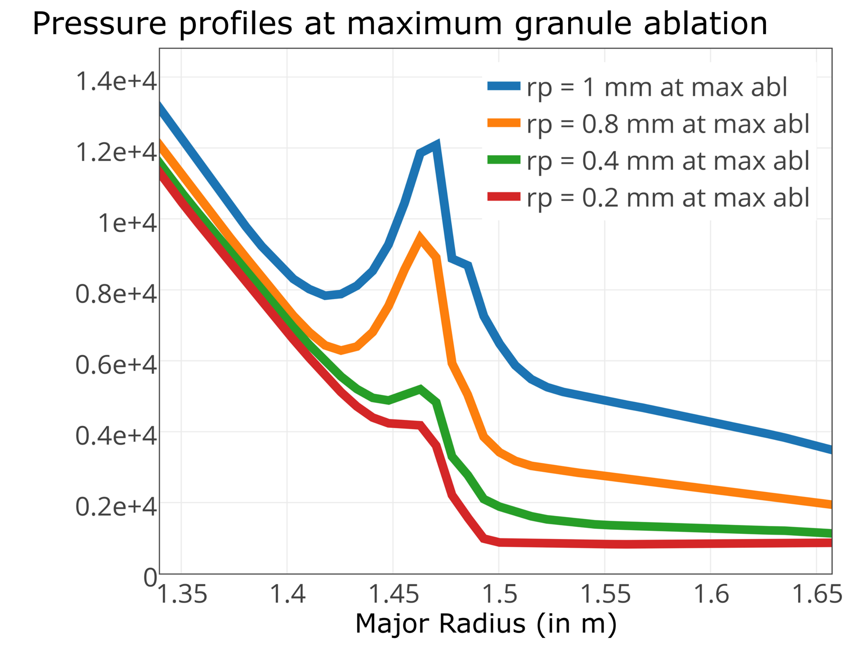
[S. Jardin, N. Ferraro et al.]

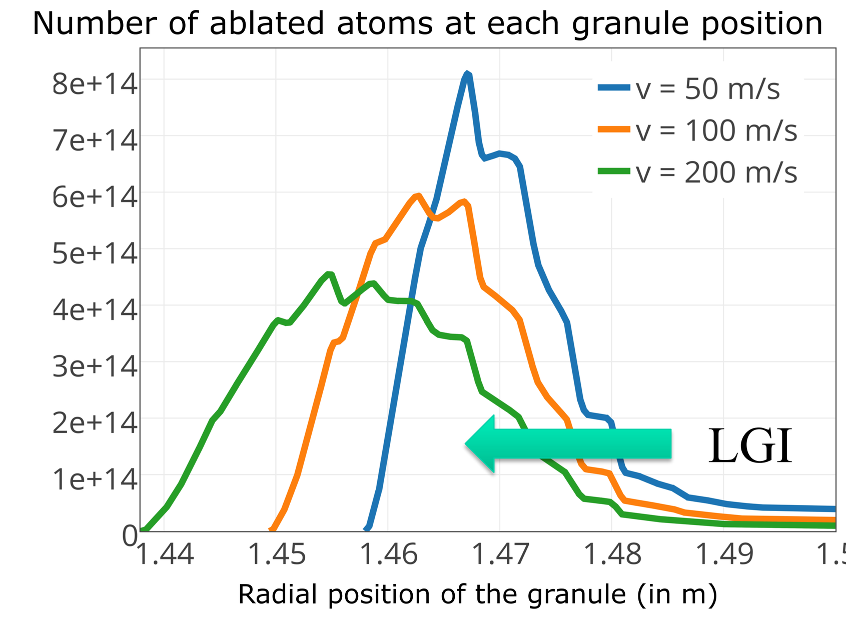
Kinetic closures extend these to include neo-classical, energetic particle, and turbulence effects.



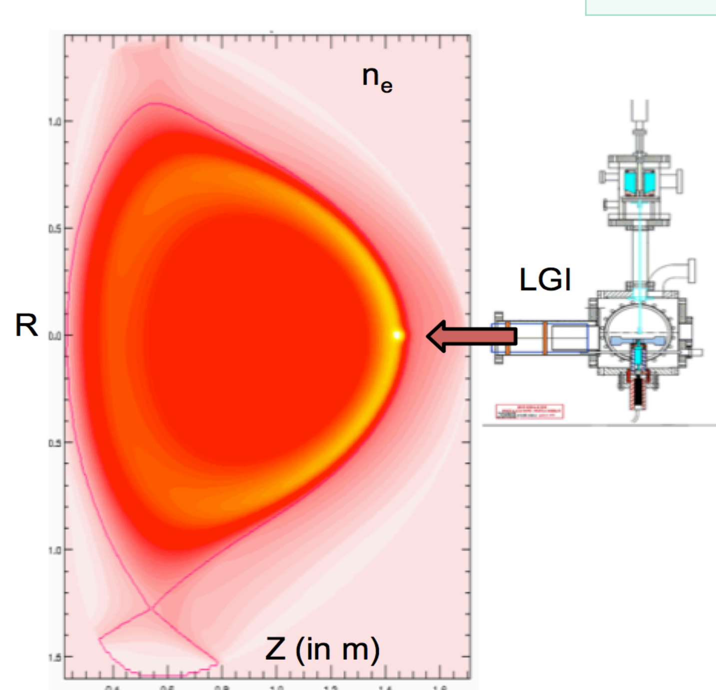
- Target plasma: NSTX 129015 (H-mode with B_T = 0.44 T, I_p = 0.785 MA, a = 0.627 m).
- Simulation started 0.4 s after discharge's beginning, within an inter-ELM time interval.
- Scan on granule injection parameters:
  - First in 2D (fast to run and allows to also scan numerical parameters).
  - Then 3D simulations (see below).
  - Granule parameters range:

Rp (in mm)	Inj. Velocity (in m/s)	Source width (in cm)	Inj. Angle
0.2 - 1	50 - 200	1 - 5	-75 to +75





- New granule ablation model (Parks, 2015) implemented in M3D-C[1].
- Density source propagating inward with a constant velocity
- Can describe small-size granule (< 1 mm).
- Simulation start from experimental NSTX profiles and equilibrium.

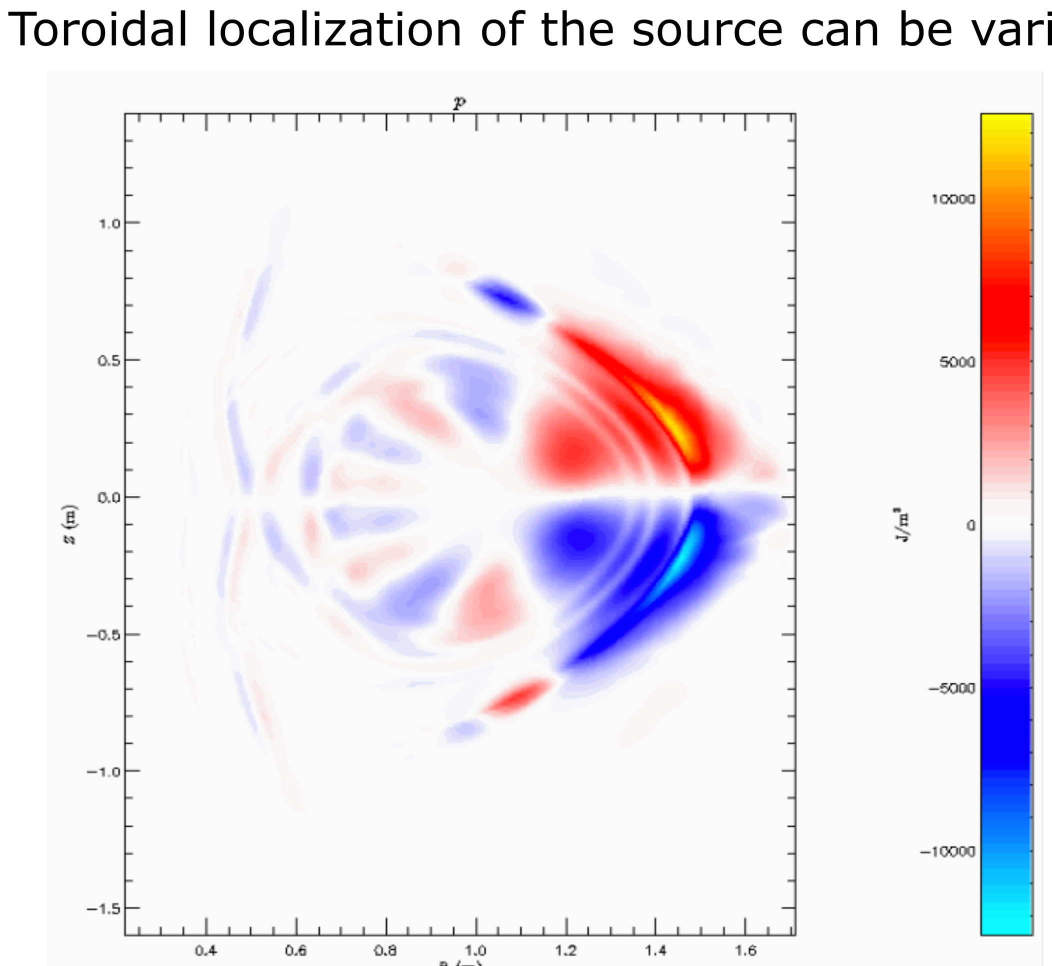


- Penetration depth increases with the granule size (example: 3 cm inside the pedestal top for 1 mm granules at 100m/s).
- Reducing the velocity allows a more peaked deposition but whose maximum can be outside the pedestal top.
- Injecting with an angle is similar to a reduction of the injection velocity.
- Pressure increase in the SOL is due to M3D-C[1] boundary conditions in the open field lines region.

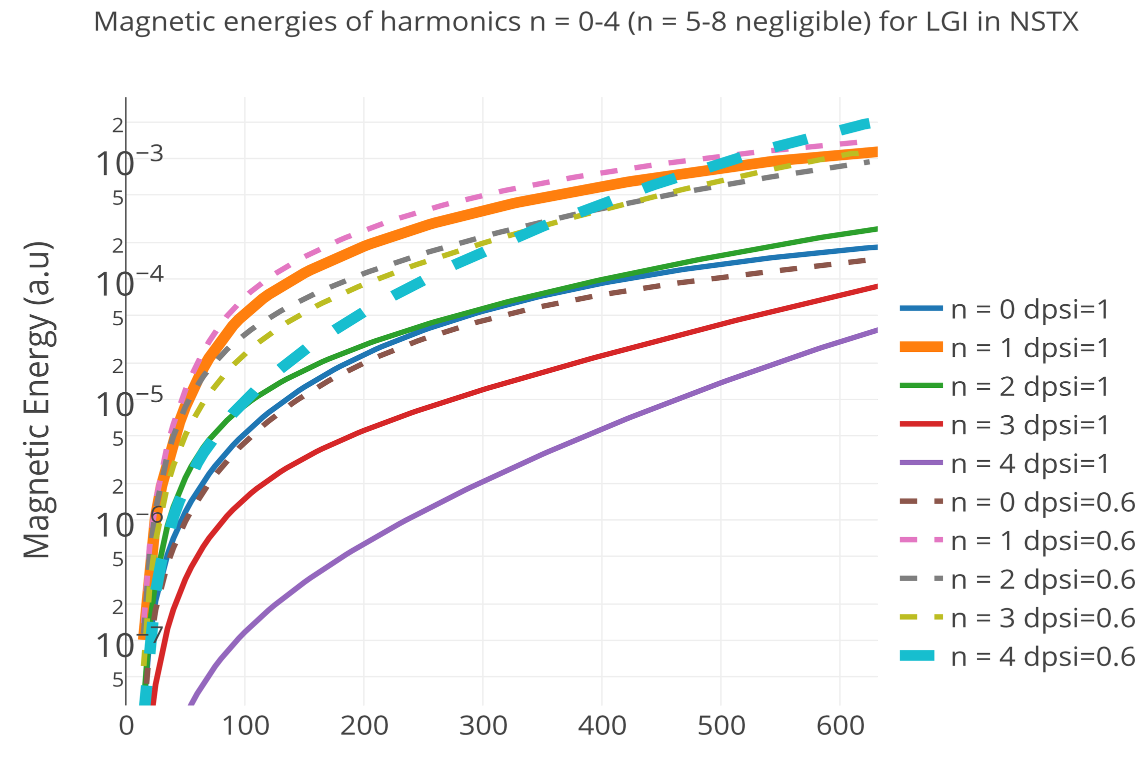
Separatrix at R = 1.48 m
Pedestal top at R = 1.46 m

3D simulations and source toroidal extension

- NSTX simulations with different number of toroidal planes (16 and 32) on Princeton clusters (~1 week to get full ablation).
- Simulation show destabilization of high-order modes (n=4-8).
- Toroidal localization of the source can be varied.



Current perturbation after Li injection in NSTX



- Reducing the toroidal width (dpsi) of the source allows to destabilize higher order modes (n = 4 instead of n = 1 in the above example).
- Also results in a more peaked localized pressure perturbation at the granule location.
- Current memory limitations prevent us from including higher-order modes.
- Testing on-going on Edison (NERSC) for higher toroidal and poloidal resolution.
- Mesh and toroidal plane packing is investigated to simulate granules with smaller toroidal width.

Perspectives

- Increase toroidal and poloidal resolutions to reduce the toroidal localization of the source.
- Comparison with future NSTX-U experiments.
- Extend simulations to the EAST tokamak.
- Develop a simple criterion for ELM-triggering by LGI to be use in control algorithms.

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