Impurity Transport Differences between NSTX and DIII-D

National campaign is an excellent opportunity to explore the impurity transport differences between NSTX and DIII-D.

NSTX Lithiated ELM Free H-modes:
Carbon density starts at ~1% builds to 10%
$n_{Li} \sim .01 n_C$ [3]

DIII-D Li Enhanced H-Modes:
300 msec Elm free pedestal enhancements
n_C in core lower than ELMy H-mode levels
$n_{Li} \sim 8 n_C$ [1]

Both results were found to be consistent with neoclassical transport theory

Preliminary XGC calculations show both results could be explained with a carbon threshold effect [C.S. Chang private communication with R. Maingi]

	DIII-D[1]	NSTX[2][3]
Delivery method, Rate	Dropper, 18 mg/s	Inter-shot evaporation, 150-300 mg
ELMs	Delayed	Eliminated
P_{RAD}, Impurities without ELMs	Steady	Increasing
D recycling	Unchanged	Reduced
Core Li	High	Low
Edge fluctuations	Increased	Decreased
Pedestal Width	Increased	Increased
Pedestal Height	Increased	Increased
H-factor	Increased	Increased

[1] T.H. Osborne et al., Nucl. Fusion 55 (2015) 063018
[2] R. Maingi et al., Nucl. Fusion 52 (2012) 083001
[3] F. Scotti et al., Nucl. Fusion 53 (2013) 083001

Granule Injector Studies of Ablation Rate, Mass Deposition and Impurity Transport

Experimental Plan :

Perform B_T and ν^* scan over NSTX-U range

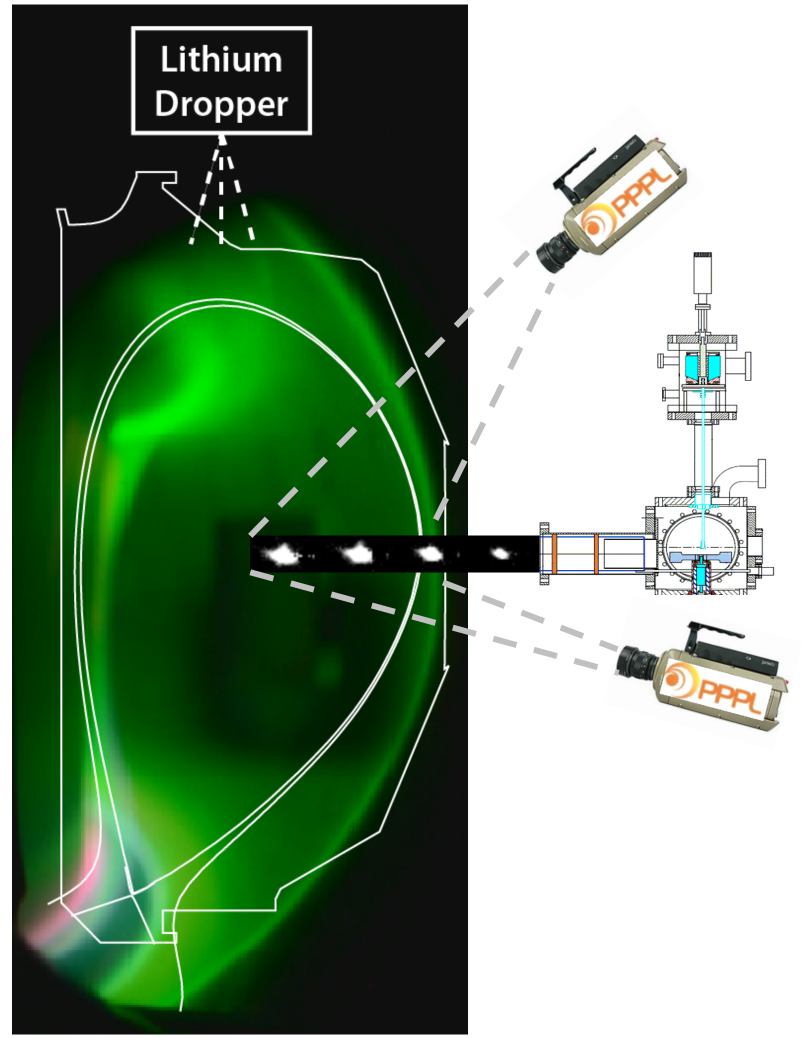
Seed discharge with lithium powder

Inject small carbon granules, attempt to drive lithum from the core

Stop granule injection and see if the Li reenters the core

Additional PPPL cameras observing ablation provide NGS model validation for solid impurity granules

Data used to expand understanding of native and injector driven impurity transport in NSTX-U, DIII-D, and EAST.



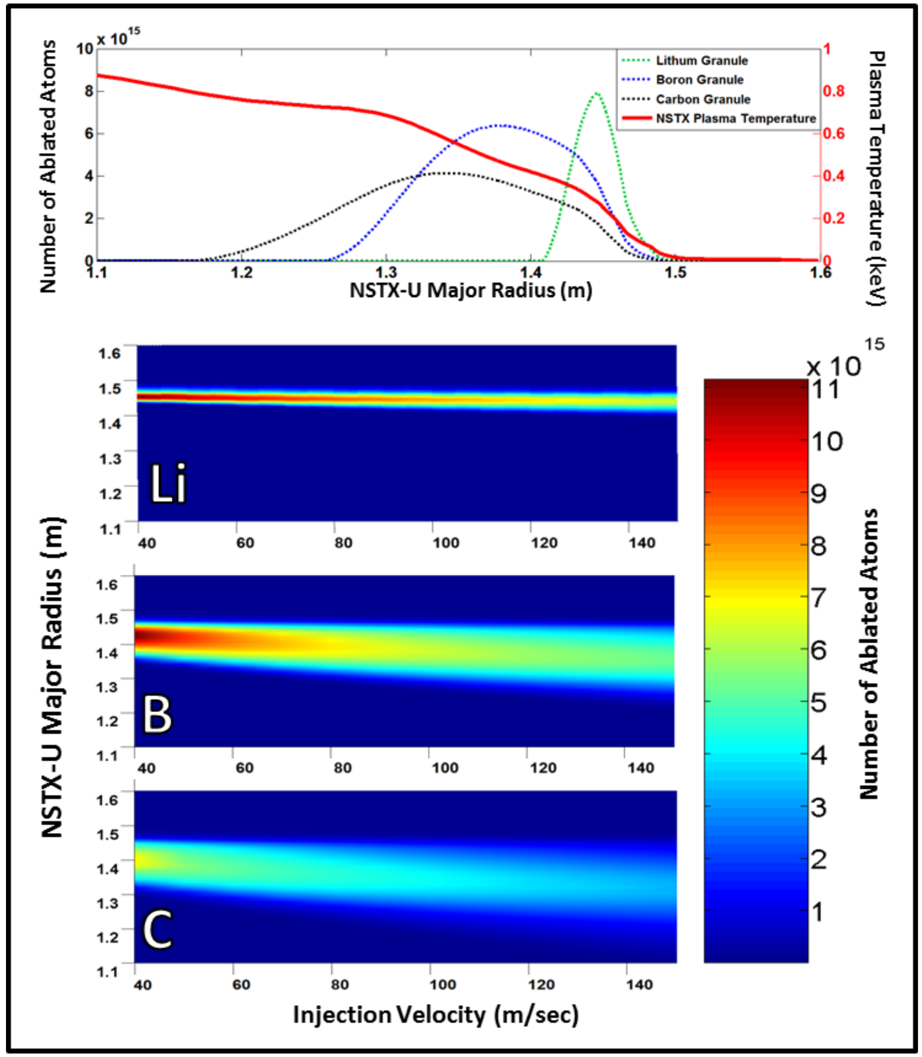
DIII-D image : S. Allen, APS 2014

Backup

Multi-species injection profiles

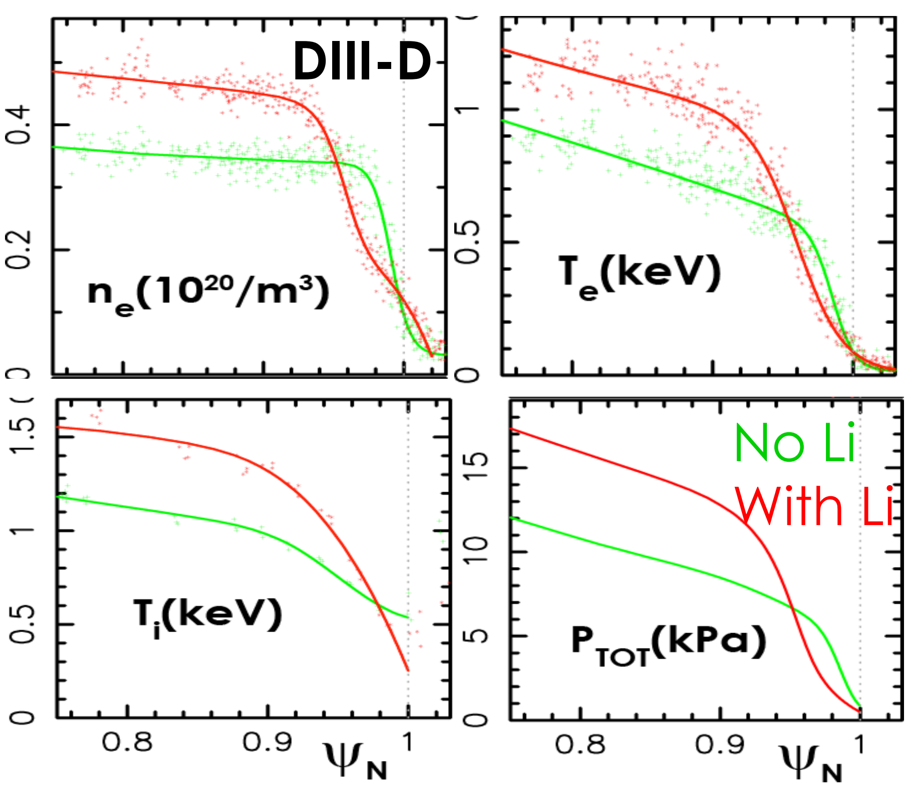
Utilizing different materials and injection velocities should allow us to tailor the pacing effect for maximum plasma performance

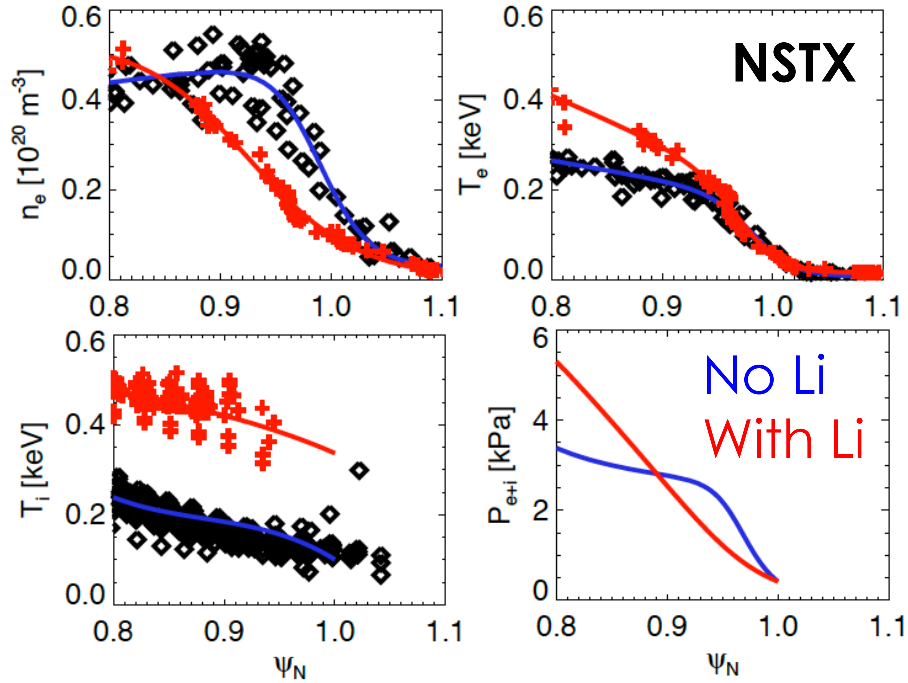
	Lithium	Boron Carbide	Carbon (Vitreous)
Density	.534 g/cm ^{3}	2.52 g/cm ^{3}	2.09 – 2.23 g/cm ^{3}
Mass in a 1mm sphere (mg)	0.279	1.319	1.131
Number of atoms/ molecules	2.426E+19	1.438E+19	5.670E+19
Sublimation Energy (eV/atom)	1.65	5.3 (B)	7.5
Sublimation Energy Per Granule (J)	6.415	61.070	68.154
First Ionization Energy (eV)	5.3917	8.2980 (B)	11.2603



Profile changes in DIII-D in ELM-free H-mode qualitatively similar to NSTX ELM-free H-mode with inter-shot Li

- Shifting gradients away from separatrix improved edge stability in both DIII-D and NSTX

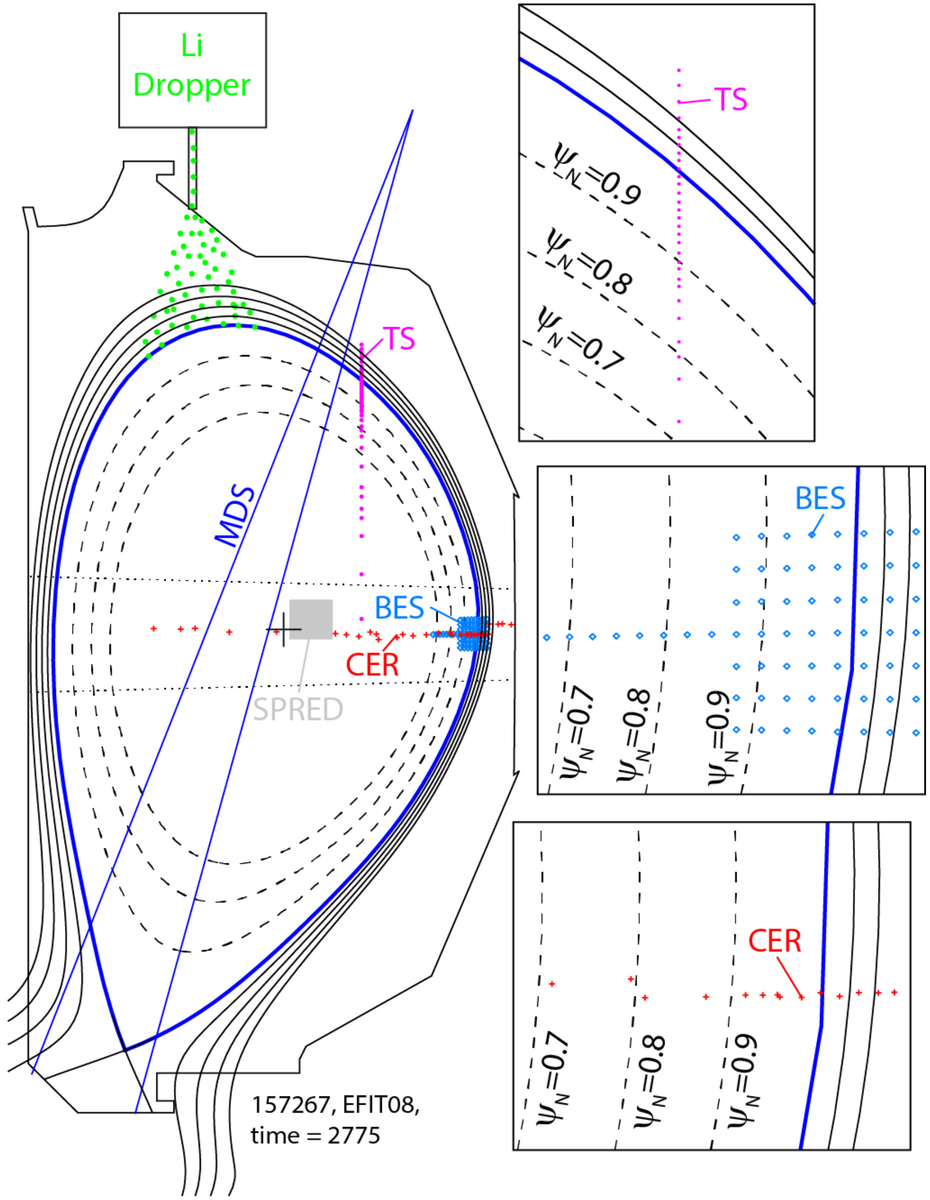




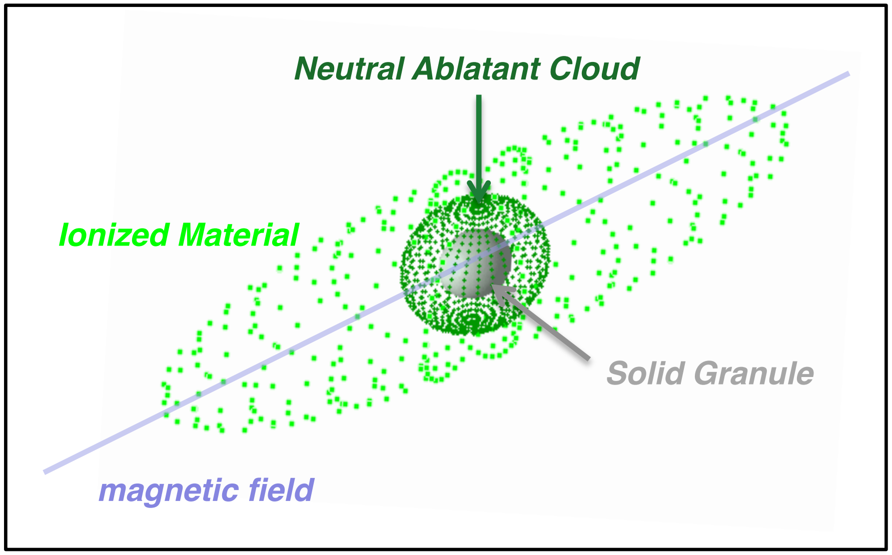
NSTX: Maingi, NF 2012

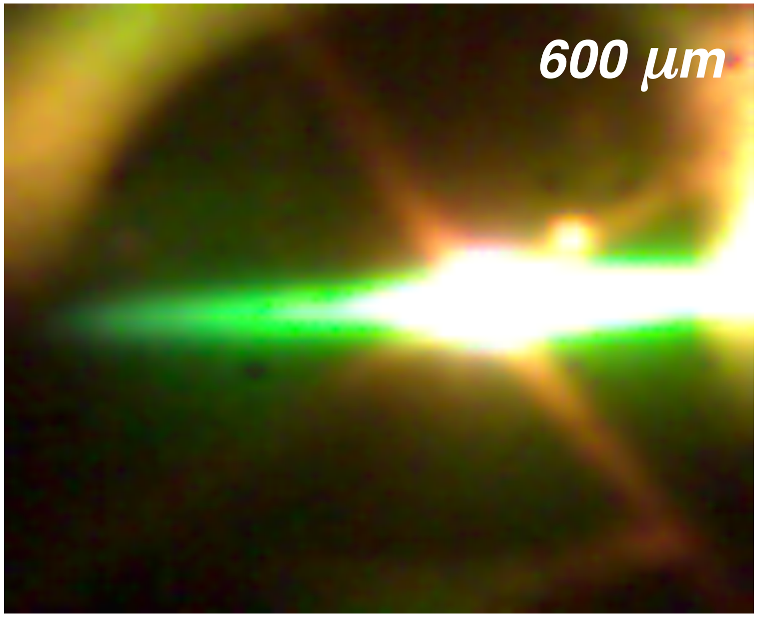
Discharge characteristics and diagnostics

- I_P = 1.2MA, B_T=2T, q_{95}= 4.4
- 1.4 < P_{NBI} < 4MW, 1.2 < β_N<2
- ∇B drift toward X-point
- 0.35 < n_e/n_{GW}<0.5, pumping of outboard divertor strike
- n_e,T_e from high resolution 10 laser TS system (w_{ped} ~ 0.1)
- n_C, n_L, T_i, v_{TOR}, v_{POL} from CER
- Longer wavelength ($k_\perp$ <3cm^{-1}) n_e fluctuations from BES
- Low to high Z central impurity lines from SPRED
- Low to medium Z divertor impurity lines with MDS; filtered photodiodes.
- IRTV for divertor heat flux; bolometers for radiated power



Neutral Gas Shielding (NGS) Model





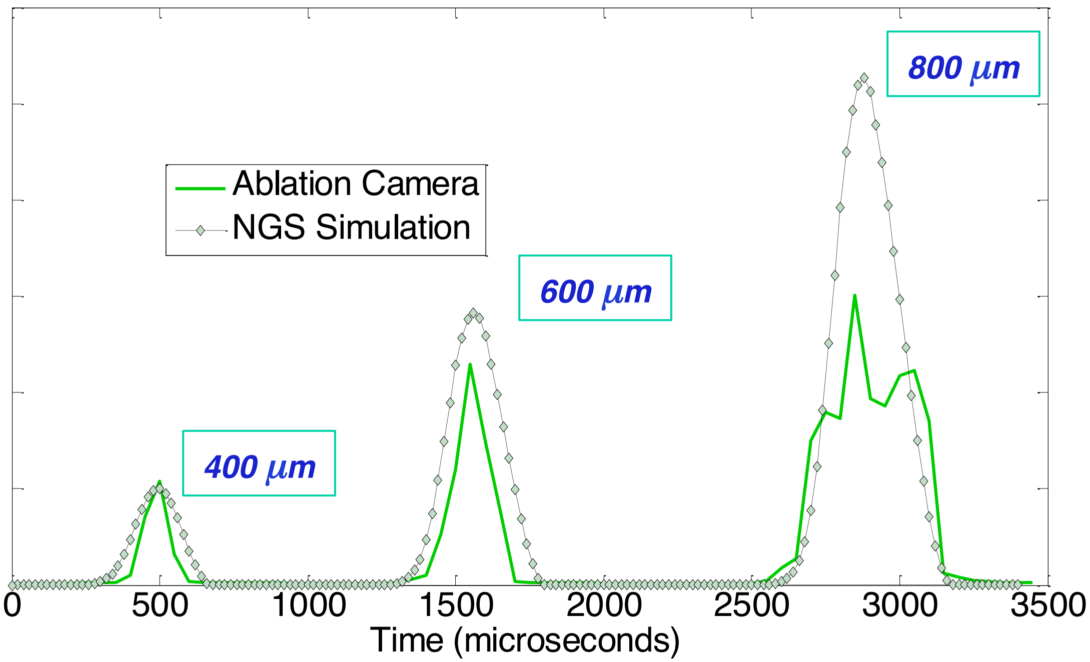
1. *Electron influx sublimates the pellet surface*
2. *High density neutral cloud forms around the granule*
3. *Heat transfer ionizes the cloud which streams along magnetic field lines*
4. *The locally overdense region of the plasma becomes unstable and generates an ELM*

Granule Ablation Model

Ablation Rate of the injected granule :

η : Cloud Shielding Parameter
f_B : Field directed heating anisotropy
ΔH_{Li} : Sublimation Energy
T_S : Granule Surface Temperature

$$G = 4\pi r_g^2 \frac{q_s \eta f_B}{n_g} \left[\Delta H + \frac{10}{3} T_S\right]^{-1}$$



$$q_s = \frac{1}{2} n_e T_e \left(\frac{8T_e}{\pi m_e}\right)^{1/2}$$

Camera saturation results in clipping of the intensity

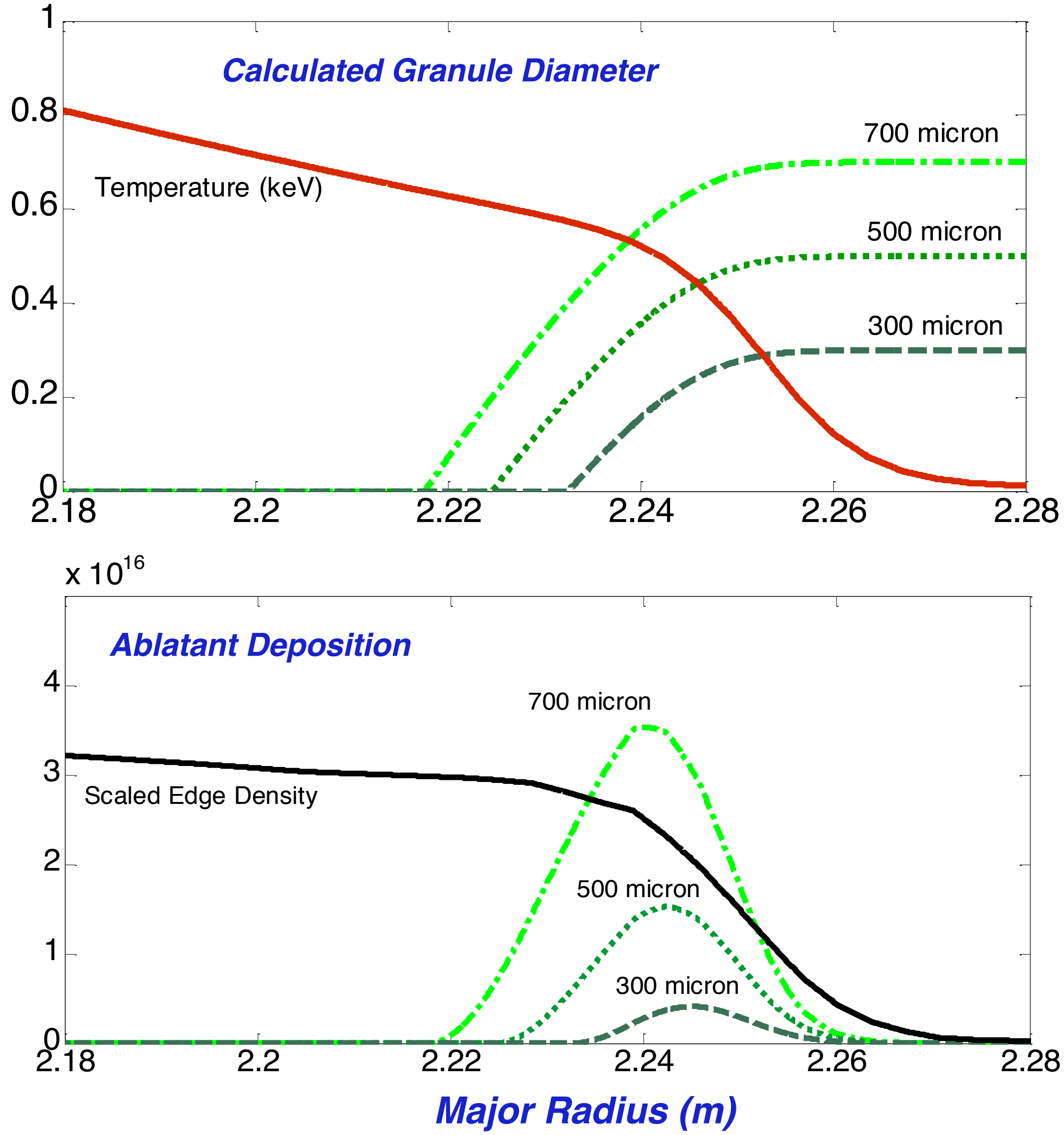
Adapted from Parks et al. Nucl. Fusion 34 (1994) & Kocsis et al. PPCF 41 (1999)

Granule Ablation Depth

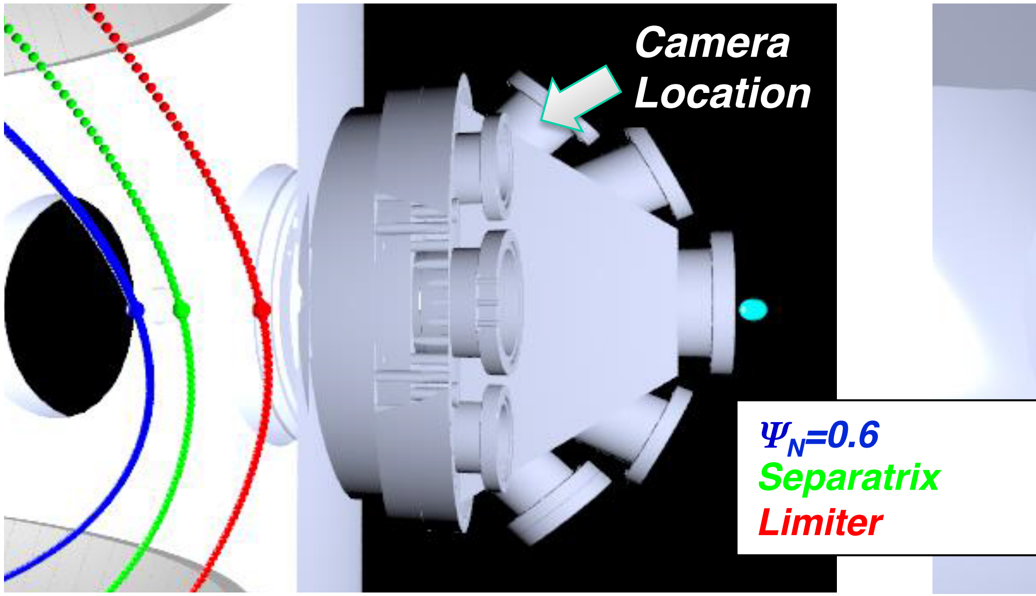
v_G = 90 m/sec

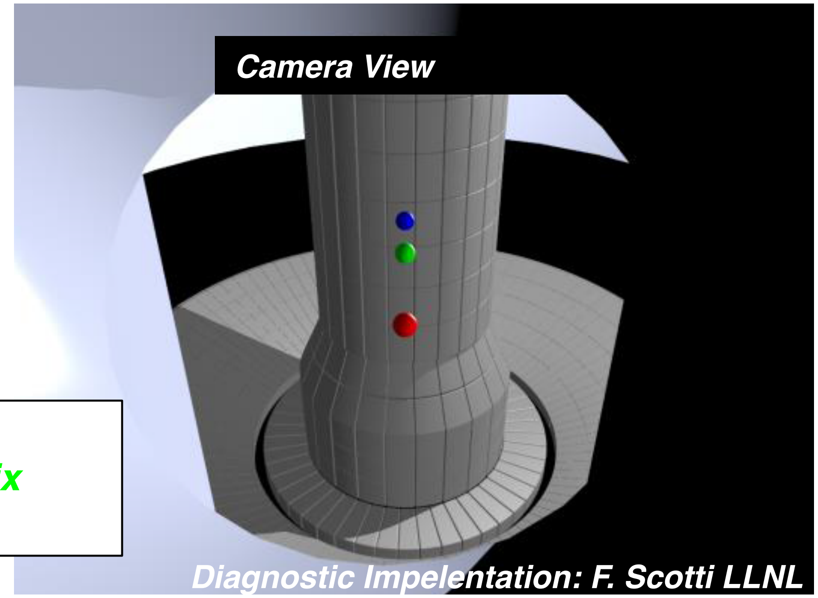
Granules ablate rapidly upon entering the pedestal region

While some portion of the granule does penetrate deeply, the primary mass deposition is located further out



Extended imaging suite will measure penetration depth





Additional cameras will be fielded on NSTX-U during LGI experiments through diagnostic collaboration with LLNL

This allows direct measurement of injection velocity and penetration depth.

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