NSTX-U

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Carbon and lithium sputtering in the NSTX divertor

Filippo Scotti

Acknowledgements:
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NSTX Monday Physics Meeting
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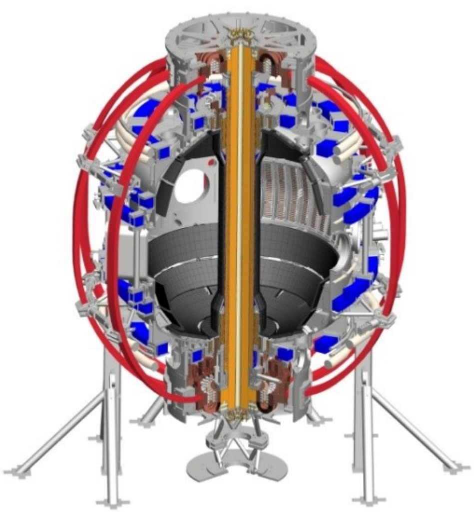

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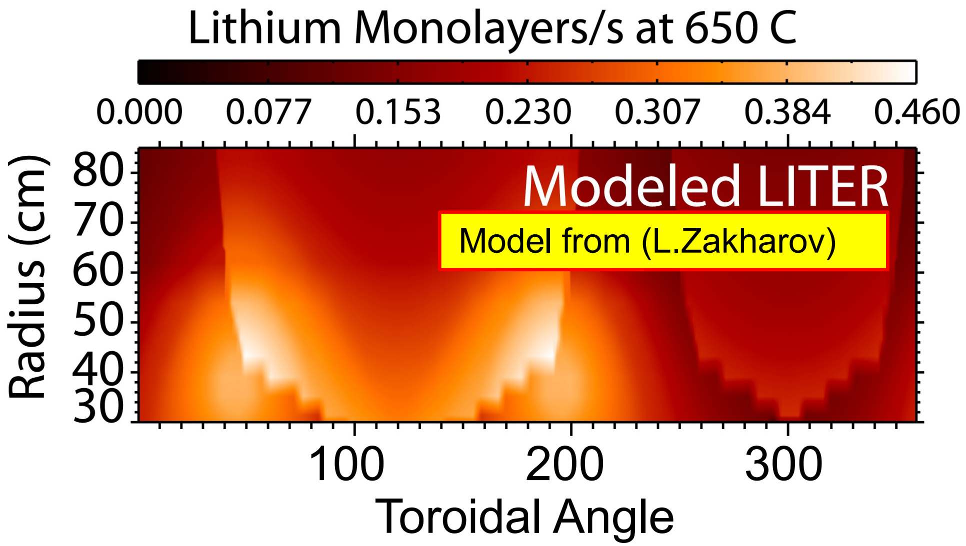
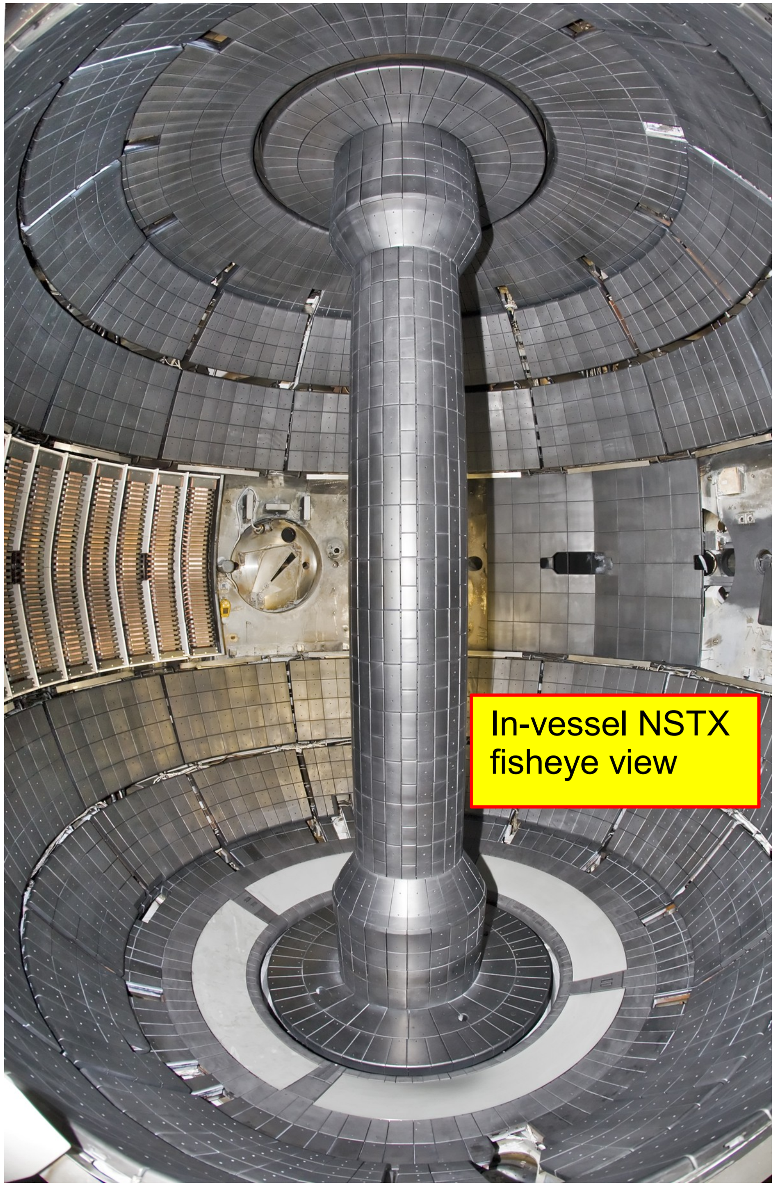
Outline

- NSTX plasma facing components (PFCs)
- Divertor diagnostics and analysis method
- Expected behavior of lithium and carbon sputtering
- Lithium sputtering in NSTX divertor
- Carbon sputtering in NSTX divertor
- Conclusions and future work

Evaporative lithium coatings are routinely applied on NSTX graphite and moly PFCs as wall conditioning technique

- Graphite is the main PFC material in NSTX:
  - ATJ graphite tiles on divertor and main wall
  - ATJ and CFC tiles on center stack
  - Porous moly segments in outer divertor (LLD)
- Lithium coatings evaporated on PFCs:
  - 100 – 300 mg of lithium are typically applied between discharges using LITERs
  - “coating” thickness ~ few 10s of nm
- Highly toroidally asymmetric deposition



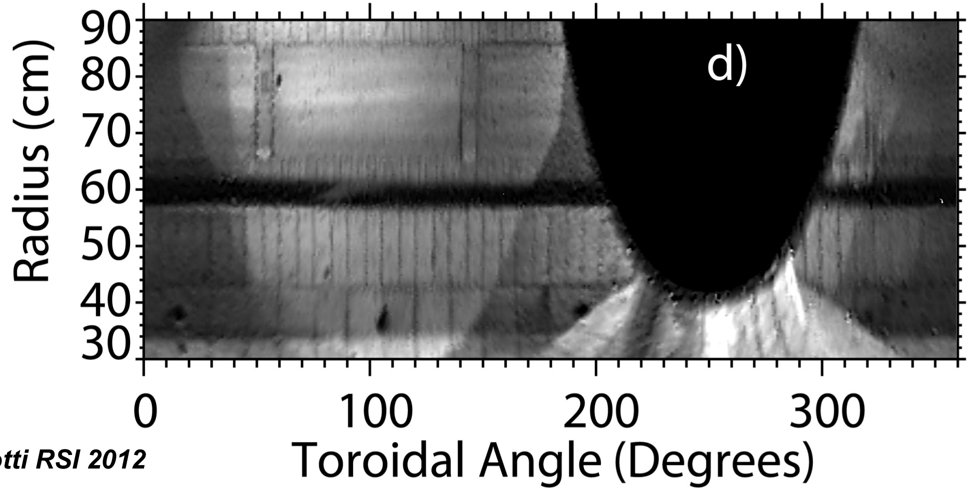


Divertor cameras, high resolution spectrometer, Langmuir probes used for analysis of impurity influxes

- Spectroscopic diagnostics for divertor impurity influxes:
  - VIPS2, 1D/2D cameras (Li I 670nm, Li II 548nm, C II 658nm, 392nm, C III 465nm)
- Langmuir probes for T_e, n_e, J_{sat}:
  - inboard (LP2913, R=49.5 cm), outboard HDLP array (4 single, 2 triple)
- Two color IR thermography for divertor T_{surf}
- Inverse photon efficiencies (S/XB) from ADAS
- Sputtering yield derived from impurity influxes:

$$\Gamma_i = \frac{S}{X\,B}\,\Gamma_{ph} \qquad Y_I = \frac{\Gamma_I}{\Gamma_{D+}} = \frac{B_I \cdot S/XB}{J_{SAT}}$$

- 2D camera data remapped in (r,Φ) for easier analysis at $\neq \Phi_{tor}$



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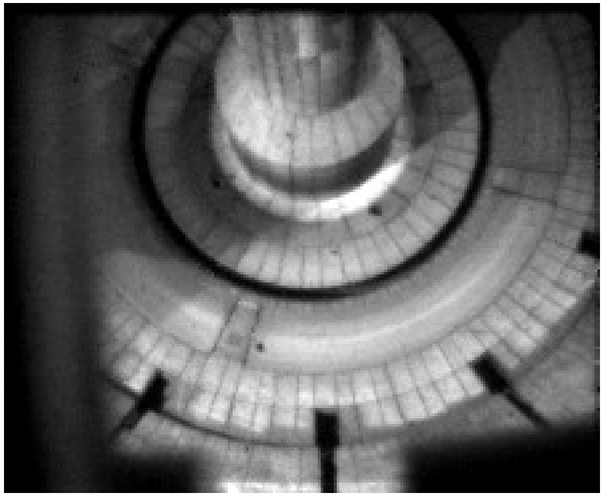


Carbon and lithium sputtering yields show incident energy thresholds and T_{surf}, T_e dependence

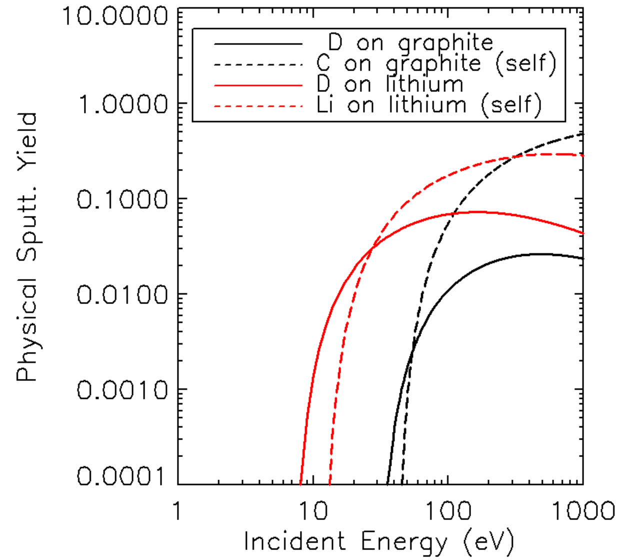
Carbon:

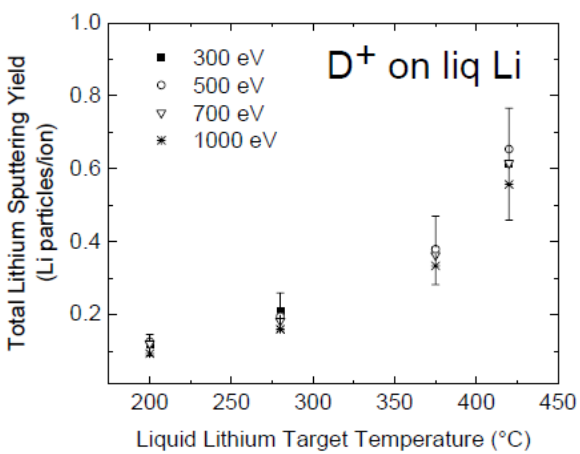
- Physical Sputtering (E_{th} ~ 30eV)
- Chemical Sputtering (no E_{th} but T_{surf} dep.)
- Sources expectations: ion impact on divertor and main wall, neutrals on first wall and divertor

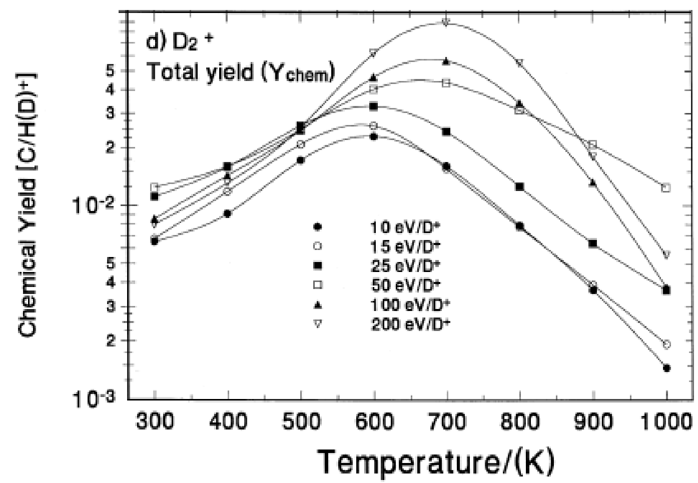
Lithium:

- Physical Sputtering only (E_{th} ~ 7eV)
- Strong T_{surf} dependence
- 2/3 of the particles are sputtered as ions
- Sources expectations: ion impact on divertor

Normal Incidence



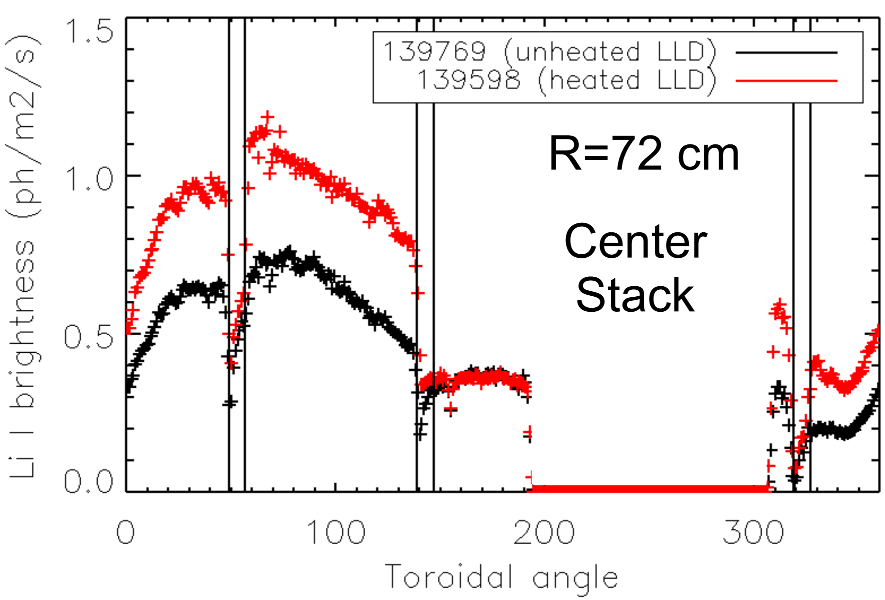


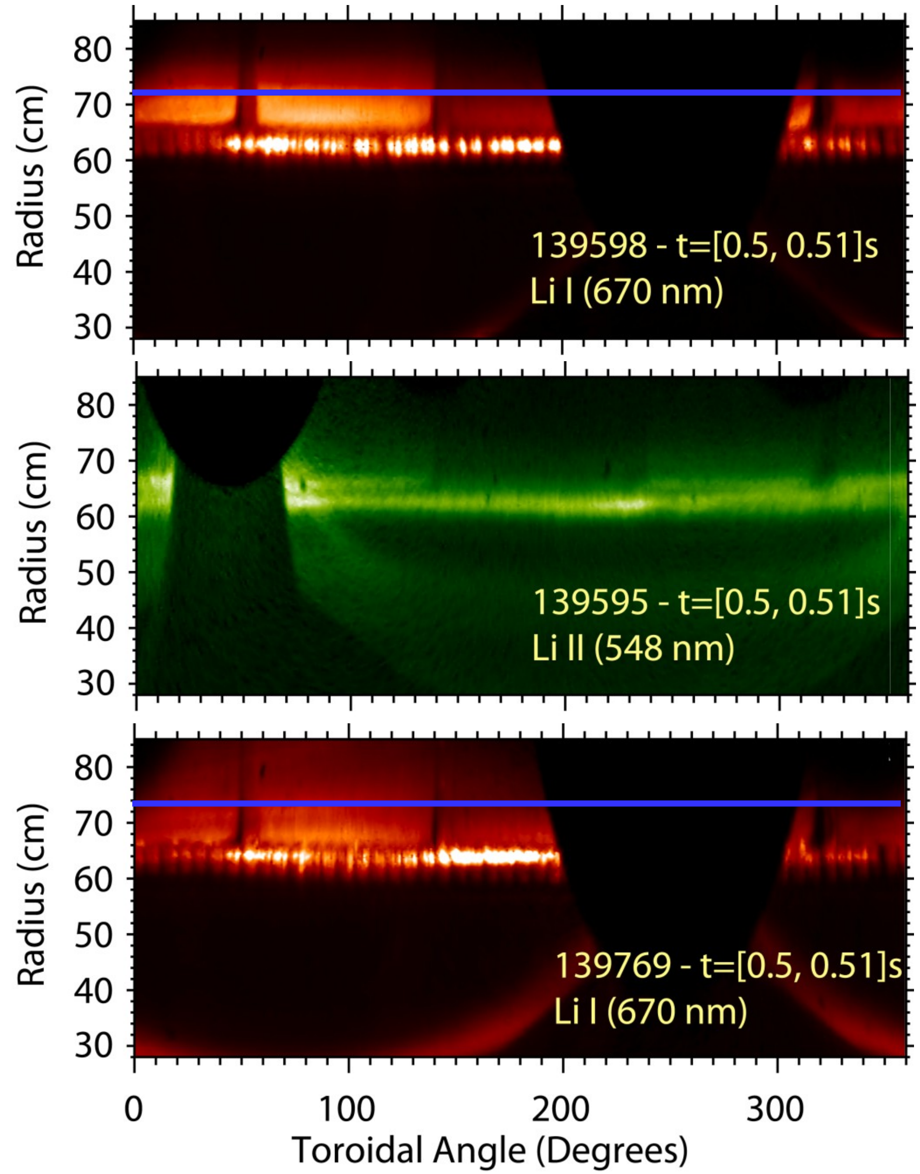


B.V. Mech et al. J. Nucl. Mater. 255, 153–164 (1998).

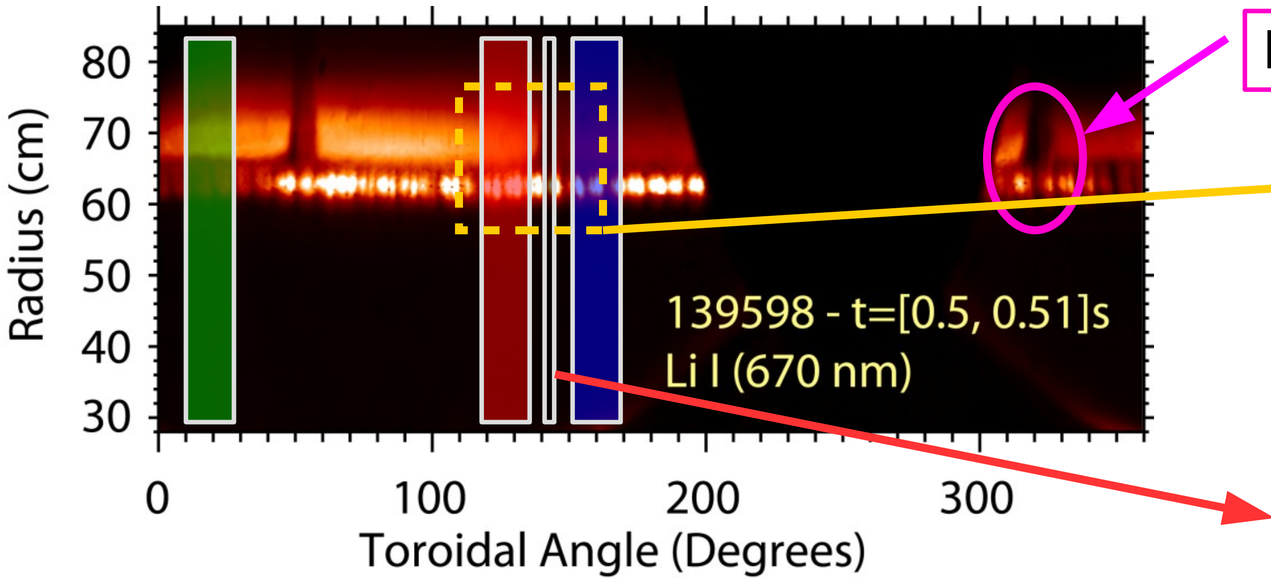
Differential heating of plasma facing components leads to toroidal asymmetries in lithium influxes

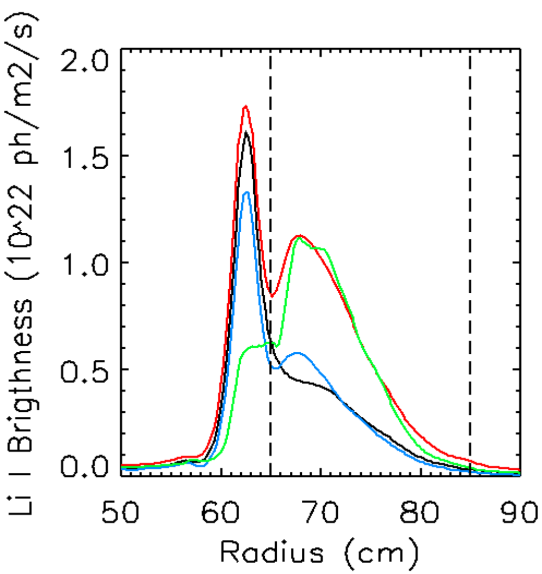
- Low δ discharges post mega evaporation (>200g): one with heated and one with unheated LLD (139598, 139769)
- At R= 63cm ~ coating thickness > 20 μm
- Differential heating of LLD segments results in non-axisymmetric lithium influxes
- 139598 representative of many of the Li sputtering behaviors





Analysis of lithium sputtering is done using 2D cameras (at different Φ_{tor}), HDLP array data and dual band IR

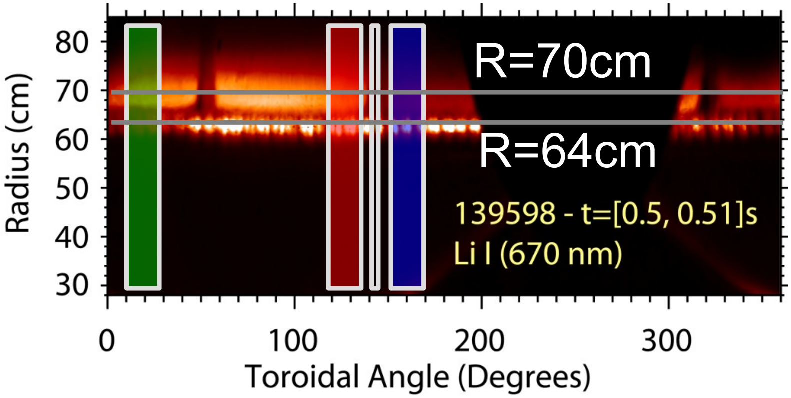


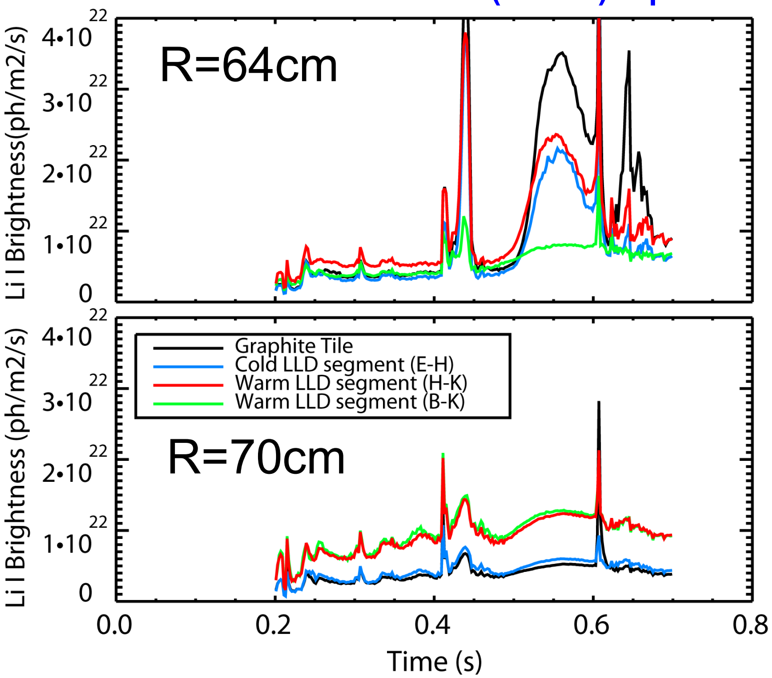


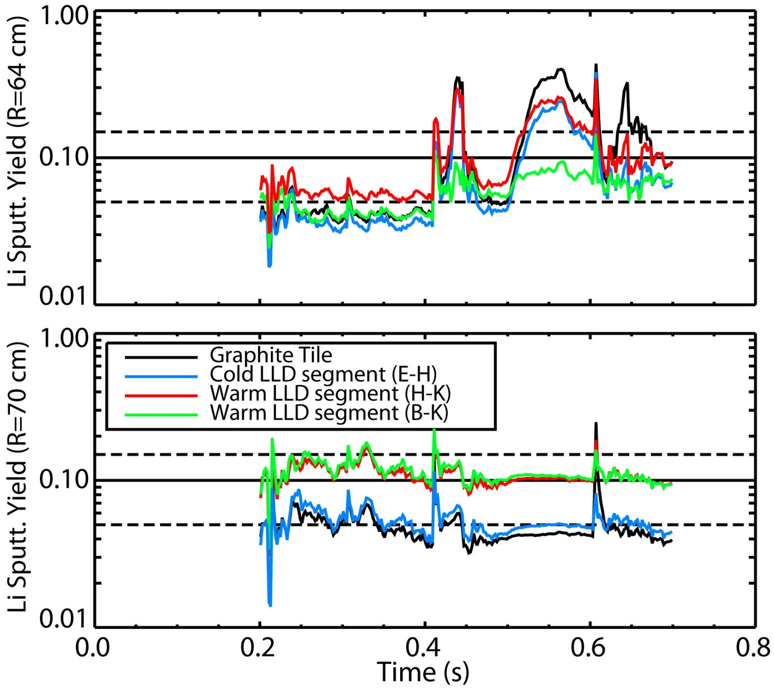
- Four different toroidal locations analyzed
    - Diagnostic graphite tile Φ=[142°-148°]
    - Cold LLD segment Φ=[150°-160°]
    - Hot LLD segment Φ=[120°-135°] + thick coating location
    - Hot LLD segment Φ=[10°-30°] + thin coating location
- Analysis at two radial locations will be presented (R=64, 70 cm) @ single probes

Analysis of different toroidal locations shows evidence of Li temperature enhanced sputtering

- T_{surf} dependence of sputtering yield (up to 2X)
- Thick coatings → same response from moly and graphite
- Evidence of Li further enhanced sputtering
  - Non linearity in yield at strike point, observed only in thicker deposition areas
  - Related to self (or C) sputtering runaway?

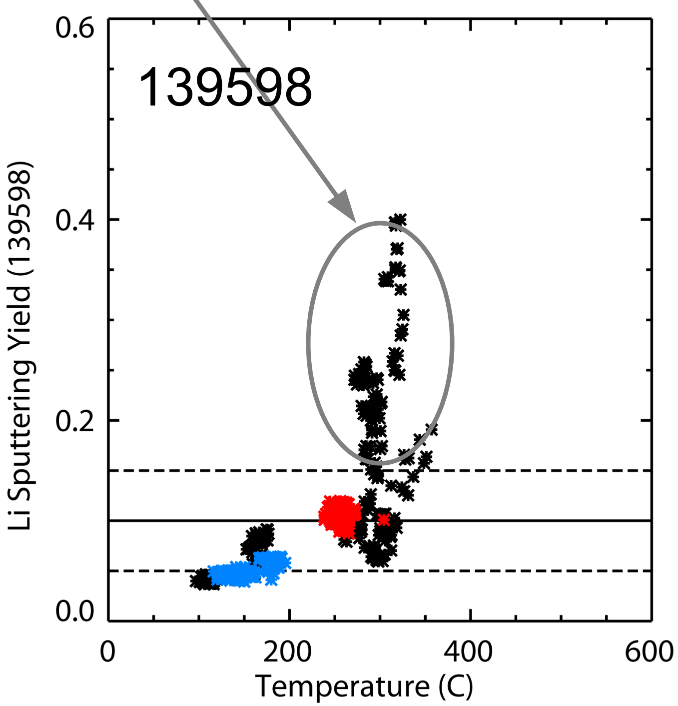


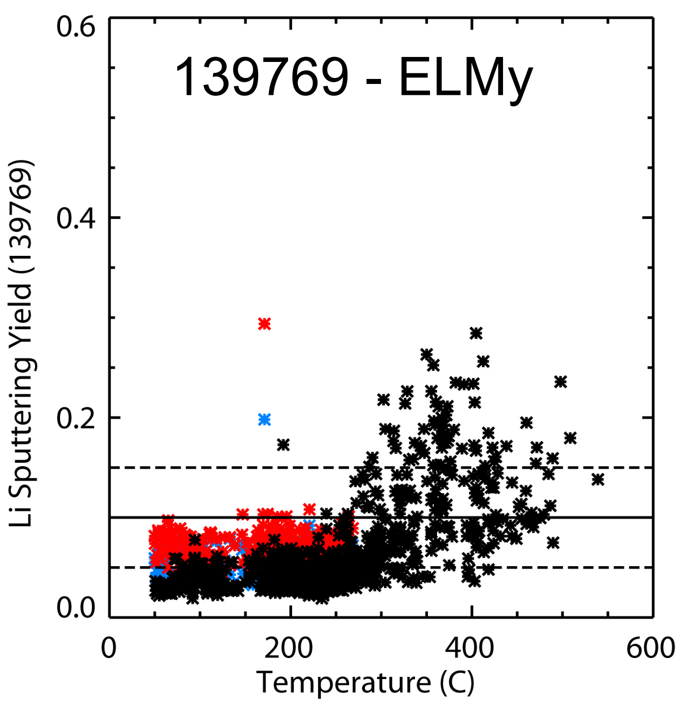




Measured lithium sputtering yield consistent with literature with signature of temperature dependent sputtering yield

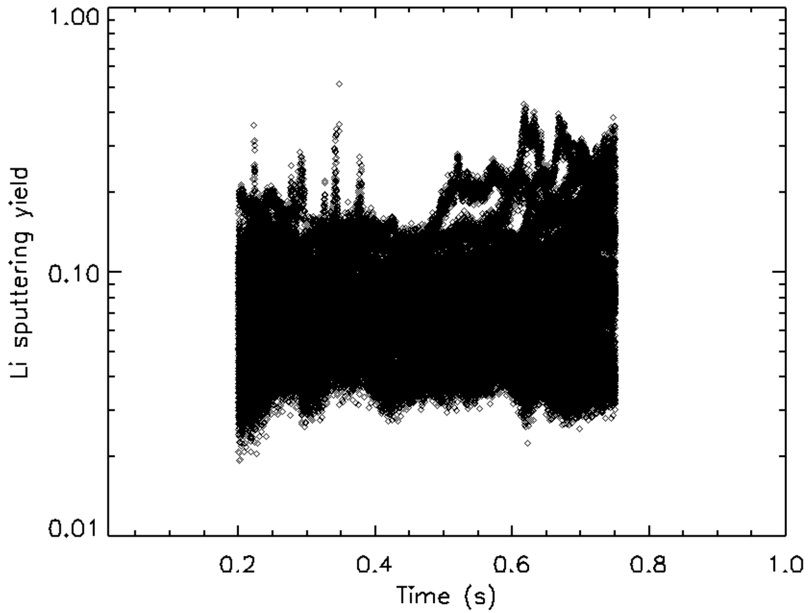
- Using local T_{surf} from 2-color IR, dependence of sputtering yield on T_{surf}
- Assuming T_{surf} is accurate, evaporation flux is negligible
- For Li bloom, T_{surf} seems to be clamped at OSP at ~300C
  - Can't be explained by evaporation or T_{surf} dependence only (at 350C evaporation rate ~5e19 atoms/m2/s)

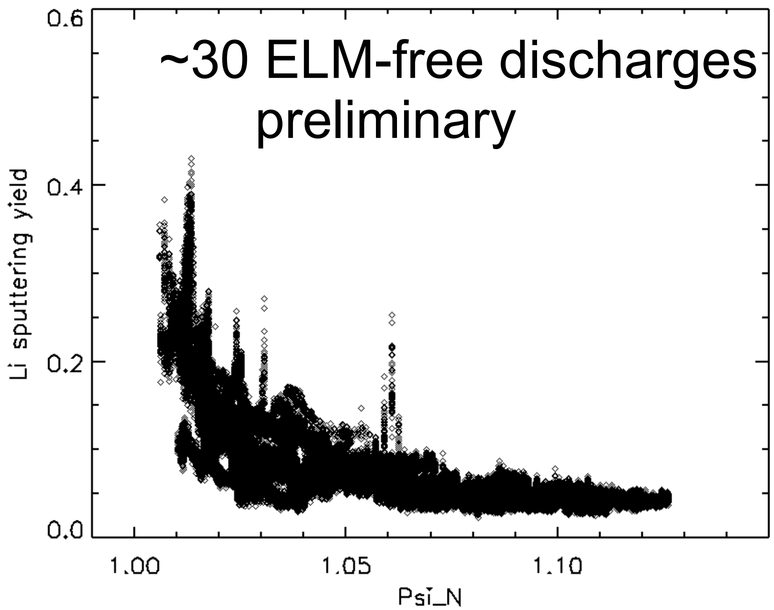




Preliminary statistical analysis carried out on graphite (high δ discharges) also suggests T_{surf} dependent lithium sputtering

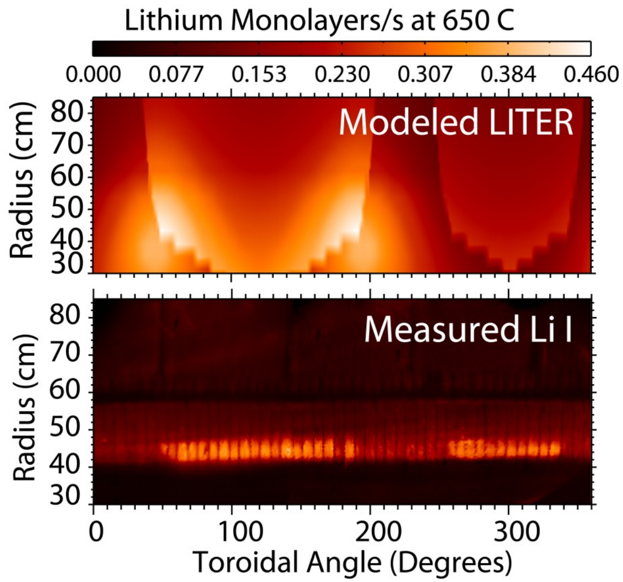
- Large variability in Li sputtering observed on LP2913 probe (R=49cm)
- No apparent decrease over time
- Plotting Yield vs Ψ_N (natural strike point sweep) reduces variability and suggest T_{surf} dependence
- Some impact of pre-applied Li amount, PFC history likely to play a role



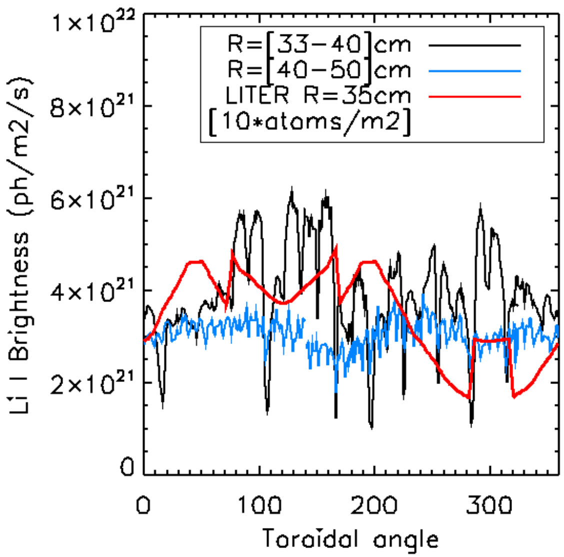


Effect of different amount of lithium in high δ discharges studied analyzing different toroidal locations in same discharge

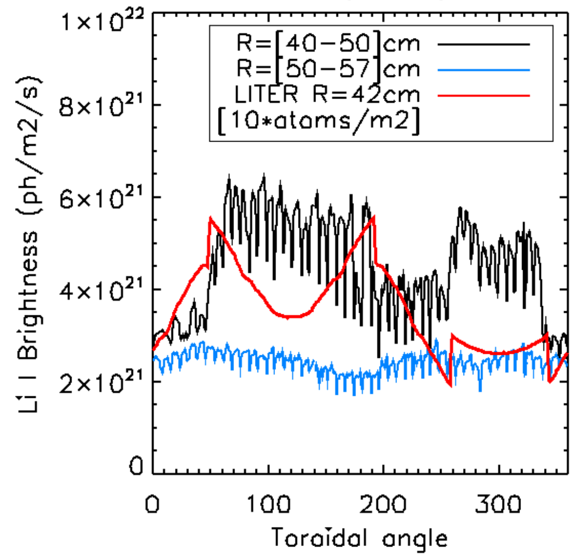
- High δ discharges at ≠ Φ_{tor}
- No ≠ in Li yield in far SOL at ≠ Φ_{tor}
  - Not expected if Li thickness > ion range
- Differences (up to 2x) observed at OSP, enhanced during transients (e.g. ELMs)
  - Qualitative agreement with LITER pattern
  - Consistent with enhanced response from thicker coatings areas (similar to Li "bloom")



139013
t=[0.4, 0.45]
ELM free

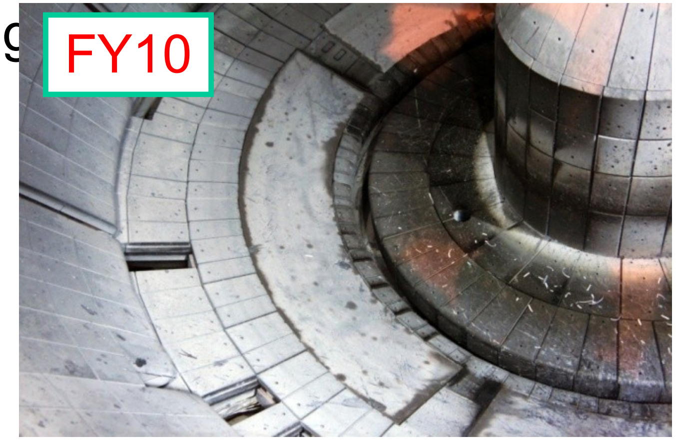


139027
t=[0.4, 0.41]
during ELM

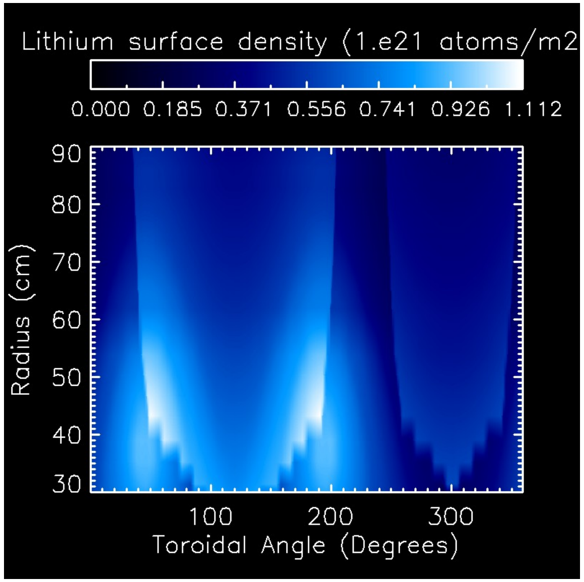


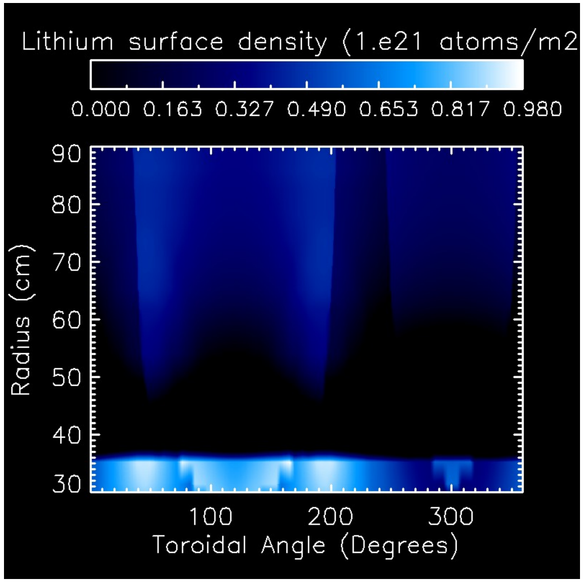
Degradation of coatings is observed from post vent visual inspection and nuclear analysis of divertor tiles

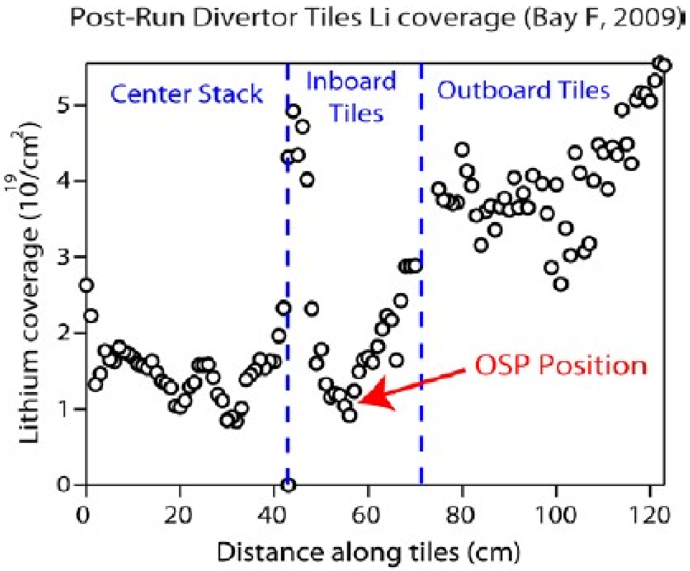
- Fresh coatings thickness ~thicker than D^+ stopping range (15-45 nm for 200 mg Li)
- Coating can be eroded from incoming ion flux
- Important role of prompt re-deposition
  - No clear OSP lithium depletion within gross erosion timescales
- Chemistry: Li intercalation, Li reacting with C and vacuum gases



200mg Li, 4e23 ion/m2 incident, Y_{Li}~0.1, Δt=0.4s

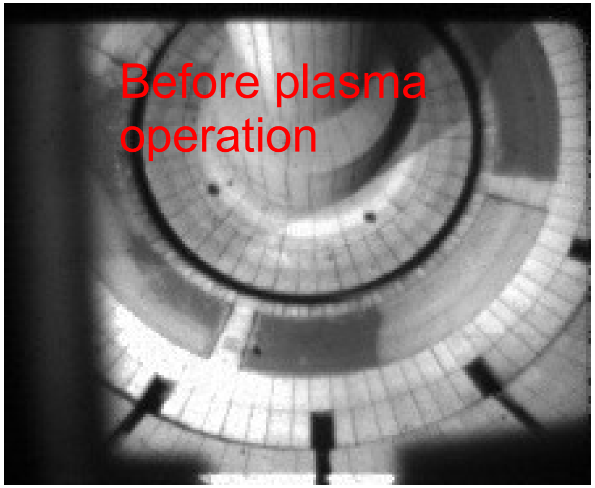


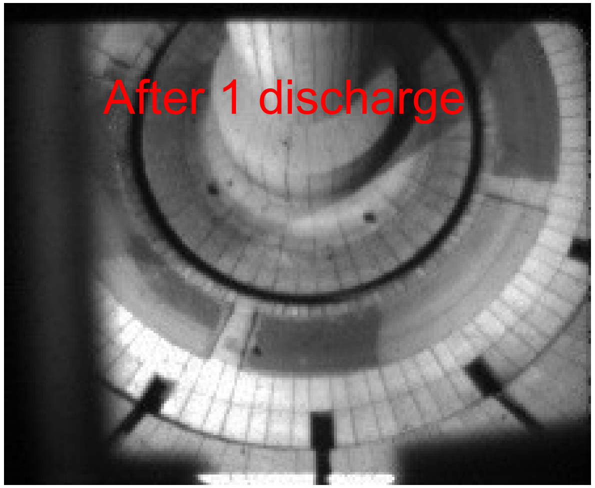


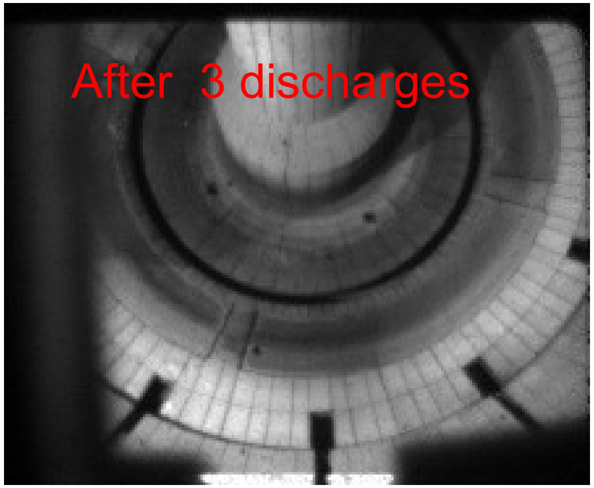


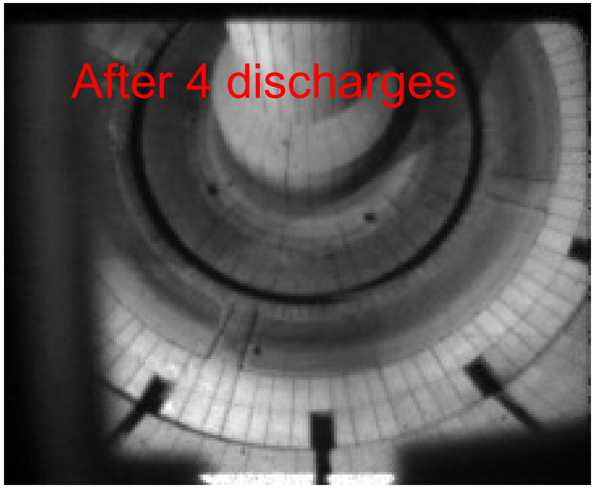
Data courtesy of W. W. Wampler (SANDIA)

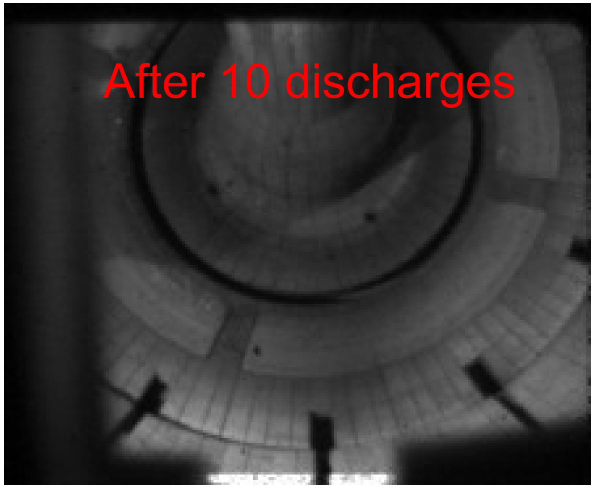
Change in surface appearance in discharges after large evaporation (6g) indicates degradation of coatings

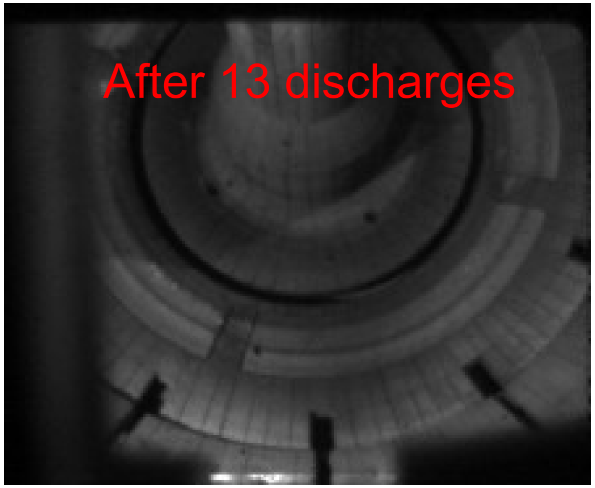




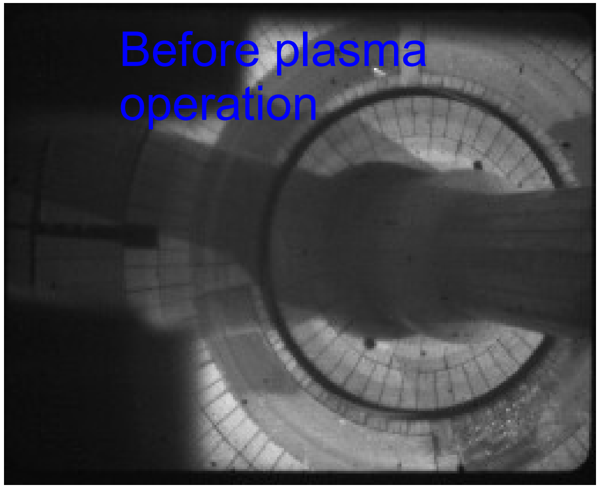


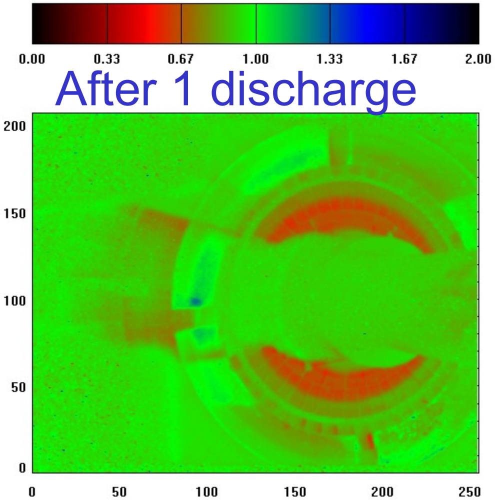


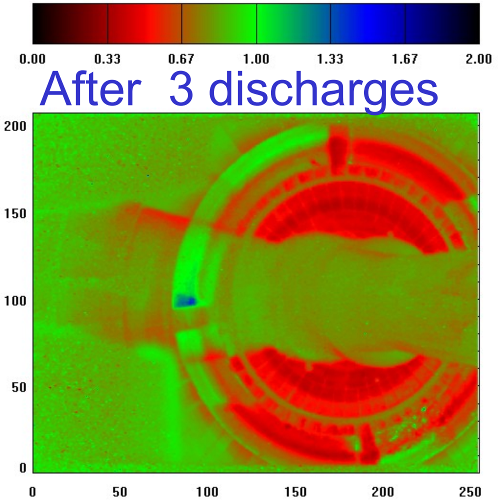


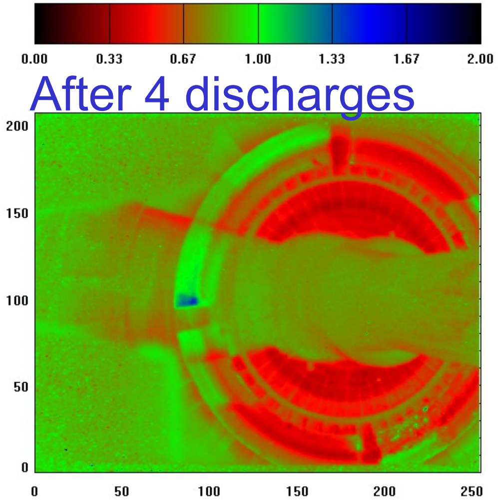


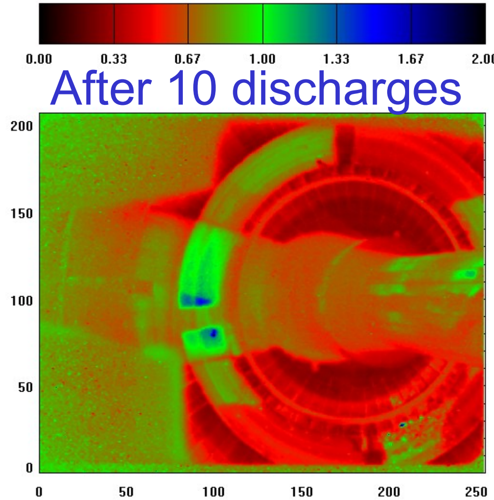
Change in surface appearance in discharges after large evaporation (6g) indicates degradation of coatings

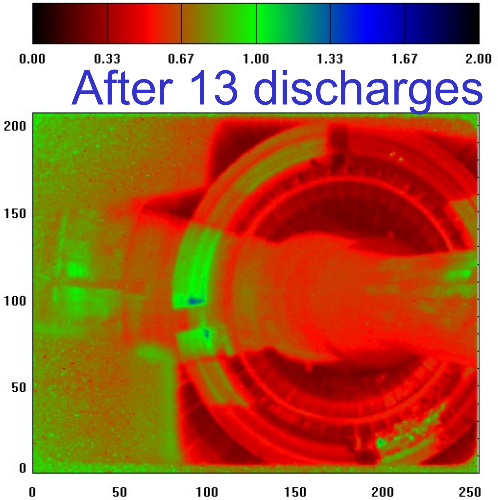










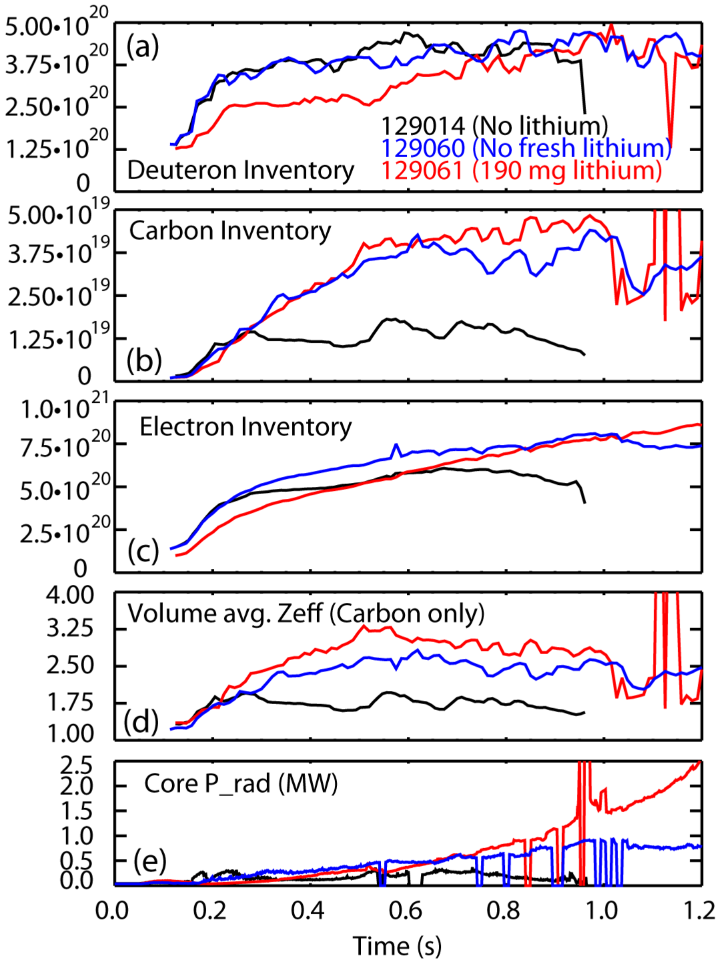


Summary of observed lithium sputtering behavior

- Evidence for lithium temperature dependent sputtering
    - From differential heating of LLD plates
    - From radial dependence of derived sputtering yields
- Consistent with published Li sputtering (IIAX, DIII-D) but uncertainties:
    - Surface composition: Li? LiD? LiOH?, Li_2CO_3?
    - Importance of self sputtering and impurity sputtering
    - Angle of incidence
- Evidence for toroidal asymmetry of influxes and coatings
- Evidence for deterioration of coating
    - Post vent: visible inspection and nuclear analysis (W. Wampler)
    - Visible imaging
    - Carbon influxes
    - BUT no apparent degradation of Li sputtering during discharge
- Role of prompt re-deposition under study
    - Li ionized fluxes << neutral influxes
    - Li coating lifetime much longer than expected from gross erosion

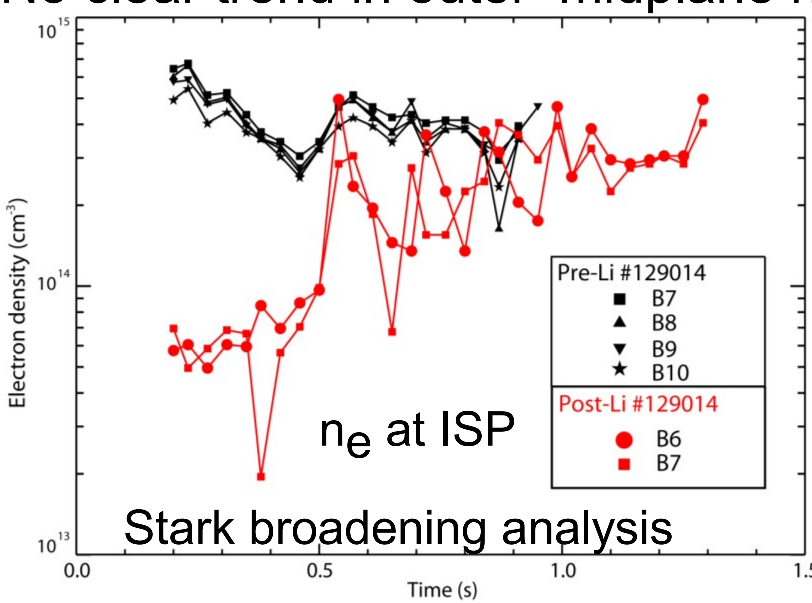
Suppression of ELMs and increase in core carbon inventory with solid lithium coatings in NSTX

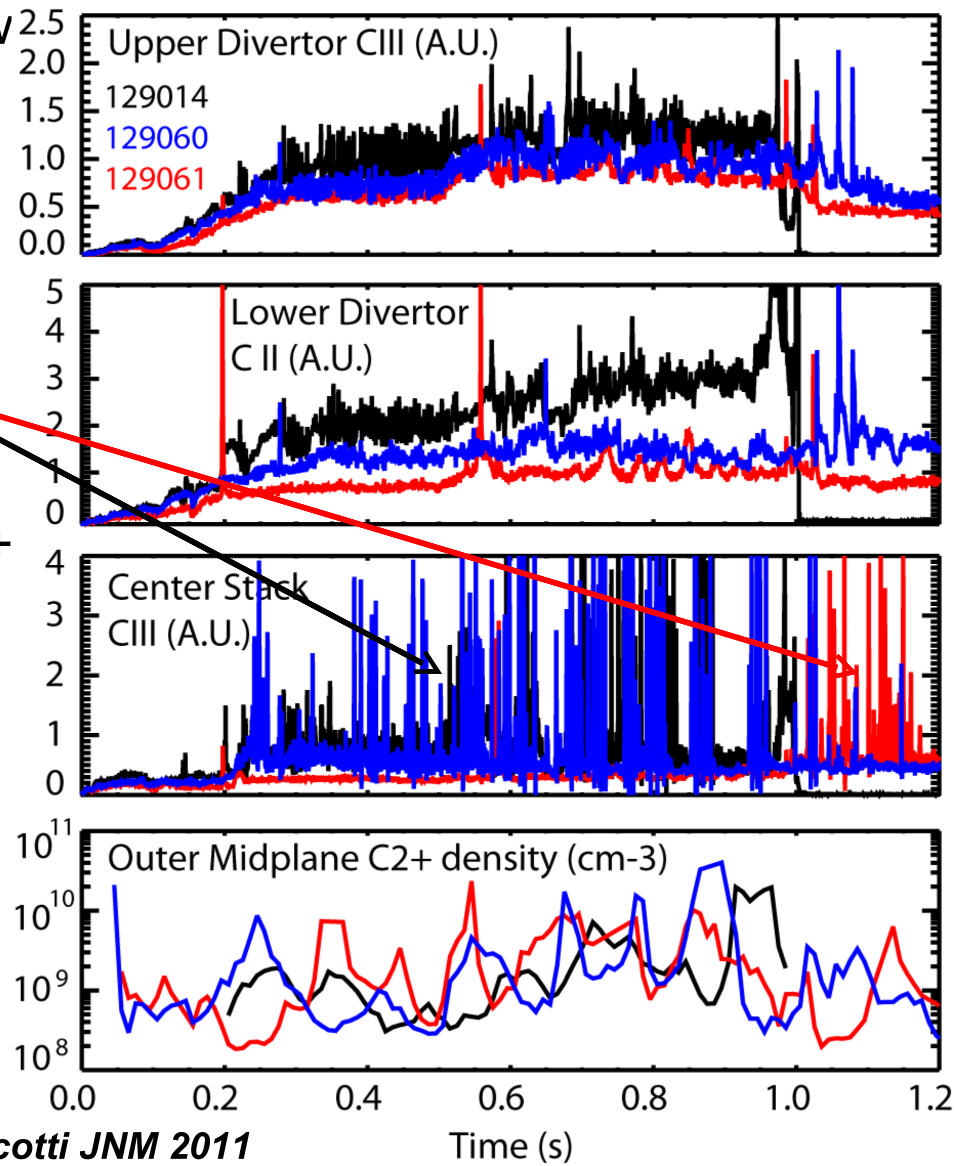
- Comparing 2008 transition from boronized graphite to lithium-coated discharges (lower single null, 4-6MW)
- Deuteron inventory reduced despite higher fueling
- Carbon inventory increased by 3-4x due to:
  - suppression of ELMs
  - changes in neoclassical inward transport
- Need to investigate role of sources and SOL transport:
  - Change in divertor/main wall carbon sources
  - Change in parallel/perpendicular transport



Reduction of carbon emission from PFCs with application of lithium may suggest reduction of carbon influxes

- Reduction in emission from carbon low ionization stages (C II, C III)
  - 2x in upper divertor (C III, 465 nm)
  - 3x in lower divertor (C II 658 nm)
  - 2x from center stack(C III, 465 nm)
- But T_e dependence of C II-III S/XBs !
- Disappearance of MARFE activity
  - from reduced ISP n_e and P_n
- No clear trend in outer midplane n_{C2+}





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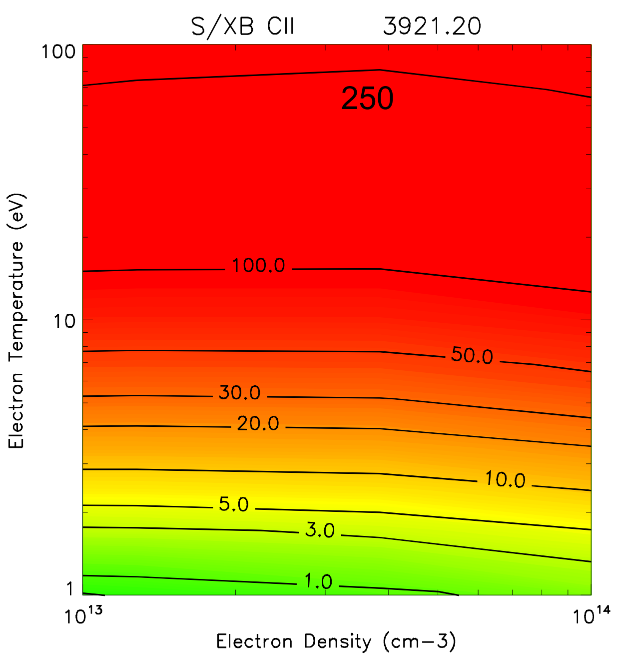
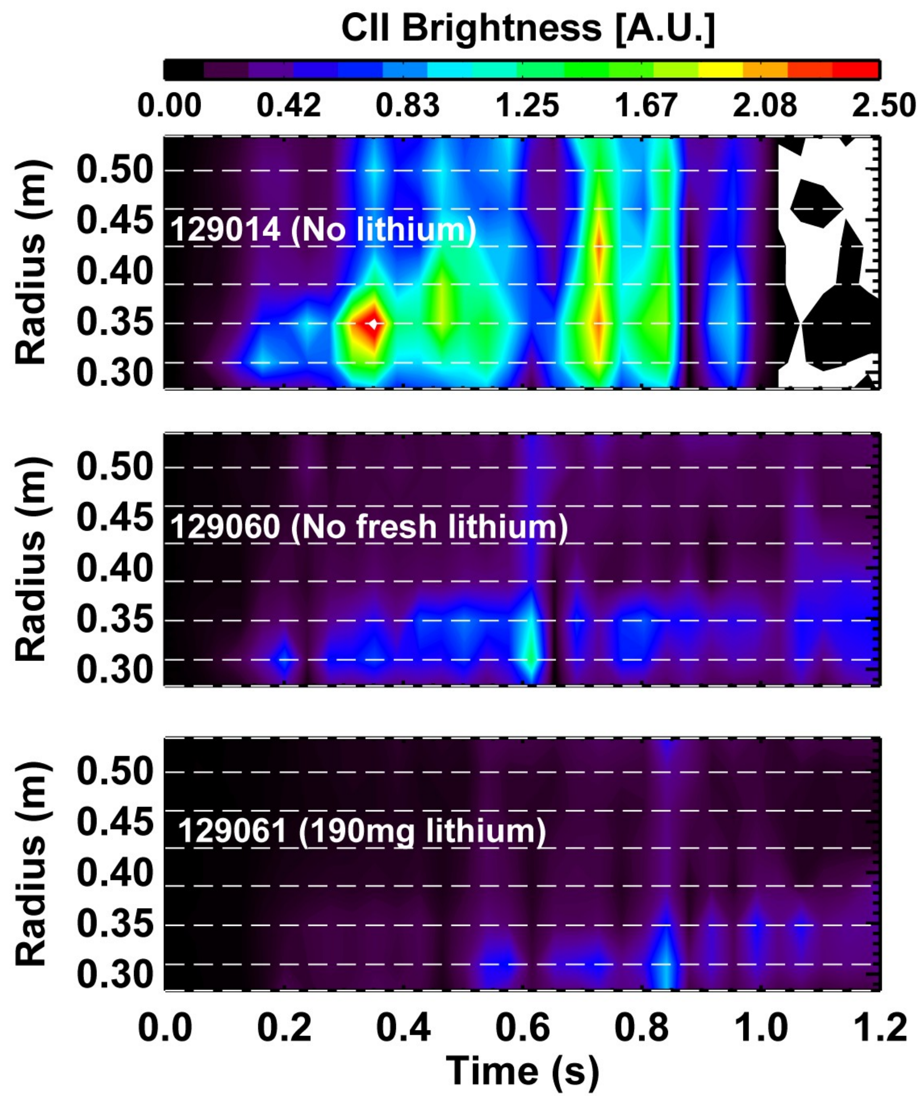
Divertor C II brightness progressively reduces with lithium application

- C II brightness (392 nm) reduces in both ISP and OSP with lithium application

- Viewing chord at R=49.5 cm used to estimate changes in sputtering
- OSP integrated brightness used for change in OSP influxes
- Probe T_e and n_e used to infer S/XB factors

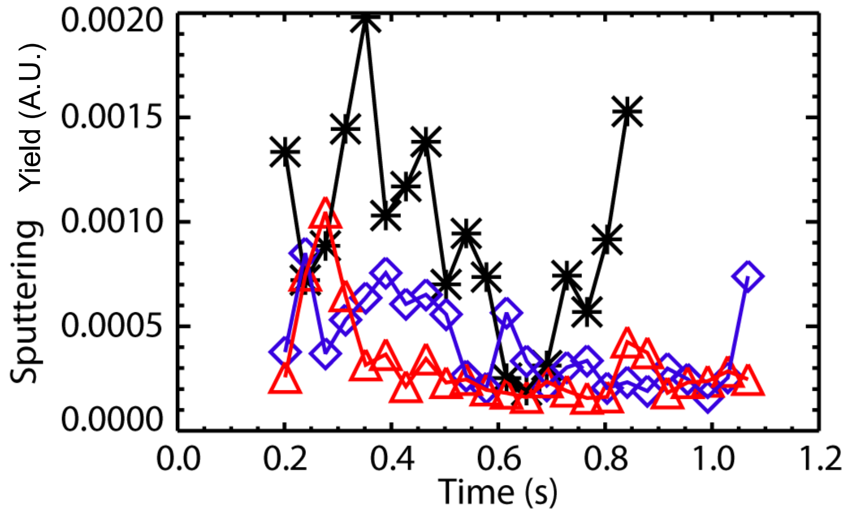


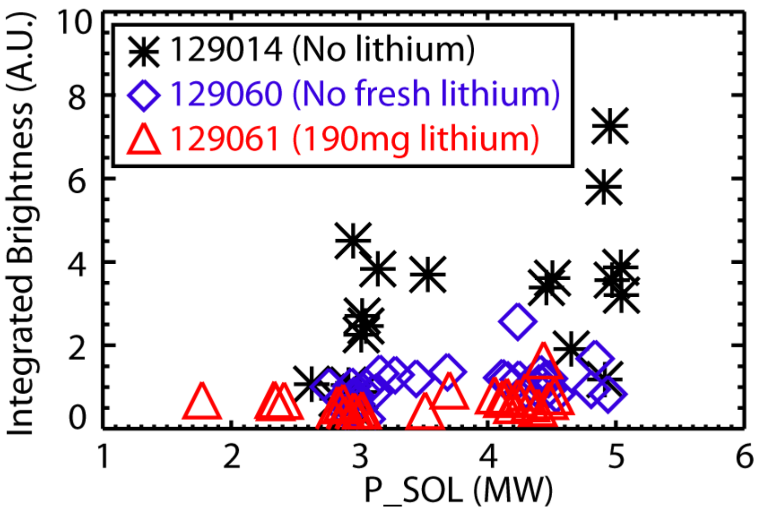


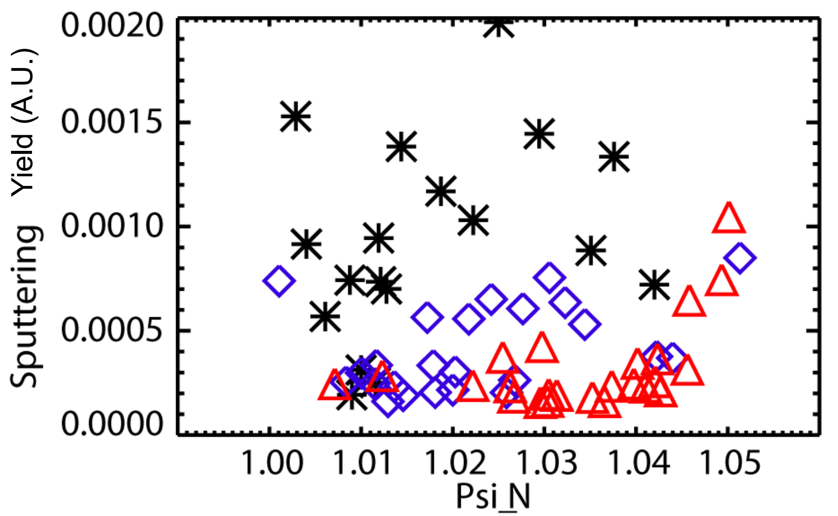
Moderate reduction in sputtering rate in near/far SOL observed with application of lithium coatings

- Sputtering rate reduced with lithium
- Intermediate conditions (e.g. 129060) hard to distinguish
- Conclusions on total OSP influx limited by lack of divertor T_e, n_e coverage
- Using the largest T_e difference measured by the probes, OSP influx is still reduced

$$Y_C = \frac{J_{CII}}{J_{D^+}} = \frac{B^{@probe}_{CII} \cdot S / XB}{J_{SAT}}$$







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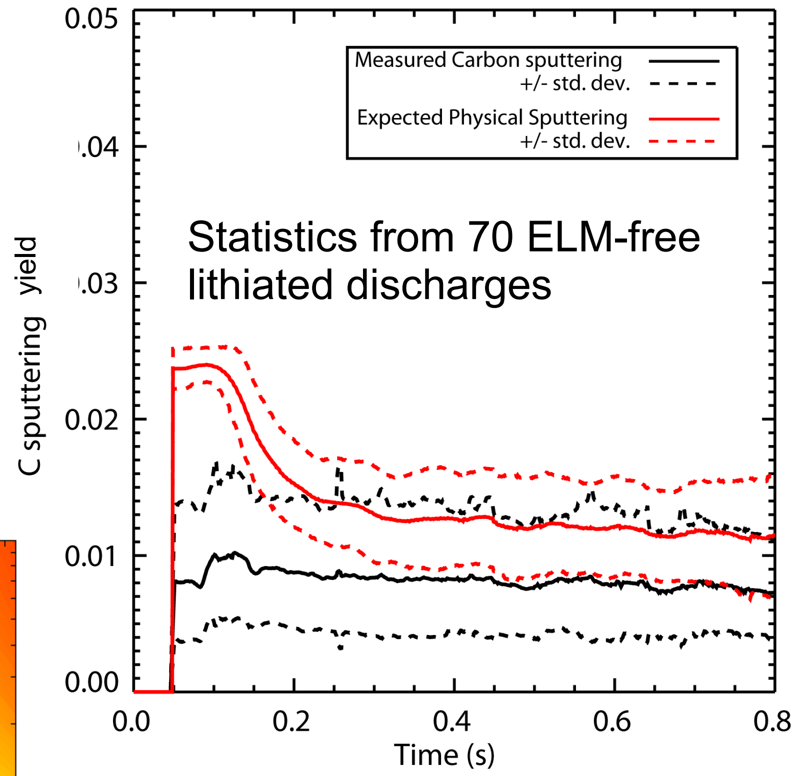
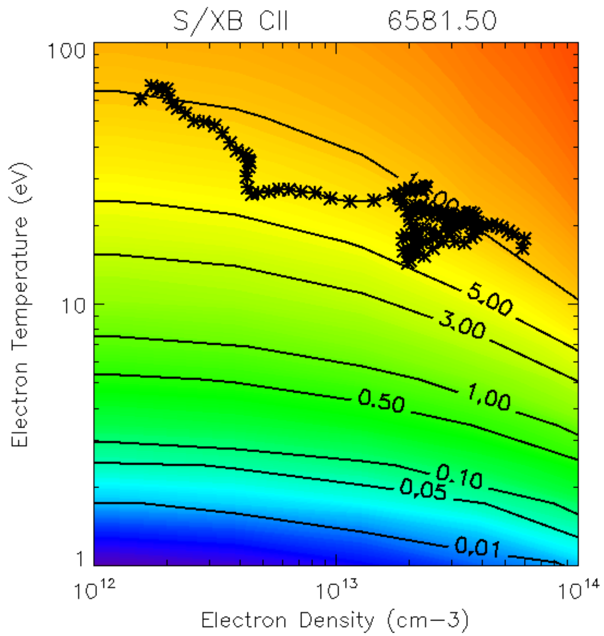
Results consistent with more recent data showing only a moderately reduced carbon sputtering rate on lithiated PFCs

- Data from absolutely calibrated high resolution filtered cameras
- Show moderate reduction in sputtering yield
- Measured rate is comparable to physical contribution (at normal incidence)
- Only lithiated conditions available
- Chemical sputtering behavior on Li coated PFCs unknown: to be investigated



S/XB factor for 658nm line
(2s2 3p1 → 2s2 3s1)
not too problematic



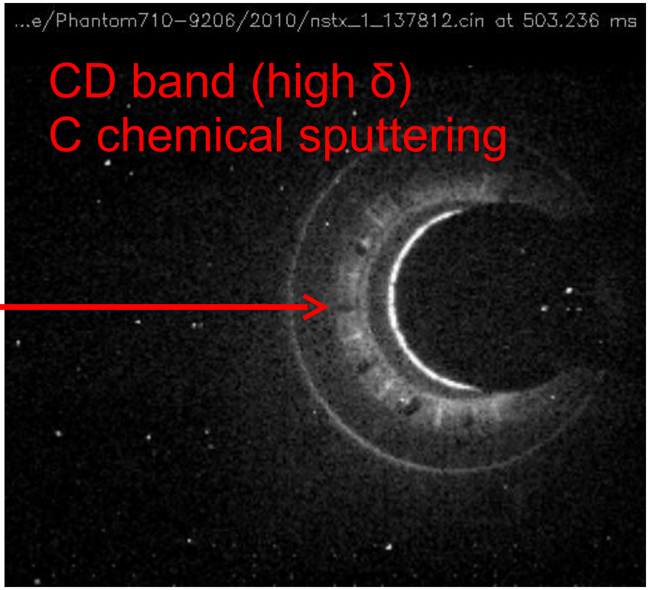
Limited lifetime of coatings and increase in divertor T_e can partially balance the expected reduction in carbon sputtering

• Reduction in carbon sputtering expected from lithium coverage can be partially balanced by:

- Limited lifetime of coatings (see previous slides)
- Transition to sheath limited regime at OSP: higher T_e can lead to higher physical sputtering

In addition:

- Typical surface roughness for unpolished graphite ~1-10 micron >> than coating thickness
- Morphology of evaporated coatings presently not clear, can have effect on carbon sputtering
- Effect of leading edges in graphite tiles can be important for carbon sputtering
- Carbon sputtered from main wall can migrate and re-deposit in lower divertor, ionize and appear as a divertor source



Summary of carbon and lithium sputtering observation in NSTX divertor

Considering the large uncertainties in this analysis:

- Evidence for lithium temperature dependent sputtering
- ~Consistent with published Li sputtering (IIAX, DIII-D)
- Evidence for toroidal asymmetry of influxes and coatings
- Evidence for deterioration of coatings

- Moderate reduction of carbon sputtering if compared to boronized graphite PFCs
- Still significant carbon sputtering observed
- Need to look at role of carbon chemical sputtering
- Work underway to investigate role of prompt re-deposition for Li vs C