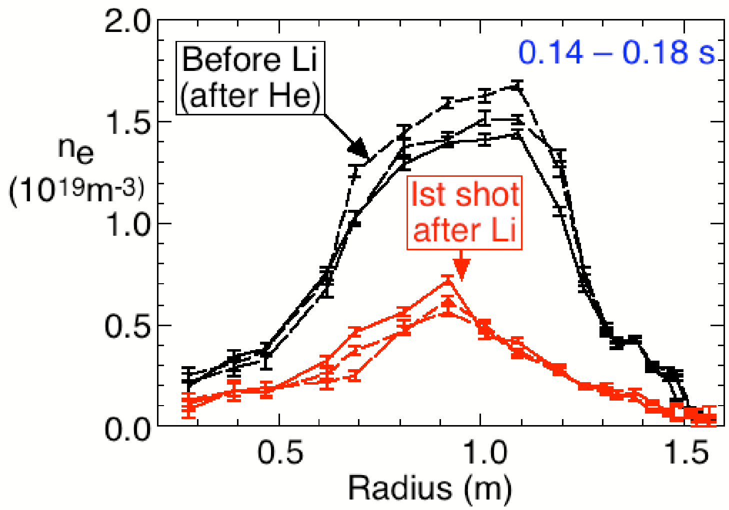
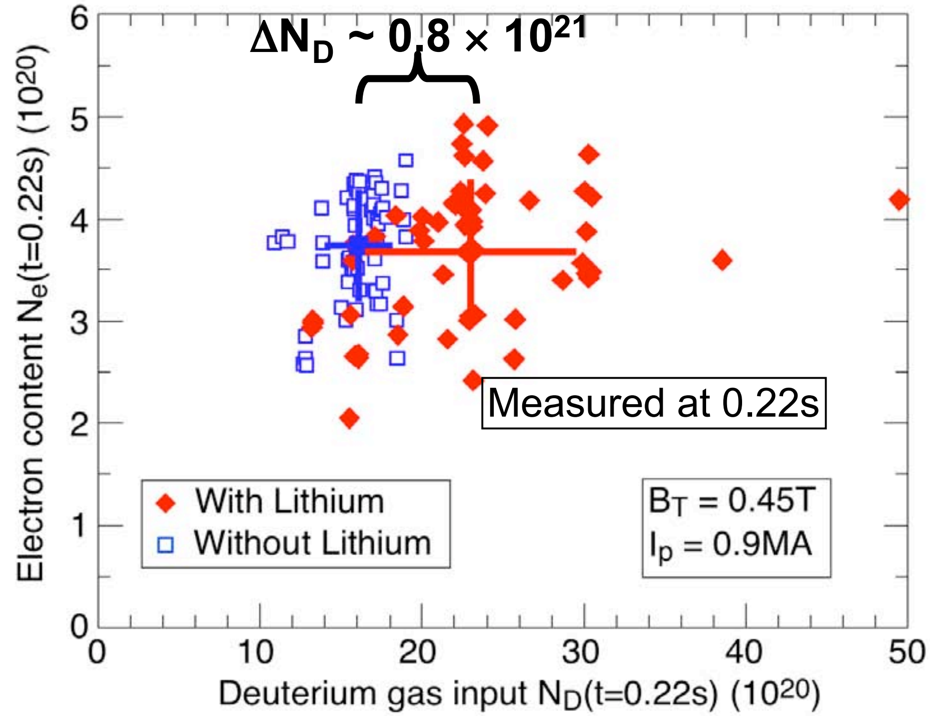
Living With (and Prospering From) the LLD

Lithium Does Pump but Normally We Increase Fueling to Avoid Early Locked Modes

CS Limiter D discharges
(0.9MA, 0.45T, 4MW NBI)
with same gas fueling after
Helium conditioning and
lithium pellets (**~30mg**) injected into
preceding 10 OH He discharges



2008-9 **LSN discharges**
100 – 600 mg fresh Li from LITER
(25 – 160 nm thick at inner divertor)



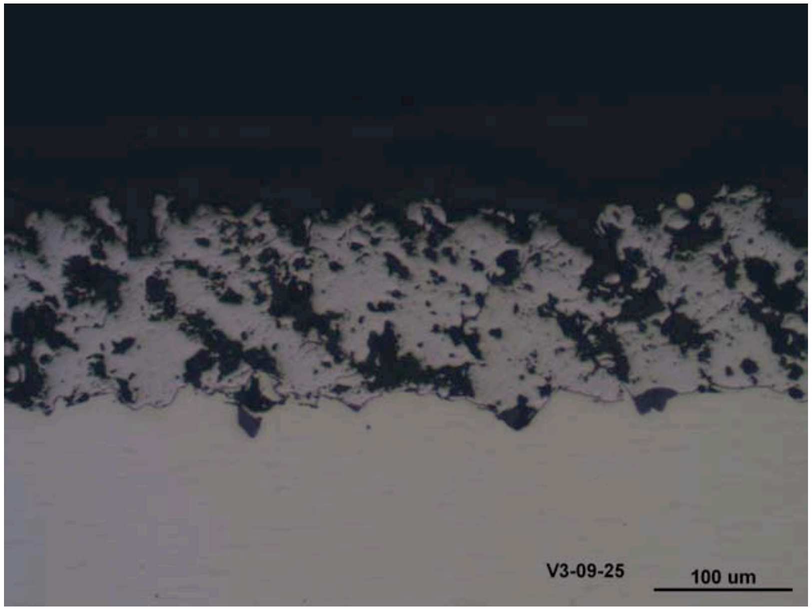
- Tangentially viewing camera for edge D_α emission shows greatly reduced neutral D density across outboard midplane with lithium from LITER
- Lower density *is* achievable early in discharges but likelihood of deleterious locked modes increases: *we need to learn to avoid locked-modes to exploit lithium*

There Are Now LLD Plates Close to Your Favorite Plasma

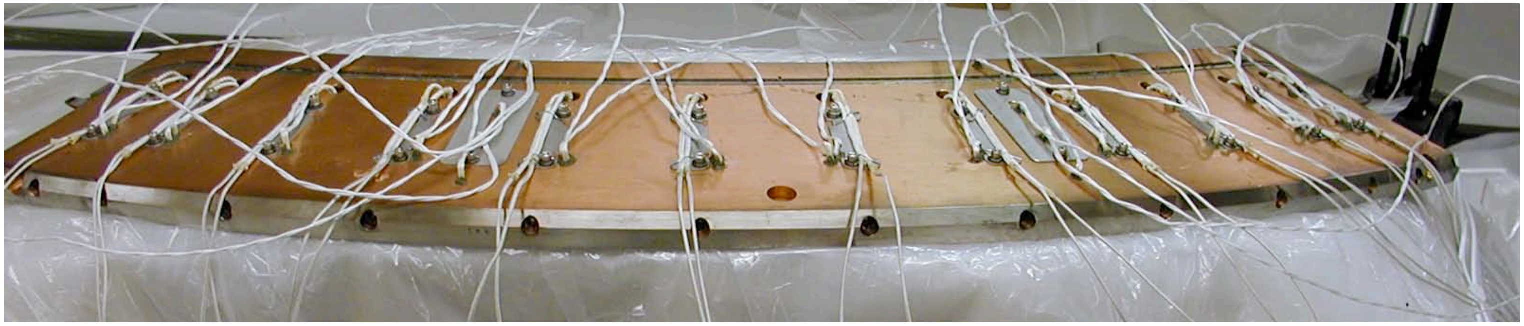
January 11, 2010

Micrograph of porous Mo layer

Note the small poorly connected surface features



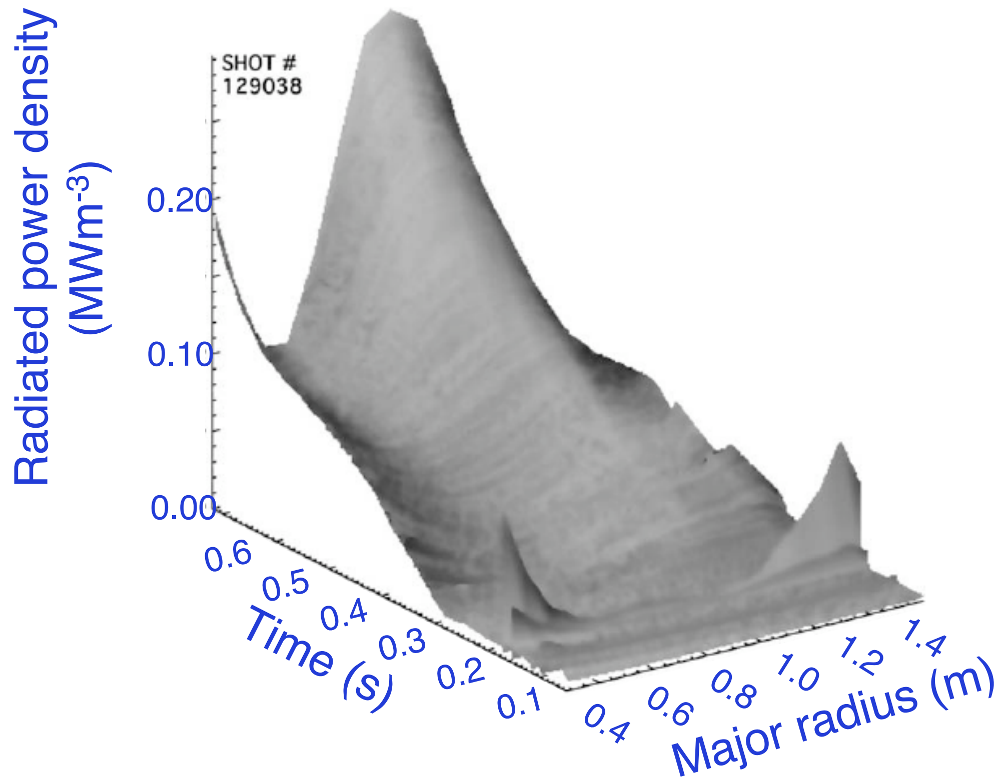
Back side of plate with heaters and thermocouples installed

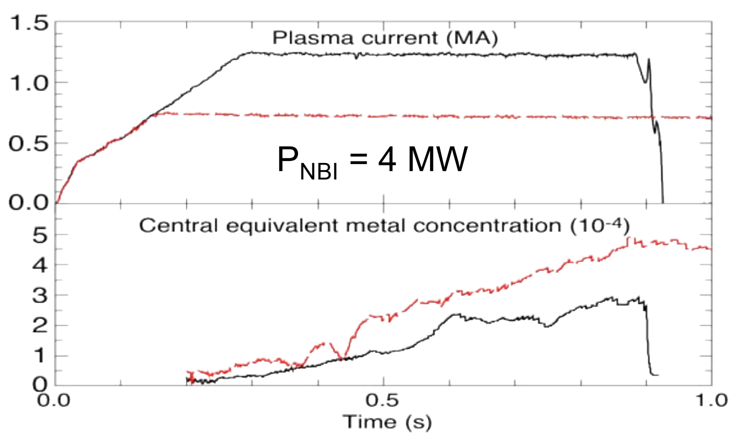


To Give the LLD a Fair Trial, We Must Protect It From the Plasma and *vice versa*, At Least Initially

- Direct plasma impingement could melt the porous surface very rapidly and affect its porosity and ability to hold lithium
  - During plasma startup when control is not tight and energetic ions are poorly confined
  - Uncontrolled transients (*e.g.* disruptions and β collapses)
  - We have seen strong divertor interactions during HHFW, particularly without lithium to reduce the SOL density
- NSTX is susceptible to metal radiation in its operating regime
  - More a problem in ELM-free H-modes produced by lithium
  - Sputtering, particularly by impurities, could lead to runaway Mo influx
- *I believe that, to protect its engineered surface and reduce the exposure of the plasma to Mo,* ***we should partially fill the LLD with lithium before running any plasma shots***

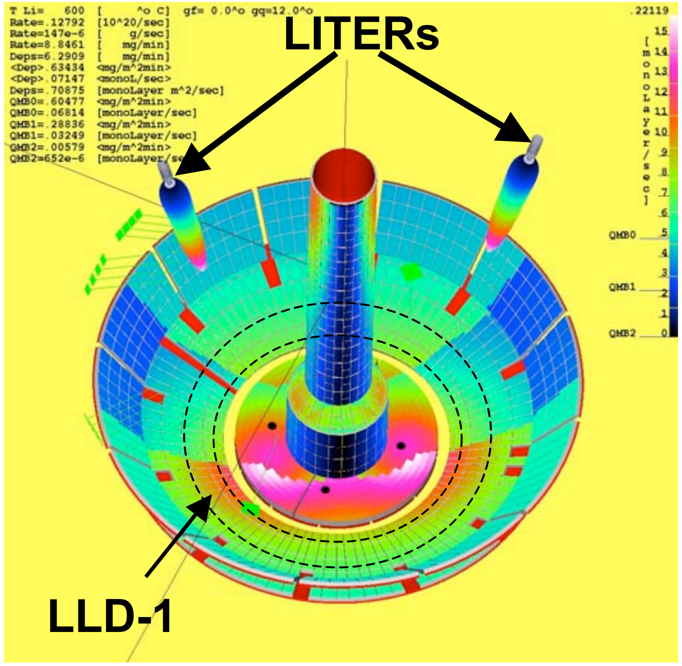
Metals Responsible for Most of the Increase in Radiation When ELMs Suppressed by Lithium

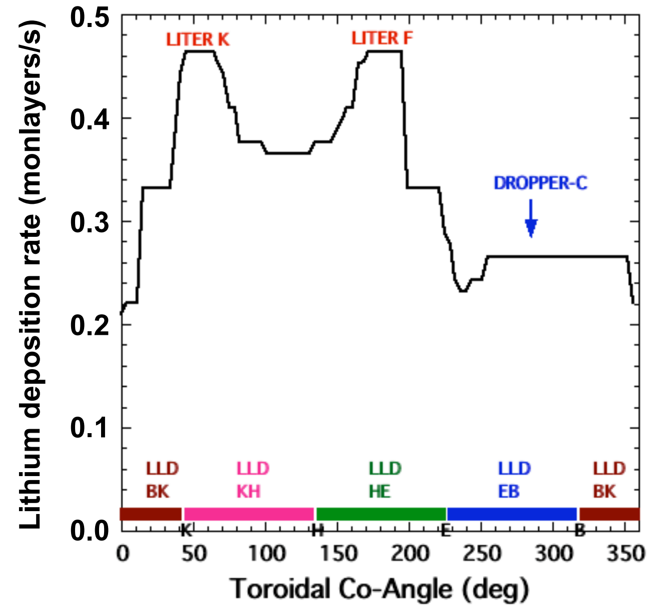




- Radiated power centrally peaked in ELM-free discharges
- VUV and SXR spectra show iron lines (Fe X – XVIII) increasing during ELM-free periods
- Radiated power profile remains hollow when ELMs are present
  - Metals still present early but do not accumulate
- If increase in radiation is ascribed to iron-like metals:
  - $n_{\text{"Fe"}}/n_e \sim 0.1\%$
  - $\Delta Z_{eff}(\text{"Fe"}) \sim 0.3$
- Dependence of rate of rise of radiation on I_p suggests sputtering by unconfined NB ions is source

Plan to Fill LLD-1 with Lithium from Dual LITERs, Possibly Supplemented by Lithium Droppers





- Rely on liquid wetting the porous Mo surface to spread the lithium
- Only 7% of lithium evaporated by LITERs reaches LLD-1 plates
- Estimate ~40g lithium required to fill porous volume in Mo coating
  - ~600g evaporation to fill ⇒ 22 days at maximum rate & ~7 loadings
- Wettable area in porous Mo estimated at ~8 times plate area
  - 1.1g lithium on LLD would coat wettable area to 250nm penetration depth of incident D^+ ⇒ 15g evaporated ~ 1 day at normal evaporation rate

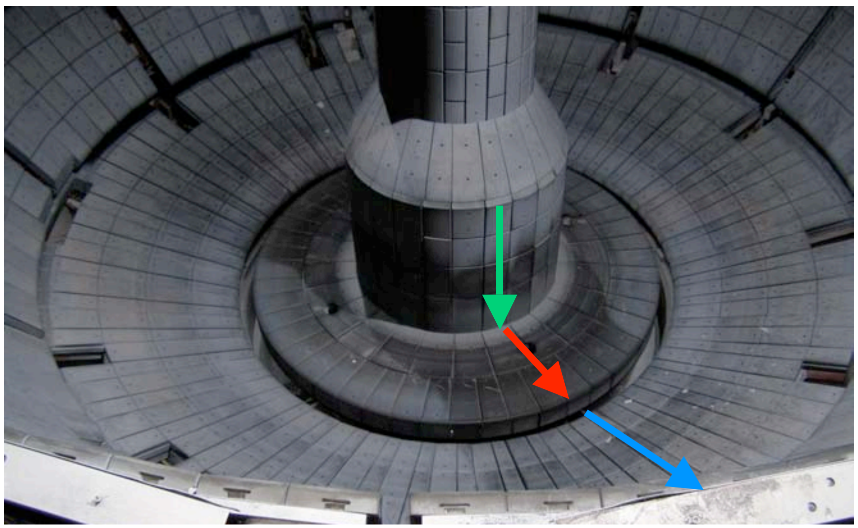
Can We Distinguish Effects of the LLD from Lithium Applied Elsewhere While Filling the LLD?

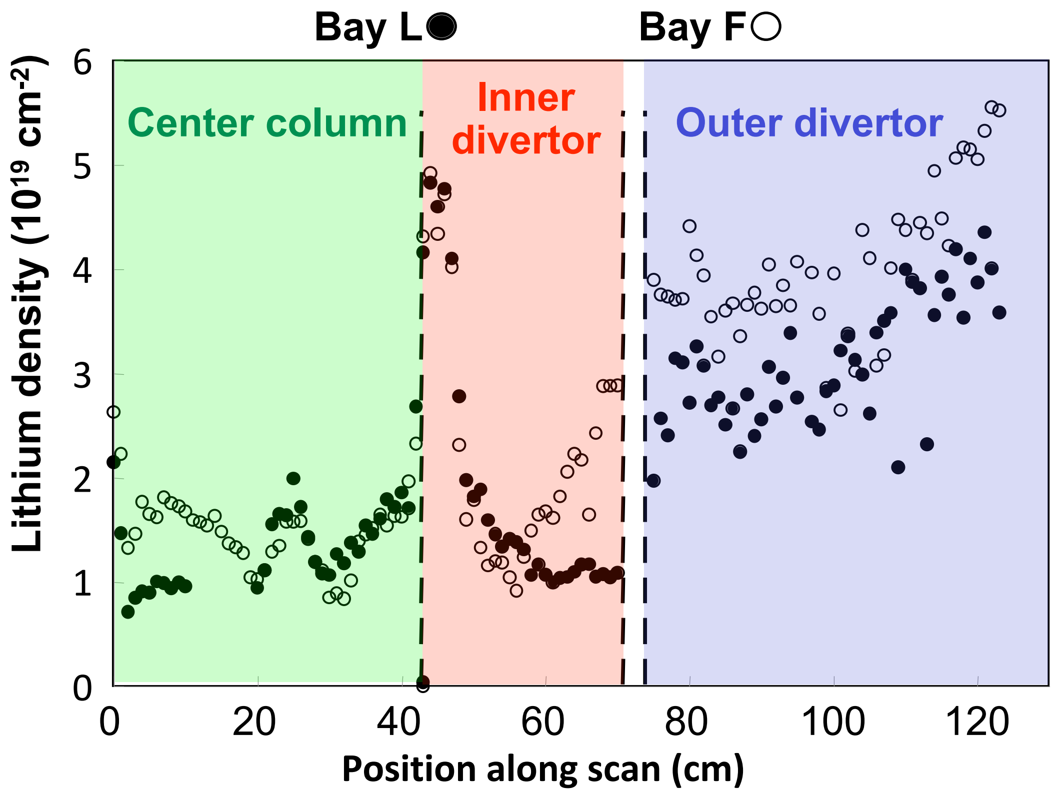
- Solid lithium ceases to absorb D when the surface to the depth of penetration (~250 nm) becomes saturated at some D:Li ratio < 1
  - 250 nm Li film contains 1.2×10^{22} Li/m^2, so absorbing 1×10^{21} D in a typical NSTX shot would fill the active area of the lower divertor, ~1m^2, with ~8% D
- A thick liquid lithium film is expected to retain its D-sequestration capability because adsorbed D remains mobile in the liquid
  - Measurements suggest that precipitation of LiD begins for D/Li ~ 0.1
- If we prefill the LLD, we can “deactivate” the lithium surface on it and surrounding PFCs by running a series of 3 – 10 standard shots
- We can then heat the LLD above the lithium melting point (180°C) and hope to restore its activity, *assuming that*
  - A saturated layer of D in solid Li will be absorbed into the Li below as it melts
  - Migration of the Li and Li-D from the contact areas on the divertor to the LLD during the discharges will not overwhelm or “poison” the LLD layer

Analysis of Carbon Tile Surfaces Confirms Migration of Lithium Under Plasma Fluxes

- In operation, effects of lithium coating decay after 3 – 10 discharges
- Ion-beam nuclear-reaction analysis measures lithium and deuterium areal density in surface layer of tiles removed from vessel
  - Tiles also accumulated lithium after run while emptying LITERs

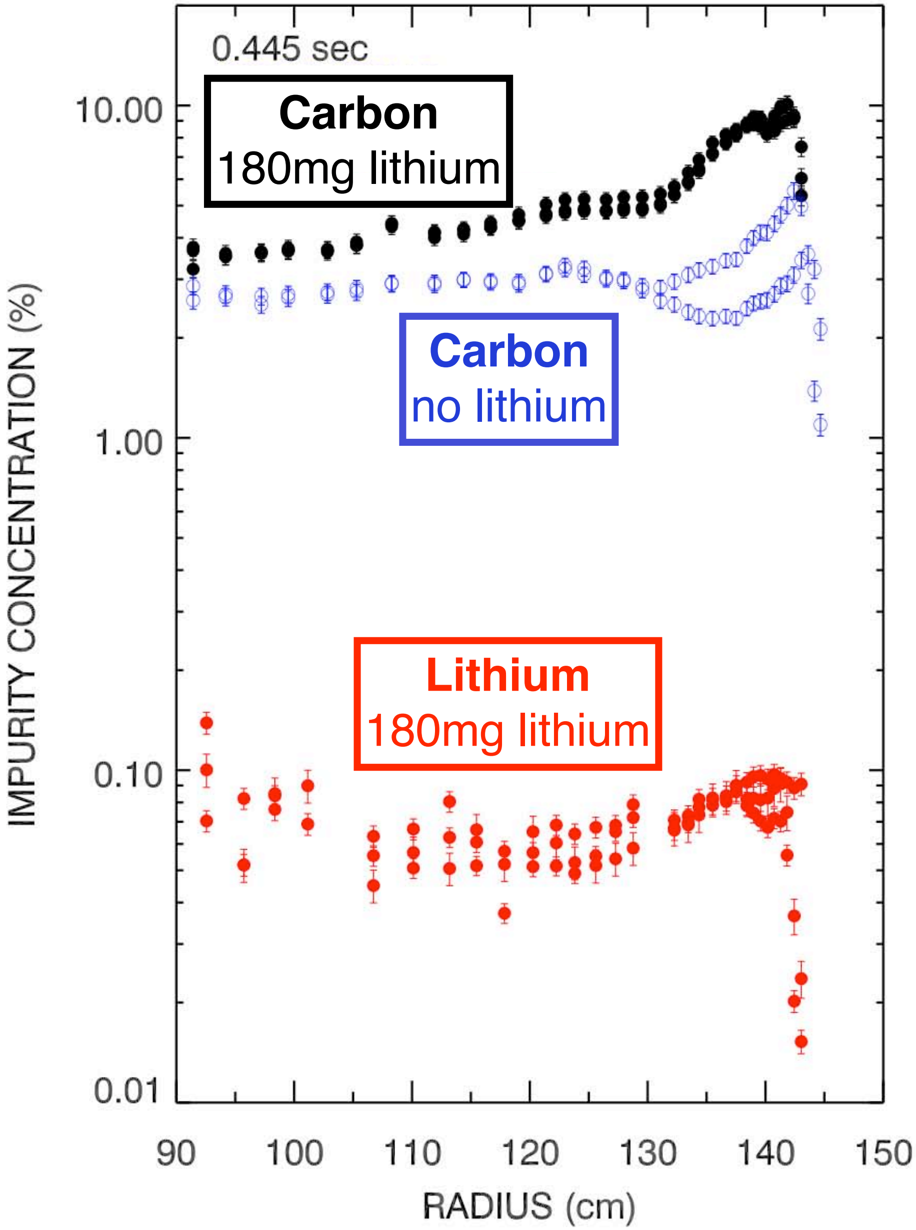
Scan across lower divertor





- Peak lithium density remaining on inner divertor ~0.6 mg·cm^{-2}
- Total deposition there estimated at ~8 mg·cm^{-2}

Lithium Concentration in Plasmas Remains Low but Carbon Concentration Rises with Lithium Coating



- Quantitative measurements of C^{6+}, Li^{3+} with charge-exchange recombination spectroscopy
- **n_C/n_{Li} = 30 – 100**
- Hollow profiles early for both C and Li fill in as time progresses