NSTX

Supported by U.S. DEPARTMENT OF ENERGY Office of Science

Measurements of core lithium concentration in NSTX

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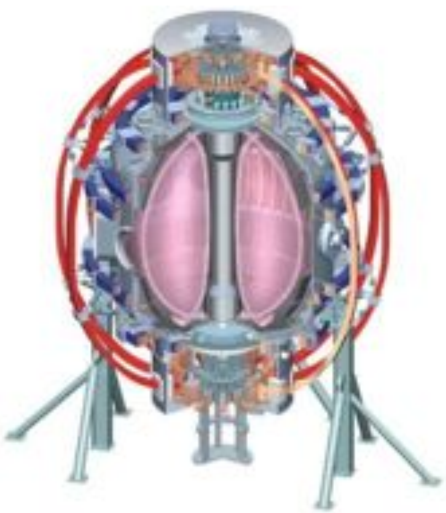

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ABSTRACT

The core lithium concentration in NSTX was measured using charge exchange recombination spectroscopy during the FY2010 experimental run, which featured routine lithium conditioning of plasma facing surfaces. Both active and background Li III emission at 5167Å (*n*=7-5) and C VI emission at 5291 Å (*n*=8-7) were monitored with spatially-interleaved vertical-viewing sightlines over the outer major radius (120-157 cm) of the plasma. These line-integrated Li and C measurements were inverted to recover profiles and to account for the differences in the charge exchange cross sections between Li and C. No significant accumulation of lithium was observed in the core plasma with ΔZ_{eff} due to lithium ≤ 0.006. A persistently low lithium concentration was observed, with N_{LI}/N_e < 0.1 %, despite heavy lithium conditioning. The ratio of lithium to carbon density remained roughly proportional, depending on plasma radius, with N_{Li}/N_C ≤1% over a wide range of plasma parameters.

Summary

- Core Li concentration monitored throughout 2010 Run
- Broad range of operating conditions covered
  - B_ϕ, I_P, aspect ratio/inner gap
  - Different Li conditioning techniques
  - Anomalous events, e.g. Li blobs on divertor

> Plasma configuration has little effect on n_{Li}

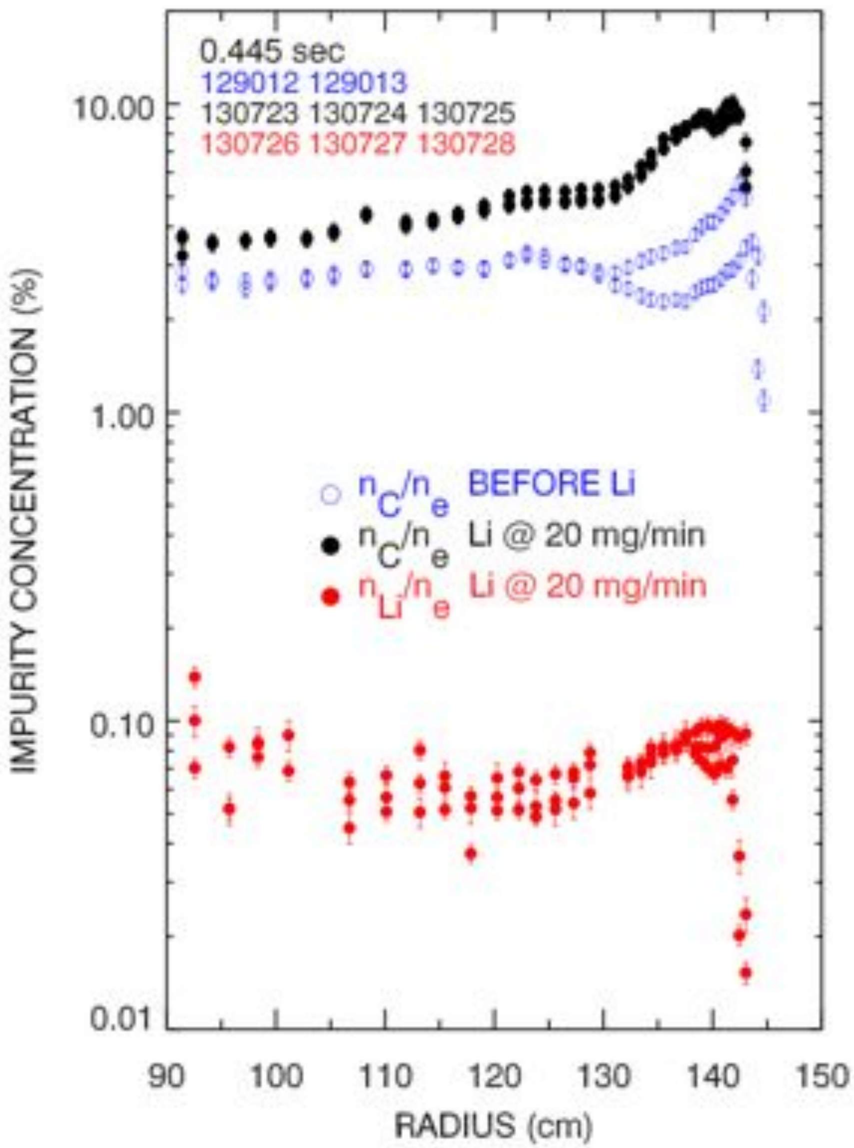
> Only systematic dependence observed is on B_ϕ, I_P

  - Attributed to general improvement in confinement

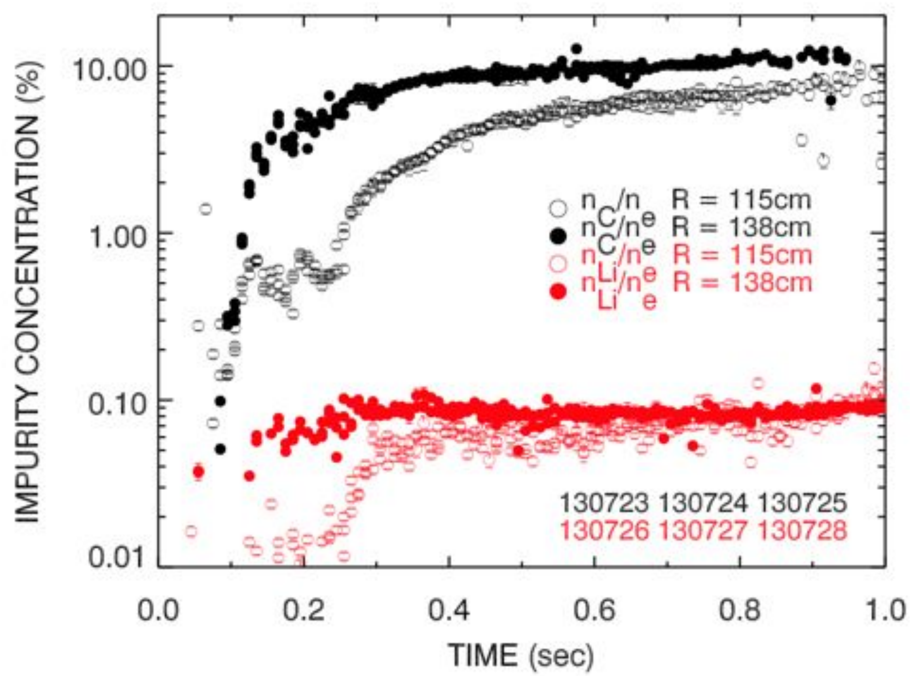
> Negligible Li concentration is a robust property of NSTX

  - $n_{Li}/n_e << 0.1\%$
  - Carbon remains dominant impurity even after massive (hundreds of milligrams) Li evaporation
  - ΔZ_{eff} due to lithium ≤ 0.006

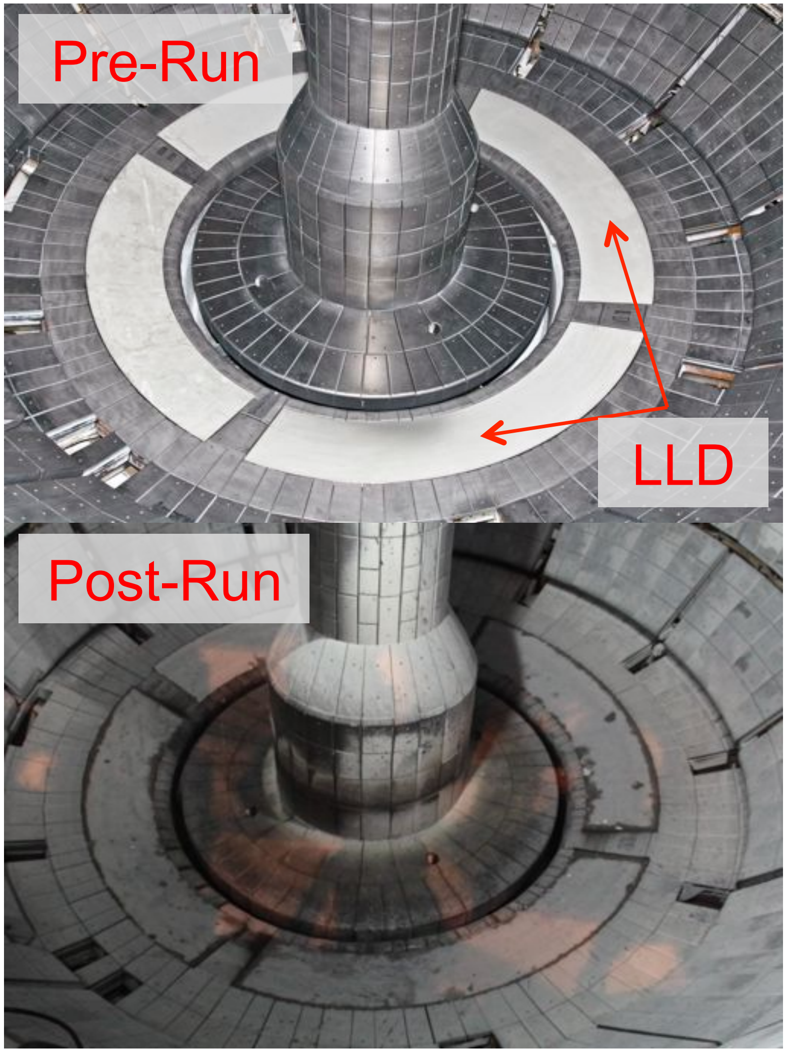
2008 Lithium and Carbon density measurements: extremely low Li concentration and higher C concentration

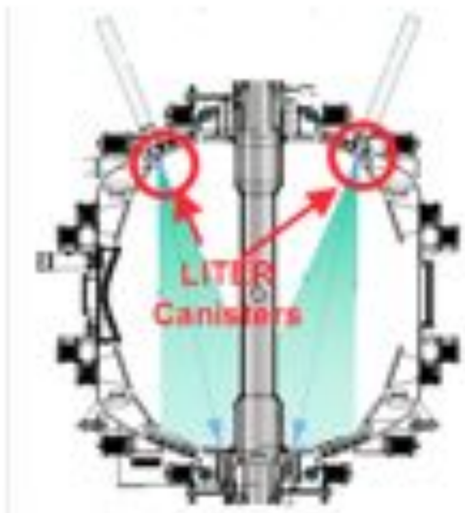


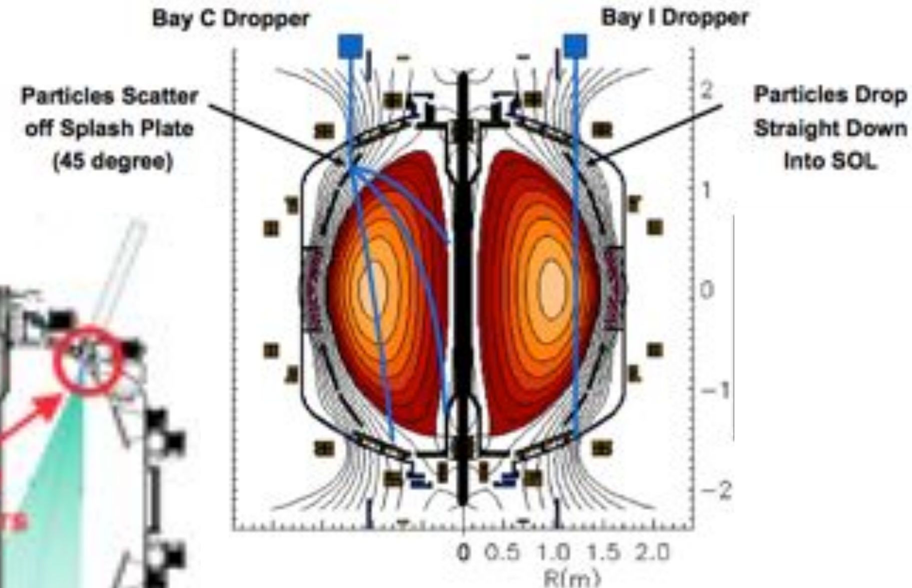
- Impurity density profiles from *toroidal* CHERS
  - C VI, n = 8-7 transition, 529.1 nm
  - Li III, n = 7-5 transition, 516.7 nm
- One operating condition (H-mode) measured
- Lithium concentration much lower than carbon concentration
  - $n_C/n_{Li} \sim 100$
- Carbon increases with Li evaporation



About 1.3 kg of lithium evaporated during 2010 Run

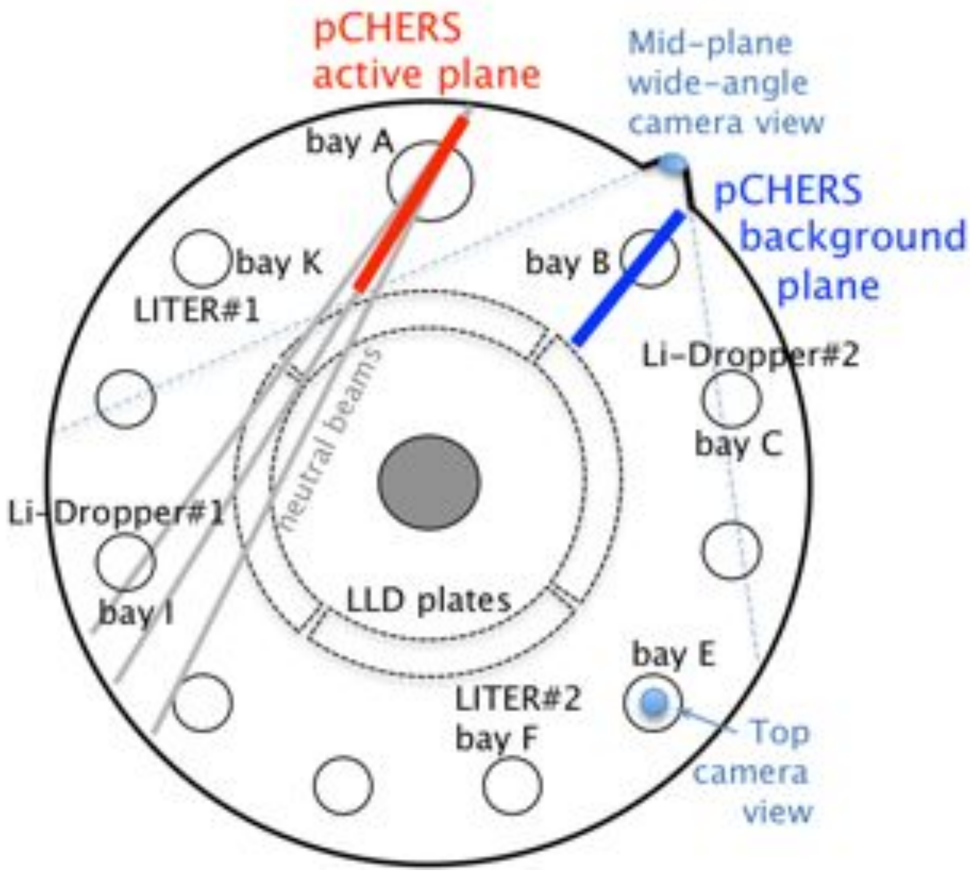


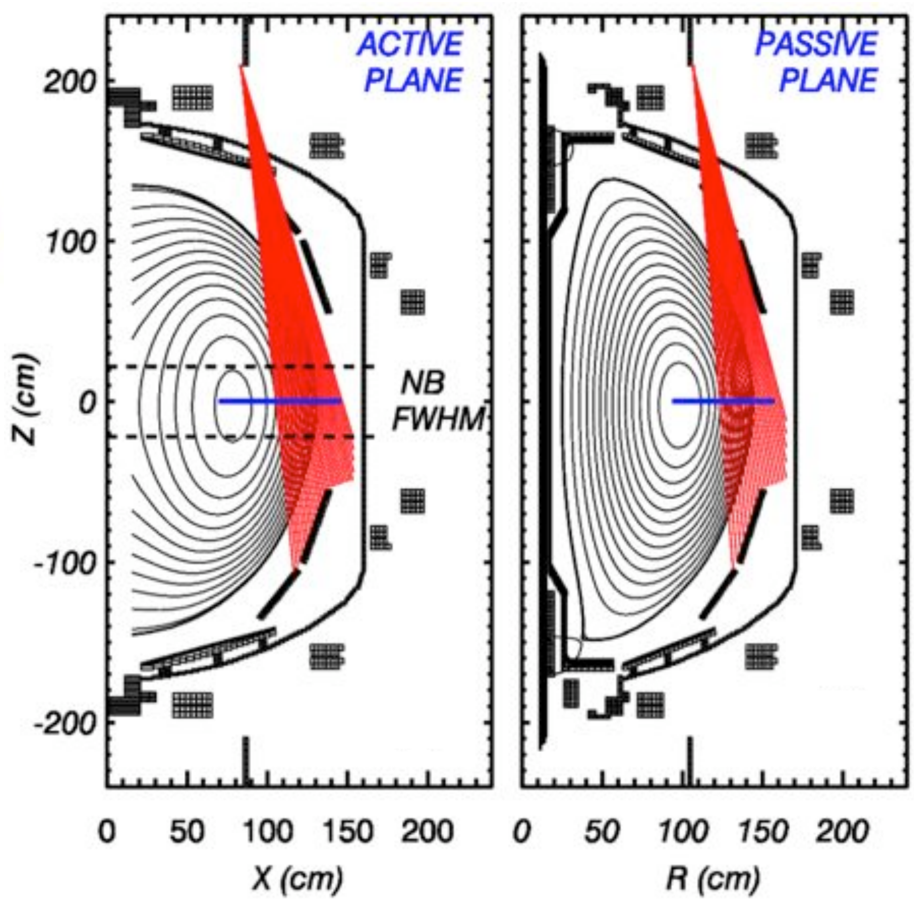




- Lithium conditioning systems
  - LITER evaporation
  - Li Dropper
  - Liquid Lithium Divertor (LLD)

Suite of CHERS diagnostics allowed simultaneous measurements of C, Li on outer midplane in 2010

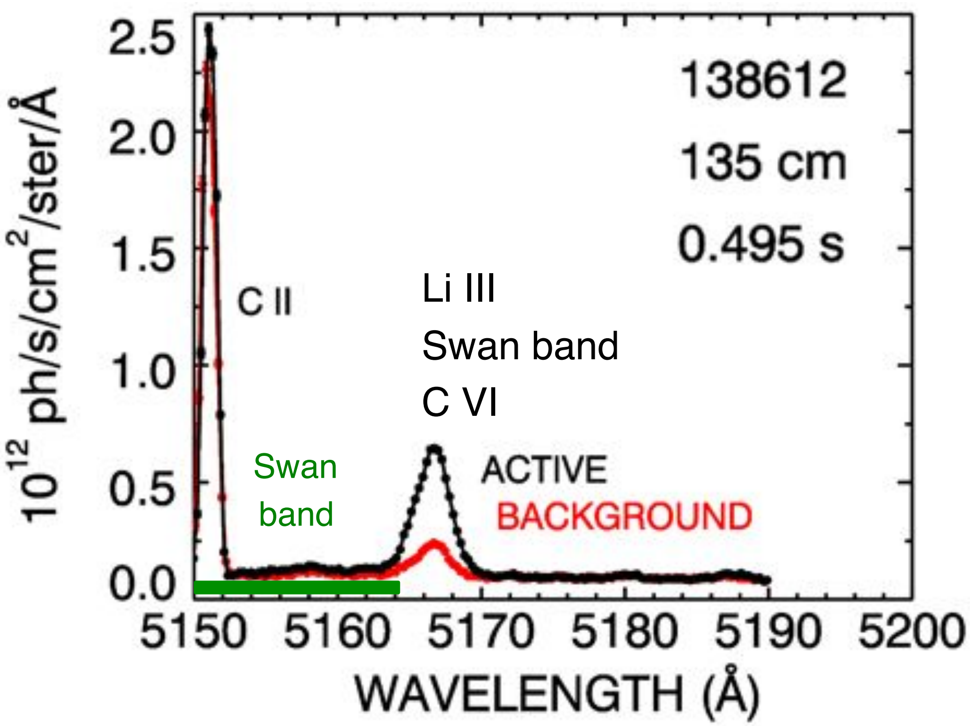




- Active/passive paired views to remove background
- Monitor Li III line (*n*=7-5) at 516.7 nm
- Interleaved measurements of C VI (*n*=8-7) at 529.1 nm
- Data from mid-radius (R~120 cm) out every 10 ms.

ANALYSIS OF CHERS LITHIUM SPECTRUM

Measured Li III spectrum complicated by low Li III content, blend with C VI, and overlap with C_2 band

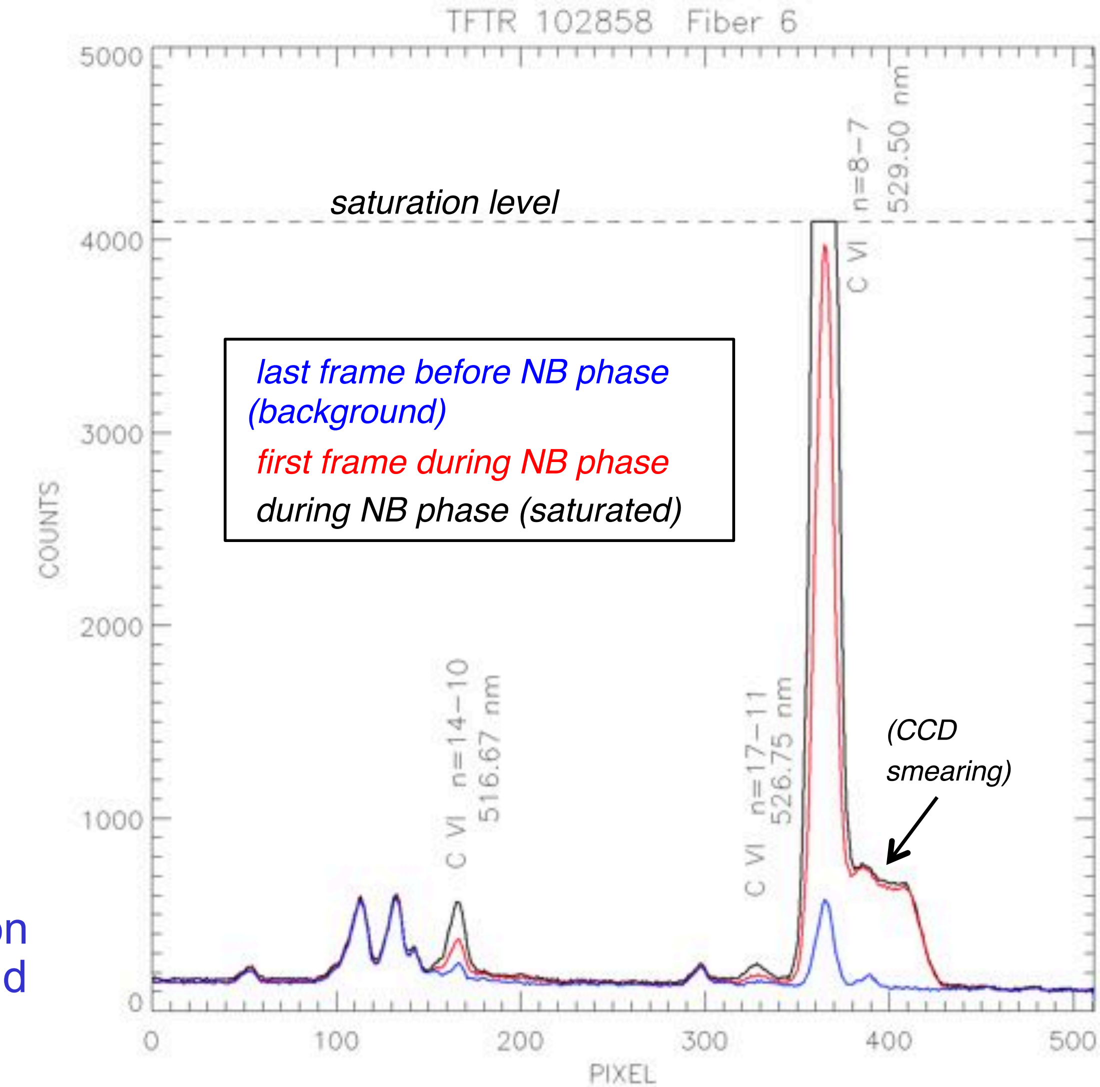


System	CHERS	pCHERS	Li-pCHERS
Views	tangential	vertical	vertical
Measured/derived quantities	n_C, v_{tor} n_i, T_i, Z_{eff}	n_c, v_{pol}	n_{Li} n_{Li}/n_C
Monitored species	C VI	C VI	Li III C VI C II
Monitored lines	5290.5 Å	5290.5 Å	5166.89 Å (Li III) 5166.67 Å (C VI) 5151.1 Å (C II)
Radial coverage	90 – 157 cm	90 – 157 cm	120 – 157 cm

- C VI line (*n*=14-10) at same wavelength as Li III (*n*=7-5)
- Molecular C_2 band (*Swan band*) partly overlaps Li III
- No NSTX lithium-free discharges available to estimate relative brightness of C VI versus Li III

TFTR spectra indicate that C VI (*n*=14-10) to C VI (*n*=8-7) brightness ratio is ~3.6 %

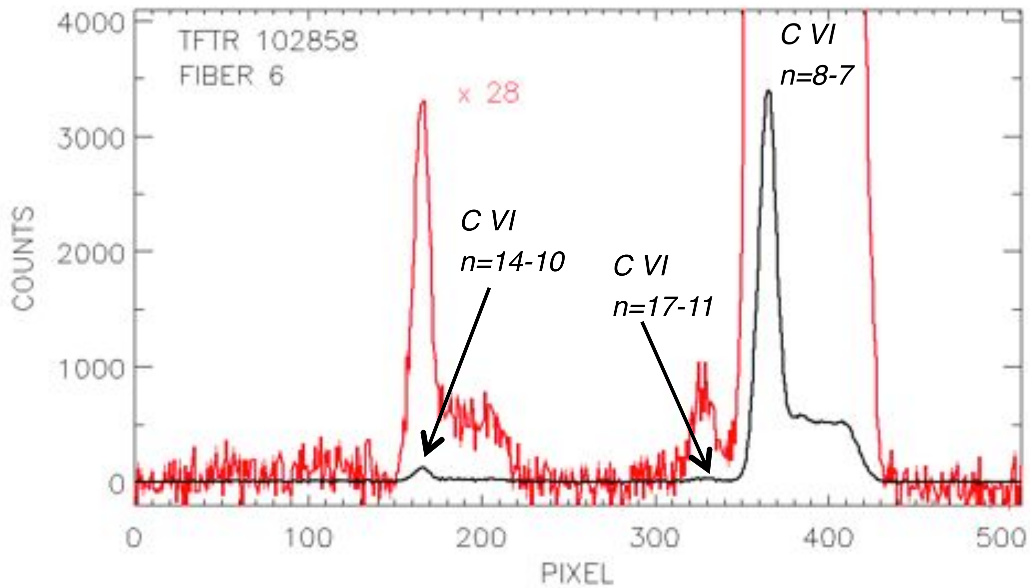
- Data taken during TFTR pCHERS commissioning near beam turn-on
- n_e~1.2 x $10^{19}m^{-3}$, T_i,T_e~ 3 keV
- Measured relative brightness of C VI
  - *n*=8-7 @ 529.5 nm
  - *n*=14-10 @ 516.7 nm
  - *n*=17-11 @ 526.8 nm
- Brightness ratio $B_{8\text{-}7}$:$B_{14\text{-}10}$ is 28:1
- Measured ratio provides an estimate for expected C VI (*n*=14-10) brightness on NSTX
  - Collisional-Radiative (CR) model for CX using n_D=1,2,3 excited donor neutrals under populates upper *n* levels compared to measurement
  - From CR model, expect little variation between these TFTR parameters and NSTX parameters



About 50% of brightness @516.7nm on NSTX can be due to C VI

Brightness ratios measure n-level population ratios

CX spectra obtained by subtracting pre-beam spectrum from post-beam turn-on spectrum.



- Assuming fully mixed levels, the TFTR measurements imply that the *n*=14 and *n*=17 levels are more populated by charge exchange with the neutral beams that the *n*=8 level
- The CR model using donor neutrals n_D=1,2,3 does not adequately populate the upper levels
- Other populating mechanisms, e.g. n_D=4,5,6 , are required to match measured brightness ratio.

$$B \propto A_{ki} N_k$$

N_k is population of n - level k

A_{ki} coefficients for C VI:

$$A_{8-7} = 2.94 \times 10^8$$

$$A_{14-10} = 7.02 \times 10^6$$

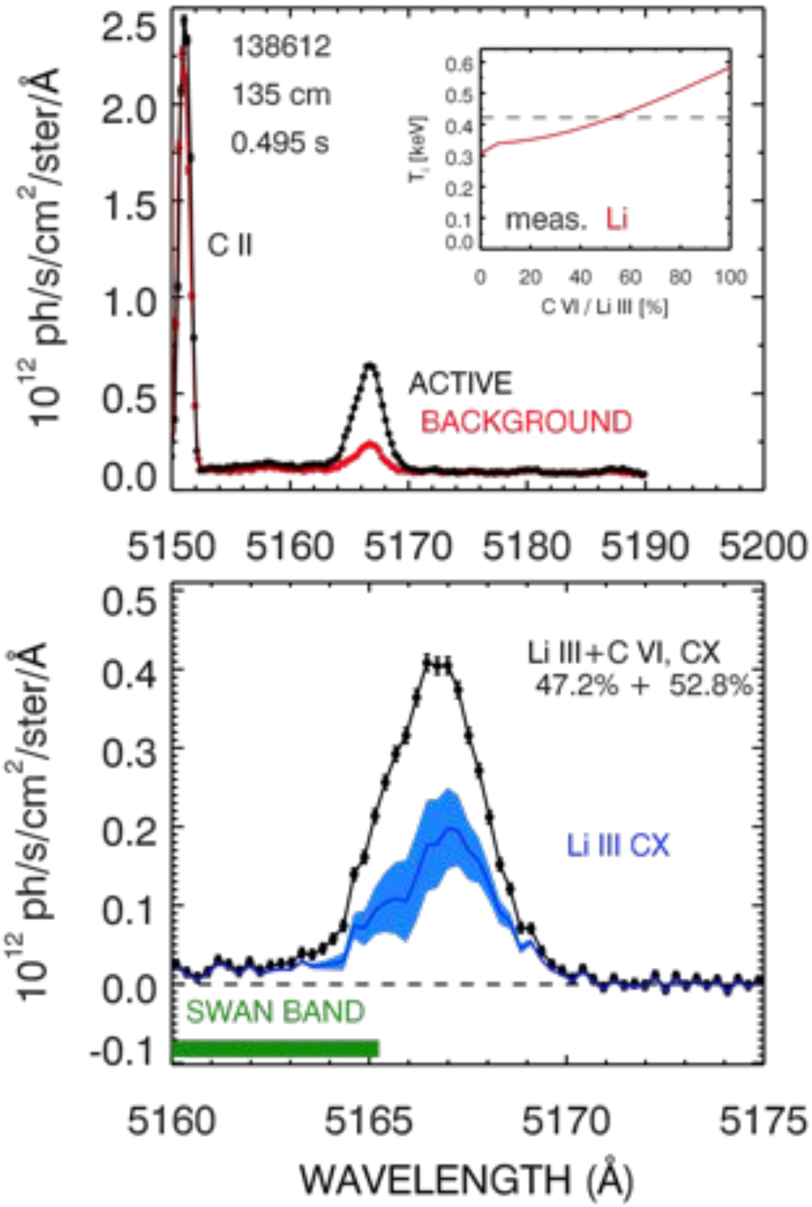
$$A_{17-11} = 2.08 \times 10^6$$

$$\frac{B_{14-10}}{B_{8-7}} = \frac{A_{14-10}}{A_{8-7}} \frac{N_{14}}{N_8} = \frac{1}{28}$$

$$\frac{N_{14}}{N_8} = \frac{B_{14-10}}{B_{8-7}} \frac{A_{8-7}}{A_{14-10}} = 1.5$$

$$\frac{B_{17-11}}{B_{8-7}} \approx \frac{1}{120} \Rightarrow \frac{N_{17}}{N_8} = 1.2$$

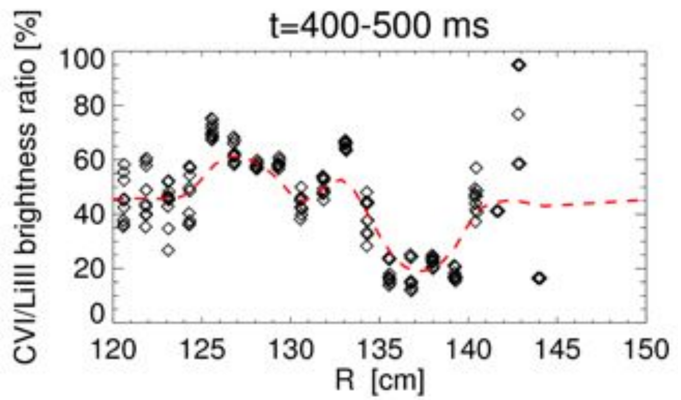
Combine information from C-pCHERS and Li-pCHERS to fit composite Li III, C VI and Swan band spectra



- Fit background-subtracted spectrum assuming
  - All species have same T_i
    - Use apparent (line-integrated) T_i from C-pCHERS as reference
  - Fixed wavelength for Swan head-band
  - Fixed wavelength for C VI (*n*=14-10) based on C VI (*n*=8-7) measurement
- Scan ratio of C VI to Li III brightness, infer FWHM ~ $(T_i/m_i)^{1/2}$
  - Inferred T_i for Li III changes with ratio
  - *Look for T_i consistency:*
    - *> Correct ratio such that $T_{Li}=T_C$*

On average, 50% of brightness is from C VI
Large uncertainties, +/- 25%

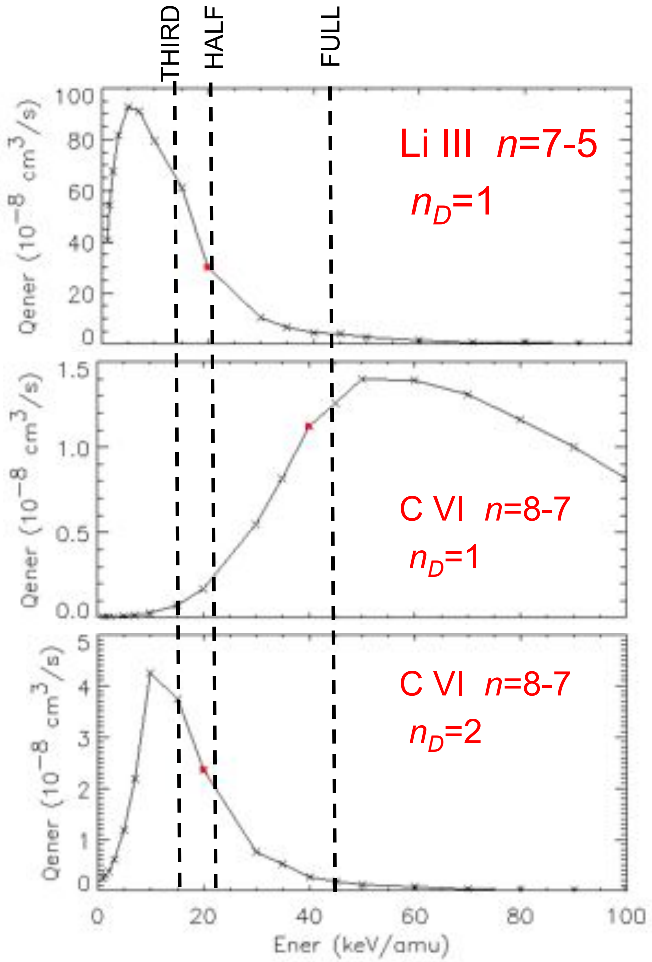
Analysis based on line-integrated measurements identifies an ***upper limit*** for n_{Li}



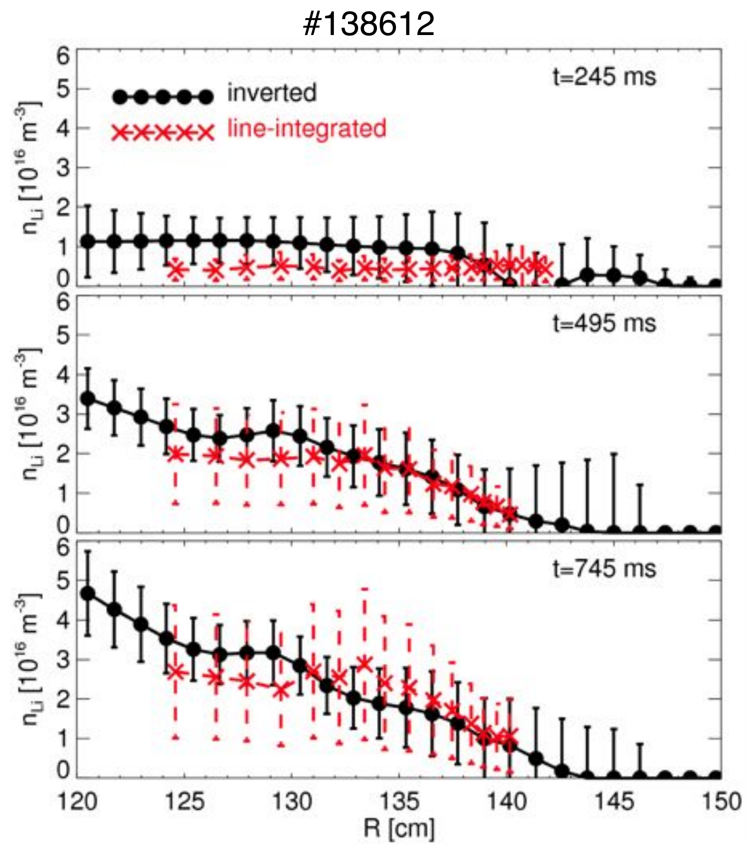
Relative brightness of Li III (*n*=7-5) compared to C VI (*n*=14-10) varies with radius

- Issues:
  - Line-integrated measurement
  - Differences among CX cross sections
  - Variations in Li III / C VI brightness ratio
- Line-integrated analysis used
  - Reduced radial resolution
  - Compared to *inverted profiles* (for a subset of discharges) compensating for differences in CX cross sections
  - Assume all emission near Li III wavelength is lithium (i.e. no C VI)
  - Scaled to toroidal CHERS with actual Carbon density
- Results *without* corrections for C VI/Li III brightness ratio shown in the following viewgraphs
  - **Upper limit for n_{Li}**
  - > **Actual lithium density (concentration) could be 2-4 times smaller than what shown hereafter**

Line-integrated analysis compensates for differences in CX cross sections for Li and C



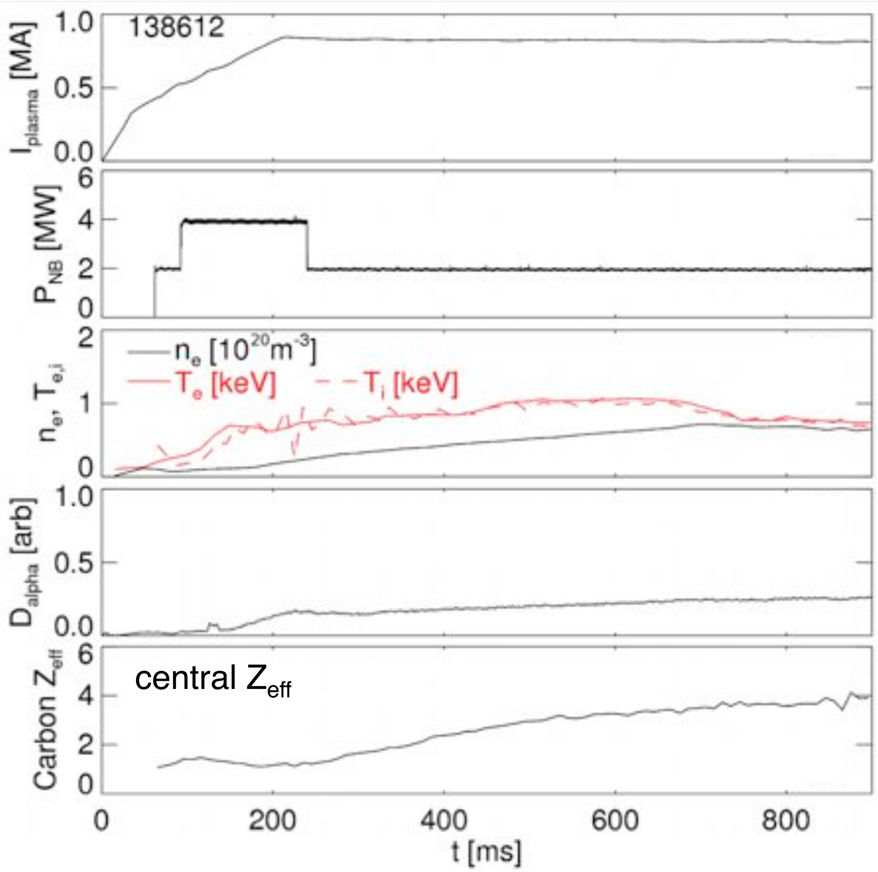
ADAS photoemission cross sections vs. collision energy



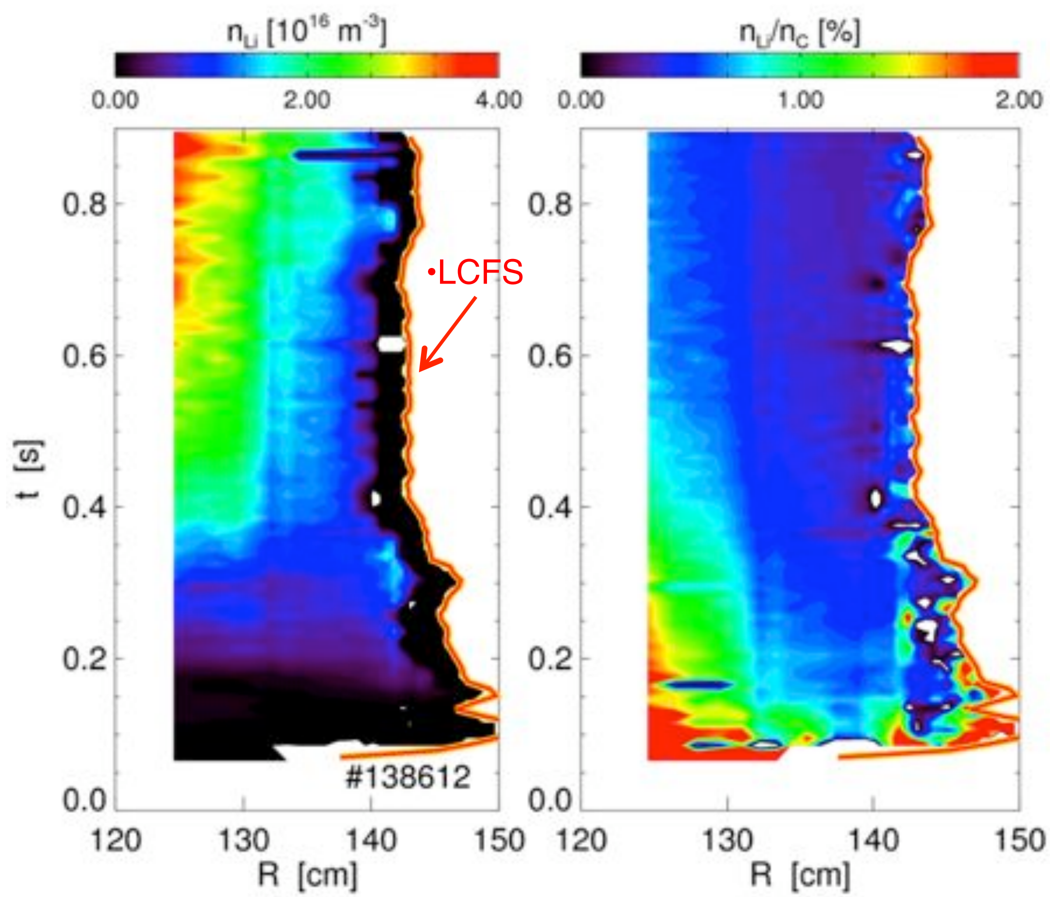
Comparison of line-integrated profiles and inverted profiles in reasonable agreement

Scans of Toroidal Field, Plasma Current, Aspect Ratio

Typical H-mode, moderate NB power discharge shows only trace amounts of lithium in the core



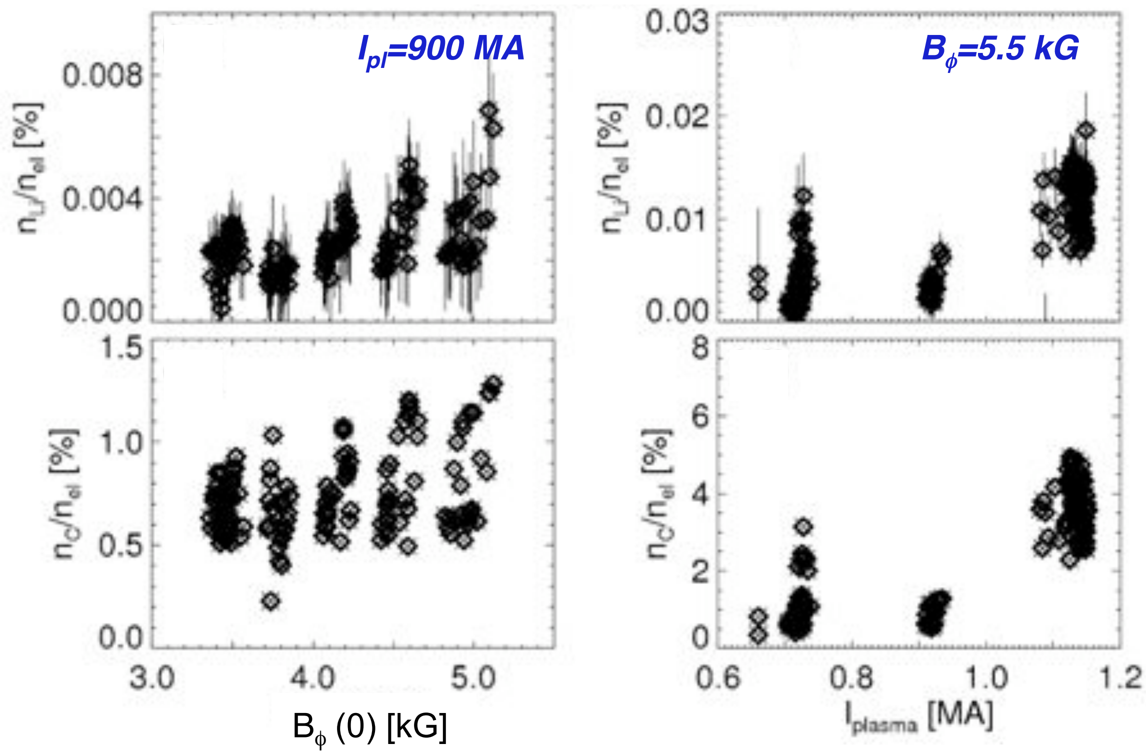
- ELM-free, 800 kA discharge
- Usual increase in Z_{eff} during the pulse



- Lithium density increases in time, but remains low
  - **Max 2% of carbon density**
  - **<<0.1% of electron density**

Both lithium and carbon relative concentrations increase with toroidal field and plasma current

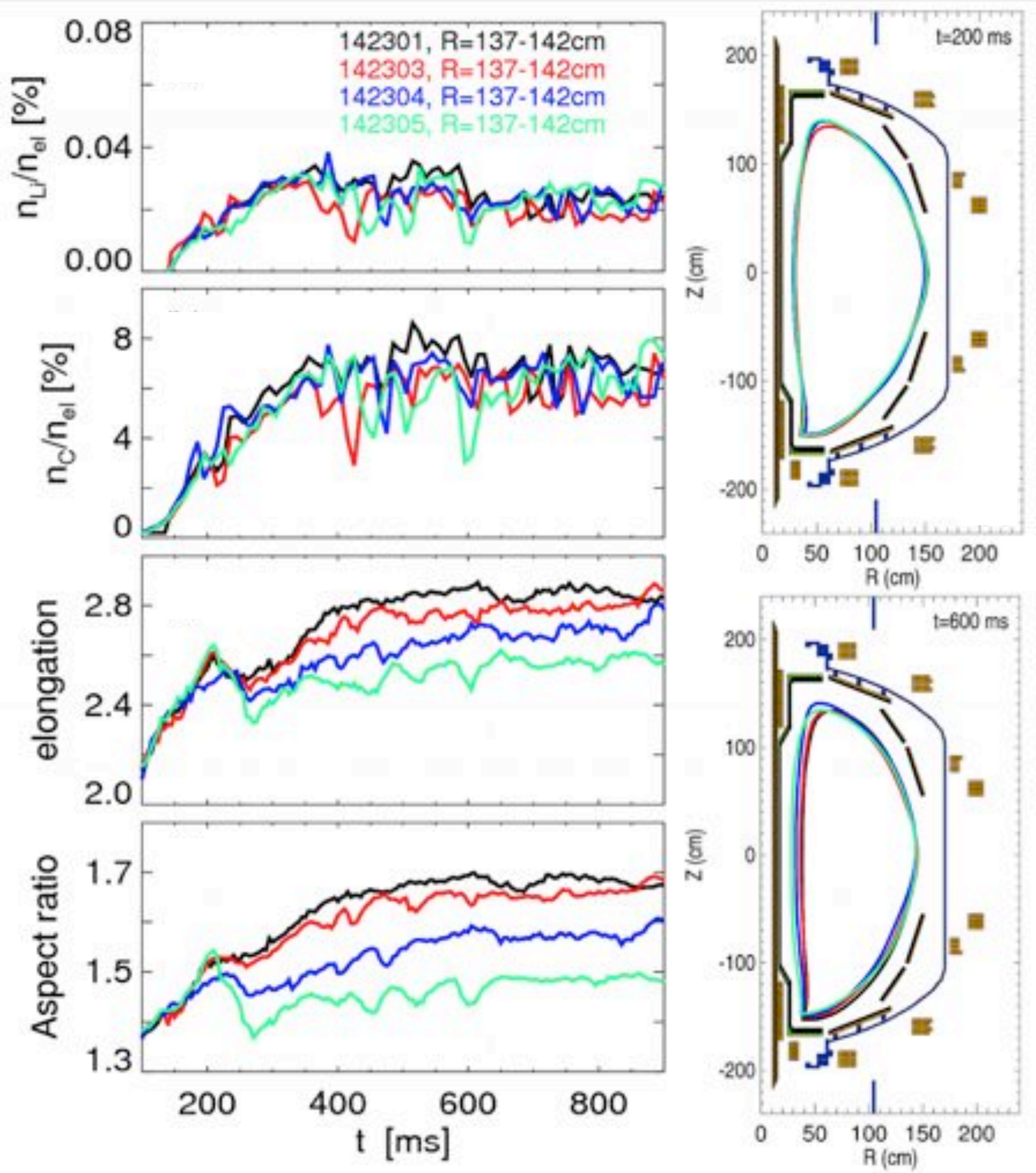
R=135-140 cm, t=250-400 ms



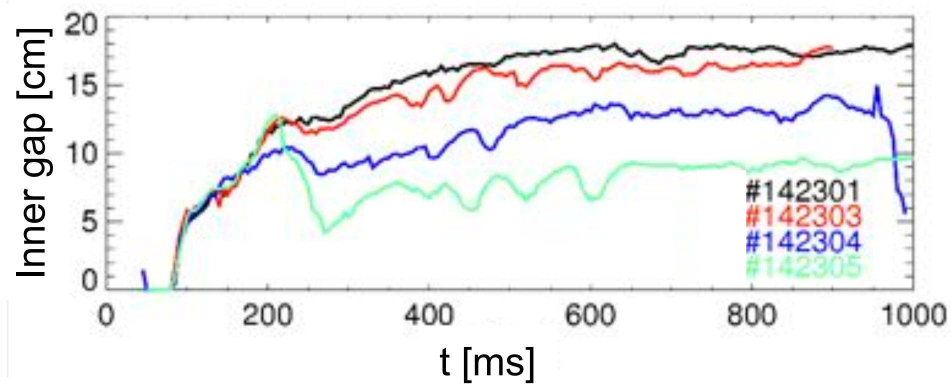
- Better confinement expected for higher B_ϕ, I_P
- Increasing Li, C concentration with plasma current
- Li, C show weak trend with B_ϕ
- Extremely low Li concentration projected for higher B_ϕ with NSTX-U

Lithium content remains insignificant.

Aspect ratio/ Inner gap scan shows no effect on average Lithium - and Carbon - concentrations

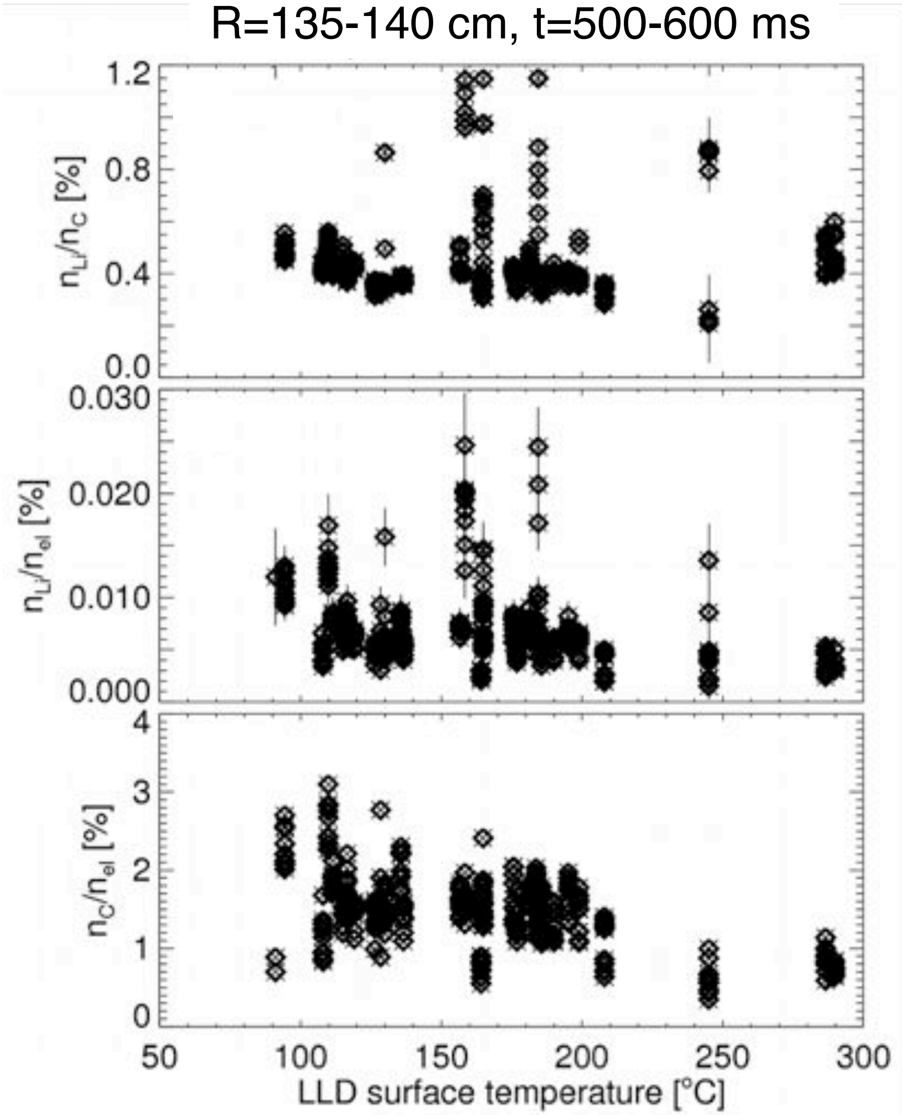


- *Are lithium/carbon sputtered in from the center stack?*
- Four discharges analyzed
  - All start the same way
  - Inner gap/aspect ratio modified after ~200 ms
  - Other parameters change at the same time (elongation, bottom gap, etc.)
- No variation of n_{Li} observed among shots
  - Slight decrease of n_{Li} in time
  - Carbon seems to saturate
  - Lithium concentration low (< 0.04%)



Dependence on Lithium Conditioning: LITER, Li-Dropper, LLD

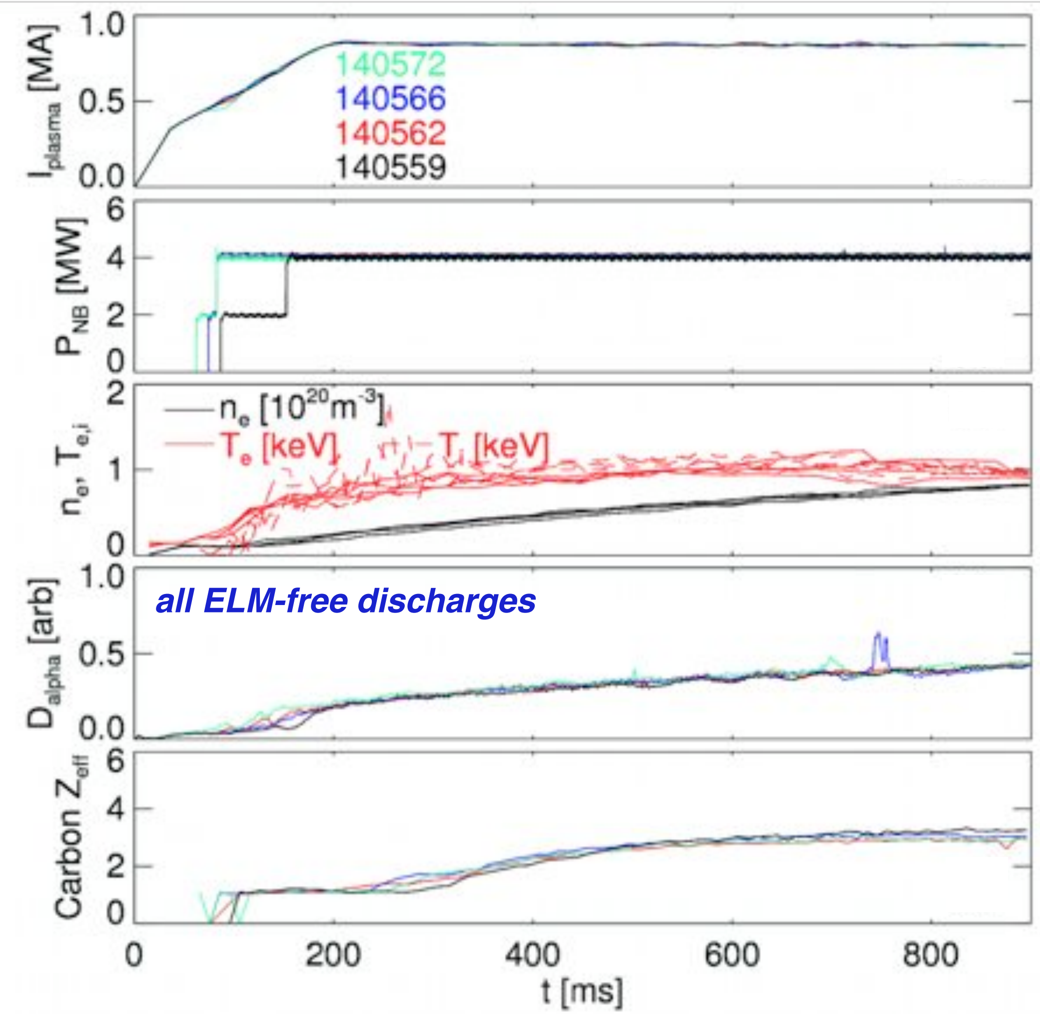
LLD well above Li melting temperature does not affect significantly Lithium and Carbon core concentration



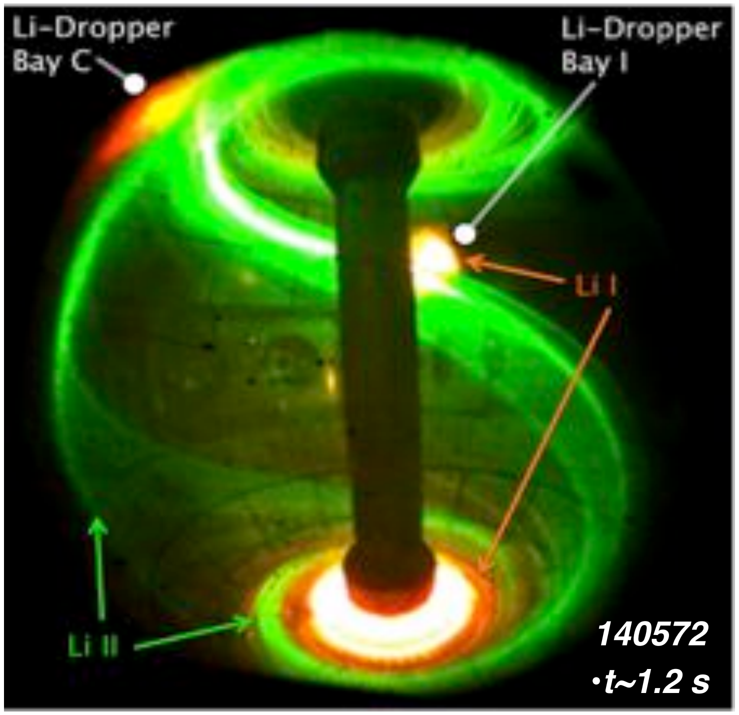
shots: 142488 - 142522

- LLD temperature increased from 90°C to 290°C
  - ‘Passive’ heating from plasma, ~10°C/shot
- No systematic change in lithium/carbon concentrations
  - Slight decrease above 200°C, but fueling also changed
- Cumulative effects of lithium evaporation dominant?
  - > Look for changes with Li introduced *during* shot

'LITER-only' and 'LITER plus Li-Dropper' discharges show different edge features, similar overall parameters

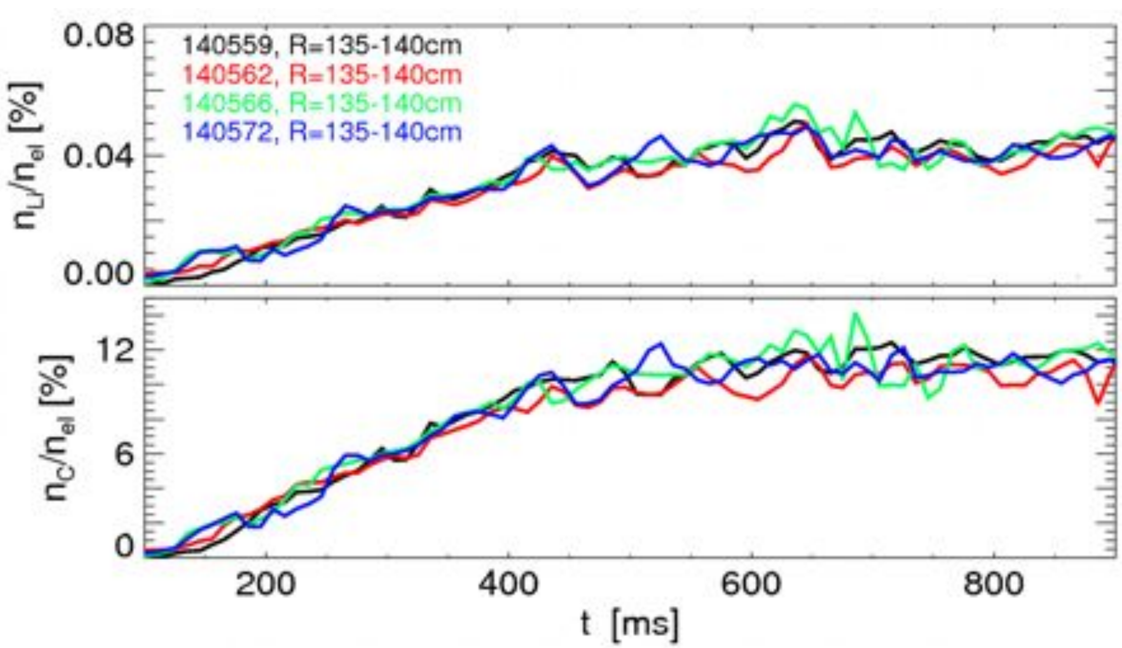


shot no.	*LITER*	*Li-Dropper*
140559	240 mg	—
140562	240 mg	240 mg + 240 mg/s × 1.2 s
140566	240 mg	0 mg + 100 mg/s × 1.1 s
140572	120 mg	240 mg + 120 mg/s × 1.2 s



- Comparable amount of lithium from LITER (pre-shot) and from Li-Dropper (pre/during shot)

Both carbon and lithium concentrations saturate in time; evolution is independent of conditioning technique

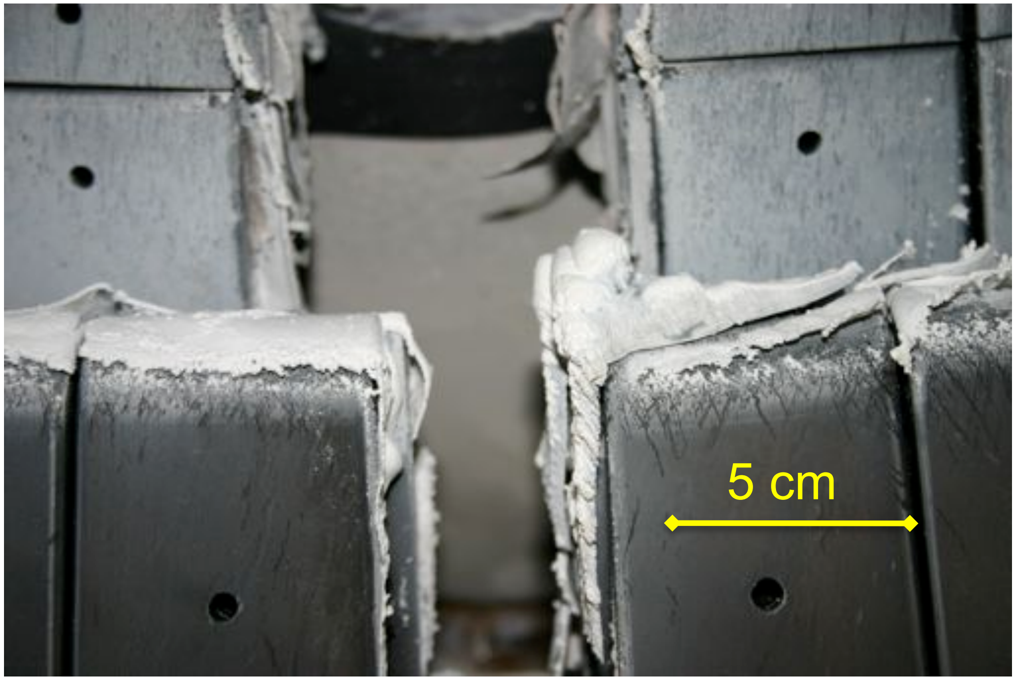


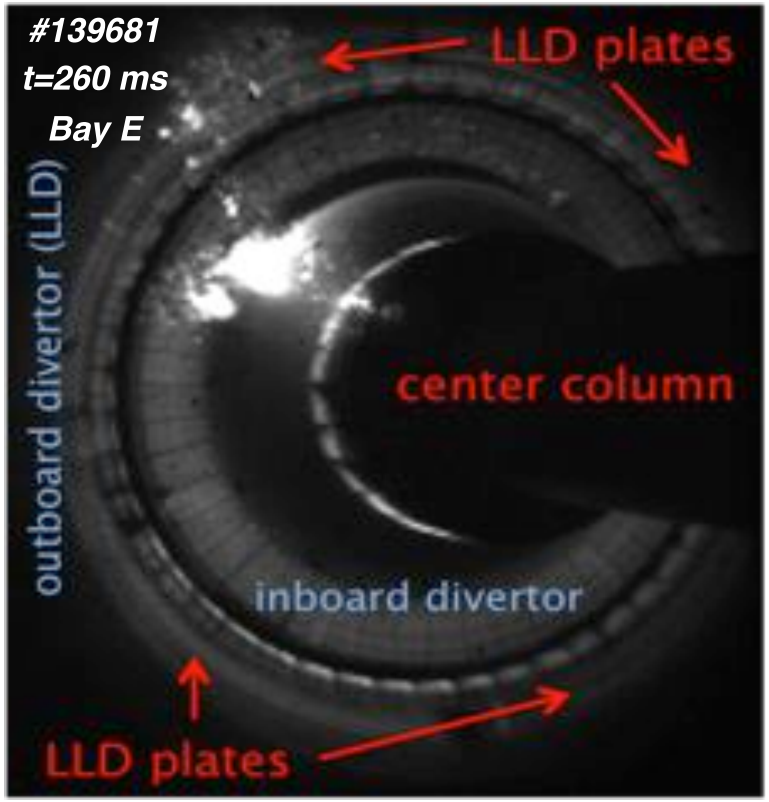
- Very similar discharges
  - Same configuration
  - Same parameters (n_e,T_e)
  - Clean comparison for the two techniques
- Large Carbon content
  - Edge Z_{eff} = 4-5 after 400 ms
- Lithium saturates to n_{Li} / n_e~0.04%

Typical Lithium operating conditions show low lithium core concentration, $n_{Li}/n_e < 0.1\%$

Anomalous Events affecting Li influx

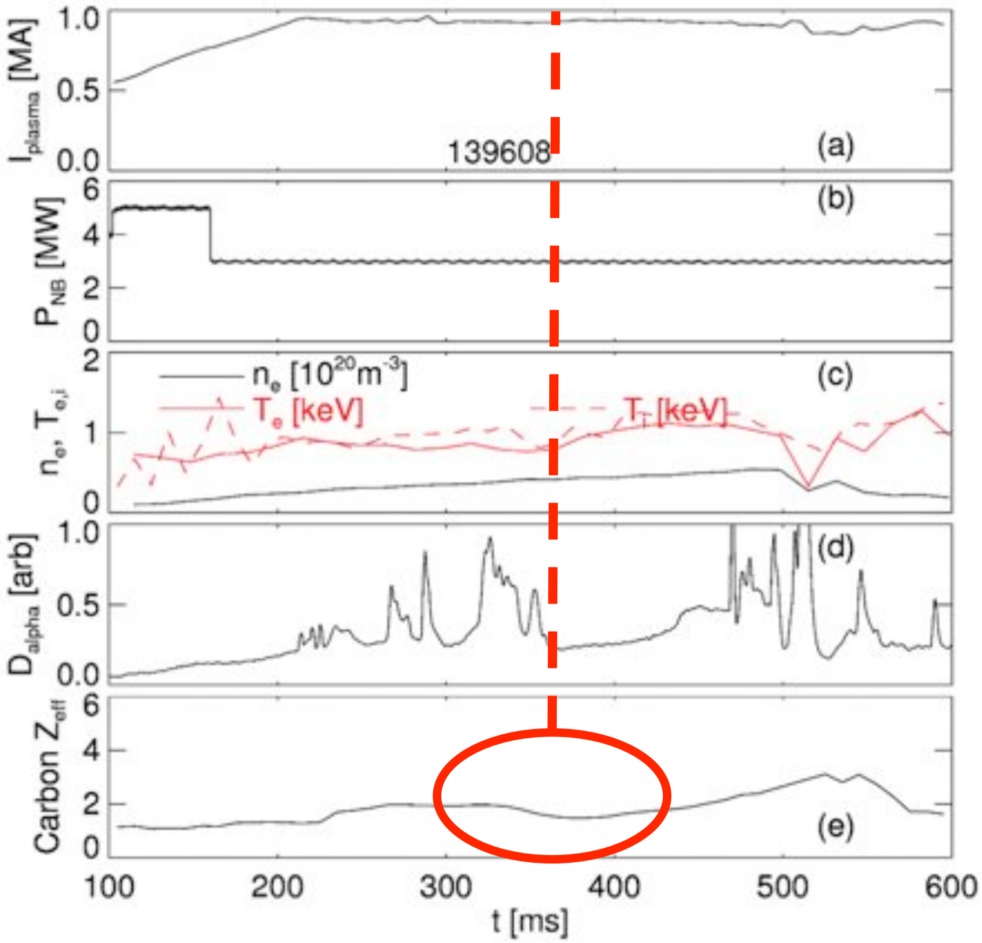
Li "*blob*" on divertor floor interacts with NSTX plasmas

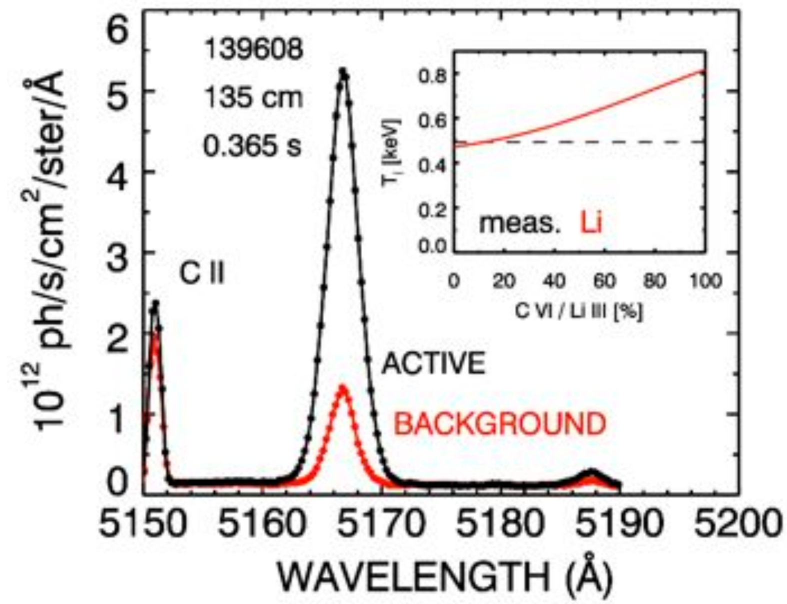


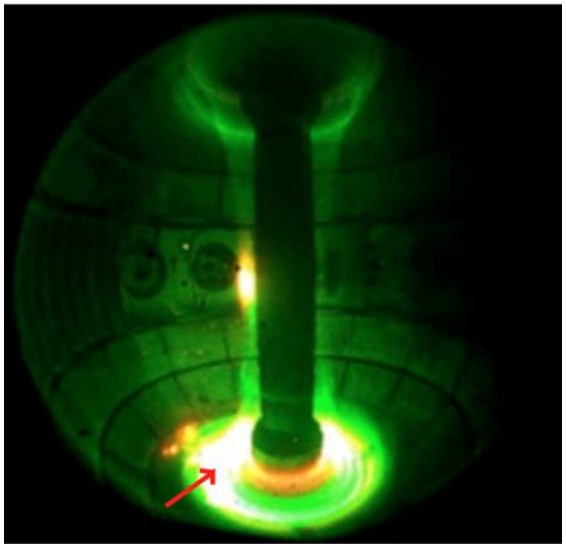


- Source of "blob" probably accumulation of Li mass near evaporator throat
- Plasma transiently and intermittently interacts strongly with Li blob
- Break up of macroscopic Li material when near strike point

Plasma survives after first interaction with Li blob, followed by increase in core Li concentration

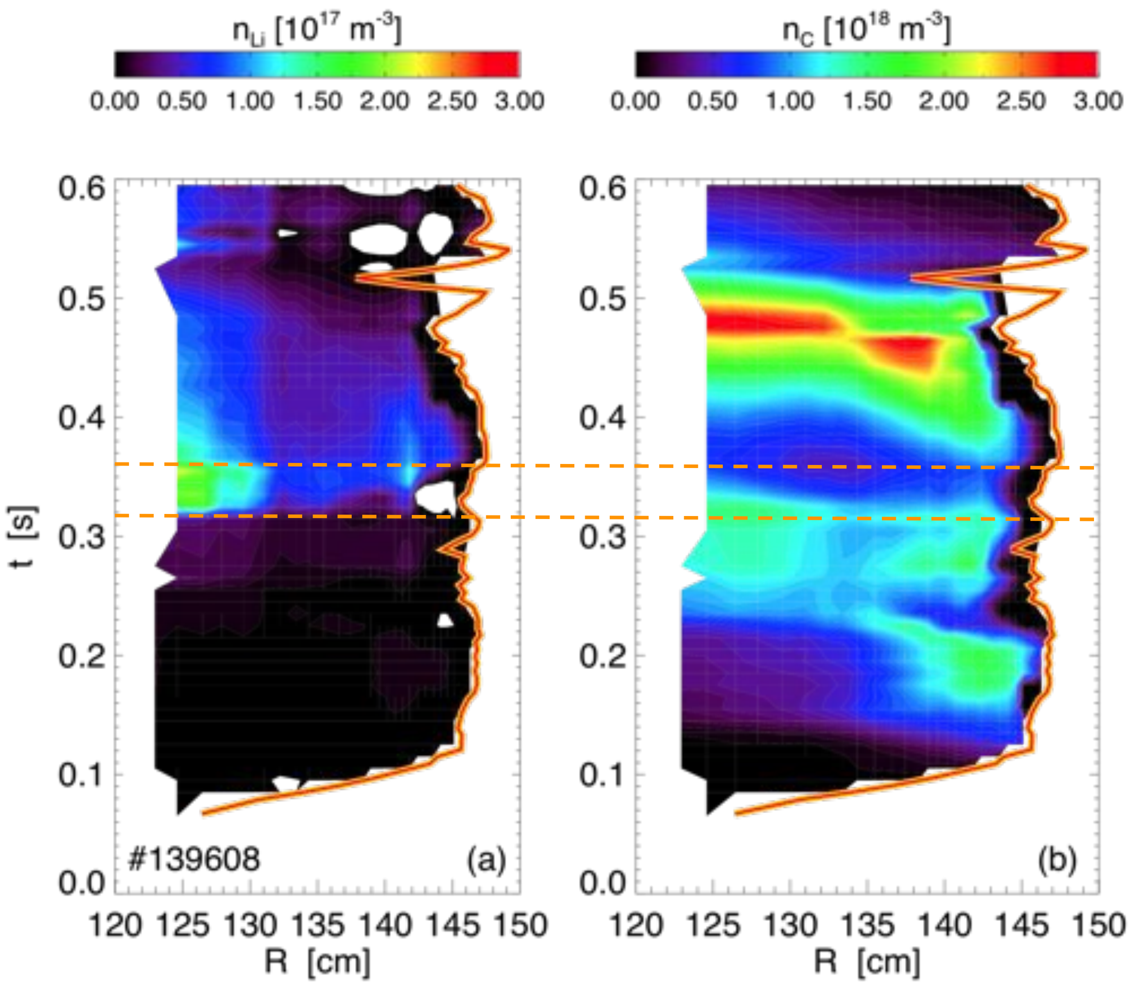






- Li-pCHERS spectrum around 360 ms dominated by Li
- **Carbon decreases, n_C/n_e~1% or less (low for NSTX)**

Lithium “blob” transiently changes impurity content: with n_{Li}/n_e~0.2% and an overall decrease in carbon.



- Large, localized Lithium source can transiently lead to higher n_{Li} in the core (as opposed to evaporated lithium or small granules)
- More similar to ‘pellet’, but completely un-controlled
- Transient decrease in Carbon content coincides with increase in Lithium content

The Lithium content with influx from “blob” higher, but still remains extremely low