NSTX

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Measurements of core lithium concentration on NSTX

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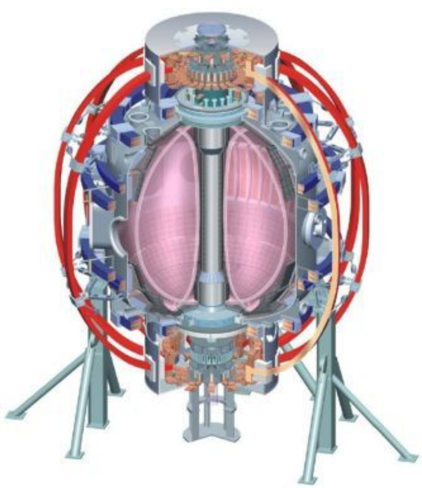
U Wisconsin

NSTX Monday Meeting
10/24/2011



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Core Li concentration in NSTX monitored throughout 2010 Run

- Li measurements on NSTX in 2008 indicate low amount of lithium, <0.1 % of n_e, accumulates in the core
  - Results inferred from a single operating condition [M. Bell *et al.*, PPCF 2009]

- About 1.3 kg of lithium evaporated during 2010 Run
  - Different techniques deployed: LITER, Li-Dropper
  - LLD plates also installed in 2010

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- About 1.3 kg of lithium evaporated during 2010 Run
  - Different techniques deployed: LITER, Li-Dropper
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- Li core measurements implemented in 2010
  - > How does lithium behave under different conditions?
  - > Does it accumulate in the core?
    - Bad, because leads to higher Z_{eff}
    - Good, if it replaces Carbon with similar concentration:

$$Z_{eff} = \frac{\sum_i n_i Z_i^2}{n_e} \Longrightarrow$$

1% of C : ΔZ_{eff}=0.3
1% of Li : ΔZ_{eff}=0.06

Outline

- Analysis of CHERS lithium measurements
- Results for NB-heated, H-mode discharges
  - Reference case and scan of operating parameters
    - Toroidal field, plasma current, aspect ratio
  - Dependence on edge conditions, Li-conditioning techniques
    - LITER, Li-Dropper, LLD
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- ***Previous results confirmed***
  - ***Core lithium concentration is negligibly small, <<0.1%, ΔZ_{eff}=0.006***
- ***Actual n_{Li}/n_e is 2-4 times lower than what previously reported***

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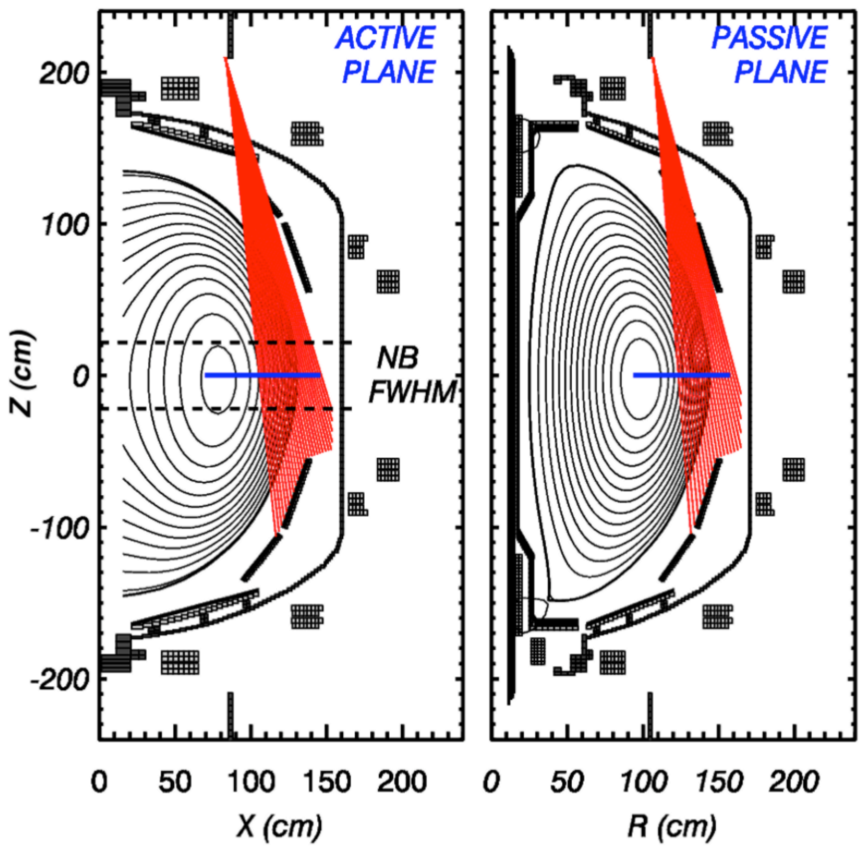
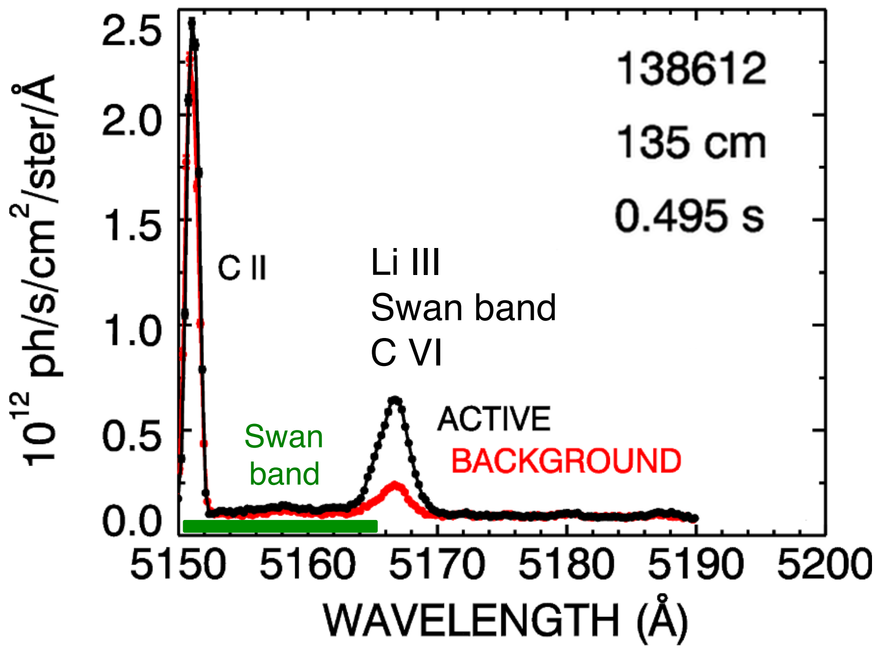
Suite of CHERS diagnostics allowed simultaneous measurements of C, Li on outer midplane in 2010



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

- Active/passive paired views to remove background
- Monitor Li III line (n=7-5) at 516.7 nm
- Data from mid-radius (R~120 cm) out at $f_{sampling}$=100 Hz

Signal is low, but peaks are clearly visible; other C lines pollute the Li III spectrum: *what are we measuring?*



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

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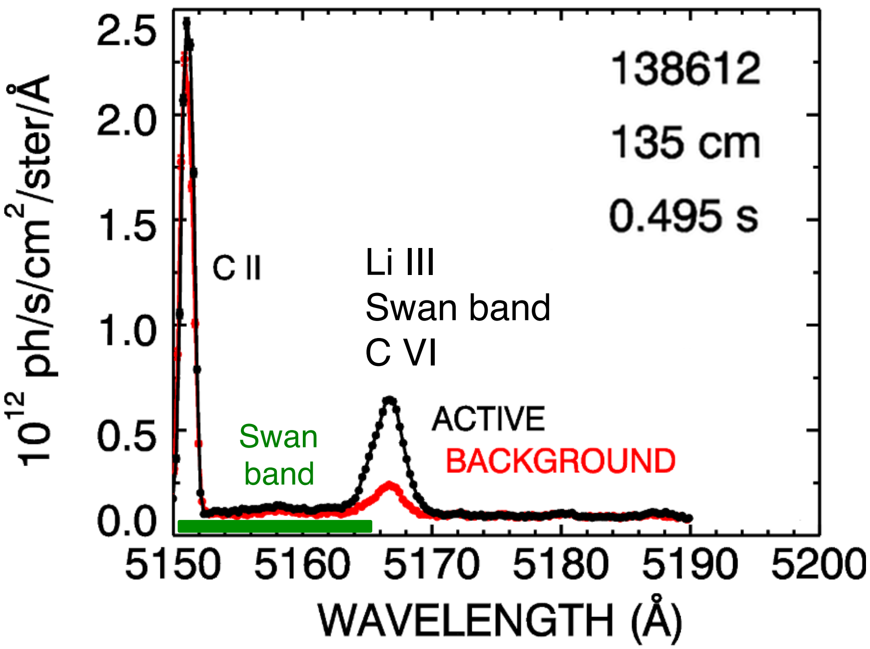

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- Molecular C_2 band (*Swan band*) partly overlaps Li III
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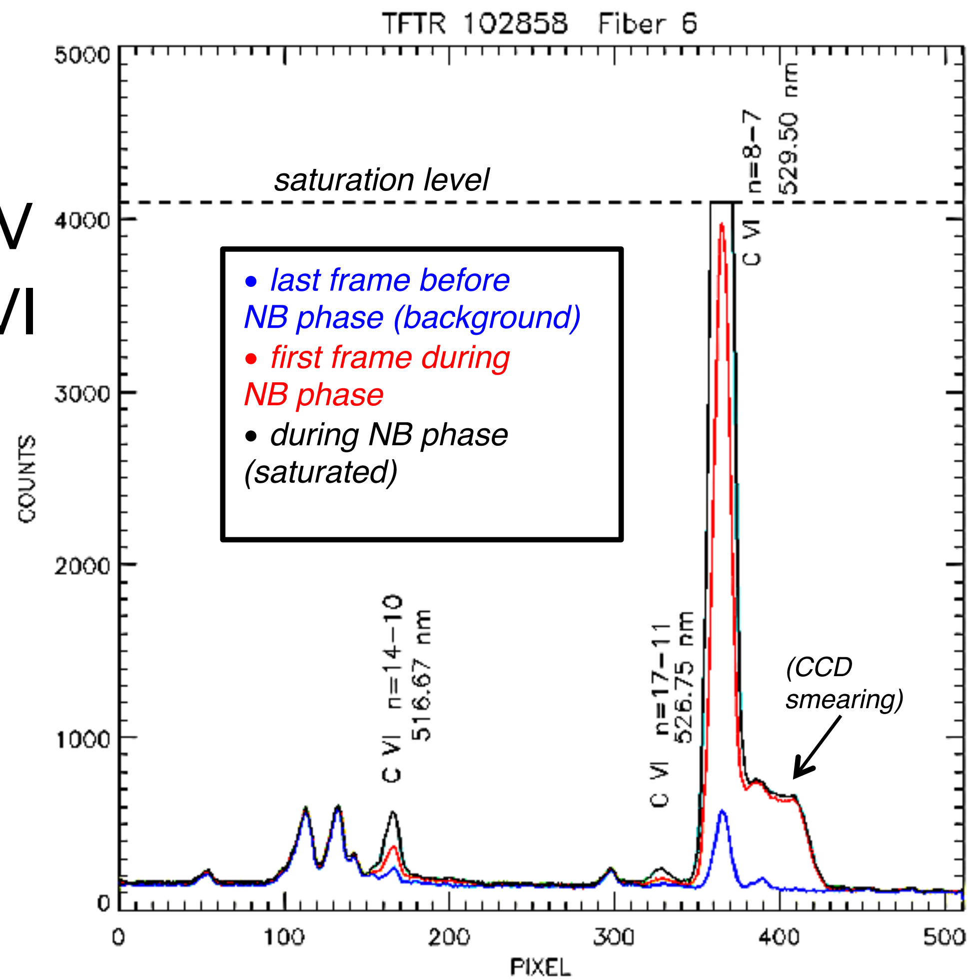
- No lithium-free discharges available to estimate relative brightness of C VI and Li III … on NSTX
  - > But, "*back in the good, old days*"...

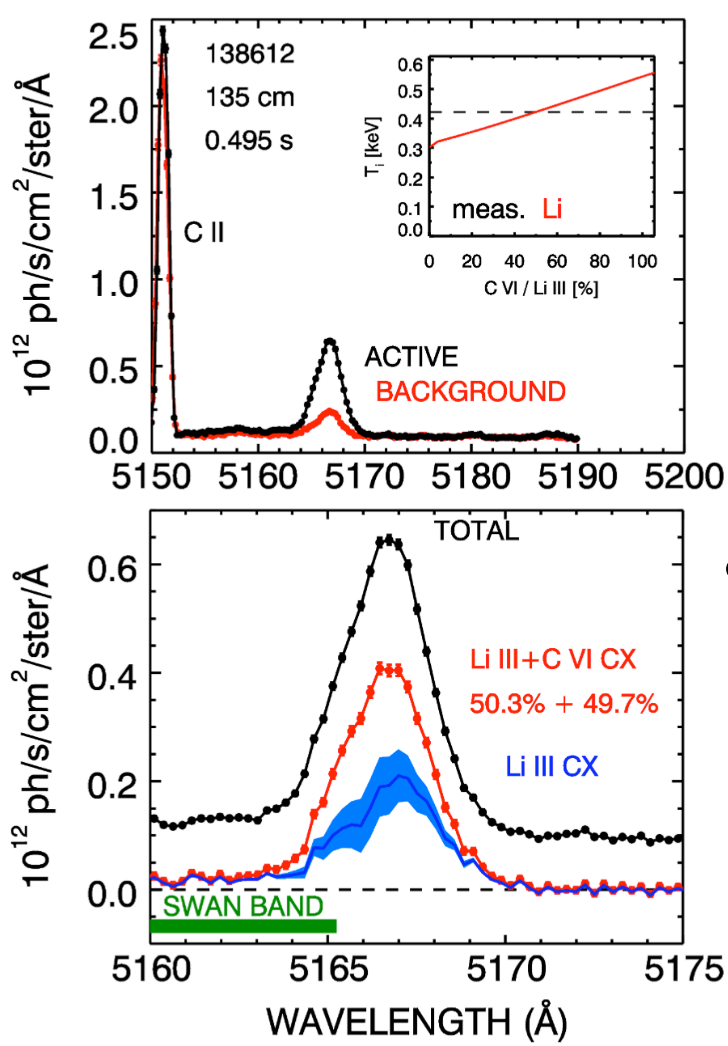
TFTR data indicate that C VI (n=14–10) to C VI (n=8–7) ratio is ~3.6 %; how does it scale to NSTX?

- Data taken during pCHERS commissioning
- n_e~1.2 x 10^{19}m^{-3}, T_e~ 3 keV
- Measured brightness of C VI
  - n=8–7 @ 529.5 nm
  - n=14–10 @ 516.7 nm
- *Ratio B_{8-7}/B_{14-10} is 28:1*
- Provides an estimate for expected C VI (n=14–10) brightness on NSTX
  - Collisional–radiative model shows no big variations between these TFTR parameters and NSTX parameters



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

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 $T_i^{Li}=T_i^{C}$*

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

Given all uncertainties in the analysis, results actually represent an *upper limit* for n_{Li}

- Full analysis also includes
  - NB attenuation
  - Reference to main CHERS, re-scale to local values
  - (Compensate for randomly closing lenses, et al. ...)

- 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**

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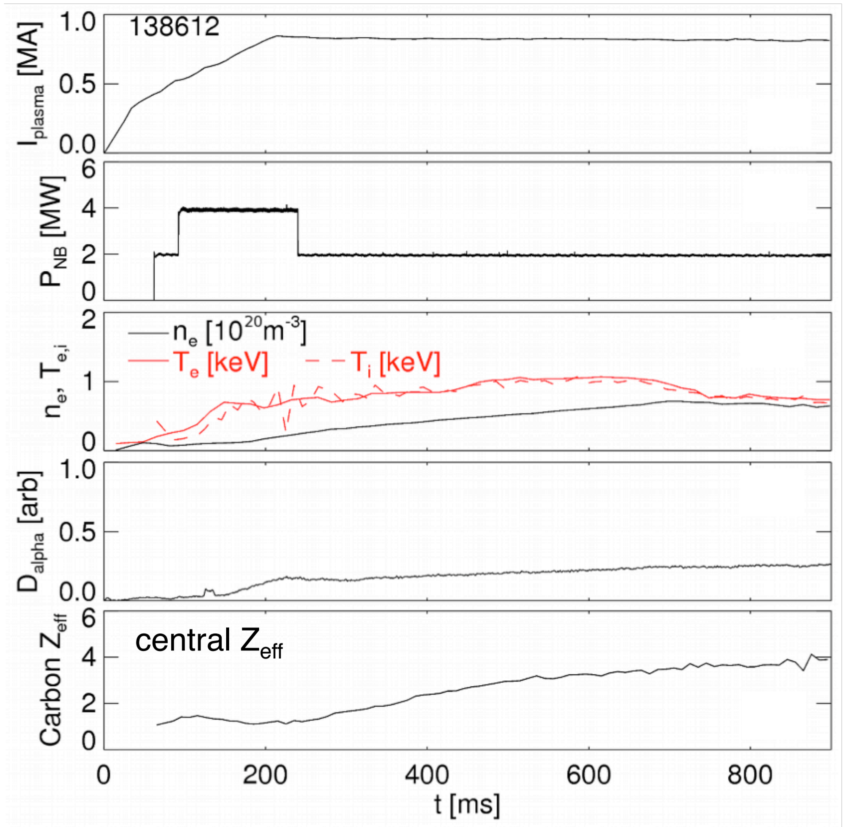
Typical H-mode, moderate NB power discharge shows only trace amounts of lithium in the core



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

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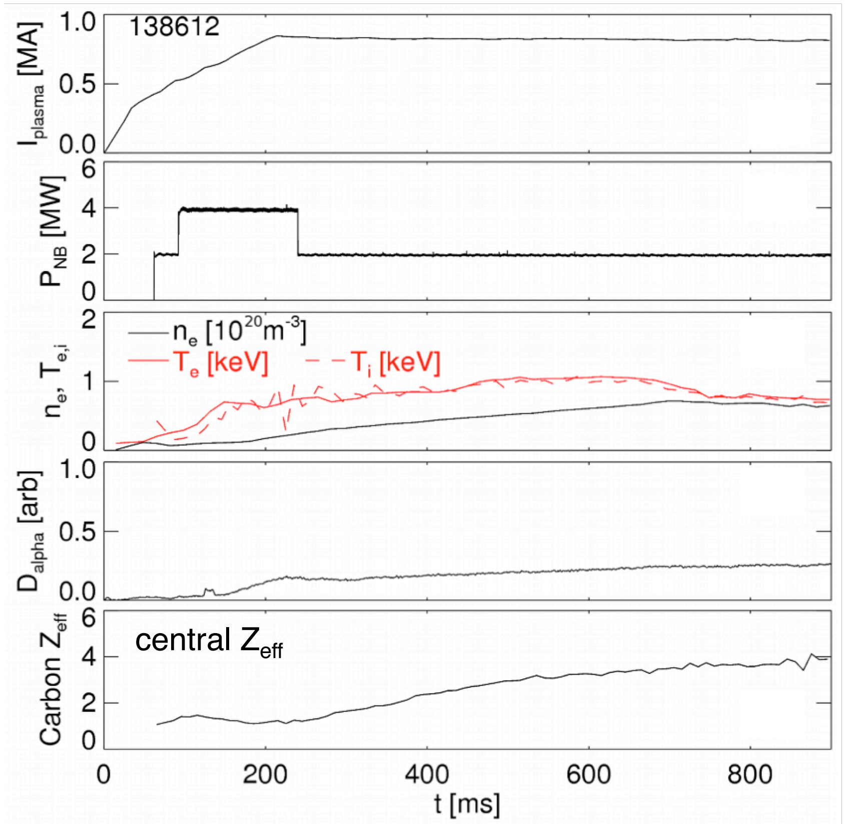

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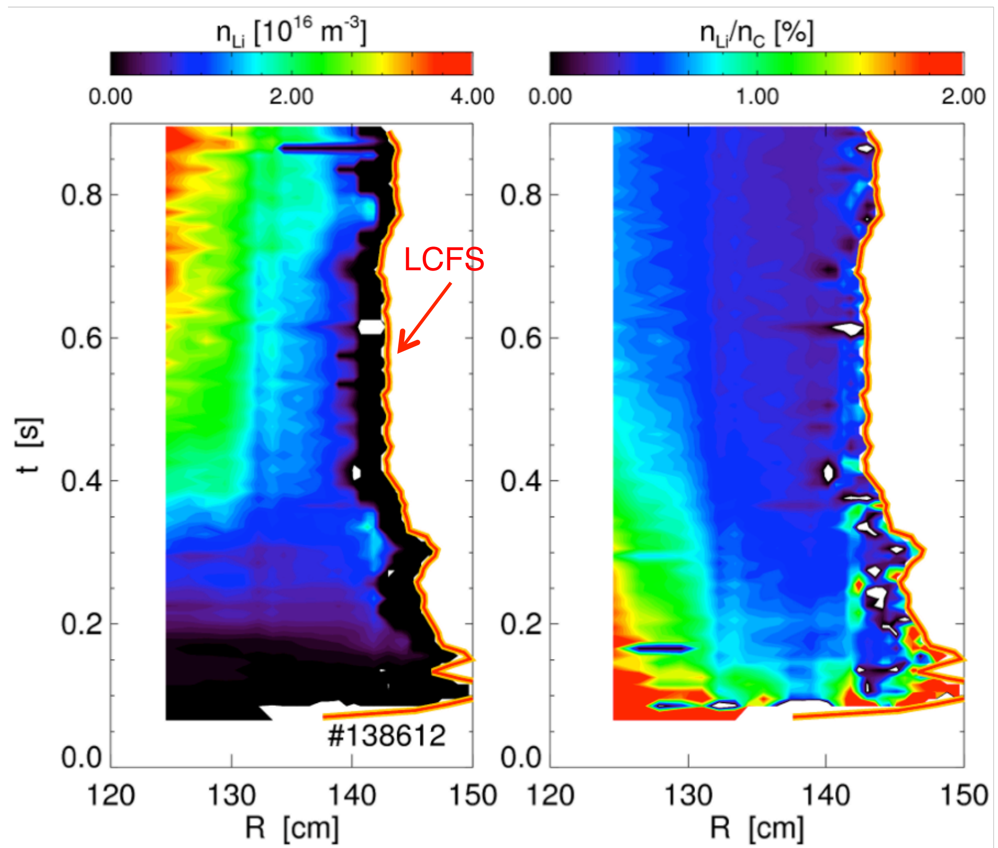
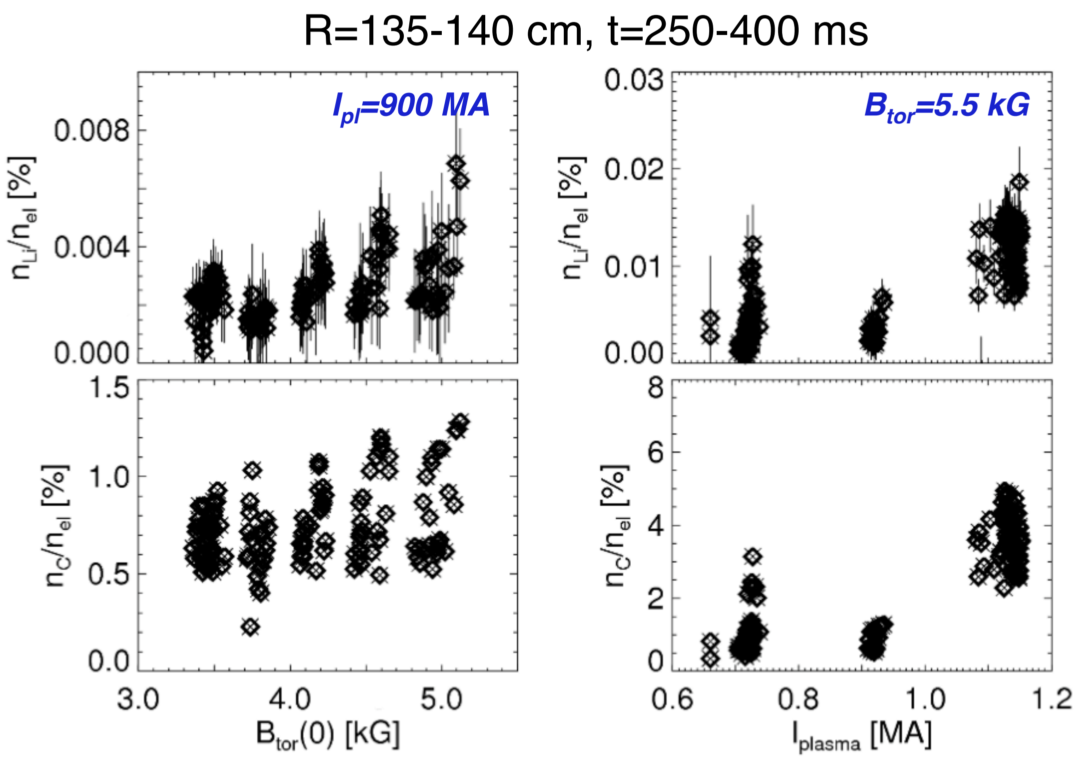


- Lithium density increases in time, but remains low
  - **Max 2% of carbon density**
  - **<<0.1% of electron density**

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

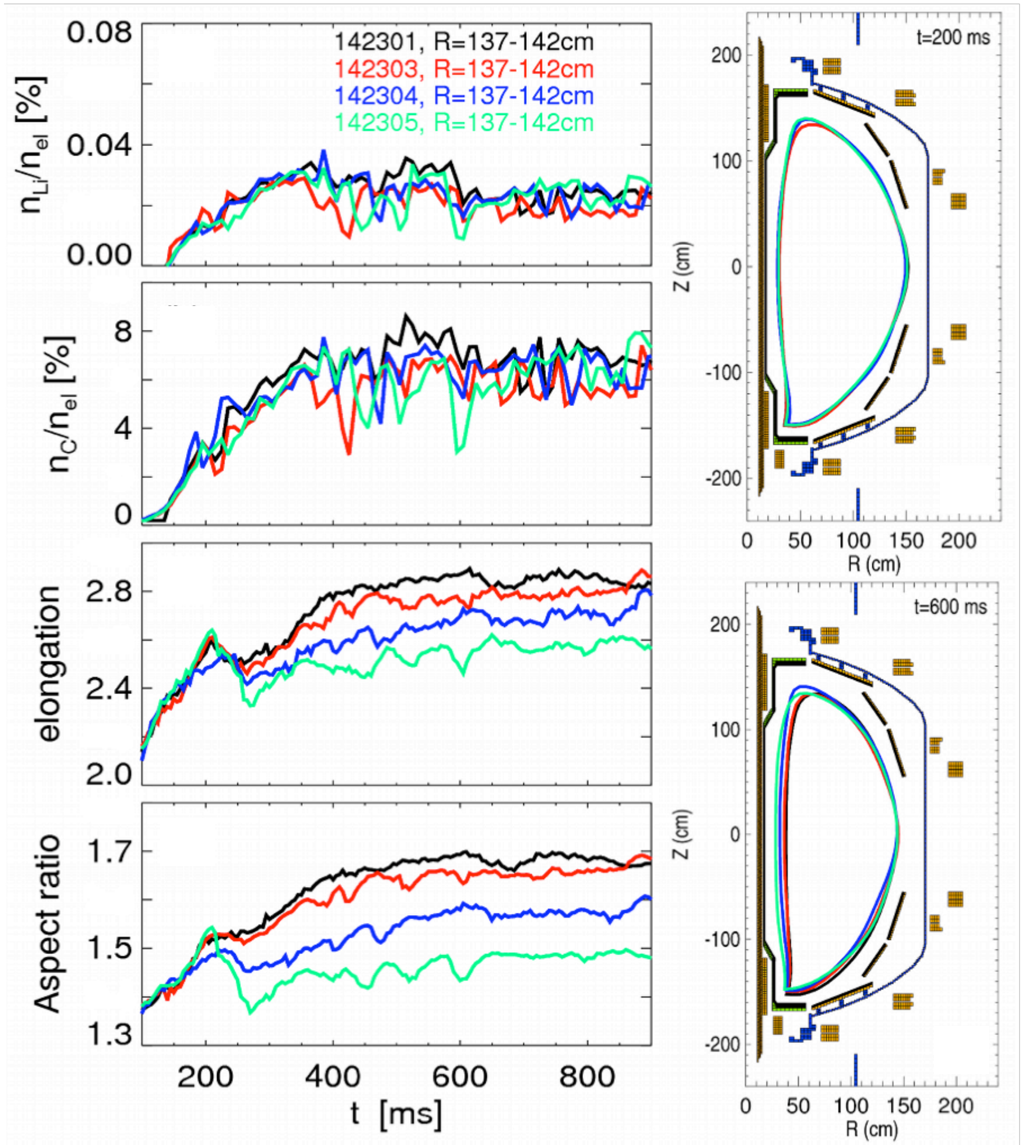


- Expect better confinement for higher B_{tor}, I_{pl}
- Linear fit* for Li gives:
  n_{Li}/n_e [%] ~ 6×10^{-4} B_{tor} [kG]
  n_{Li}/n_e [%] ~ 7.4×10^{-3} I_{pl} [MA]
- To be compared with
  n_C/n_e [%] ~ 1.8×10^{-1} B_{tor} [kG]
  n_C/n_e [%] ~ 2.27 I_{pl} [MA]

*assume fit goes through origin

Plasma current has larger effect.
Lithium remains insignificant.

Aspect ratio (-> *inner gap*) scan shows no effect on average Lithium – and Carbon – concentrations



- *Are lithium/carbon sputtered in from the CS?*
- Four discharges analyzed
  - All start the same way
  - Inner gap (aspect ratio) increased after ~200 ms
  - Other parameters change at the same time
    - Elongation, bottom gap, ...
- No variation of n_{Li} observed between shots
  - Slight decrease of n_{Li} in time
  - Carbon seems to saturate

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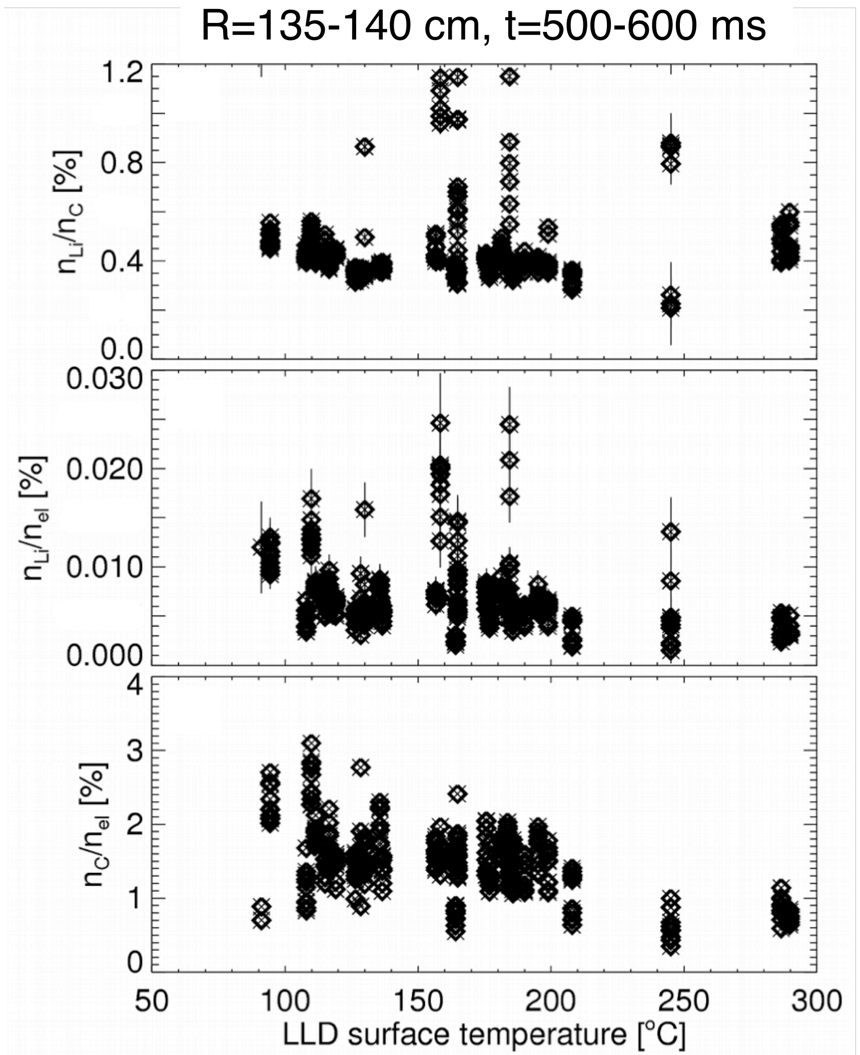
Look for variations in edge conditions in a well-controlled experiment: LLD temperature scan

- LLD temperature increased from 90^{o}C to 290^{o}C
  - 'Passive' heating from plasma, ~10^{o}C/shot

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

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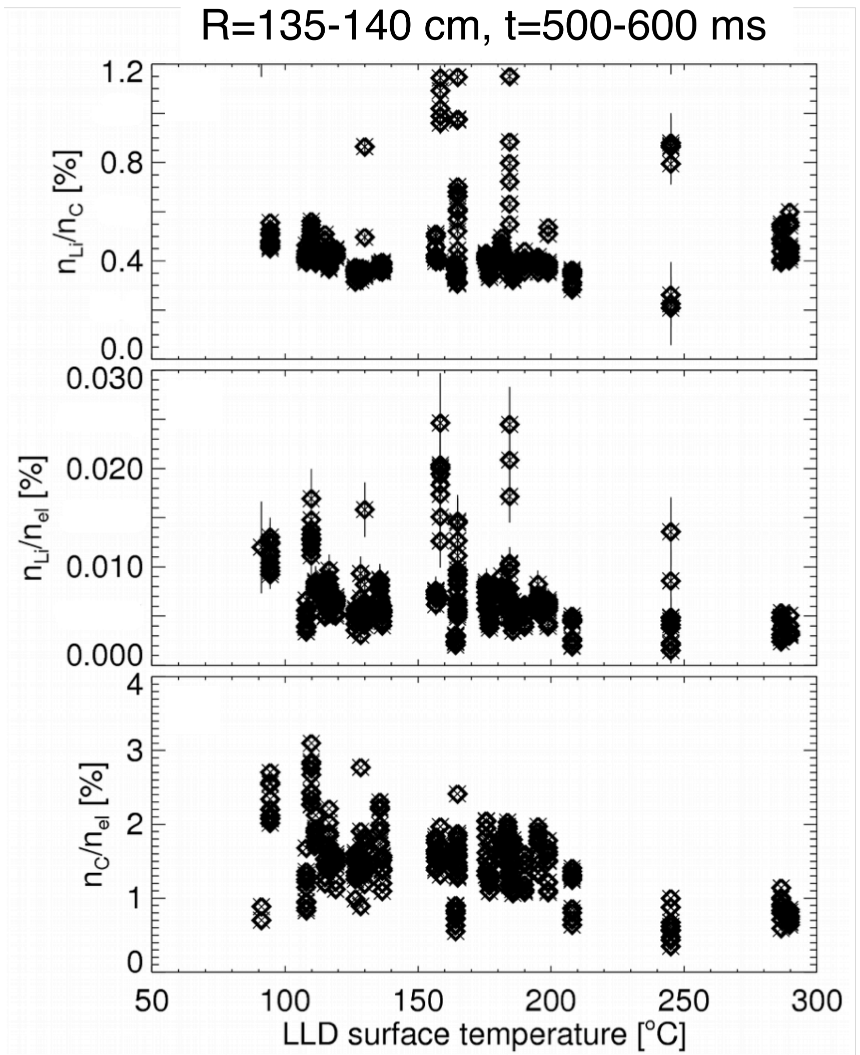

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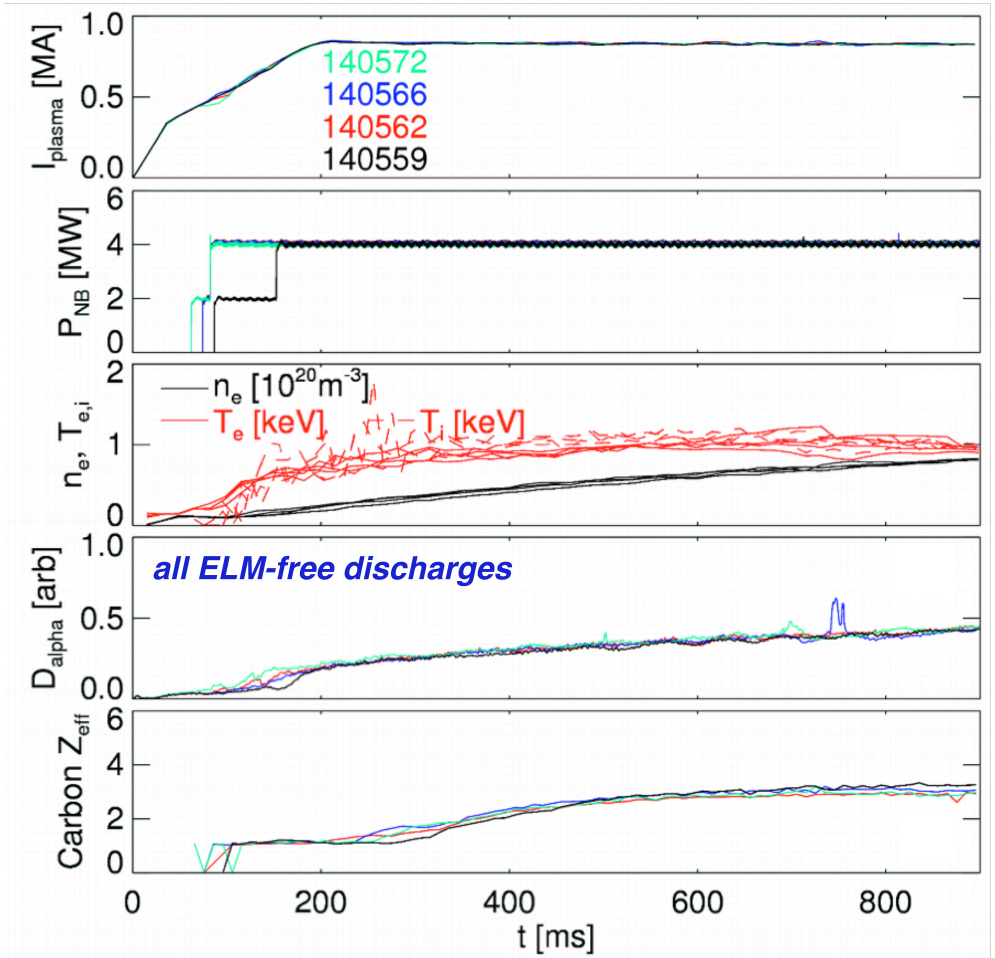
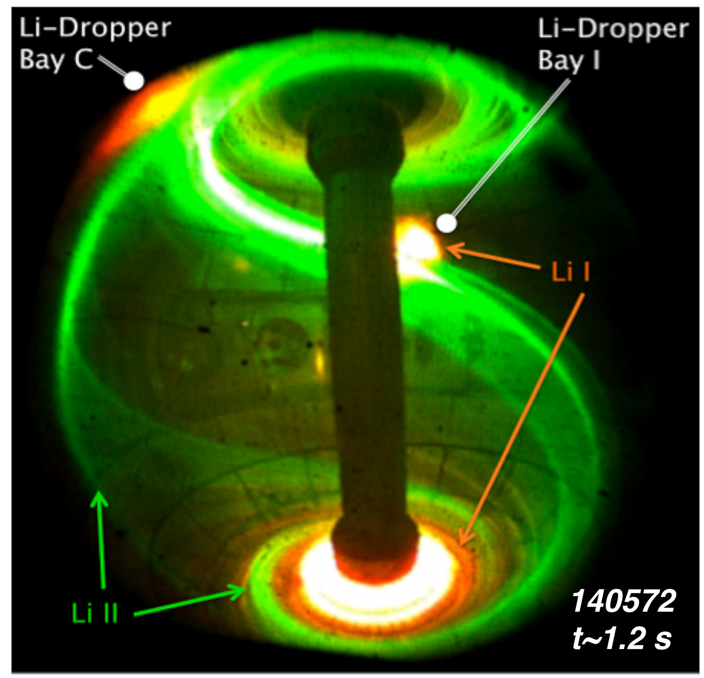
- No systematic change in lithium/carbon concentrations
  - Slight decrease above 200°C, but fueling also changed
- Cumulative effects of lithium evaporation dominant?
  - > Look for changes with Li introduced *during* shot

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

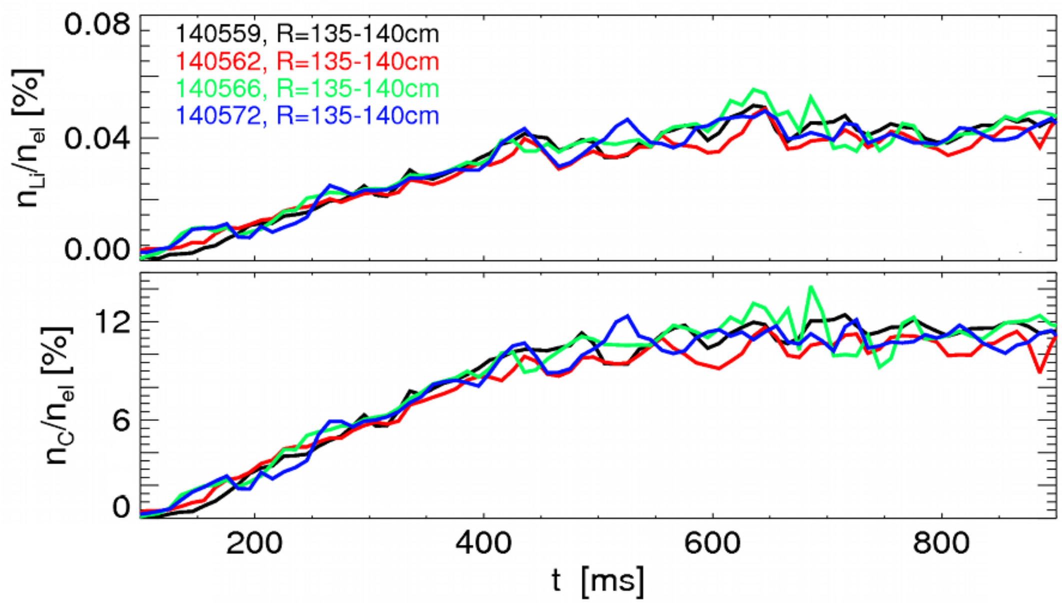


shot no.	*LITER*	*Li-Dropper*
140559	240 mg	—
140562	240 mg	240 mg + 240 mg/s × 1.2 s
140566	240 mg	0 mg + 100 mg/s × 1.1 s
140572	120 mg	240 mg + 120 mg/s × 1.2 s



- 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%

Is there any condition for which lithium core concentration is n_{Li}/n_e>0.1% ?

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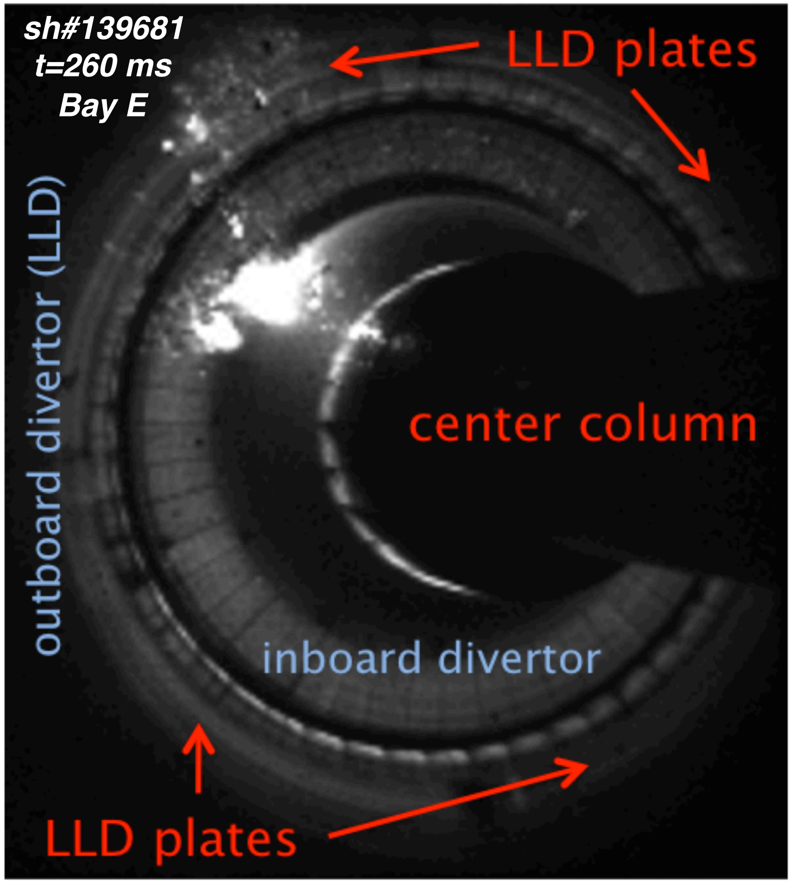
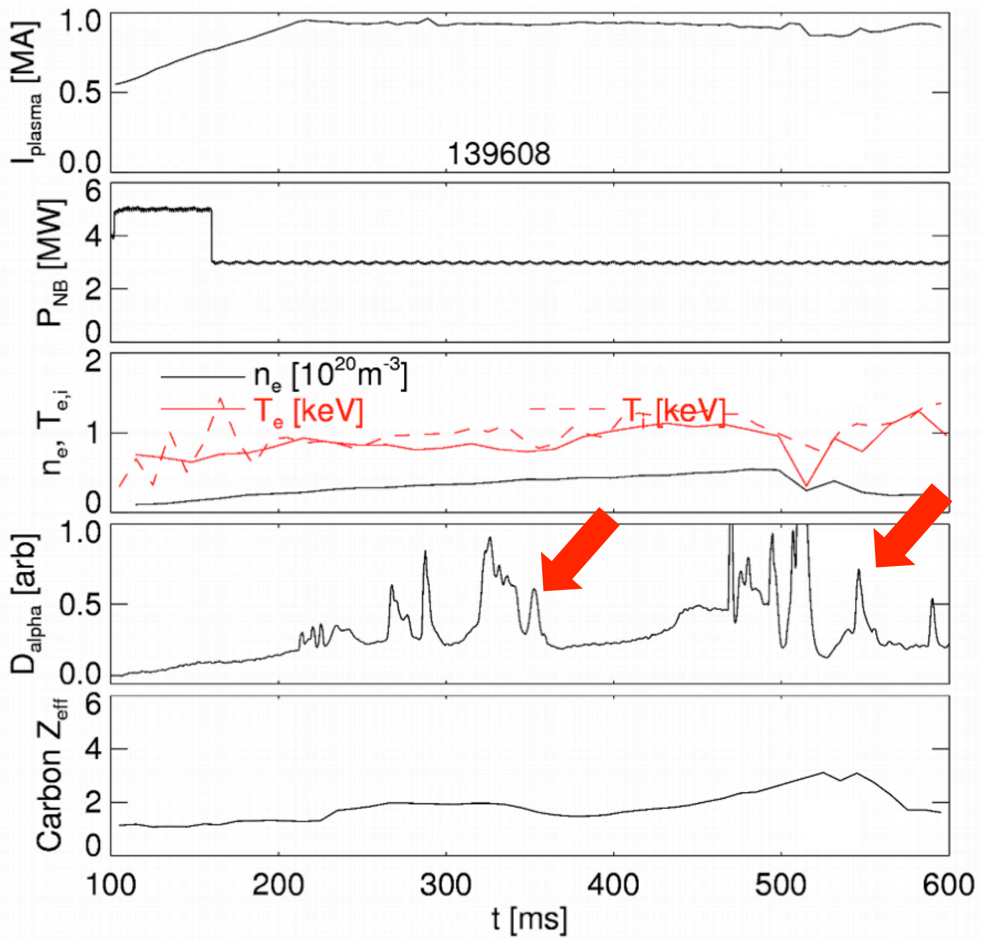
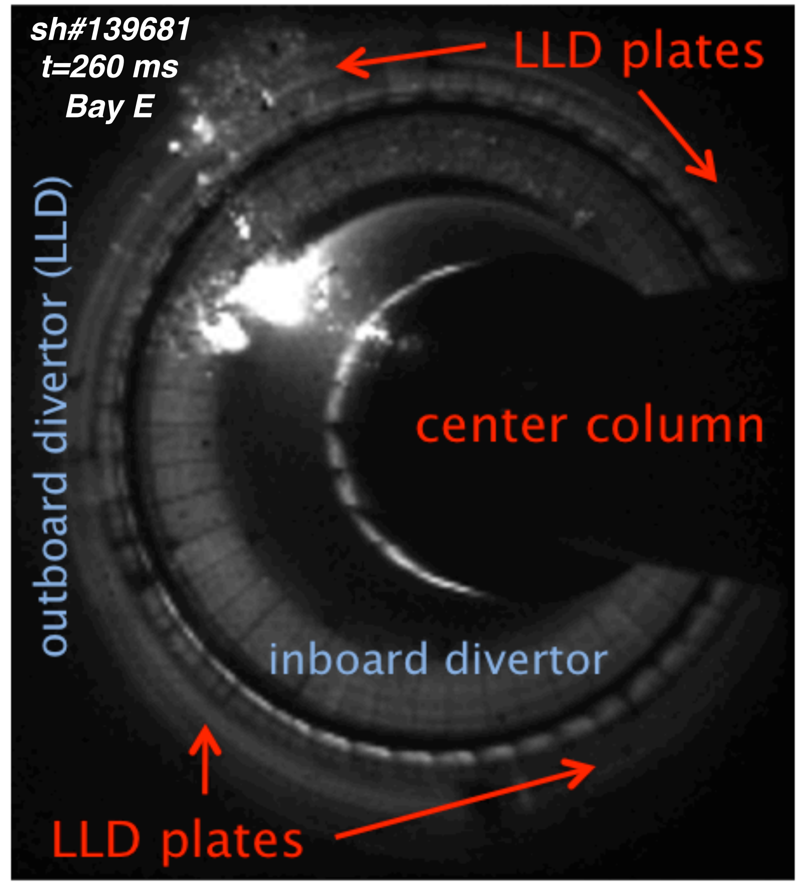
Discharges with Li *blob* on the lower divertor may provide large Li source, boost core n_{Li} up



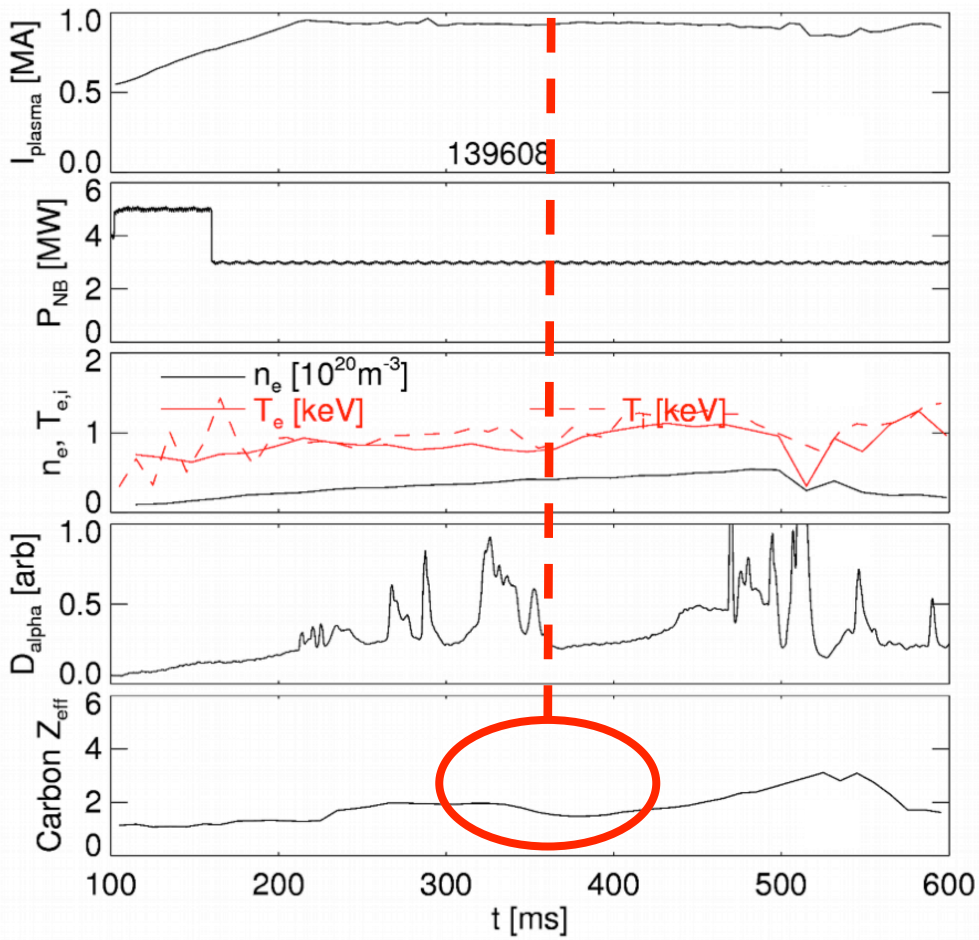
Interaction with Li *blob* clear from D-alpha

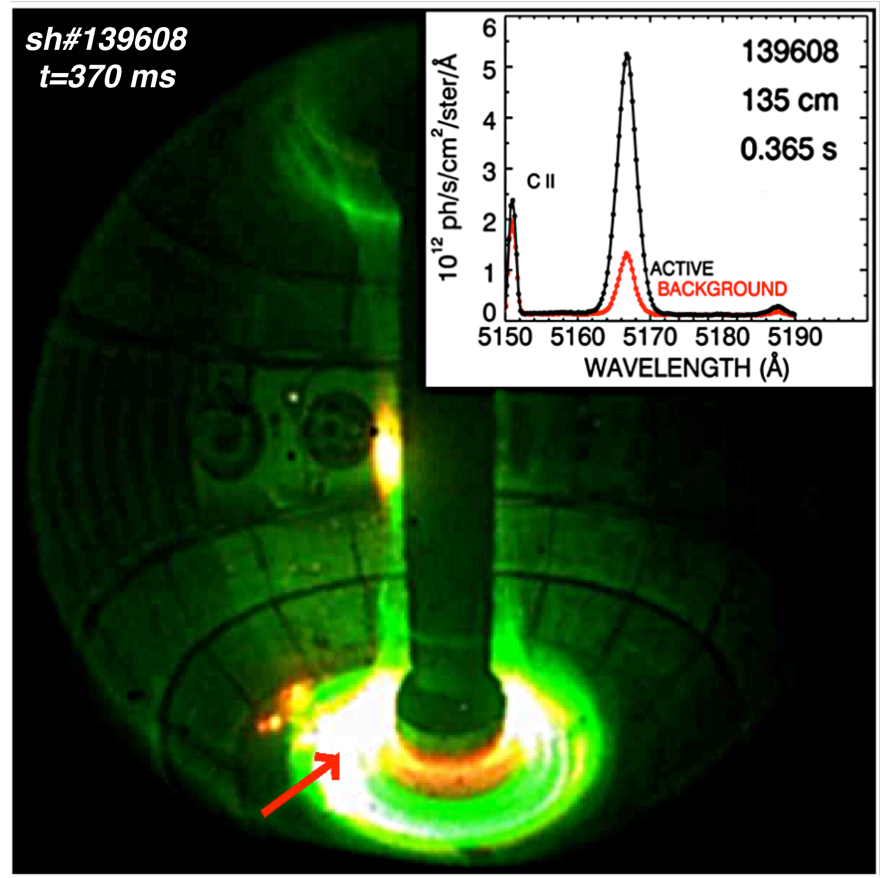




- Plasma interacts strongly with Li blob (e.g. 360, 550 ms)
- Eventually, plasma disrupts

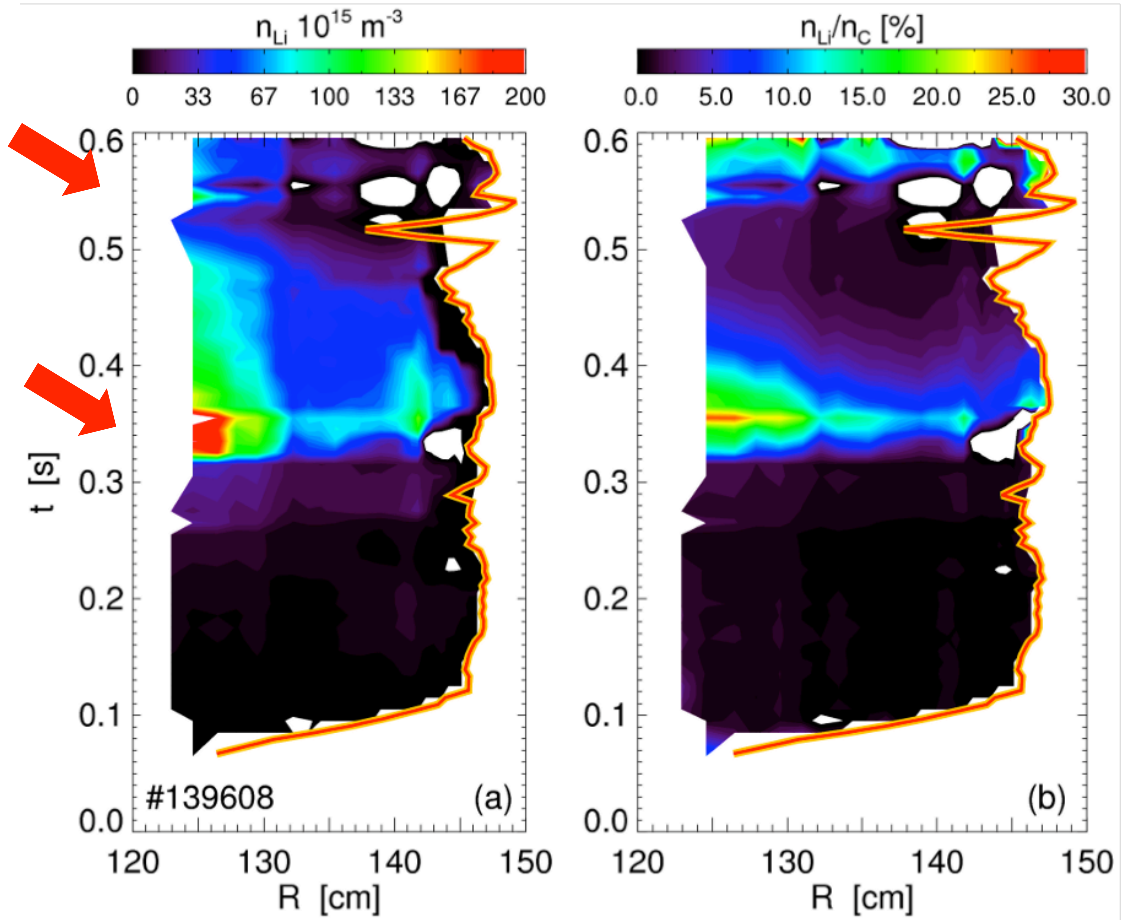
Plasma survives after first interaction with Li blob, followed by increase in core Li concentration





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

Record n_{Li}/n_C~25% attained here, with n_{Li}/n_e~0.2% and an overall decrease in carbon.



- Large, localized Li 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

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- Core Li concentration monitored throughout 2010 Run
- Broad range of operating conditions covered
  - B_{tor}, I_{pl}, aspect ratio/inner gap
  - Different Li conditioning techniques
  - Anomalous events, e.g. Li blobs on divertor
  - (Plasma shape, ELMs, large MHD modes – not shown here)

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> Plasma configuration has little effect on n_{Li}

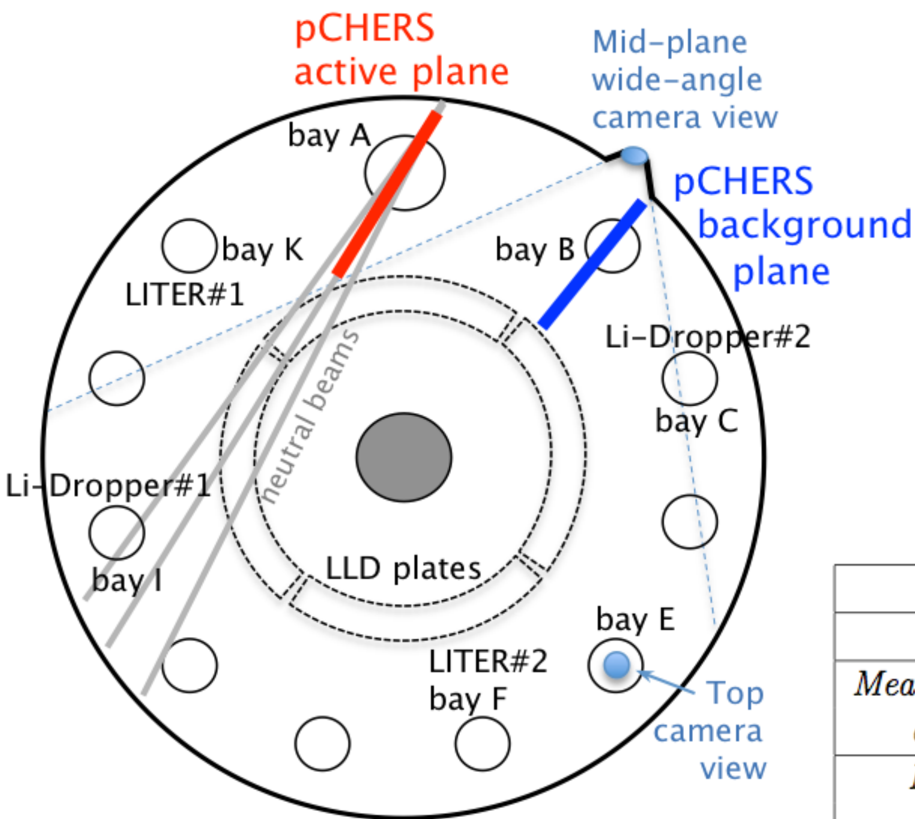
> Only systematic dependence observed is on B_{tor}, I_{pl}
  - Attributed to general improvement in confinement

> 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

- Investigation of C (and Li) sources and transport in progress (F. Scotti's PhD thesis)
- High C concentration represents a barrier for Li influx?
  - Li transported outward by scattering on heavier C ions

Backup viewgraphs

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



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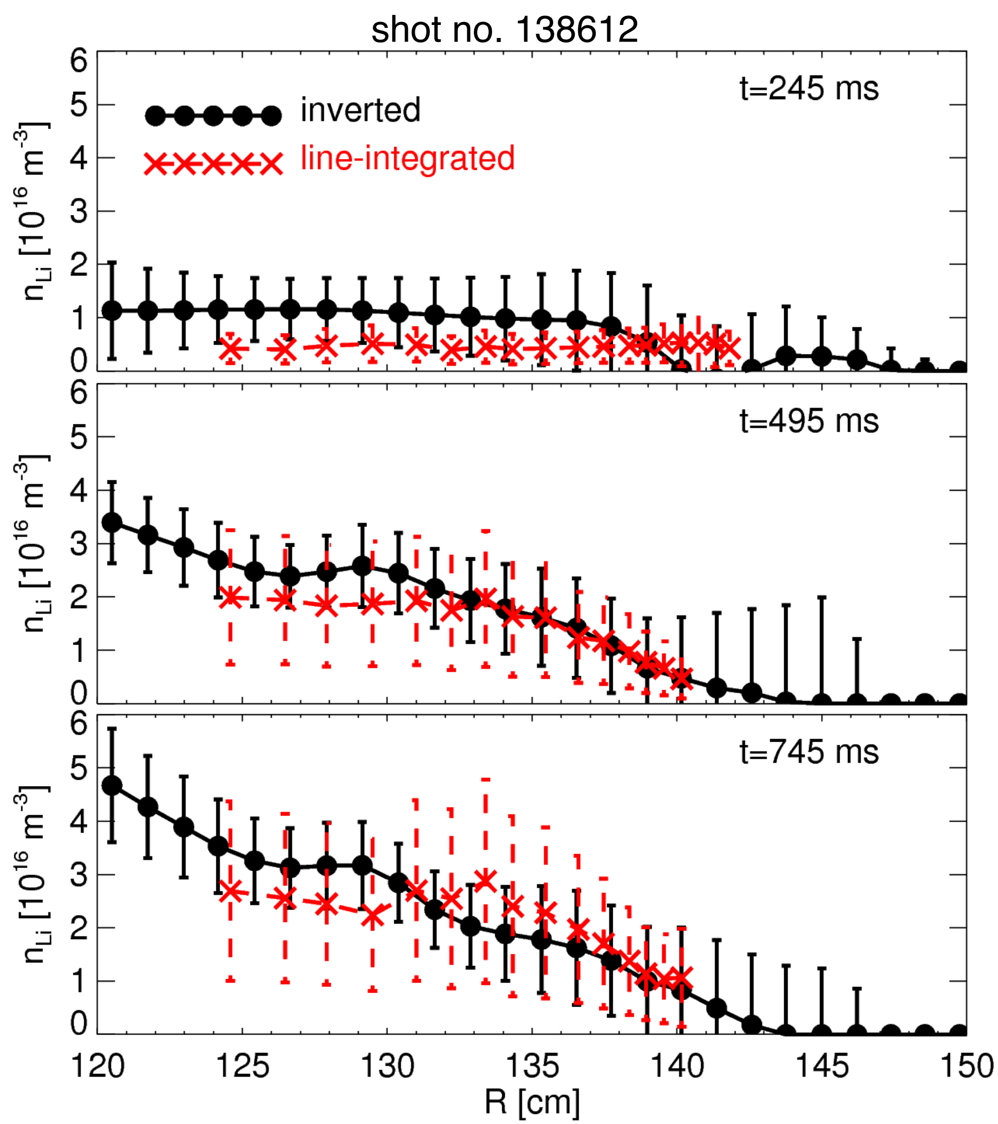
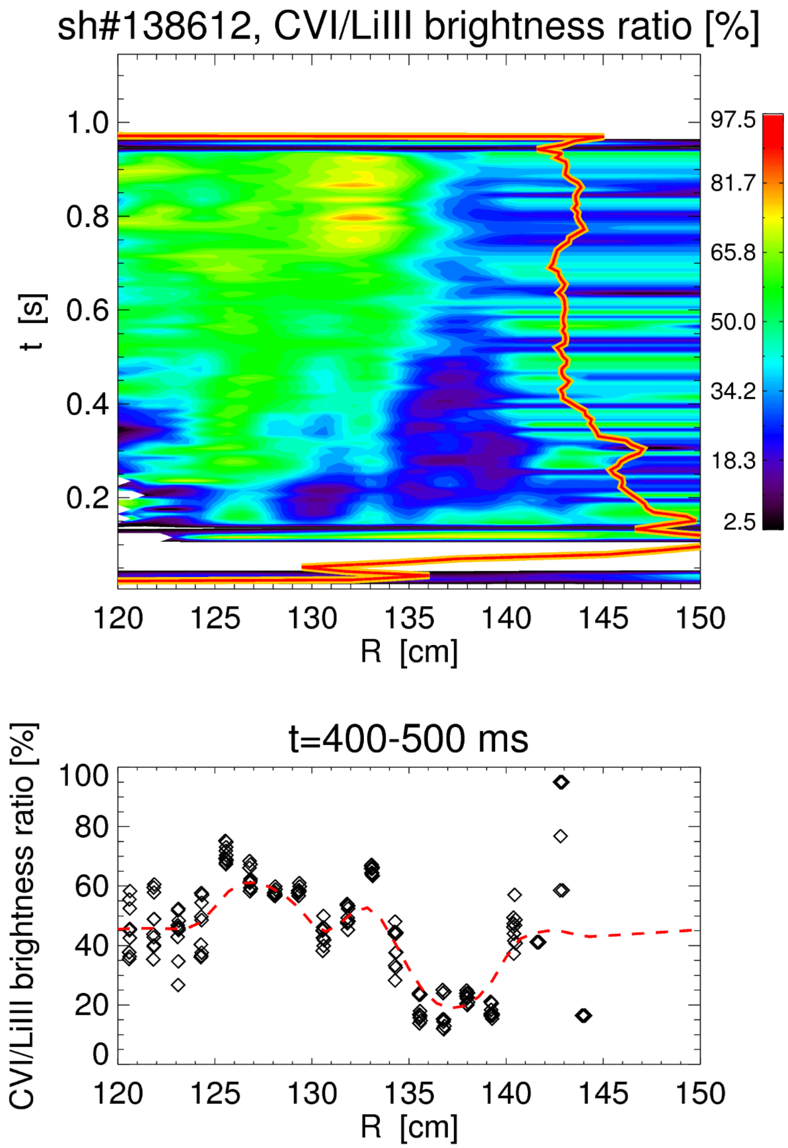
Line-integrated data are representative of average trend, upper limits of core lithium concentration



- Assume all measured brightness is from Li III
- Reasonable agreement in profile shape, time evolution

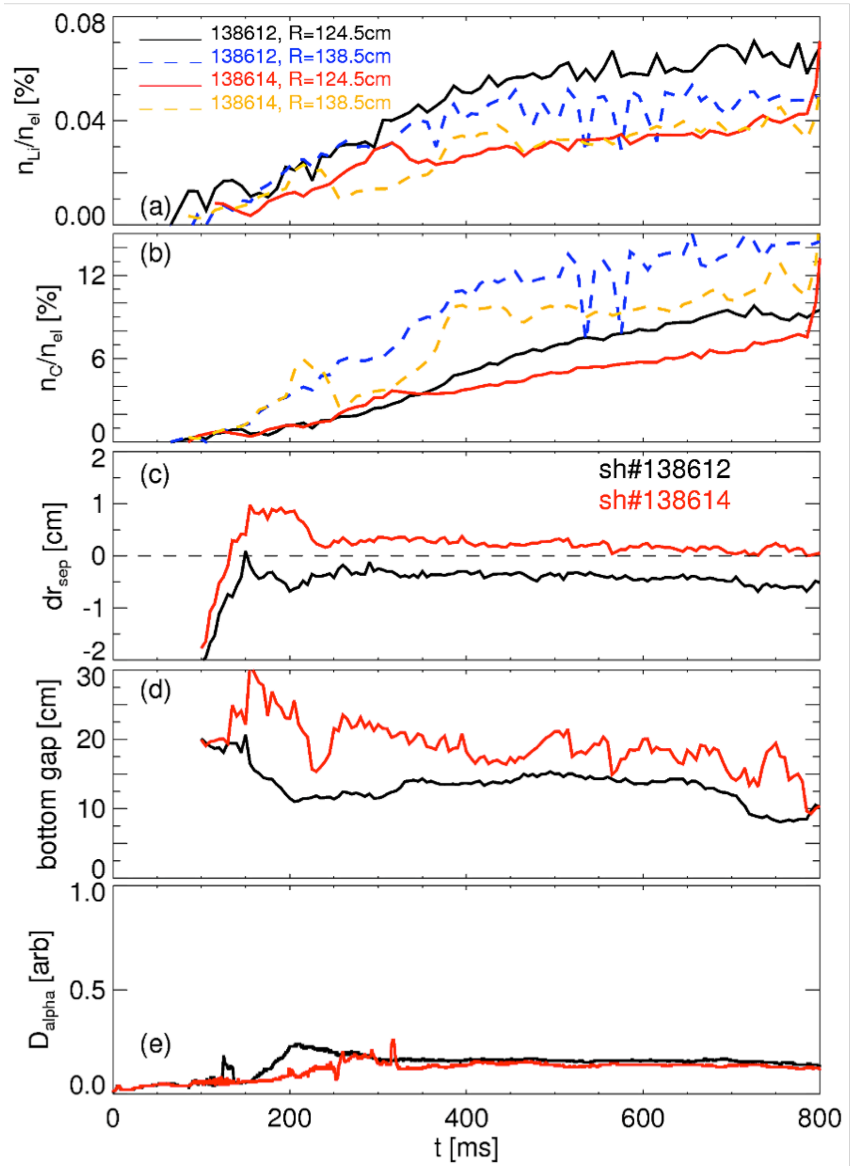
Uncertainties in C VI/Li III brightness fraction and cross sections make full inversion difficult



Shown is (smoothed) C VI to Li III brightness fraction

- Large spread in values as a function of radius, time
- Inversion must take into account line blending, profile of each species
- Many cross sections for C VI (n=14–10) missing
- Cross sections at low (E<40 keV) NB energy inaccurate

Shifting plasma far from divertor in ELM-free discharges appears to reduce impurity accumulation



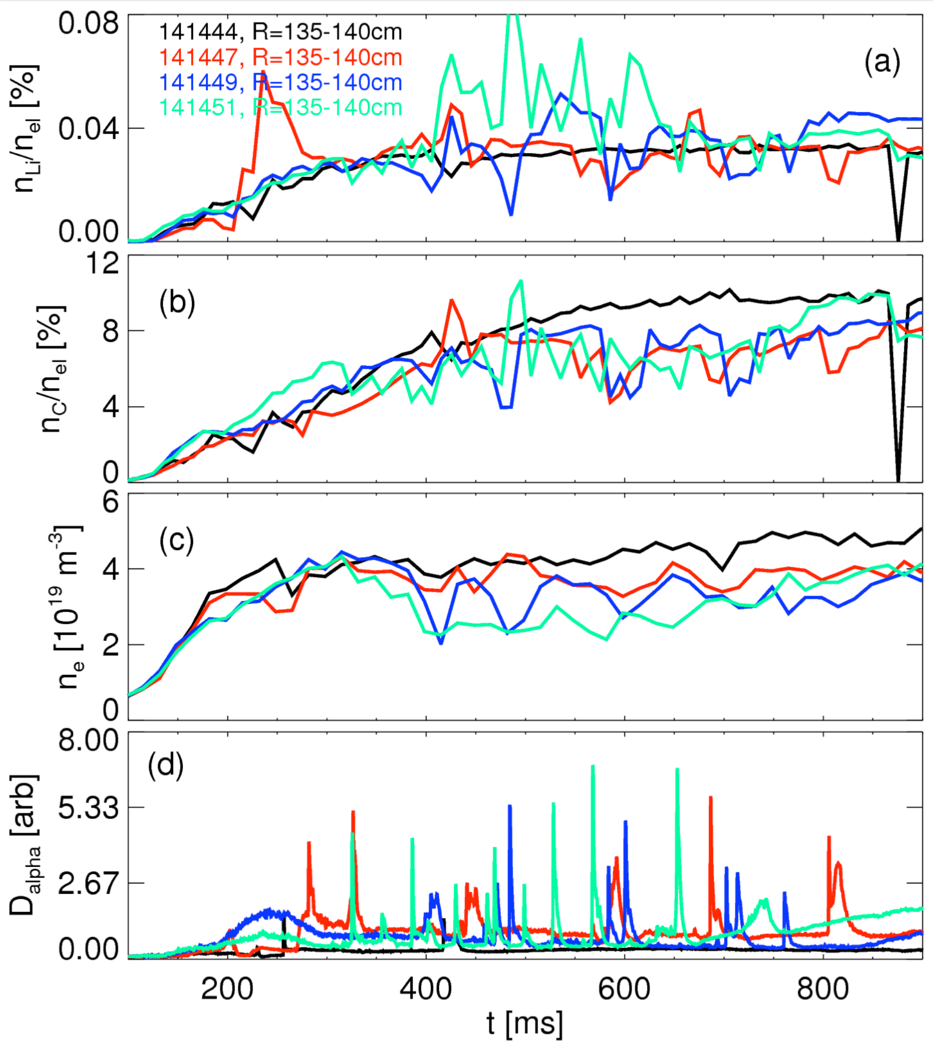
- Same B_{tor}, I_{pl}
- Bias plasma up after ~150 ms

- Both lithium and carbon concentrations reduced during current flat-top

> Reduced influx from divertor?

- How representative are these *two* discharges?

Analysis of ELMy discharges with increasing $|dr_{sep}|$ (downward) show different effects for C and Li



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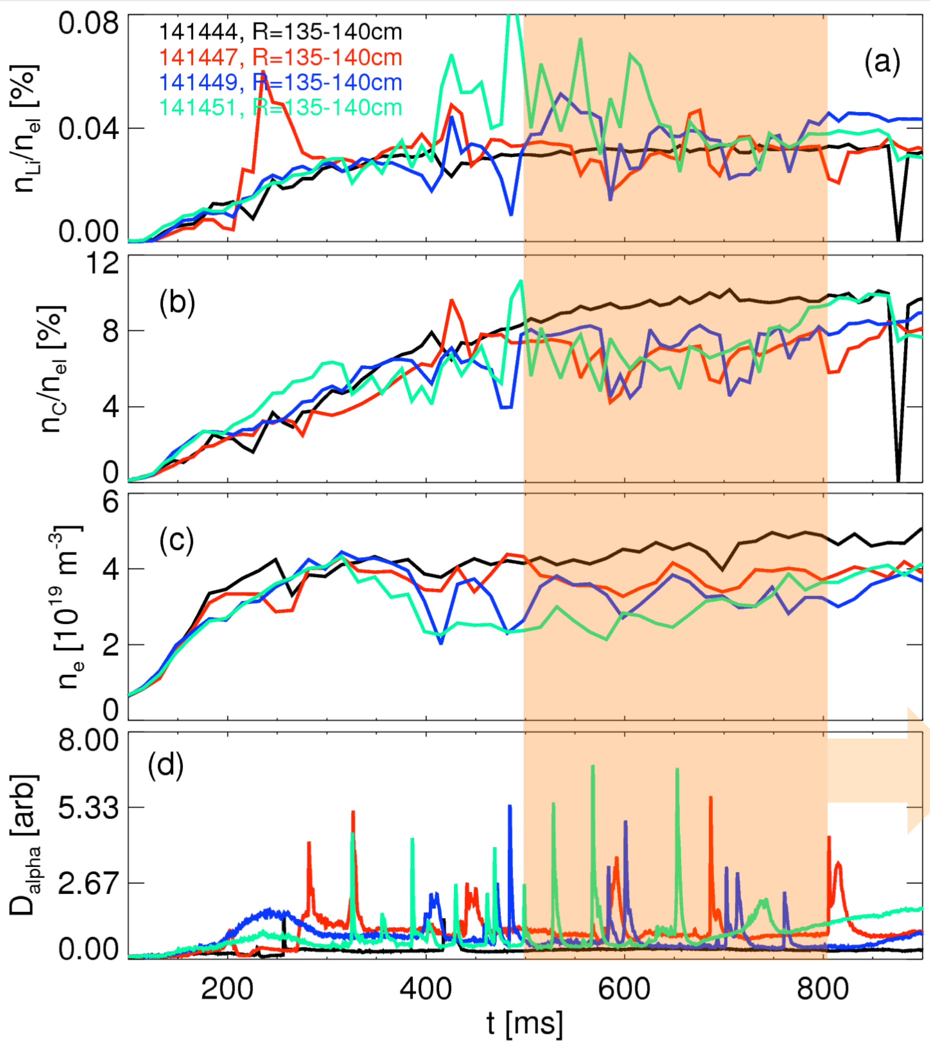
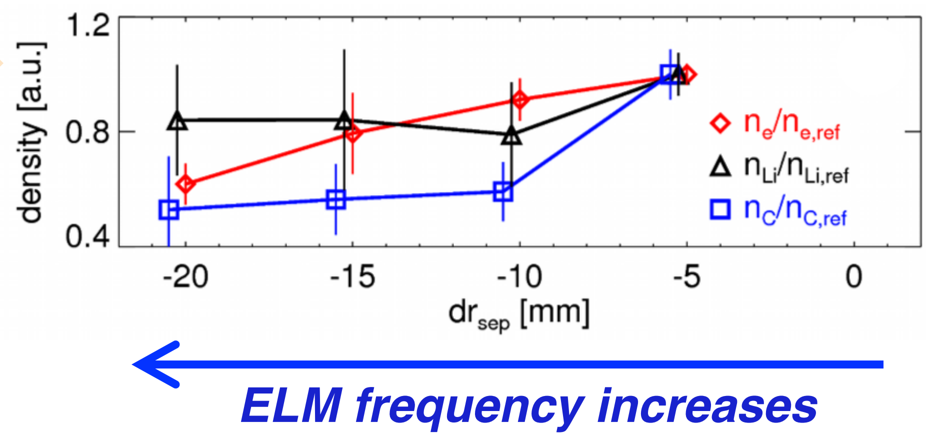
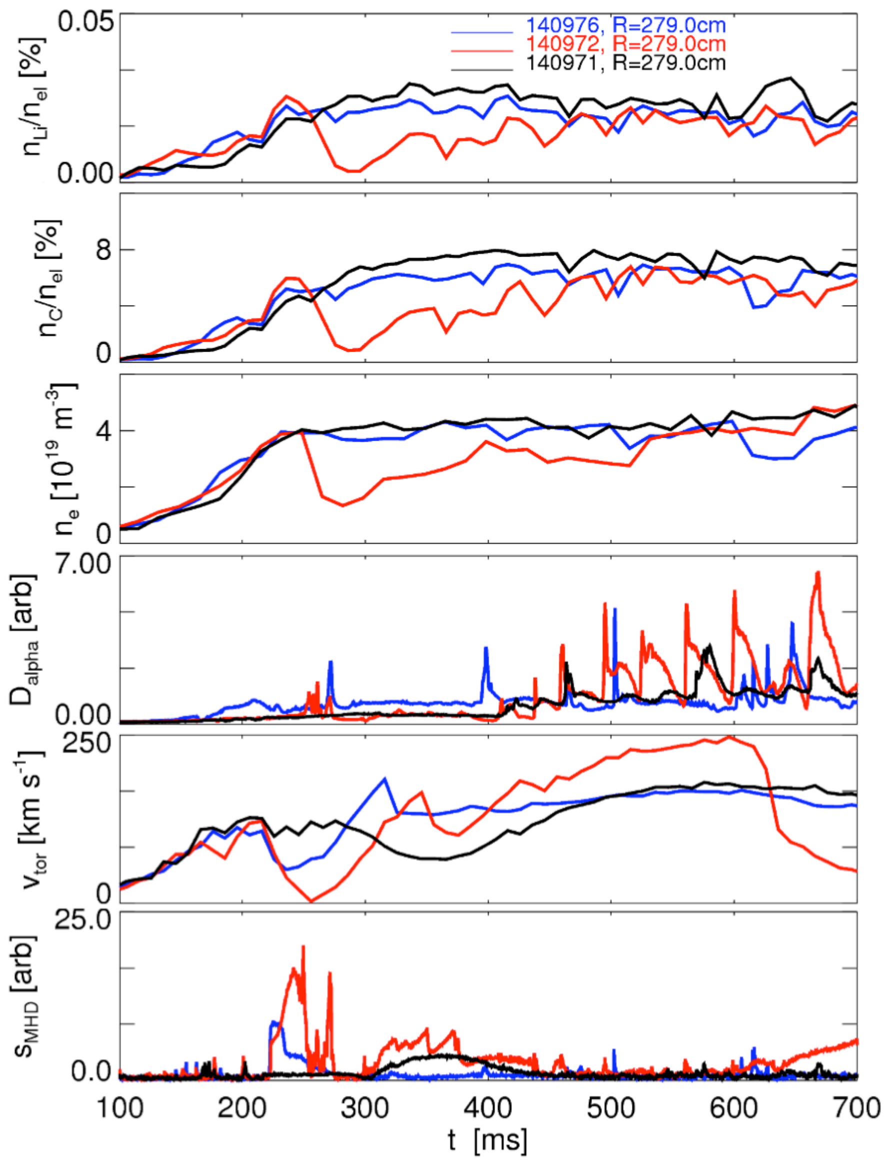


- Bias plasma toward lower divertor
- Lithium concentration not strongly affected
- Carbon conc. decreases for plasmas with ELMs
  - Rather insensitive to ELM frequency



Try with more controlled experiment: ELM triggering (n=3, jogs); MHD has strongest effects, unclear conclusion



140976: no ELM pacing (reference)
140972: static n=3 + vertical jogs
140971: vertical jogs only

- Strong MHD *before* ELM triggering phase
- Changes observed in n_{Li}, n_C
- How relevant are these conditions?
  - Strong modes
  - Plasma locks, v_{tor} collapses
  - Loss of confinement