VUV/XUV measurements of impurity emission in plasmas with liquid lithium surfaces on LTX

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APS 2014 - New Orleans, LA
Oct. 27th-31st

Liquid lithium has been proposed as a plasma facing component for tokamak divertors

- Advanced Limiter-divertor Plasma-facing Systems program formed to investigate liquid metals for fusion

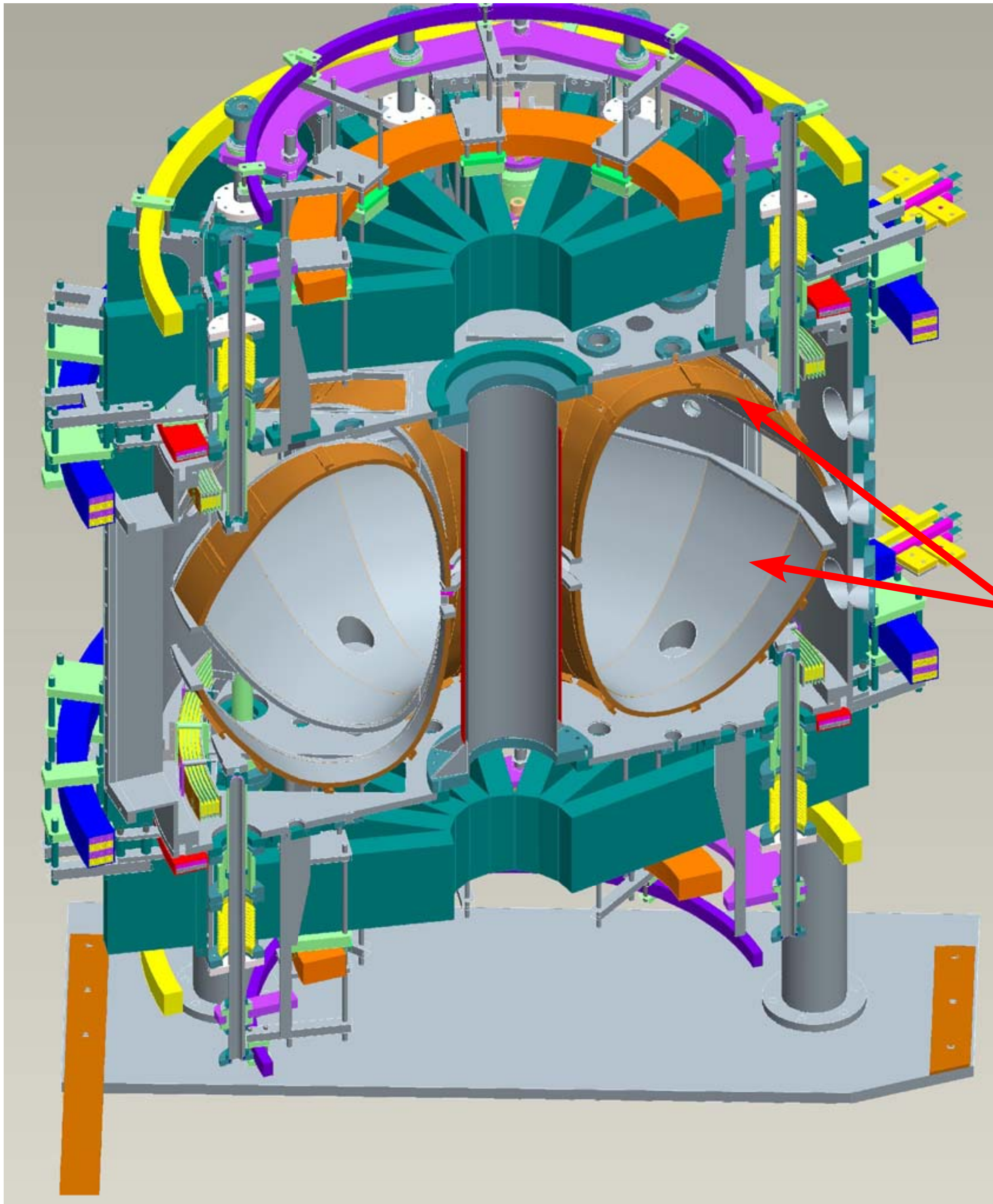
  - Liquid metals (gallium, tin, **lithium**) to address:
    peak heat flux, erosion lifetime limits, and heat extraction
  - Multi-machine experimental program:
    CDX-U, DIII-D, PISCES, ARIES, FLR, IIAX, MTOR, LIMITS, IMPACT, NSTX

- Previous results with liquid lithium surfaces inconsistent

  - CDX-U → improved confinement, plasma performance
  - NSTX → increased D_α recycling, no plasma improvement
  - LTX (previous) → large impurity influx, plasma degradation

- New LTX liquid lithium results show robust impurity control

Lithium Tokamak eXperiment (LTX) uses close-fitting metallic shells for lithium surface substrate



LTX parameters

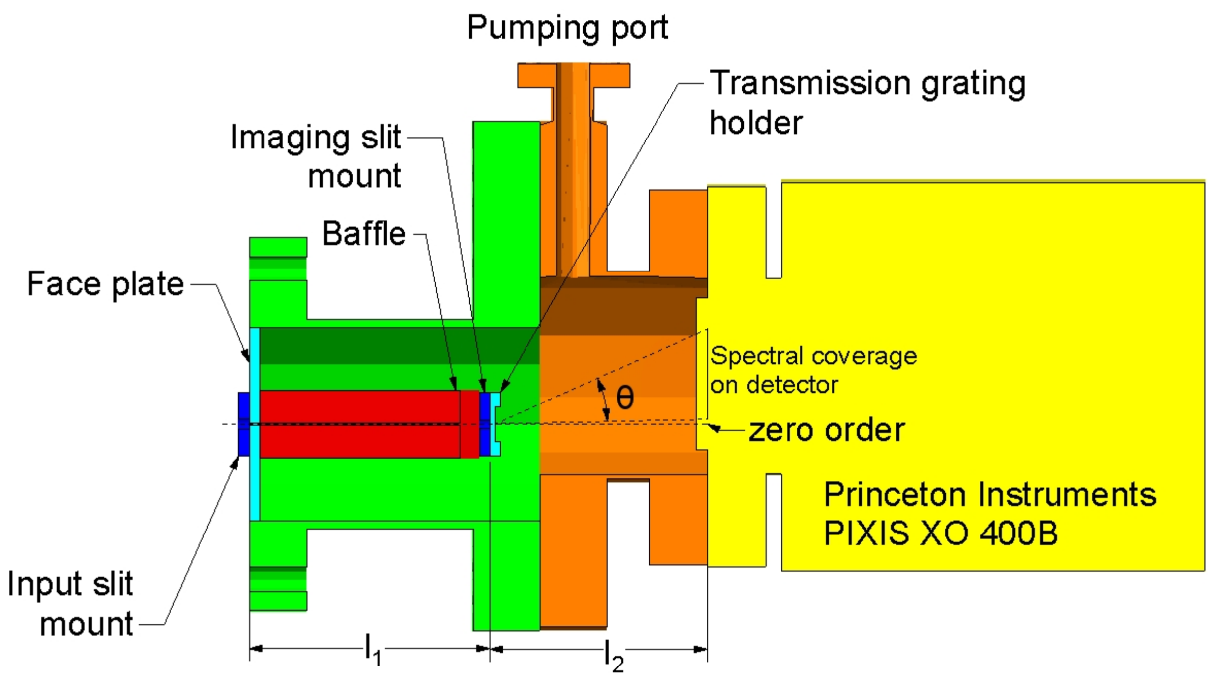
R_0	0.4m
a	0.26m
A	1.6
B_T	0.17T
I_p	<100kA
t_{pulse}	<40ms

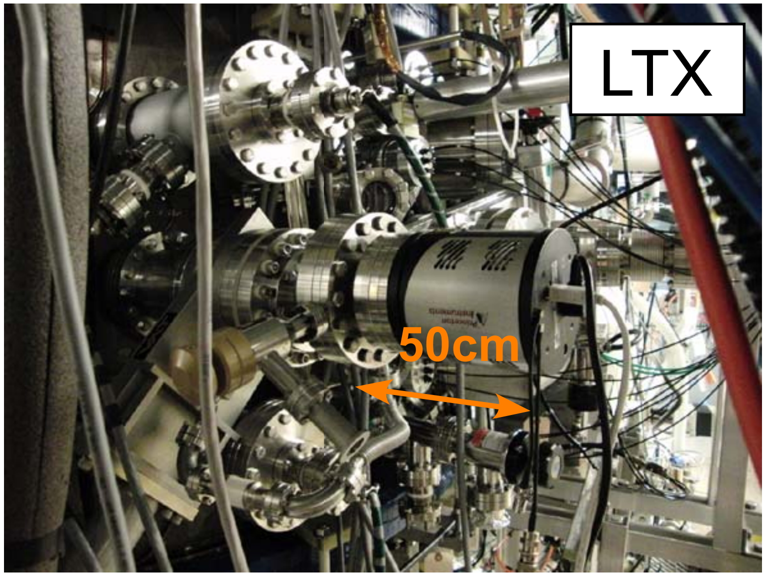
Shell upper/lower quadrants:
1.5mm stainless + 10mm copper
electrical heating up to 350°C

Lithium evaporation with cruicible

e^- beam heating/stirring of quadrant lithium reservoirs

JHU Transmission Grating Imaging Spectrometer (TGIS) measures impurity line emission on LTX

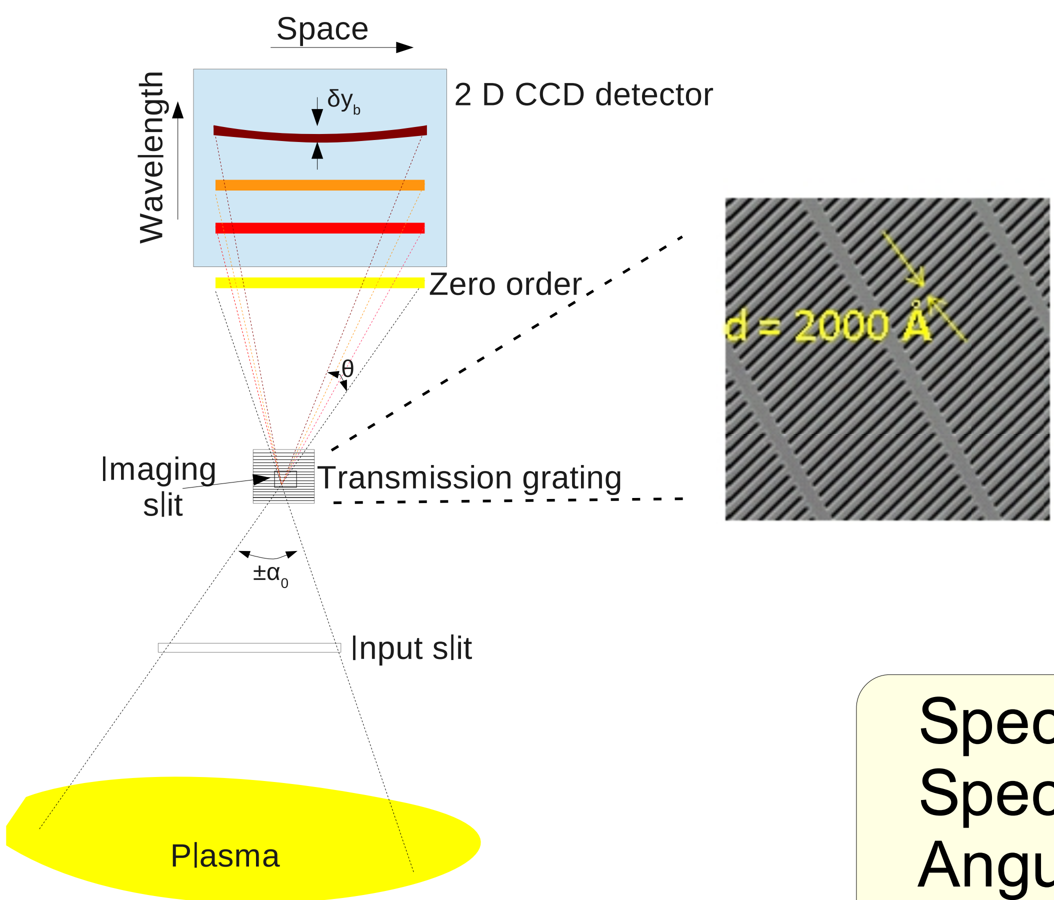


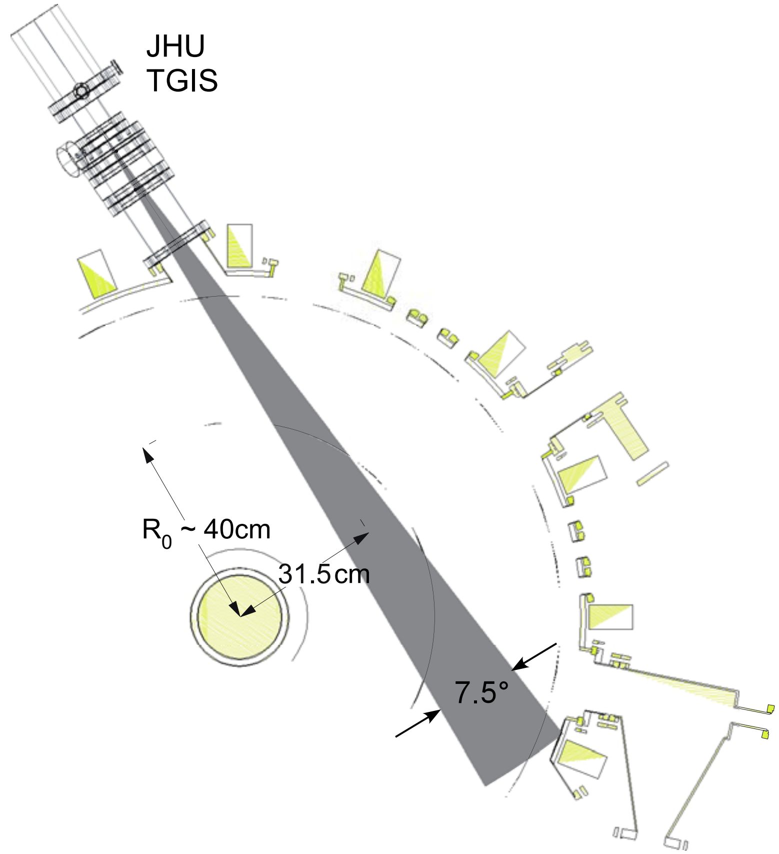


D. Kumar, et al., Rev. Sci. Instrum. 83, 10E511 (2012)

- TGIS used to assess effects of lithium on plasma impurity content
  - spectroscopic T_e estimate
  - validate TGIS for use on NSTX-U divertor

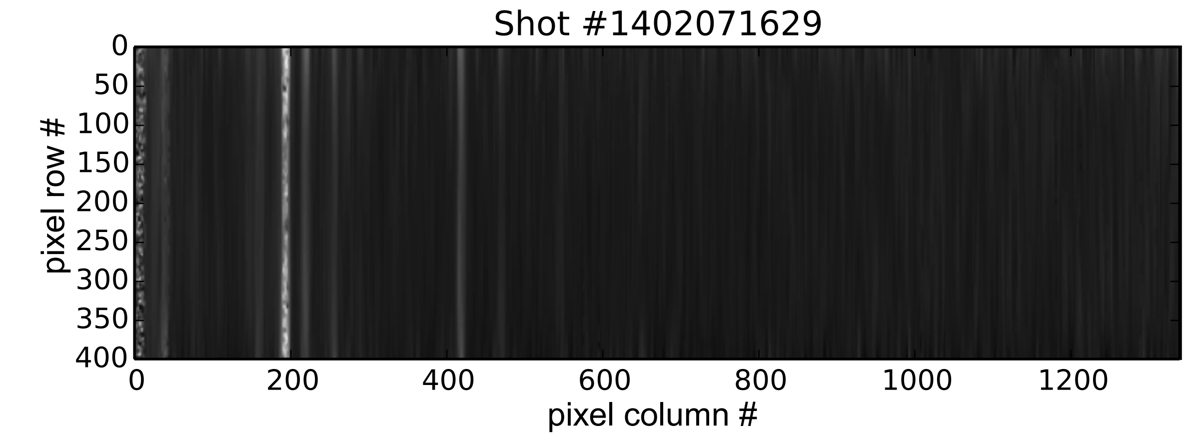
CCD detector for improved sensitivity, absolute $P_{rad}(\lambda,x)$

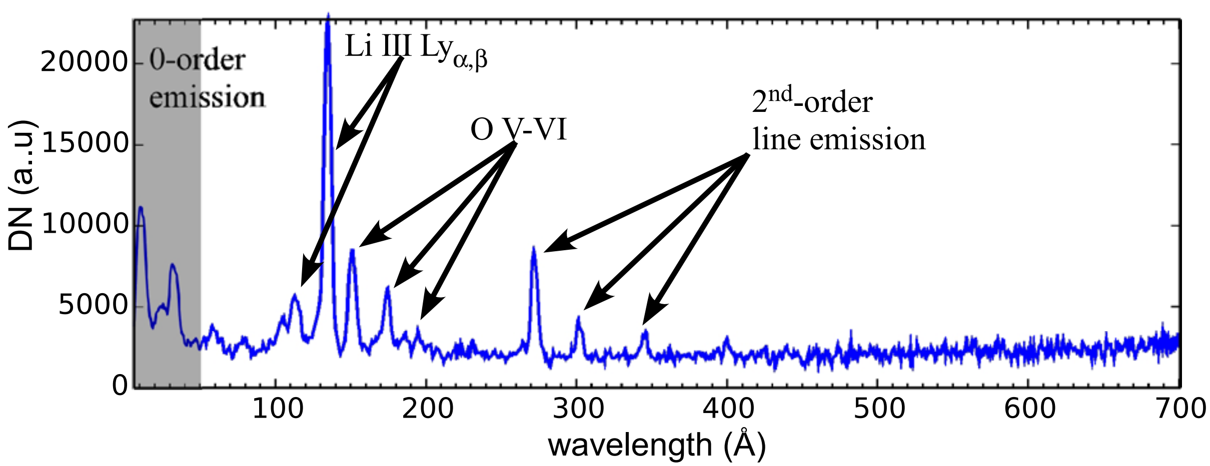




Spectral coverage	60 - 700 Å
Spectral resolution	9 Å
Angular view	±3.75°
Angular resolution	0.44°
Time resolution	10 - 20 ms

TGIS XUV spectrum from LTX dominated by oxygen and lithium impurity line emission

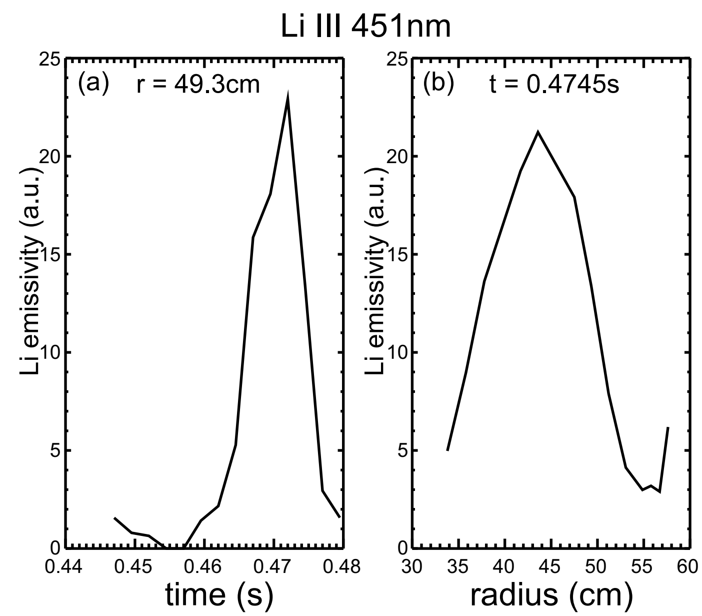




Ion	Wavelength (A)	Level transitions
Li III	113.9	1*s* 3*p*
Li III	135.0	1*s* 2*p*
O VI	150.1	$1s^2 2s$ $1s^2 3p$
O V	172.2	$1s^2 2s^2$ $1s^2 2s 3p$
O VI	172.9-173.1	$1s^2 2p$ $1s^2 3d$
O VI	183.9-184.1	$1s^2 2p$ $1s^2 3s$
O V	192.7-192.9	$1s^2 2s 2p$ $1s^2 2s 3d$

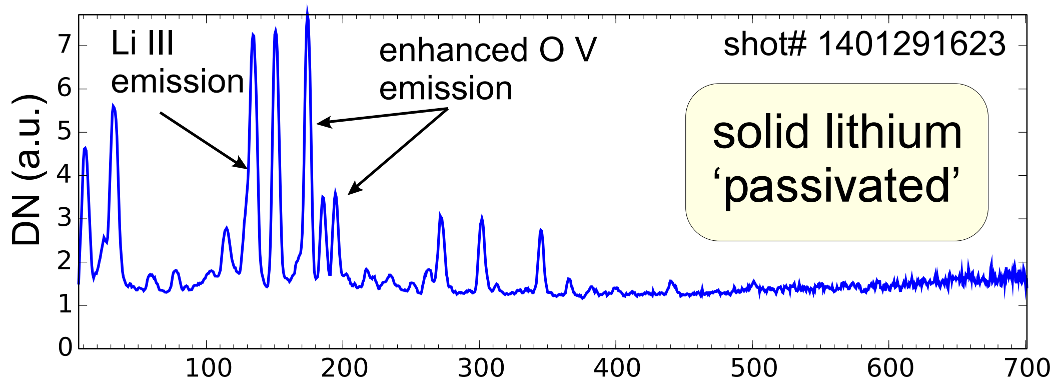
Li III, O VI selected for line ratio measurements

Visible Li III line from HAL spectrometer localizes emission to core plasma/peak I_p



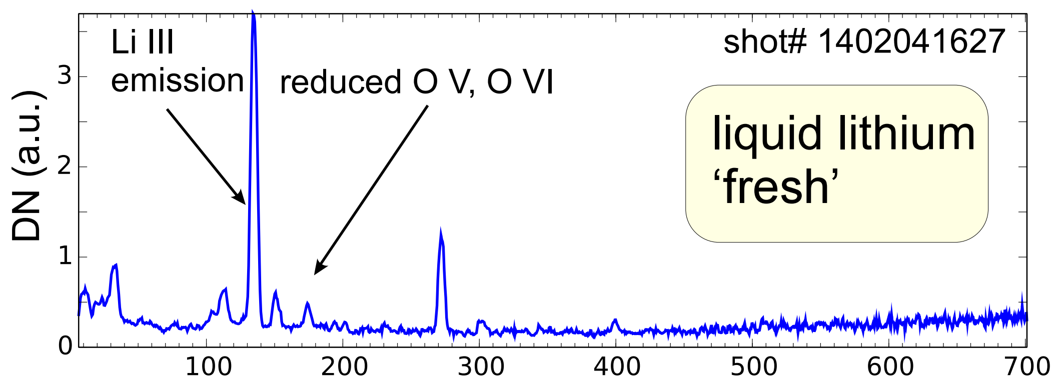
LTX lithium surface conditions show differences in TGIS measured oxygen impurity line emission

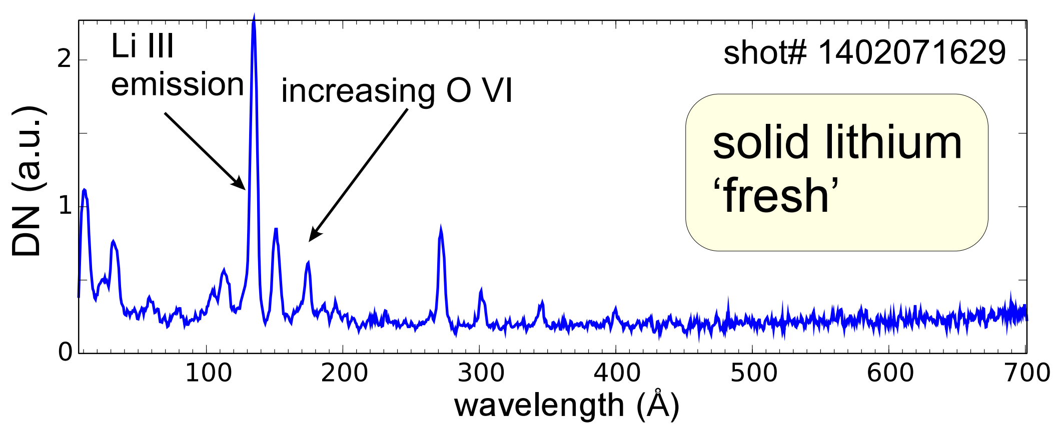
K. Tritz, et al., submitted PPCF (2014)



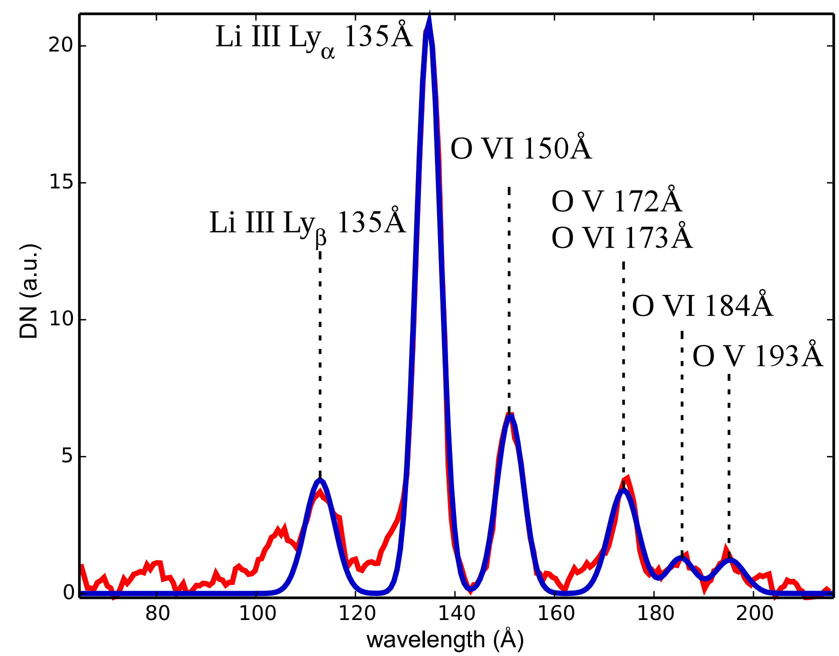
enhanced O V indicates T_e ~40eV with passivated lithium surface

O emission strongly reduced with fresh lithium surfaces, T_e ~100eV

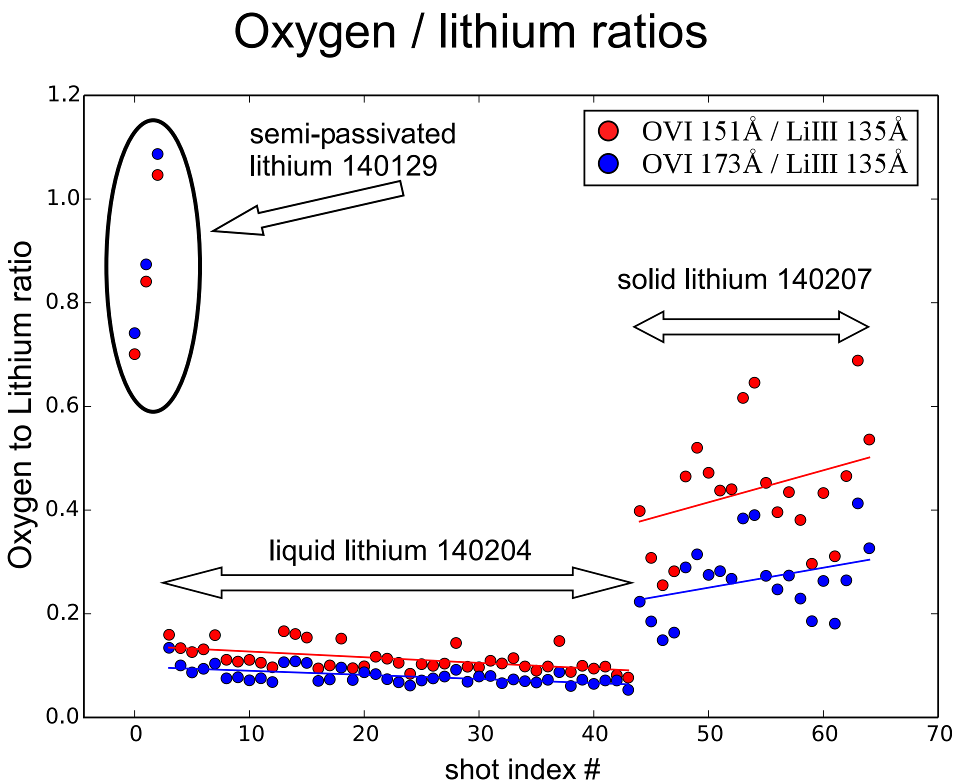


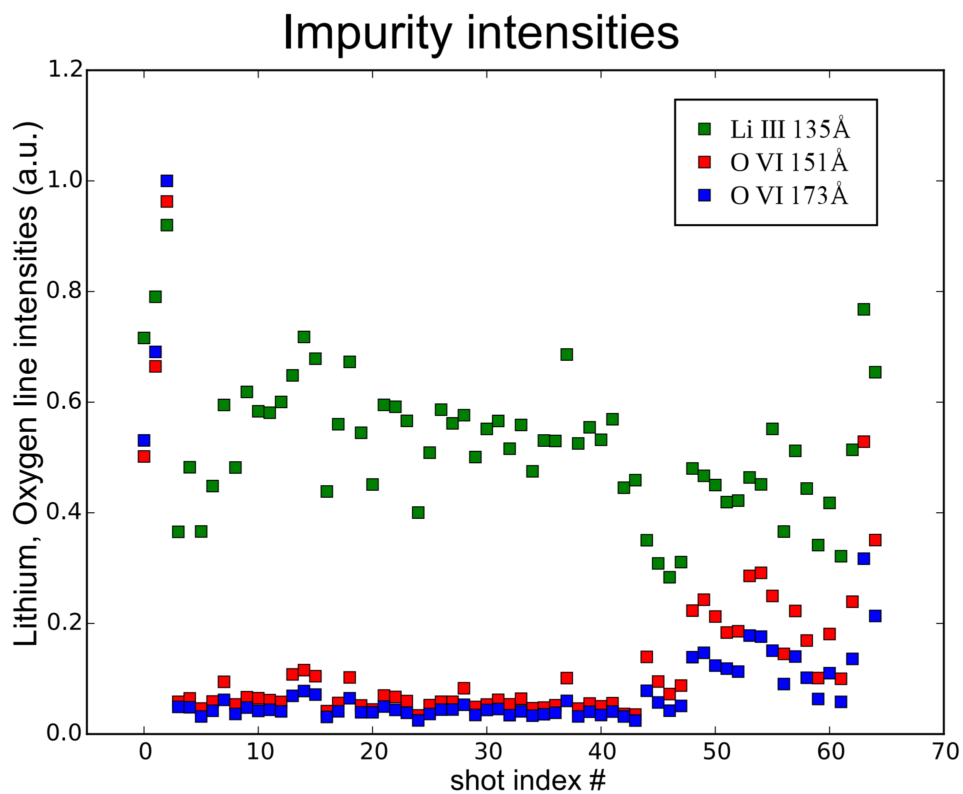


impurity line intensities/ratios measured using multi-peak Gaussian fitting



Oxygen-lithium ratios show different magnitudes and trends for solid and liquid lithium surfaces



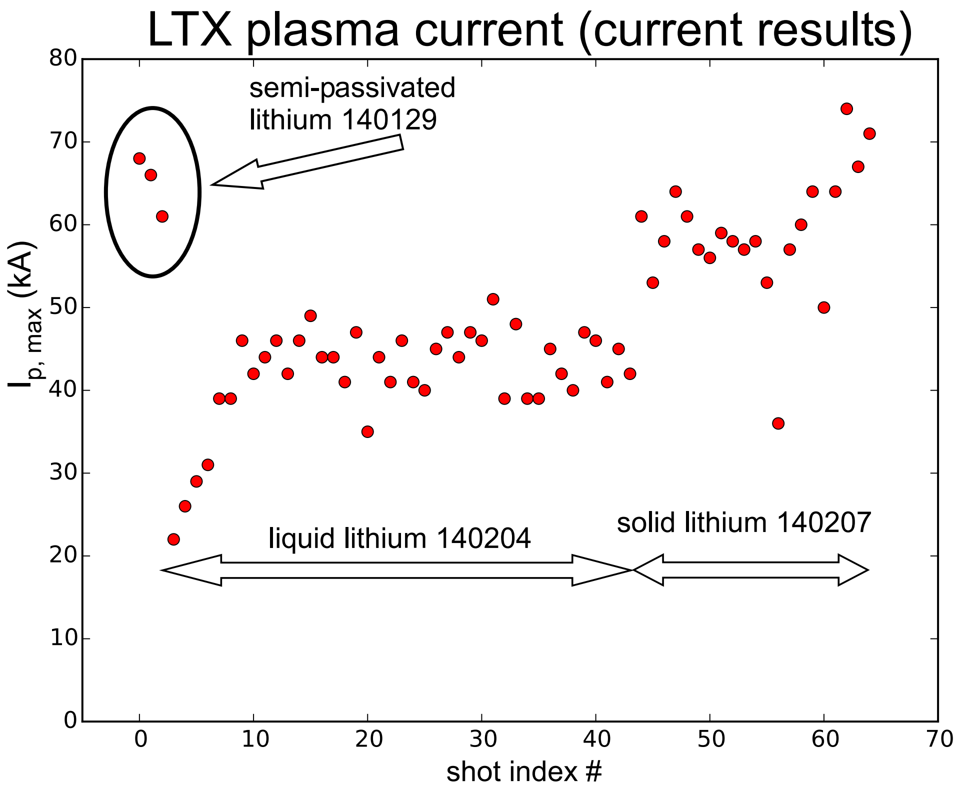


O/Li ratios lower by ~x3-6 with liquid lithium surface

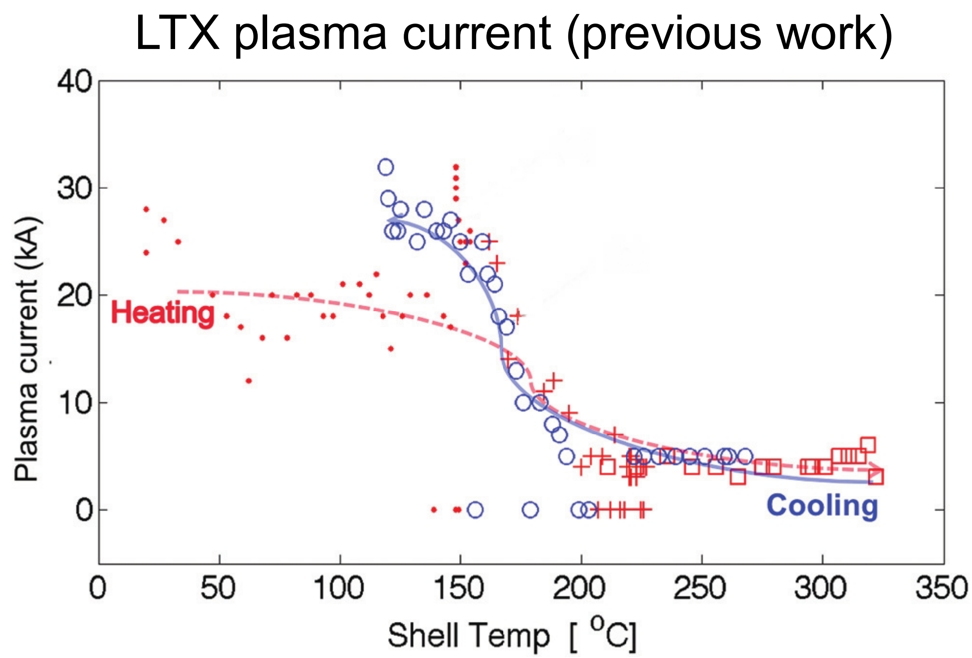
Liquid lithium less susceptible to discharge surface degradation

Reduction in O/Li ratio primarily from reduced O emission

Plasma performance maintained during liquid lithium operations



Majeski *et al.* Phys. Plasmas **20**, 056103 (2013)

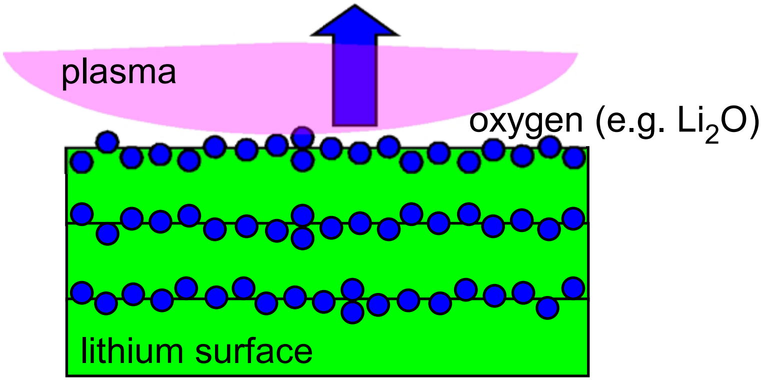


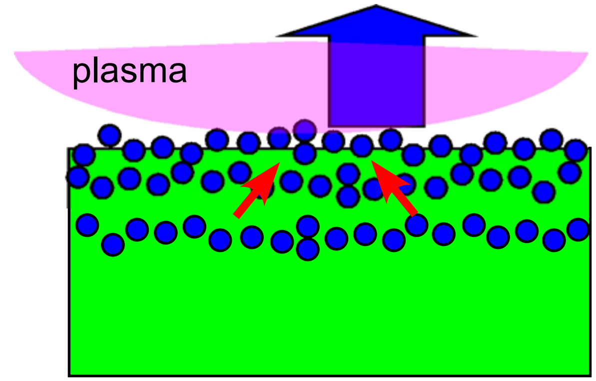
Previous LTX results show severe plasma performance degradation above the Li melting point

Current results: I_p ~40-50kA (liquid) and ~50-70kA (solid)

I_p difference due to changing fueling needs and coil currents for different eddy currents with higher resistivity, hot shells

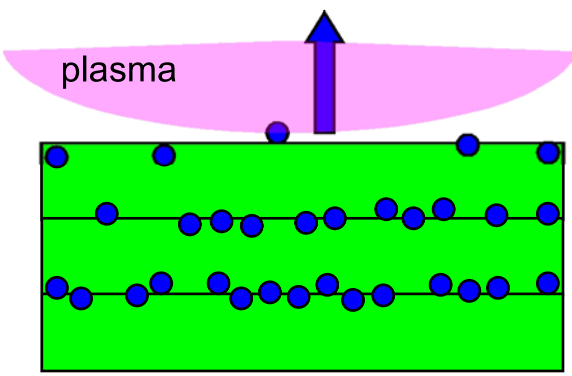
What is the lithium doing?

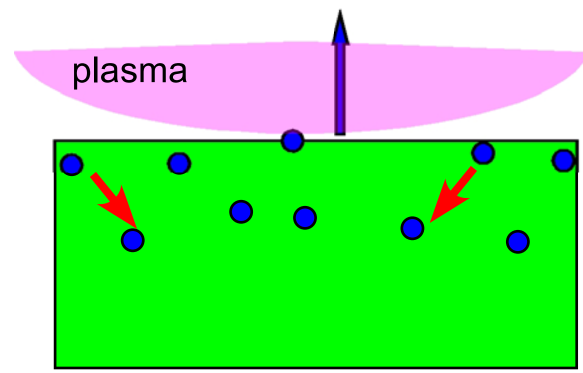




solid ‘passivated’ → large plasma influx
plasma interacts with impurity saturated surface
buried oxygen remains sequestered

liquid ‘passivated’ → v. large plasma influx
plasma interacts with surface impurity ‘slag’
dissolved oxygen quickly refreshes surface





solid ‘fresh’ → moderate plasma influx
plasma interacts with initially clean surface
degradation as impurities accumulate

liquid ‘fresh’ → low plasma influx
plasma interacts with clean surface
liquid volume has large impurity capacity

Liquid lithium surfaces can provide impurity and recycling control for tokamak divertors

- Maintaining reservoir of ‘clean’ liquid lithium is critical

  - flowing liquid lithium system for refreshing first wall surface

  - burying passivated layers only suitable for solid lithium

Wednesday afternoon poster session

PP8.83 Overview of results from the Lithium Tokamak eXperiment (LTX)
PP8.84 Diagnostic Overview of the Lithium Tokamak Experiment (LTX)
PP8.87 Impurities in the Lithium Tokamak Experiment
PP8.89 Dependence of LTX plasma performance on surface conditions as investigated by the Materials Analysis and Particle Probe

Friday morning invited talk

YI2.03 High Performance Discharges in the Lithium Tokamak eXperiment (LTX) with Liquid Lithium Walls
YI2.05 The Effects of Temperature and Oxidation on Deuterium Retention in Solid and Liquid Lithium Films on Molybdenum Plasma-Facing Components

BACKUP

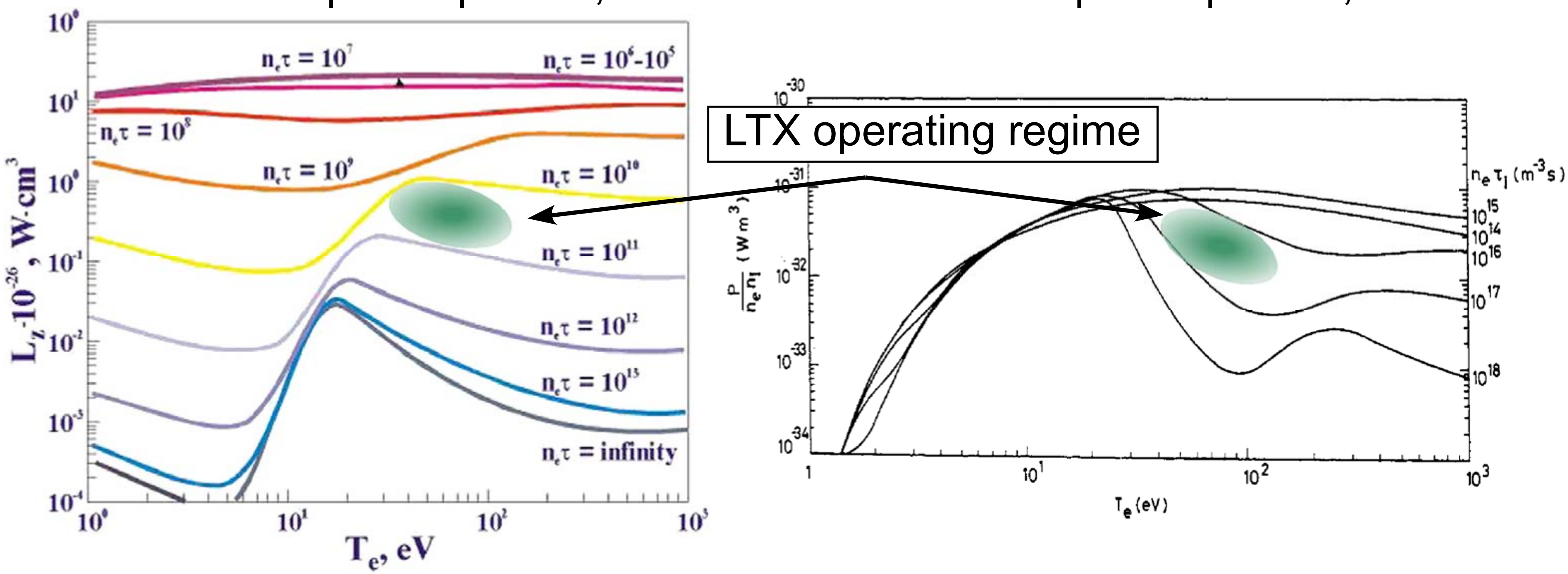
Oxygen/lithium line ratios reduce measurement dependence on electron temperature and densities

Impurity line intensities depend on local n_e, T_e, n_i, τ_p

Li III, O VI: similar ionization potentials, dependence on T_e, τ_p

O VI / Li III ratio provides robust measurement of relative n_i

Li radiated power per-ion, e^- | O radiated power per-ion, e^-



S V Mirnov, *et al.*, Plasma Phys. Control. Fusion **48** 821 (2006). P. G. Carolan, V. A. Piotrowicz, Plasma Phys. **25** 1065 (1983).