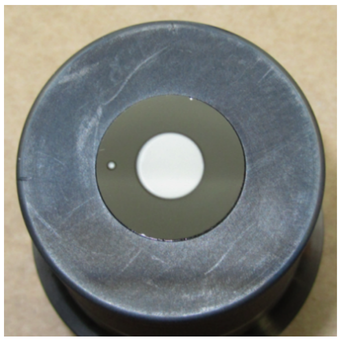
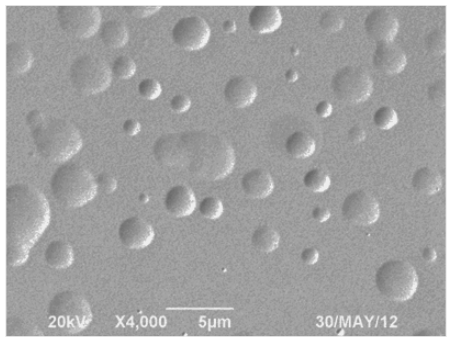
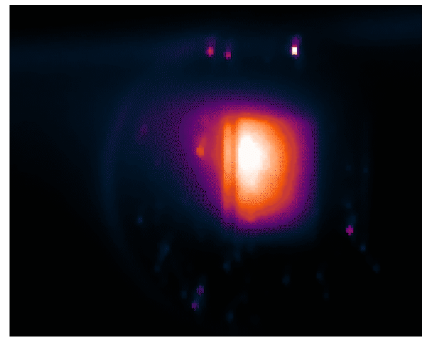
SAND2014-0053C

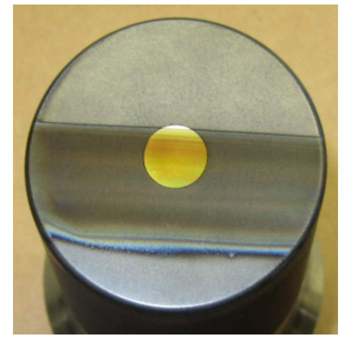
Net Versus Gross Erosion of W and Other Recent DiMES Experiments

D.L. Rudakov, for the DiMES team
Presented by D. Buchenauer









Presented at the US-Japan Workshop HR/PMI
Sandia Livermore,

January 7-8, 2014

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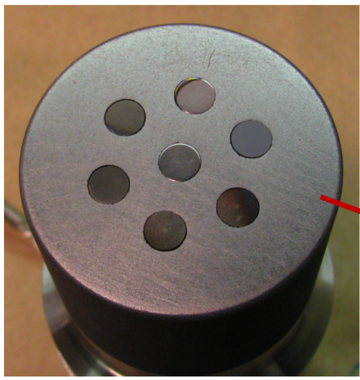
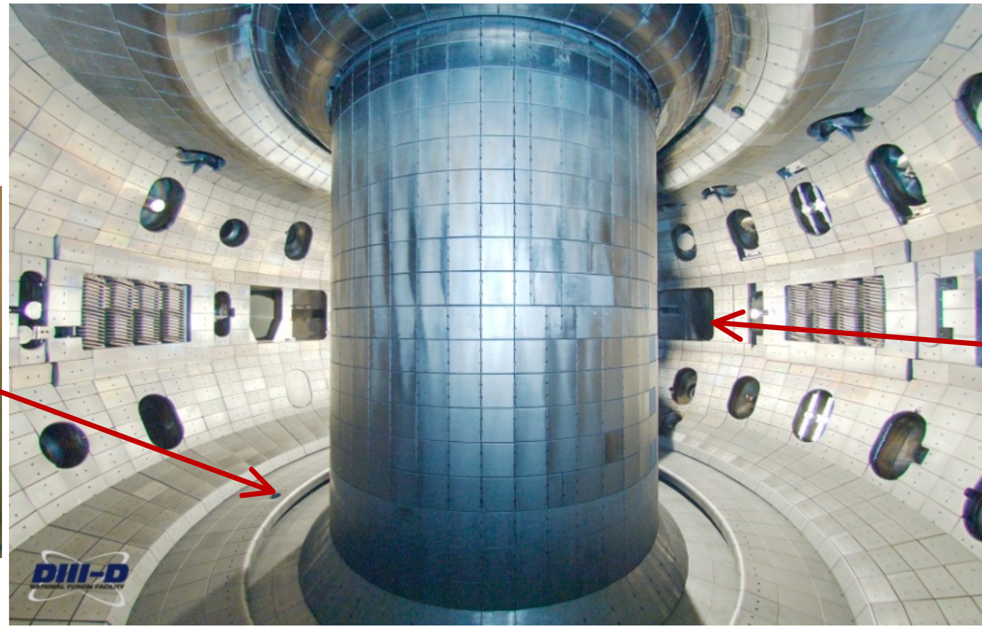
UCSD

Divertor Material Evaluation System – DiMES
Midplane Material Evaluation Sample – MiMES

DiMES





MiMES

- **DiMES is a standalone system used to insert material samples in the lower divertor of DIII-D**
- **MiMES is an add-on to the midplane reciprocating probe allowing exposure of material and mirror samples**
- **A minimum exposure in each system is for 1 plasma discharge**

DiMES/PSI Team Members and Collaborators

• C. Wong, N. Brooks*, B. Chen, C. Chrobak,	
• A. Leonard, R. Tao, D. Wall	GA
• D. Rudakov, J. Boedo, R. Doerner, E. Hollmann, R. Moyer	UCSD
• R. Bastasz*, D. Buchenauer, D. Donovan, J. Watkins, J. Whaley	SNL-Livermore
• W. Wampler	SNL-Albuquerque
• J. Brooks, A. Hassanein, T. Sizyuk	Purdue
• M. Fenstermacher, C. Lasnier, A. McLean	LLNL
• G. Wright	MIT
• M. Wright	Ultramet
• E. Unterberg	ORNL
• P. Stangeby, D. Elder	University of Toronto
• A. Litnovsky, M. Matveeva, O. Schmitz	Forschungszentrum Jülich
• S. Ratynskaia, H. Bergsåker, I. Bykov	KTH Stockholm
• M. Balden, V. Rohde	IPP Garching
• G. Luo	ASIPP
• G. Zhong	SWIP

* retired

Experiments to be Covered

This talk

- Net versus gross erosion of W
- Net versus gross erosion of Al - preliminary results
- Control of high-Z PFC erosion by local gas injection

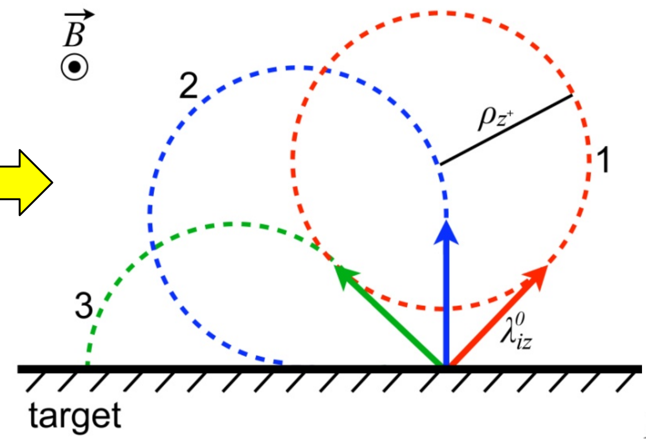
Covered by others

- T. Rognlien: Heat flux reduction by impurity radiation / alternate magnetic configurations
- D. Donovan: Sheath power transmission studies
- R. Nygren: Modeling of heat transport in tiles & fast TCs

Net versus Gross Erosion of W

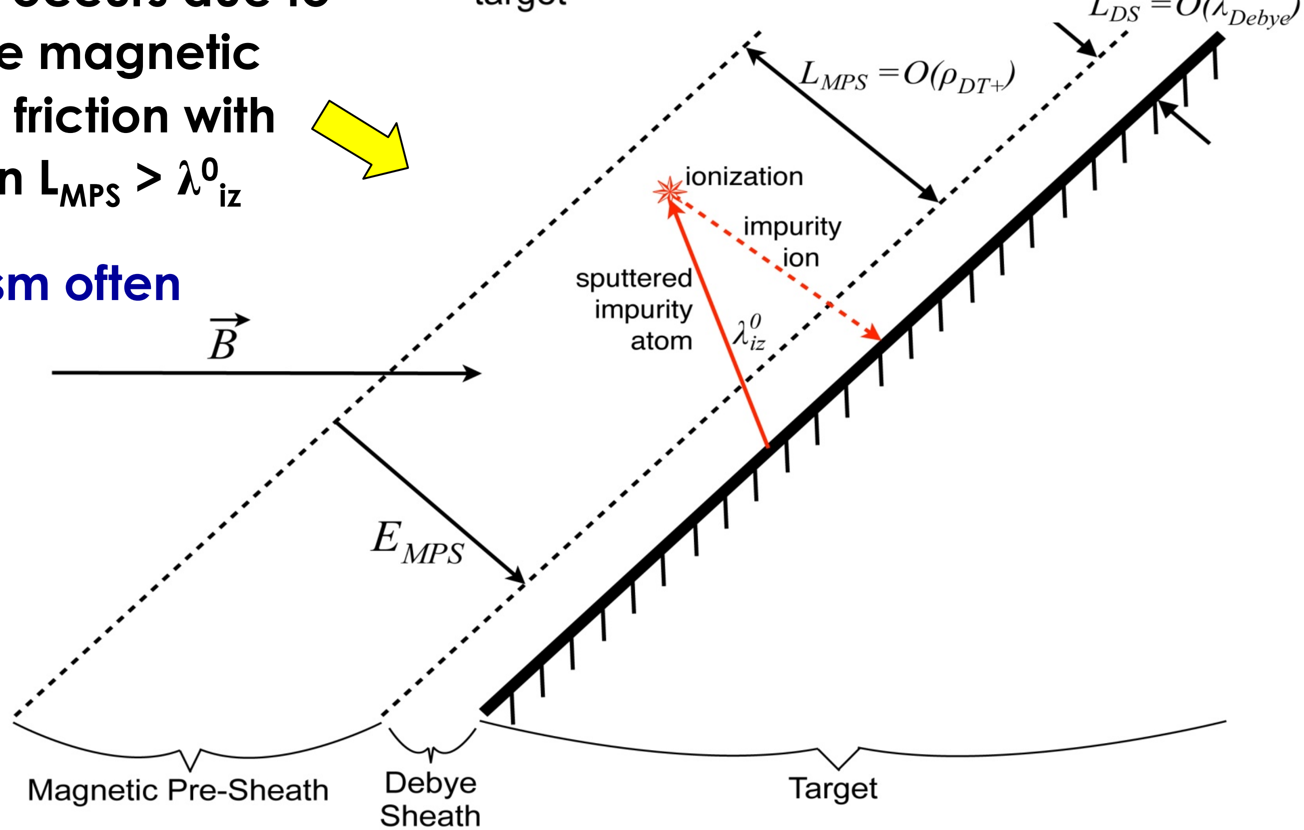
Prompt Redeposition in the Magnetized Sheath is Expected to Reduce Net Erosion

- **If ionization mean free path λ^0_{iz} is comparable or less than the ion Larmor radius ϱ_{z+}, sputtered impurity ions return to the surface during the first gyro-orbit**

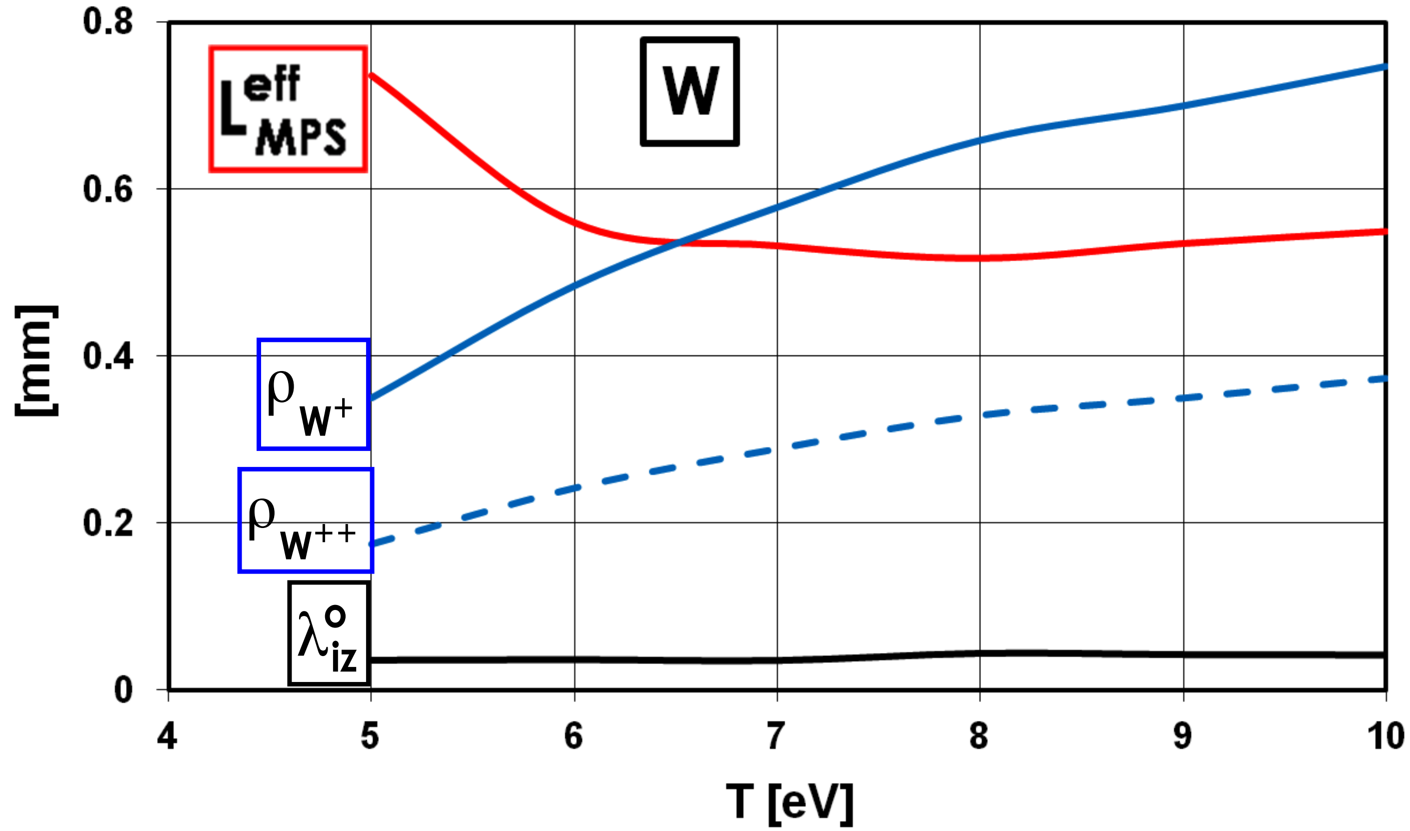


- **Fast redeposition also occurs due to the strong E-field in the magnetic pre-sheath (MPS) and friction with fast plasma flow, when $L_{MPS} > \lambda^0_{iz}$**

- **The second mechanism often dominates**



For Tungsten, Prompt Deposition Should be Effective in DT Devices Via Both Strong MPS Forces and Large ϱ_W

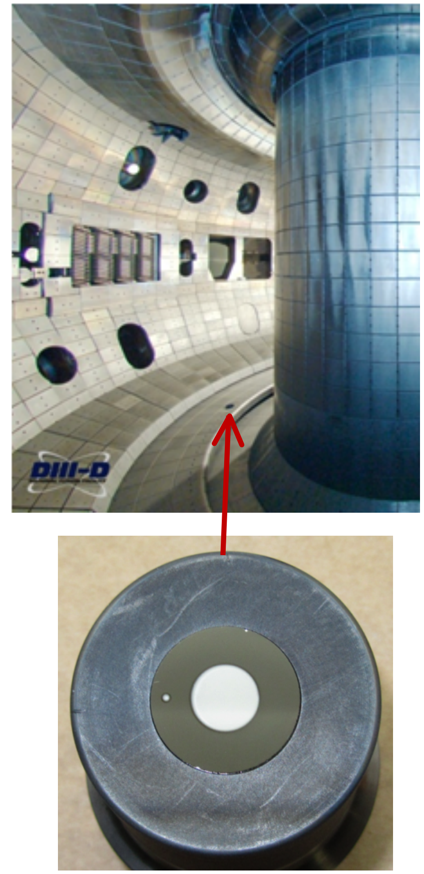


ITER case with $n_e = 10^{21}$ m^{-3} , B = 5 T

Courtesy of P. Stangeby

High-Z Erosion Experiments on DIII-D

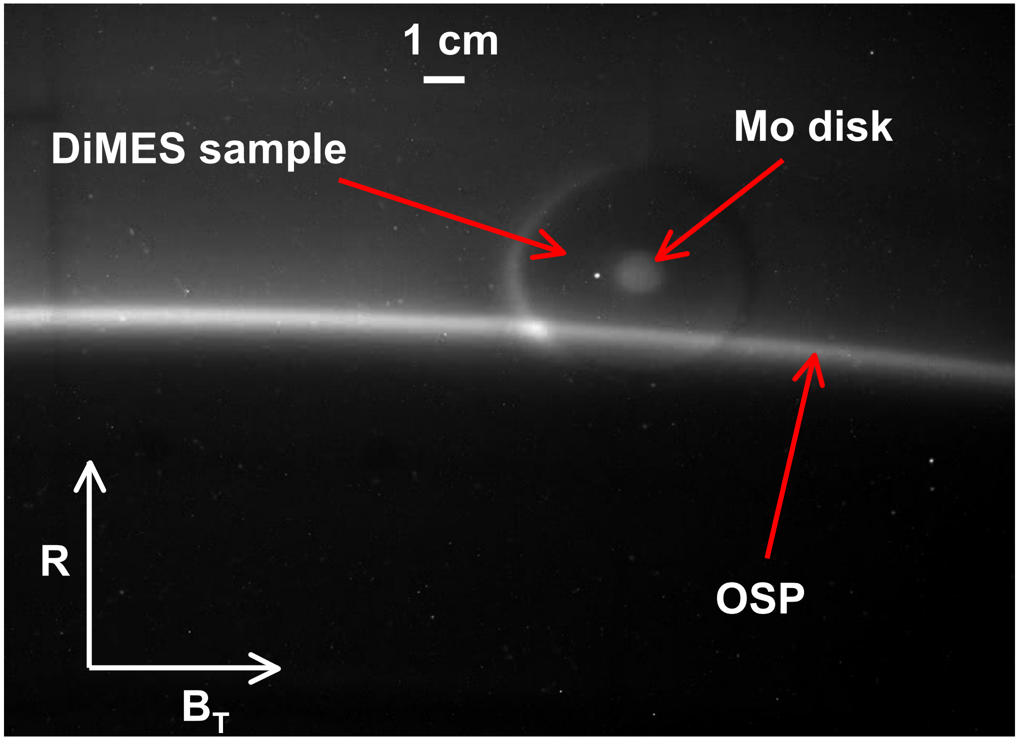
- ITER, FNSF require that target *net erosion* be very *small*
- A definitive test of net vs gross erosion under well-characterized stable conditions has been proposed by P. Stangeby
- Pre-characterized Mo and W samples were exposed in the lower divertor using DiMES
- Samples were Mo and W films 15-25 nm thick deposited on Si substrate
- Net erosion measured by post-exposure Rutherford Backscattering (RBS) from the change of the film thickness
- Gross erosion of Mo measured spectroscopically using MoI line at 386 nm and S/XB coefficient measured on PISCES by Nishijima et al
- Non-spectroscopic method for gross erosion measurement was also developed with the 1 mm dot

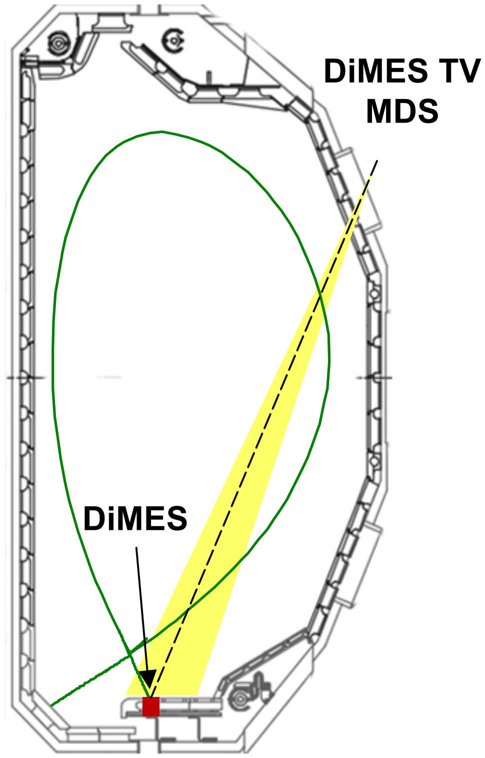


DiMES

Reproducible Stable L-mode Conditions Used

- All exposures were in L-mode with attached OSP
- OSP was placed 0.7–1.5 cm inboard of the 1 cm sample for ~4 s of stable flat top conditions
- During discharge startup and ramp-down OSP was off DiMES
- Repeated reproducible discharges were used when needed





DiMES TV image using 390 nm MoI filter with 10 nm pass band

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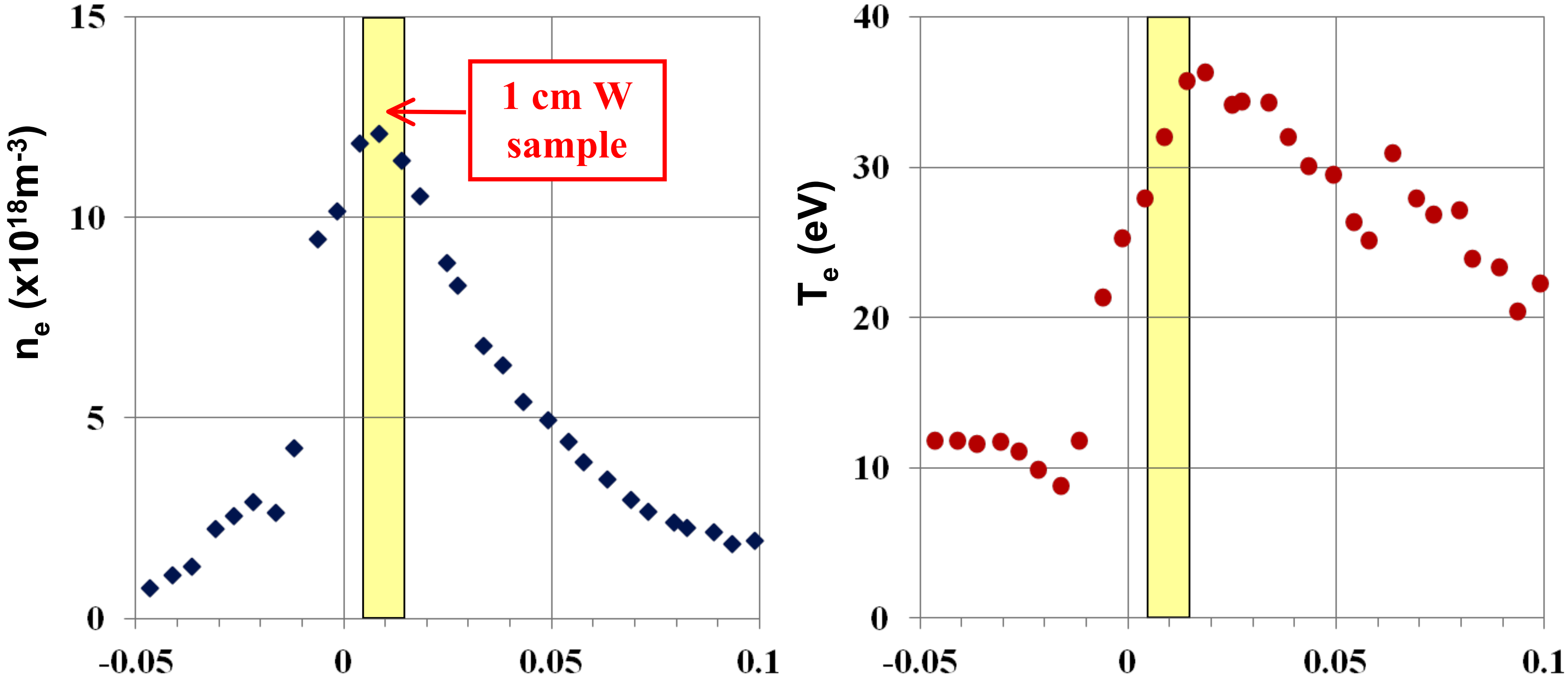
Discharge and Divertor Plasma Parameters, W Experiment

- **Main discharge parameters:**

B_T = 2 T, I_p = 1.1 MA, P_{ohm} = 0.7 MW, P_{NBI} = 0.6 MW, $\langle n_e \rangle$ = 2.6x10^{19} m^{-3}



Langmuir probe profiles across the sample

Courtesy of J. Watkins

Conditions similar to previous Mo experiments

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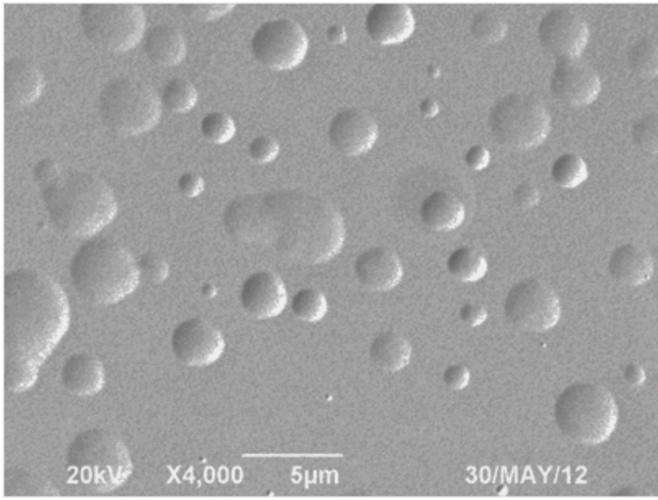
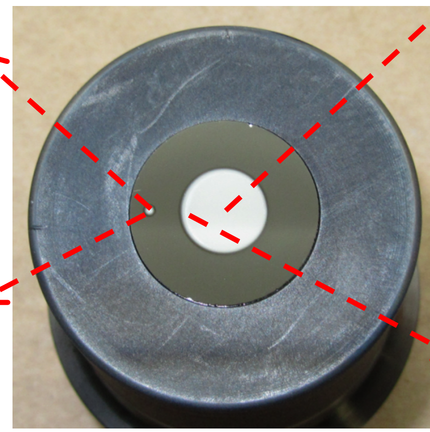
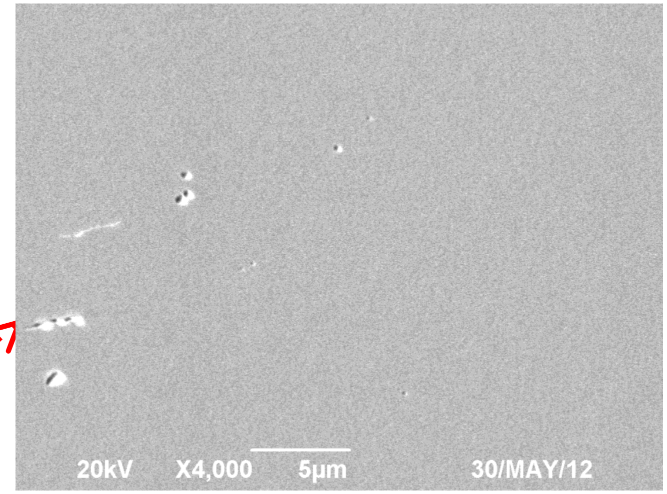
SEM Showed Some Blistering After the 16 Sec Exposure



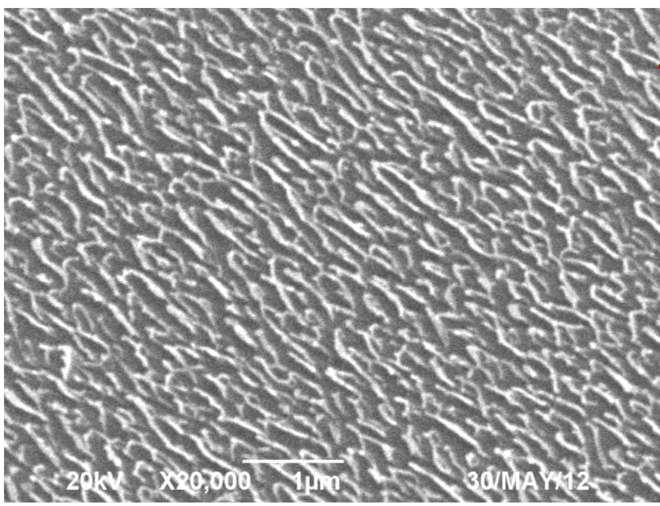
Center of 1 mm spot, blisters

W

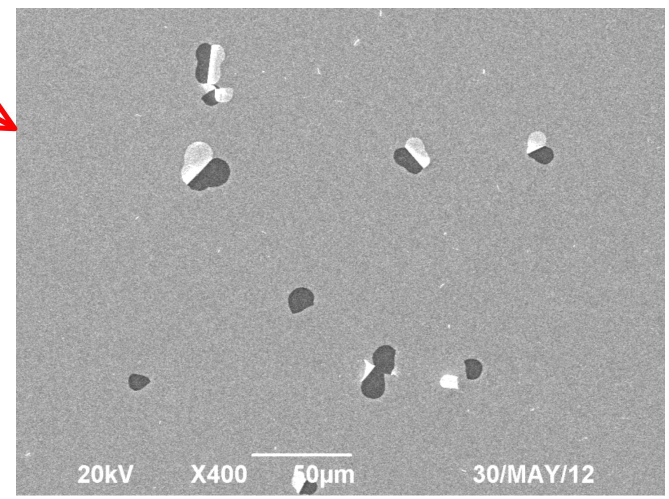




Center of 1 cm spot, no blisters



Edge of 1 mm spot, ripples

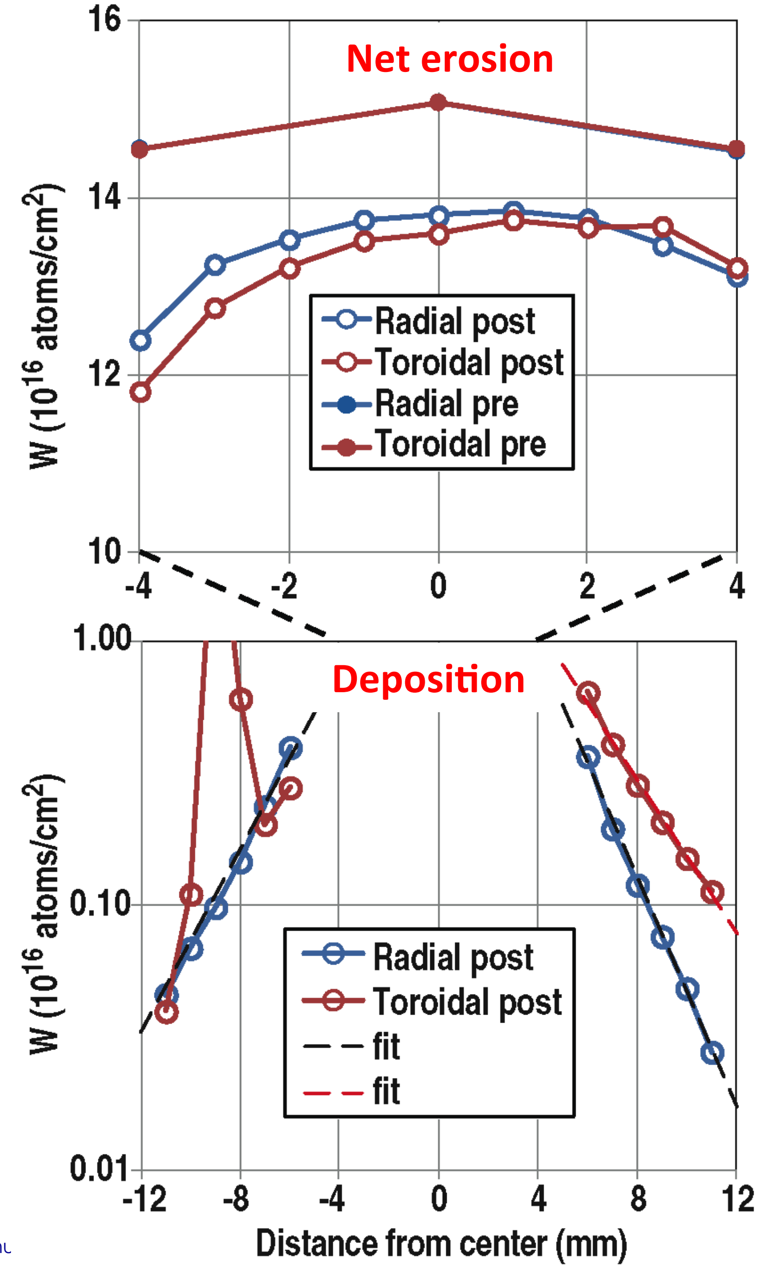


Edge of 1 cm spot, popped blisters

Courtesy of C. Chrobak

Summary of the W Experiment Results

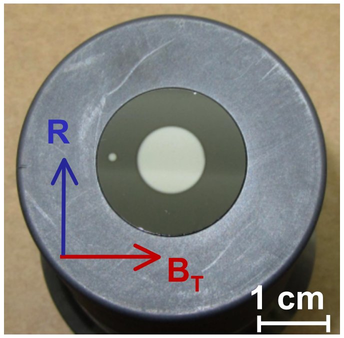
- No spectroscopic measurement of gross erosion was obtained due to light leakage through the WI filter
- Net erosion and deposition of W on C were measured by RBS
- Net (~ gross) erosion on the 1 mm spot ~7.6 nm
- Net erosion at the center of 1 cm spot ~2.16 nm
- Ratio of net/gross erosion = 0.29
- Modeling gives net/gross erosion = 0.33
- About 44 % of the net eroded W deposited on the C part of the sample

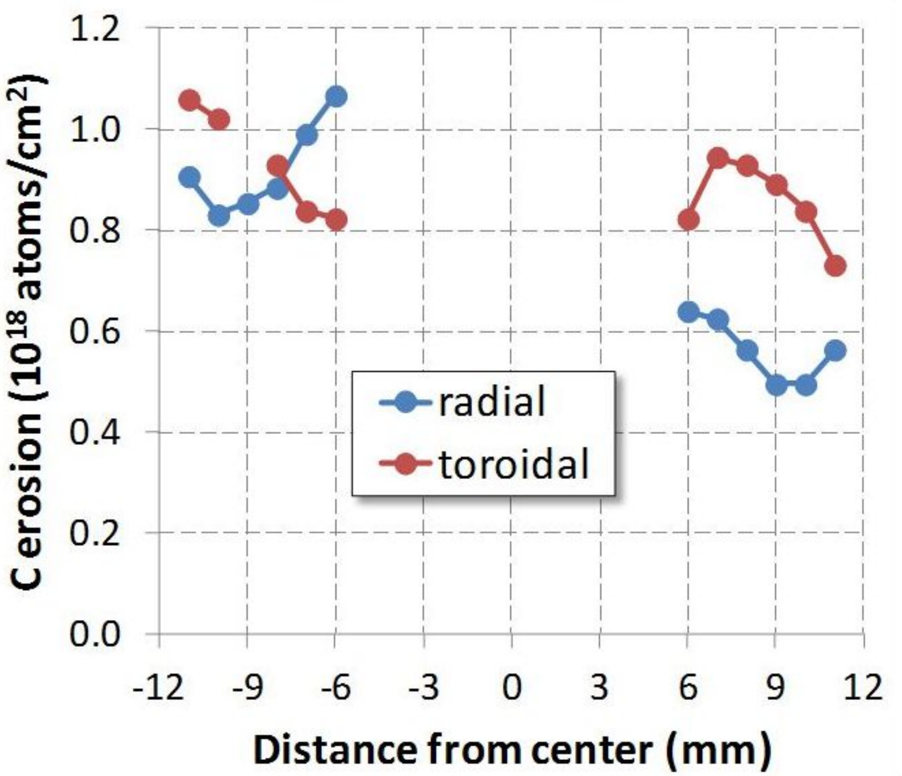


Measurements by W. Wampler

C Erosion Rate was ~100 Times Higher than that of W

- **Post-exposure net erosion of carbon was measured on Si disk around W film**
- **C net erosion rate was ~100 times higher than that of W**
- **It is reasonable to assume that no carbon layer was formed on top of the W surface**
- **Even for a surface undergoing net erosion, the carbon should be present as a mixed layer, which should reduce the effective sputtering yield of the W though a dilution effect**
- **This should not, however, strongly affect the ratio of net to gross erosion rates**





Measurements by W. Wampler

Summary on High-Z erosion

- For one specific divertor plasma condition the measured net/gross erosion for both Mo and W was found to agree with code modeling, i.e. is in accord with the 'standard' idea of prompt, local re-deposition
- Modeling predicts ~100% redeposition in the divertor: positive implications for reduction of net erosion for high-Z in ITER, FNSF
- There is also long range transport of some ions, which had not been generally anticipated. This appears to be a mixed materials effect involving increased sputtering yield for metals deposited on carbon
- A new, non-spectroscopic method for measuring gross erosion rates has been demonstrated
- The latest experiment used stronger-ionizing (higher n_e and T_e) plasmas. W coatings on Mo were exposed to get different set of mixed materials effects.

Preliminary result: W net erosion .33 nm/s (compared to .14 nm/s prior)

Net versus gross erosion of Al

C. Chrobak, PhD thesis

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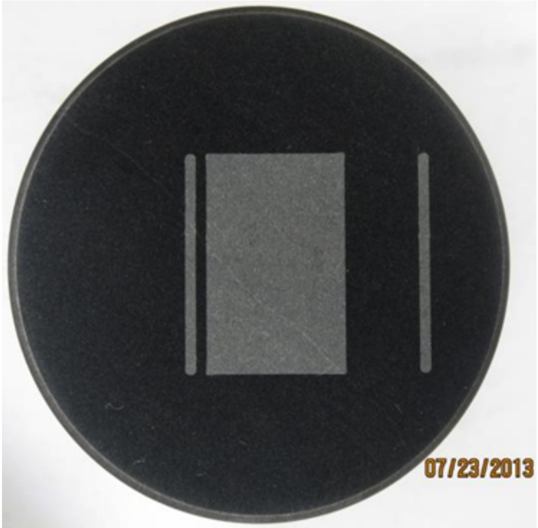
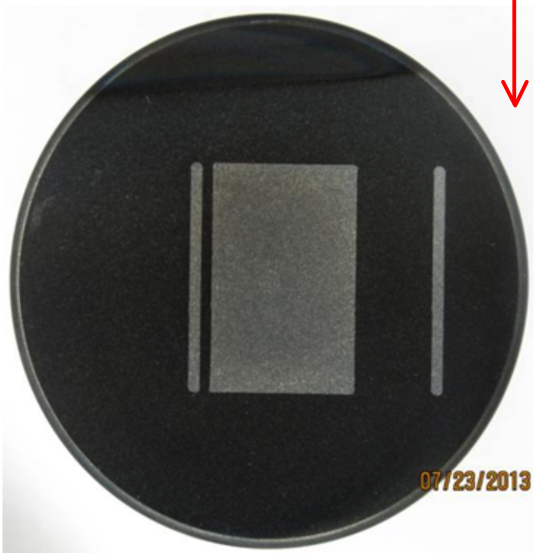
Summary of Al Erosion Experiments

- Test of Al as a non-hazardous simulation proxy for Be
- DiMES exposure of 100 nm aluminum thin film on polished ATJ graphite substrate
- Film deposition performed and surface roughness characterized at SNL-CA
- Sample exposed to 4 L-mode shots for a total of ~14 s (LSN attached conditions)
- Spectroscopic estimates of gross erosion made by C. Chrobak
- IBA measurements at MIT complete (G. Wright) and analysis in progress



Before

Radial direction

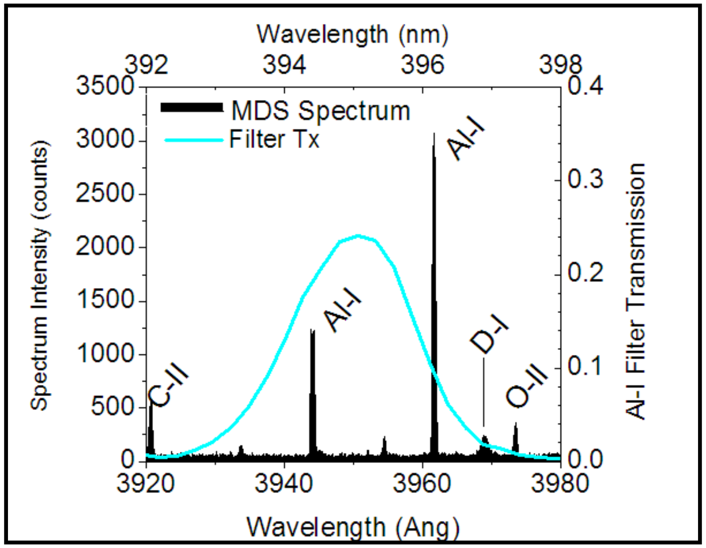


After

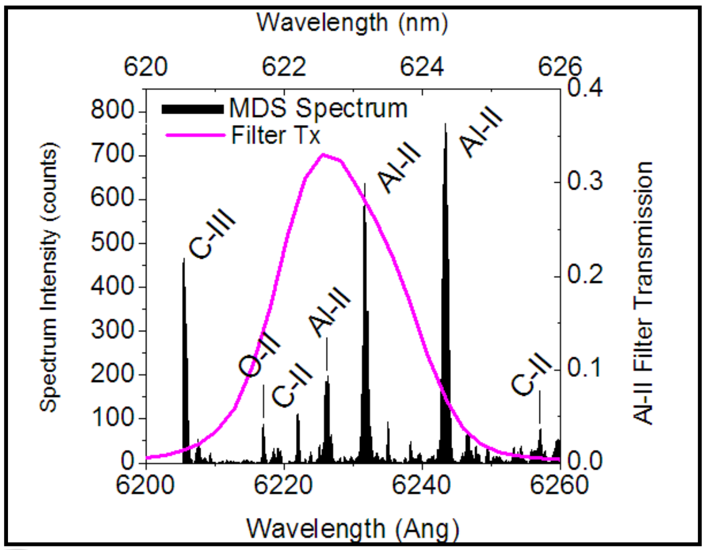
Bt direction

Sample Imaged in Al-I and Al-II Light

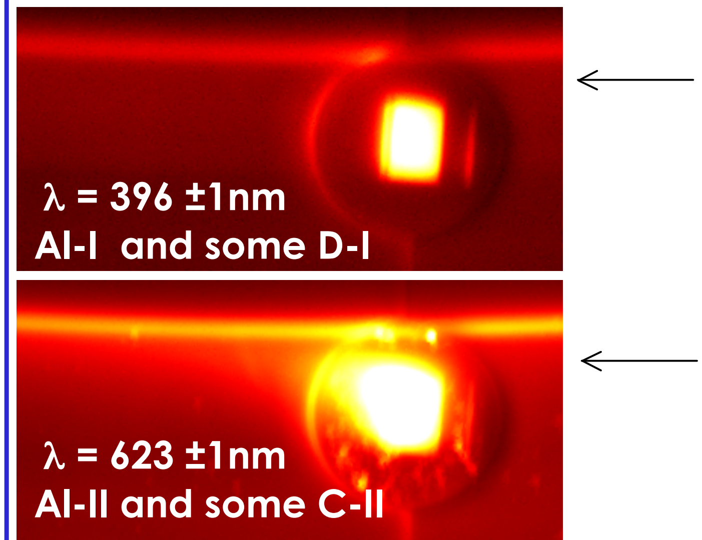
Al-I
396.1 nm



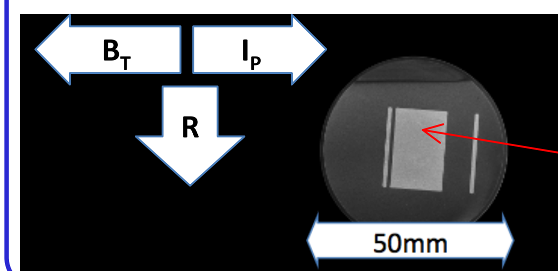
Al-II
624 nm



Spectroscopically filtered visible light images



DiMES sample reference photo

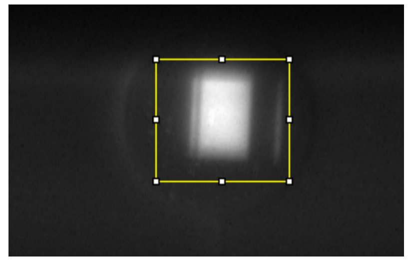


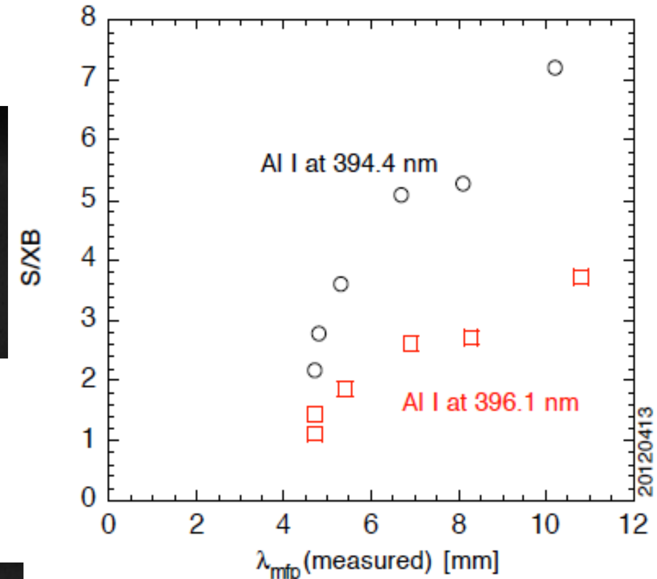
100nm Al thin film stripes

Courtesy of C. Chrobak

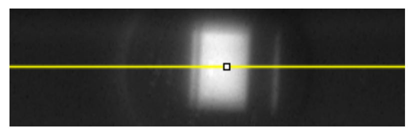
Estimates of Gross Erosion based on Spectroscopic Data

Average method:
Integrating all photons in Al area,
Adjust by 10% for reflectivity,
Subtracting background,
Use S/XB = 3.55 (based on filter transmission of both Al-I lines)
Scale by total Al coating area,
Total erosion estimate = 1.28 nm

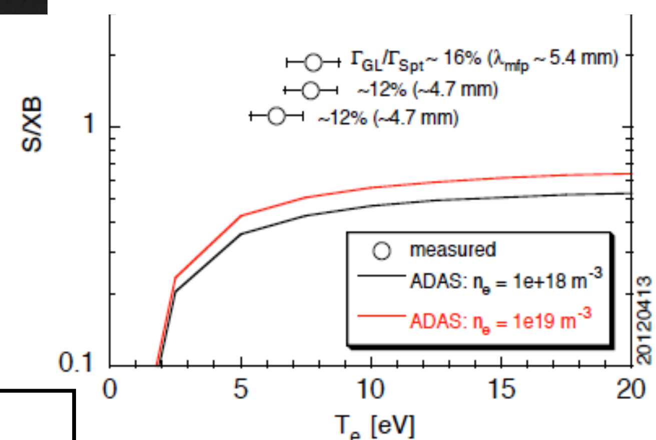




Emission convolution method:
Make toroidal line profile of image,
Subtract background,
Fit profile based on superposition of emission kernels
Integrate photons in emission kernel,
Use S/XB = 3.55 (based on filter transmission of both Al-I lines)
Scale by emission kernel area,
Total erosion estimate = 1.62 nm



n_e ~ 7.5e18 m^{-3} for the experimental data above.

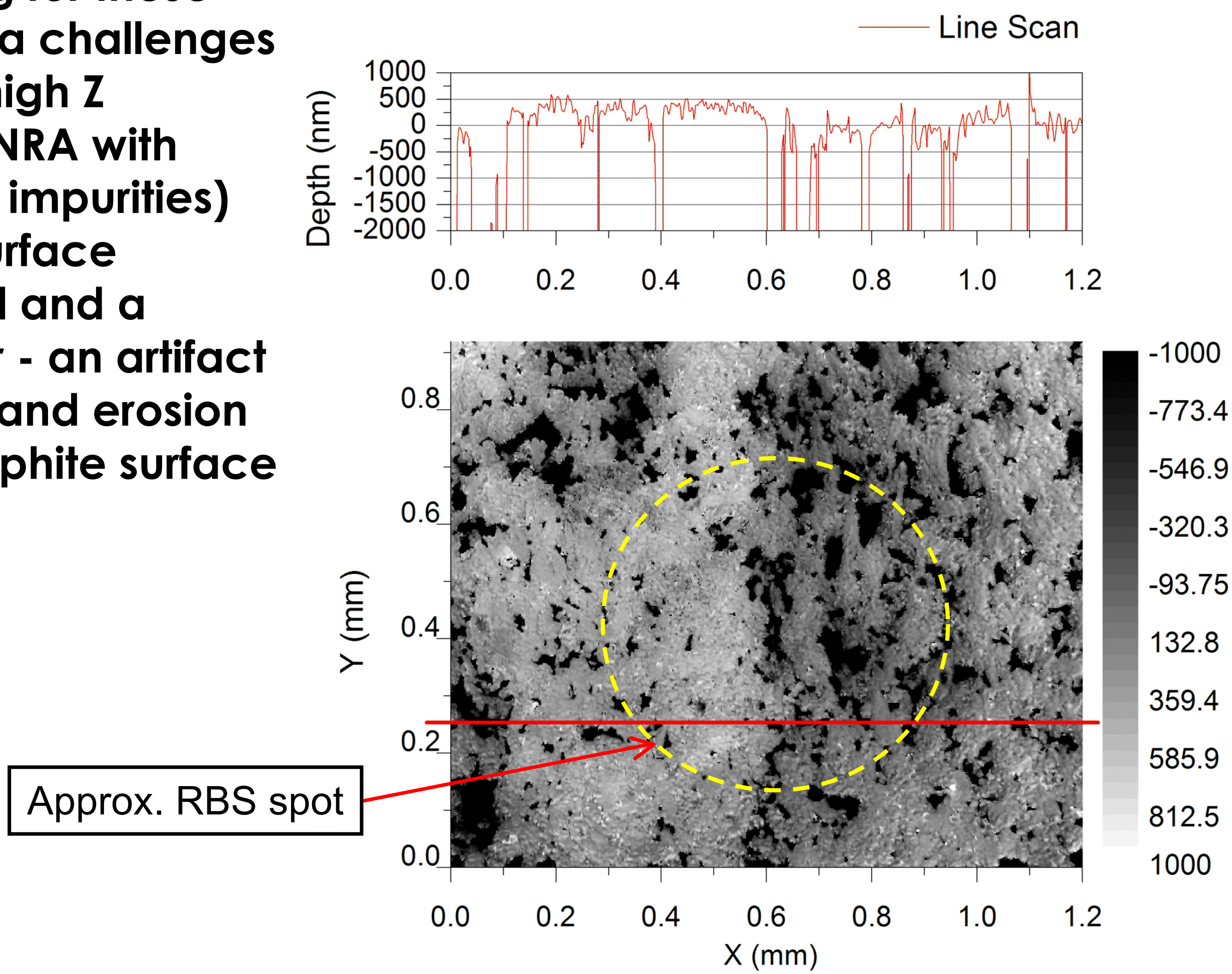


Further work to determine S/XB in progress due to low spectroscopic erosion (~ 16x) compared with RBS

Courtesy of C. Chrobak

Estimates of Gross Erosion based on RBS Measurements

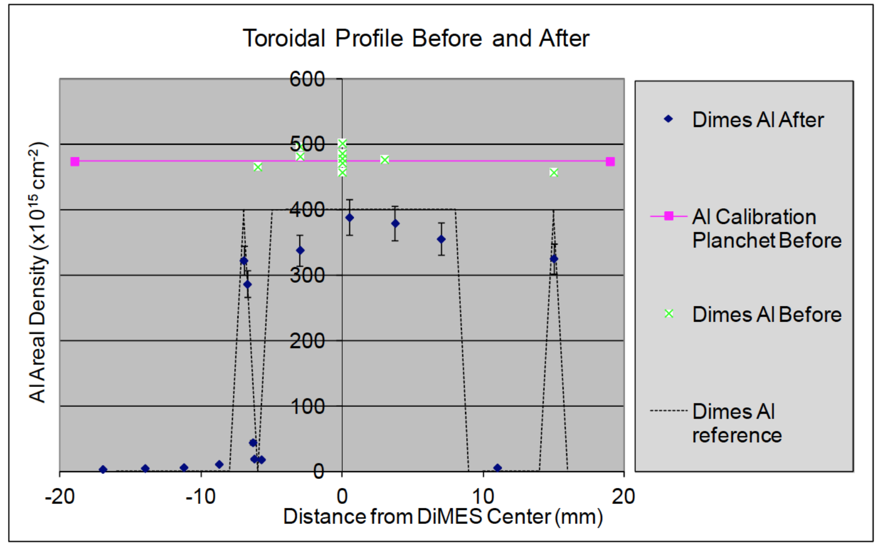
- **RBS spectra fitting for these surfaces has extra challenges compared with high Z experiment (SimNRA with base materials & impurities)**
- **Fitting requires surface roughness model and a mixed Al/C layer - an artifact of deposition on and erosion from a rough graphite surface**



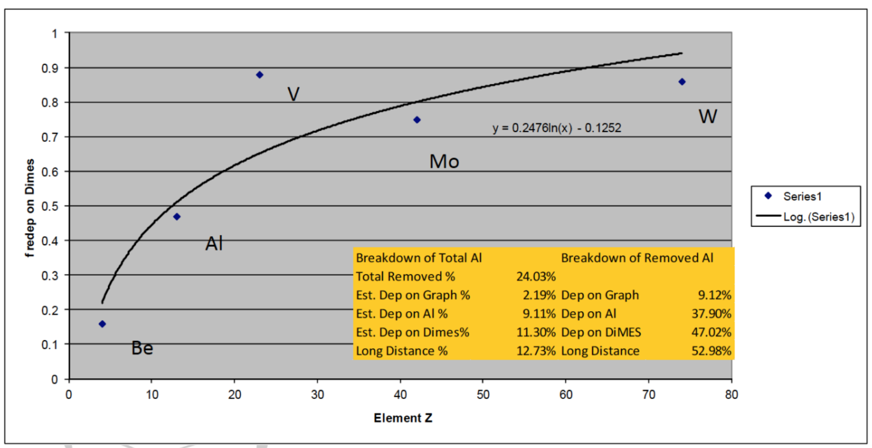
Courtesy of C. Chrobak

Preliminary Estimate of Gross Erosion

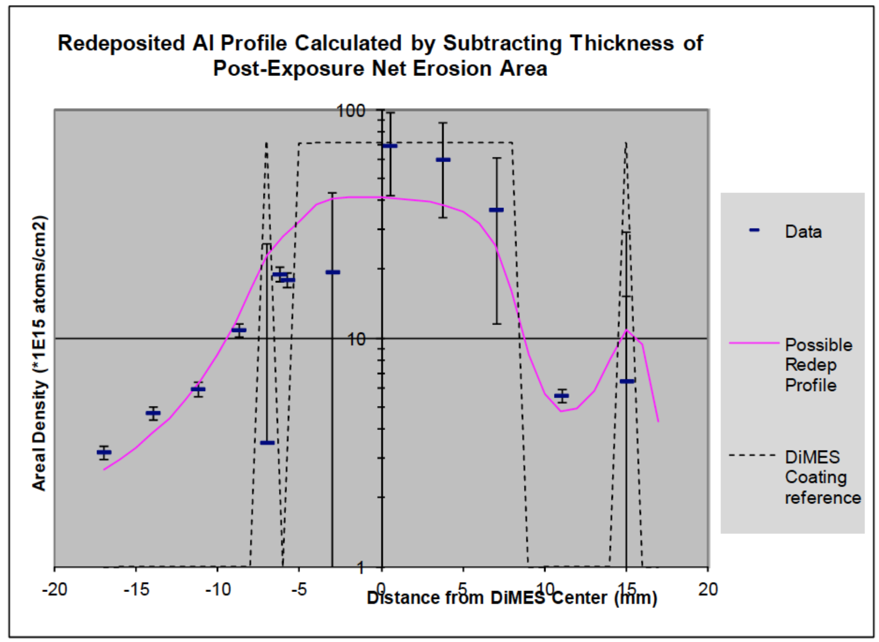
- Preliminary estimate indicates gross and net erosion much closer together than for high Z materials
- Despite large uncertainty, estimate of redeposited Al fraction agrees with earlier experiments
- Refinements of RBS fitting in progress



Estimated redeposited fraction compared with 1996 experiments



Breakdown of Total Al		Breakdown of Removed Al	
Total Removed %	24.03%		
Est. Dep on Graph %	2.19%	Dep on Graph	9.12%
Est. Dep on Al %	9.11%	Dep on Al	37.90%
Est. Dep on Dimes%	11.30%	Dep on DiMES	47.02%
Long Distance %	12.73%	Long Distance	52.98%



Data from Whyte, Brooks 1999 Nucl. Fus.

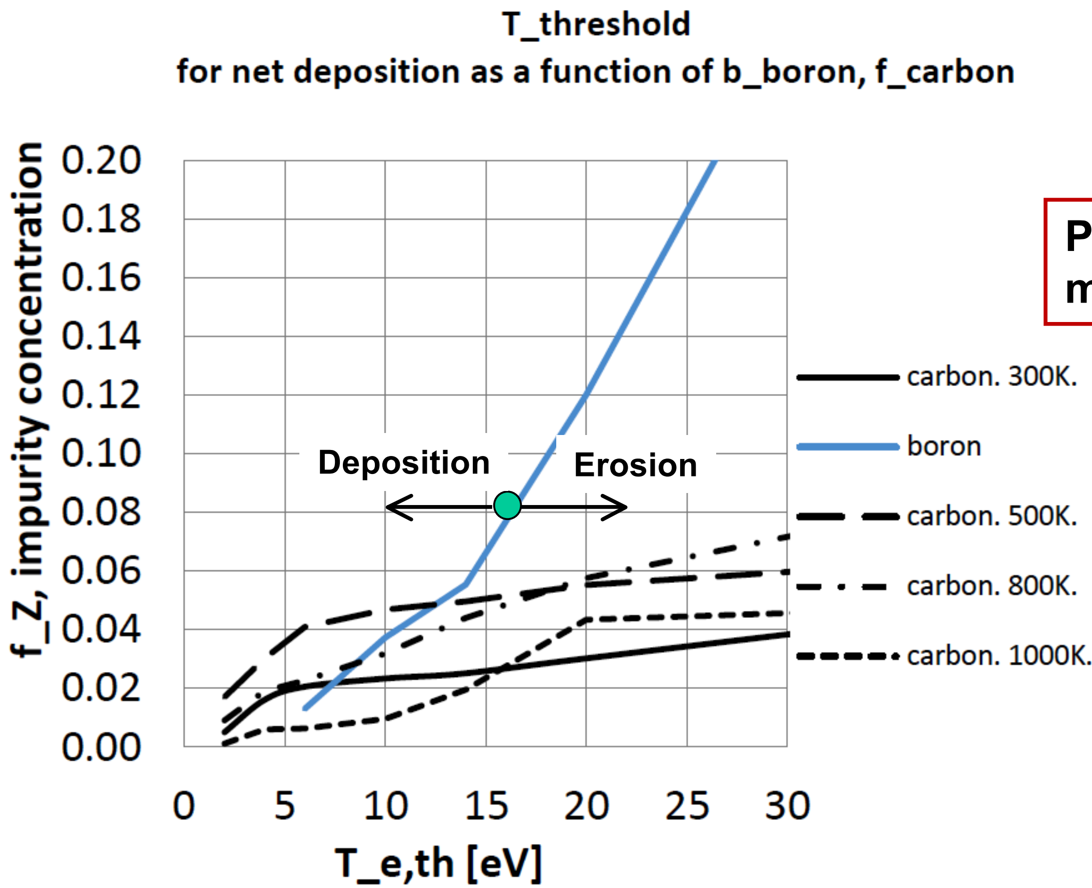
Courtesy of C. Chrobak

Control of high-Z PFC erosion by local gas injection

Control of High-Z PFC Erosion by Local Gas Injection

- **Date:** August 29 2013
- **Aim:** demonstrate control of high-Z PFC erosion by local gas injection via in-situ deposition of a sacrificial low-Z coating
- **Experimental approach:**
  - Use attached L- and H-mode discharges with plasma conditions known to cause net erosion of Mo and C in DIII-D divertor
  - Inject $^{13}CH_4$ upstream of Mo-coated DiMES sample to suppress Mo erosion without affecting global discharge or divertor plasma parameters
- **Preliminary results:**
  - Puff at a moderate puff rate of 1.5-2.8 Torr-L/s about 12 cm upstream of the sample resulted in suppression of Mo erosion, as evidenced by disappearance of MoI light emission
  - Carbon deposition observed on both samples upon removal
  - Success in both L- and H-mode, at least at the conceptual level

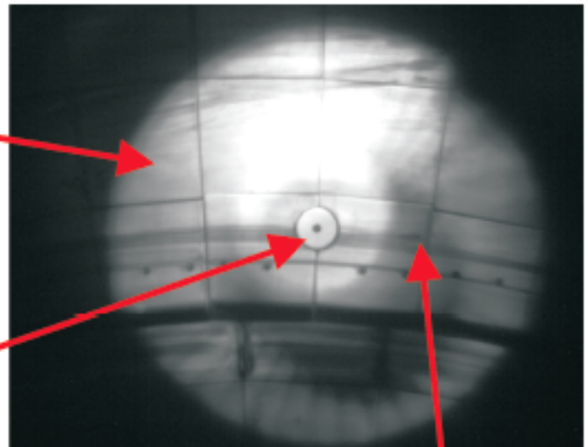
Local $^{13}CH_4$ Injection will Lower T_e and Increase C Content



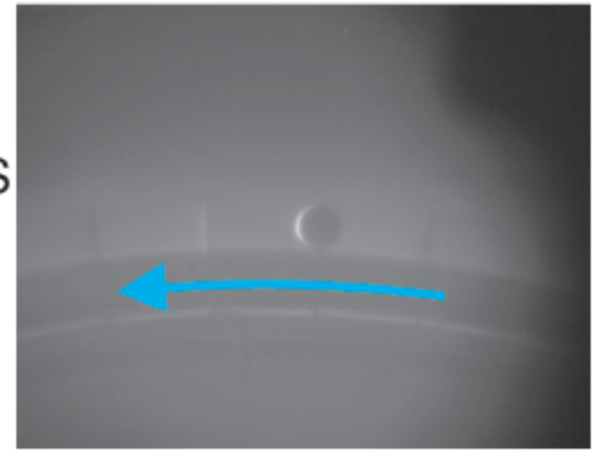
P. Stangeby memo from 7/31/13]

- In earlier experiments we observed net erosion of Mo and C at 30 – 40 eV with estimated 2% carbon concentration
- Lowering local T_e and/or increasing C concentration will tilt erosion/deposition balance towards net deposition

DiMES TV CMOS Camera Confirms Capillary Gas Puff Leads to Particles Transporting Across the DiMES Sample

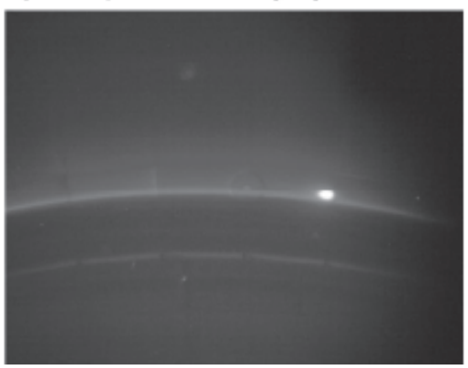


L-mode, no DiMES sample CD-filter

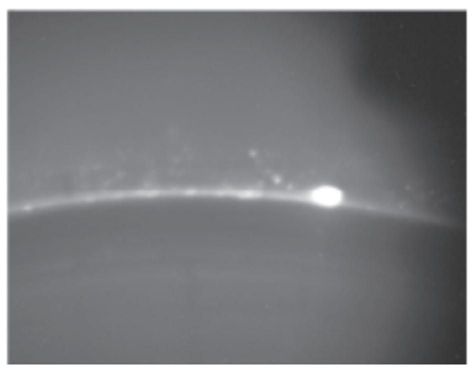


Downstream plasma direction (blue arrow)

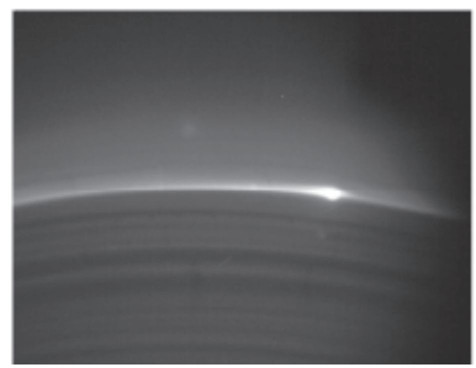
CD/CH filter (CH_4 breakup product)



CI (carbon neutral) filter

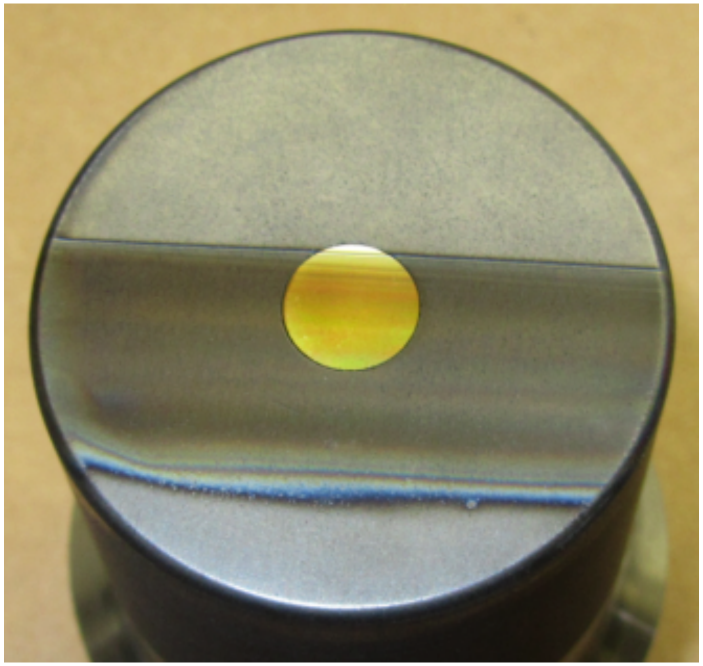


CII (carbon ion) filter

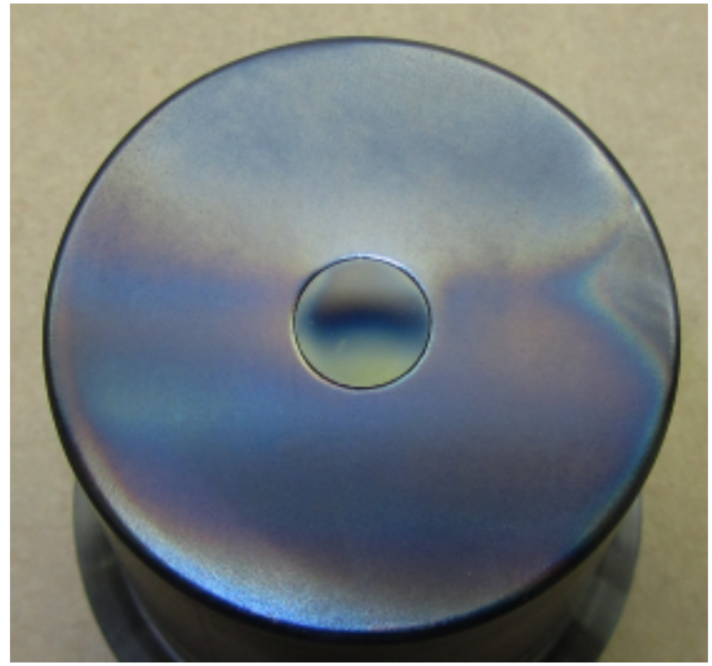


Courtesy of A. McLean

Carbon Deposition Observed on Both Samples



Sample exposed to 4 L-mode shots
154588-91



Sample exposed to 2 H-mode shots
154593,95

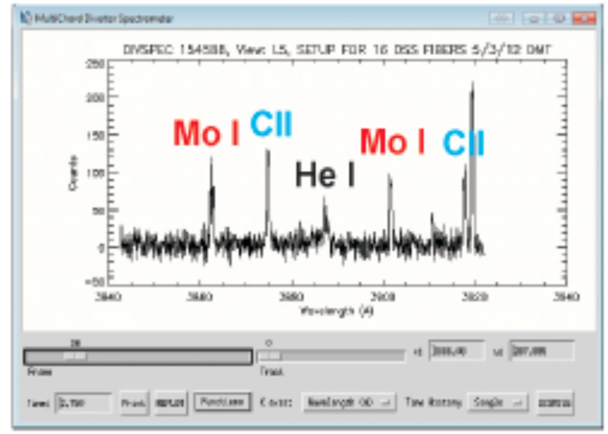
- **Exposed samples have been analyzed by RBS at SNL Albuquerque for Mo erosion and carbon deposition**
- **The use of ^{13}C will allow distinguishing carbon deposited due to the local puff versus that from the plasma carbon background**

Preliminary result: very low net Mo erosion and higher C & D/C ratio for L-mode plasma

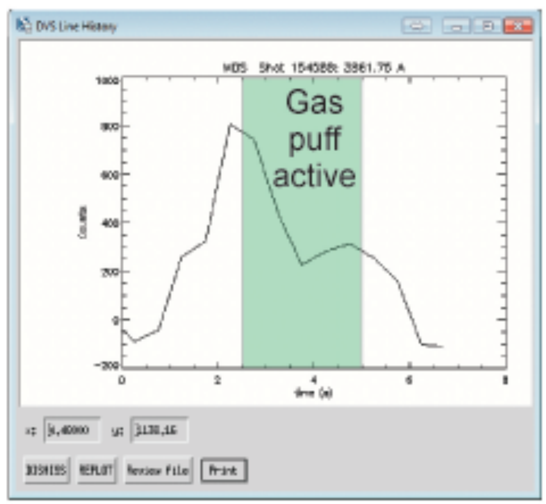
High Resolution Spectrometer Shows Mo Emission/ Erosion Extinguishing with the Capillary Puff Active

- **MDS spectrometer viewing the DiMES port directly, 0.2-1.0 s integration time**
- **Small gas puff (154588), 0.5 Torr-L/s CH_4 leads to ~3X reduction in Mo I**
- **Larger gas puffs (154589 onwards), 1.5-3.0 Torr-L/s CH_4 leads to no observable Mo I emission at all**

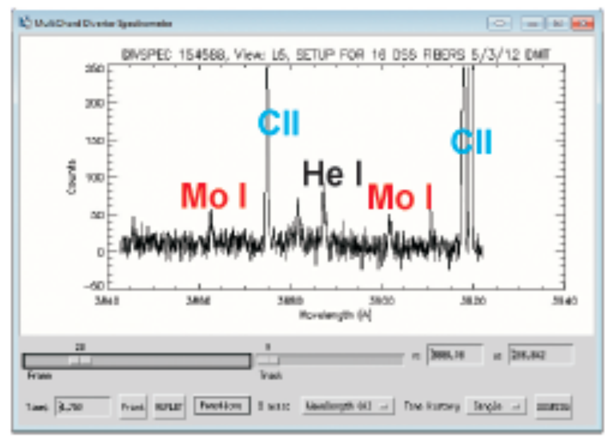
Pre capillary puff



Mo I emission with time



With capillary puff 0.5 torrL/s 2.5-5.0 s



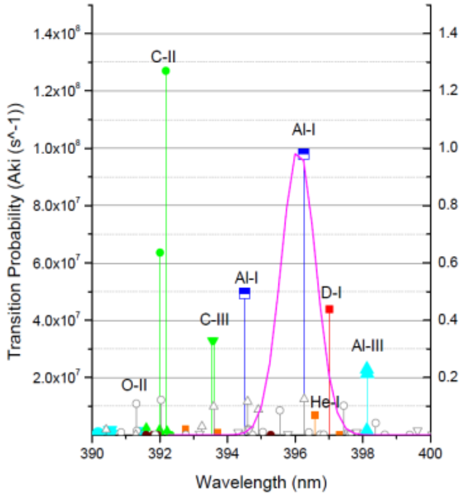
Mo I emission ~3X lower
CII (C+) emission 2X up

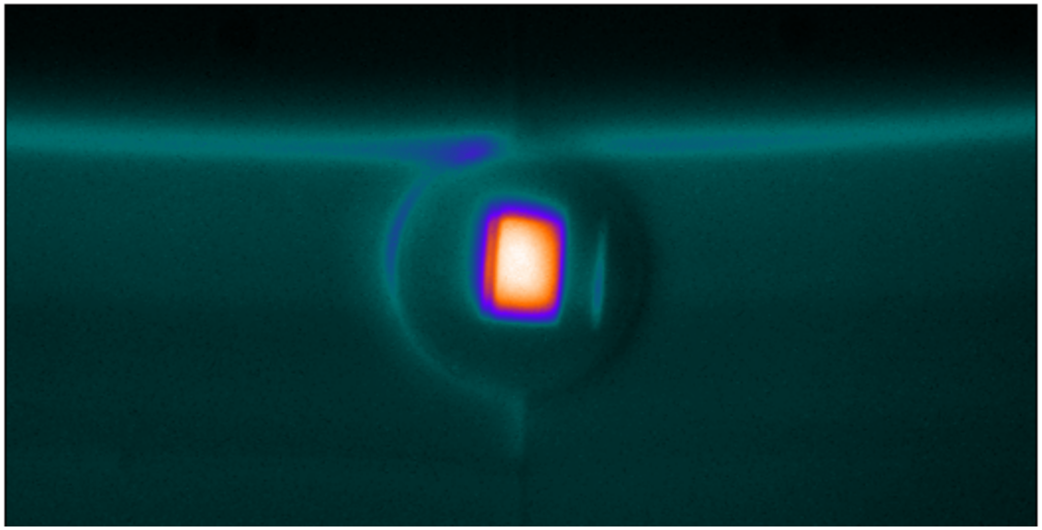
Courtesy of A. McLean

Thanks for your attention!

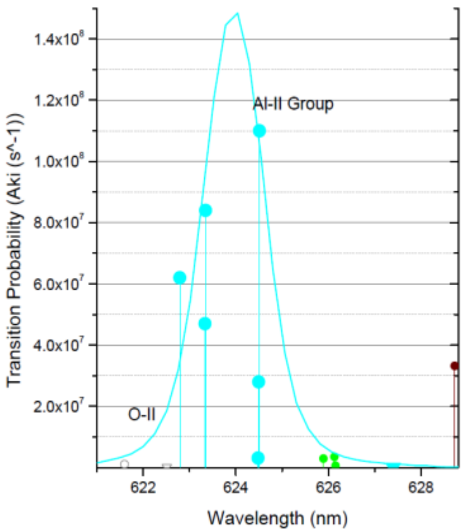
Sample Imaged in Al-I and Al-II Light

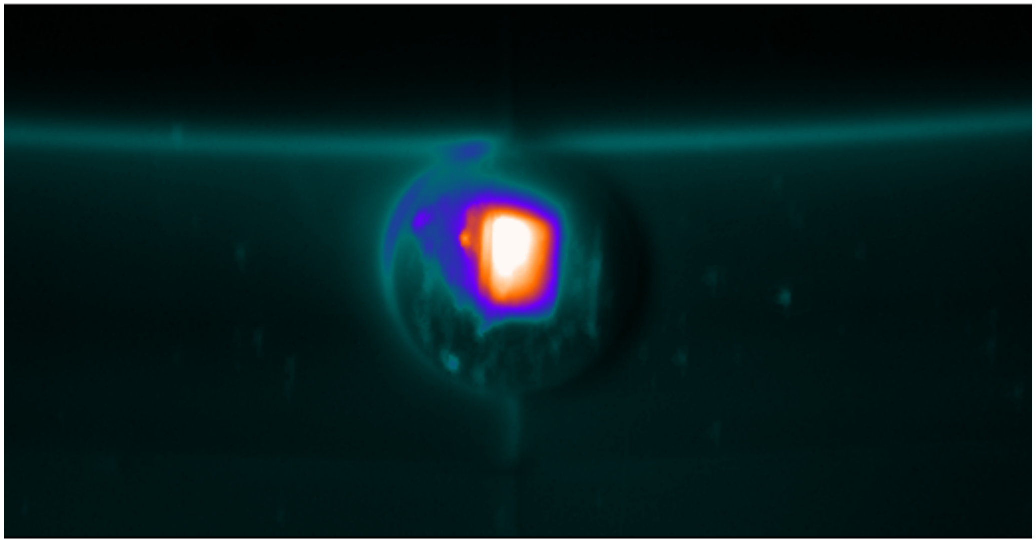
Al-I
396.1 nm





Al-II
624 nm





Courtesy of C. Chrobak