High-Z erosion and other recent DiMES and MiMES experiments

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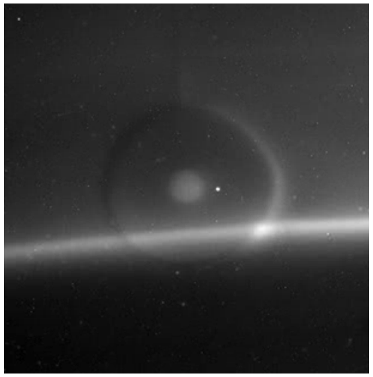
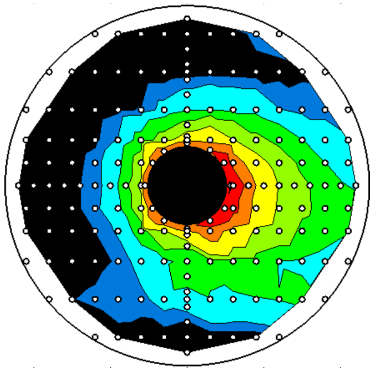
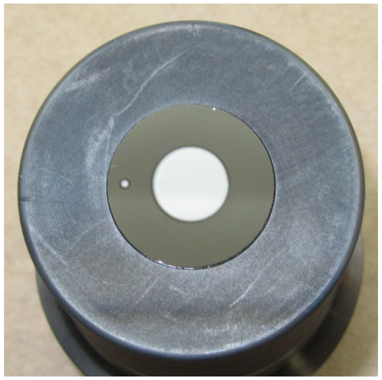
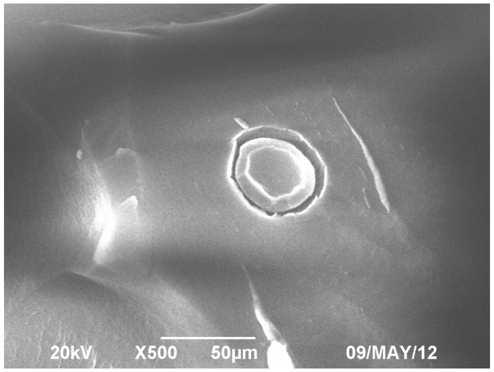
DiMES Team and Collaborators

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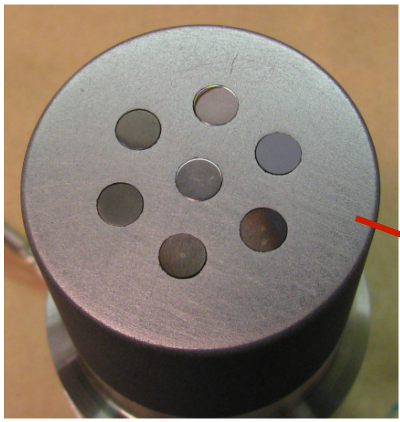
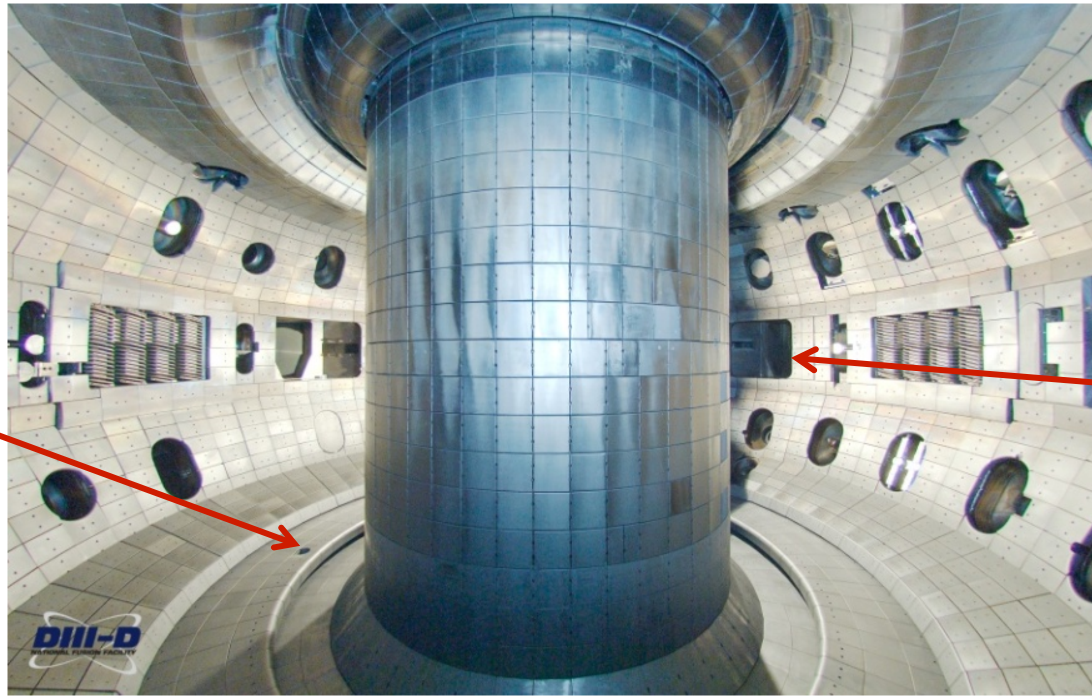
Presented at the PFC Meeting at PPPL
Princeton NJ, June 20-22, 2012

UCSD

Divertor Material Evaluation System – DiMES
Mid-plane Material Evaluation Sample – MiMES

DiMES





MiMES

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

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Experiments to be covered

This talk — **Dedicated time**

- **Gross versus net erosion of Mo – 3 experiments**
- Gross versus net erosion of W and Al - preliminary results

- Dust studies
  - Dust capture with aerogel in MiMES
- First mirror studies
  - Advanced duct geometry for mirror protection
- Arcing studies

Covered by others

- C. Wong: Si-W surface material development
- D. Donovan: Sheath power transmission studies

Gross versus net erosion of high-Z material

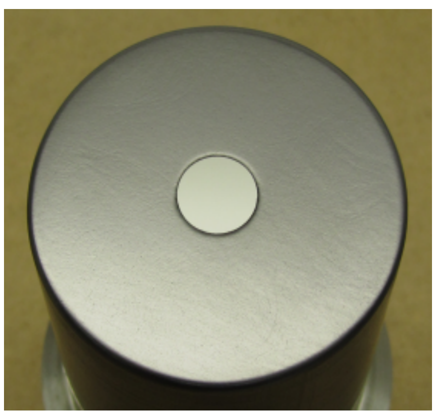
Experiment proposed and led by Peter Stangeby

- **Motivation**
  - Net erosion of high-Z plasma-facing surfaces in a tokamak divertor is expected to be reduced by redeposition due to gyro-motion, strong E-field in the magnetic pre-sheath and friction with fast plasma flow
  - Although the theoretical ideas underlying these processes are basic and while there is also evidence for their validity, e.g. Krieger, 1998 PSI, Brooks & Whyte NF 1999…
  - …in C-mod measured net erosion of Mo (campaign-integrated) ~ an order of magnitude larger than expected from simple basic considerations and also contrary to detailed (WBC) code modeling [Brooks, 2010 PSI]

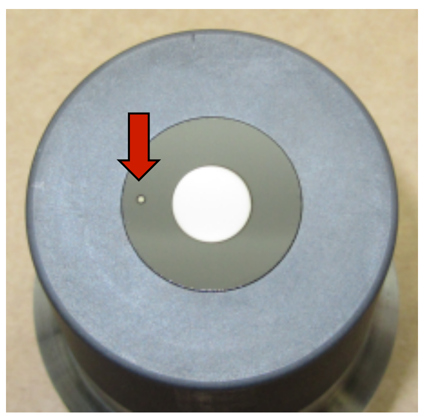
- **Experimental approach in DIII-D**
  - Expose pre-characterized Mo sample (for better known S/XB) using DiMES under reproducible well-characterized plasma conditions
  - Measure gross erosion spectroscopically, net erosion by IBA
  - Compare with modeling

3 Mo exposures have been performed

Date	Exposure time [s]	Initial Mo thickness [nm]	Probe data T_{emax} [eV], n_{emax} [10^{19} m^{-3}]	MoI filter passband [nm]	with 1 mm sample
8/1/2011	28	24.16	30, 1.5	10	no
4/23/2012	12	23.81	no data	1	no
5/1/2012	4	16.13	40, 1.2	1	yes



Experiments #1, 2



Experiment #3

- All samples featured a1 cm diameter Mo coating deposited on Si substrate
- A 1 mm Mo spot was added in the 3rd experiment to get non-spectroscopic measurement of gross erosion (since redeposition for such small spot is small, ~ 5% from WBC/REDEP code)

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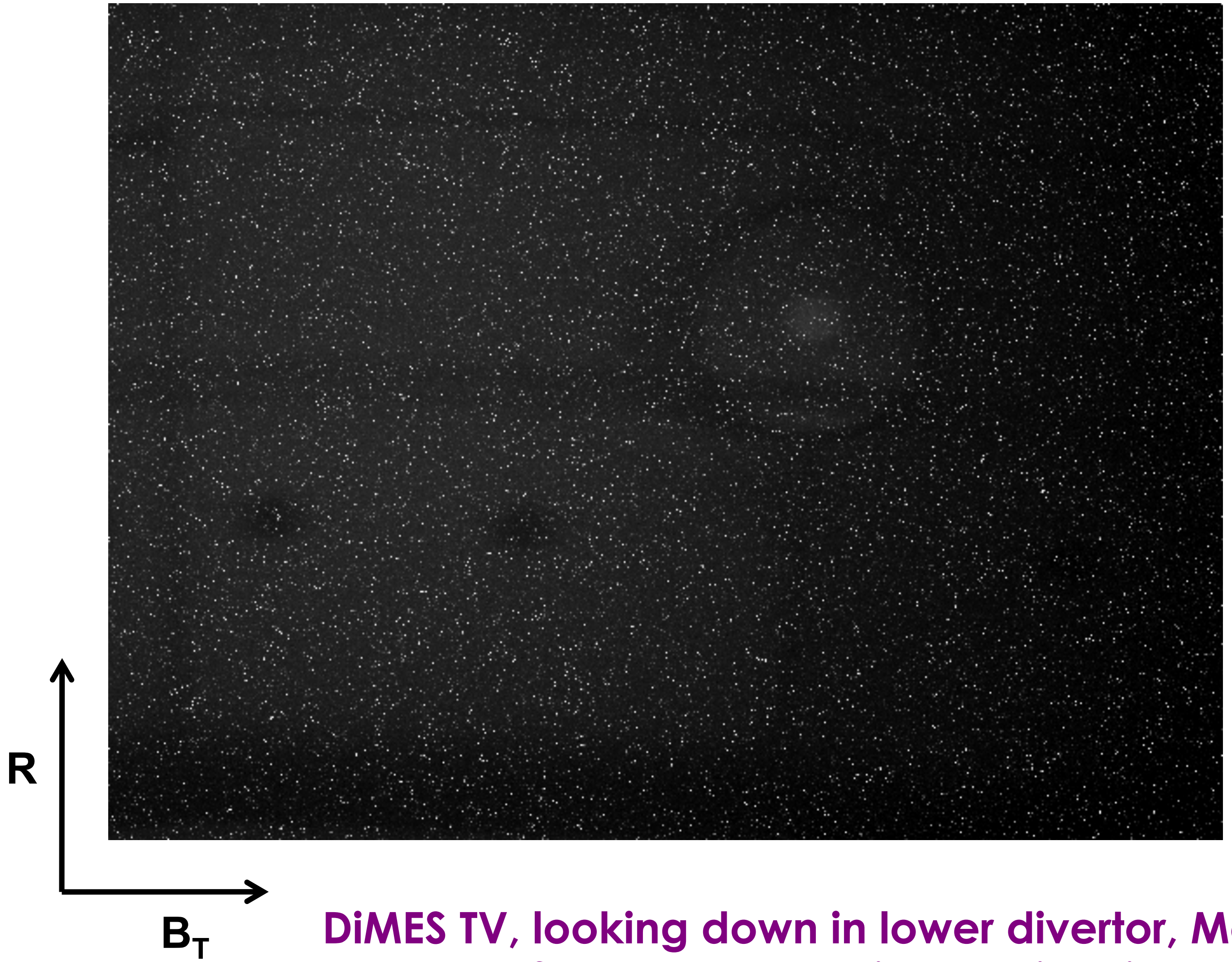
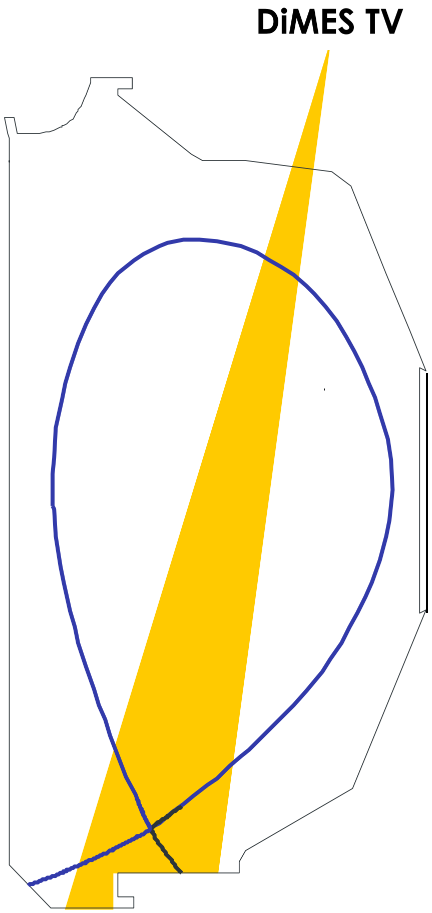
MoI light observed by CCD camera

Shot number 145673





DiMES TV, looking down in lower divertor, MoI filter 390 nm, frame rate 5 Hz, integration time 50 ms

Courtesy of N. Brooks

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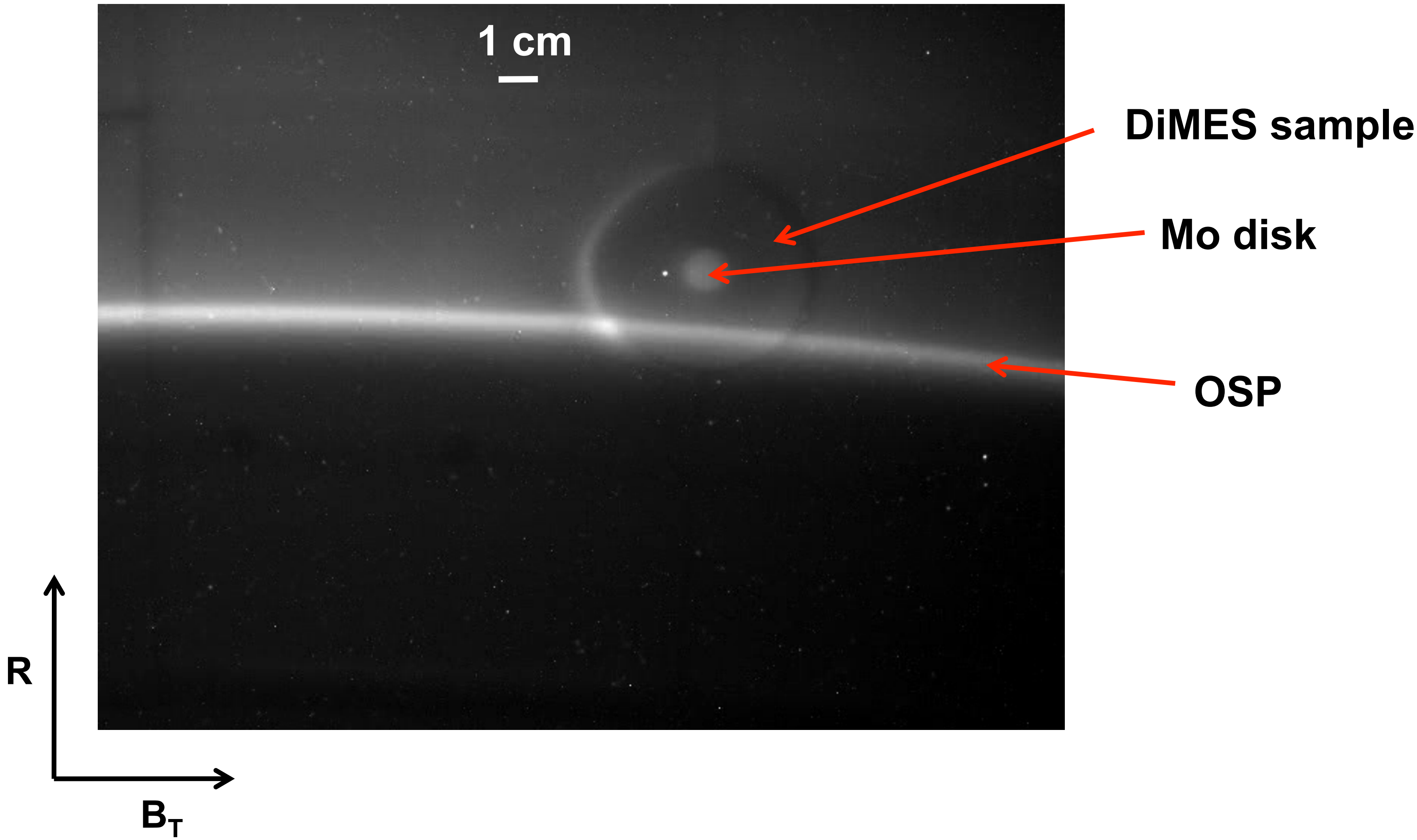
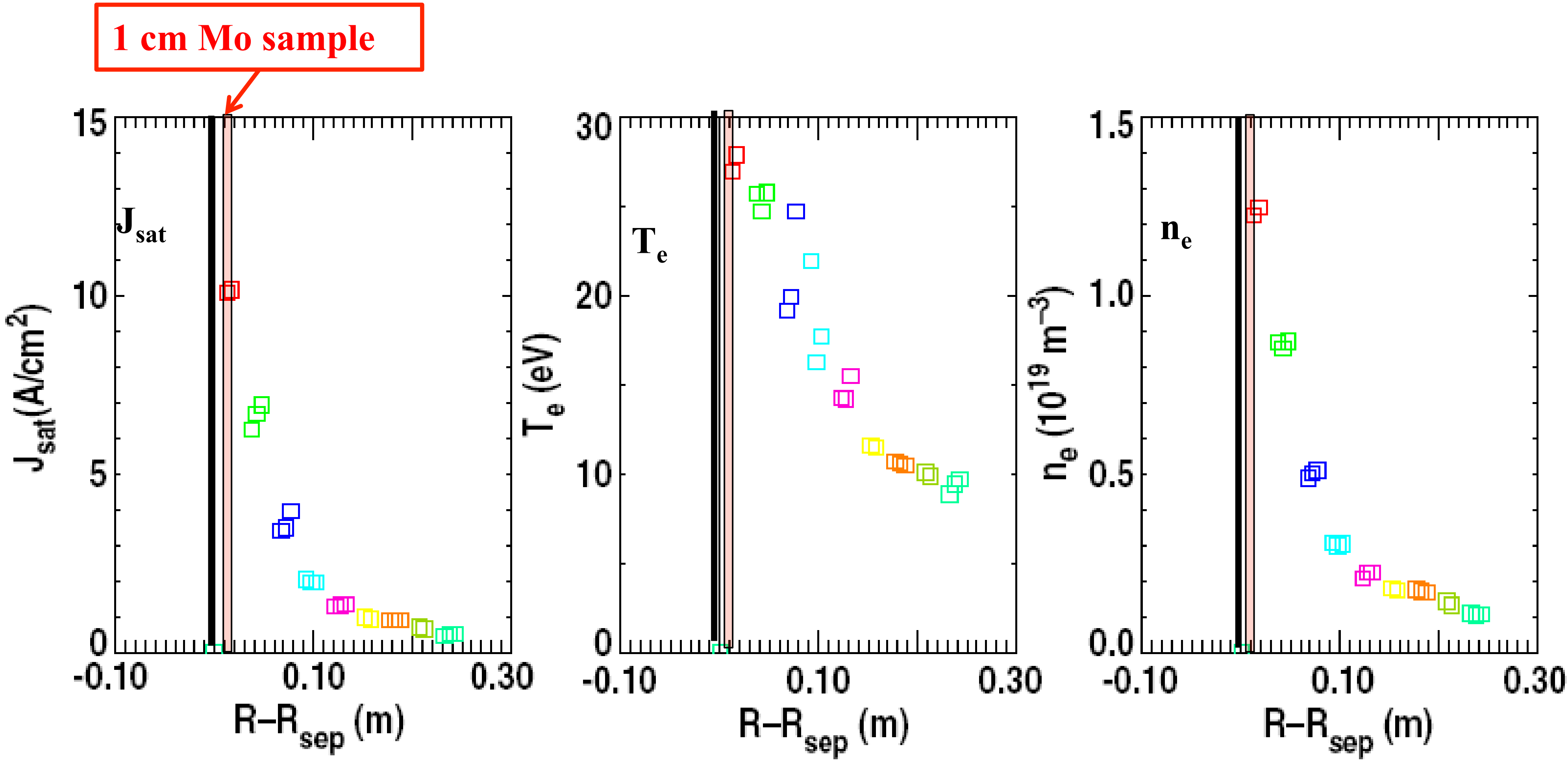
OSP was ~ 1.5 cm inboard of the Mo disk



Good OSP position control

Langmuir probe profiles across the sample



Mo sample center at ~ 1cm outside OSP

Profiles for Experiment #1

Courtesy of J. Watkins

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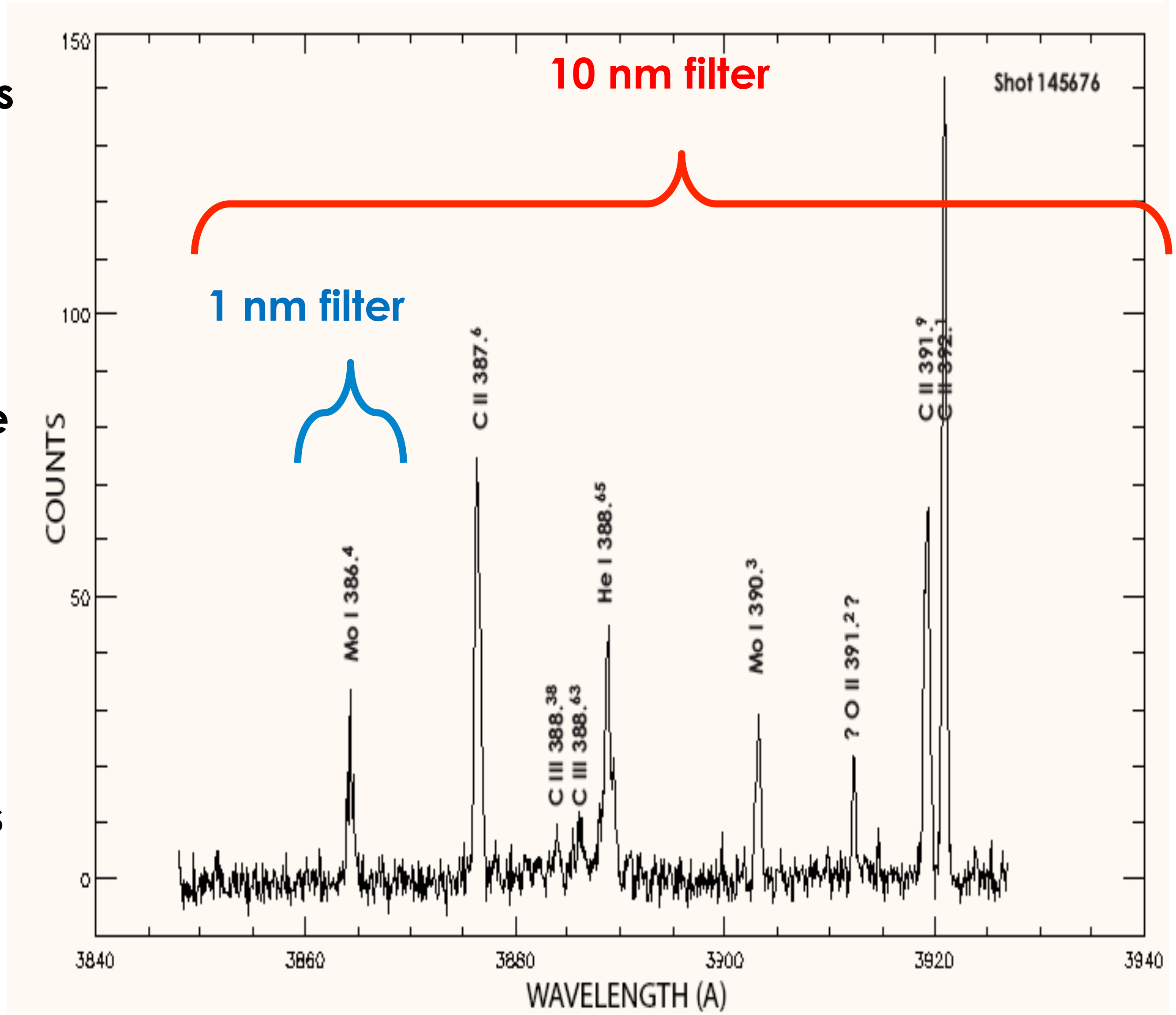
Computer code modeling

- The Langmuir probe data were input to the OEDGE code which generated a 2D plasma solution for the region near DiMES
- The latter was used as input to the REDEP/WBC/ITMC erosion/redeposition code package coupled to the ITMC-DYN mixed-material evolution/response code for re-sputtering of Mo deposited on the C surface
- WBC computes the 3-D, sub-gyro-orbit, full-kinetic motion of sputtered atoms/ions, subject to the Lorentz force motion, and velocity-changing and charge-changing collisions with the plasma
- More detail in a talk by Jeff Brooks, next session

With 10 nm filter signal was dominated by C and He lines

- In the 1st experiment a **10 nm pass band filter** was used, which passed non-MoI lines
- As a result, errors bars for the spectroscopic measurements were large
- A gross/net erosion rate ratio of ~10 was derived, a factor of ~5 larger than predicted by modeling
- In 2nd and 3rd experiments a **1 nm pass band filter** was used, isolating MoI line at



MDS data courtesy of N Brooks and A McLean

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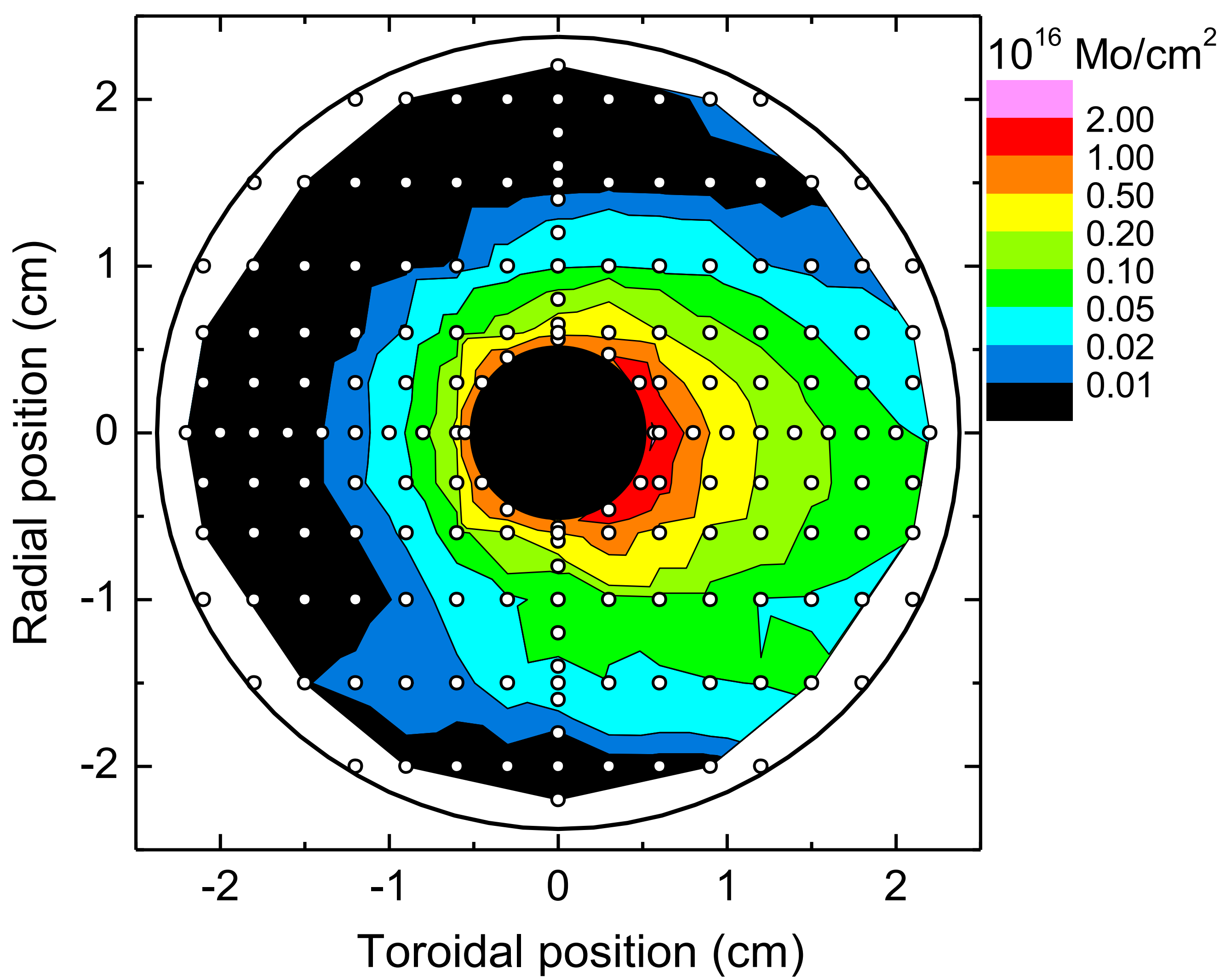
Summary of results from the latest experiment

- For Experiment #3 (1 shot, 4 s exposure) the average thickness of:
  - 1 cm sample was reduced from 16.1 nm by 2.93 nm
  - 1 mm sample was reduced from 12.9 nm by 5.26 nm
- Thus net/gross erosion = 0.56 $\pm$ 12%
- Allowing for 5% redeposition on 1 mm sample = 0.56 -> 0.59
- Compared with code net/gross ratio = 0.46 – Good agreement!
- Gross erosion *rate* = 1.3 nm/s -> 1.4 nm/s

- Spectroscopic measurement of gross erosion performed by absolutely calibrated CCD camera with 1 nm MoI filter centered at 386 nm, assuming S/XB ~ 1 photon efficiency
- Spectroscopically inferred gross erosion rate: 2.45 nm/s
- Ratio = 1.75 is within the uncertainty of the spectroscopic method

Evidence for both local deposition and long range transport of Mo sputtered from 1 cm sample

- RBS found only 19% of the Mo lost from the 1 cm sample, on the surrounding graphite DiMES surface.
- WBC/REDEP/ITMC calculation gave 13%
- Long range migration is due to multiple step erosion of Mo on C surface
- Hopefully, more on this from Jeff Brooks



Experiment #1, measurements by W. Wampler

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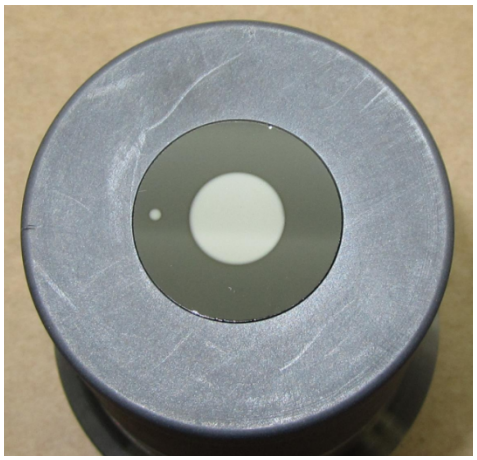
Summary on Mo erosion

- For a specific divertor plasma condition (low density, high T_e, no ELMs) the measured net/gross erosion was found to agree with code modeling, i.e. is in accord with the 'standard' idea of prompt, local re-deposition
- 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 Mo deposited on C
- A new, non-spectroscopic method for measuring gross erosion rates has been demonstrated
- Future studies will use W, Al as proxy for Be, or even Be itself (if allowed)
- For the 'weak' plasma used here, net was only somewhat < gross erosion. In future studies 'stronger' plasmas will be used

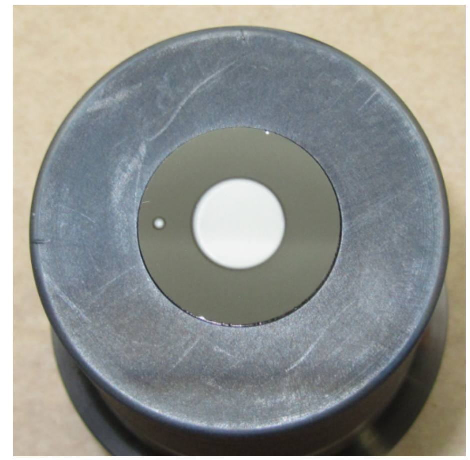
New experiments – erosion of W and Al

- Samples with W and Al coatings have been exposed to 4 L-mode shots each on May 14 2012
- Plasma conditions close to those in Mo experiments

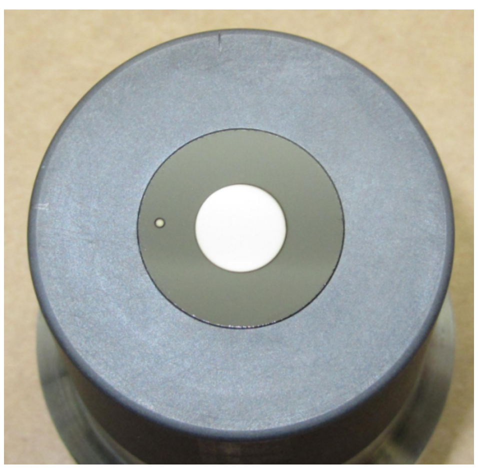
W



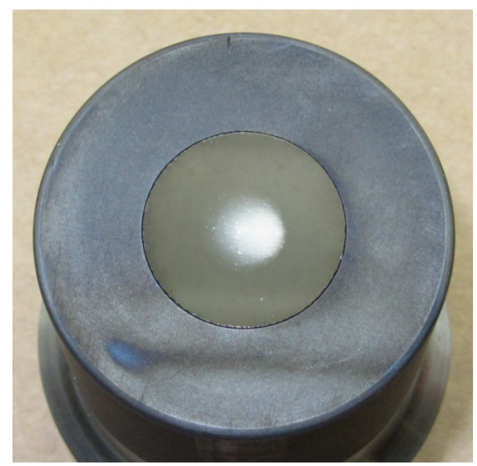
No visible change



Al



Strong erosion
Evidence of melting
1 mm spot gone



Before exposure

After exposure

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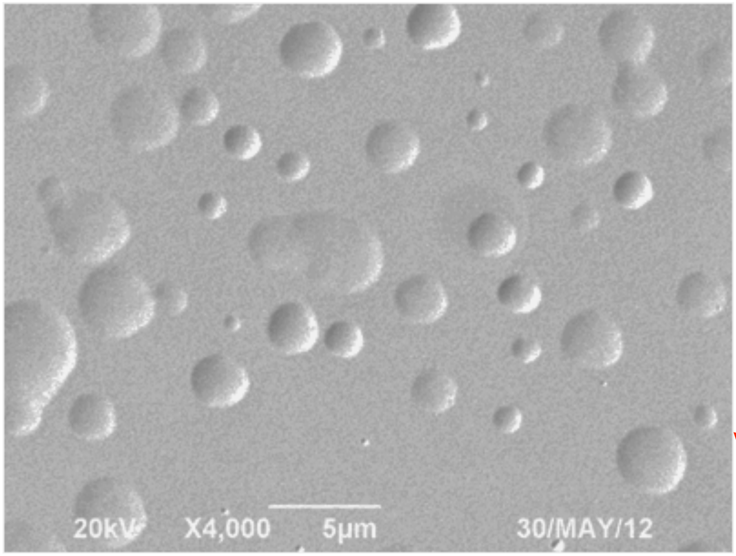
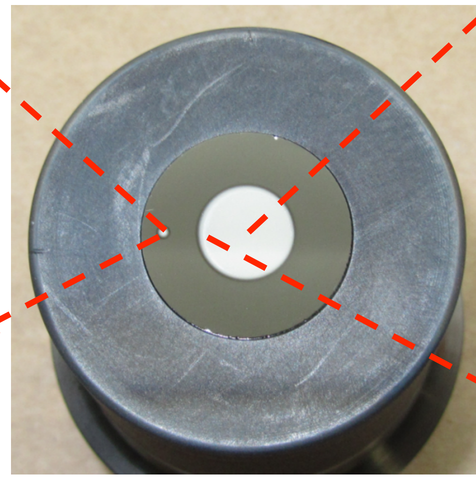
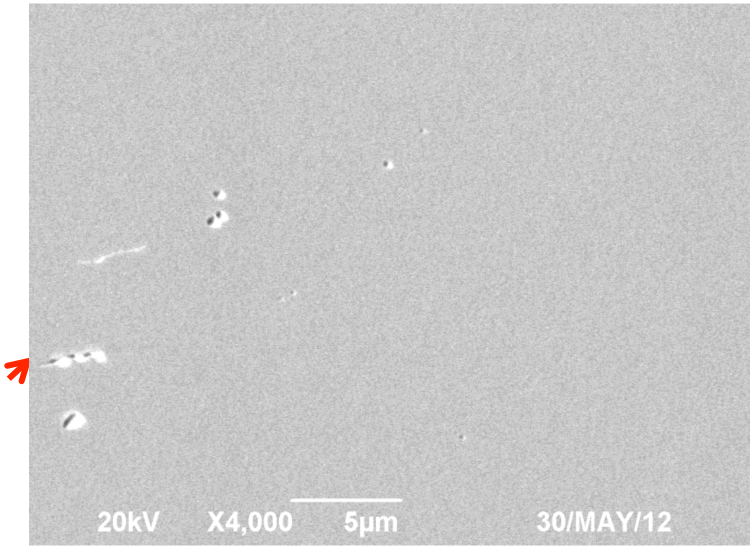
Preliminary analysis results (SEM)



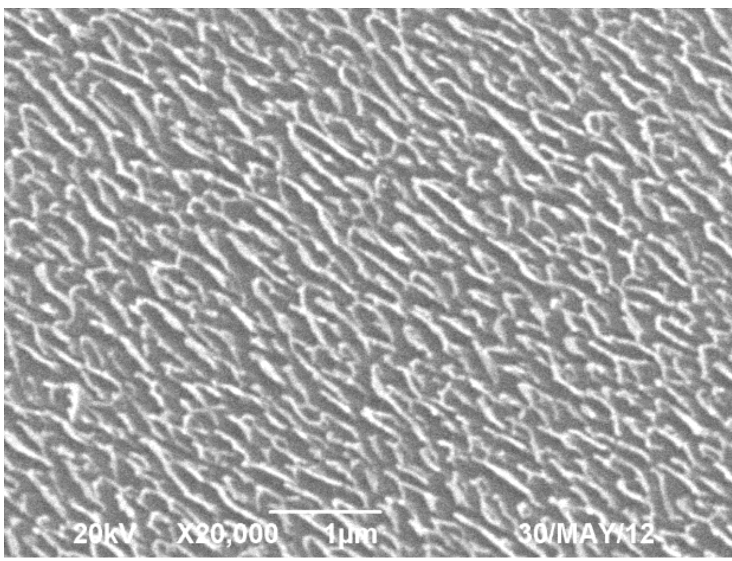
Center of 1 mm spot, blisters

W

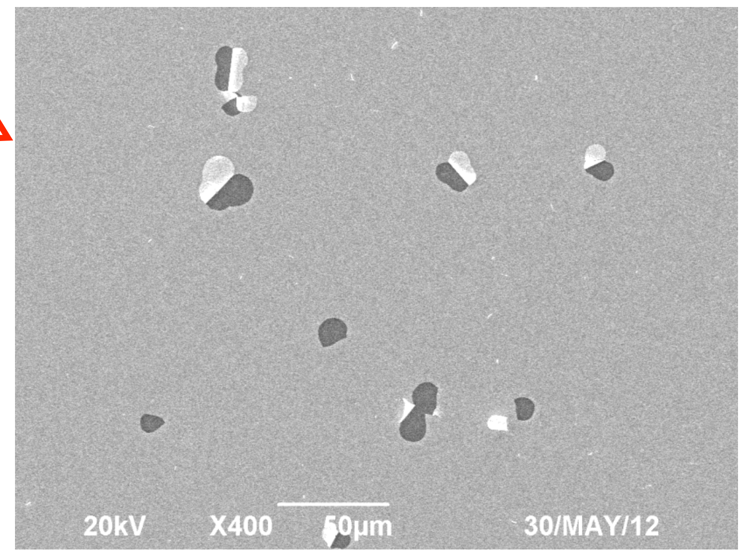




Center of 1 cm spot, no blisters



Edge of 1 mm spot, ripples

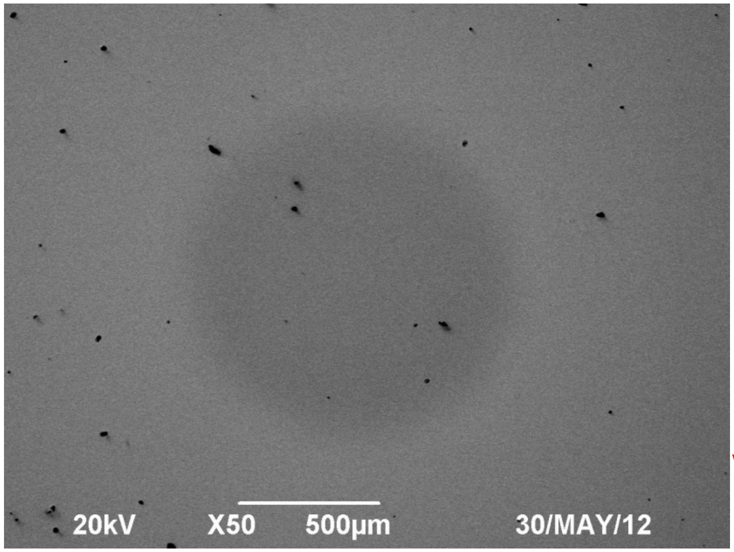


Edge of 1 cm spot, popped blisters

Prospects for IBA look good

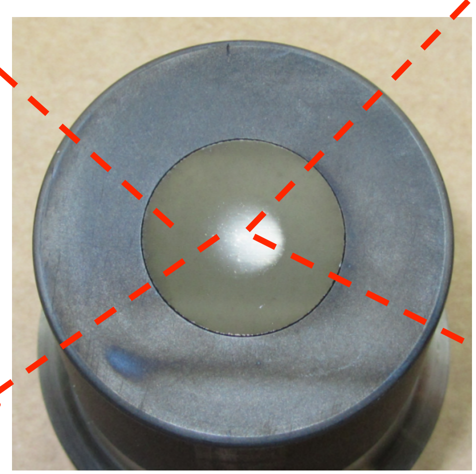
Courtesy of C. Chrobak

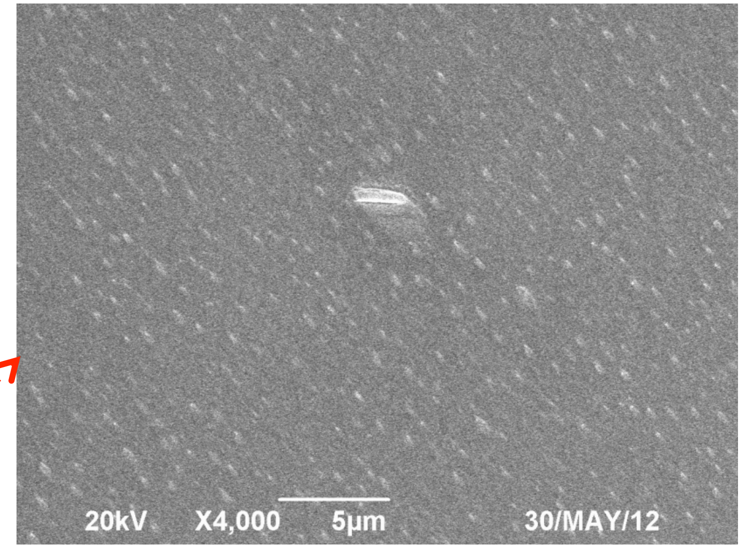
Preliminary analysis results (SEM)



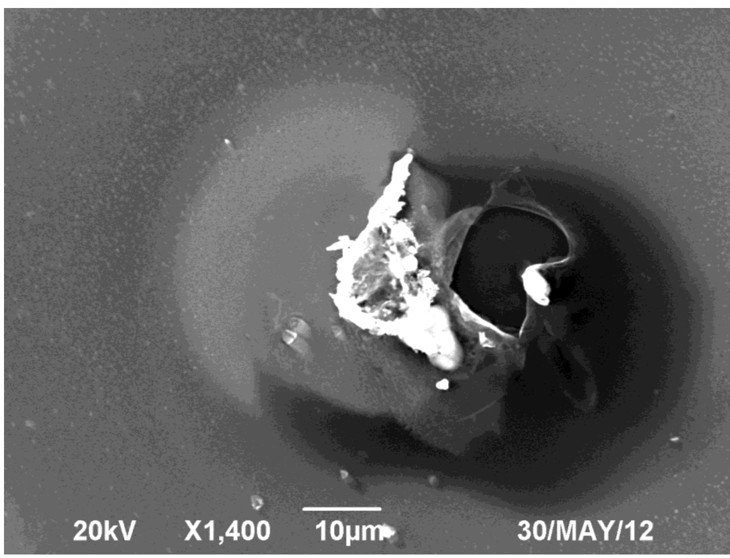
Where 1 mm spot used to be

Al

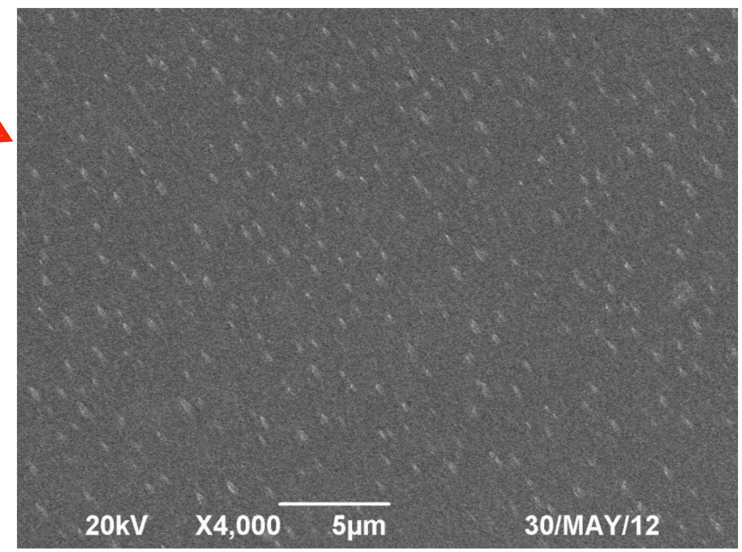




Center of 1 cm spot, an Al droplet



Molten Al speck and film delamination



Center of 1 cm spot, some Al remains

Interpretation will be tough

Courtesy of C. Chrobak

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Dust studies

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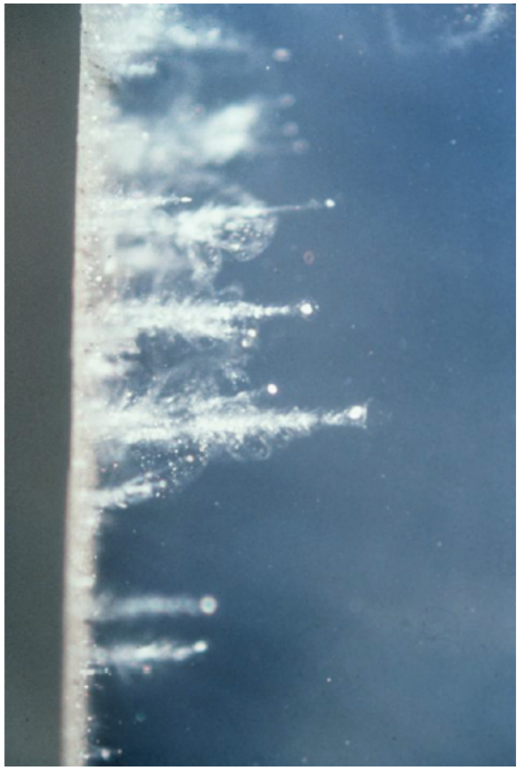
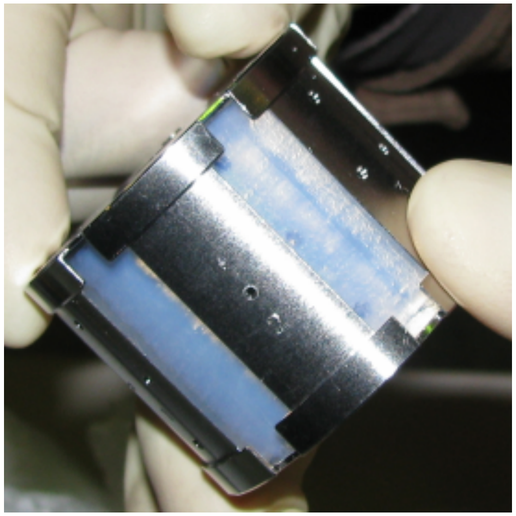
New Dust Collection Technique: Aerogel

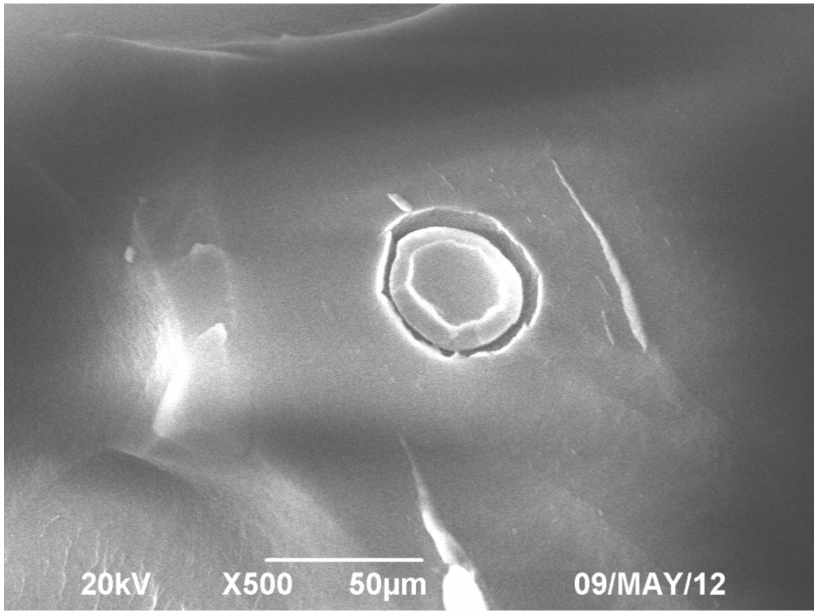
- Highly porous, very low density material
- Used in space programs to collect dust
- Allows capture of dust particles without destroying them
- From the penetration depth particle velocity can be derived
- Tests of aerogel performed in HT-7, TEXTOR and EXTRAP-T2 with encouraging results
- Most recent experiments performed in TEXTOR in May 2011





Aerogel tests in DIII-D using MiMES

- Aerogel sample exposed in MiMES just behind the port edge over 4 days of plasma operations
- Some surface melting observed on Aerogel
- No trapped dust particles found
- Some craters observed, possibly due to dust impacts



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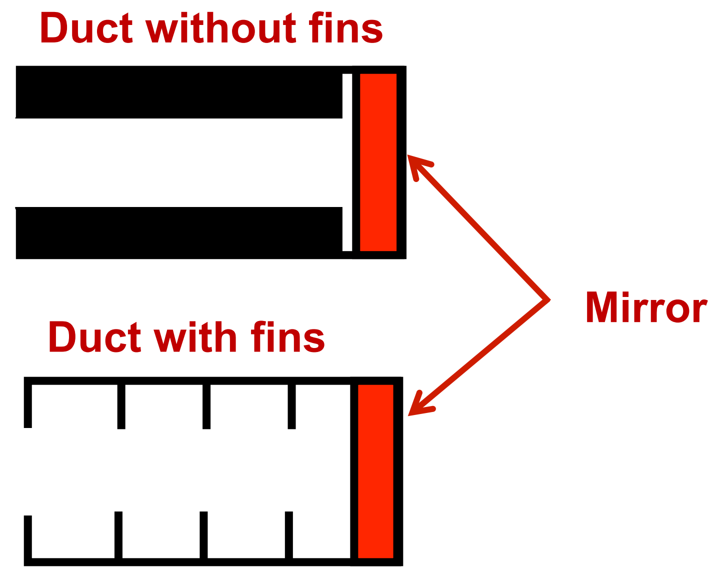
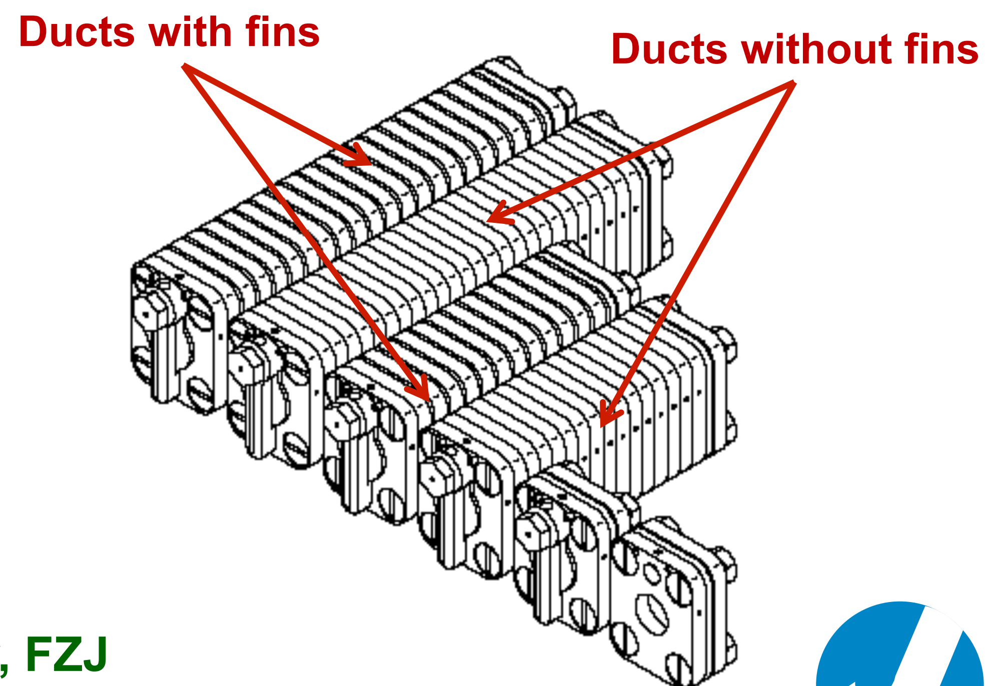
Collaboration with S. Ratynskaia, KTH

First mirror studies

Mirrors with varying duct geometry in DIII-D

- Modeling results show that ducts with ribs or “fins” in front of a mirror can significantly reduce deposition rates compared to smooth ducts of similar length and apperure
- 6 similar Mo mirrors will be exposed in DIII-D with ducts of different length with and without fins
- 5 mirrors will have shutters activated by the B-field to prevent any effect from the glow discharge
- Mirrors and ducts were pre-assembled at FZJ and delivered to DIII-D for exposure in a mid-plane port during FY 2012 campaign
- The results will be used to benchmark modeling





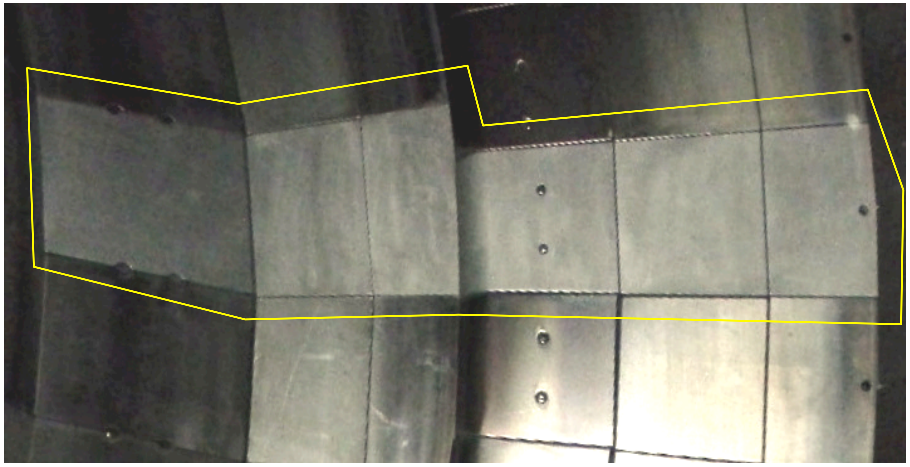
Collaboration with A. Litnovsky, FZJ

Mirrors station installed in DIII-D

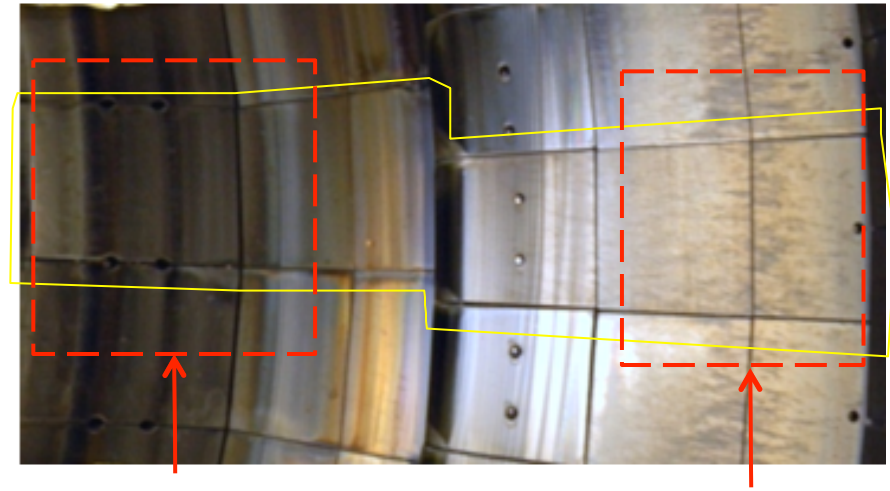
Arcing studies

From single-year tile exposure, net erosion of C by arcing in the lower divertor is ~1.2g/year

Before 2011 campaign



After 2011 campaign



- A poloidal row of 6 tiles sand-blasted and pre-characterized by profilometry has been installed prior to 2011 campaign
- Upon the vessel opening, the tiles were removed and re-analyzed
- The total amount of carbon removed from the tiles by arcing is ~9 mg
- Assuming toroidal symmetry, for the whole lower divertor area one gets

  ~1.2 g of carbon eroded by arcing in a single year
- Previous estimate based on multi-year exposure gave < 1 g per year for the whole machine. Possibly more arcing in 2011 due to frequent boronizations

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Thanks for your attention!