Recent ORNL measurements of chemical sputtering of ATJ graphite by slow D^+ and D_2^+, future plans

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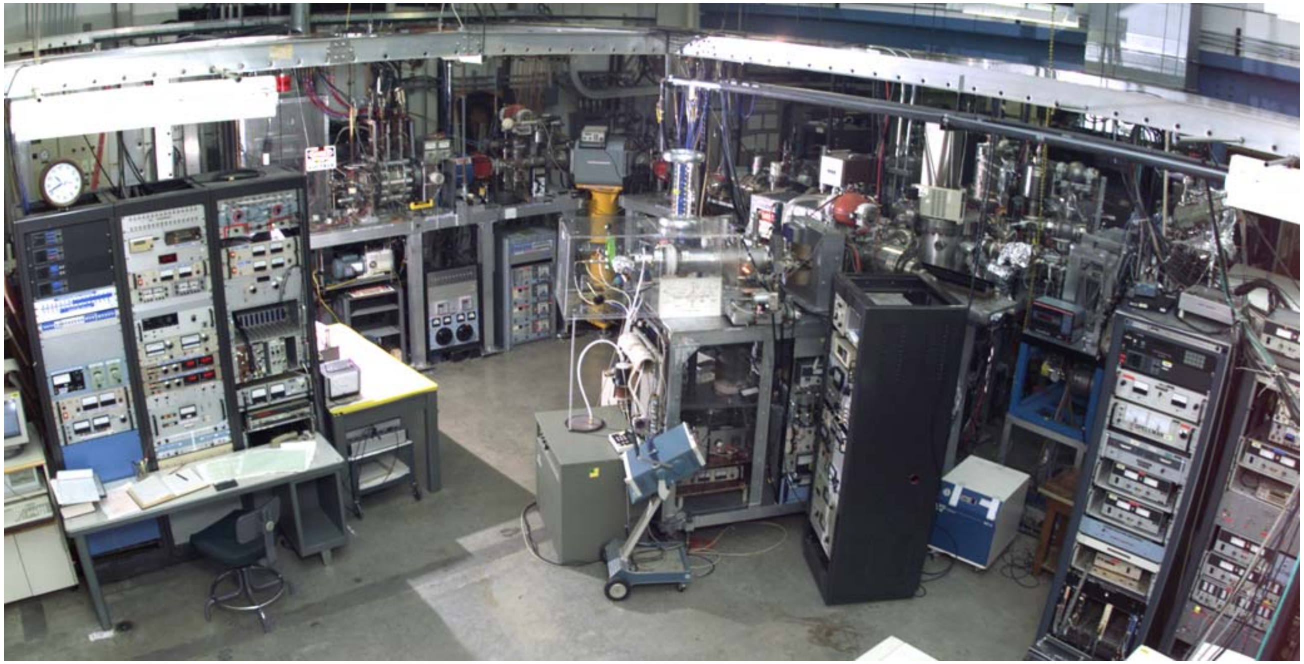
UT-BATTELLE
Oak Ridge National Laboratory

The ORNL Multicharged Ion Research Facility (MIRF)

Electron Cyclotron Resonance (ECR) source-based atomic, molecular, and optical physics studies supported by DOE OBES and OFES, at the ORNL Physics Division

Dedicated on-line experiments studying interactions of ions with electrons, atoms and molecules, and surfaces



MIRF-based plasma relevant ion-surface interaction studies

- ***Research Goal:***
  Improved understanding of mechanisms underlying plasma-wall interactions (PWI) occurring at the plasma-edge region of present (e.g. DIII-D) and future (ITER) magnetic fusion devices, and other plasma environments

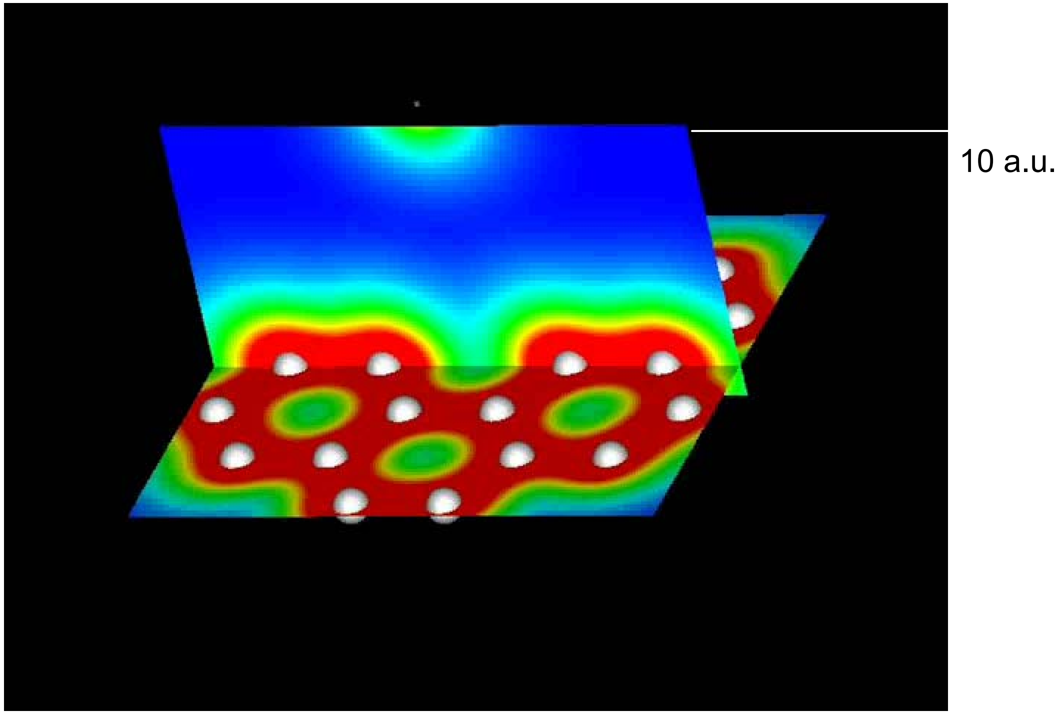
- ***Scope:***
  e- emission
  ion neutralization, negative ion formation
  dissociation
  sputtering
  particle reflection and trapping

- ***Materials:***
  PFC's such as graphite, refractive metals, Li overcoatings.

- ***Impacting species:***
  singly charged D, D_2, D_3, He, C_nH_m species, low charge state impurity species - B^{q+}, C^{q+}, N^{q+}, O^{q+}, Si^{q+},..., and higher Z metallic ions

- ***Common Feature:***
  Investigations down to very low energies (as low as a few eV/q)
  close co-ordination with in-house theory (Krstic, Reinhold, Schultz)

H⁺ incident on graphite surface: single layer, 24 C-atoms, HOPG

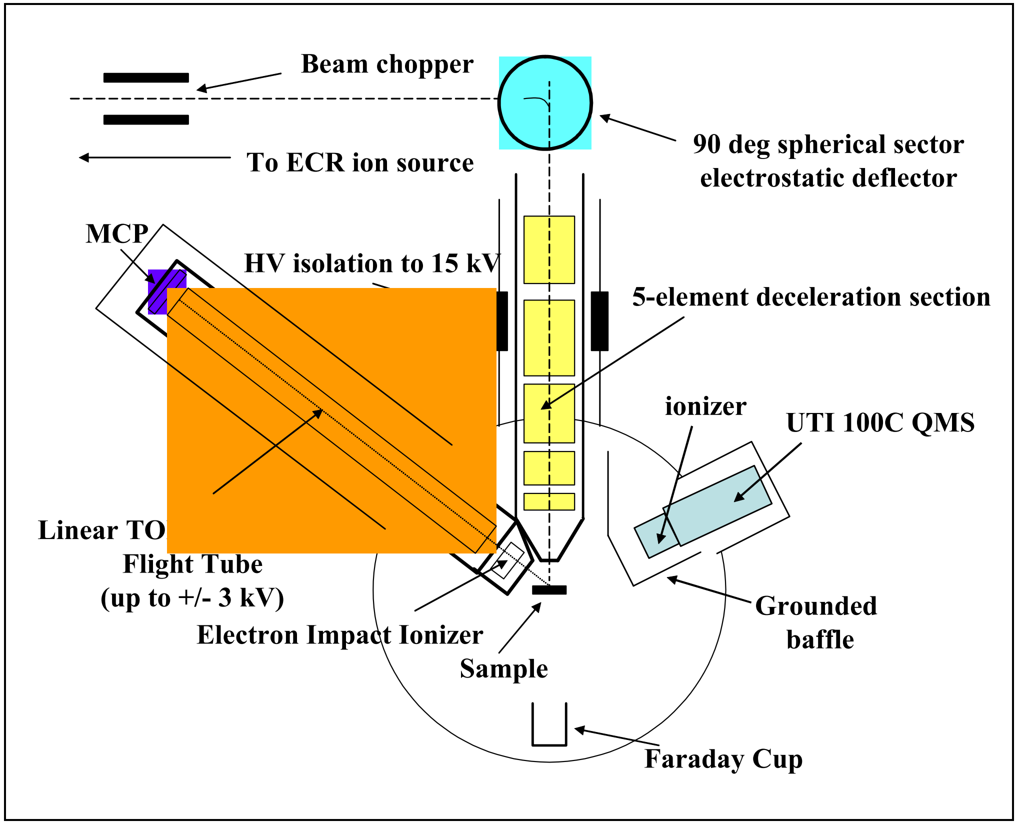


P. Krstic, NWCHEM calculation

MIRF measurements to date: D^+, D_2^+ normally incident on ATJ graphite at energies down to 10 eV/D

Experimental Apparatus

Floating scattering chamber
for beam deceleration



Ion impact energies down to few eV/q

Full range of incidence angles: normal to grazing

TOF and electrostatic projectile energy
And charge state analysis

UHV environment: clean well characterized Surfaces – low 10^{-10}T base, low 10^{-9}T with μA beam loading

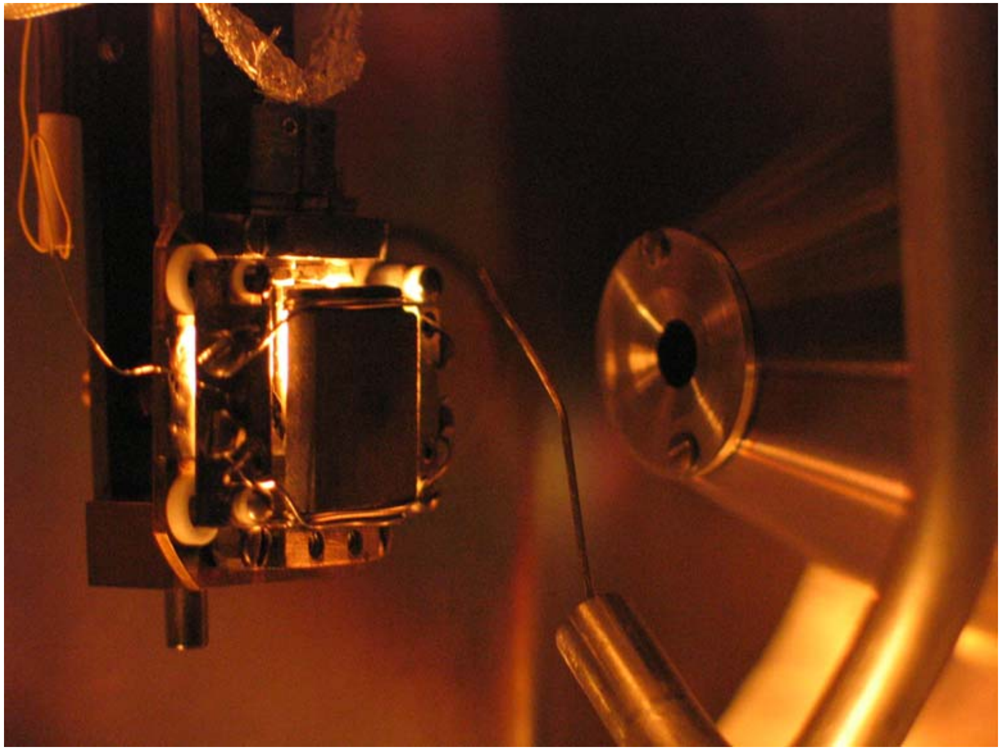
Quadrupole mass spectrometer (QMS) recently added

Present approach:

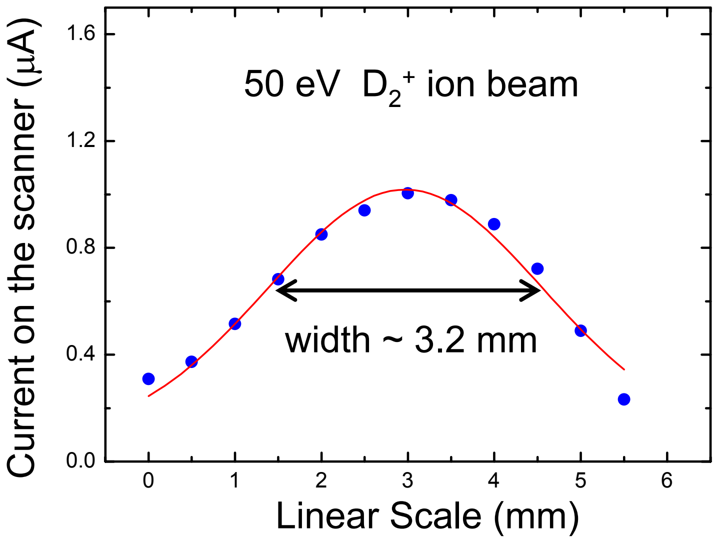
- Use sensitive quadrupole mass spectrometer to monitor partial pressure evolution of selected masses in UHV chamber resulting from hydrogen ion dosing of ATJ graphite sample
- determine decelerated beam profiles using wire scanner
- e-beam heated sample up to T >1000° C

Near term:

- absolute yield determinations
- sample temperature dependences
- transient analysis, effects of H-loading
- sample comparison: ATJ, both virgin and fusion-plasma exposed, pyrolytic, a-C:H films

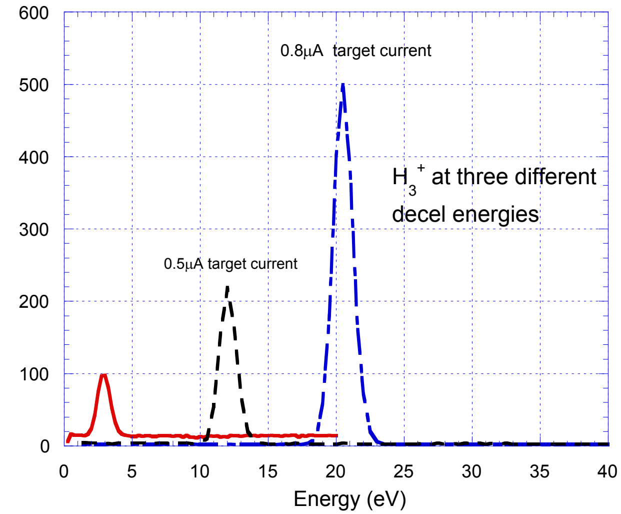


Typical characteristics of the decelerated beams



Current on the sample = 7.2 μA

Flux > $1x10^{15}/cm^2/s$

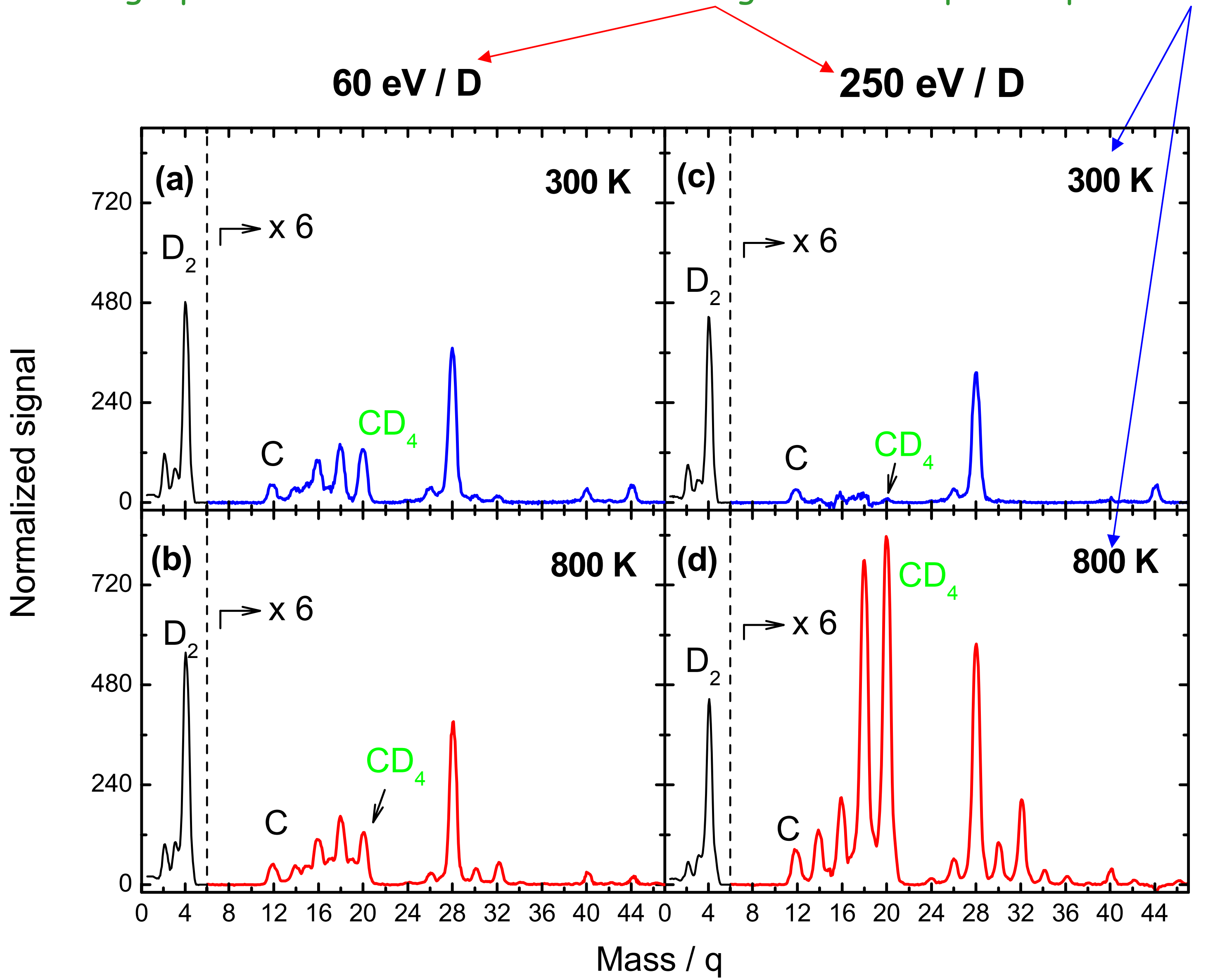


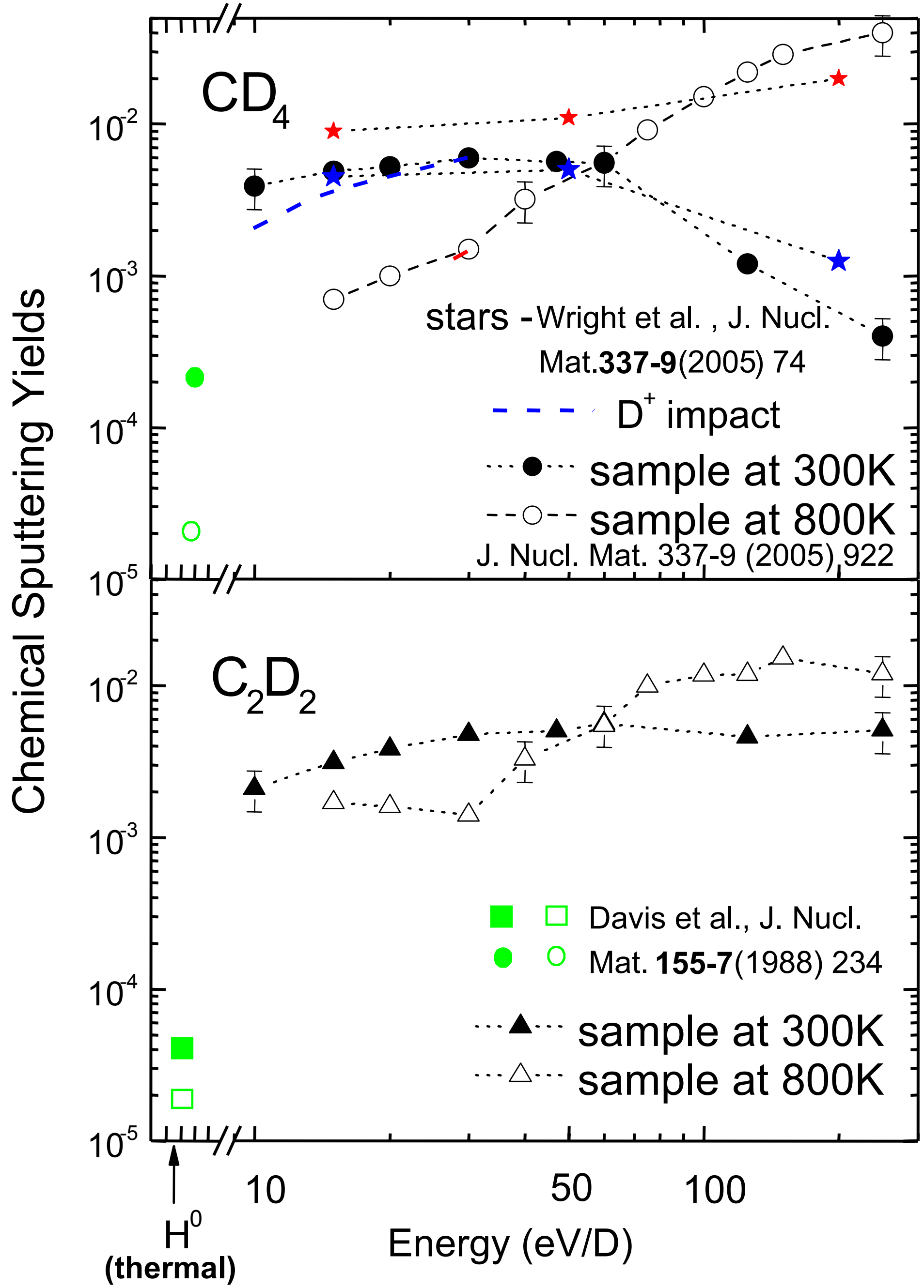
Electrostatic energy analyzer scans

Flux determines H(D) – surface saturation time constant

Energy spreads of H_3^+ ion beams at different impact energies

D_2^+ on ATJ graphite: two different incident energies and sample temperatures





Total C removal data needed for wall erosion lifetime estimate; simulation studies need hydrocarbon specific yield data; heavier hydrocarbon yields to be determined after additional calibrations

Thermally activated H release and abstraction reduce population of sp^3 and sp^x hybrid. states

J. Küppers, Surf. Sci. Rep. 22 (1995) 249

Energetic ion impact opens additional CH_3 and C_2D_x production and emission channels

J. Roth, C. Garcia-Rosales, Nuc. Fus. 36 (1996) 1647

B.V. Mech et al, J. App. Phys. 84 (1998) 16

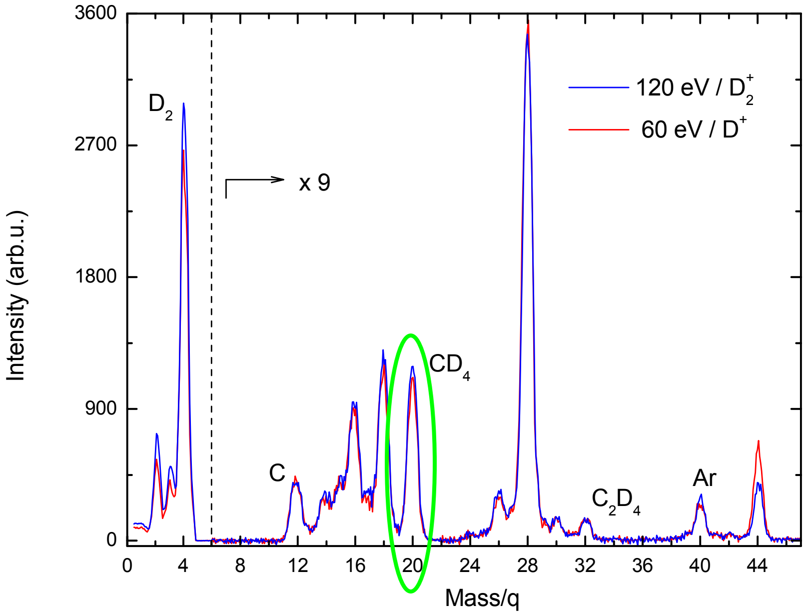
C. Hopf, A. von Keudell, and W. Jacob, Nucl. Fusion 42 (2002) L27

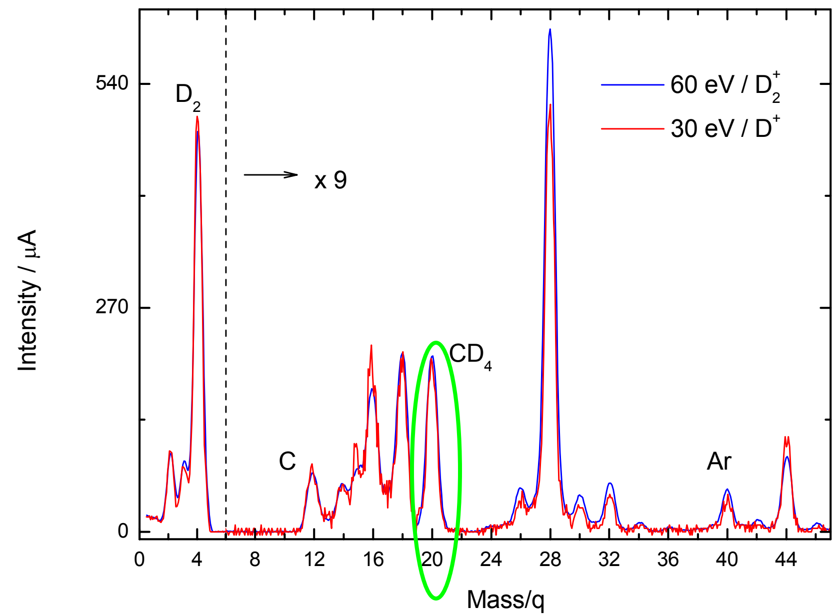
D thermalization occurs progressively deeper within bulk with increasing impact energy – diffusion of erosion products back to surface is temperature dependent

D^+ incidence results start to deviate from D_2^+ results for energies below 30 eV/D:

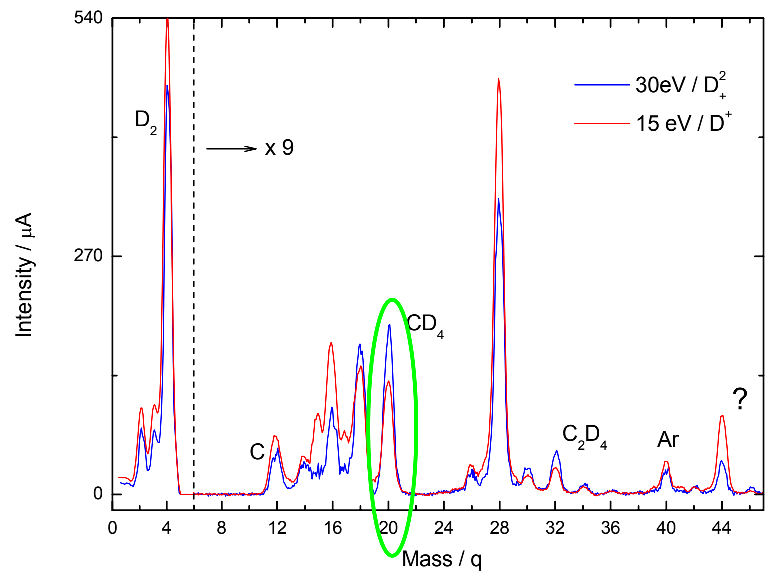
3-4 eV/D energy release after dissociative electron capture may broaden range of impact energies and incidence angles

Comparison between mass spectra obtained with D_2^+ and equivelocity D^+ beams



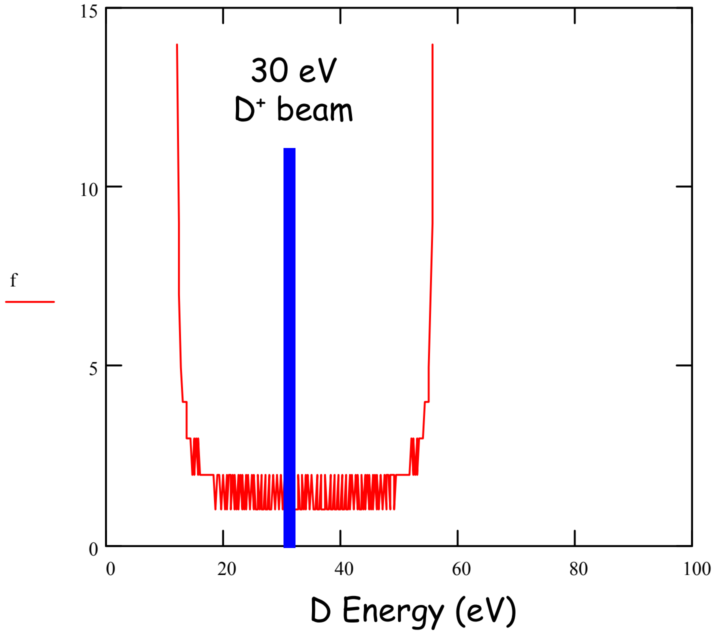


Almost factor of two difference at 10 eV/D !

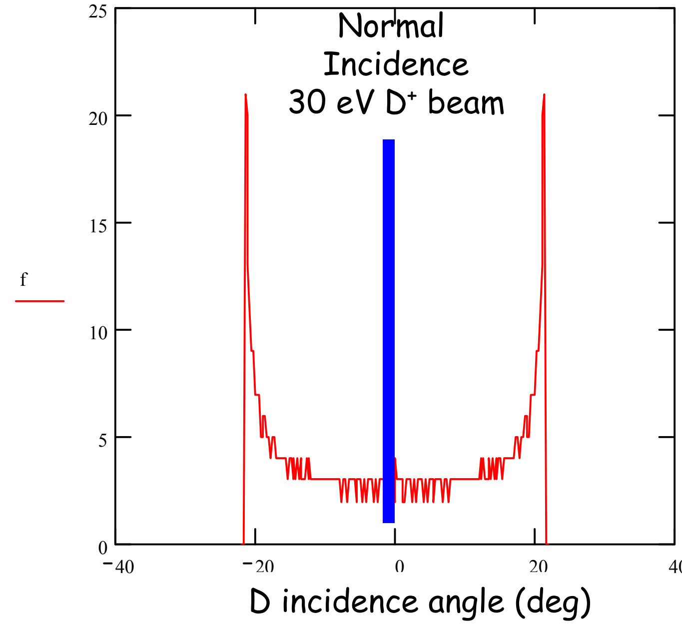


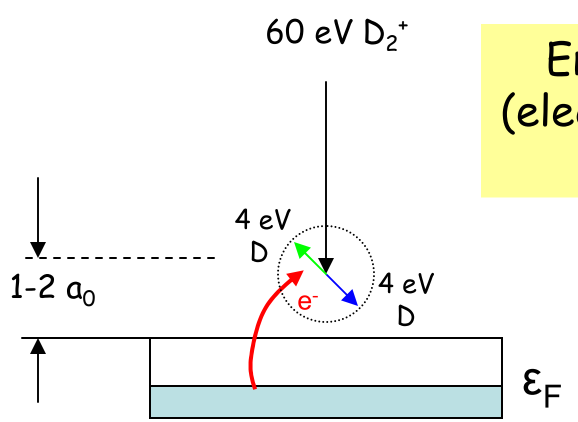
Why are D^+ and D_2^+ results different at low energies?
D energy and angular distributions after dissociative electron capture of 60 eV D_2^+

Incident energy distribution



Incidence angle distribution

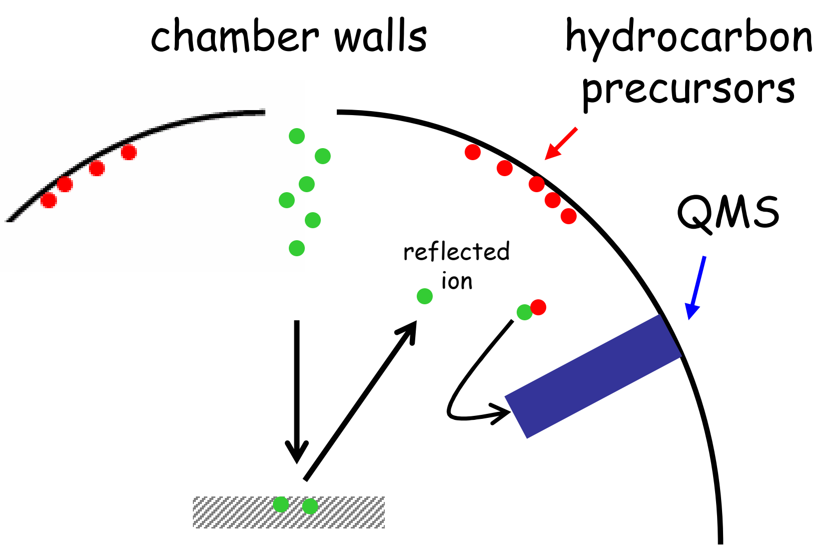


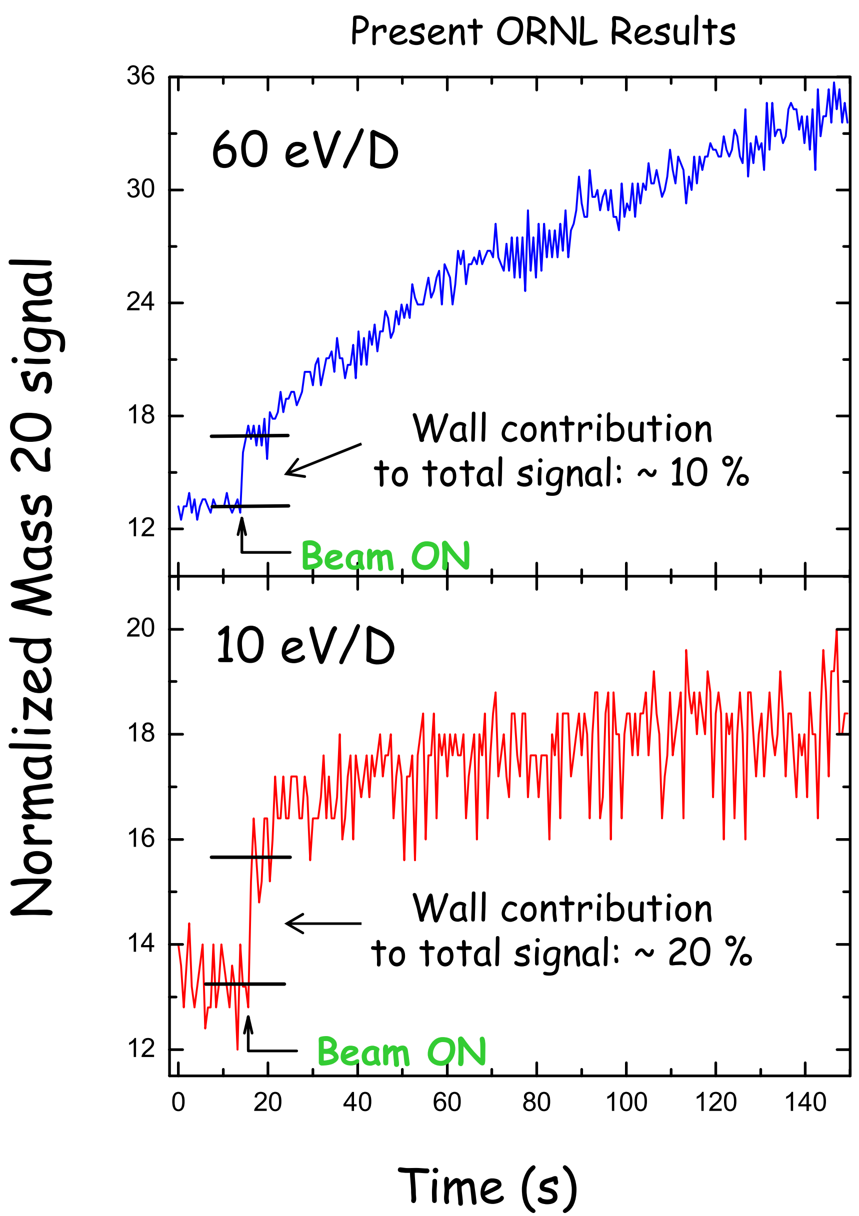


Energy release from dissociative neutralization (electron capture) is amplified in laboratory frame, and introduces angular spread

Issue: to what extent are these energy and angular spreads reduced by e.g. screening effects after surface penetration?

Significantly reduced corrections due to "wall contributions"





Significantly lower than other work:

~ 30 % for 200 eV impact,
~ 75 % for 10 eV impact.

B. V. Mech, PhD Thesis, U. Toronto (1998)

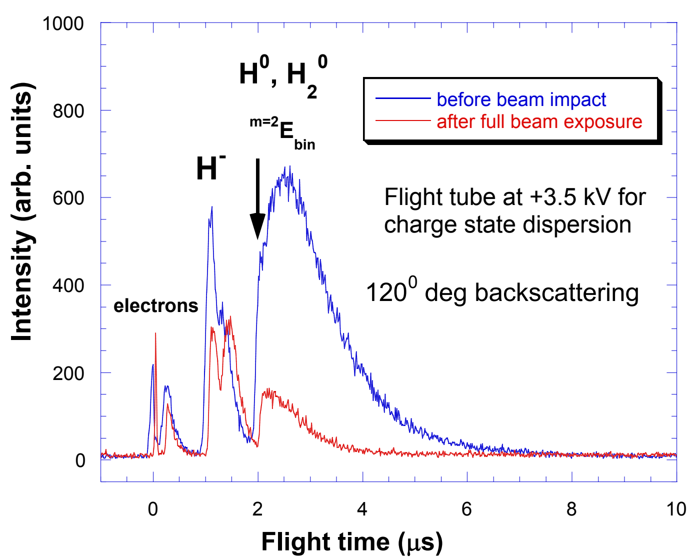
Next step: implement TOF approach

- direct line of sight measurements – can see radicals as well as stable molecules
- "wall correction" issues minimized
- charge state distributions (neutrals, positive, as well as negative ions)
- energy distributions of sputtering products
- angular distributions of sputtering products

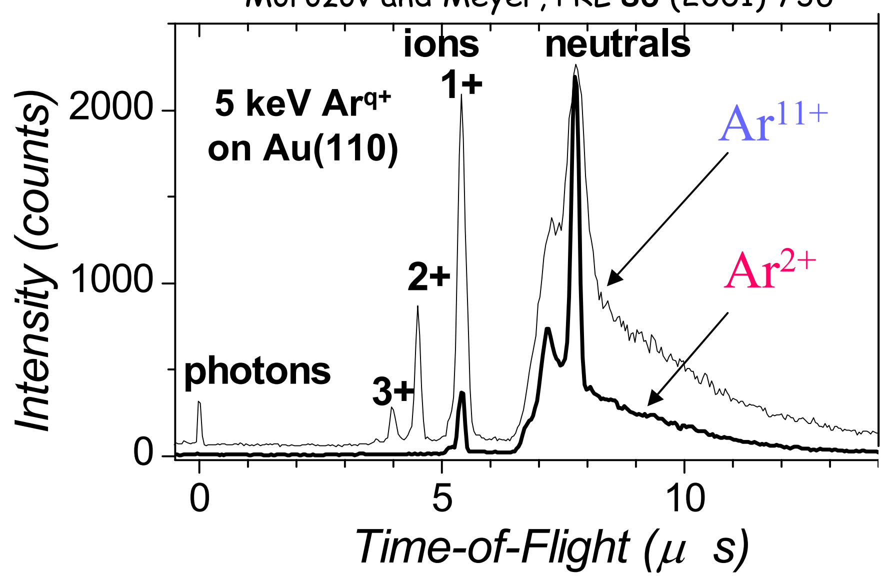
May be more suitable approach for validation of simulation studies

Sample TOF spectra with present apparatus

2.5 keV H_2^+ incident on ATJ Graphite



Morozov and Meyer, PRL **86** (2001) 736



Can we help with fusion-device related issues?

- Analyze ATJ graphite tile exposed to 8 years of DIII-D discharges

  similar study already reported by Wright et al. at last year's PSI conference in Portland

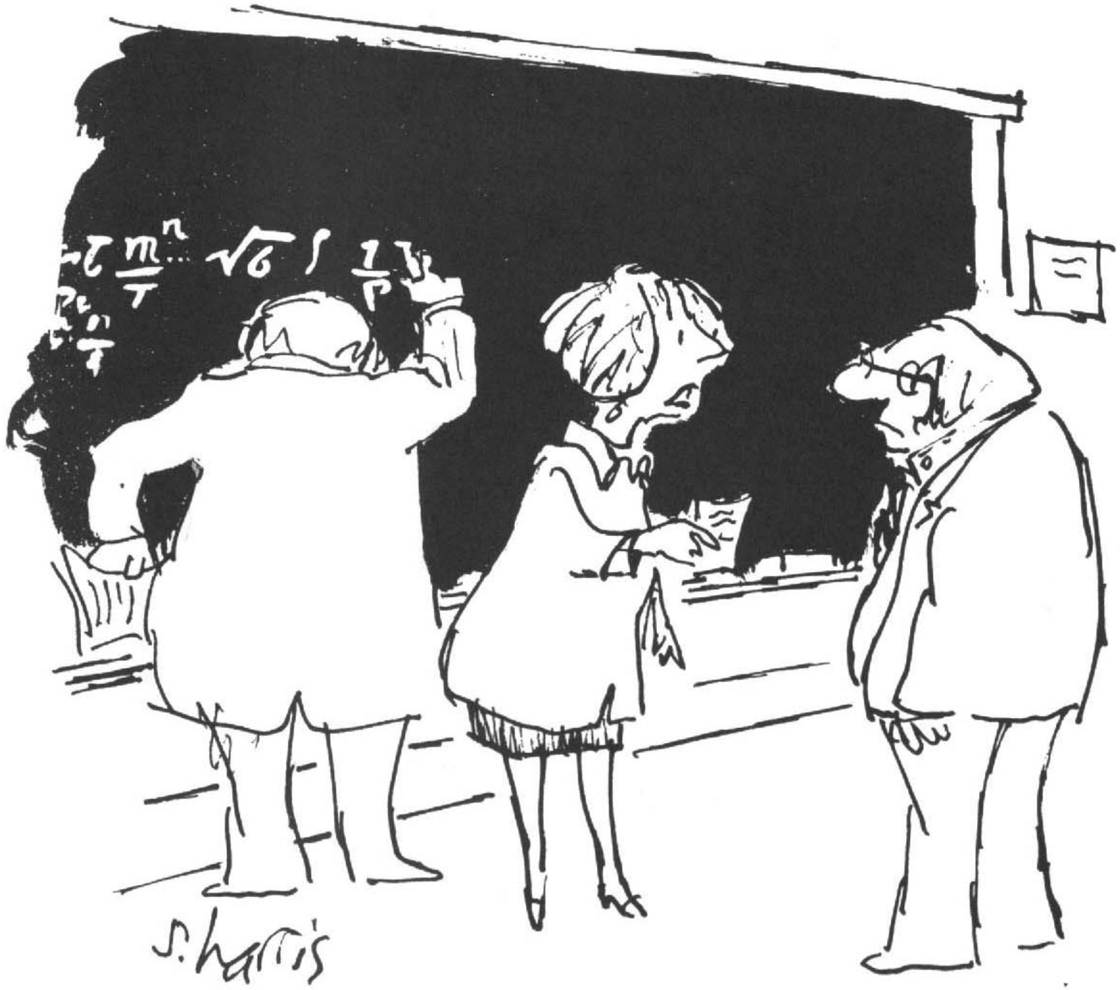
Reduction in observed CI,II emission due to reduced chemical sputtering?

ATJ graphite tile, Φ = 187.5 ,
row 14 of lower divertor in DIII-D

- Comparative study of a-C:H thin films (redosition issues)
- ITER-related issues ?

We look forward to feedback identifying those needs of emerging simulation effort and of fusion-device modelers that we have capability to address

Perhaps after this Workshop…



"WE COLLABORATE. I'M AN EXPERT, BUT NOT AN AUTHORITY, AND DR. GELBIS IS AN AUTHORITY, BUT NOT AN EXPERT."