Chemical Erosion and Critical Issues for ITER

J. Roth
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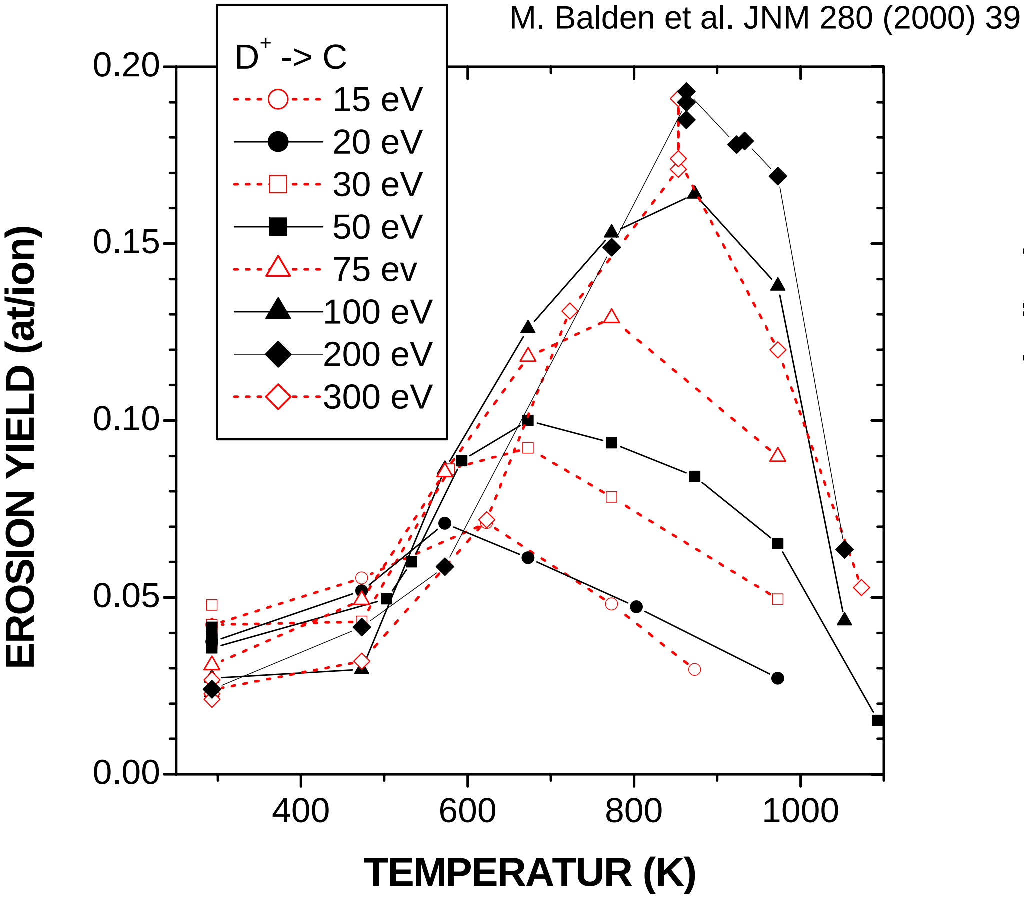
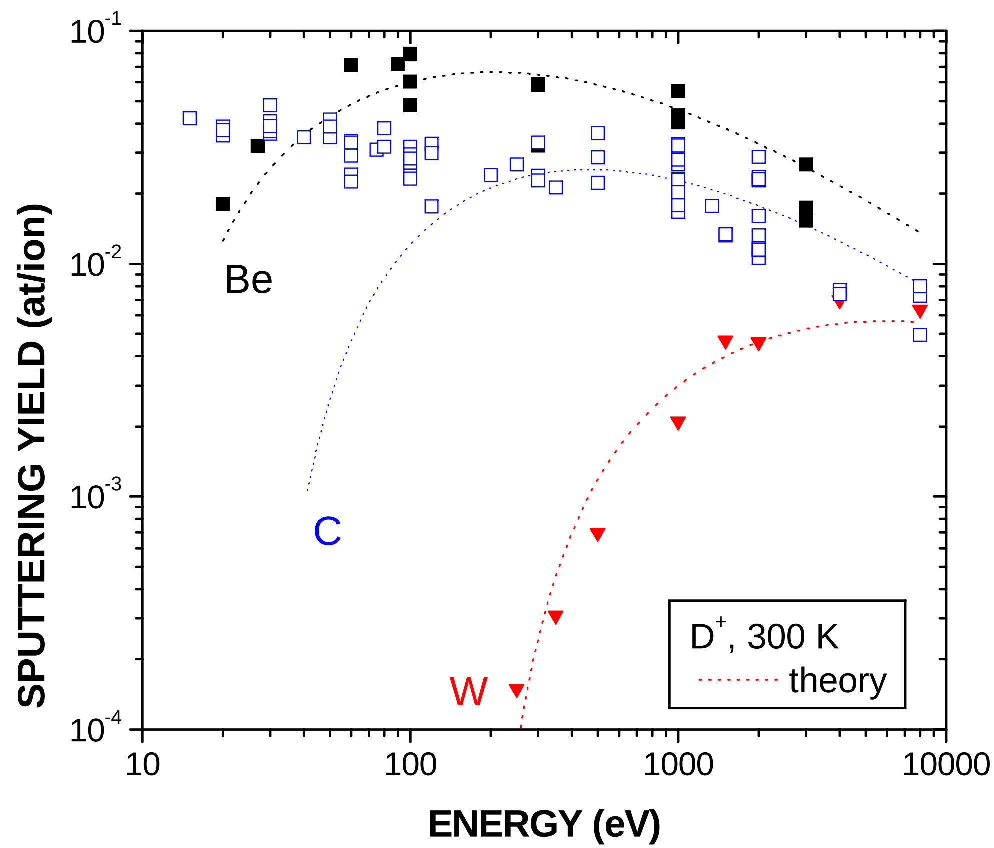
- **Chemical Erosion Studies**
  - Erosion yields: Dependence on temperature, energy and flux
  - Emitted hydrocarbons and radicals
- **Erosion Process and Modeling**
  - Individual atomic steps
  - Analytic description
- **Sticking Coefficient of Emitted Species**
  - In ion beam studies
  - In fusion devices
- **Summary of unresolved Issues**

Chemical Erosion:
Dependence on temperature

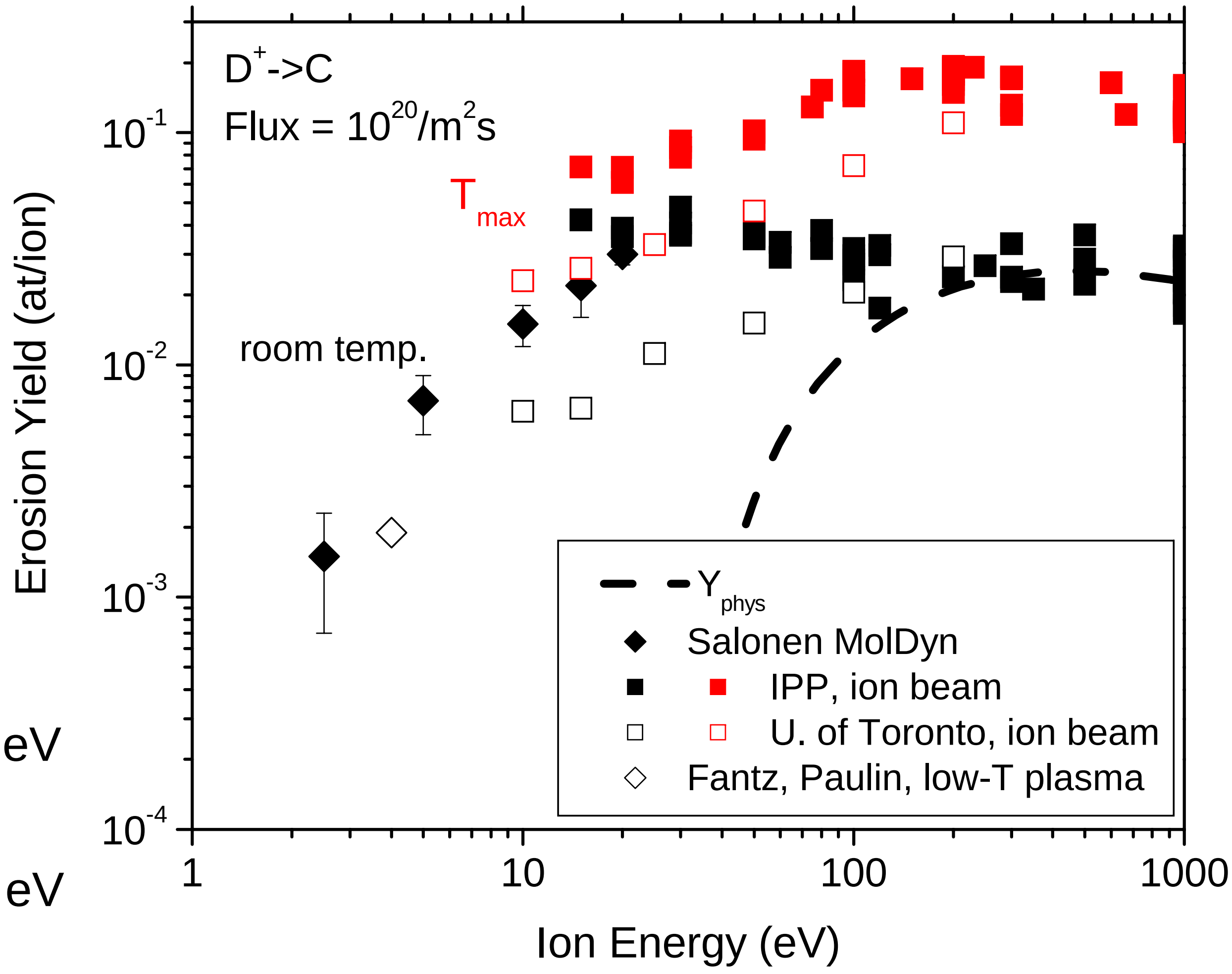




- Chemical erosion depending on temperature and energy

Chemical Erosion:

Dependence on energy



- Threshold for physical sputtering 30 eV
- Chemical sputtering at room temperature has threshold around 1 eV
- No threshold for chemical erosion at high temperature

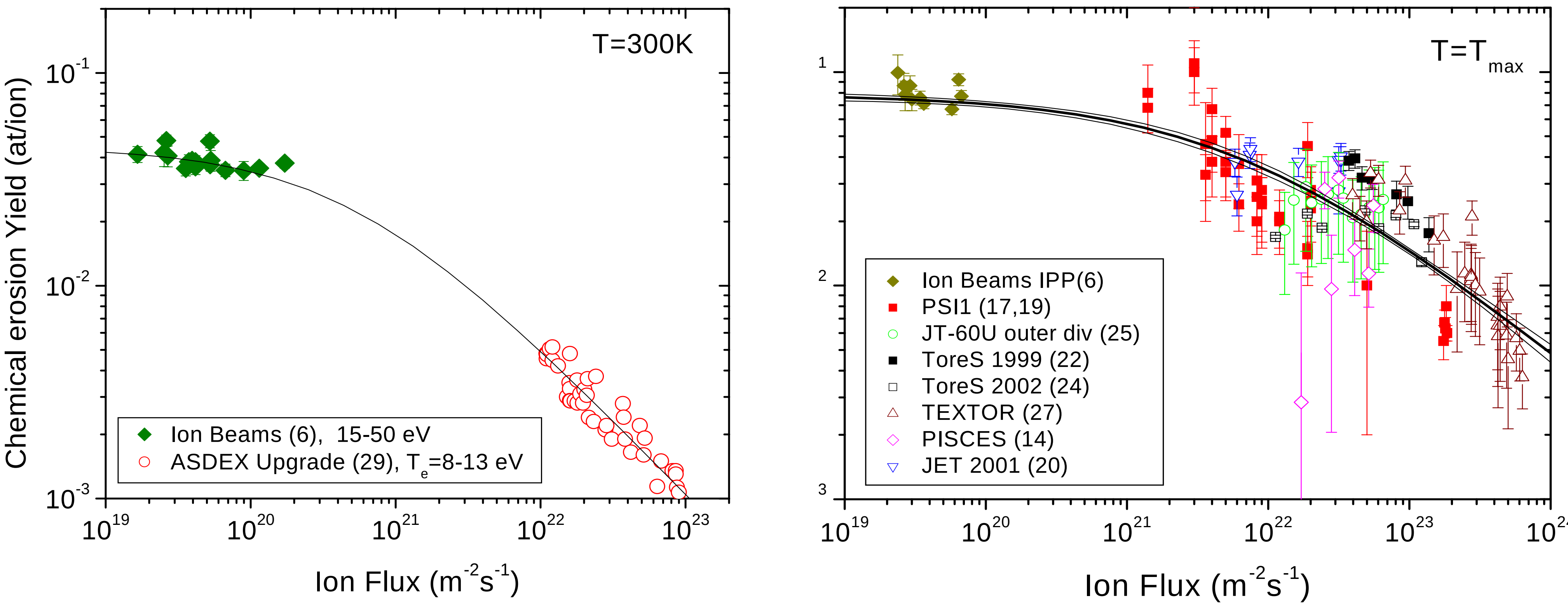
Chemical Erosion:
Dependence on ion flux

EFDA
EU Plasma-Wall Interactions Task Force

IPP

Collaboration in the framework of EU Task Force und ITPA

J. Roth et al. NF 44 (2004) L21



- Flux dependence resulting from normalized data
- Chemical erosion is adequately described as function of temperature, energy and flux

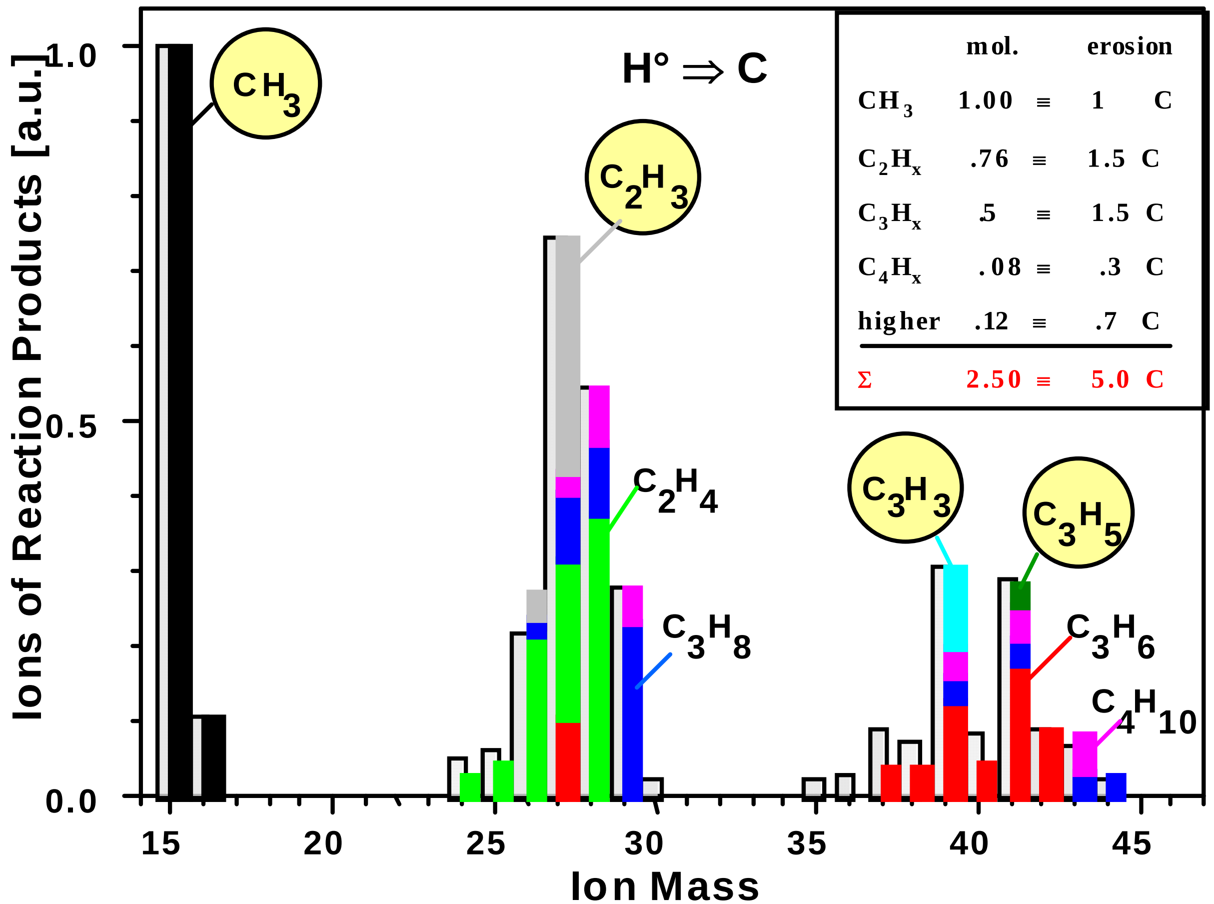
Chemical Erosion:

Eroded species

- Emission of a variety of hydrocarbons
- Composition changes with ion energy

Missing information:

- Mechanism of emission of higher hydrocarbons
- Origin of energy dependence (diffusion?)
- Contribution of radicals



E. Vietzke et al. JNM 145-147 (1987) 443

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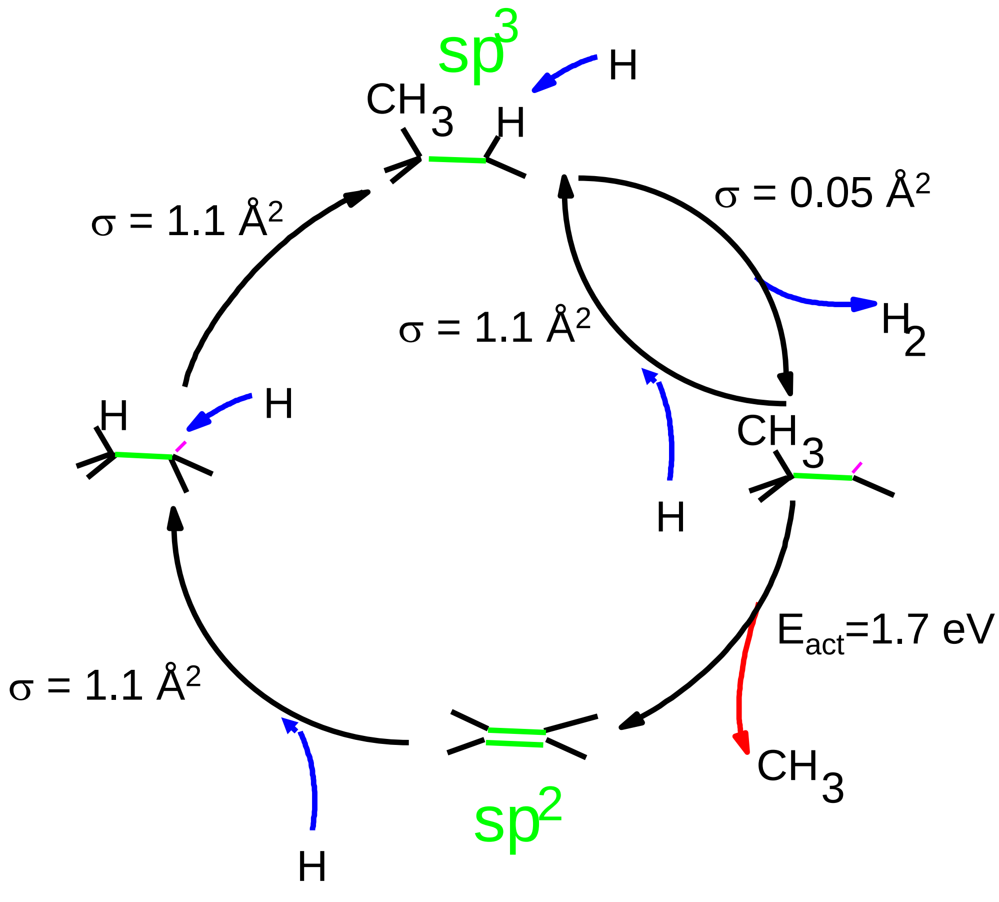
Chemical Erosion:

Status of atomistic understanding

Hydration and erosion circle:

thermal H°, HREELS, TDS, isotope exchange,
A. Horn et al., Chem. Phys. Lett. 231, 193 (1994)

- Hydration at room temperature of all possible absorption sites
  Steady state of abstraction and hydration
- Thermal release of CH_3 radicals from activated sites



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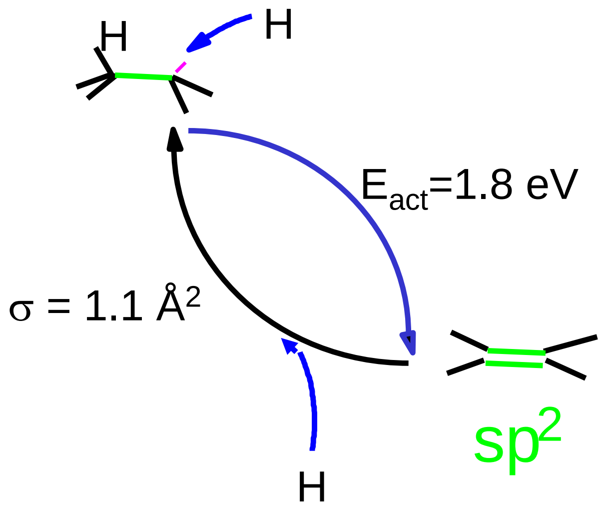
A. Horn et al., Chem. Phys. Lett. 231, 193 (1994)

- Hydration at room temperature of all possible absorption sites
  Steady state of abstraction and hydration
- Thermal release of CH_3 radicals from activated sites
- At higher temperature thermal release of hydrogen
- Good description of temperature dependence



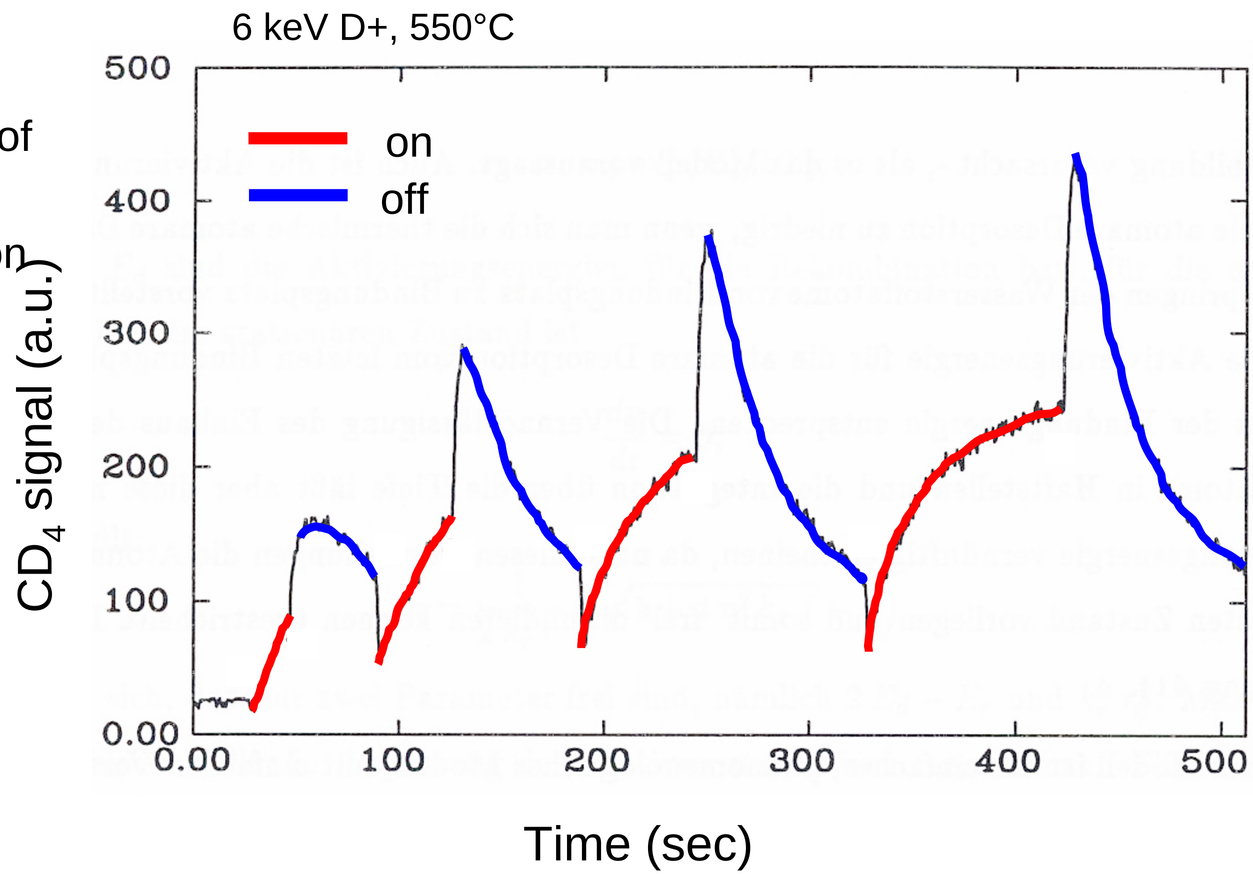
Chemical Erosion:
Status of atomistic understanding

Application to energetic ions:

energetic H^+, C-isotope marker,
J. Roth et al., Appl.Phys.Lett. 51 (1987) 964

- Thermal release of hydrocarbon at end of ion range
- Yield increase due to damage production
- Steady state of methane production and breakup during out-diffusion

P. Franzen, thesis IPP9/92 (1993)
A.A. Haasz et al, JNM 220-222 (1995) 815
S. Chiu et al., JNM 218 (1995) 319



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J. Roth et al., Appl.Phys.Lett. 51 (1987) 964

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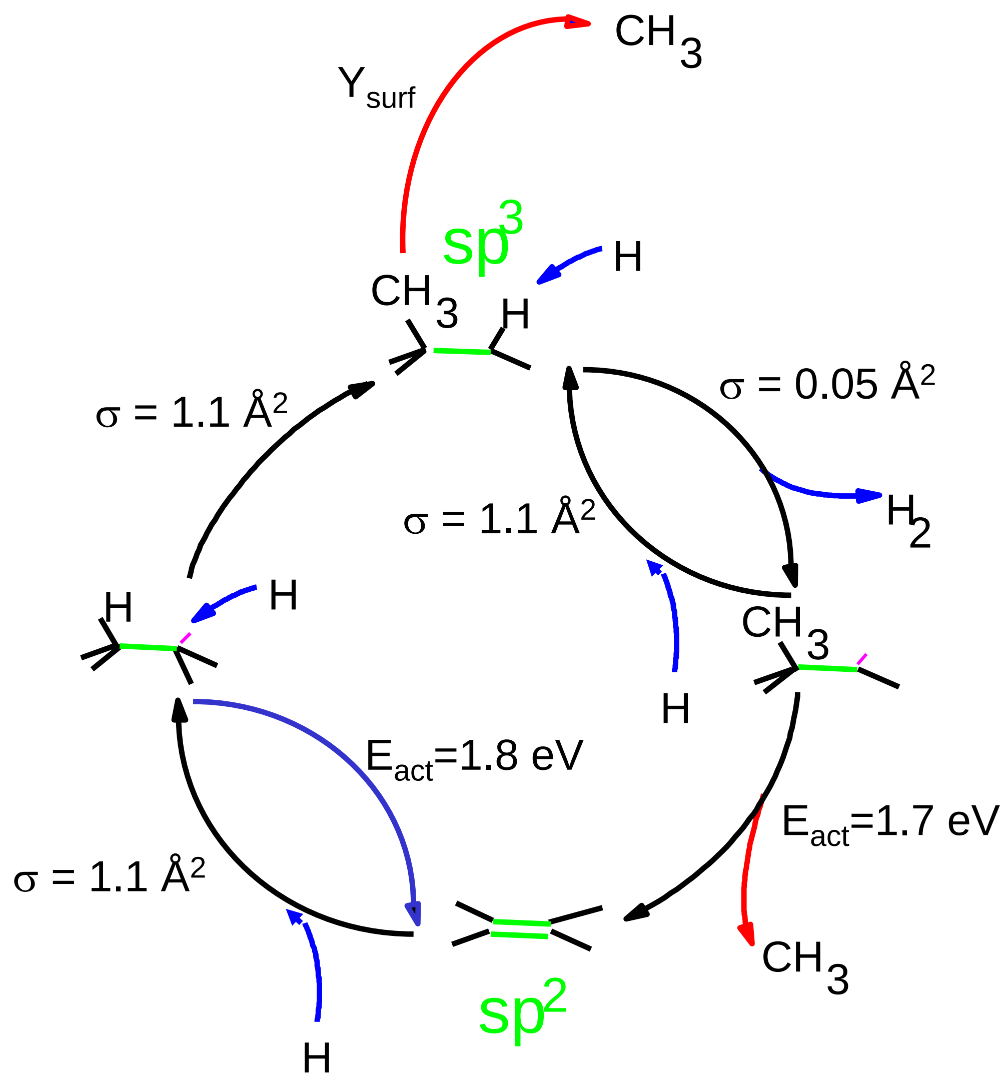
- Ion induced release of weakly bound hydrocarbon radicals complexes

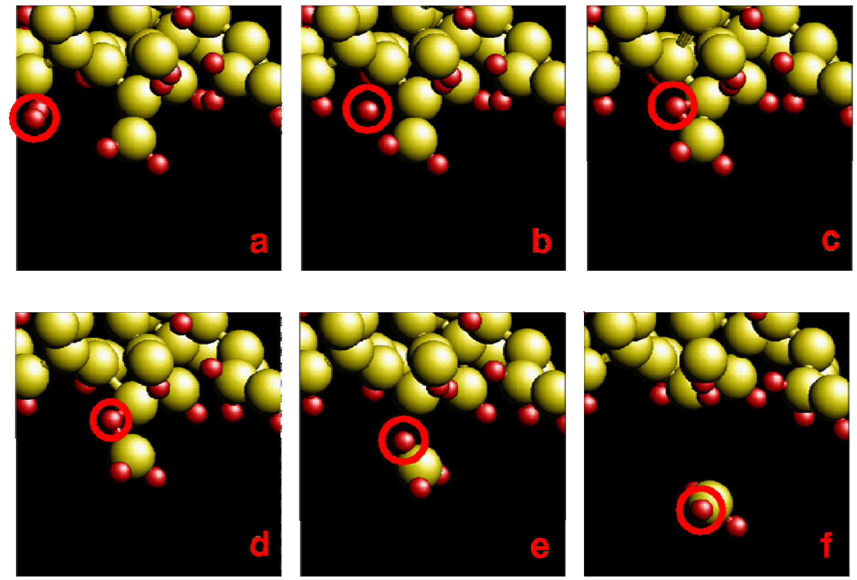


Chemical Sputtering:

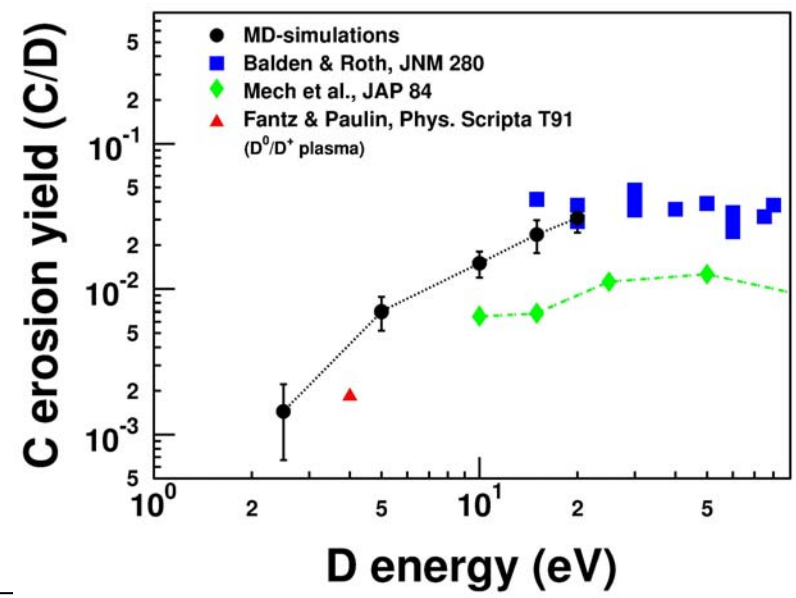
Status of atomistic understanding

E. Salonen et al., Phys. Rev. B63 (2001) 195415

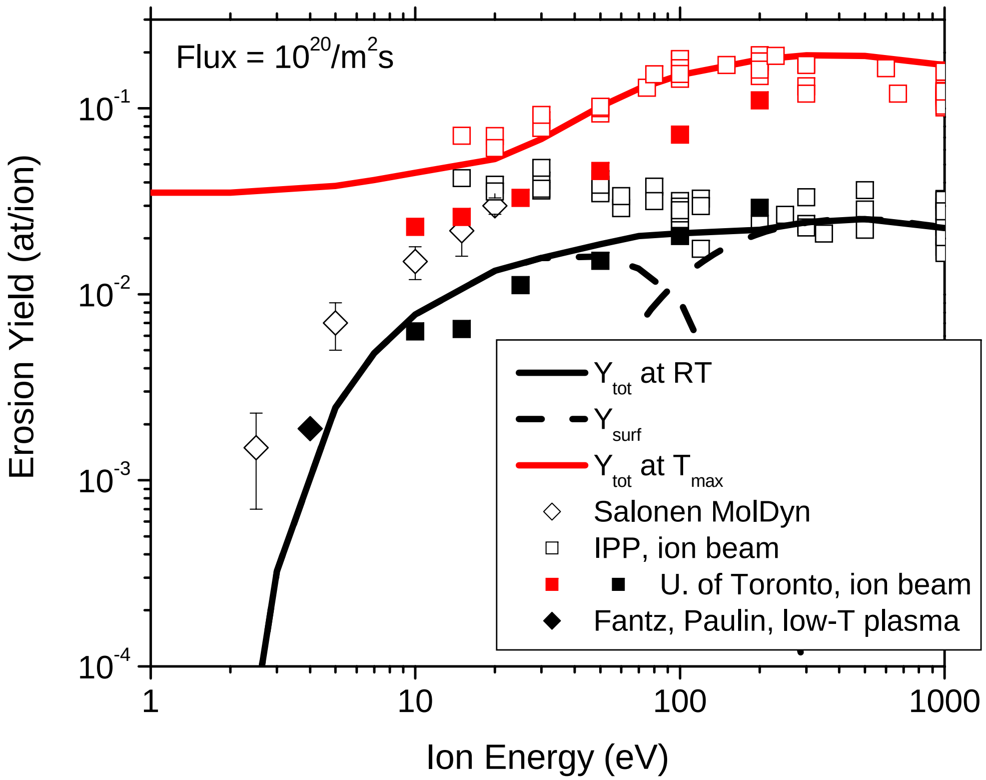
- Hydrogenic atom attacks the region between two carbon atoms
- Core-core repulsion pushes the C atoms apart from each other
- Increase in potential energy is sufficient to result in bond rupture

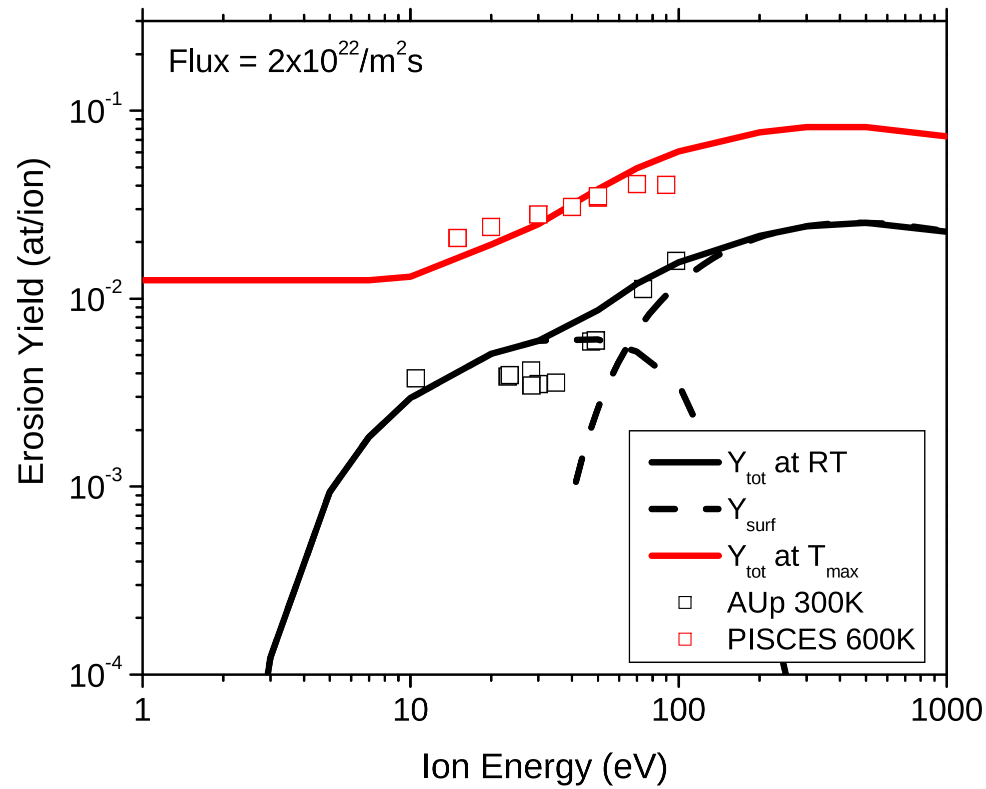


- Resulting yields in good agreement with experiments



Chemical Erosion:
Analytic description of the data





Full description of chemical erosion as function of temperature, energy and ion flux

$$Y_{tot} = Y_{therm}(1+Y_{dam}) + Y_{surf} + Y_{phys}$$

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- **Development of low erosion graphites**
- **Sticking Coefficient of Emitted Species**
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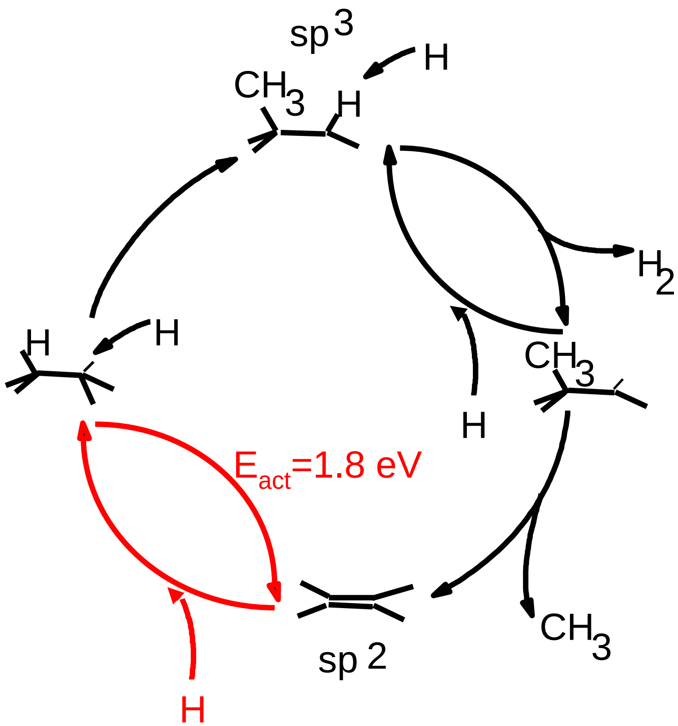
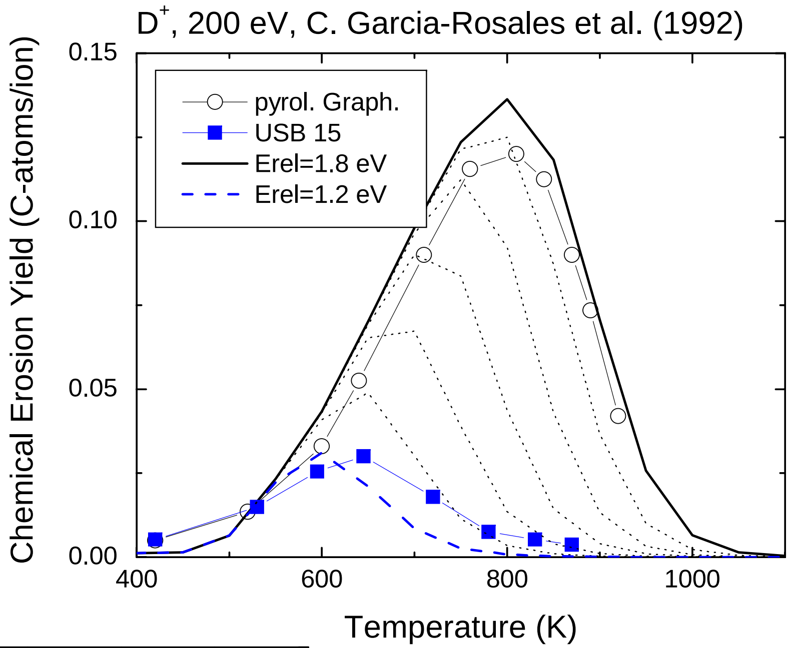
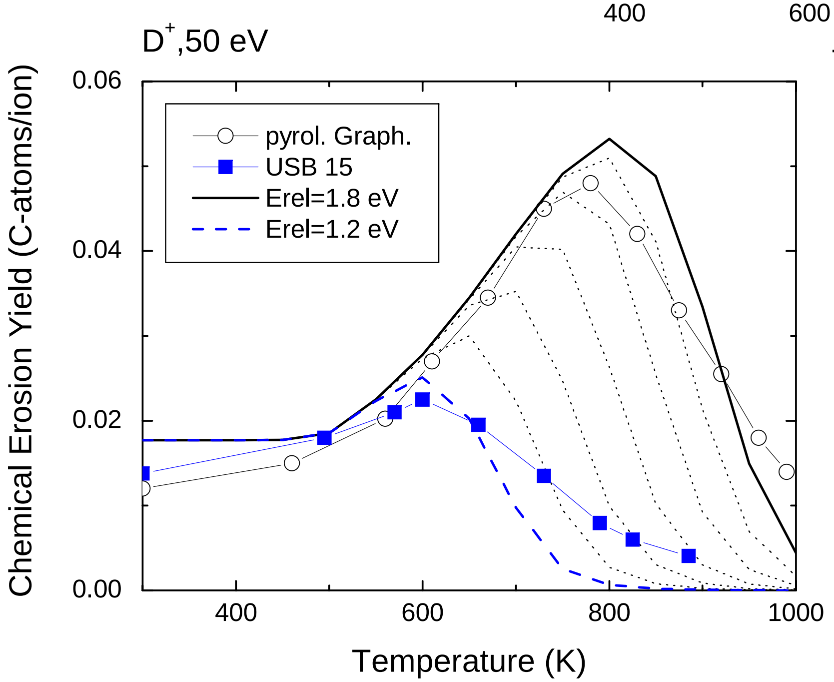
Mechanism of chemical erosion:

Methods of reduction

- Enhancement of hydrogen desorption by addition of metallic impurities



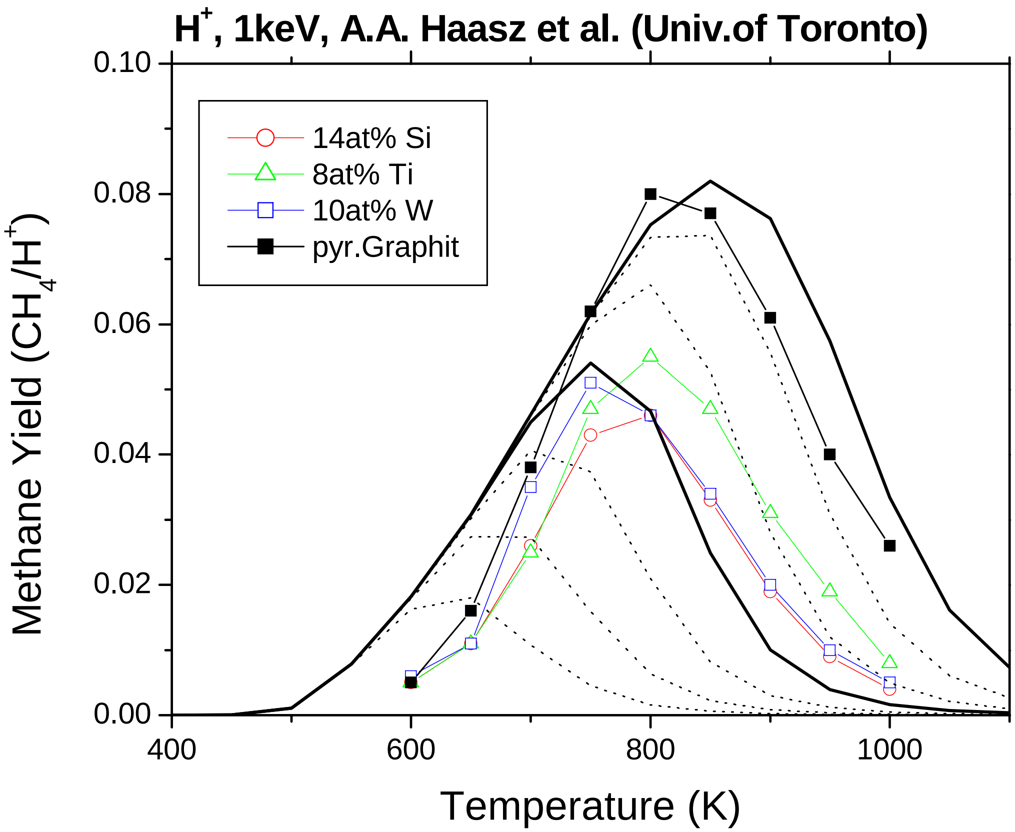


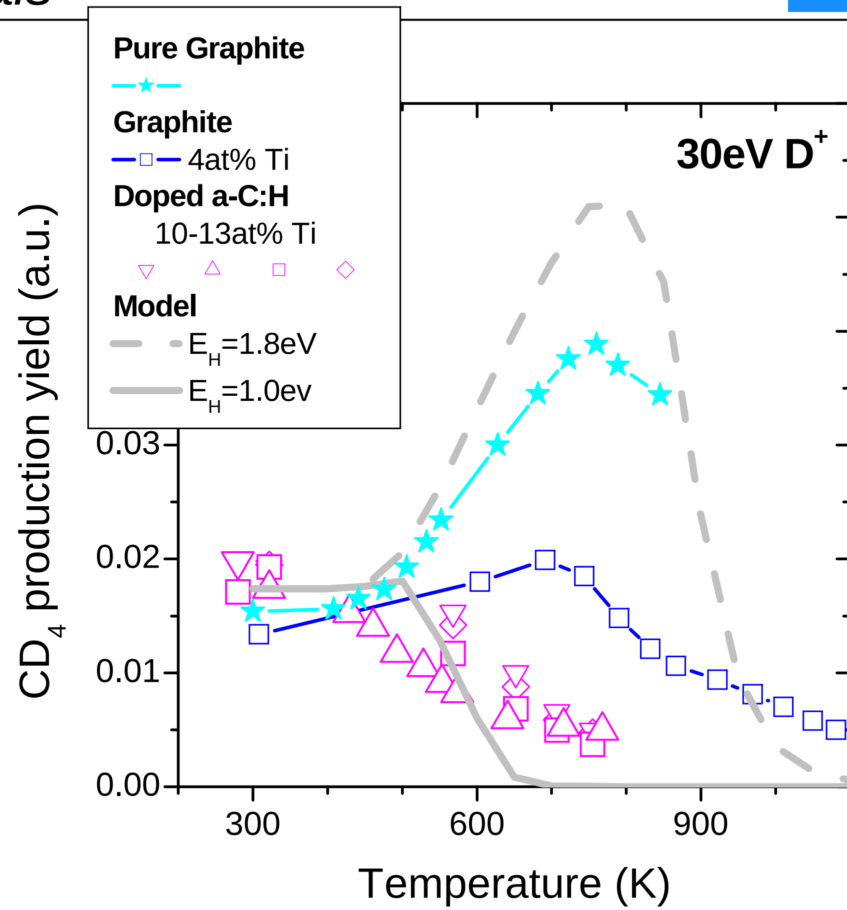


Variation of E_{act} from 1.2 to 1.8 eV

Erosion of plasma-facing materials:

Development of low-erosion materials





- Development of fine grain graphites with high heat conductivity:

  UTIAS (Toronto), IPP Hefei (China), CEIT (Spain) and IPP Garching
- Doping can eliminate thermal chemical erosion

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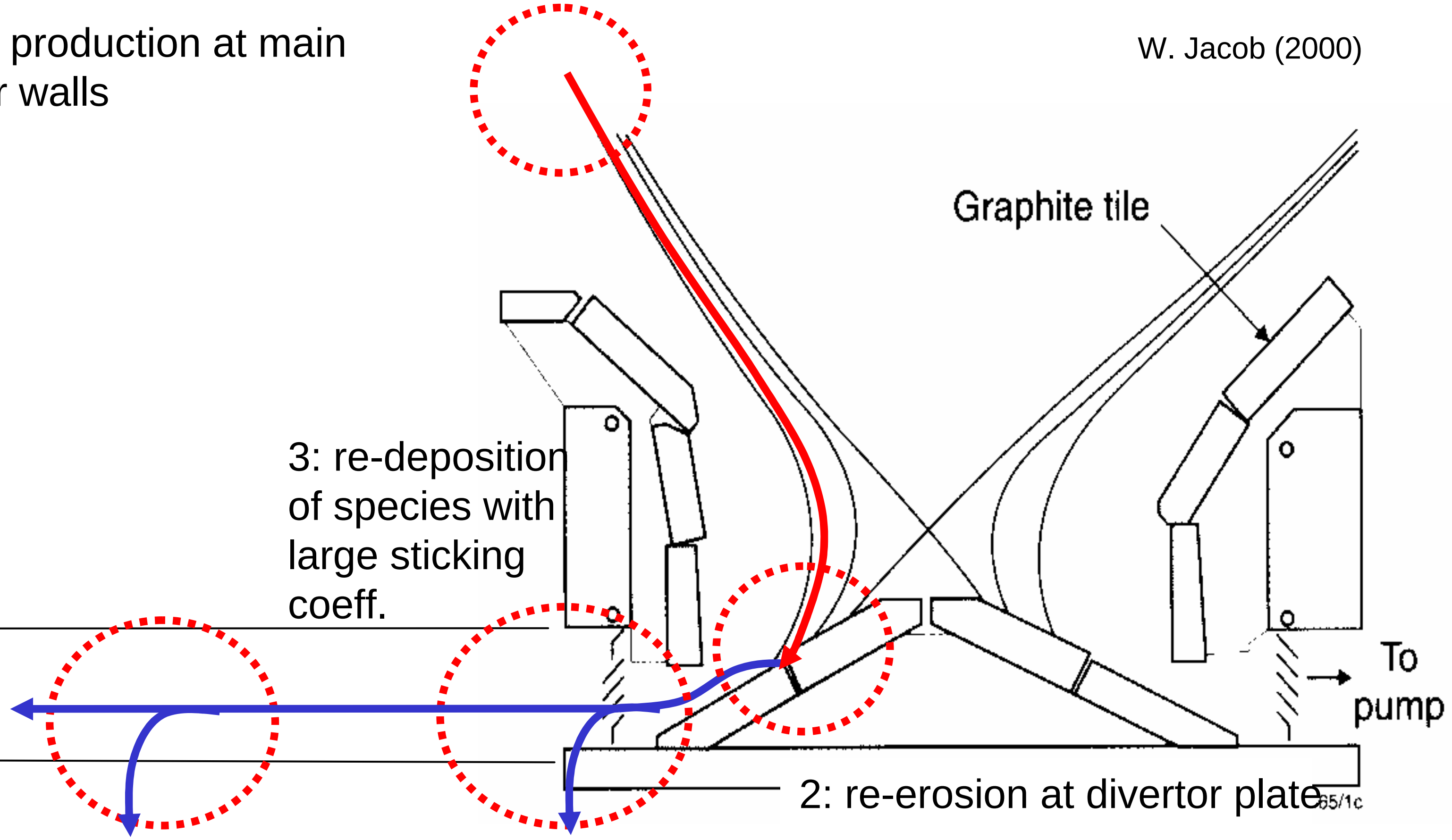
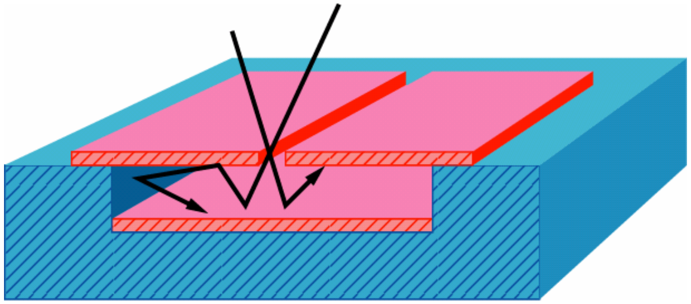
Carbon transport to remote locations in the JET vessel



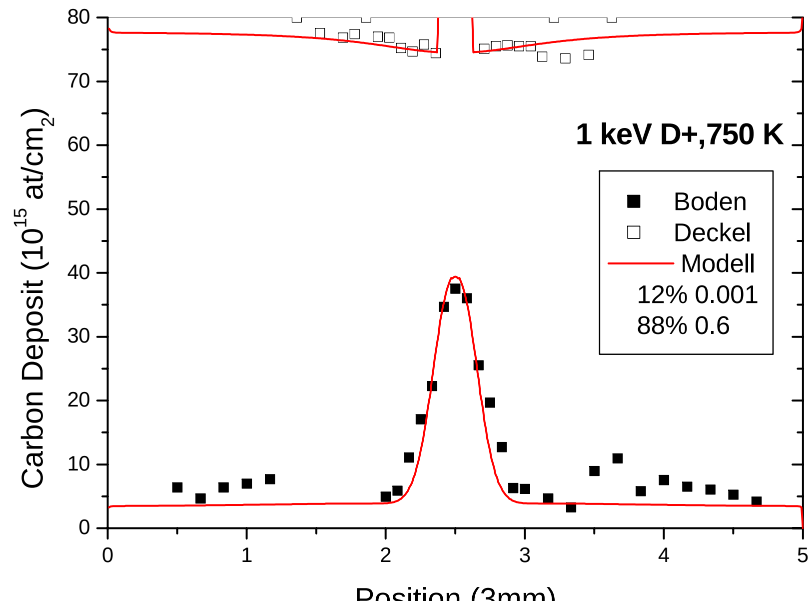
Chemical Erosion

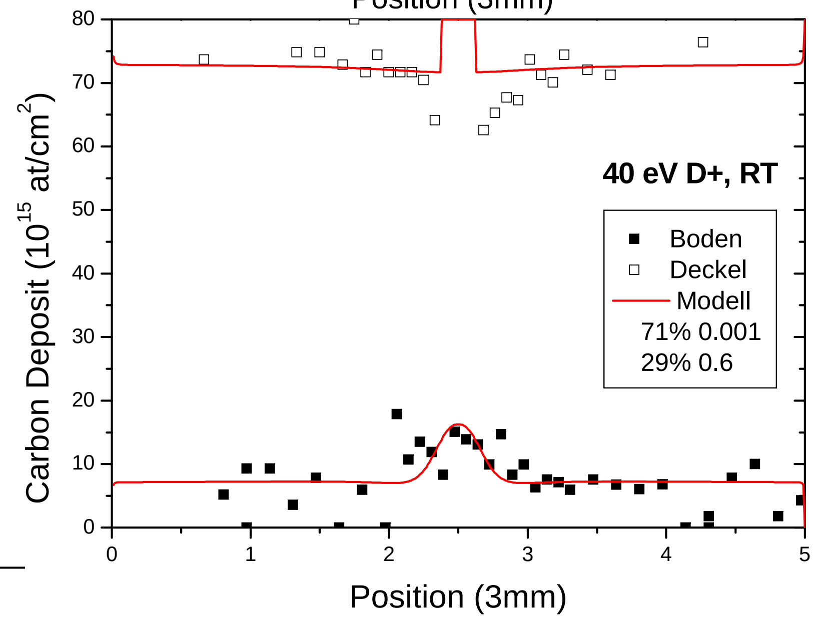
Eroded species and sticking coefficient

J. Roth, C. Hopf, JNM 334 (2004) 97



	Phys. Sputtering	Thermal chem. Erosion	Chem.Enhanced Sputtering
Sticking Coeff. 60%	**100%**	**88%**	**29%**
Sticking Coeff. <1%	**0**	**12%**	**71%**
Sticking Coeff. close to 0	**0**	**factor 4 from weight loss**	**0**

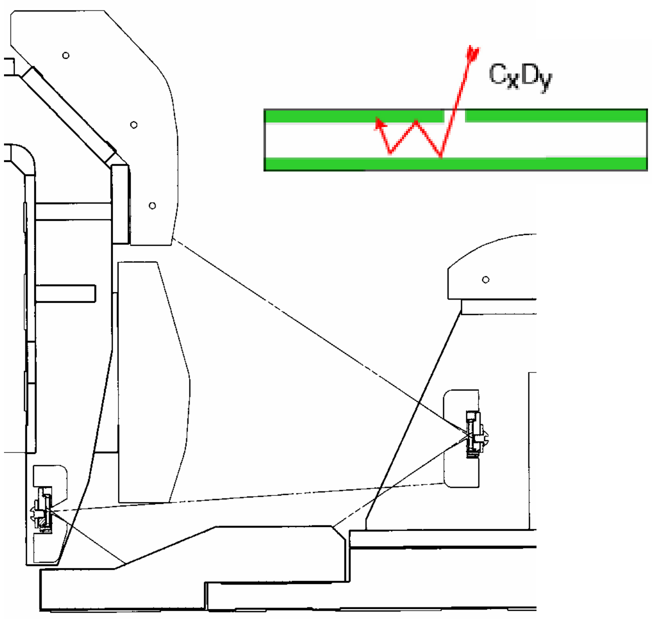




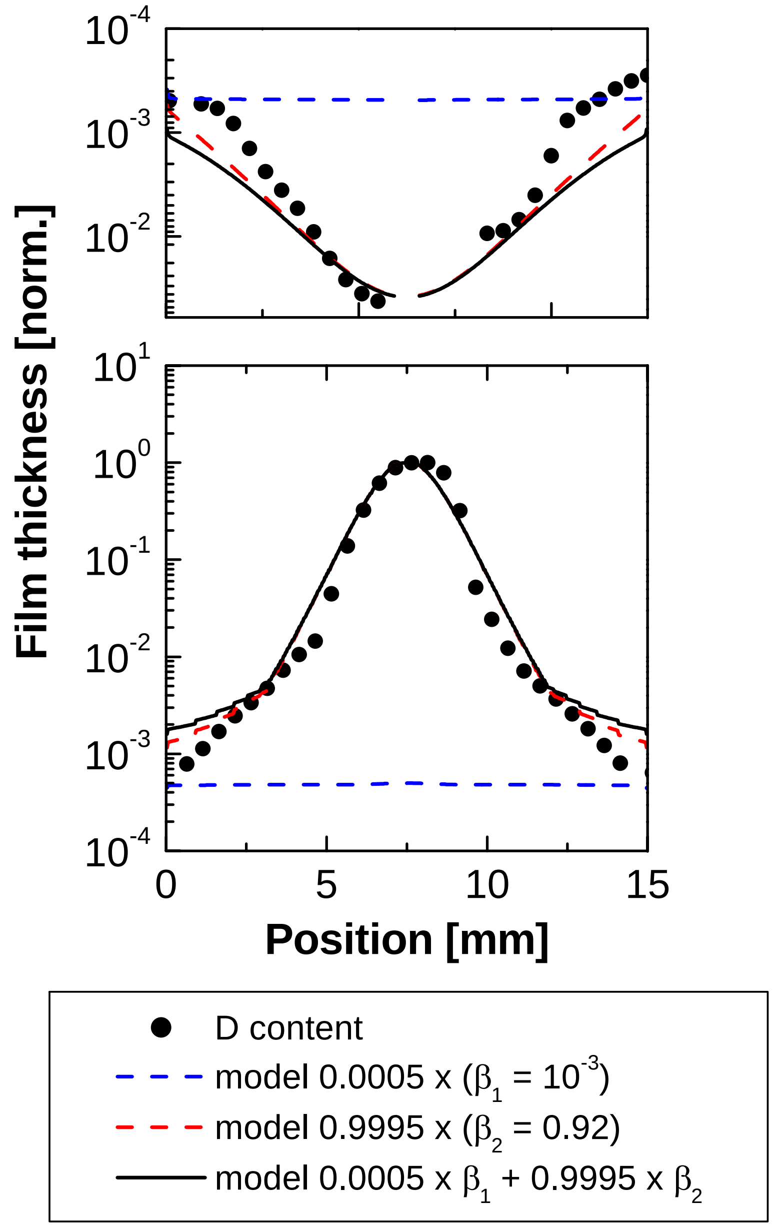
- Multiple species are emitted under chemical erosion conditions
- Sticking coefficient ranging from 0.6 to 10^{-3}
- More data needed on **eroded species**

Co-deposition in JET

Cavity probes



M. Mayer, Final Report Task FT-3.4 (2003)
M. Mayer, et al., EPS St. Petersburg (2003)

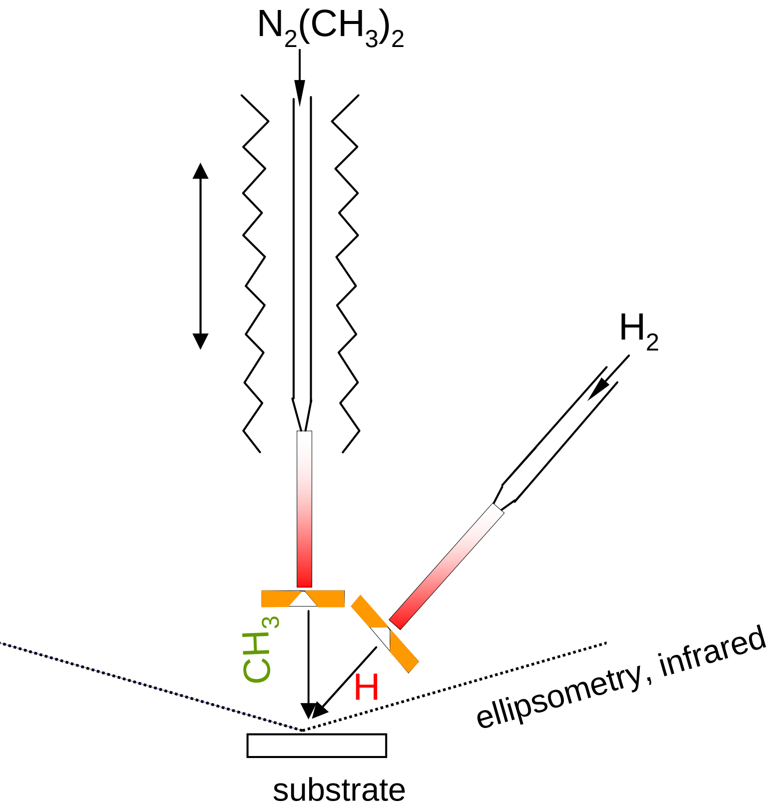


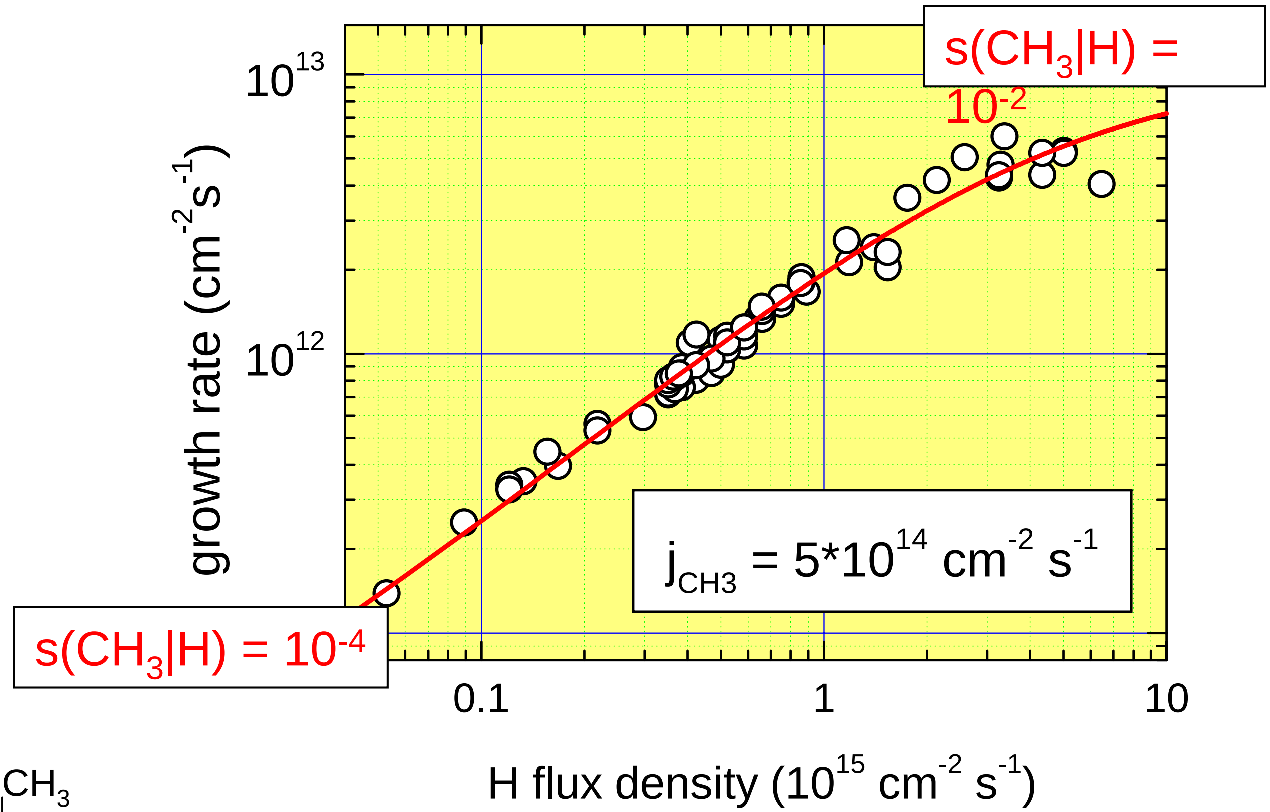
In JET and ASDEX Upgrade:

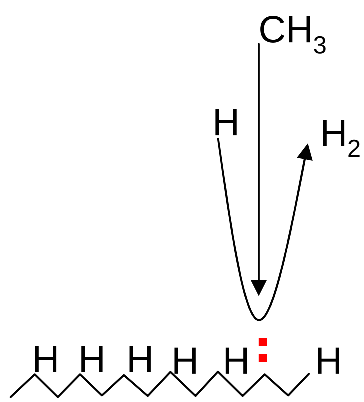
Co-deposition predominantly due to **high sticking species** within few wall collisions

Redeposition:

Deposition of hydrocarbon radicals





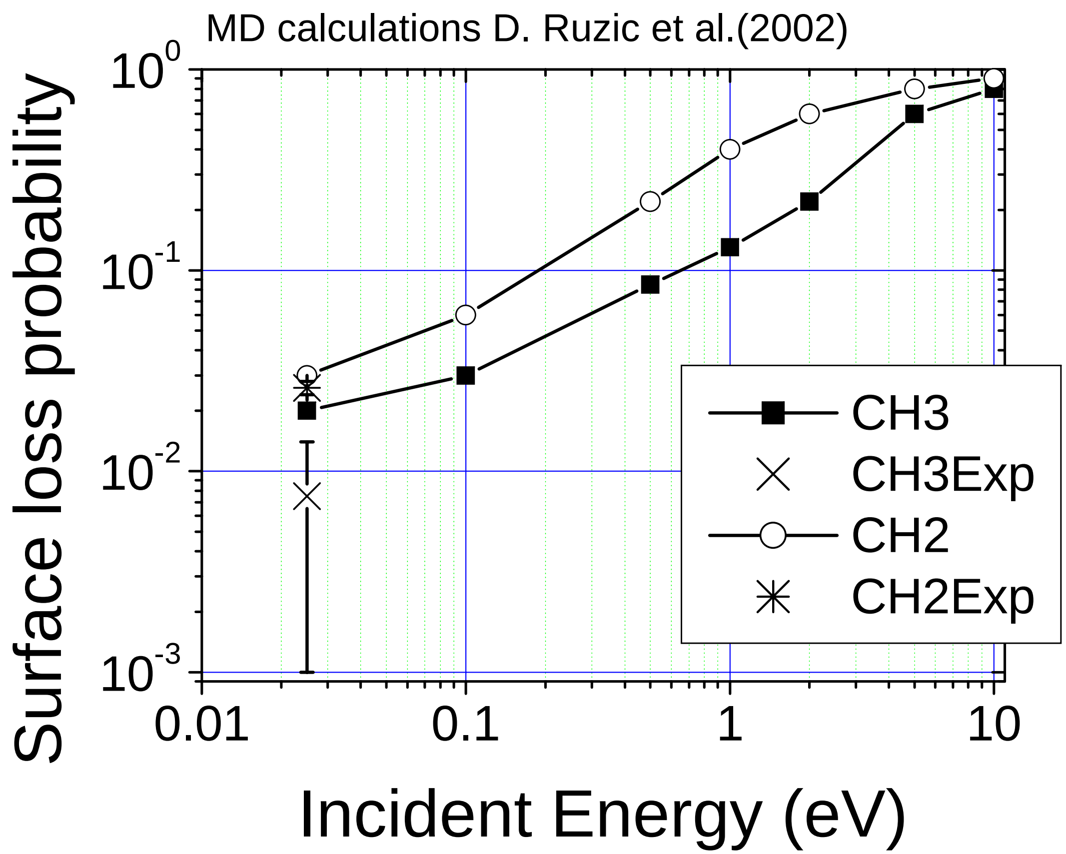


W.Jacob et al. (2002)

Redeposition of carbon:
Sticking coefficients

Sticking coefficients for hydrocarbon molecules and radicals

Sticking Coeff.	Experimental for 1100 K [v. Keudell'01]	0.02 to 10eV [Ruzic'02]
CH_4	0	n.a.
CH_3	10^{-4} to 10^{-2}	0.02 to 1
CH_2	0.02	0.03 to 1
CH	n.a.	n.a
C	1	1
C_2H	<0.92	0.15 to 1
C_2H_3	<0.35	0.02 to 1
C_2H_5	$<10^{-3}$	n.a.



- Surface loss probability depends on hybridization state of the radical ($sp^1 > sp^2 >> sp^3$).

Extrapolation to ITER

Steady state divertor erosion and wall co-deposition

Extrapolations from JET:

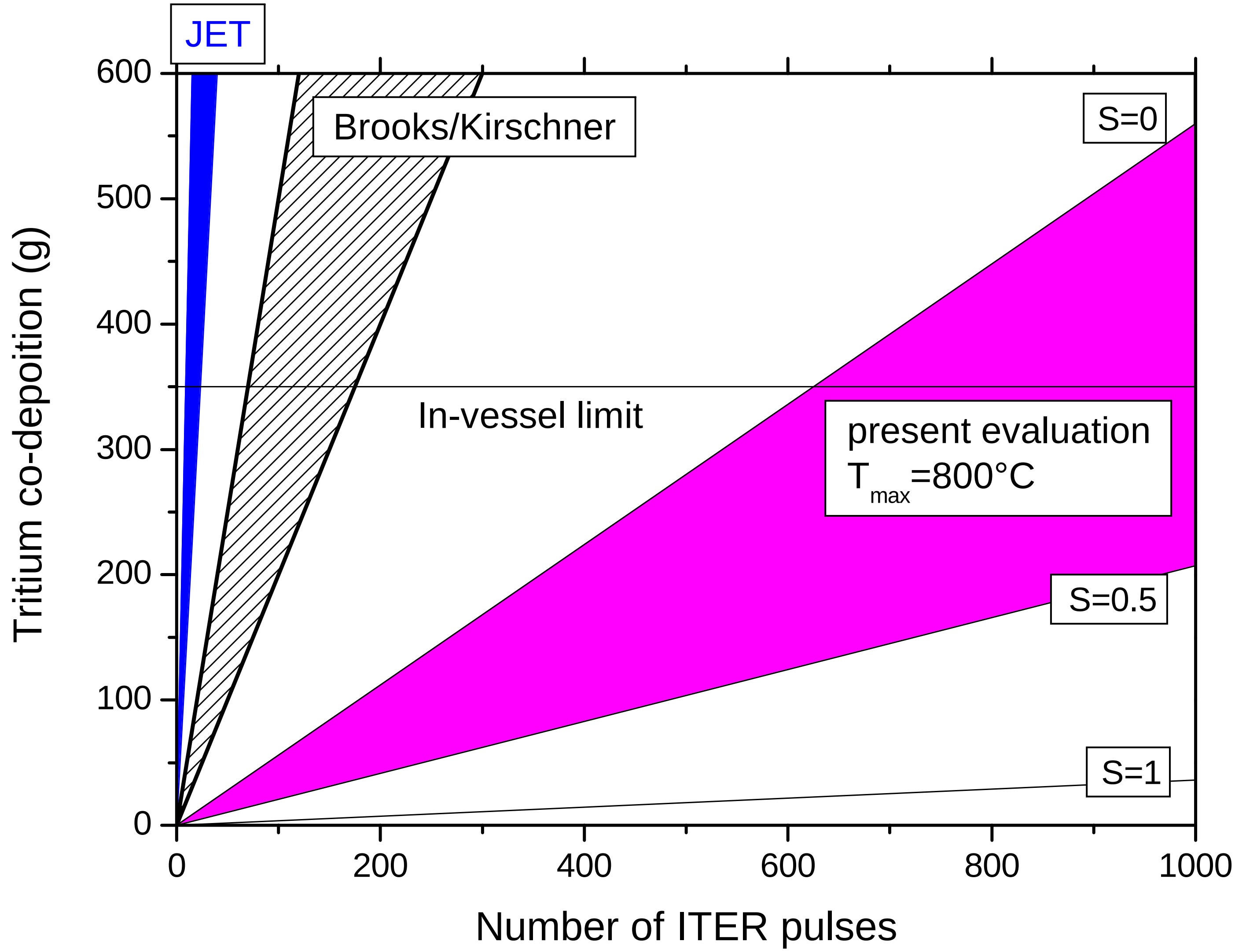
Scaling of carbon deposition with power and/or ion fluences

Extrapolation Brooks:

Erosion at divertor only, erosion yield = 1.5%
Carbon deposition together with tritium at areas other than divertor plates

„Present“ extrapolations:

Full description of erosion yield, variation of sticking coefficient for radicals and carbon atoms



G. Matthews et al., ETP Workshop Heraklion (2003)
J. Roth et al., JNM 337-339 (2005) 970

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Open Questions and Data Needs

How are hydrocarbons released from end of ion range?

Are diffusional and breakup processes involved?

What is the origin of the composition of hydrocarbons and its change with ion energy?

What is the origin of the flux dependence? Are individual steps with time duration of the order of 0.1-1 ms necessary?

More information is needed on sticking coefficients of radicals.

More information is needed on the re-erosion of deposited a-C:H layers.

MD calculations D. Ruzic et al.(2002)