Isotopic Fractionation in the Solar System

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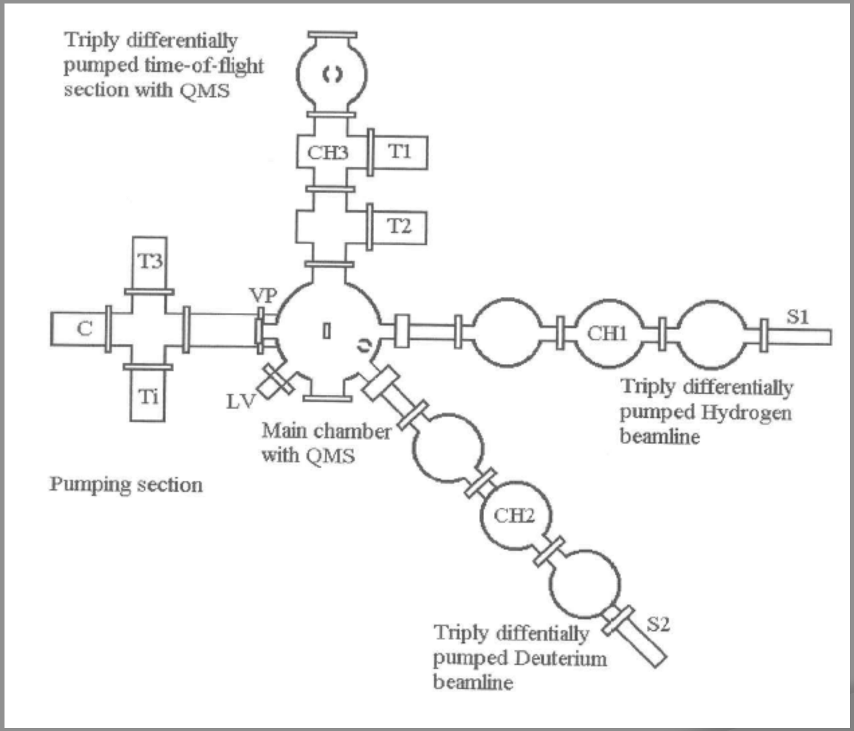
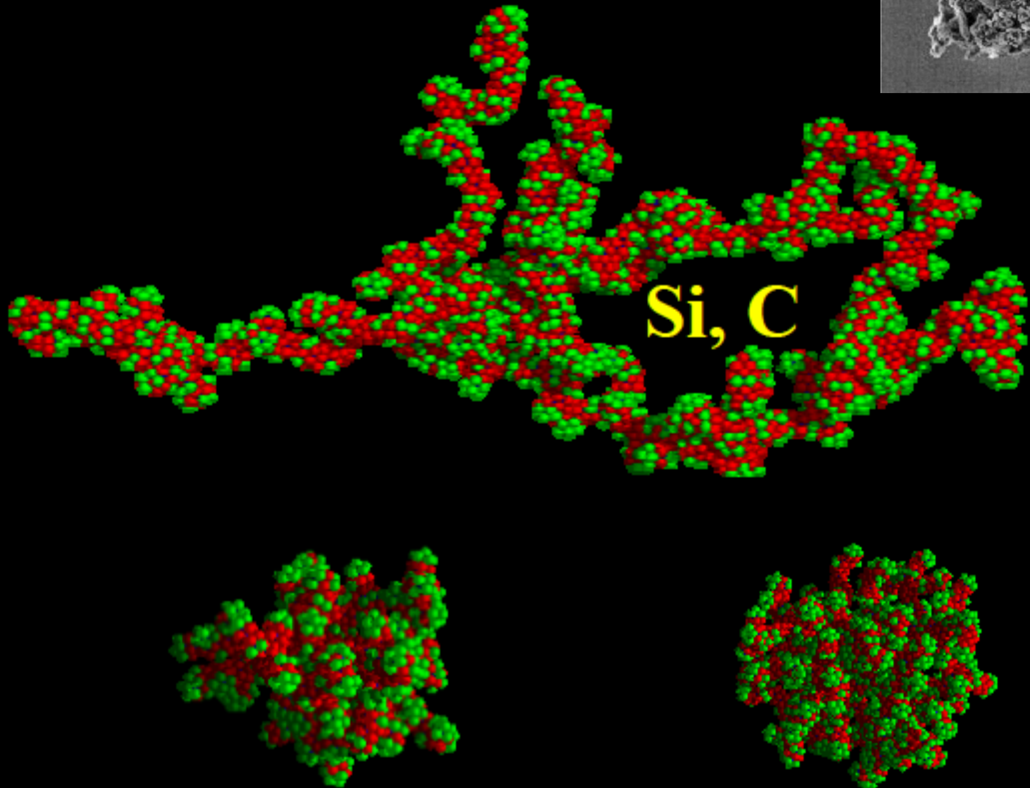


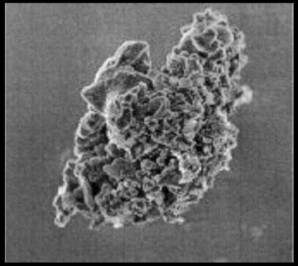
There are a number of interstellar processes that can produce significant isotopic fractionation in the product:

- Gas phase ion-molecule interactions;
- Low-temperature gas-grain reactions;
- Gas phase unimolecular photodissociation;
- Ultraviolet photolysis and photodesorption in ice mantles
- Isotopic substitution due to ion irradiation.

Dust particles: the seeds of planets and molecules

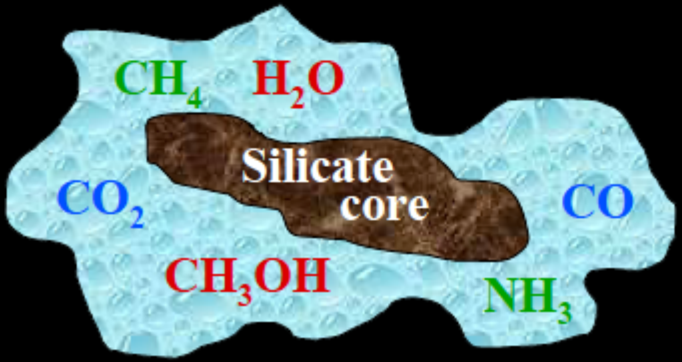
T > 100 K





T < 100 K

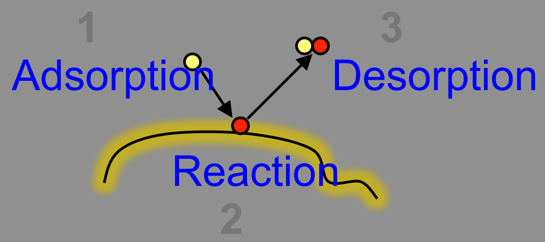
Ice coating ….



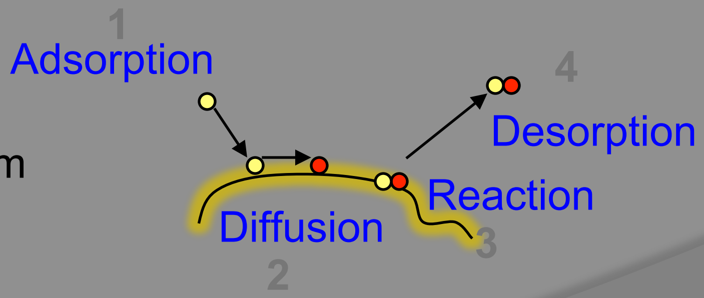
Surface catalysis

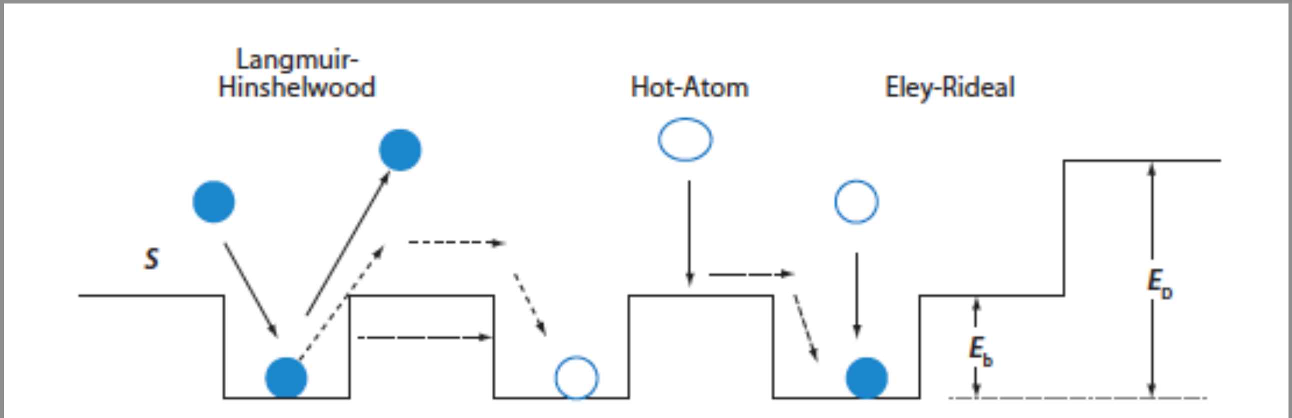
Surface catalysis allow molecules formation that are not possible in the gas phase. It opens pathways for the chemical evolution in space.

Eley-Rideal mechanism



Langmuir-Hinshelwood mechanism





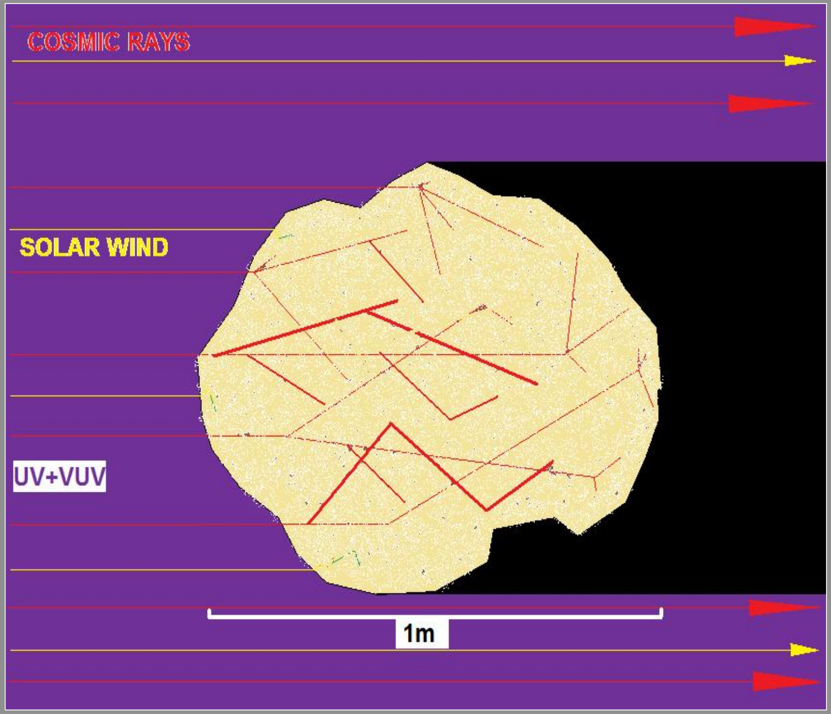
Tunnelling probability through this rectangular barrier is given by

rectangular barrier of height Ea and width a

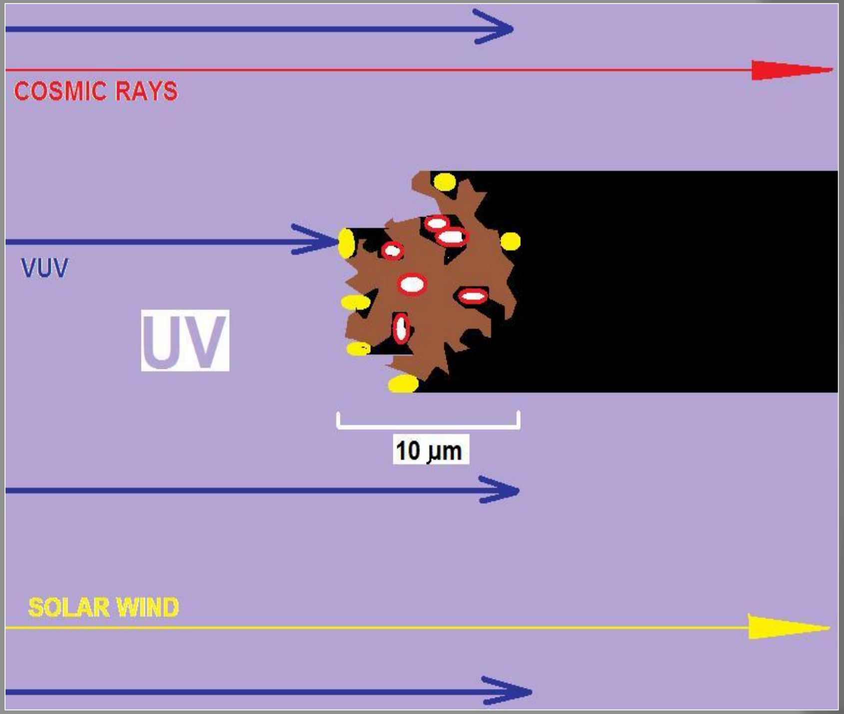
$$P_r = \exp\left(-\frac{2a}{\hbar}\sqrt{2\mu E_a}\right)$$

Reduced mass

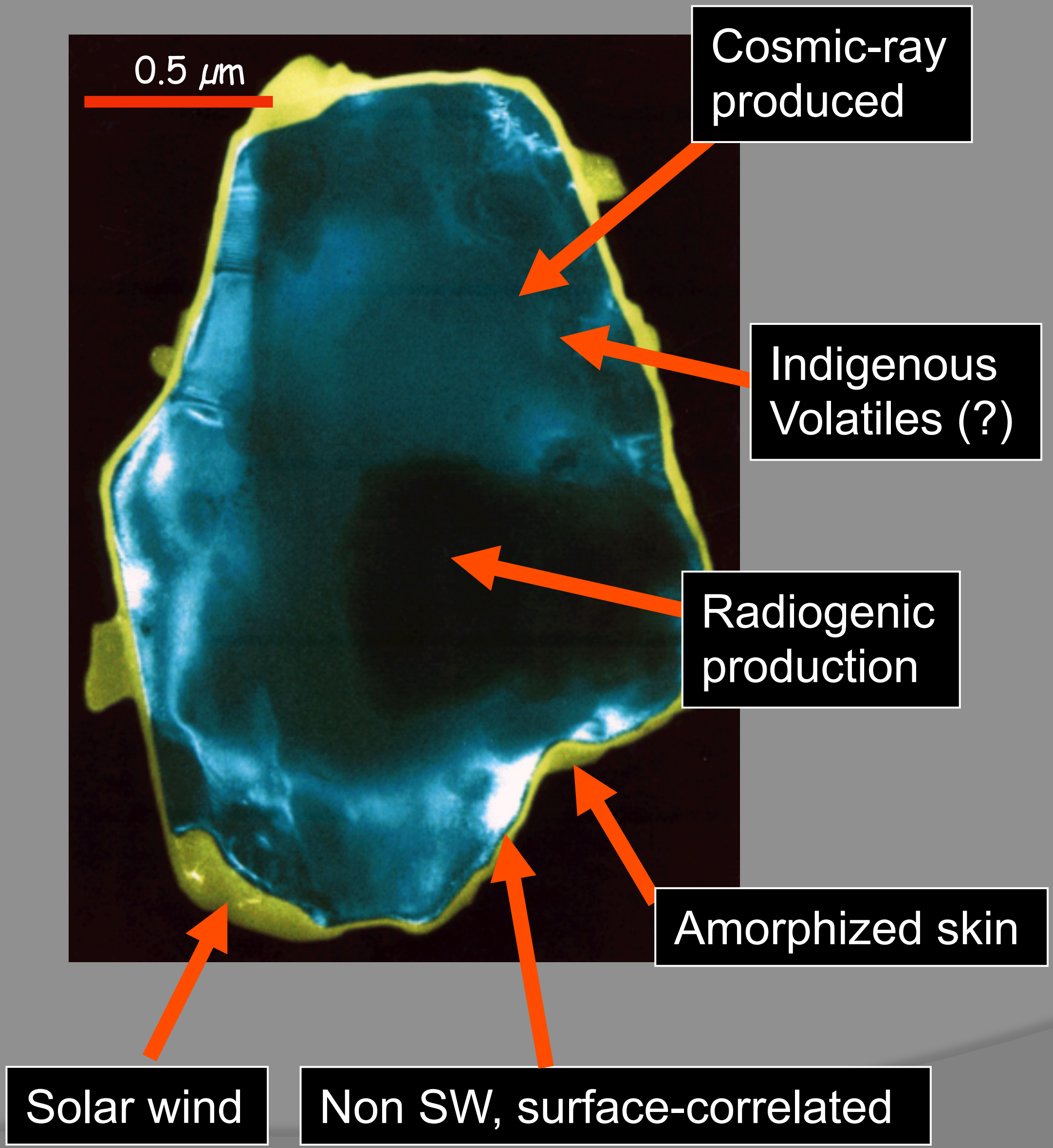
Big Rocks



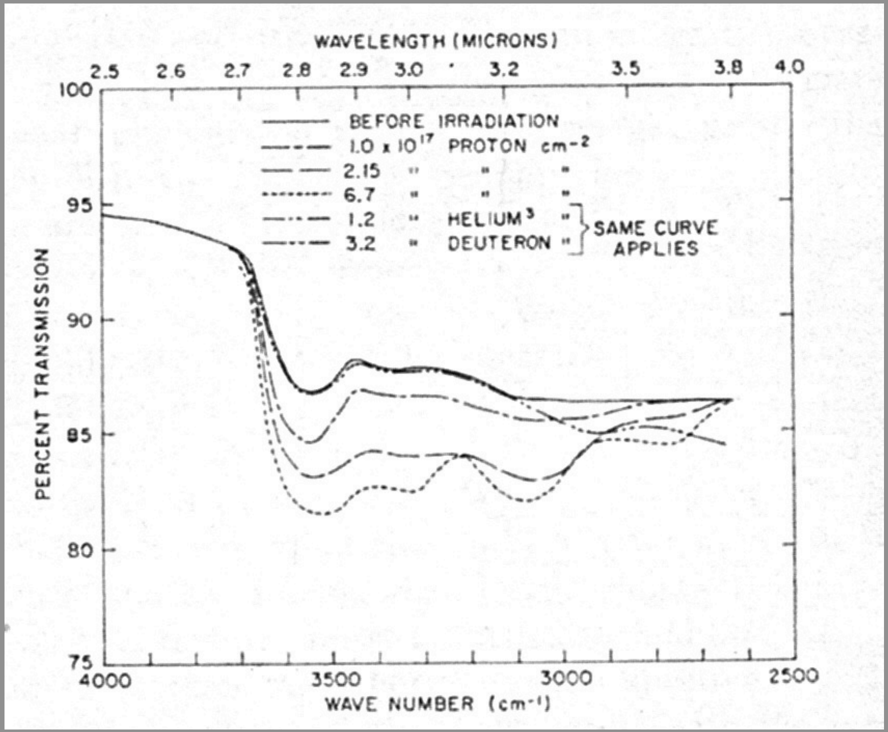
Small grains

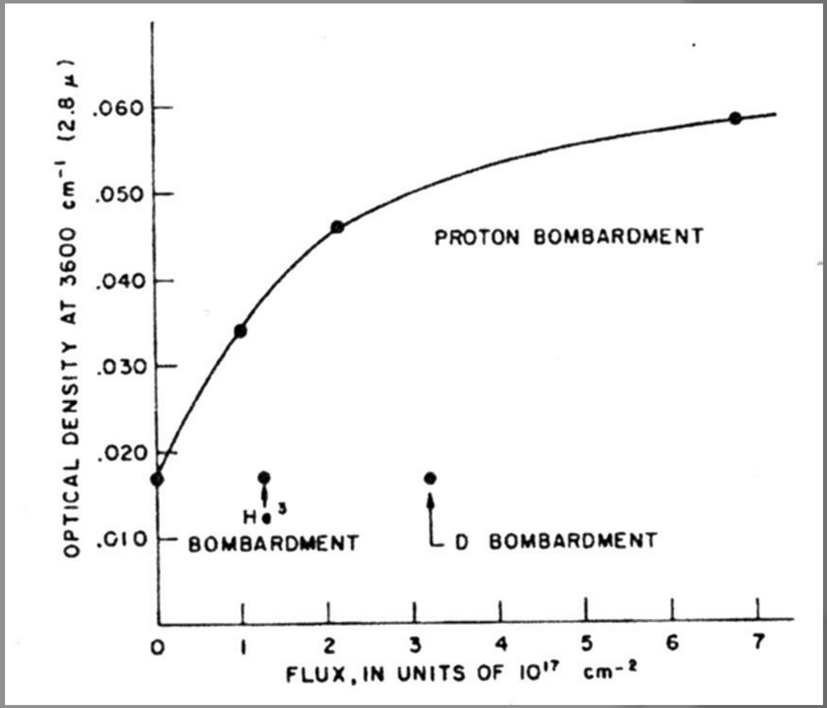


	Energy inputs (%) and		Fluxes (cm^{-2} s^{-1})
Solar Photons	2 eV	Visible (50%)	$2.0 \cdot 10^{17}$
	4 eV	NUV (10%)	$1.5 \cdot 10^{16}$
	6 eV	FUV (0.02%)	$3.0 \cdot 10^{13}$
Solar Wind (1 AU)	1keV	H^+ (95%)	$3.0 \cdot 10^{8}$
	4keV	He^{2+} (5%)	
Solar Flares (1 AU)	>1 MeV	H^+(95%)	10^{10} (cm^{-2} yr^{-1})
	>1 MeV	He^{2+} (5%)	
Galactic cosmic rays	>1 MeV	H^+ (87%)	10^{1}
	>1 MeV	He^{2+} (12%)	


0.5 μm
Cosmic-ray produced
Indigenous Volatiles (?)
Radiogenic production
Amorphized skin
Solar wind
Non SW, surface-correlated

Proton-induced hydroxyl formation

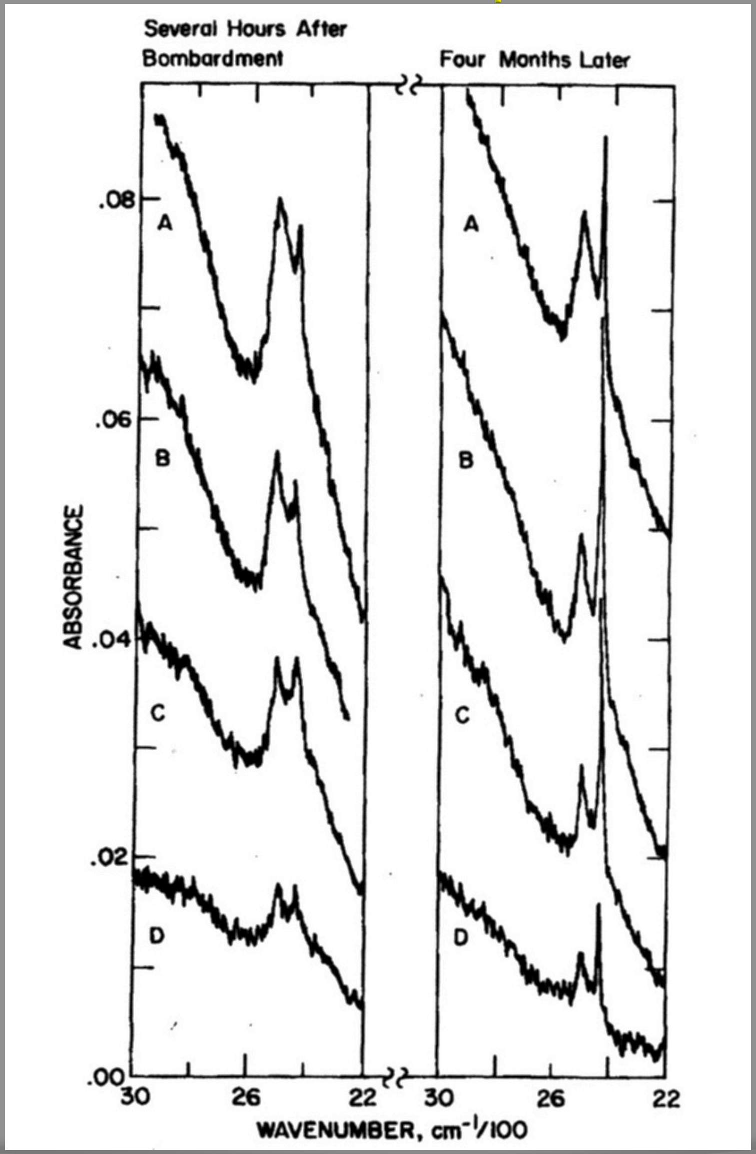




Estimate of the OH produced in the upper centimeter of the lunar surface material by proton bombardment: 4×10^{16} OH cm^{-3}

(Zeller et al. 1966)

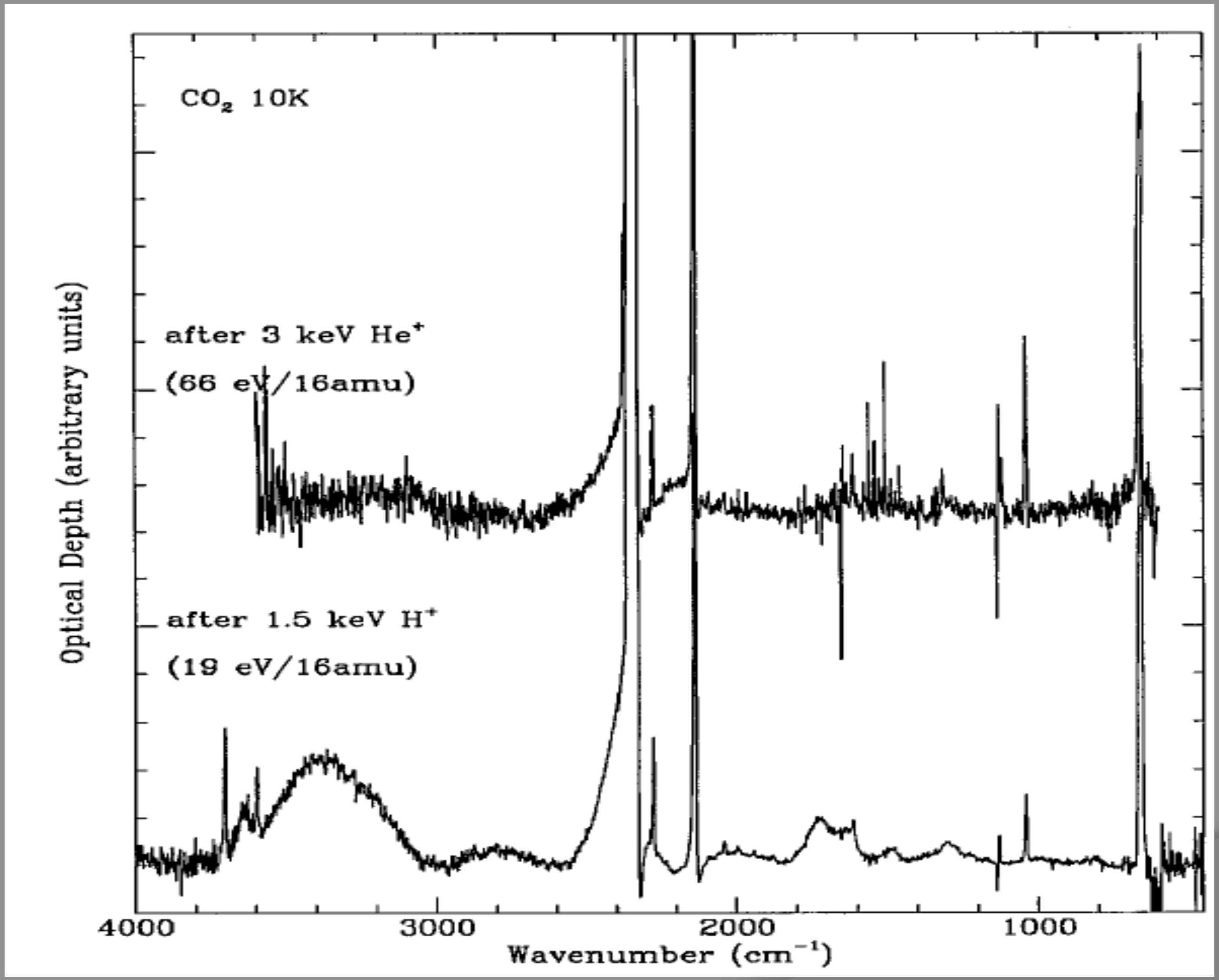
Chemical implantation of 10 keV H^+ and D^+ in rutile



(Siskind et al. 1977)

- OD stretching: 2505 and 2438 cm^{-1}
  - In same implanted samples no sharp peak exists initially
- The intensity ratio of the two peaks changes with time:
  - slow, partial reordering of the damage
  - diffusion of deuterium and exchange with hydrogen

Water formation by ice irradiation



Brucato et al. 1997

1) $H + O_2 \xrightarrow{H} HO_2 \xrightarrow{H} H_2O_2 \xrightarrow{H} H_2O + OH \xrightarrow{H} H_2O$ (Ioppolo et al. 2008, 2010)

2) $O + O_2 \rightarrow O_3 \xrightarrow{H} O_2 + OH \xrightarrow{H_2} H_2O + H$ (Tielens & Hagen 1982)

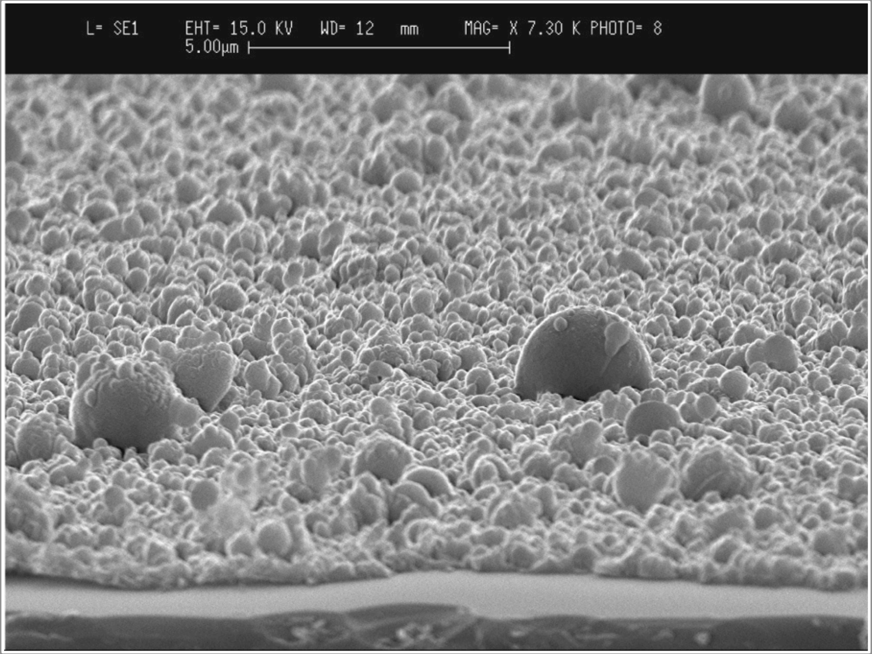
3) $H + O \rightarrow OH \xrightarrow{H} H_2O$ (Dulieu et al. 2010)

Some argues that species formed by these exotermic reactions will immediately desorb (Paoupular 2005). However, models predicts that most (99.1%) of OH and H_2O formed remain on surfaces (Cupper and Herbst 2007).

Silicate production in laboratory

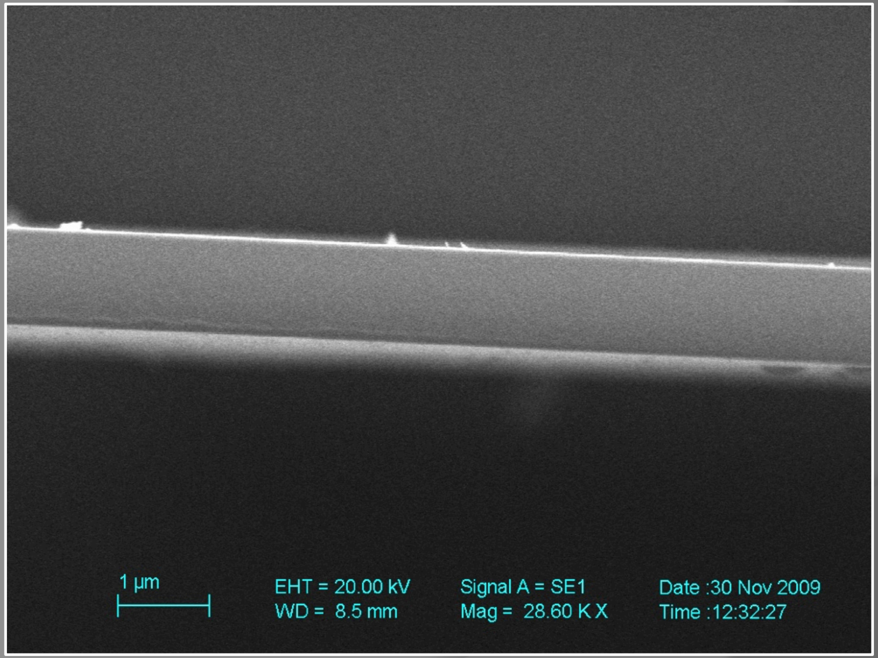
Amorphous olivine & pyroxene

Laser ablation



P= 10 mbar O_2

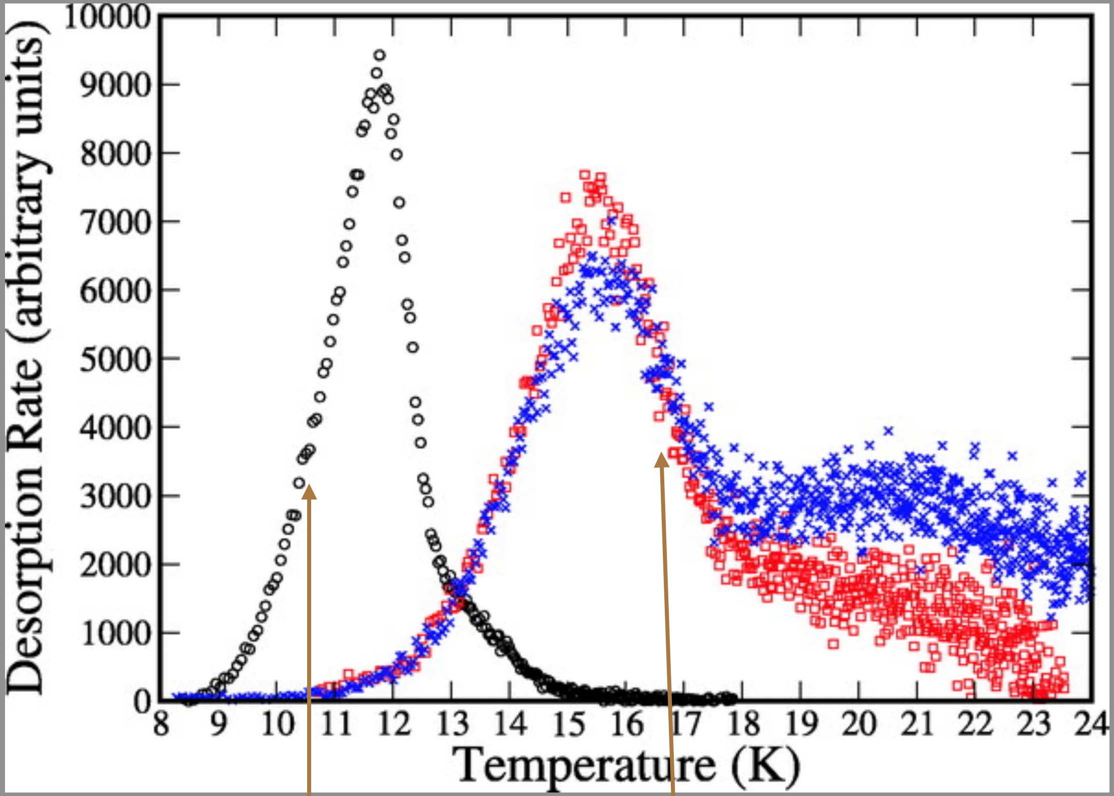
Electron Beam



P= 10^{-5} mbar

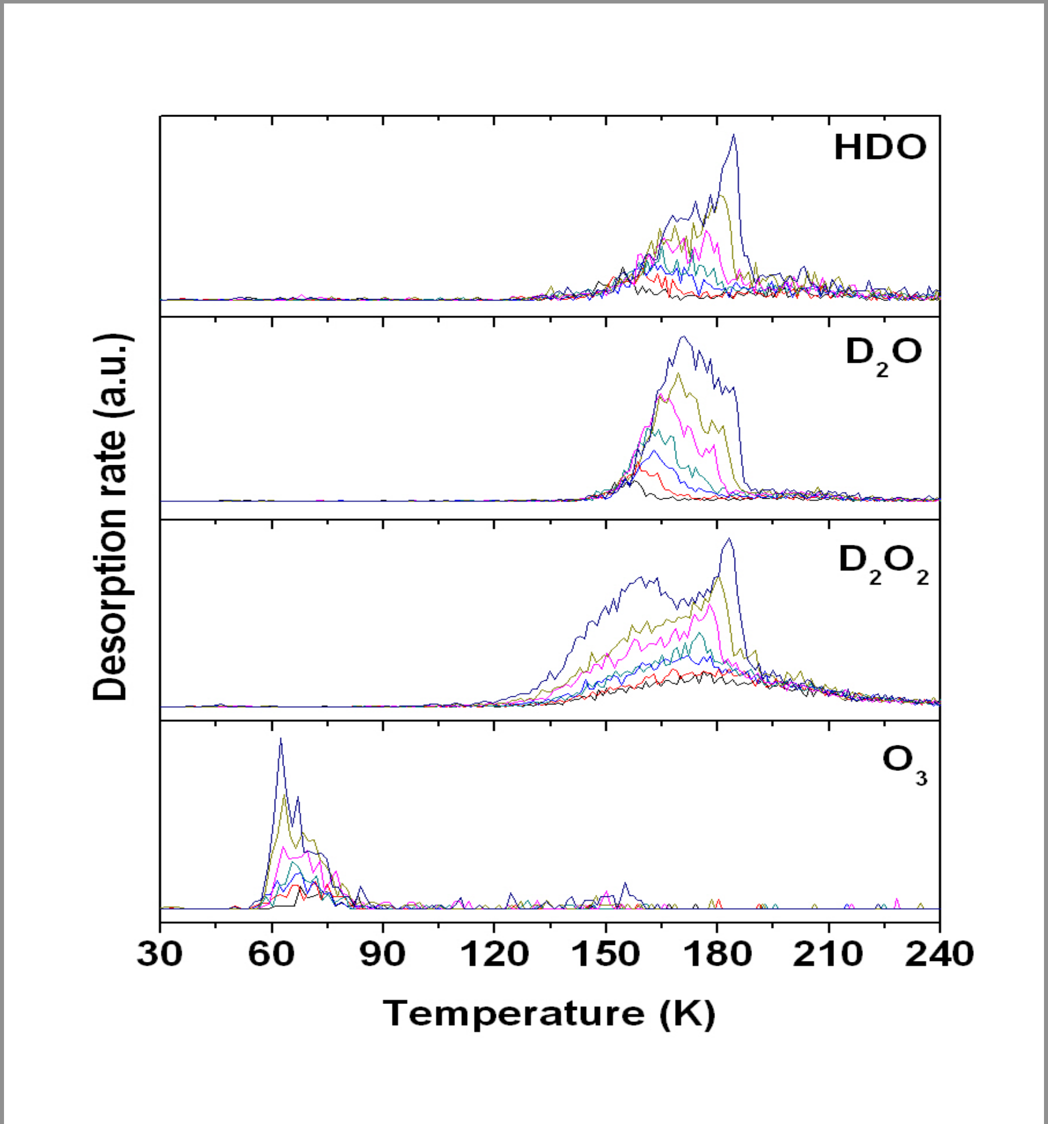
H & D beams irradiation of amorphous olivine silicate (Fe, Mg)SiO_4

(Perets et al. 2007)



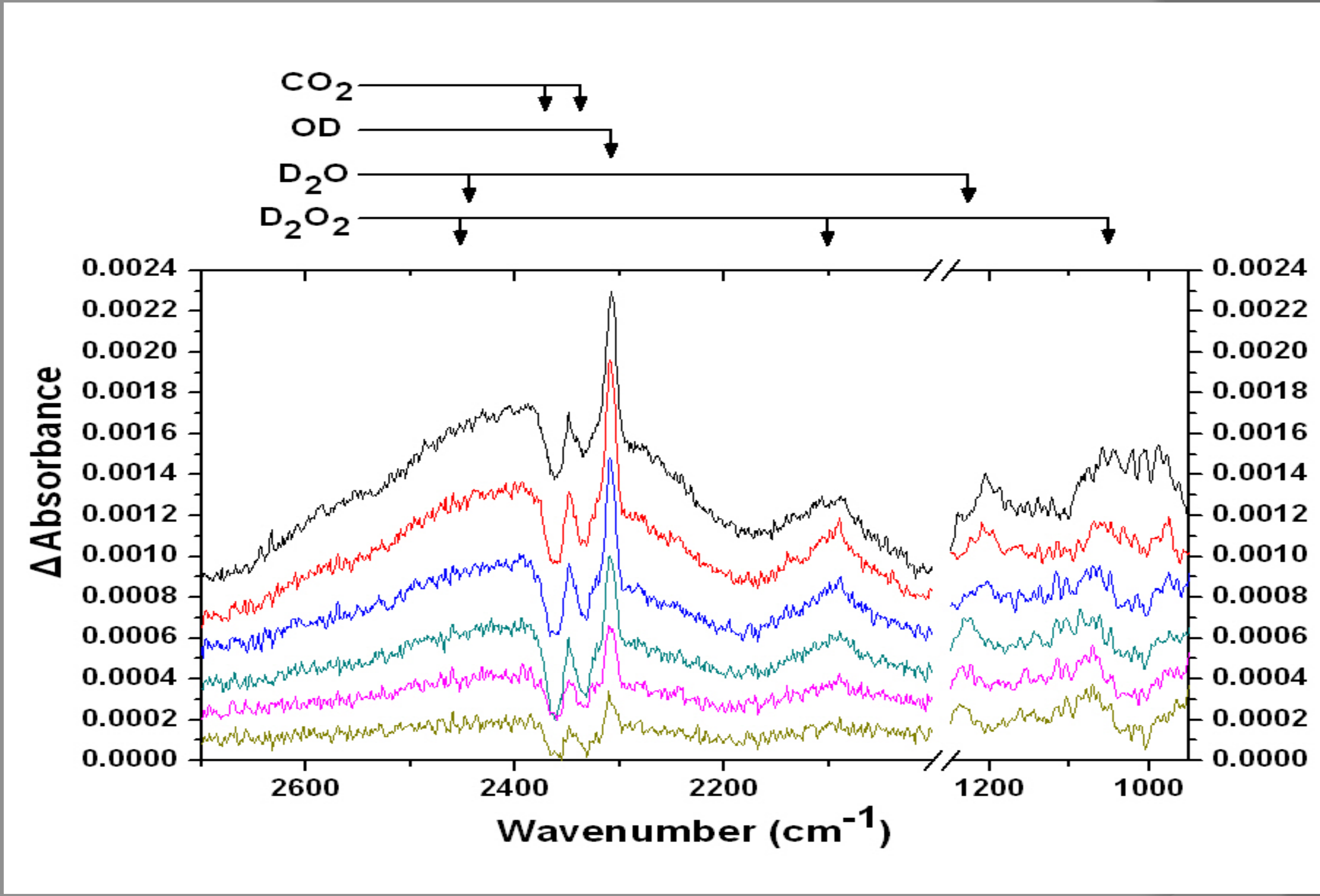
Desorpion rate of HD molecules vs. surface temperature during TDP on polycrystalline and amorphous silicates

Perets et al. 2007



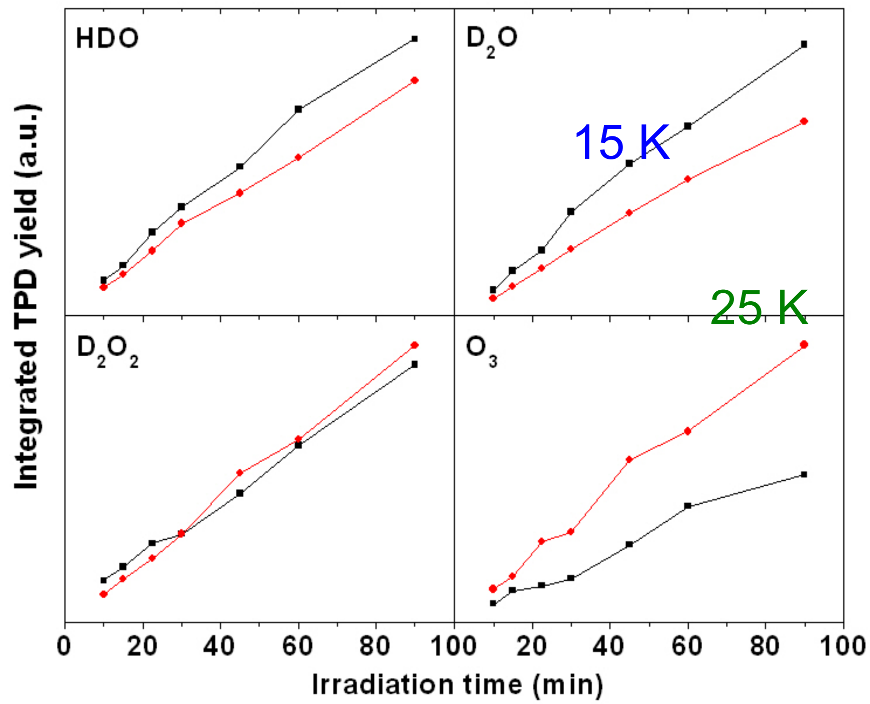
Desorption peaks for various species after D and O co-exposure. From bottom to top: 10 min, 15 min, 22.5 min, 30 min, 45 min, 60 min and 90 min.

Jing et al. 2011



RAIR spectra of D and O co-exposure for (from bottom to top) 1 hour, 2 hours, 3 hours, 4 hours, 5 hours and after annealing the sample at 70 K for 5 min after exposure. The spectra are displaced on the vertical axis for clarity.

Jing et al. 2011

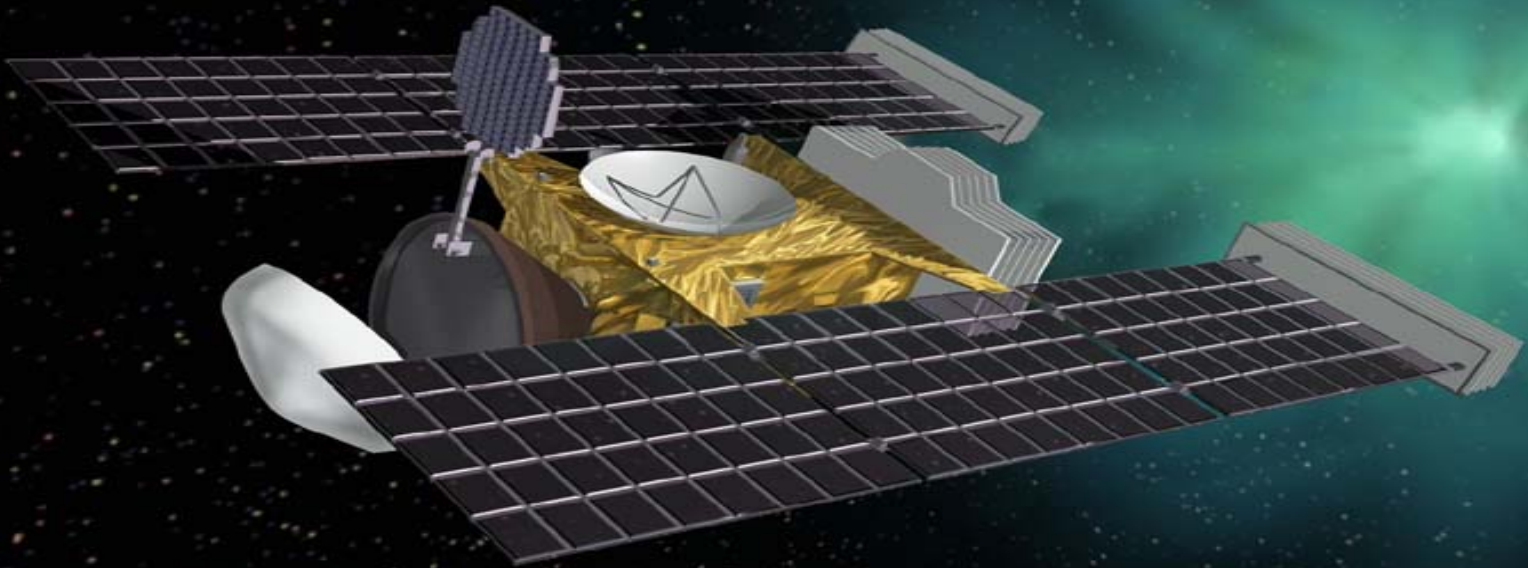


Binding energy

HDO 390 meV
D2O 400 meV
H2O 170 meV
D2O2 430 meV

	HDO	D_2O	D_2O_2	O_3
15 K Slope ($cm^{-2}min^{-1}$)	1.5×10^{13}	4.2×10^{13}	7.6×10^{13}	2.6×10^{12}
25 K Slope ($cm^{-2}min^{-1}$)	1.2×10^{13}	3.0×10^{13}	8.9×10^{13}	4.9×10^{12}
15 K Formation efficiency	0.043	0.12	0.22	0.007
25 K Formation efficiency	0.034	0.087	0.26	0.014

Dust from comet Wild 2:
Laboratory results on Stardust samples



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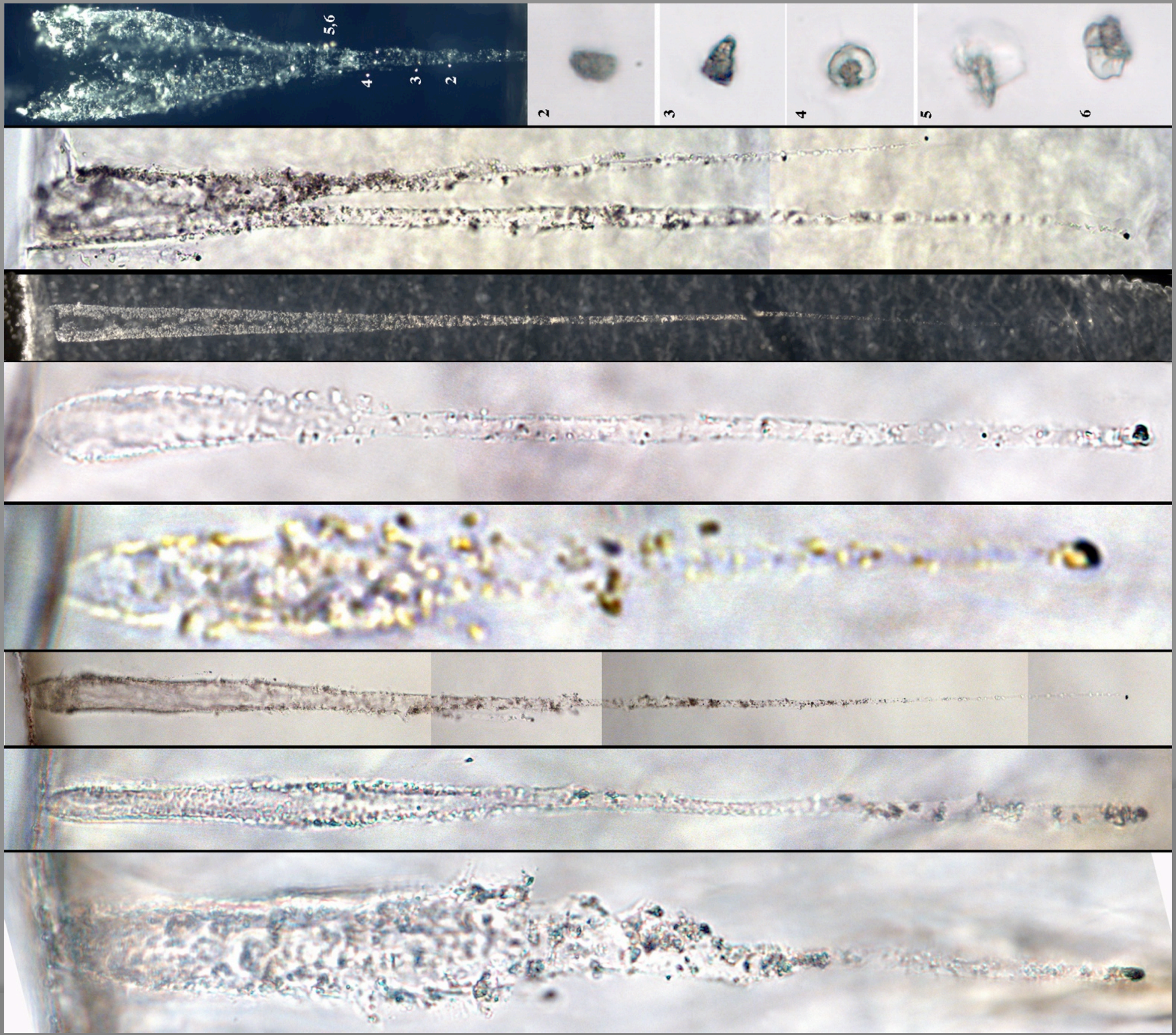
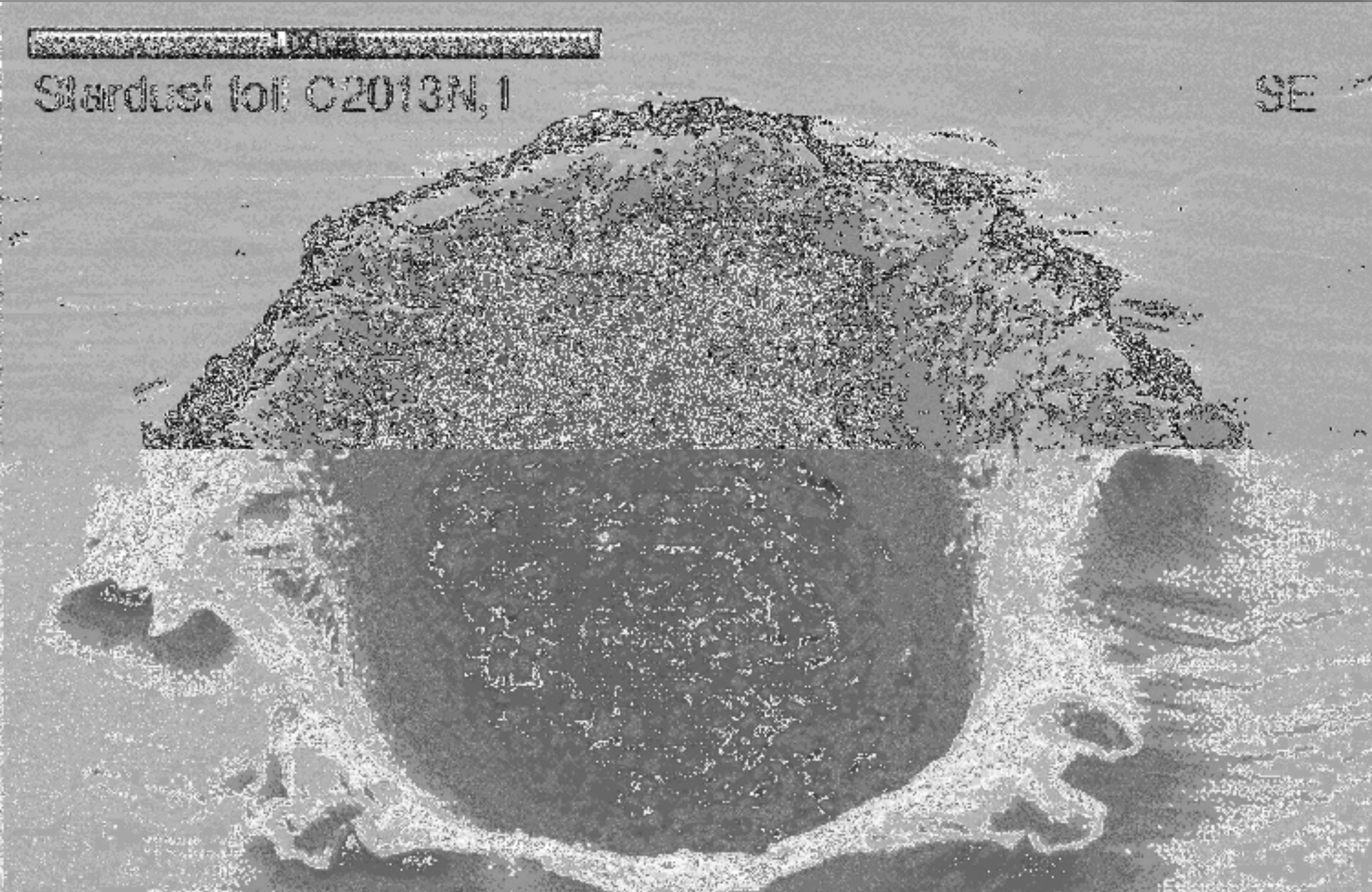
Isotopic Compositions of Cometary Matter Returned by Stardust

i) Does the comet consist of a mechanical agglomeration of essentially unprocessed, or perhaps only thermally annealed, presolar materials?
ii) Do comets provide a well-preserved reservoir of circumstellar dust grains with distinct nucleosynthetic histories (i.e., stardust)?
iii) Can isotopic signatures establish whether extraterrestrial organic materials are present above contamination levels?
iv) What are the relations to known isotope reservoirs in meteoritic samples and in IDPs?
v) What are the implications for mixing and thermal processing in the early solar system?

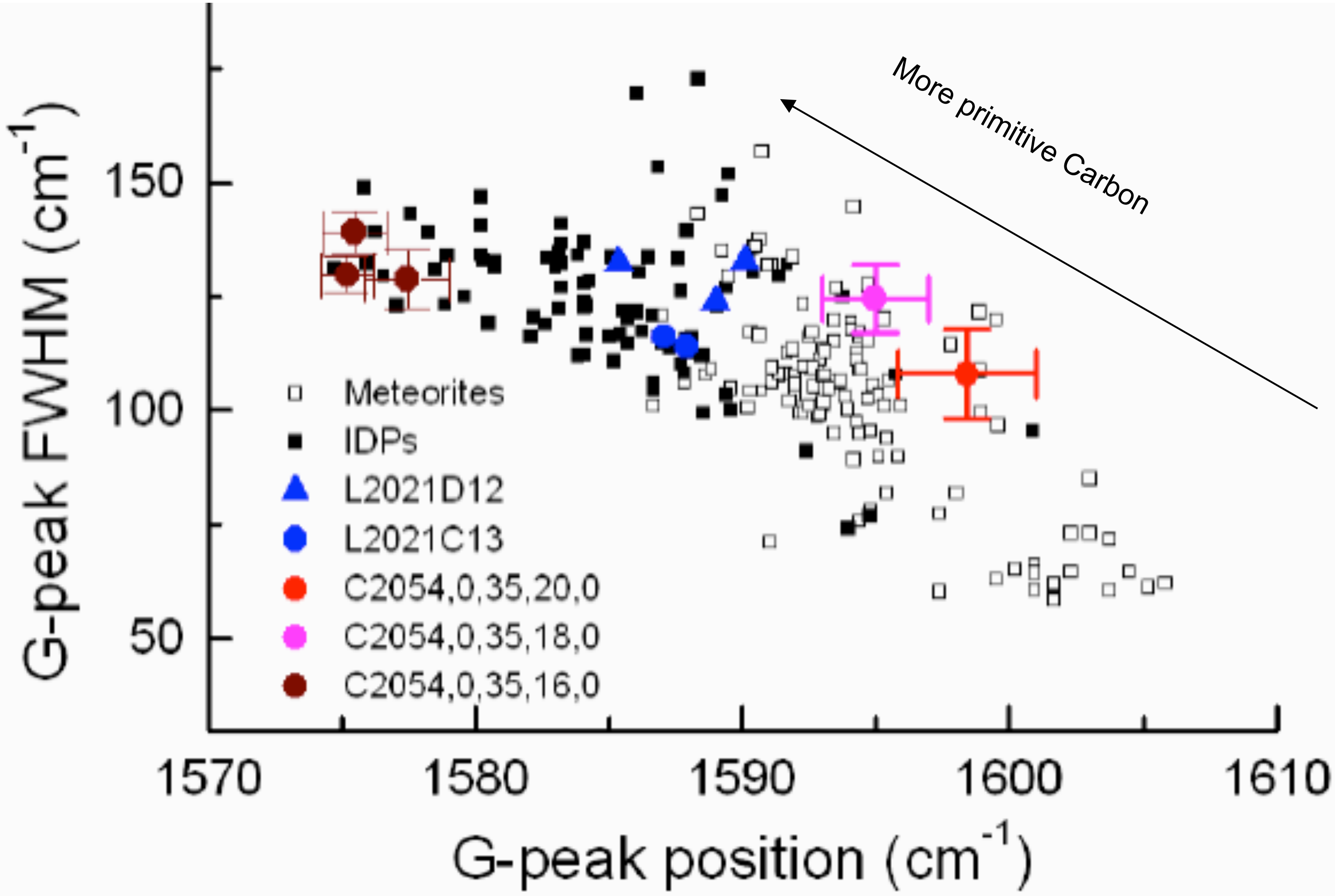
Tracks

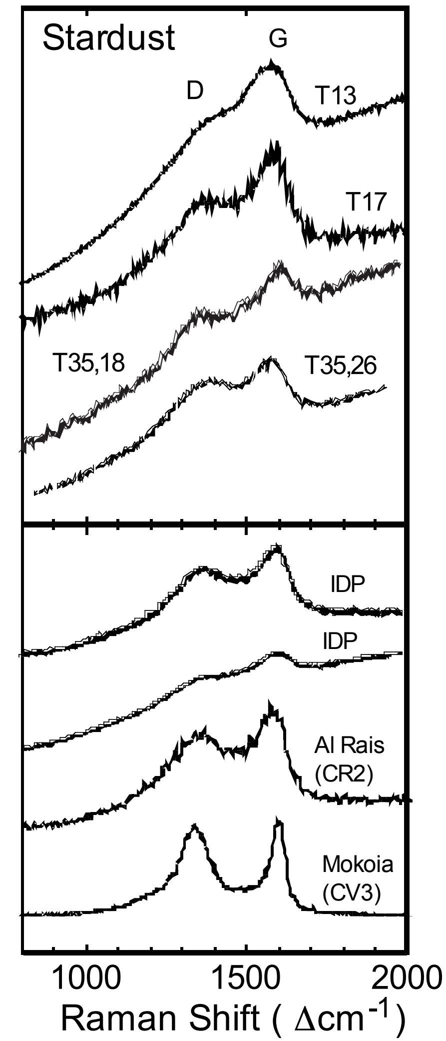


Craters on Al foils



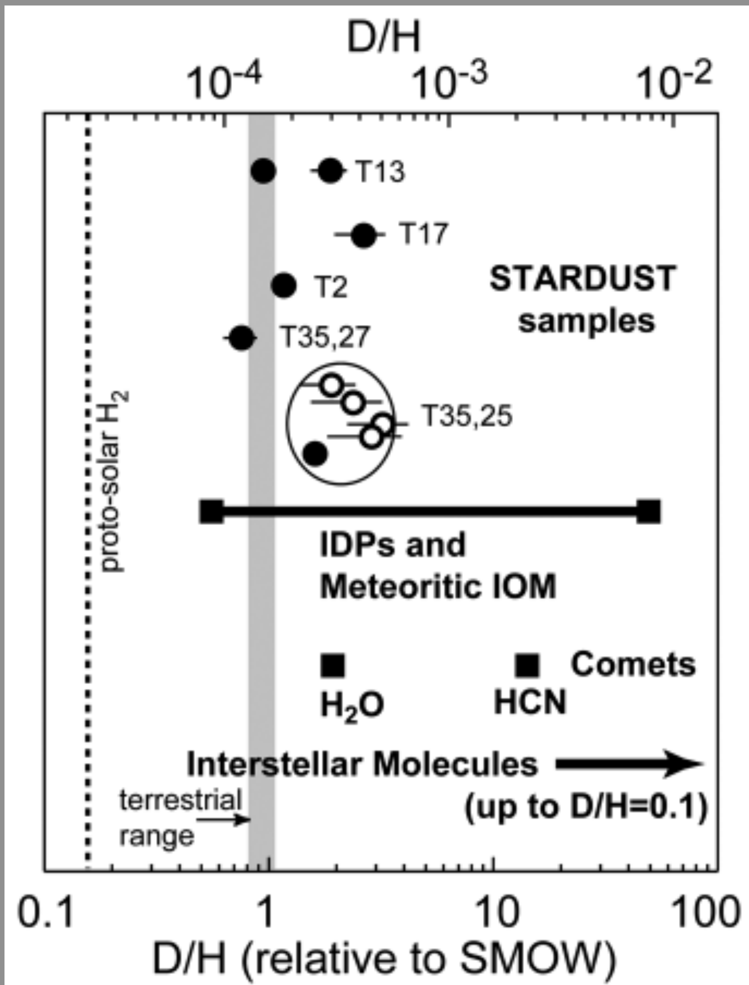
Raman analyses

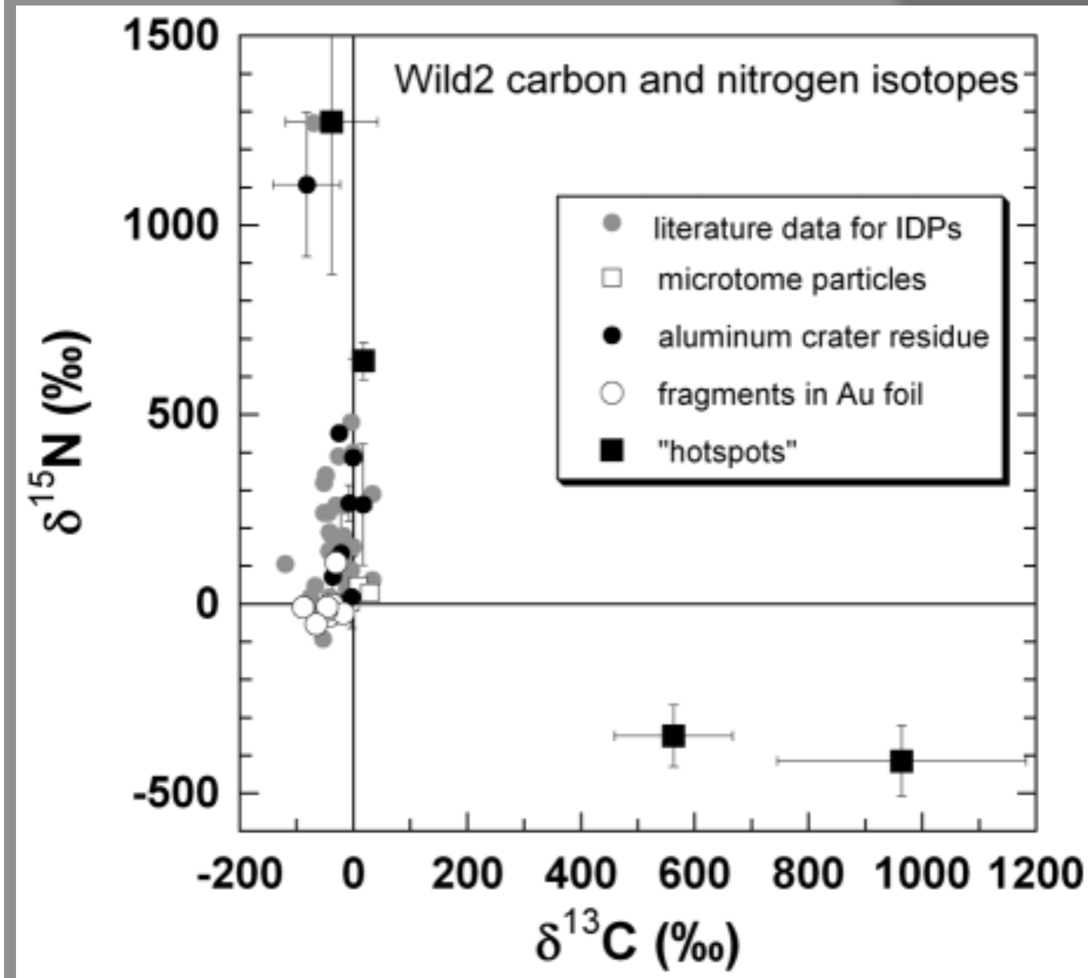




Rotundi et al. 2006, 2008

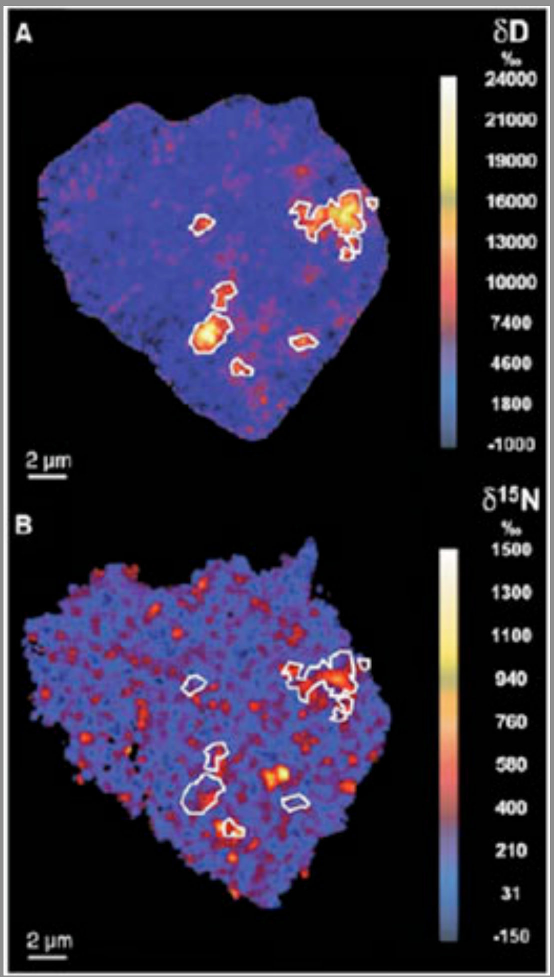
Raman G band parameters (center vs. Full Width at Half Maximum) of Stardust samples compared to those of meteorites and interplanetary dust particles (IDPs).



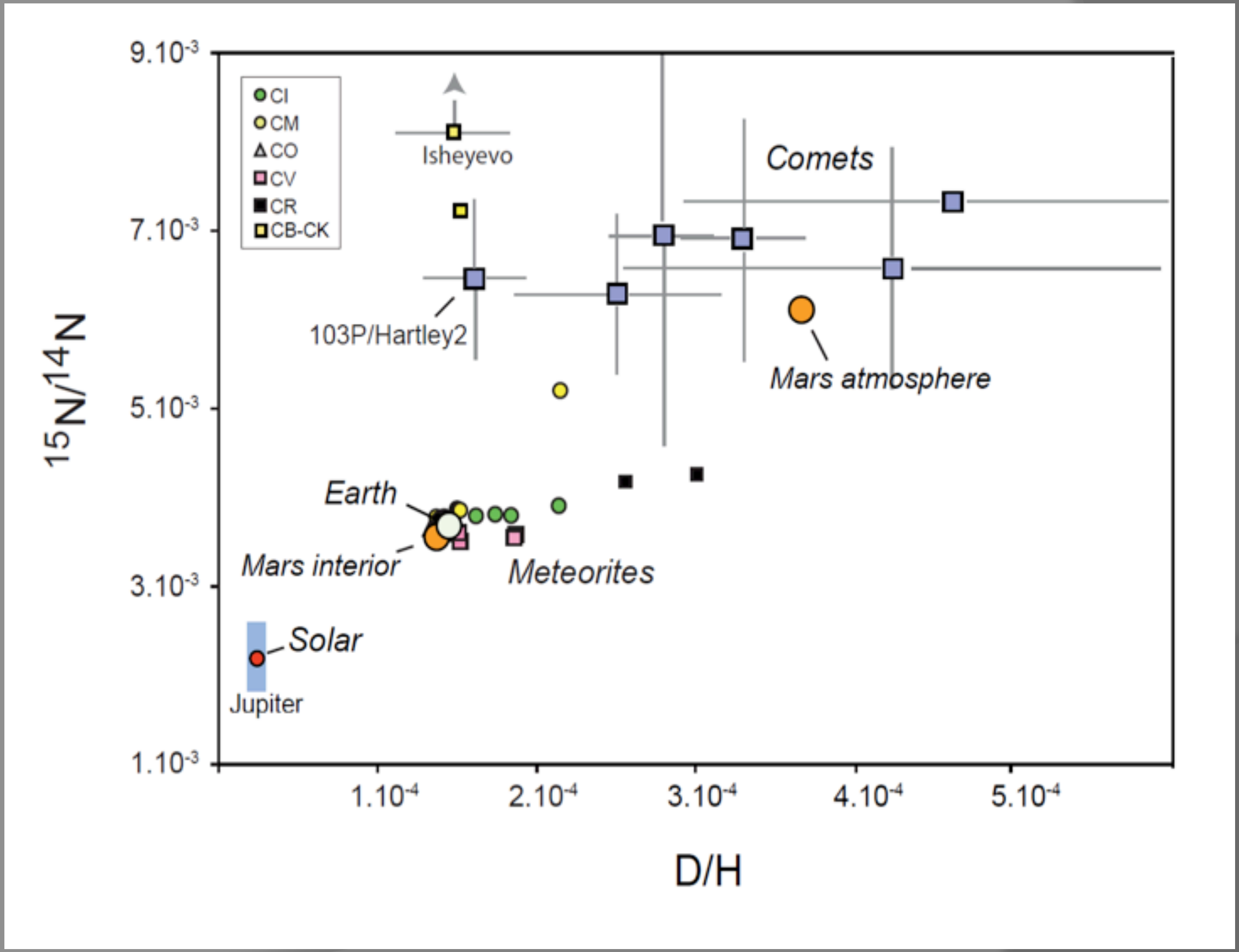


McKeegan et al. 2006

Hydrogen and nitrogen isotopic anomalies in organic matter from Primitive meteorites

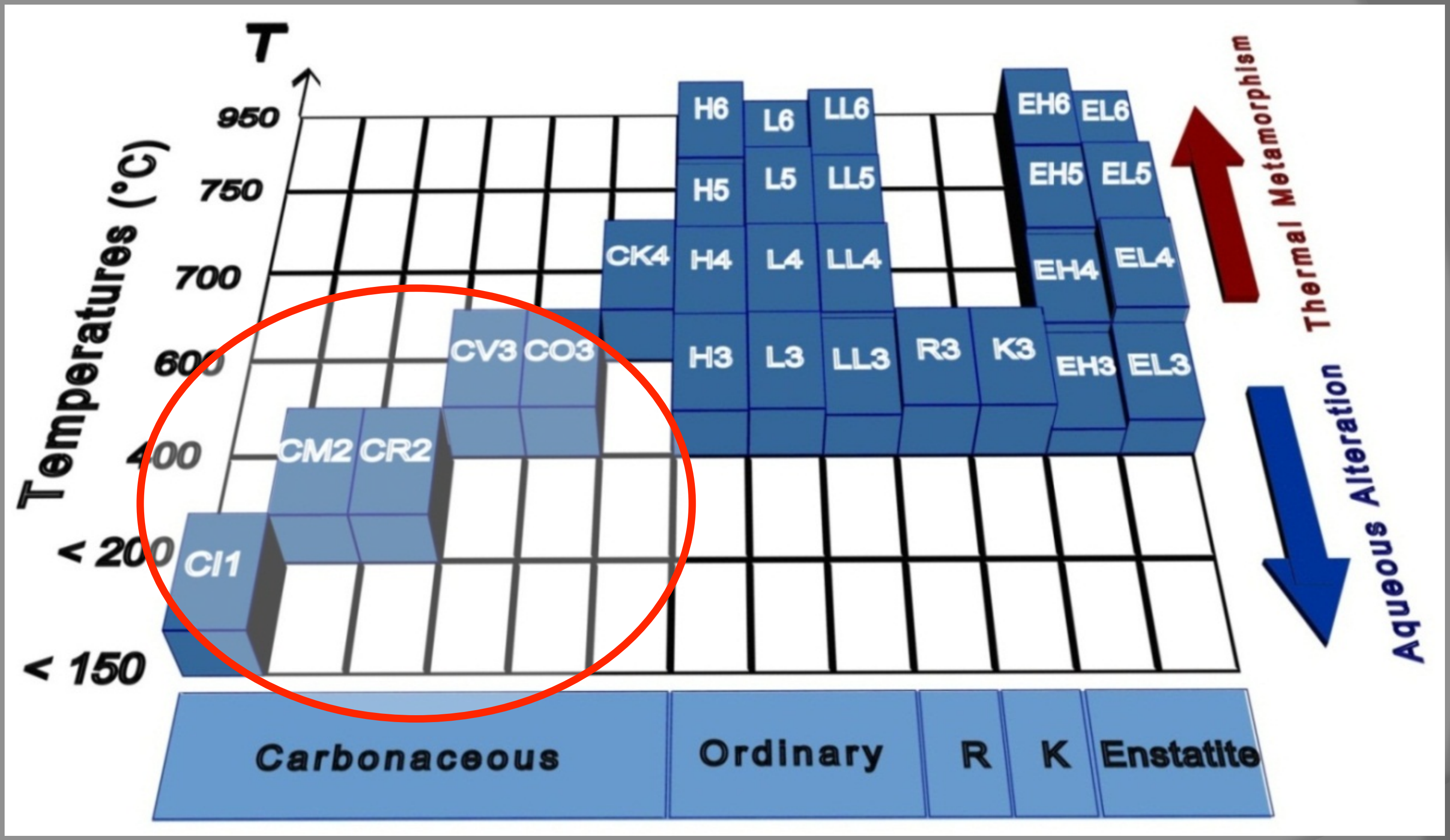


Busemann et al. 2006



Marty 2012

Meteorites processing



Primitive Objects

SUMMARY

The abundance of presolar grains appears to be low compared with that of primitive meteorites and IDPs;

The comet contains high-temperature silicate and oxide minerals with oxygen isotopic compositions essentially identical to those of analogous minerals in carbonaceous chondrites;

The great majority of Wild-2 silicates and oxides measured so far have Solar System O isotopic compositions;

Crystalline silicates have a very narrow range of O isotopic compositions indicating Solar System origins;

Refractory particles resembling Chondrules, CAI, and AOA fragments have been identified, indicating large scale transport of material in the solar nebula;

Intact organic matter is uncommon H and N isotopic anomalies observed in both craters and tracks;

First hint on isotopic fractionataion of water sublimation.