IR Spectroscopy and physicochemical effects on astrophysical ices produced by energetic ions collisions

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INTERNATIONAL SYMPOSIUM AND WORKSHOP ON ASTROCHEMISTRY

Understanding extraterrestrial molecular complexity through experiments and observations

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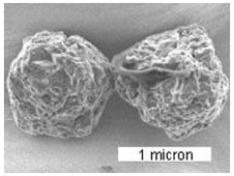
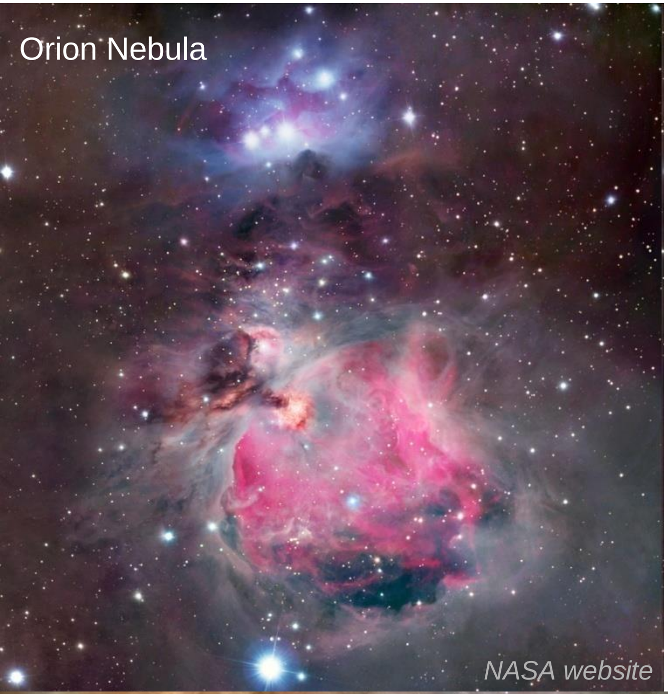
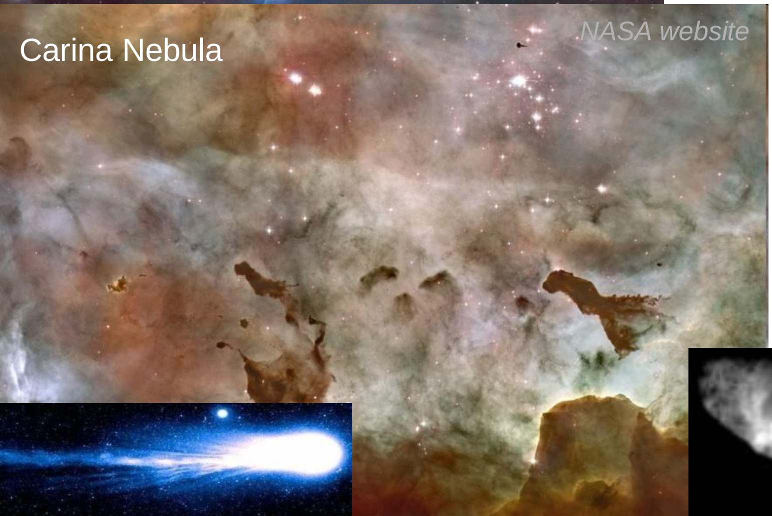
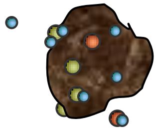
Astrophysical ices

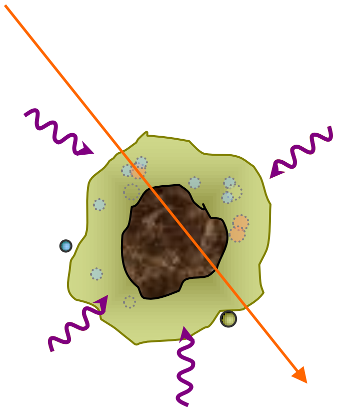






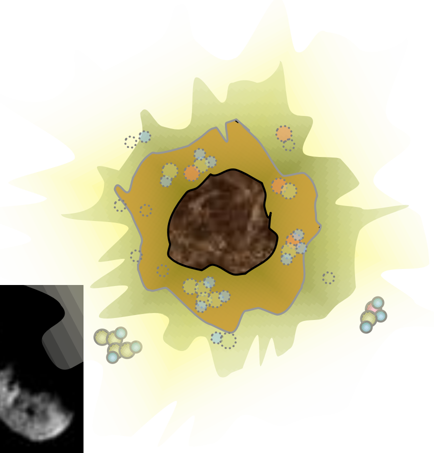


The grains are covered with an icy mantle formed from simple molecules (H_2O, CO, CO_2, N_2O, CH_4, etc).



Energetic processes induced by:

- photons,
- electrons (high and low-energy),
- ions (cosmic rays, solar wind).



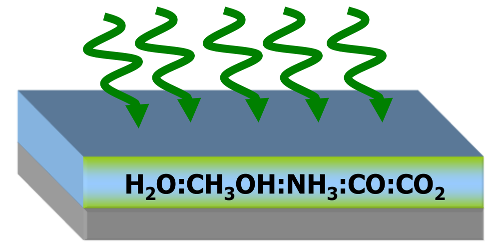
Irradiation induces chemical modification and desorption of species from the ice.

Astrophysical ices: energetic processes – state of the art

Projectiles:

• photons

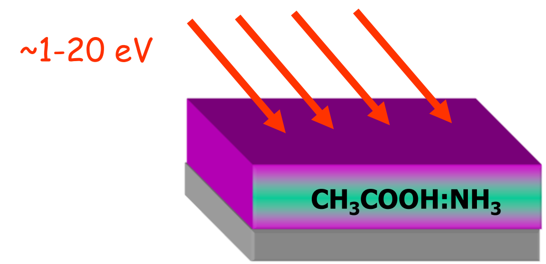
(e.g. new molecules, destruction/formation cross sections, photodesorption)



Muñoz Caro *et al.*, Nature **416** (2002) 403

• electrons (low and high energy range)

(e.g. same as Photons)

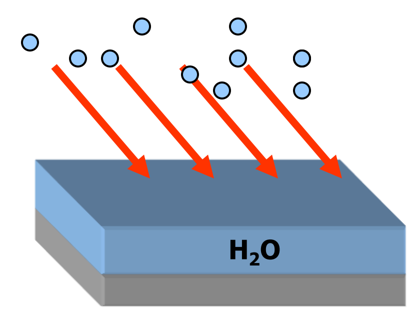


Lafosse *et al.*, PCCP **8** (2006) 5564

• ions

(mainly **H**, **He**, **C**, **O** ions in ~**50 keV** and **~2 MeV** energy range)

(e.g. new molecules, destruction/formation cross sections, sputtering)



Strazzulla & Baratta, Europhysics Letter 18 (1992) 517

In this work H^+ and He^+ at 1.5 MeV…

PUC – Van de Graaff Accelerator

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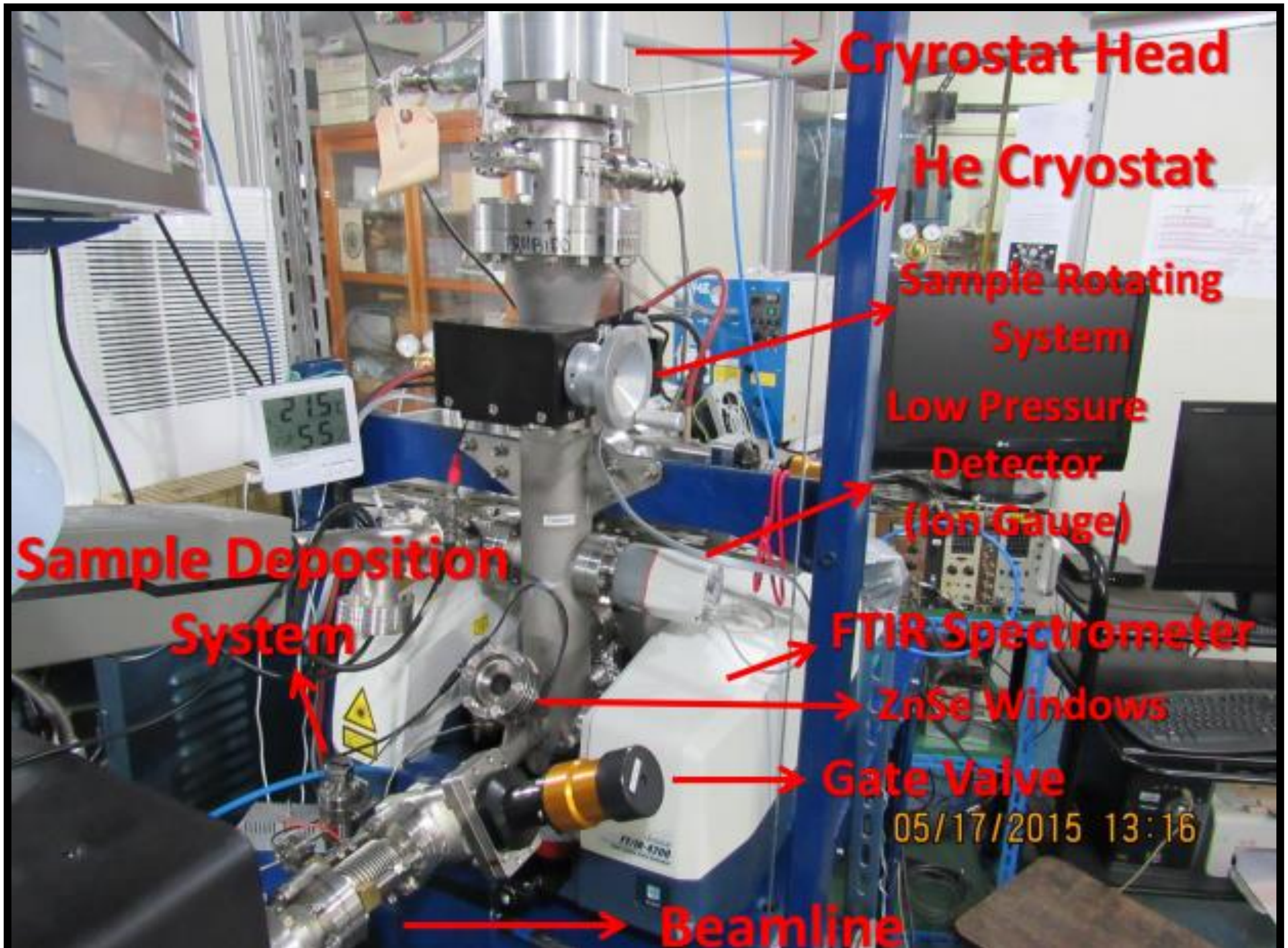
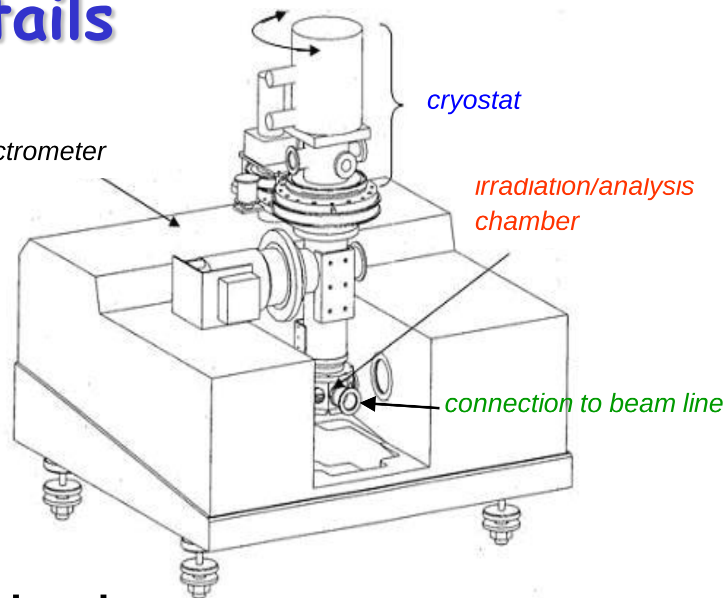
PUC – Van de Graaff Accelerator

FTIR Beamline UHV Chamber Overview



Experimental details



Substrate
Kbr window

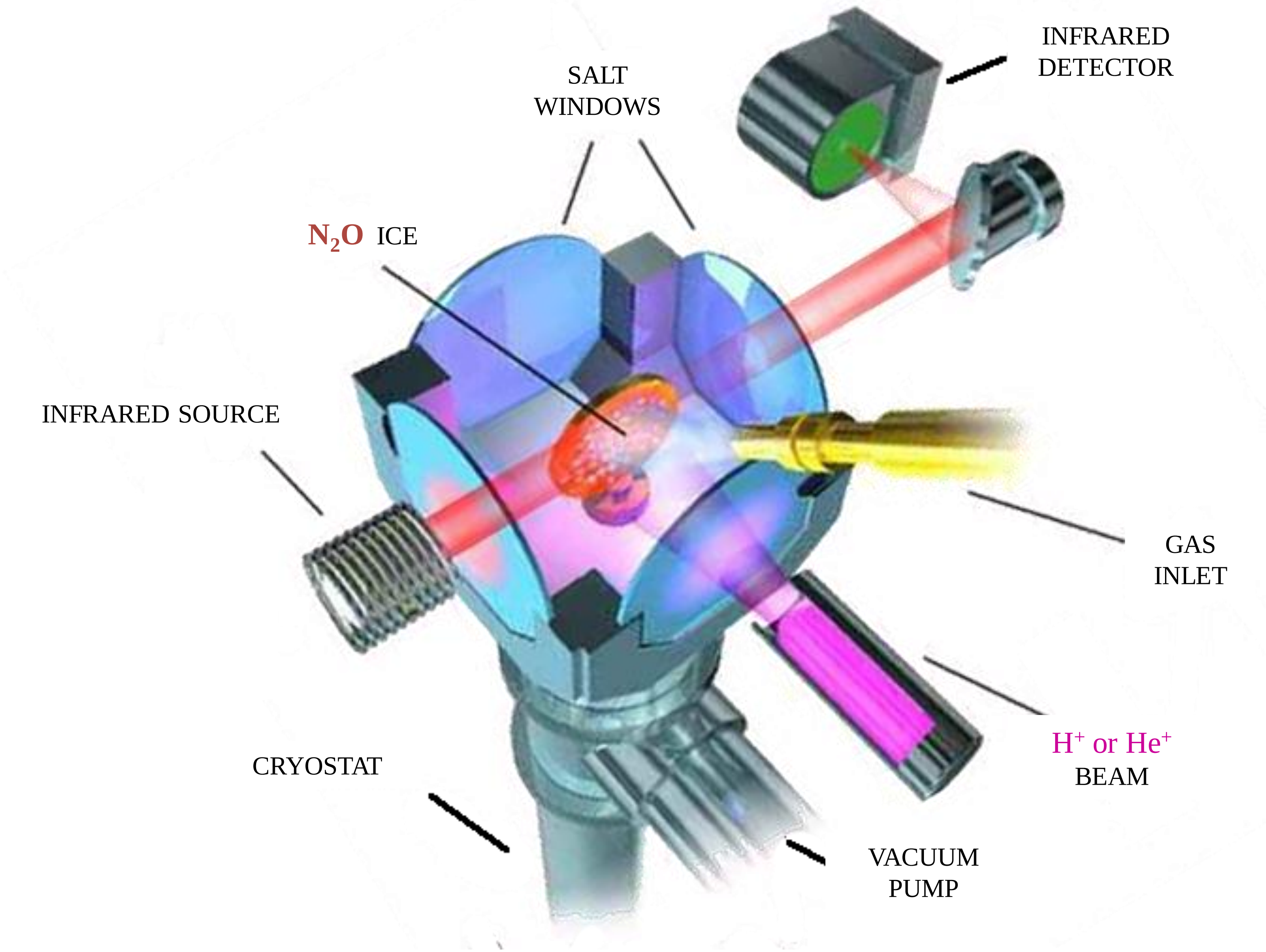
Temperature
T = 10 K

Pressure in irradiation chamber
~ 2 x 10^{-8} mbar (~10 K)

Samples (ices- N_2O)
- *in situ* gas deposition
- thickness ~ 0.1 - 2 μm (10^{16}-10^{17} molecules/cm^2)
- ion penetration depth > ice thickness

Ion beam
- 1.5 MeV H^+ and He^+
- flux ~10^9 ion/cm^2 s
- fluence up to 2.0 x 10^{13} ions/cm^2

Irradiation Process

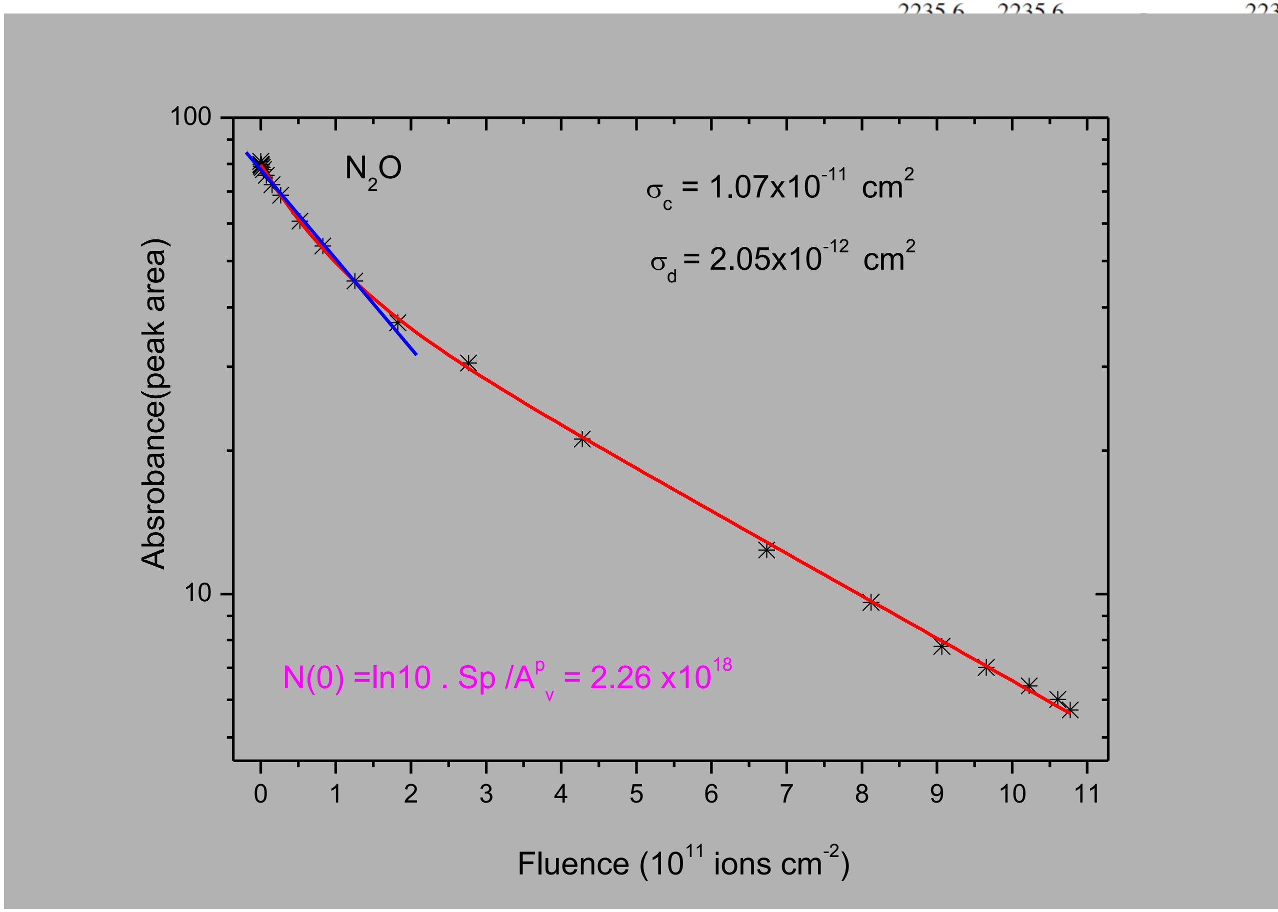


http://www.astrochem.org/sci_img/chamberschematic.jpg

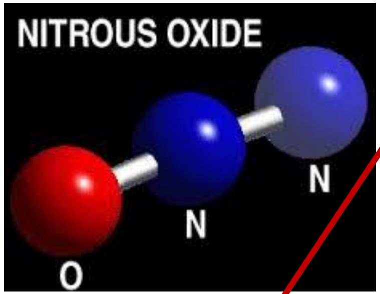
FTIR spectrum of N_2O ice

	Absorption		(cm^{-1})		Vibration	Isotopomers	A-value
11 K	80 K	[a]Fulvio	[b]Ioppolo	[c]L'apiski			This work
589.2	589.2	-	-	588.8	ν_2	$^{14}N^{14}N^{16}O$	3.1
1165.5	1165.5	1166	1167	-	$2\nu_2$	$^{14}N^{14}N^{16}O$	0.32
1297.8	1297.8	-	-	-	ν_1	$^{14}N^{14}N^{16}O$	2.7
1293.5	1293.5	1295	1290	1291.2	ν_1	$^{14}N^{14}N^{16}O$	**10.7**[a]
2187.5	-	-	-	2185.7	ν_3	$^{14}N^{15}N^{17}O$	0.26
2196.1	2196.1	-	-	2194.0	ν_3	$^{15}N^{14}N^{18}O$	0.32
2221.0	2221.0	-	-	2200.1	ν_3	$^{14}N^{14}N^{17}O$	3.0
2235.6	2235.6	-	2235	2235.6	ν_3	$^{14}N^{14}N^{16}O$	41
				-	ν_3	$^{14}N^{14}N^{16}O$	56
				2465.0	$2\nu_1$	$^{15}N^{14}N^{18}O$	0.34
				2565.2	$\nu_1 + 2\nu_2$	$^{14}N^{15}N^{16}O$	0.58
				2575.3	$2\nu_1$	$^{14}N^{14}N^{16}O$	1.9
				-	$\nu_2 + \nu_3$	$^{14}N^{14}N^{16}O$	0.09
				-	$2\nu_2 + \nu_3$	$^{14}N^{14}N^{16}O$	0.08
				3499.3	$\nu_1 + \nu_3$	$^{14}N^{14}N^{16}O$	0.35
				-	$\nu_1 + \nu_3$	$^{14}N^{14}N^{16}O$	1.81

oppolo et al. (2014), [c]L'apiski et al. (2001)



Wavenumbers (cm^{-1})

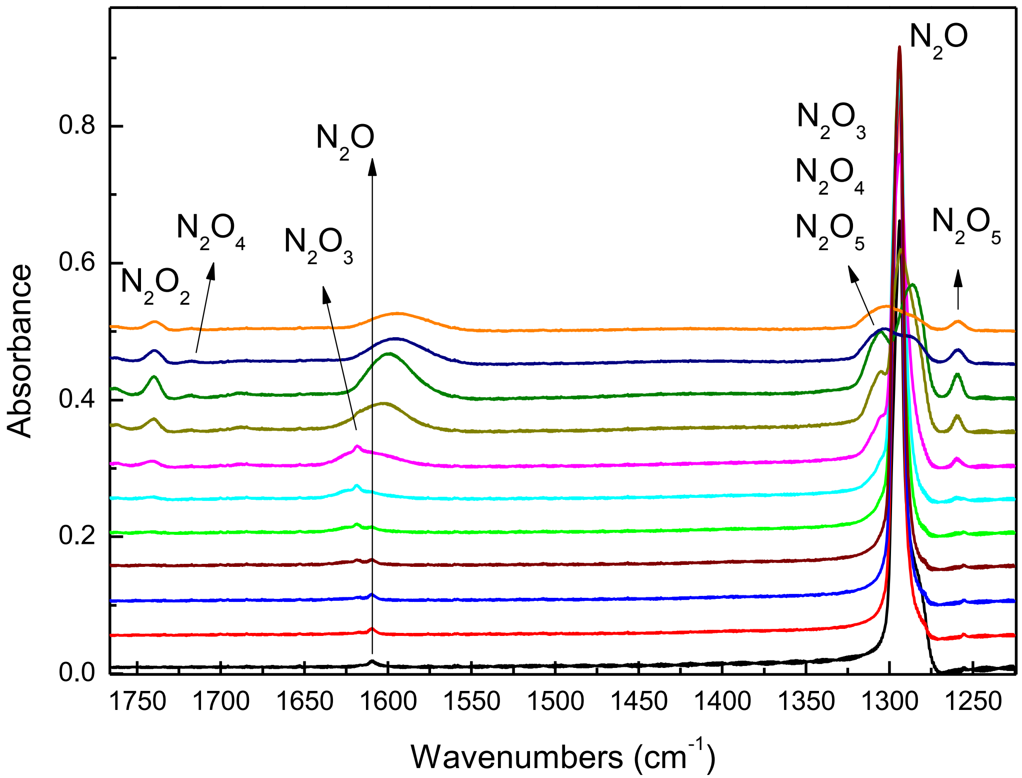


$$N = \ln(10)\frac{\int Absorbance \cdot d\nu}{A(cm/molecule)}$$

$Abs(\nu)$ – total band absorbance

A – integrated absorbance

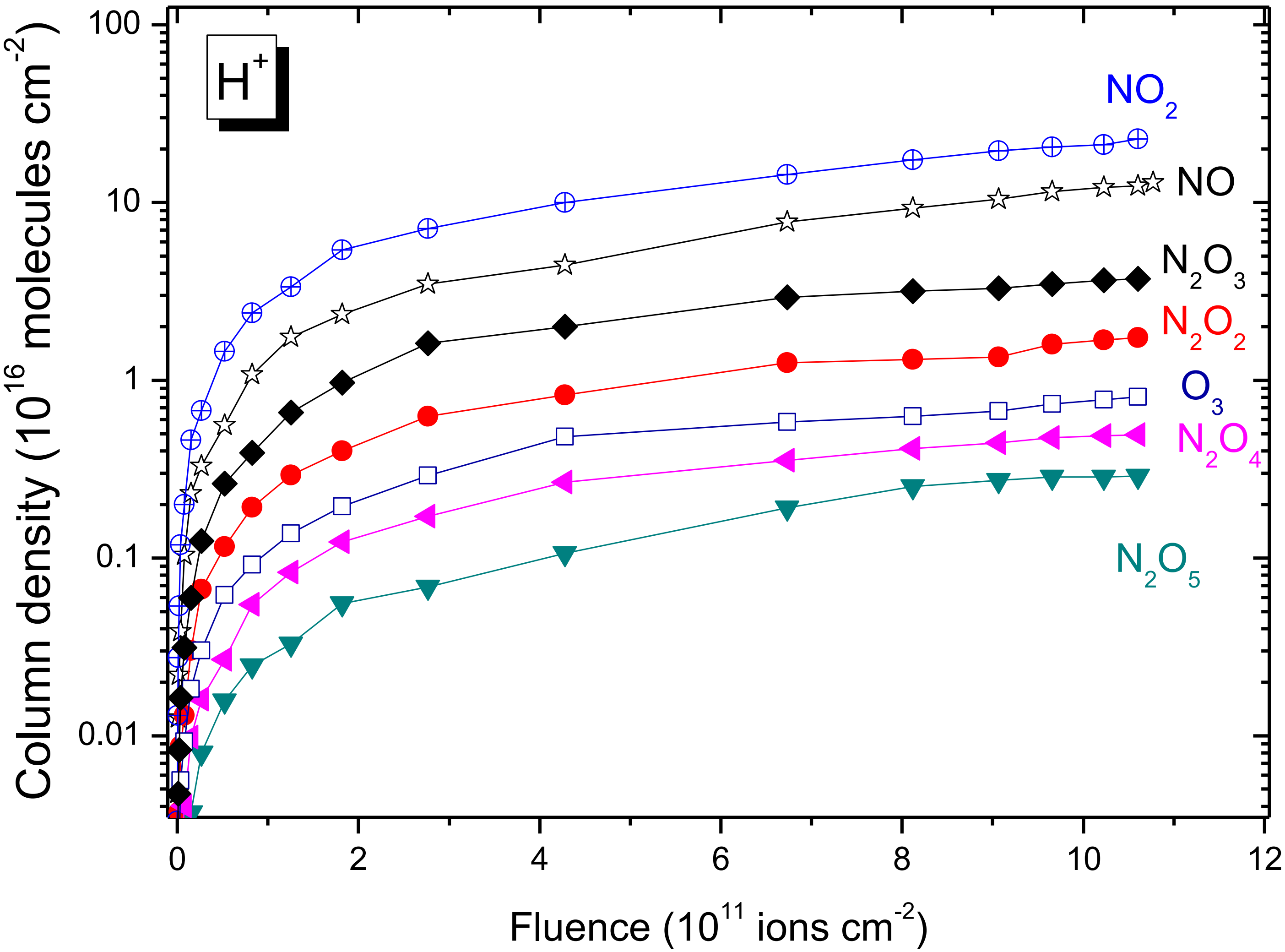
Observed Daughter Species



Species	Position (cm^{-1})	Vibration	A-value	Ref.
NO	1889.3	ν_1	0.68	[2]†
NO_2	752.4	ν_2	-	[4]
	1613.4	ν_3	6.36* /6.24	[2]/[5]
N_2O_2	1740.5	ν_5	2.72	[2]
	1765.8	ν_5	15	[2]
	1866.0	ν_1	-	[2]
N_2O_3	784.7	ν_4	6.0	[4,6]
	1305.9	ν_1/ν_3	4.63	[2]
	1653.2	ν_2	6.24	[2]
N_2O_4	1259.4	ν_{11}	8.5	[2]
	1305.9	ν_3	5.60	[2]
	1627.5	ν_2	5.95	[2]
	1719.5	ν_7/ν_5	-	[5]
	1861.3	$\nu_4 + \nu_5/\nu_1$	-	[5]
N_2O_5	752.4	ν_{11}	-	[6]
	1243.2	ν_{10}	-	[4]
	1305.9	ν_2	0.7	[2]
	1740.5	ν_1	2.75	[2]
O_3	1039.7	ν_3	1.40	[2]†

[1]Zheng et al. (2008), [2]Jamieson et al. (2005),[3]Hudson & Moore (2002), [4]Manion et al., [5]Fulvio et al. (2009), [6]Ioppolo et al. (2014). † Not seen at 80 K. *Value used in the current work.

Daughter Species 1.5 MeV $H^+ \rightarrow N_2O$



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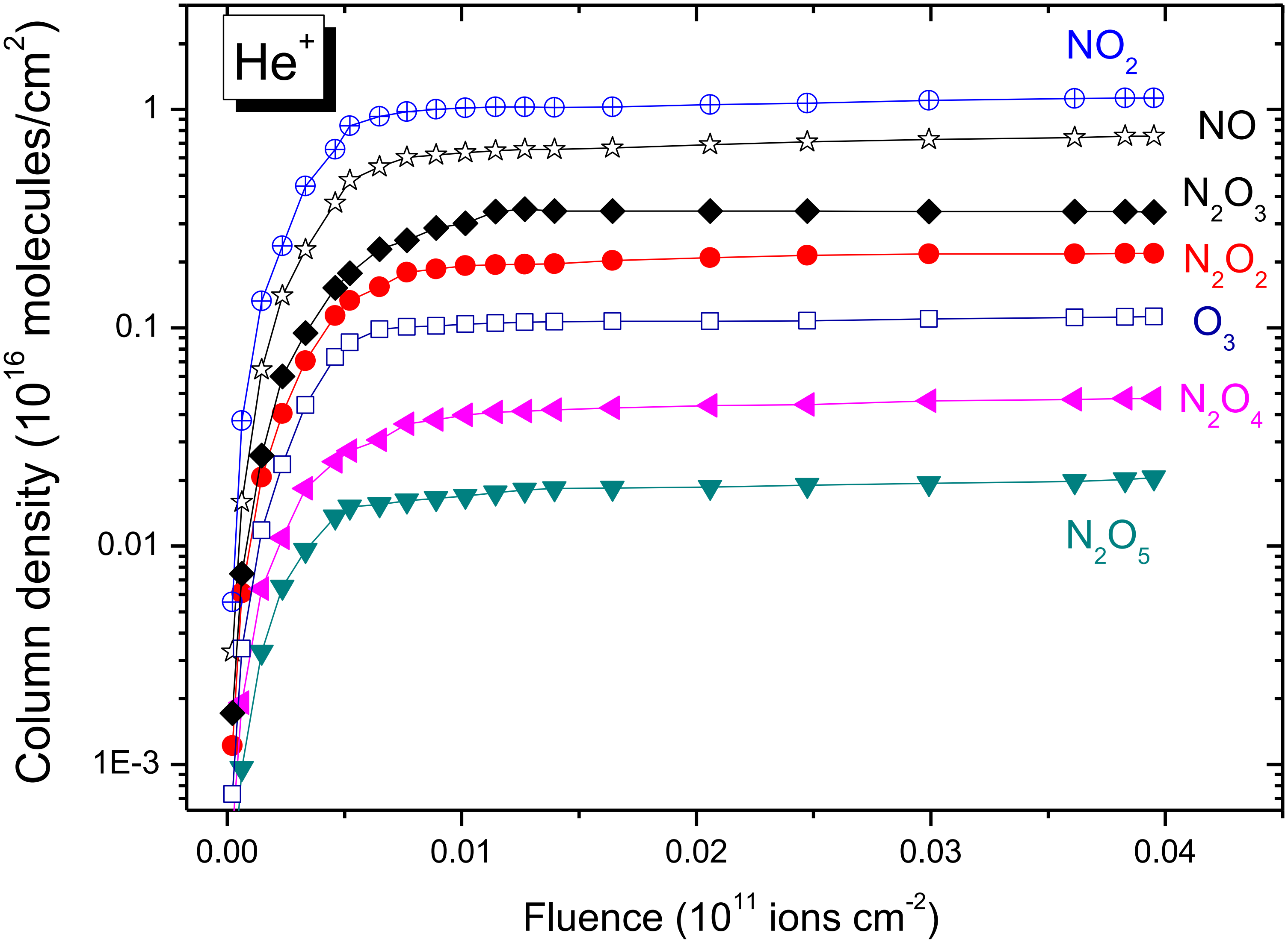
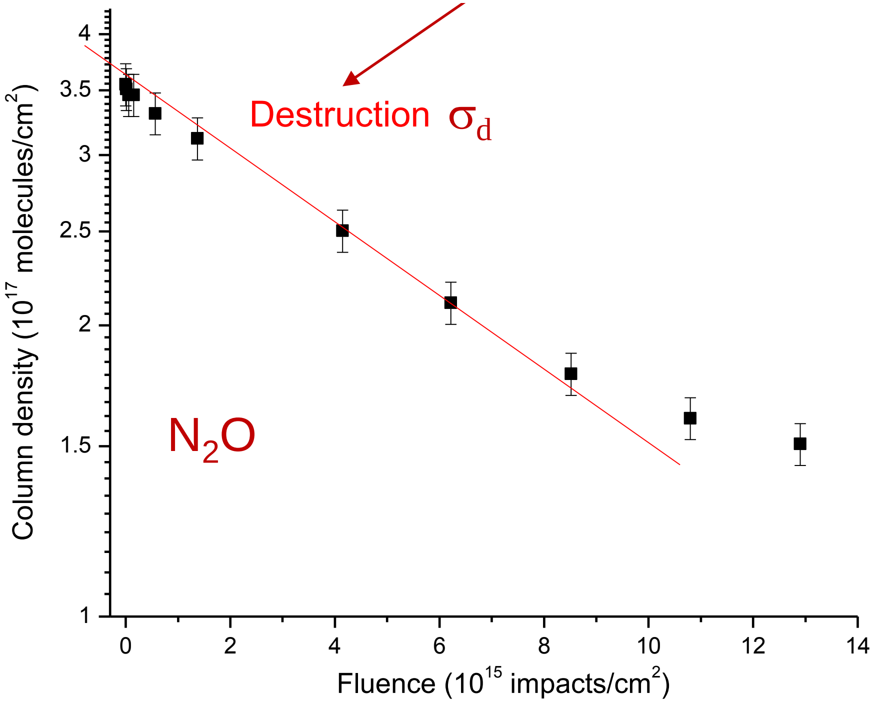
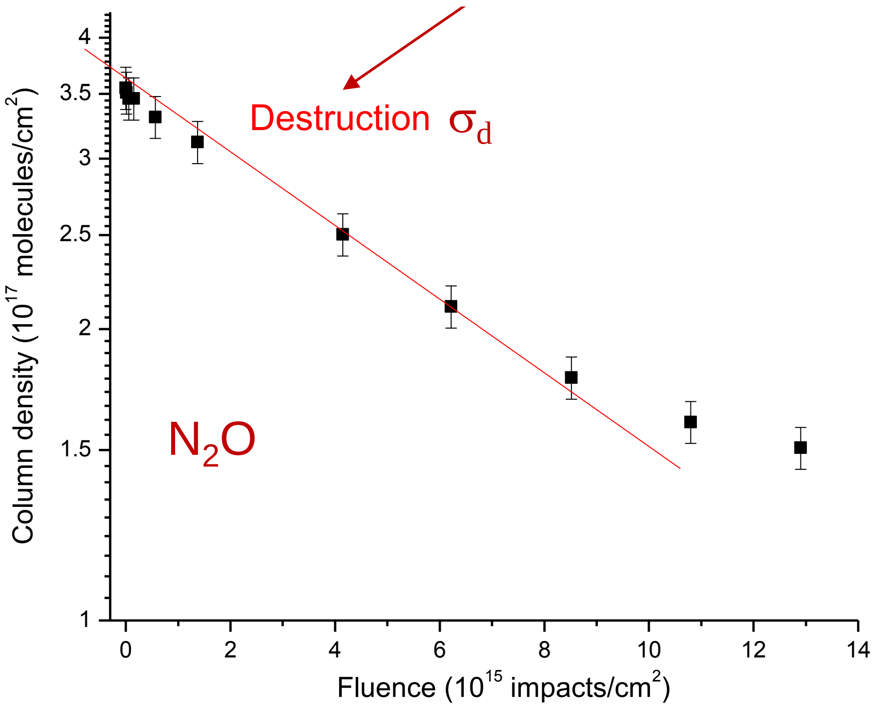
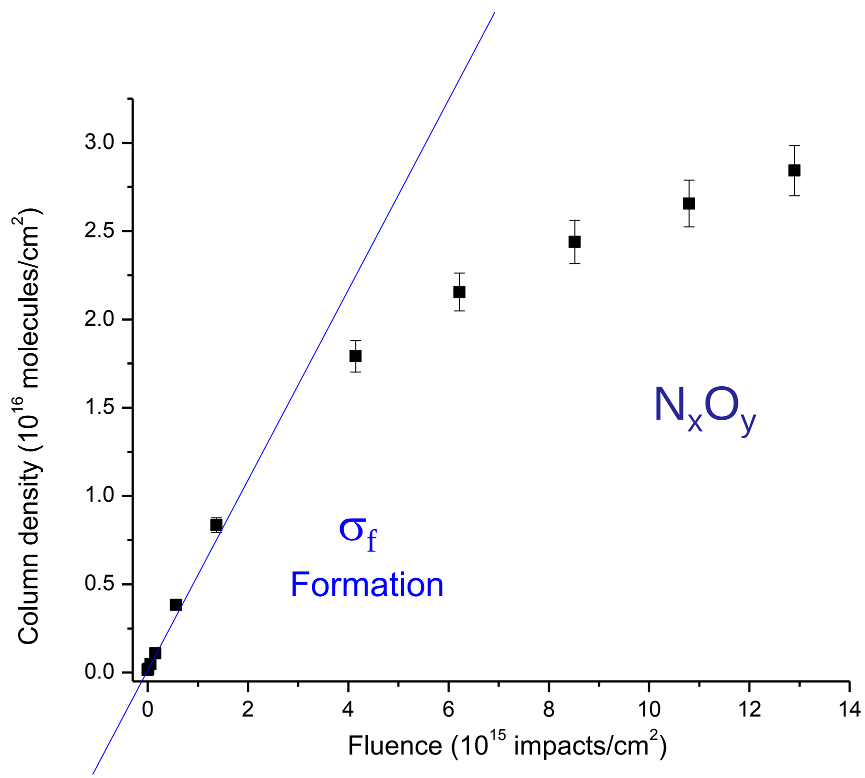


Precursors Integrated (Destruction +) Cross Sections



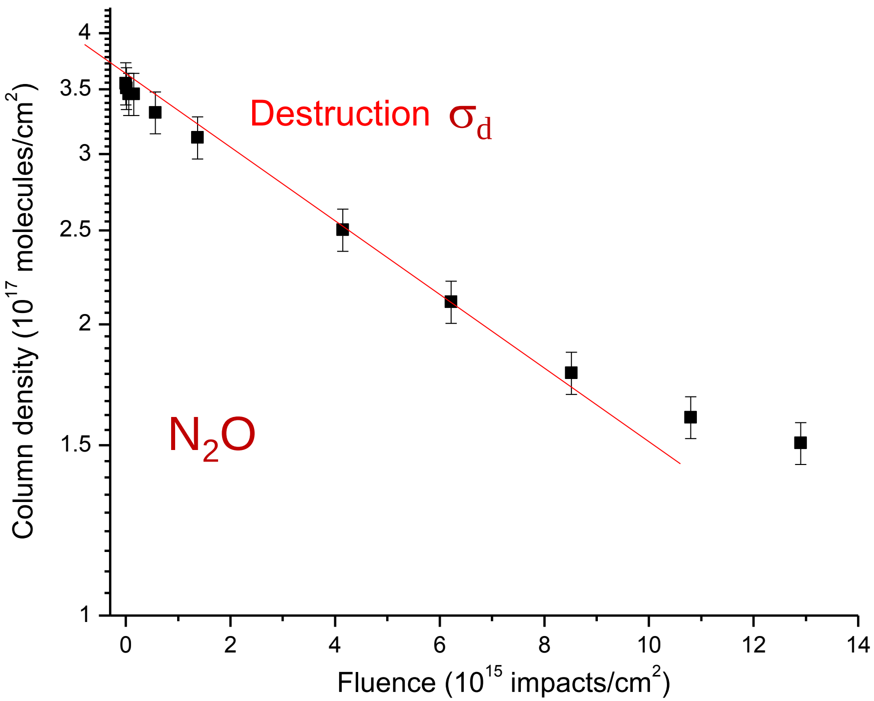
Precursors Integrated (Destruction +) Cross Sections

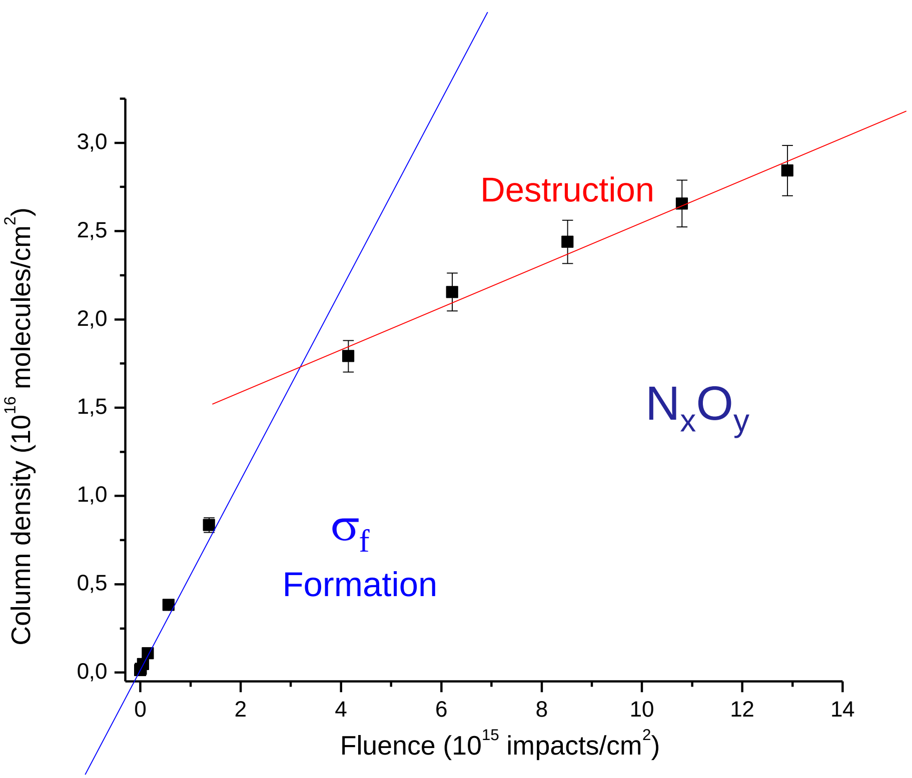




N_xO_y (Formation +) Cross Sections

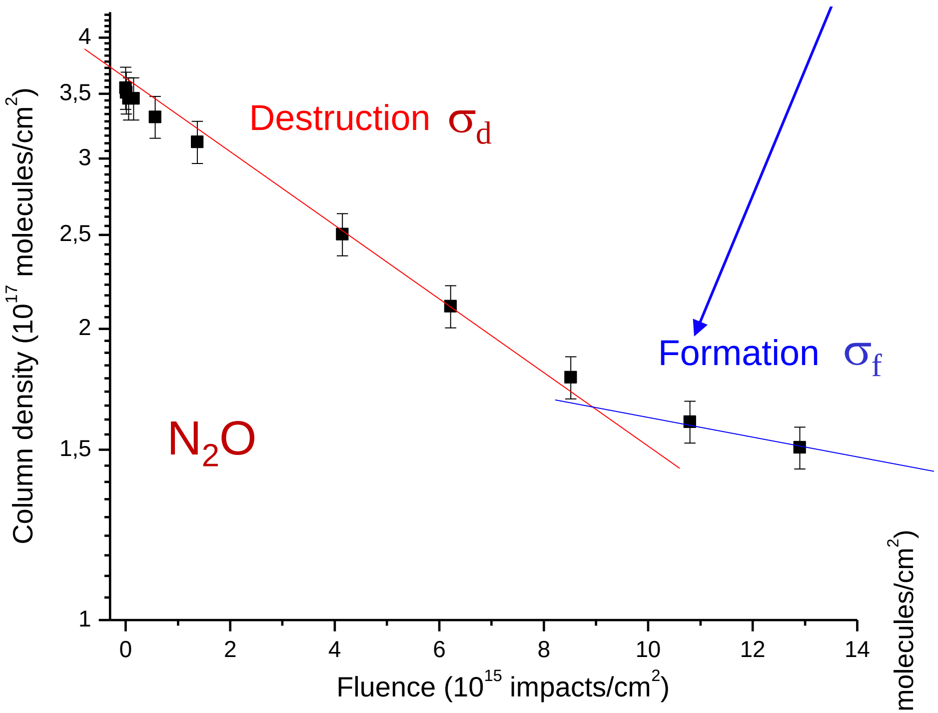
Precursors Integrated (Destruction +) Cross Sections

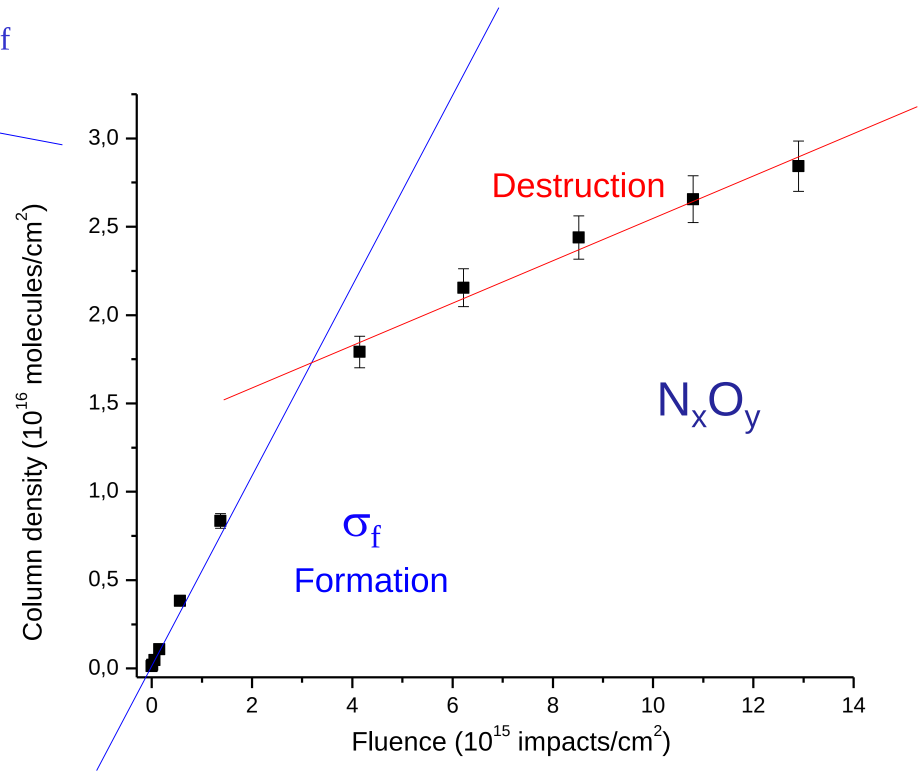




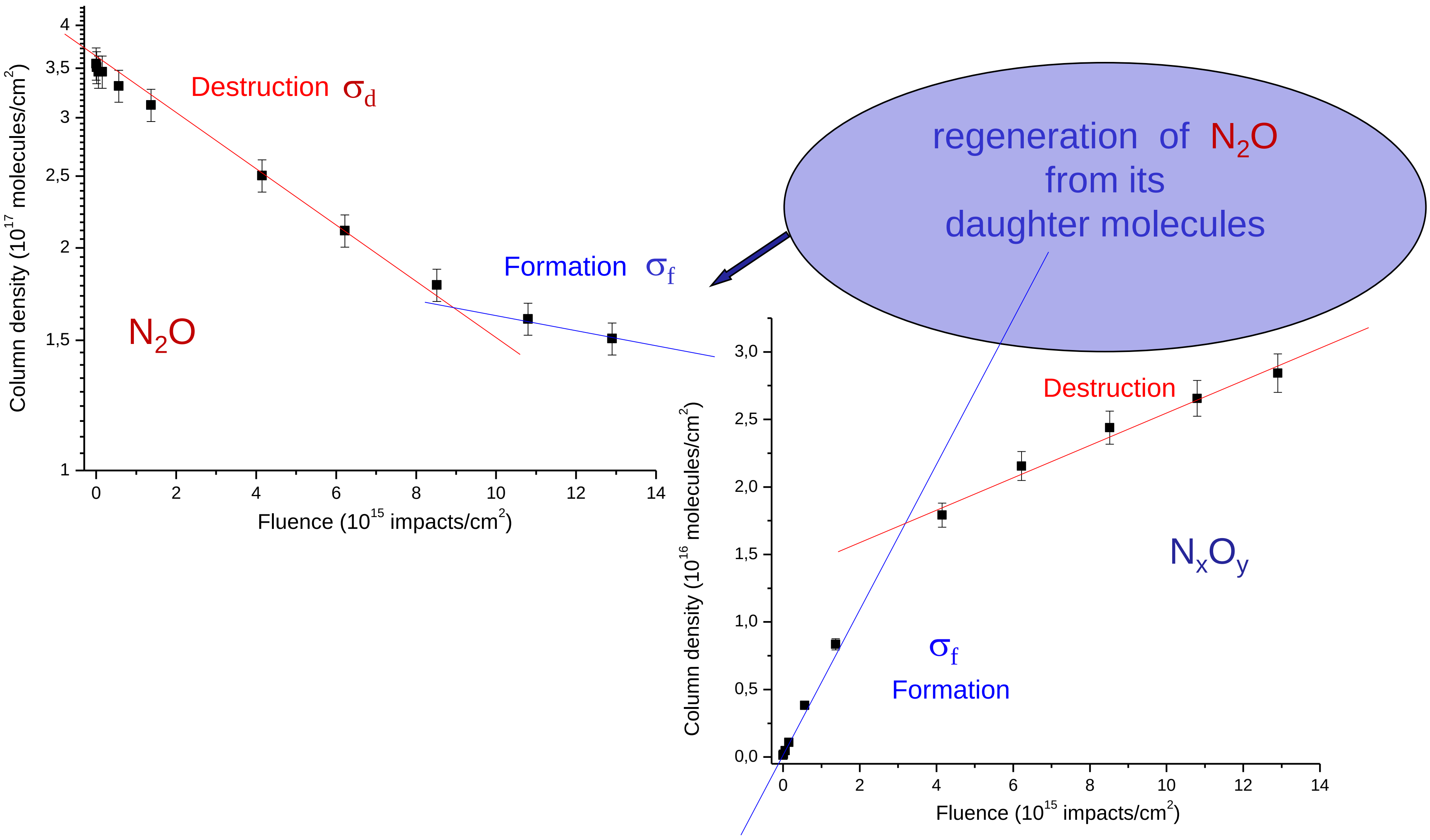
N_xO_y (Formation + Destruction) Cross Sections

Precursors Integrated (Destruction + Formation) Cross Sections

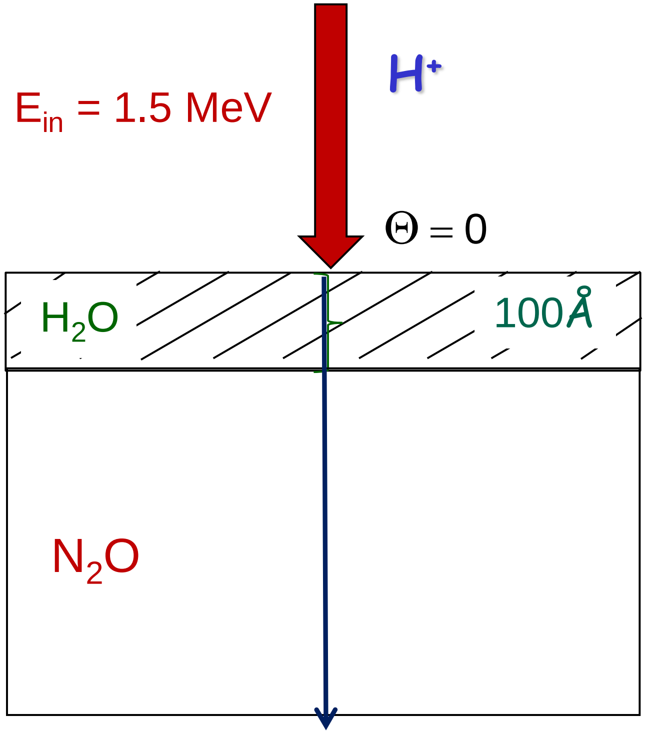




Precursors Integrated (Destruction + Formation) Cross Sections



Average (integrated) Cross Sections



$$\frac{dN_i}{dF} = \sum_{j \neq i} \sigma_{f,ij} N_j + \cancel{L_i} - \sigma_{d,i} N_i - \cancel{Y_i}$$

N_i is the column density of molecular species i;

σ_f and σ_d formation and destruction cross sections;

~~L_i and Y_i are their layering and sputtering yields;~~

Approximate Equations ...

Precursor molecule

$$\frac{dN_1}{dF} = \sigma_{f,1k} \sum_k N_k - \sigma_{d,1} N_1$$

Daughter molecule

$$\frac{dN_k}{dF} = \sigma_{f,k1} N_1 - \sigma_{d,k} N_k$$

Cross Sections

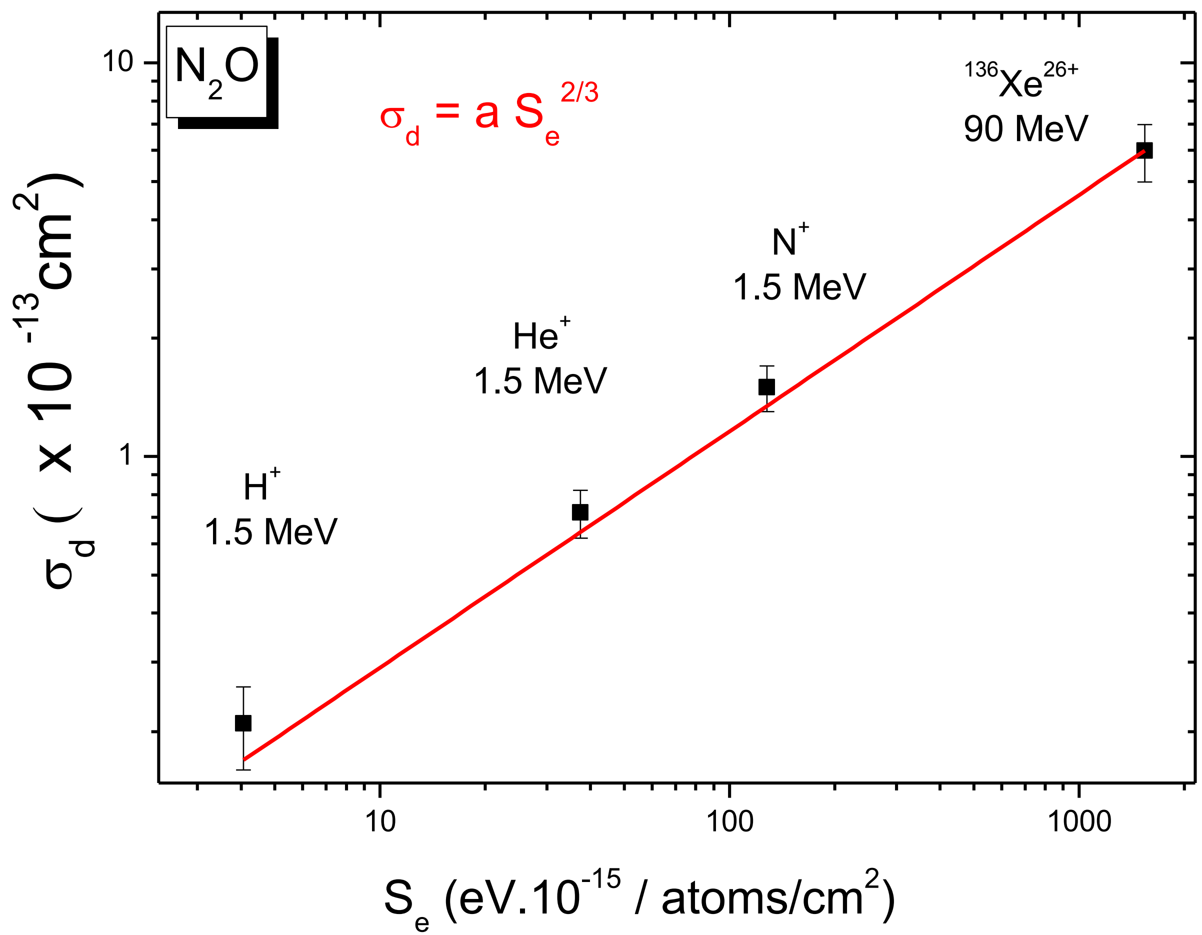
Destruction and formation cross-sections (10^{-14} cm^2) of N_2O with H^+

Molecules 10 K at 1.5 MeV	Formation cross-section	Destruction cross-section
Precursor: N_2O	-	(2.1 ± 0.5)
Daughters: NO_2	(1.1 ± 0.2)	(1.3 ± 0.2)
N_2O_2	(0.09 ± 0.01)	(3.1 ± 0.6)
NO	(0.54 ± 0.08)	(1.0 ± 0.5)
N_2O_3	(0.25 ± 0.02)	(5.4 ± 0.7)
N_2O_4	(0.03 ± 0.01)	(3.8 ± 0.8)
N_2O_5	(0.02 ± 0.01)	(3.3 ± 0.8)
O_3	(0.05 ± 0.02)	(4.8 ± 0.4)

$\Sigma = 2.08$

de Barros et al., in press

The dissociation cross-sections due to 4 projectiles at different energies are determined, assuming validity of the $\sigma_d \sim S_e^{2/3}$ power law.



Summary

- Our experiments demonstrate that 1.5 MeV ion irradiation of nitrous oxide with H^+ leads to production of molecules NO_2, N_2O_2, NO, N_2O_3, N_2O_4, N_2O_5 and O_3;

- The most abundant daughter species are NO_2 and NO;

- Same results where observed for the He^+ beam irradiation;

- The formation and destruction cross sections of both ion beams where determined;

- For the N_2O matrix, the dependence of the destruction cross section on the stopping power is found to follow a power law, i.e., $\sigma_d \propto S_e^n$, where $n \sim 2/3$.

Acknowledgments

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