Ion bombardment of materials relevant to Astrobiology

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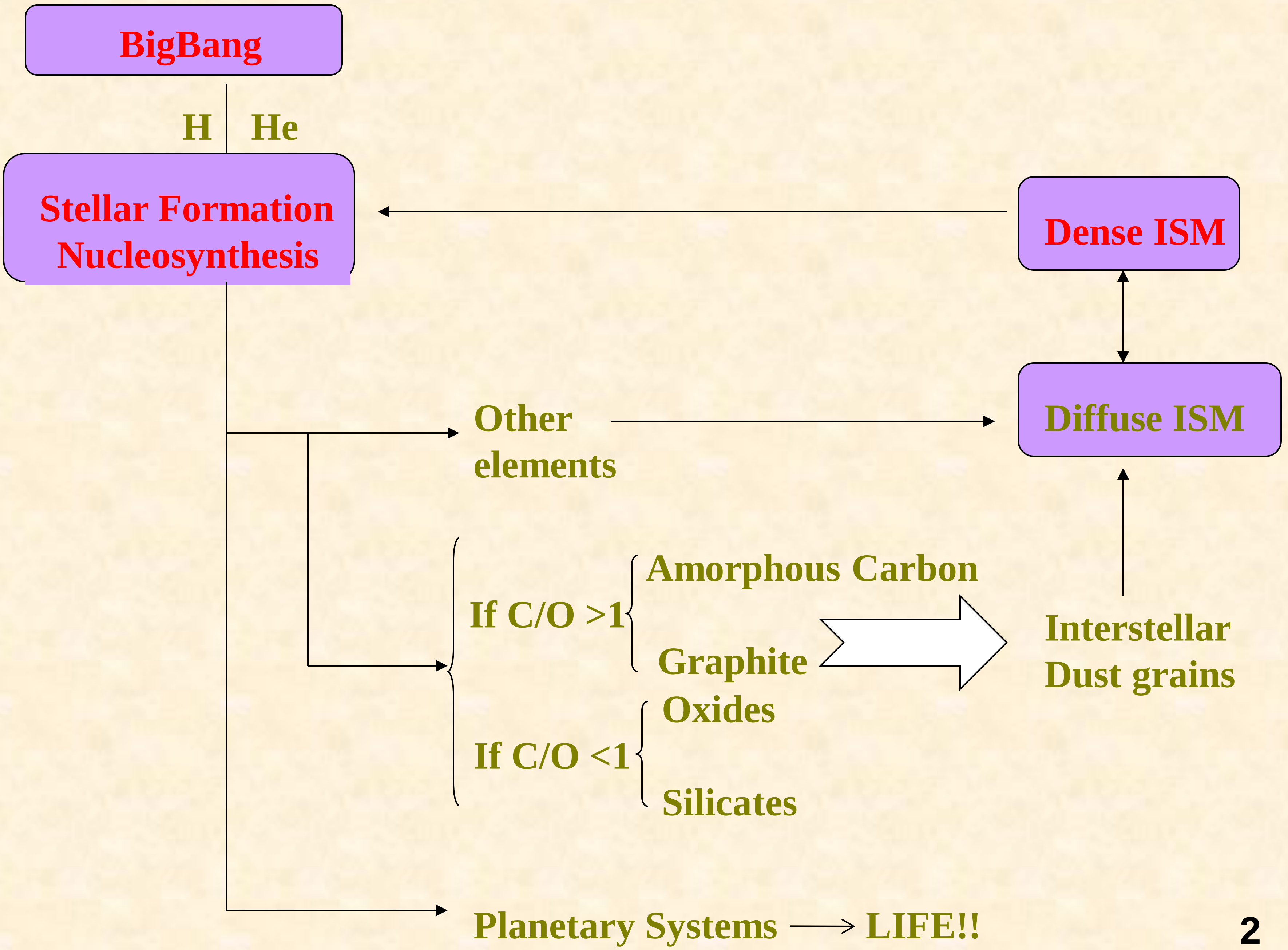
http://web.ct.astro.it/weblab/


BigBang
H
He
Stellar Formation
Nucleosynthesis
Dense ISM
Diffuse ISM
Other
elements
If C/O >1
Amorphous Carbon
Graphite
Interstellar
Dust grains
If C/O <1
Oxides
Silicates
Planetary Systems
LIFE!!

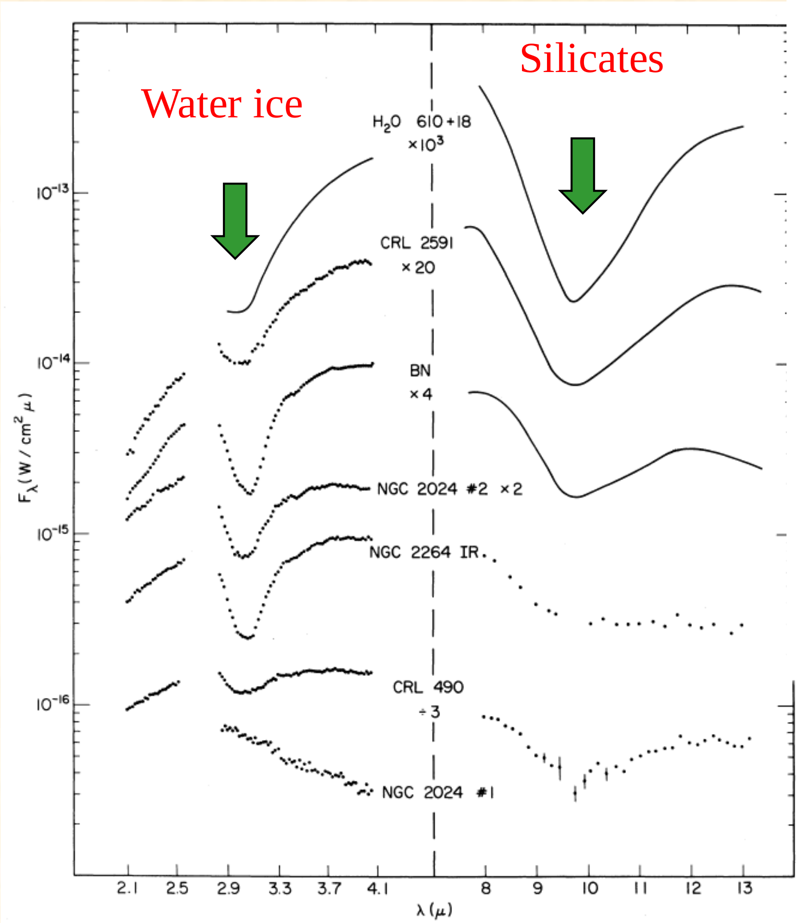
Solid Materials in Space

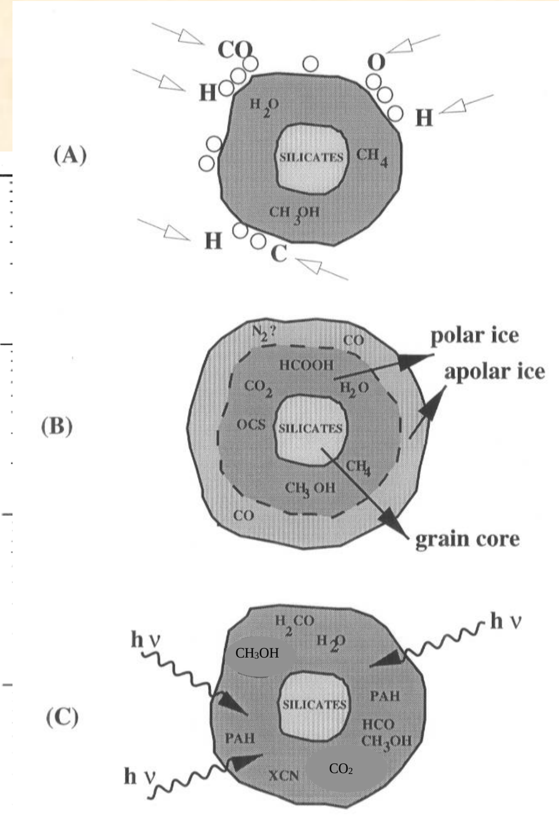
	SILICATES	CARBONS	ICES
WHAT:	olivines	PAHs	H_2O
	piroxenes	graphite	CO_2
		Amorphous carbons	CO
			NH_3
			CH_4
			OCS

WHERE:

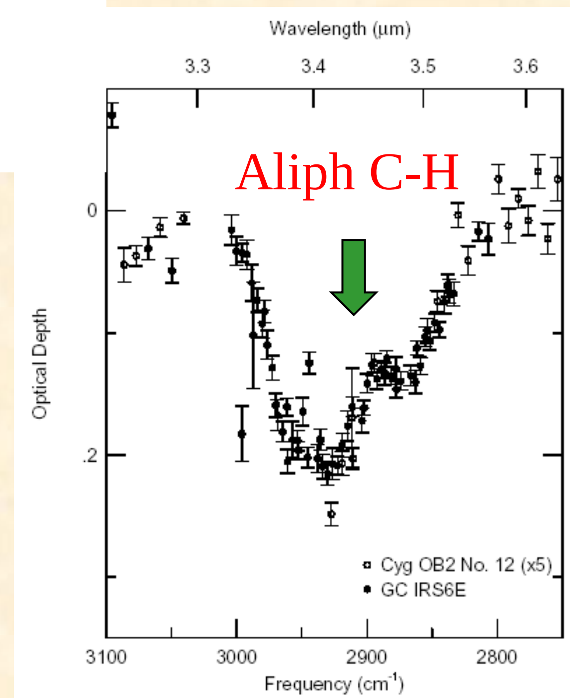
Interstellar medium (ISM)
Circumstellar regions
Interplanetary medium
Planets and satellites
Minor objects (asteroids, comets, TNOs)

Dense clouds





Diffuse clouds



ICES

Species	Abundance
H_2O	100
CO	0 – 40
CO_2	10 – 25
CH_3OH	3 – 60
SO_2	0.3-0.8
OCS	0.04 – 0.1
CH_4	0.3 – 4
H_2CO	3 – 7
NH_3	5 – 10
NH_4^+	1-10
OCN^-	1 – 8

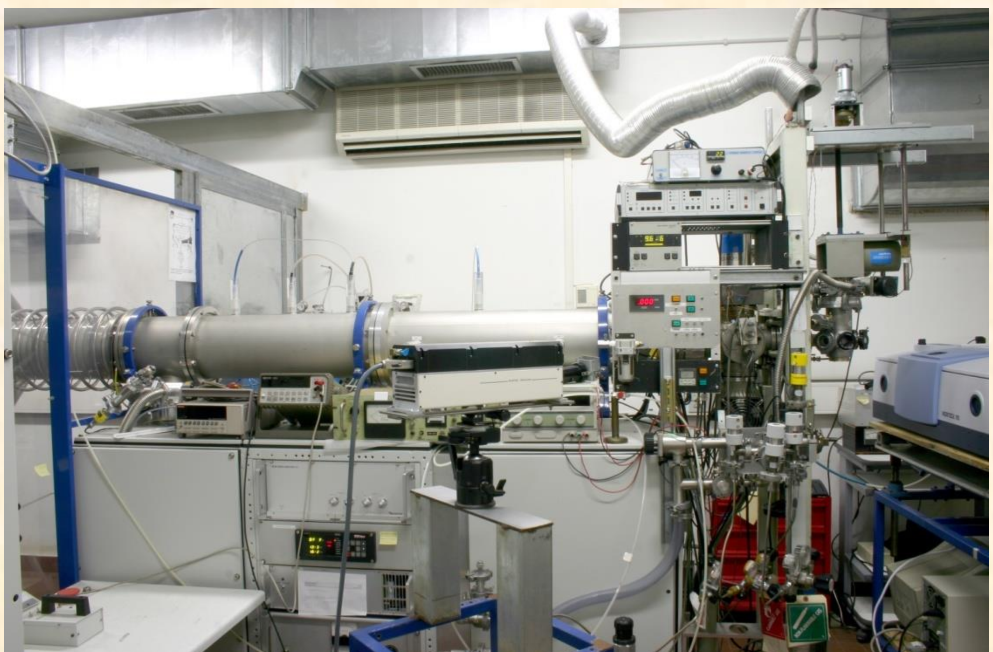
Table 1: Known Interstellar Molecules

2		3		4	5	6	7	8	9
H_2	CH^+	H_2O	C_3	NH_3	SiH_4	CH_3OH	CH_3CHO	CH_3CO_2H	CH_3CH_2OH
OH	CN	H_2S	HNC	H_3O^+	CH_4	NH_2CHO	CH_3NH_2	HCO_2CH_3	$(CH_3)_2O$
SO	CO	SO_2	HCN	H_2CO	HCOOH	CH_3CN	CH_3CCH	CH_3C_2CN	CH_3CH_2CN
SO^+	CS	NNH^+	CH_2	H_2CS	HCCCN	CH_3NC	CH_2CHCN	C_7H	$H(CC)_3CN$
SiO	C_2	HNO	H_2D^+	HNCO	CH_2NH	CH_3SH	$H(CC)_2CN$	H_2C_6	$H(CC)_2CH_3$
SiS	SiC	CCS	HOC^+	HNCS	NH_2CN	C_5H	C_6H	CH_2OHCHO	C_8H
NO	CP	NH_2	NaCN	CCCN	H_2CCO	HC_2CHO	$c\text{-}CH_2OCH_2$		C_8H^-
NS	CO^+	H_3^+	MgNC	HCO_2^+	C_4H	$CH_2{=}CH_2$	$H_2CC(OH)H$		CH_3CONH_2
HCl	HF	NNO	AlNC	CCCH	$c\text{-}C_3H_2$	H_2C_4	C_6H^-		
NaCl	SH	HCO	SiCN	$c\text{-}C_3H$	CH_2CN	HC_3NH^+			
KCl	HD	HCO^+	KCN	CCCO	C_5	C_5N			
AlCl	PO	OCS	MgCN	C_3S	SiC_4				
AlF	AlO	CCH	CCP	HCCH	H_2C_3	10	11	12	13
PN		HCS^+	HCP	$HCNH^+$	HCCNC	CH_3COCH_3	$H(CC)_4CN$		$H(CC)_5CN$
SiN		$c\text{-}SiC_2$		HCCN	HNCCC	CH_3C_5N			
NH		CCO		H_2CN	H_2COH^+	$(CH_2OH)_2$			
CH				$c\text{-}SiC_3$	C_4H^-				

Gas 123

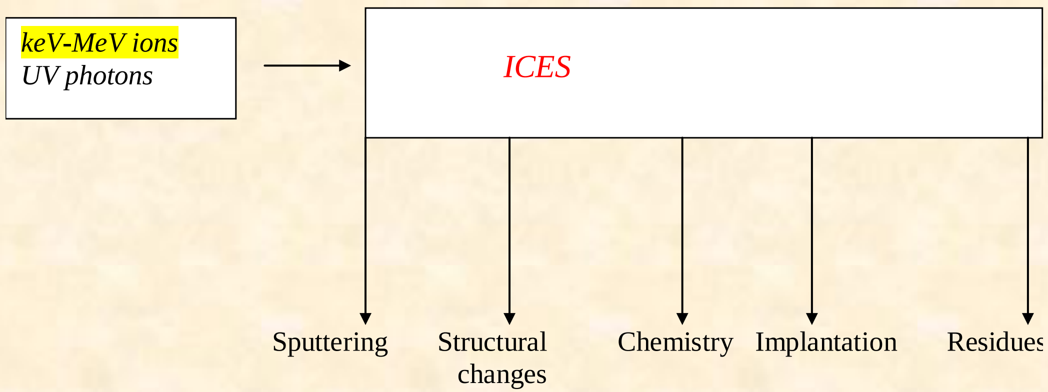
Molecules in Space

GANIL Laboratories (Caen, France)
Ion Beams: Multi Charged; E from a few keV to hundreds MeV



LASp (Catania, Italy)
Ion Beams:30-400 keV singly or double charged

Experimental study of the effects induced by fast ions on solids of astrophysical interest have been performed in several laboratories in the world



Techniques of analysis :

- IR Spectroscopy
- Raman Spectroscopy
- Mass Spectrometry

Studied materials

ICES: H_2O, CO, CO_2, CH_3OH, CH_4, NH_3, SO_2,…

CARBONS: graphite, amorphous carbons,
diamond, fullerene, …

SILICATES: olivine, piroxene, …

METEORITES: Murchison, Orgueil (carbonaceous)
Epinal (ordinary condrite)

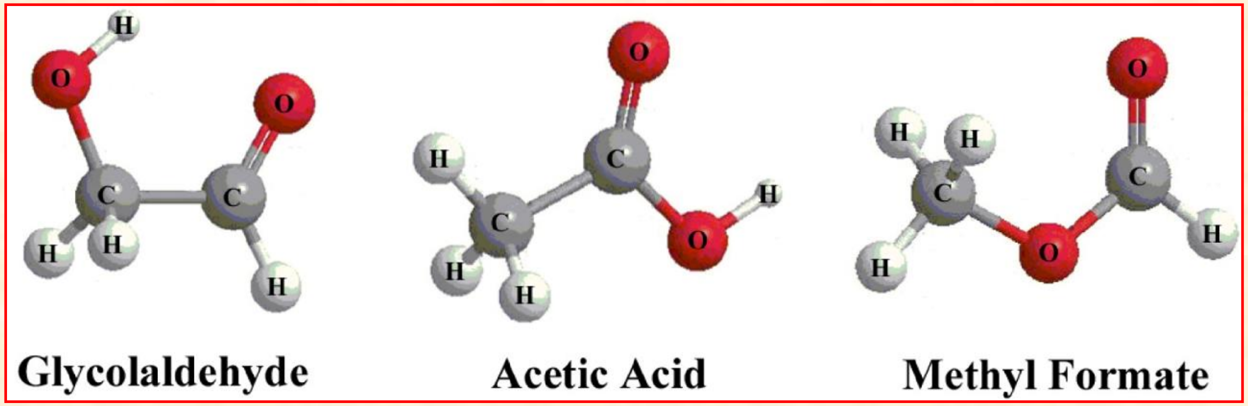
COSMIC DUST: Stratospheric IDPs, *Stardust*

✓Syntesis of complex organics → How complex are the molecules synthesized by energetic processing and/or annealing of ices?

Synthesis of Methyl formate

- $CH_3OH:HCOOCH_3$ = 10:1
- $HCOOCH_3$
- CH_3OH
- $CO:CH_3OH$ = 1.6:1

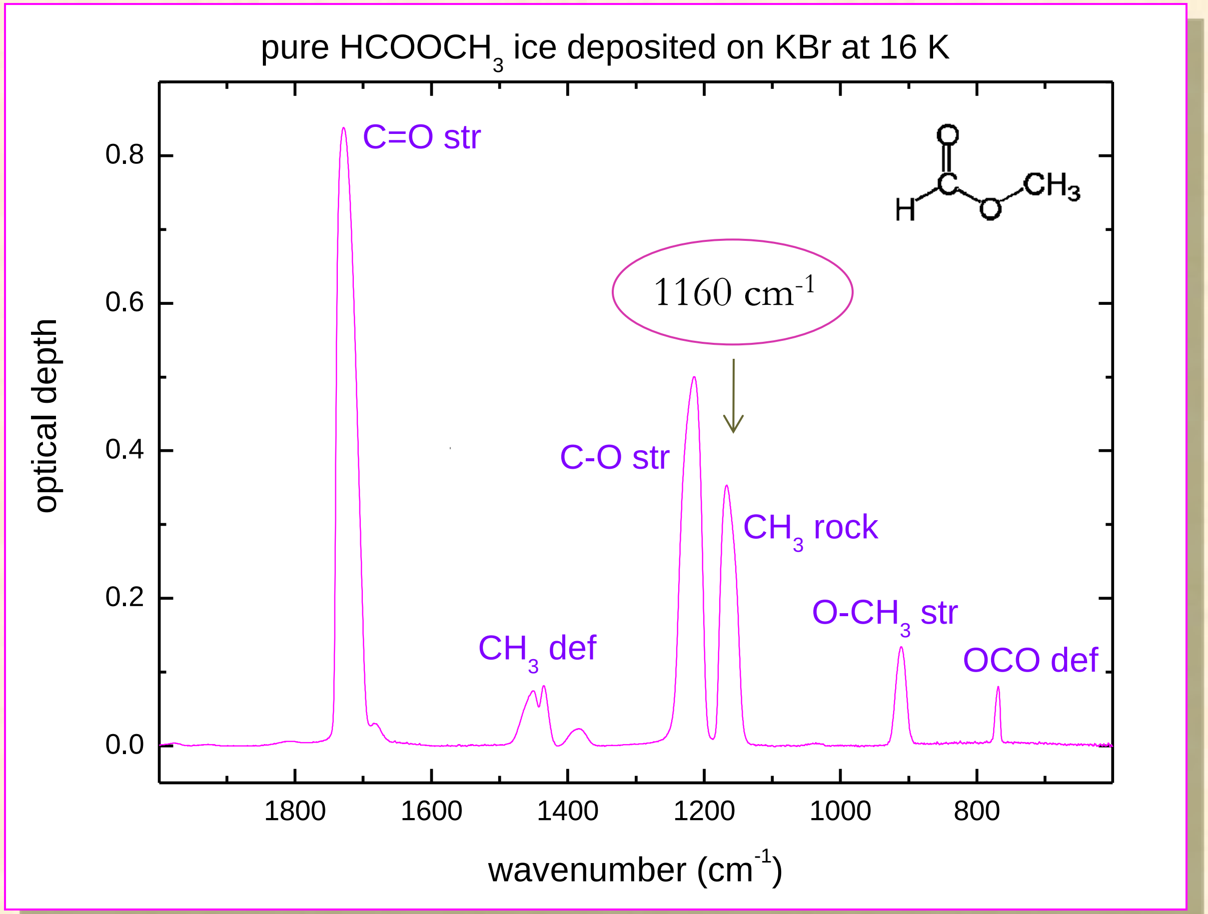
$C_2H_4O_2$ isomers



P. Modica, M.E. Palumbo Formation of methyl formate after cosmic ion irradiation of icy grain mantles, A&A 519, A22, 2010

P. Modica, M.E. Palumbo, G. Strazzulla, Methyl formate in comets, *PlSpSci* 73, 425, 2012

Methyl formate mid-IR spectrum



$$\int_{\nu_1}^{\nu_2} \tau_\nu d\nu = A \times N$$

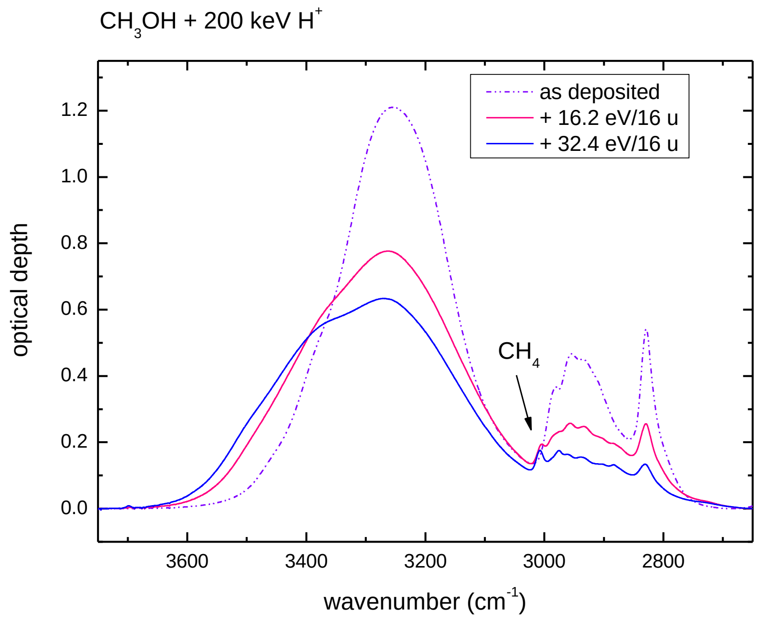
N column density (mol/cm^2)
A band strength (cm/mol)
τ_ν optical depth
ν wavenumber (cm^{-1})

$$N = \frac{\rho\, s}{\mu}$$

ρ density (g/cm^3)
s thickness (cm)
μ molecular weight (g)

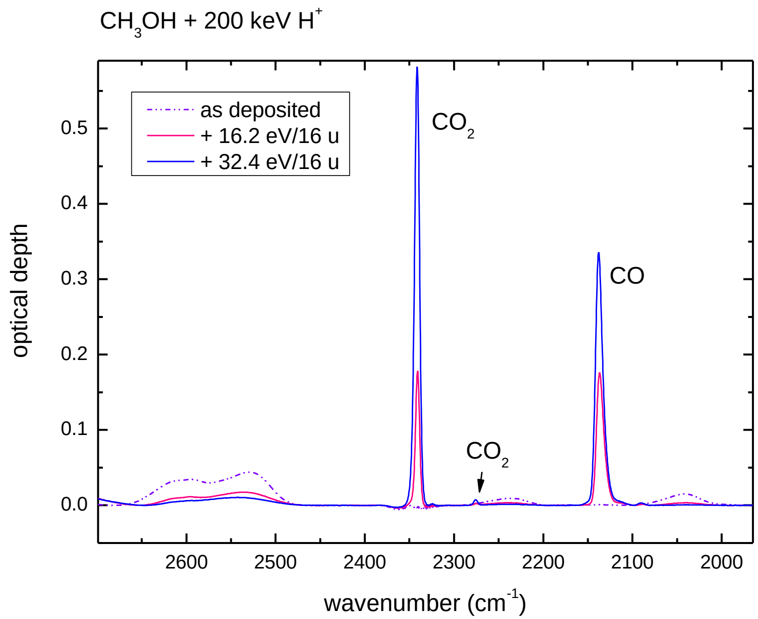
Spectral range: 2000-600 cm^{-1} (5-16 µm)

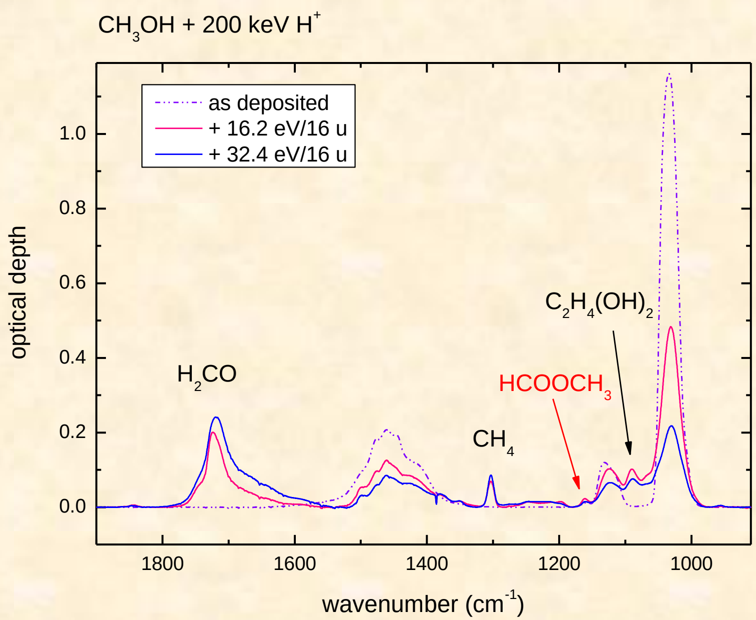
Chemistry on solid CH_3OH



After ion irradiation at 16 K:

- CH_3OH bands intensity decreases
- New bands appear





PCCP

PAPER

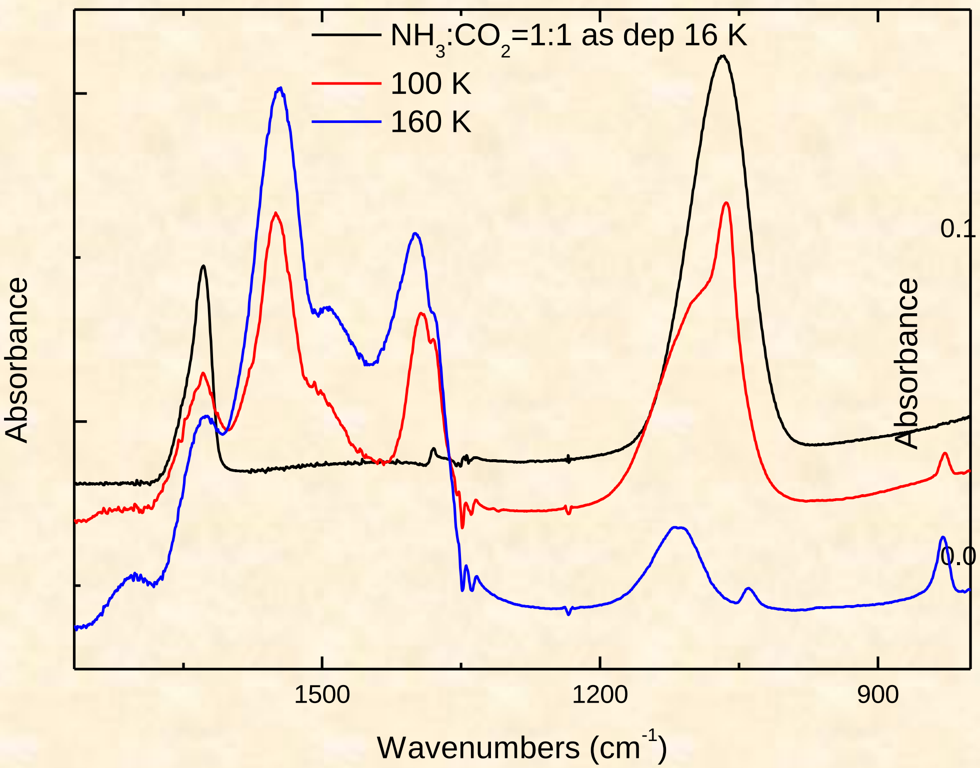
Thermal and energetic processing of ammonia and carbon dioxide bearing solid mixtures

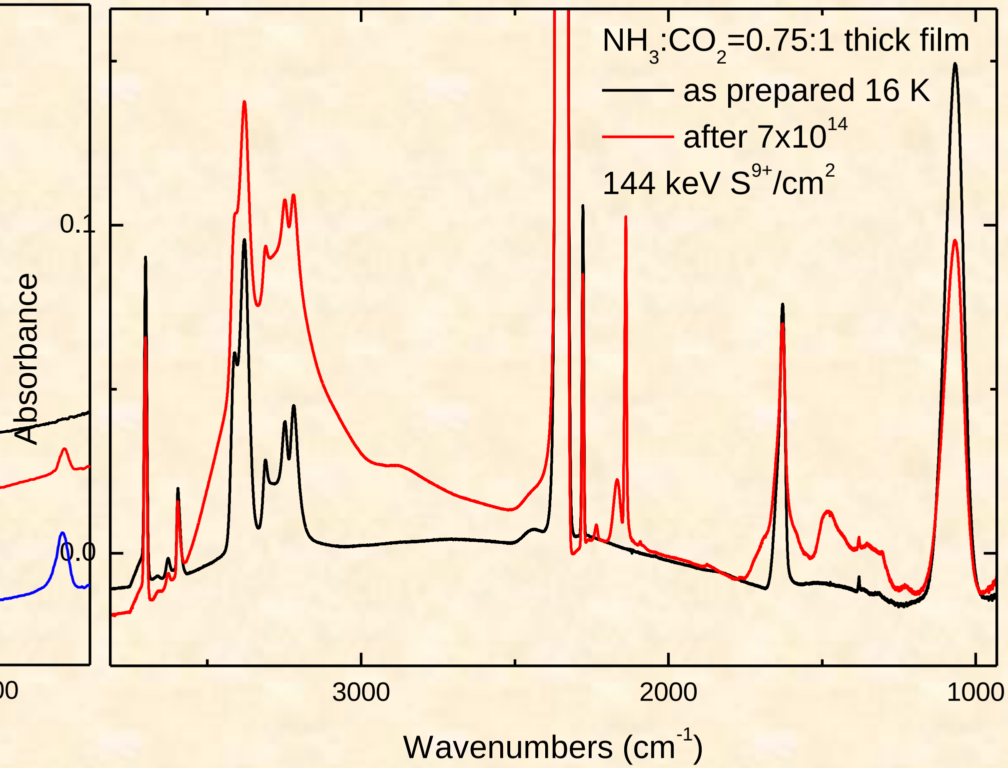
Cite this: *Phys. Chem. Chem. Phys.*, 2014, 16, 3433

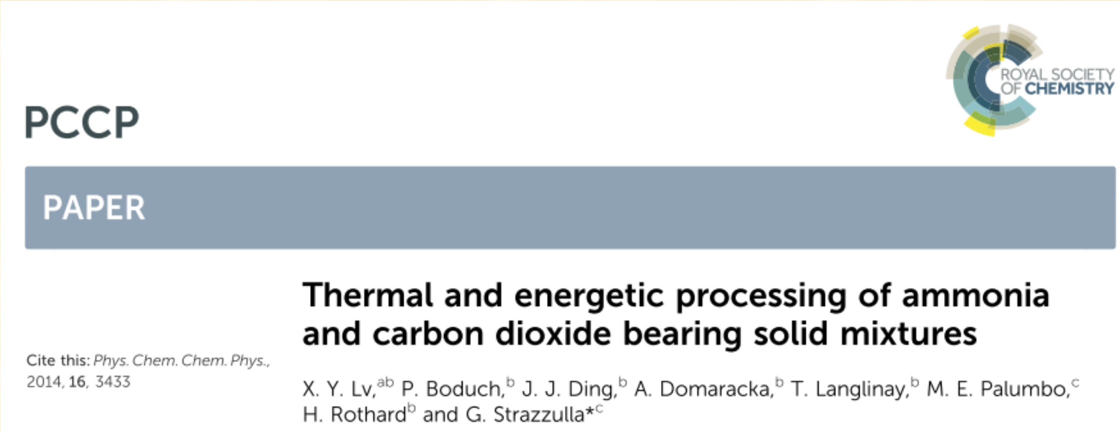
X. Y. Lv,[ab] P. Boduch,[b] J. J. Ding,[b] A. Domaracka,[b] T. Langlinay,[b] M. E. Palumbo,[c] H. Rothard[b] and G. Strazzulla*[c]

Thermal

Ion Bombardment






PCCP

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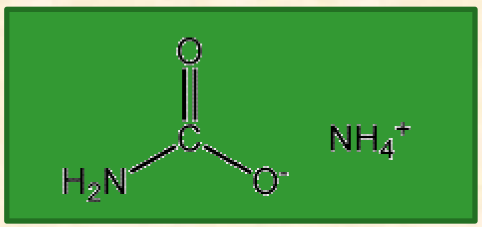
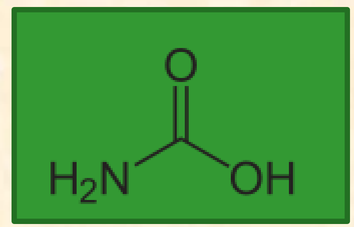
Thermal processing

Ammonium carbamate

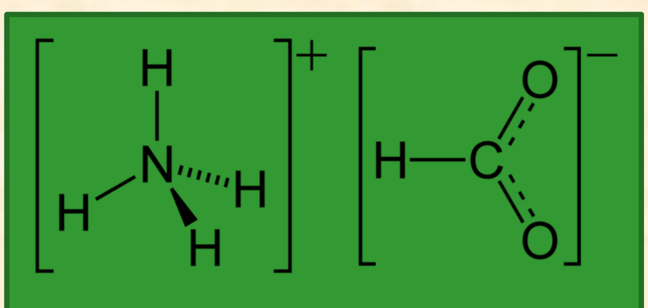


Carbamic acid (dimer)



Ion bombardment

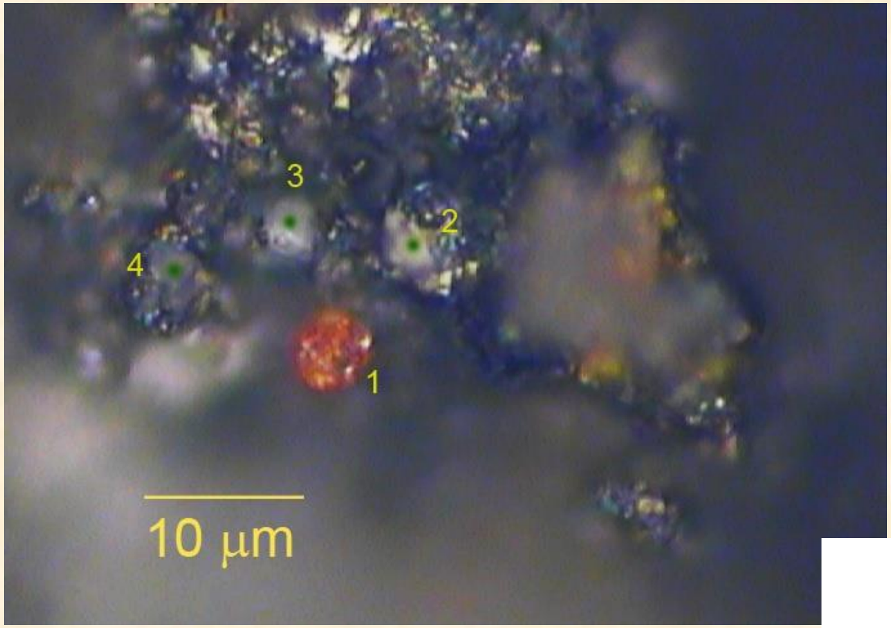
Ammonium formate

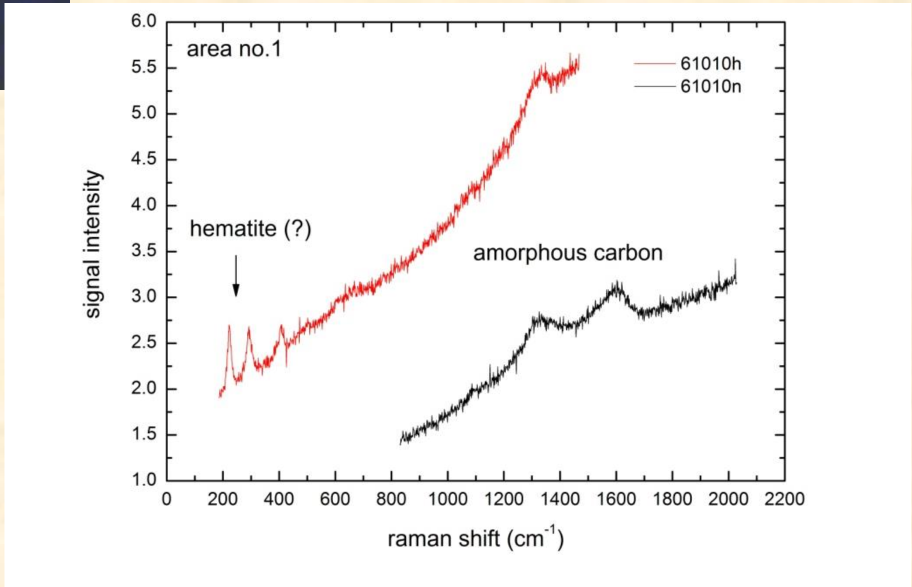


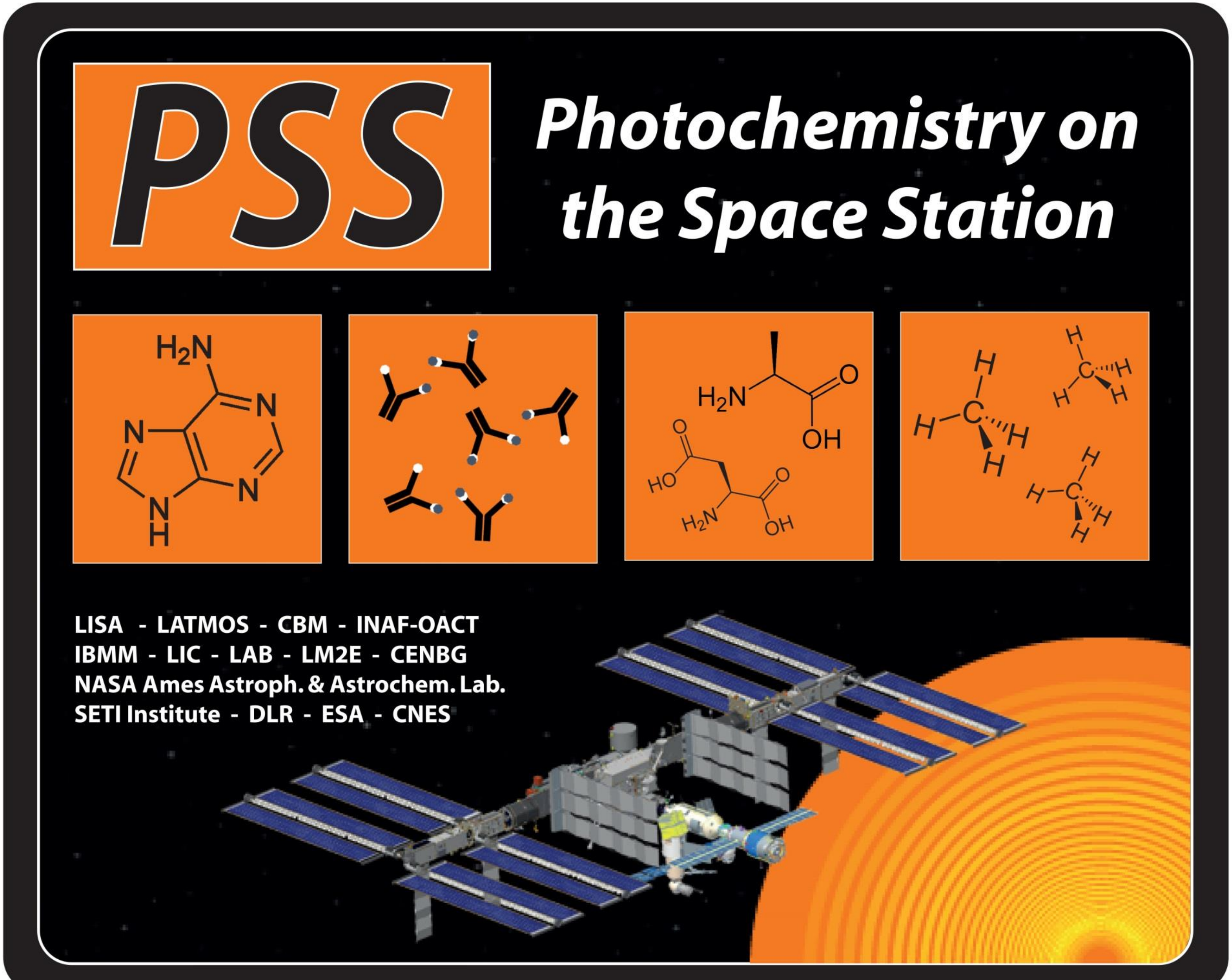
CO, OCN^-

Do comets/asteroids play a role in delivering biologically relevant material on Earth(s)?

- March 20, 2010   - Found 64 samples of the meteorite (total 3.92 kg)


3
2
4
1
10 μm


area no.1
61010h
61010n
hematite (?)
amorphous carbon
signal intensity
raman shift (cm-1)


PSS
Photochemistry on the Space Station
LISA - LATMOS - CBM - INAF-OACT
IBMM - LIC - LAB - LM2E - CENBG
NASA Ames Astroph. & Astrochem. Lab.
SETI Institute - DLR - ESA - CNES

ION BOMBARDMENT OF COMETARY ICES ANALOGUES: PRODUCTION OF ORGANIC SAMPLES FOR THE EXPOSE-R2 MISSION ON THE INTERNATIONAL SPACE STATION

G. A. Baratta[(1)], D. Chaput[(2)], H. Cottin[(3)], L. Fernandez Cascales[(1)], M.E. Palumbo[(1)], **G. Strazzulla[(1)]**

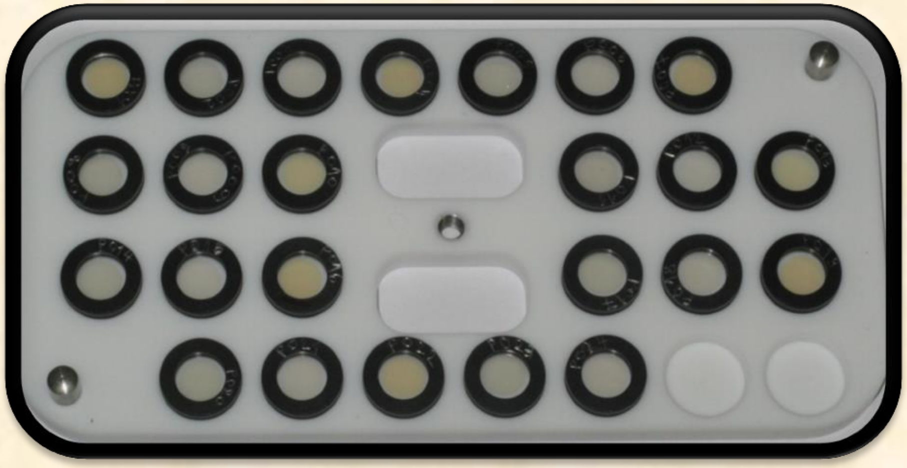
[(1)]INAF-Osservatorio Astrofisico di Catania, Italy
[(2)]Centre National d'Etudes Spatiales (CNES), Toulouse, France
[(3)]Laboratoire Interuniversitaire des Systemes Atmospheriques (LISA), UMR CNRS 7583, Université Paris Est Creteil et Université Paris Diderot, Institut Pierre Simon Laplace, France

Research supported by the Italian Space Agency (ASI)

“Photochemistry on the Space Station (PSS)”

Launch : July 23, 2014
Exposition will start in October, for 12-18 months

30 samples:
10 190 nm thick
10 130 nm thick
10 65 nm thick



MgF_2 windows with organic samples

For each thickness :

4 will fly on board of the ISS
2 *exposed &* ***2*** *kept inside*

6 sent to the ESA laboratories
2 *in vacuum and same T variations as the ISS exposed ones*
2 *in vacuum and at room temperature*
2 *exposed to visible - near UV electromagnetic radiation*

Additional samples will be exposed to
vacuum UV (mostly Ly-alfa) photons in our laboratory

SAMPLE PREPARATION

Deposition of frozen gases N_2:CH_4:CO

experimental apparatus: a stainless steel ultra high-vacuum chamber
pressure: lower than 10^{-9} mbar
cold finger: 16-300 K

Picture of the cold finger with the MgF_2 window used as substrate

Irradiation of frozen N_2:CH_4:CO (1:1:1)

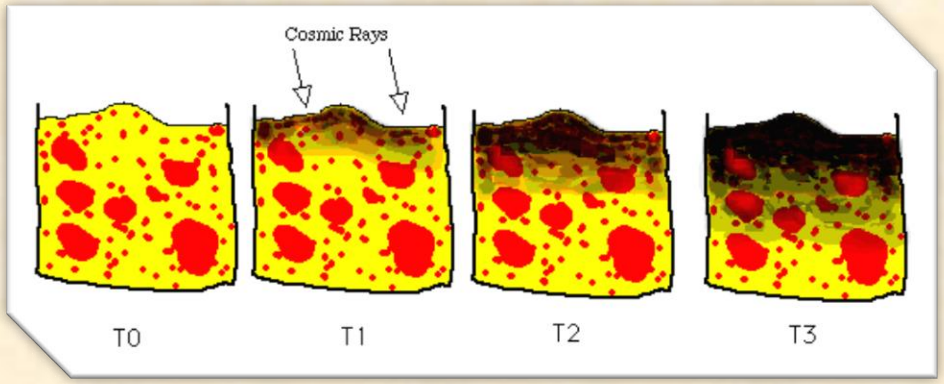
irradiation: 200 keV helium ion beams
beam current density: 2×10^{-1} µA cm^{-2}
energy received by each of the 30 samples: 110±5 eV/16u

Warm up to room T and extraction of the residues

Irradiation effects on comets and TNOs

The surfaces of all the atmosphereless Solar System bodies are continuously irradiated by energetic ions from the Sun and the Galaxy.

Modification of the spectral signatures:
band intensity, profile (shape, width, peak position), color etc.



The Rosetta Mission

-Was approved in November 1993 by ESA

-'The target is comet 67 P/Churyumov-Gerasimenko.

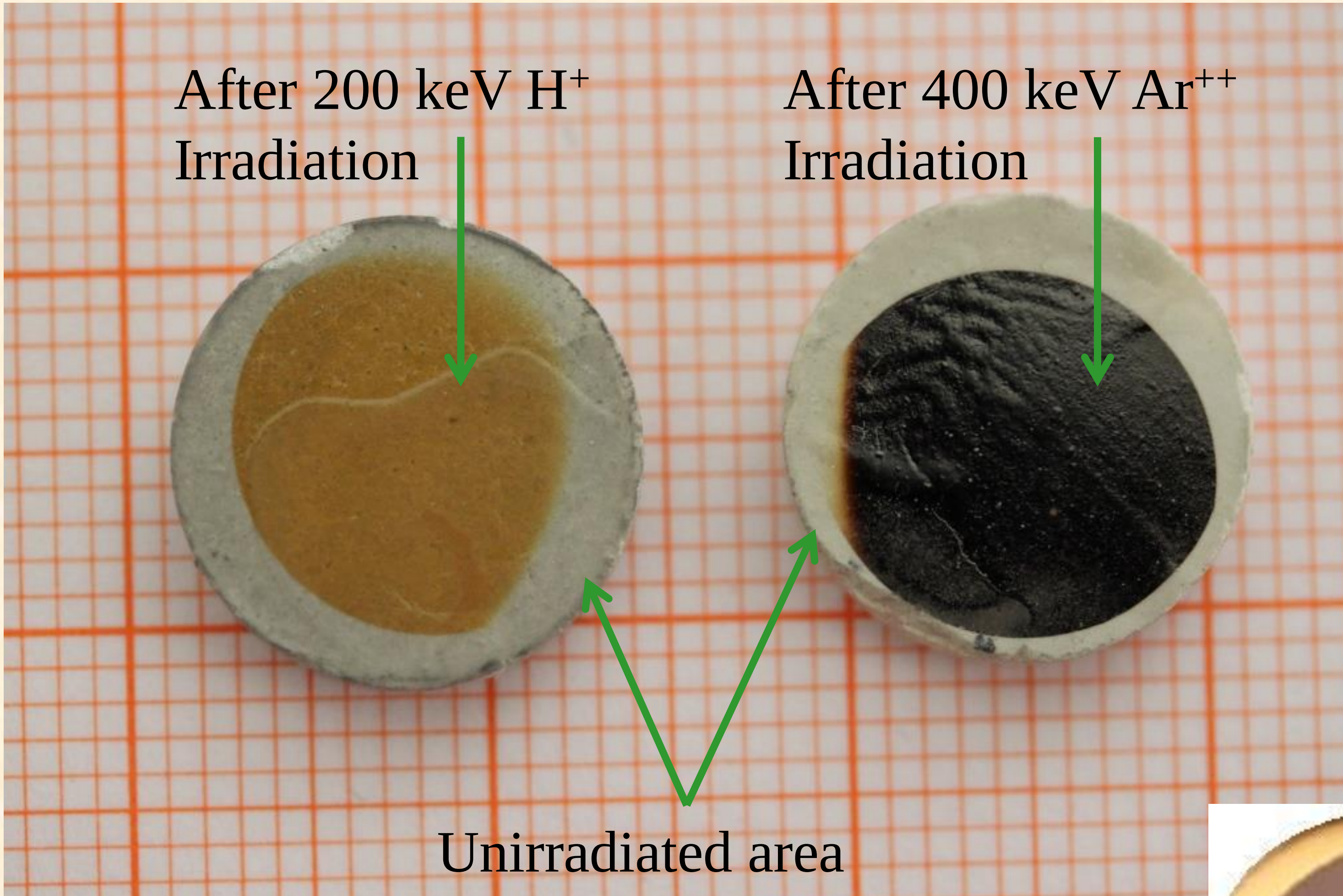
-During its 10 year journey towards the comet, the spacecraft has passed by two asteroids: 2867 Steins (in 2008) and 21 Lutetia (in 2010).

-The spacecraft entered deep-space hibernation mode in June 2011.

-On 20 January 2014 at 18:18 UTC, a signal was received by NASA's Goldstone and Canberra ground stations: hibernation exit sequence had been completed.

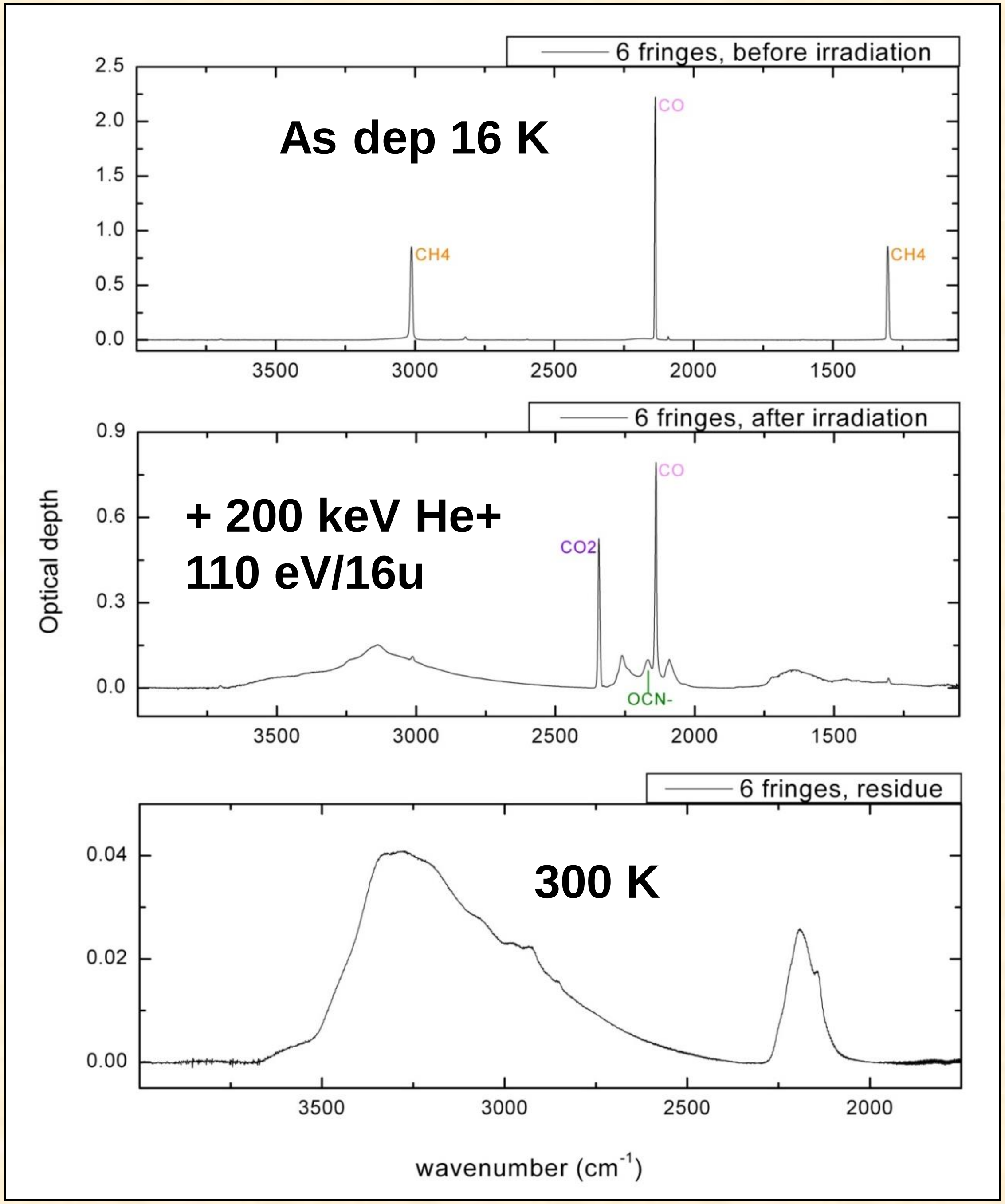
-Arrived at comet August 2014
-Started global mapping August 2014
-Lander delivery November 2014
-Perihelion passage 13 August 2015
-End of mission 31 December 2015

Polystyrene film deposited on olivine



After 200 keV H^+
Irradiation of frozen methane

N_2:CH_4:CO (1:1:1)



CH_4: 1302 cm^{-1}

CO: 2140 cm^{-1}

CH_4: 3010 cm^{-1}

CO_2: 2340 cm^{-1}

OCN^-: 2167 cm^{-1}

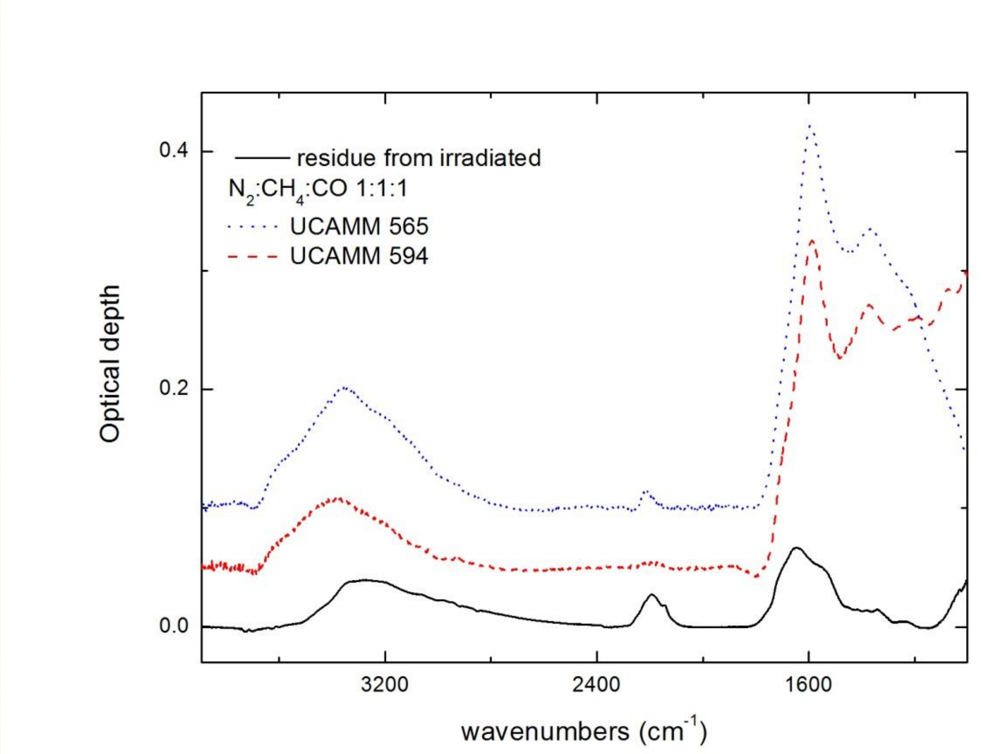
CO: 2140 cm^{-1}

from 3600 to 2400 cm^{-1}:
C-H, O-H & N-H *groups*

At about ***2200 cm^{-1}*** *:*
CN *double & triple bonds*

$N_2:CH_4:CO$: representative of ices present on the surfaces of comets and TNOs

Comets release organic materials (thought to be similar to the present ones) when near to the Sun



The spectra of ultracarbonaceous antartic meteorites are courtesy of E. Dartois and C. Engrand
<u>(Dartois et al 2013, Icarus 224, 243)</u>

How organic materials are modified by solar vacuum UV irradiation?

ASTROBIOLOGY
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DOI: 10.1089/ast.2011.0649

Survival of *Deinococcus radiodurans* Against Laboratory-Simulated Solar Wind Charged Particles

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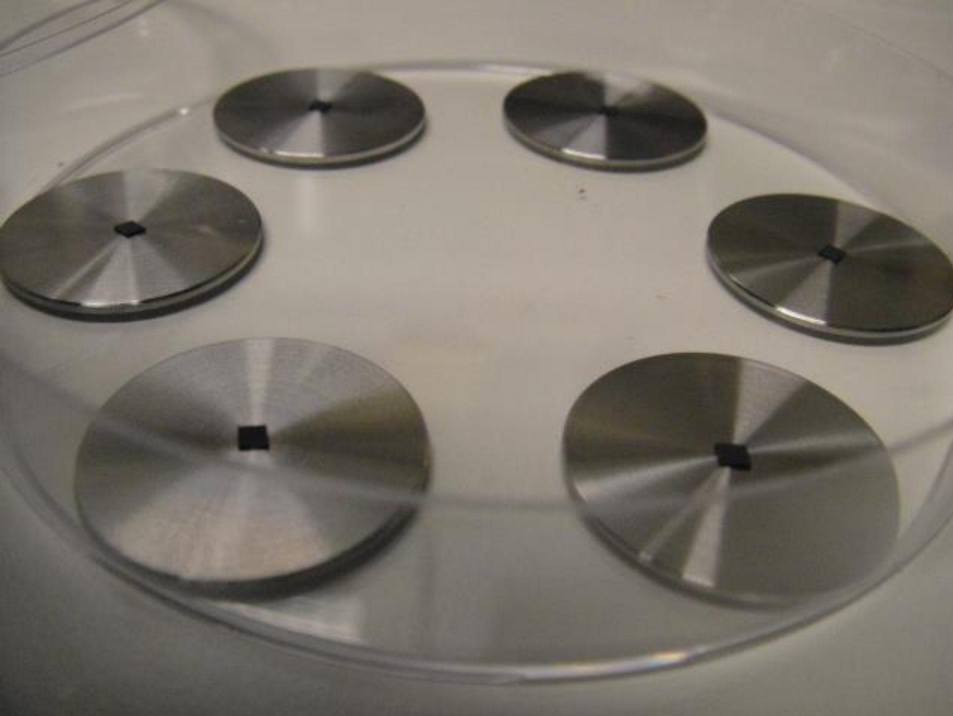
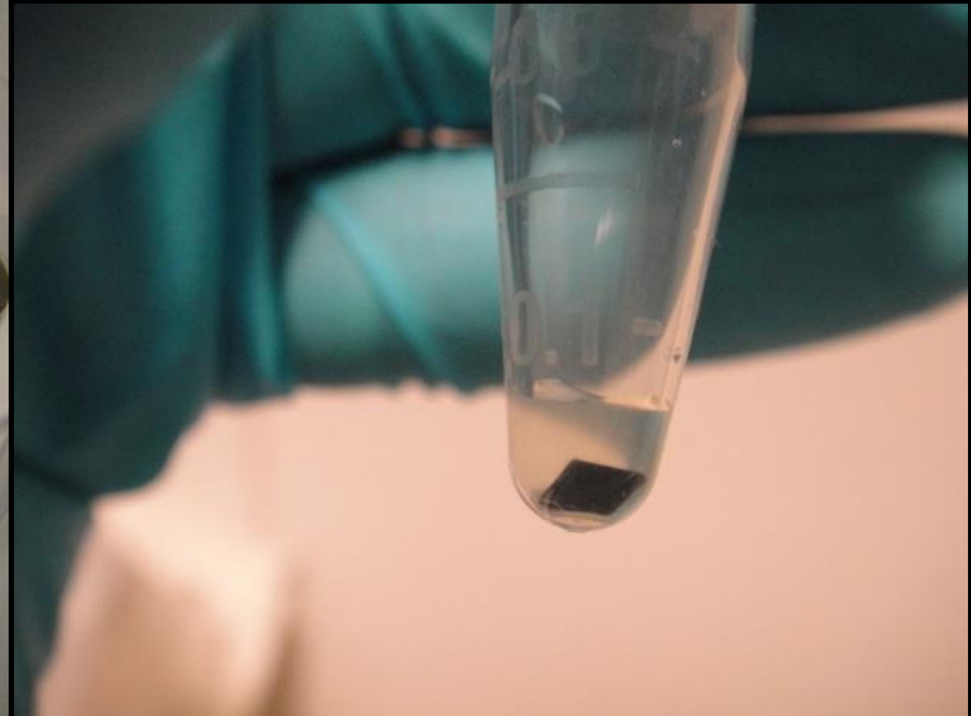
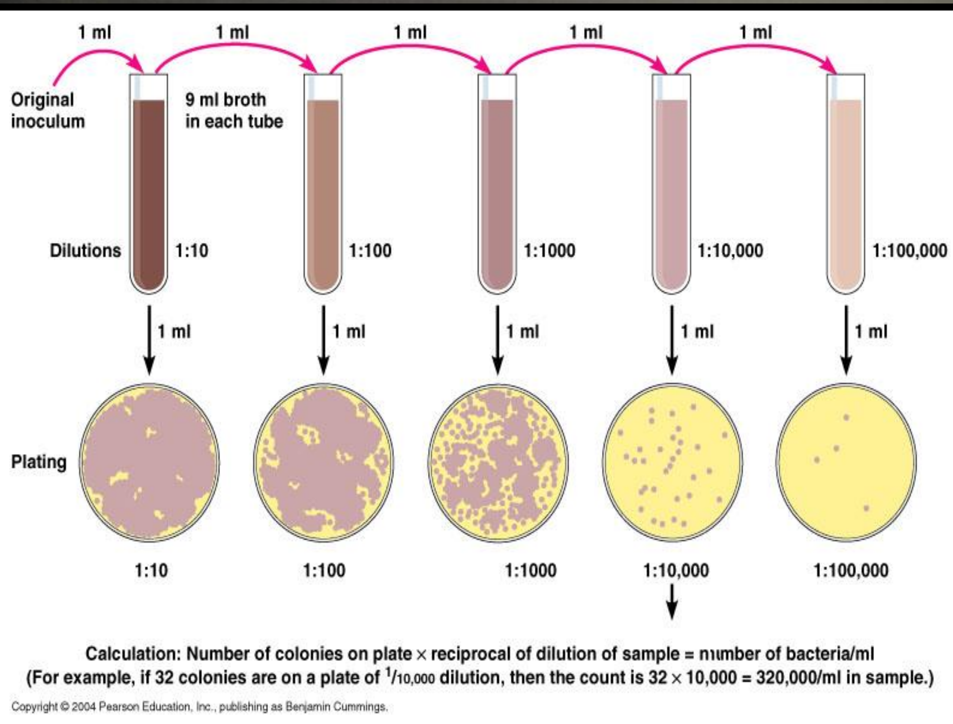
✓Effects on living organisms → Is panspermia possible?






1 ml
1 ml
1 ml
1 ml
1 ml
Original inoculum
9 ml broth in each tube
Dilutions
1:10
1:100
1:1000
1:10,000
1:100,000
1 ml
1 ml
1 ml
1 ml
1 ml
Plating
1:10
1:100
1:1000
1:10,000
1:100,000
Calculation: Number of colonies on plate × reciprocal of dilution of sample = number of bacteria/ml
(For example, if 32 colonies are on a plate of 1/10,000 dilution, then the count is 32 × 10,000 = 320,000/ml in sample.)
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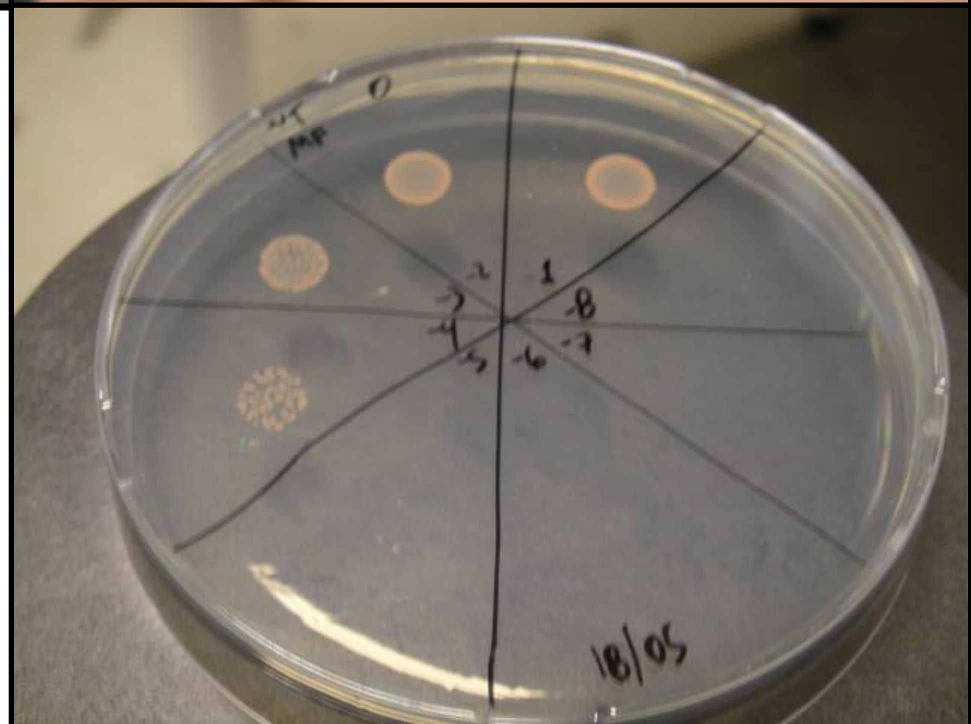
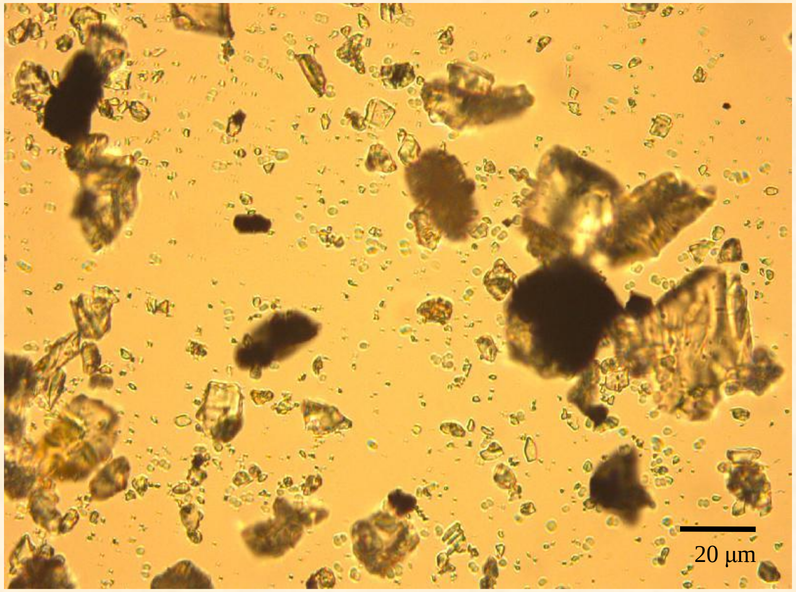
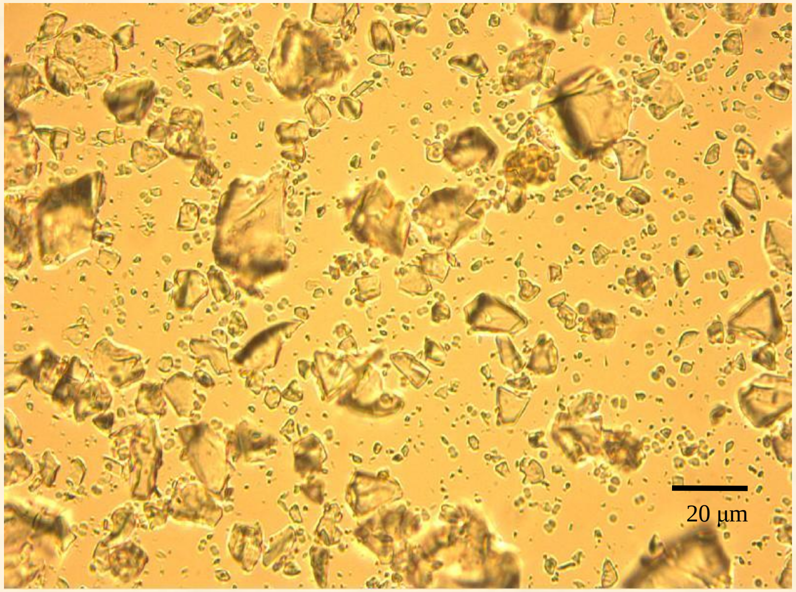

18/05

Basalt



Sandstone



Major elements

wt. %	BASALT	1:1 MIX	SANDSTONE
SiO2	47.24	71.06	93.72
TiO2	2.956	1.538	0.052
Al2O3	16.51	10.21	3.88
Fe2O3	11.19	5.77	0.21
MnO	0.167	0.085	0.004
MgO	5.82	2.79	0.03
CaO	10.03	5.16	0.03
Na2O	3.51	2.10	0.64
K2O	2.23	2.01	1.77
P2O5	0.581	0.301	0.020
LOI	0.32	0.34	0.31

Trace elements

X1936T	BASALT	1:1 MIX	SANDSTONE	Det.Lt.
Rb	56	46	35	**2**
Sr	849	478	117	**2**
Y	28.8	15.6	3.7	**2.0**
Zr	308	179	55	**2**
Nb	69.4	34.8	1.1	**1.5**
Ba	568	558	494	**12**
Pb	8	7	10	**5**
Th	11	7	0	**4**
U	3	2	0	**3**
Sc	22	11	1	**5**
V	288	139	6	**5**
Cr	77	39	4	**4**
Co	29	14	1	**2**
Ni	31	15	3	**3**
Cu	53	29	2	**3**
Zn	78	40	3	**3**
Ga	20	11	4	**3**
Mo	3	1	1	**2**
As	0	0	0	**5**
S	4	99	180	**50**
TiO2%	2.74	1.46	0.05	
Fe2O3%	10.16	4.79	0.63	

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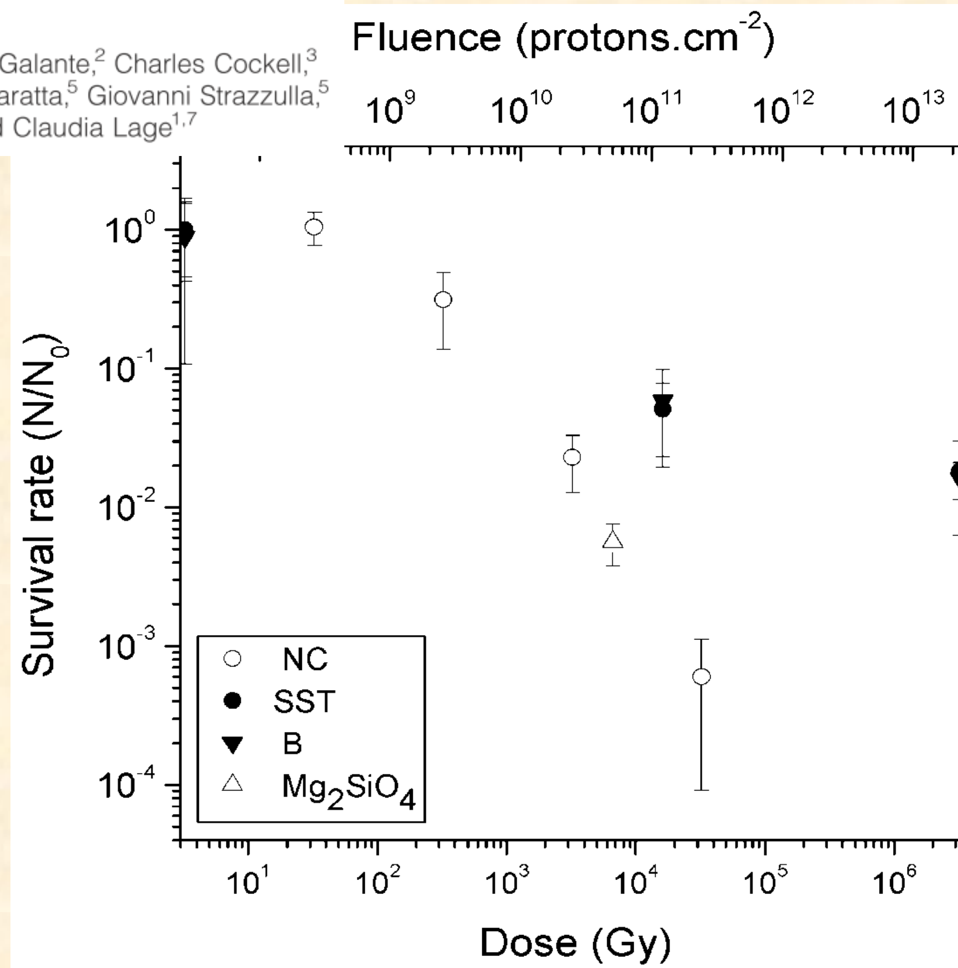

Survival curves of *D. radiodurans* after irradiation by a proton beam at 200 keV. NC = naked cells, SST = cells mixed with grains of sandstone, B = cells mixed with grains of basalt. Mg_2SiO_4 represents cells deposited on forsterite substrate.

Target	Dose (rad)	Dose (eV/molecule)	Effect
Molecules	10^{10}-10^{12}	5 (1-10^{3})	Phys-Chem alteration
Polymers	10^{8}-10^{10}	5 (10^{-1}-10)	Phys-Chem alteration
DNA	10^{6}	5 10^{-3}	Inactivation
Enzymes	10^{5}-10^{7}	5 (10^{-4}-10^{-2})	Inactivation
Virus	10^{5}	5 10^{-4}	Lethal
Bacteria	10^{4}-10^{5}	5 (10^{-5}-10^{-4})	Lethal
Fungi	10^{3}-10^{5}	5 (10^{-6}-10^{-4})	Lethal
Cells	10^{3}-10^{4}	5 (10^{-6}-10^{-5})	Lethal
Mammalians	10^{2}-10^{3}	5 (10^{-7}-10^{-6})	Lethal

Gray (Gy)	rad	Joule(J)/gr	eV/gr	eV/molec
1	100	10^{-3}	6.25 10^{15}	5 10^{-7}