Formation of complex molecules after energetic processing of icy grain mantles

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Molecules in space

Table B1.1: List of detected molecules adapted from http://www.astrochymist.org/astrochymist_ism.html

Number of atoms								
2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
CH	H_2O	NH_3	HC_3N	CH_3OH	CH_3CHO	$HCOOCH_3$	$(CH_3)_2O$	$(CH_3)_2CO$
CN	HCO^+	H_2CO	HCOOH	CH_3CN	CH_3CCH	CH_3C_3N	CH_3CH_2OH	$HOCH_2CH_2OH$
CH^+	HCN	HNCO	CH_2NH	NH_2CHO	CH_3NH_2	C_7H	CH_3CH_2CN	CH_3CH_2CHO
OH	OCS	H_2CS	NH_2CN	CH_3SH	CH_2CHCN	CH_3COOH	HC_7N	CH_3C_5N
CO	HNC	C_3N	H_2CCO	C_2H_4	HC_5N	H_2C_6	CH_3C_4H	*NH_2CH_2COOH*
H_2	H_2S	HNCS	C_4H	C_5H	C_6H	CH_2OHCHO	C_8H	
SiO	N_2H^+	$HOCO^+$	SiH_4	*CH_3NC*	c-C_2H_4O	C_6H_2	CH_3CONH_2	
CS	C_2H	C_3O	c-C_3H_2	HC_2CHO	CH_2CHOH	CH_2CHCHO	C_8H^-	
SO	SO_2	C_3H	CH_2CN	H_2CCCC	C_6H^-	CH_2CCHCN	CH_2CHCH_3	
SiS	HDO	$HCNH^+$	C_5	HC_3NH^+		NH_2CH_2CN		
.NS	HCO	H_3O^+	SiC_4	C_5N				
C_2	HNO	C_3S	H_2CCC	C_4H_2				
NO	OCN^-	c-C_3H	CH_4	HC_4N				
HCl	HCS^+	C_2H_2	HCCNC	c-H_2C_3O				
NaCl	HOC^+	HC_2N	HNCCC	CH_2CNH				
AlCl	c-SiC_2	H_2CN	H_2COH^+	C_5N^-				
KCl	MgNC	SiC_3	C_4H^-					
AlF	C_2S	CH_3	CNCHO					
PN	C_3	C_3N^-						
SiC	CO_2	*PH_3*						
CP	CH_2	HCNO						
NH	C_2O	HOCN						
SiN	NH_2	HSCN						
SO^+	NaCN	HOOH						
CO^+	N_2O							
HF	MgCN							
LiH	H_3^+							
SH	SiCN							
FeO	AlNC							
N_2	SiNC							
CF^+	HCP							
PO	CCP							
AlO	AlOH							
CN^-	H_2O^+							
OH^+	H_2Cl^+							
SH^+	KCN							
O_2	FeCN							

Number of atoms								
					11	**12**	**13**	**>13**
					HC_9N	C_6H_6	$HC_{11}N$	C_{60}
					CH_3C_6H	*$CO(CH_2OH)_2$*		C_{70}
					C_2H_5OCHO	C_3H_7CN		

Origin of interstellar molecules

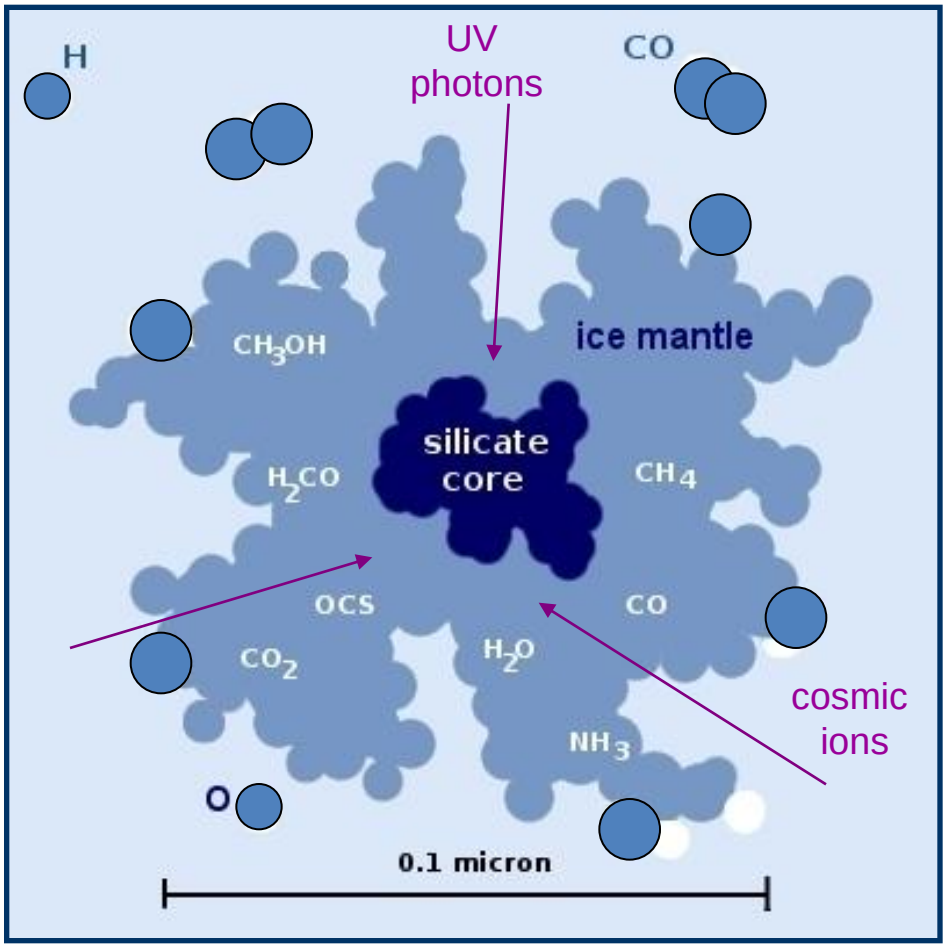
Gas-phase reactions

Solid phase → **Grain-surface reactions**

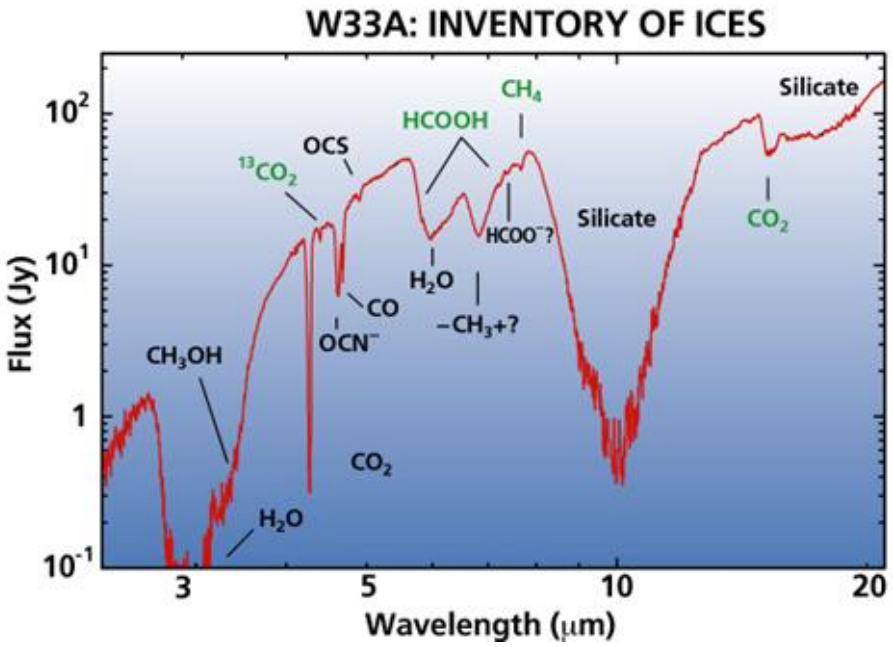
Solid phase → **Energetic processing of icy mantles**

(molecules are released to the gas phase after desorption of ices)

Icy grain mantles



- **Freeze out of gas phase species (CO)**
- **Grain surface reactions (H_2O, CH_3OH, CH_4, H_2S)**
- **Energetic processing of icy mantles (CO_2 , OCS)**

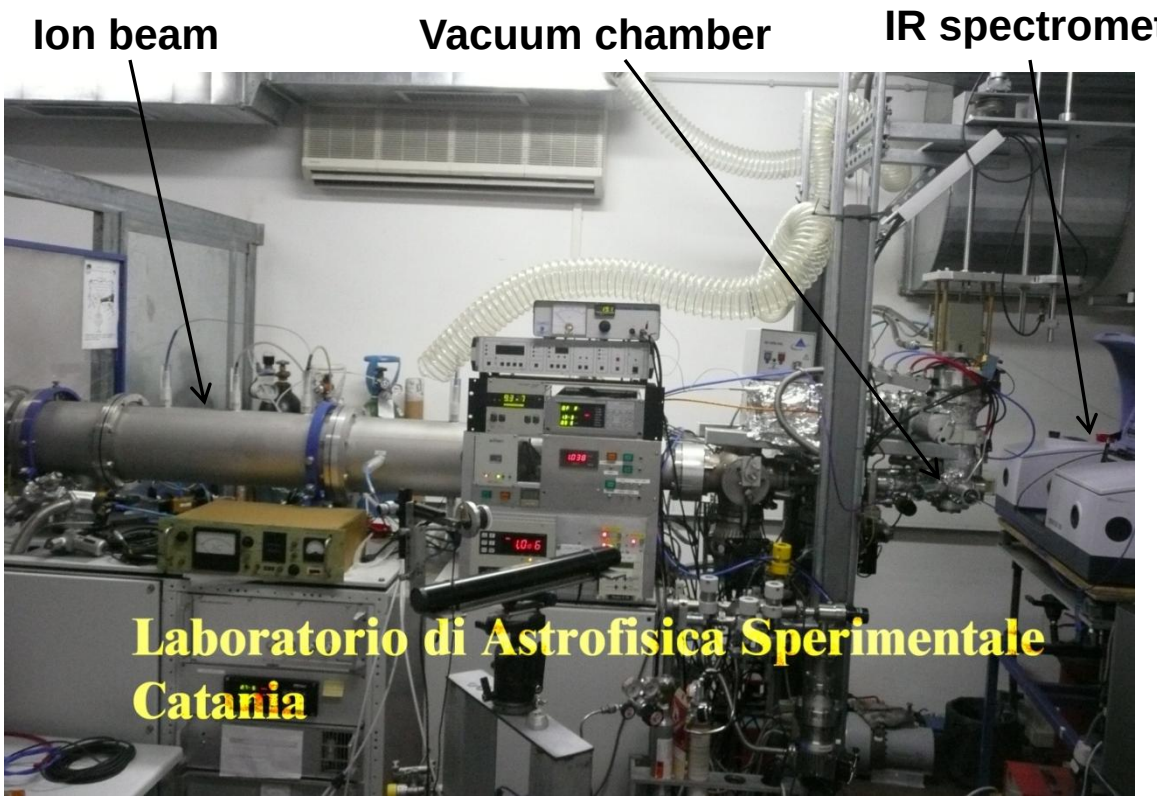


Abundance of solid-phase molecules

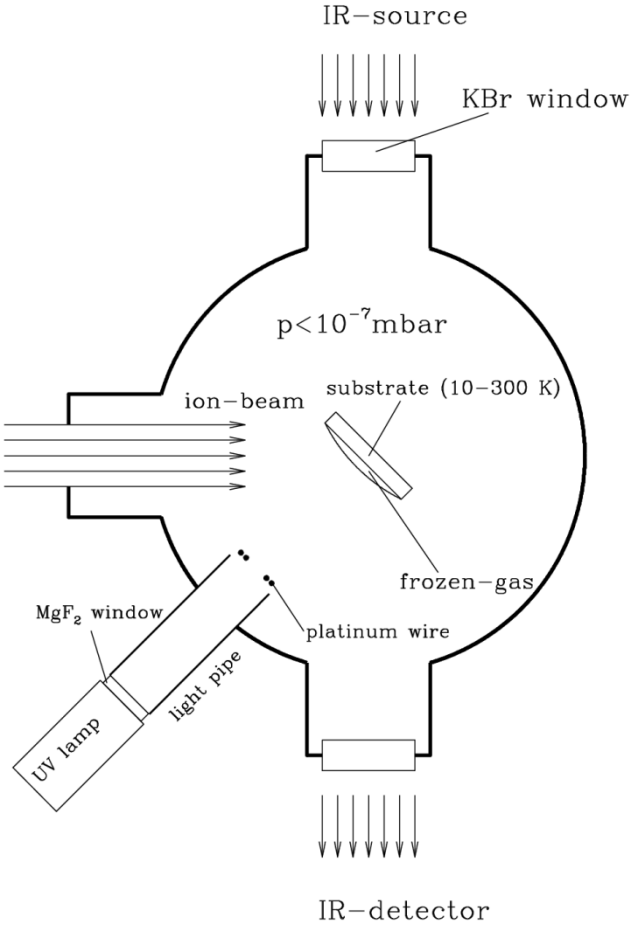
(with respect to H_2O=100)

species	abundance	references
H_2O	100	
CO	0-144	Chiar et al. 1994; Pontoppidan et al. 2003
CO_2	10-32	Gerakines et al. 1999 ; Pontoppidan et al. 2008
CH_3OH	3-30	Allamandola et al. 1992; Dartois et al. 1999; Boogert et al. 2008
CH_4	2-10	Boogert et al. 1997; Oberg et al. 2008
NH_3	5-10	Tielens 1984; Lacy et al. 1998
H_2CO	3-7	Schutte 1994
OCN^-	1-8	Tegler et al. 1995
SO_2	0.3-0.8	Boogert et al. 1997
OCS	0.04-0.1	Palumbo et al. 1997

It is generally accepted that other molecules are also present in icy grain mantles



Vacuum chamber details

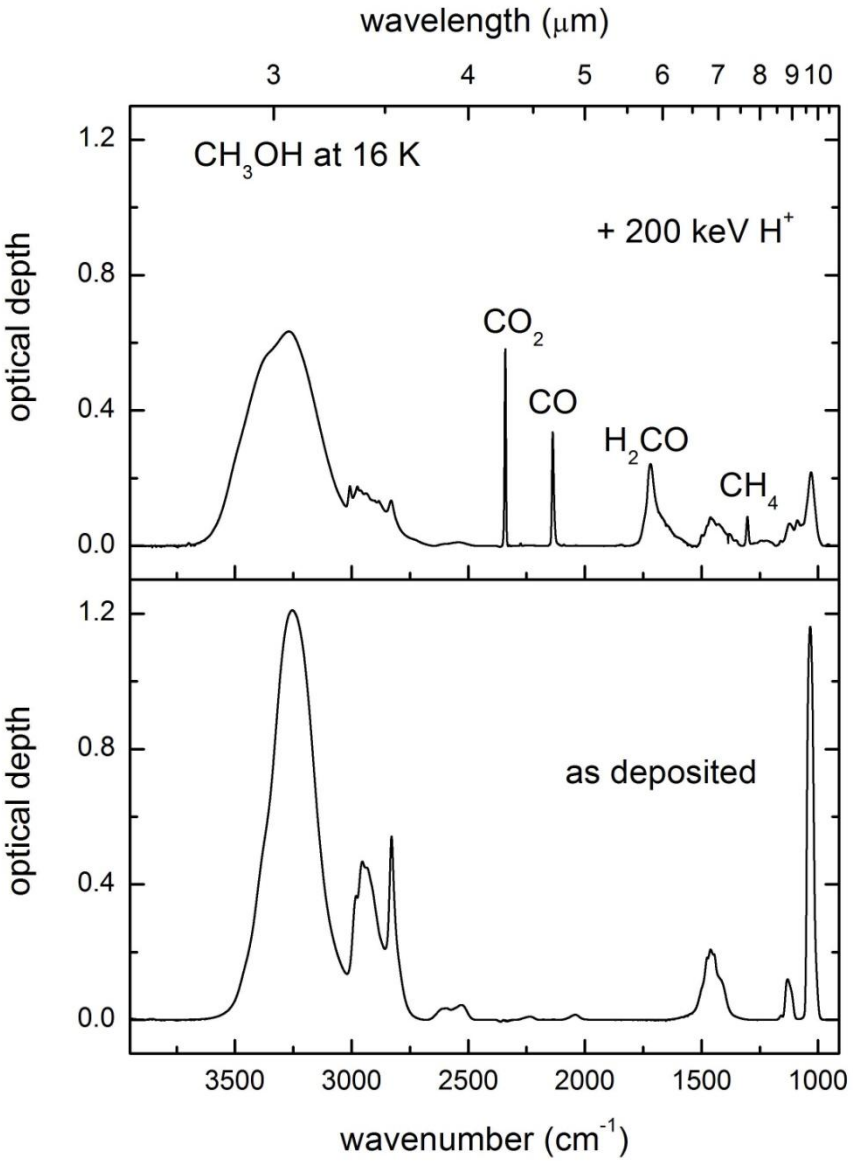


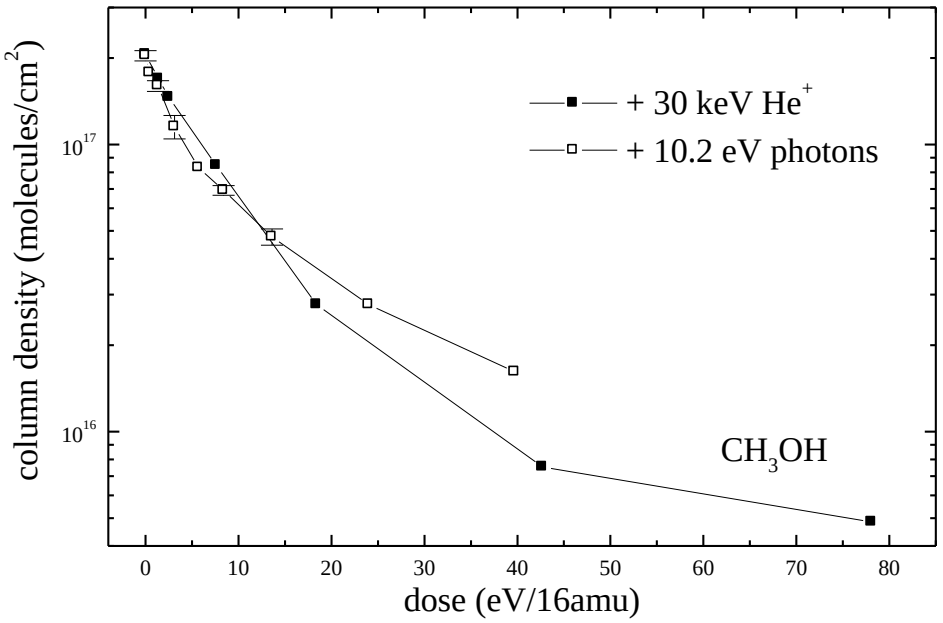
The sample is processed by energetic ions (200-400 keV) and by UV photons separately or simultaneously.

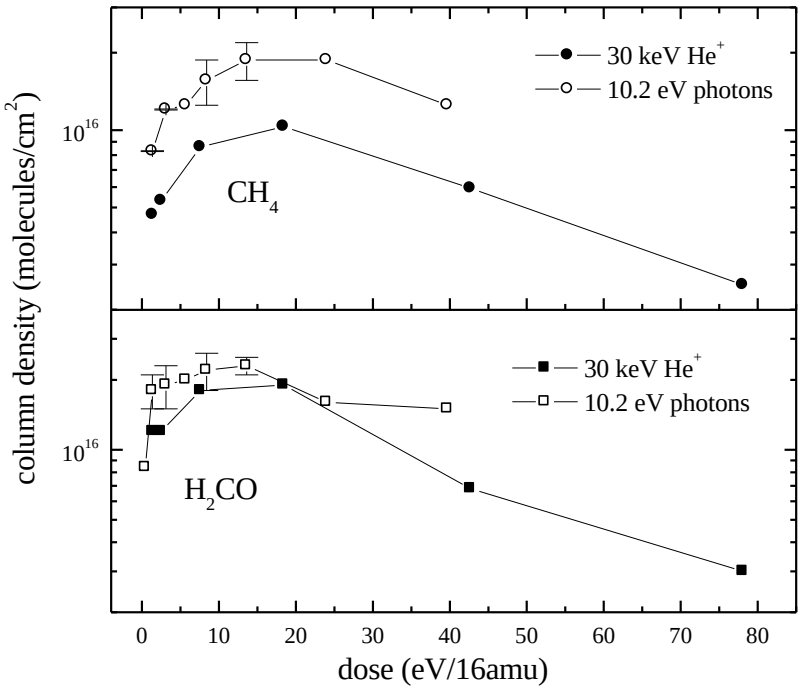
IR spectra are taken before and after processing.

CH_3OH

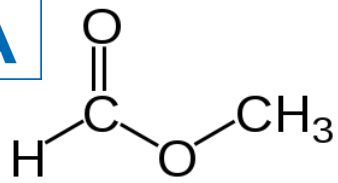
Palumbo et al. 1999, A&A 342, 551
Baratta et al. 2002, A&A 384, 343

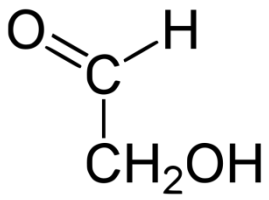


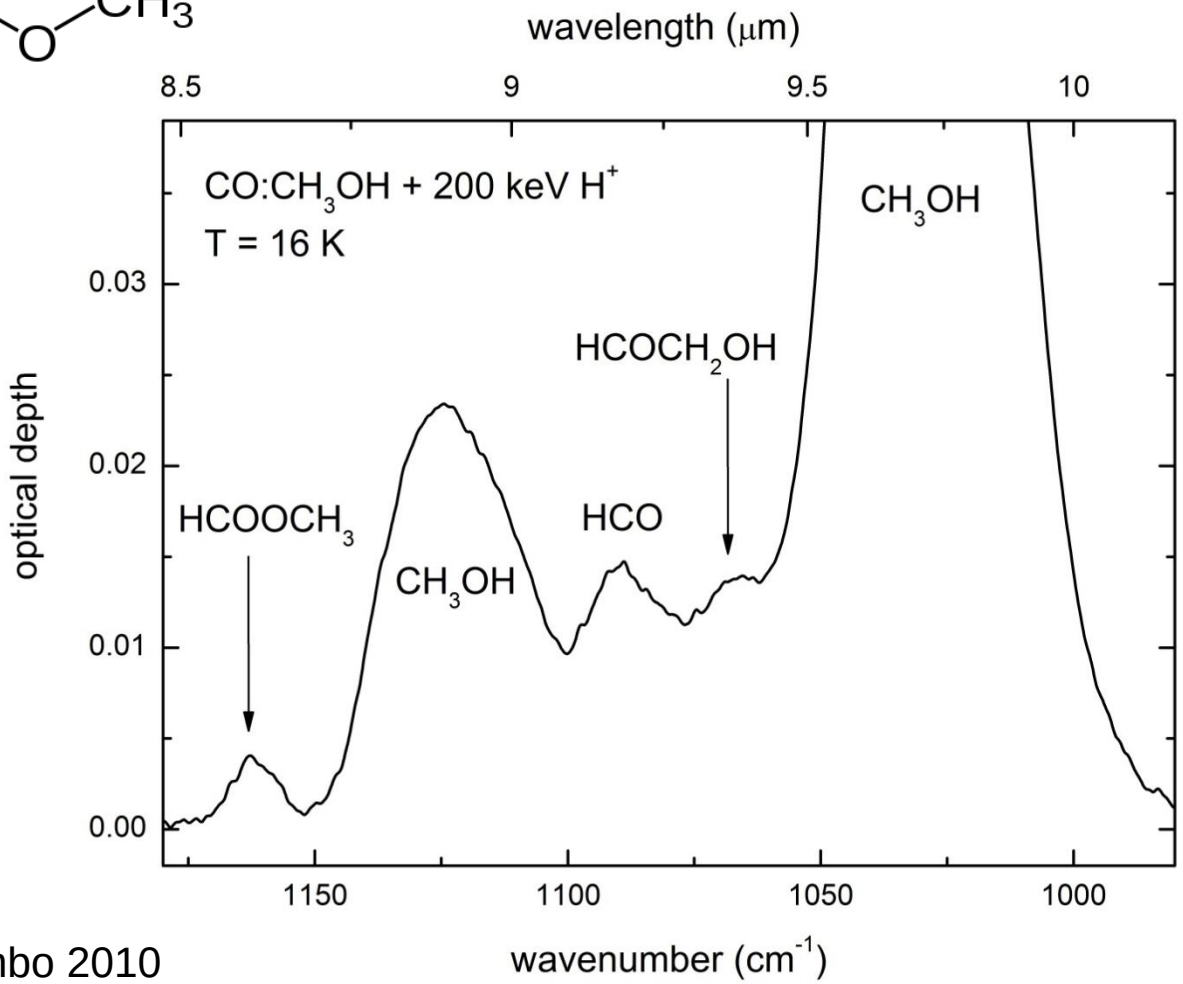




Methyl formate and glycoladehyde







Modica and Palumbo 2010
A&A 519, A22

Methyl formate in star-forming regions

source	$N(HCOOCH_3)/N(H_2)$	references
Sgr B2 N(LMH) (hot core)	1.1×10^{-8}	Snyder 2006
IRAS 16293-2422 B (hot corino)	$> 1.2\times10^{-8}$	Remijan & Hollis 2006
NGC 2264 MMS (hot core)	$(0.7- 5.3)\times10^{-8}$	Sakai et al. 2007

$N(CO) \approx 10^{-4}\, N(H_2)$ (Frerking et al. 1982)

$N(CH_3OH) \approx 10^{-1}\, N(CO)$ $CO \rightarrow HCO \rightarrow H_2CO \rightarrow CH_3O \rightarrow CH_3OH$ (Watanabe et al. 2007 Fuchs et al. 2009)

$N(CH_3OH) \approx 10^{-5}\, N(H_2)$ assuming high CO depletion

$N(HCOOCH_3) \approx 10^{-3}\, N(CH_3OH)$ this work

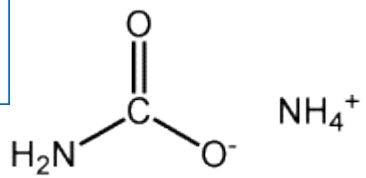
⇩

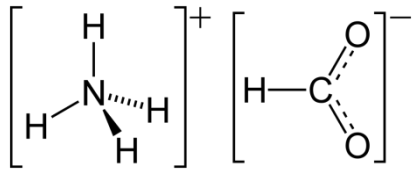
$N(HCOOCH_3) \approx 10^{-8}\, N(H_2)$

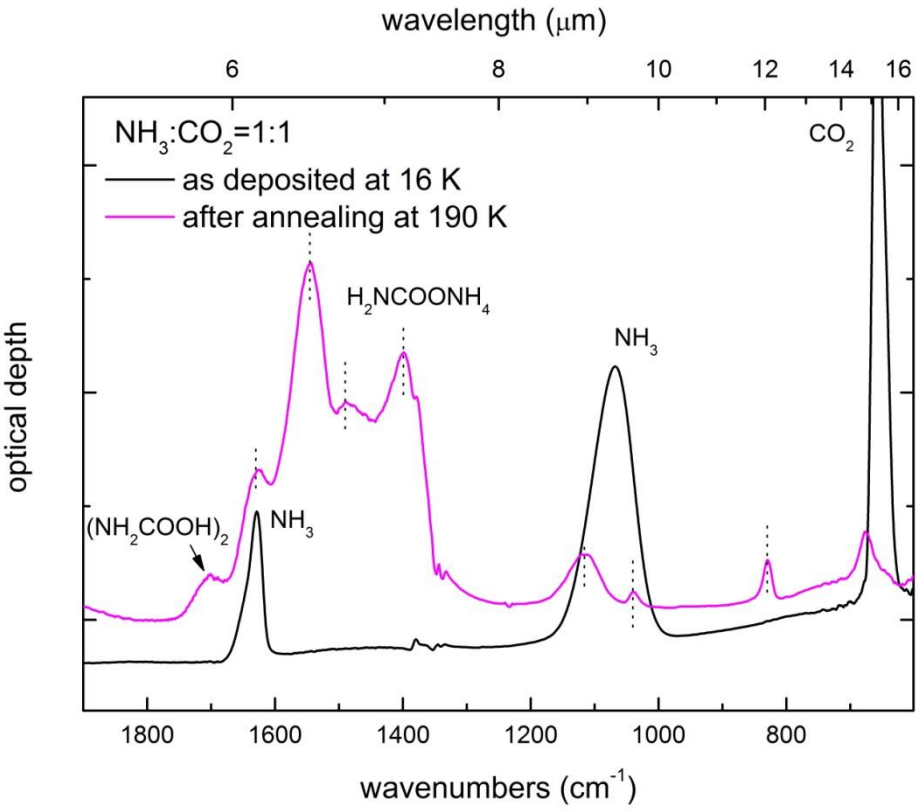
The amount of methyl formate formed after ion irradiation can account for the observed abundances

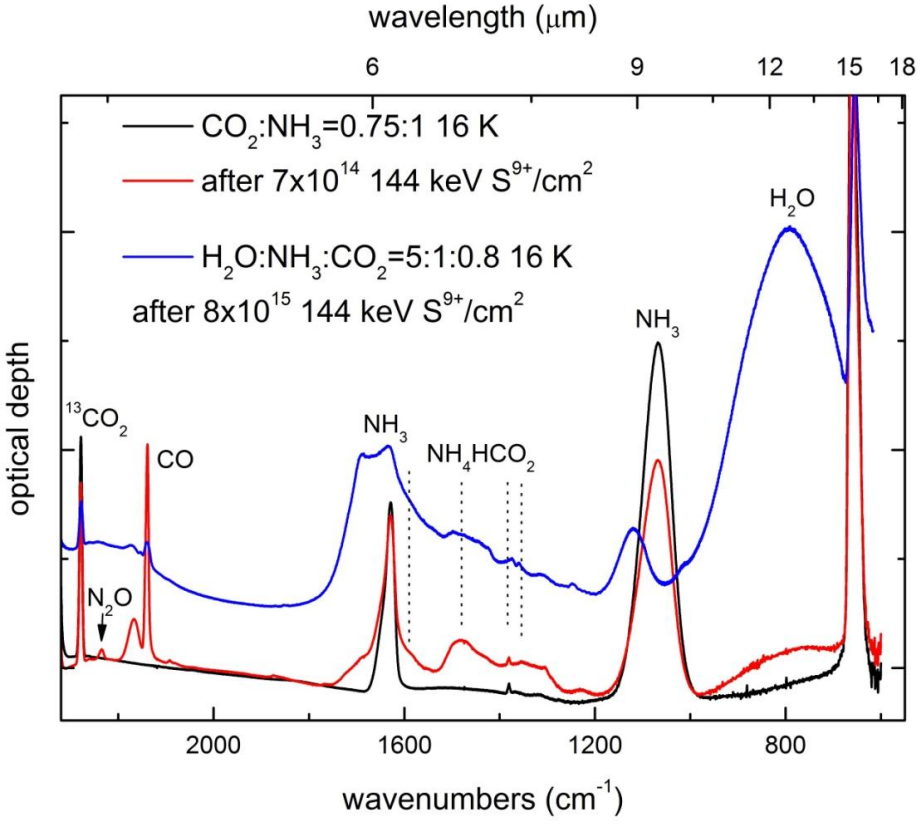
Modica and Palumbo 2010, A&A 519, A22

Ammonium carbamate and ammonium formate









Lv et al. 2014
PCCP 16, 3433

Present limits

Solid CH_3OH

Species not present before processing

CO	→	20% w.r.t. CH_3OH
H_2CO	→	10%
CO_2	→	6%
CH_4	→	5%
$HCOOCH_3$	→	0.2% (methyl formate)
$HCOCH_2OH$	→	0.1% (glycolaldehyde)

Modica and Palumbo, 2010

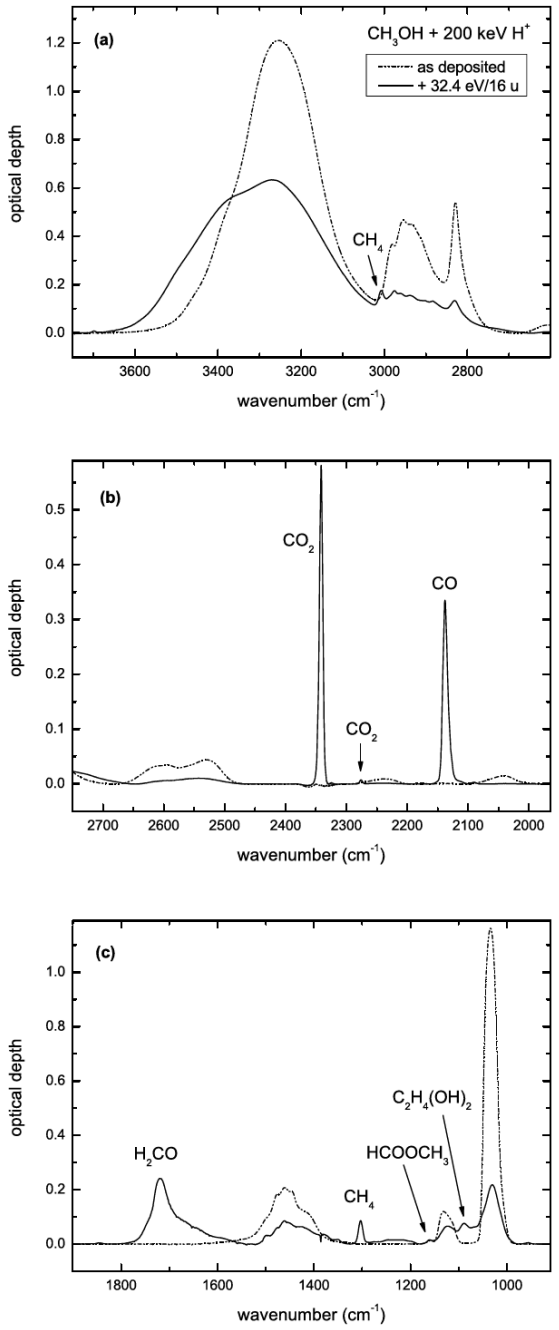


Fig. 8. Infrared spectra of a CH_3OH pure ice as deposited (dotted lines) and after irradiation with 200 keV protons (solid lines) in three different spectral regions from 3700 to 900 cm^{-1} (2.70–11.11 μm).

WP6. Laboratory Astrophysics

➢**Open question:**

What and how many complex molecules are formed in icy grain mantles by energetic processing?

➢**Aim:**

To build up a new and original experimental set-up that will detect molecules formed after energetic ion bombardment of simple ices, using a combination of laser desorption, He jet cooling and UV-tunable photo-ionization followed by high resolution mass-spectrometric analysis.

➢**Gain:**

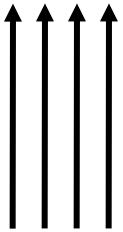
Present relative sensitivity (i.e. IR spectroscopy) ~10^{-3} (column density)

Expected relative sensitivity ~ 10^{-7} (mass abundance)

Future experimental procedure

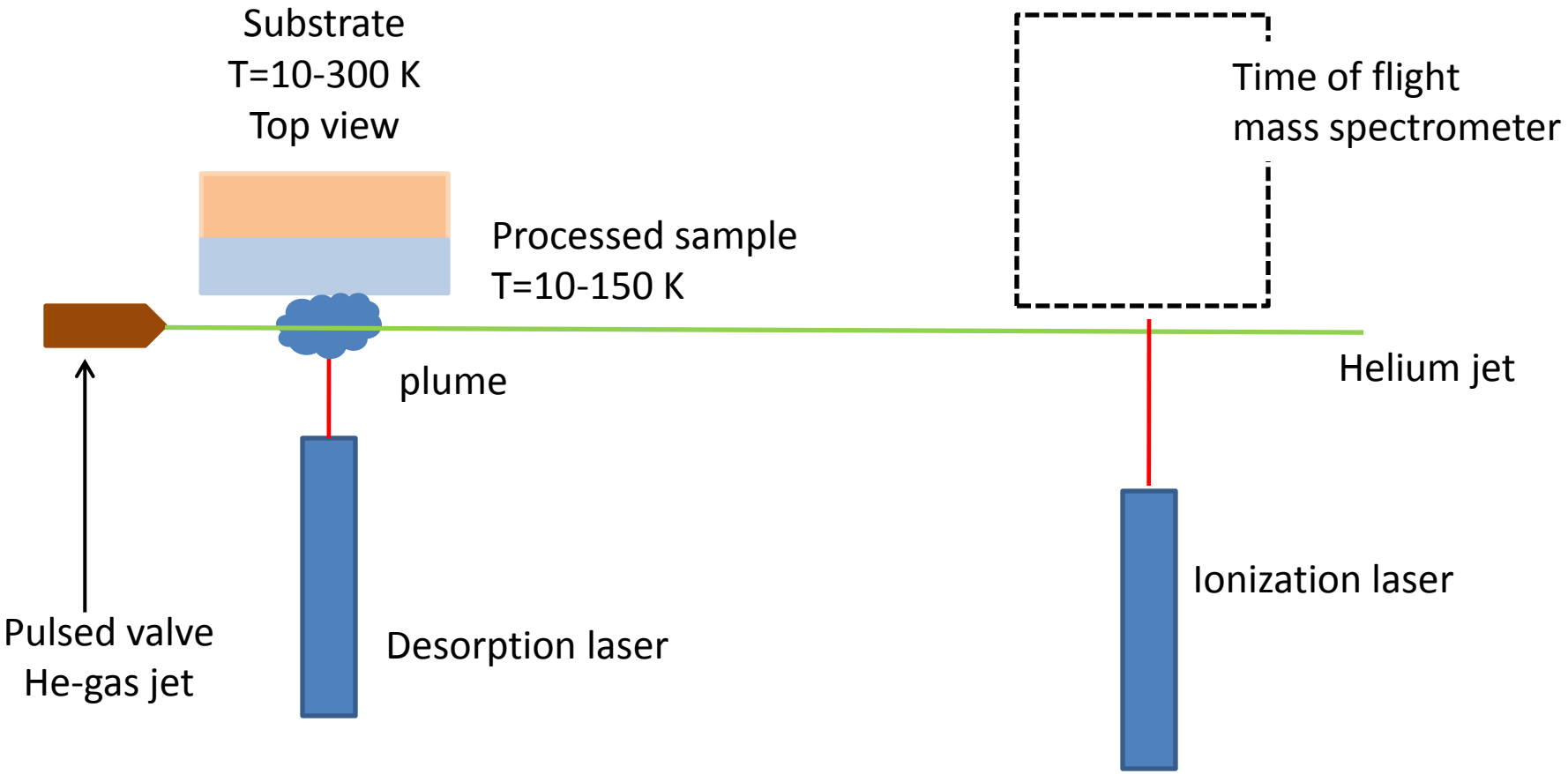
Substrate
T=10-300 K
Top view

Sample
T=10-150 K

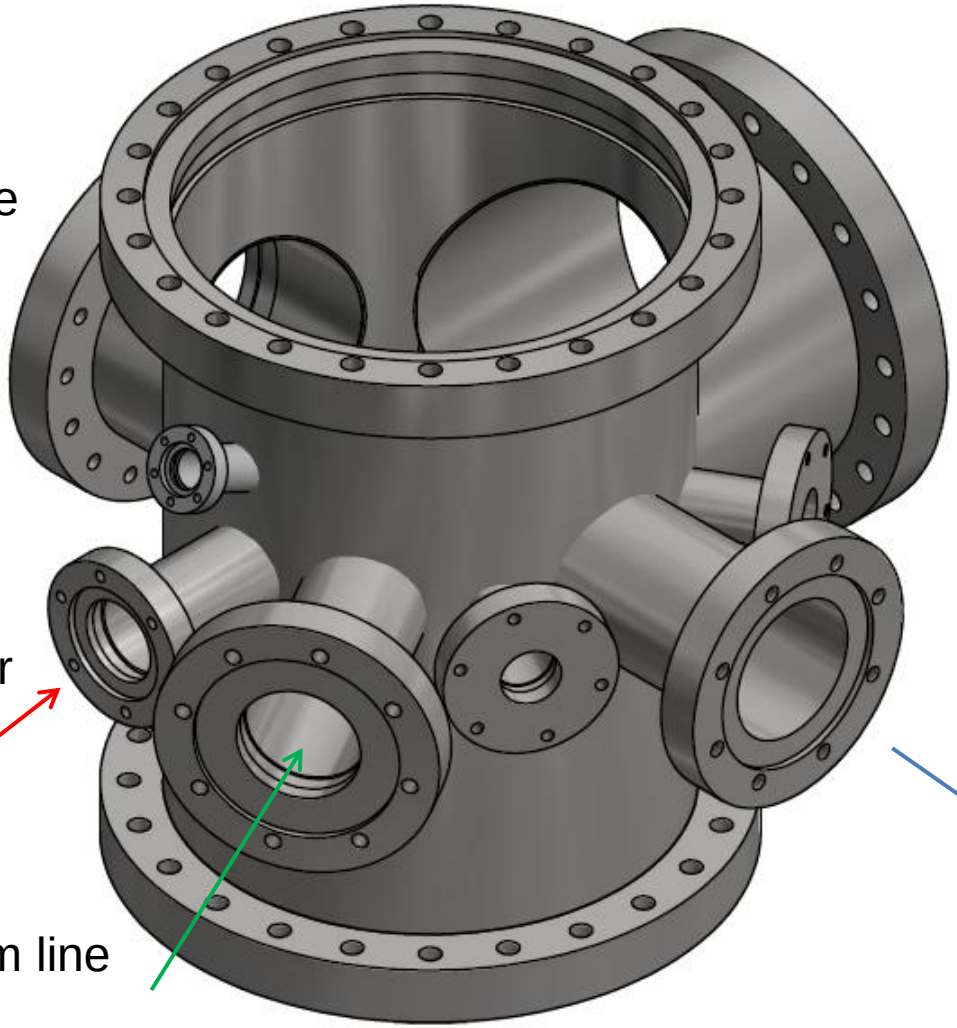


200-400 keV ions

Future experimental procedure



Schematic of the new vacuum chamber



Pulsed valve position

UHV chamber inner diameter 20 cm

Desorption laser

to the TOF-MS

Ion beam line

Recruitment

1 PhD student (cycle XXX)

Dottorato in Scienza dei Materiali e Nanotecnologie
Università degli Studi di Catania

1 post-doc fellow

Submission deadline **26 February 2015** at 13.00

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