Interstellar ices as a source of complex organic molecules of interplanetary solar system objects

Grégoire DANGER

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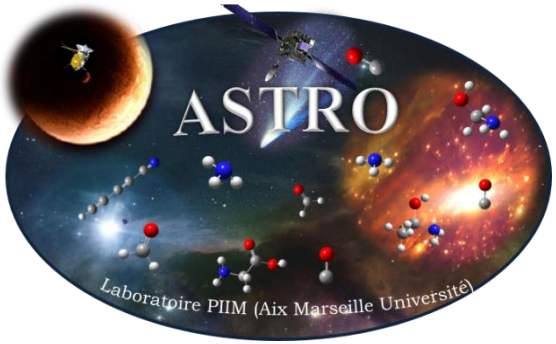
http://piim.univ-amu.fr/Equipe-ASTRO



Evolution of interstellar icy grains
Toward the formation of complex organic matter in interplanetary bodies

Molecular Cloud

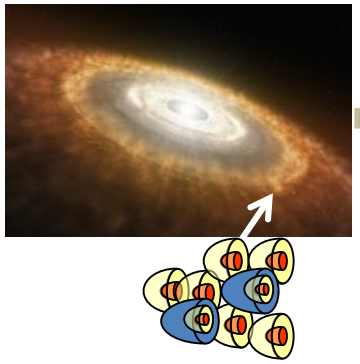
T=10 K

Protostar

enveloppe

Hot core

Protoplanetary disk

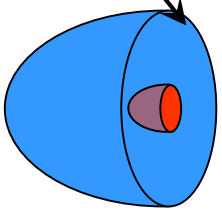


Planetesimal formation

Planetary system formation

(Planets, Asteroids, Comets)

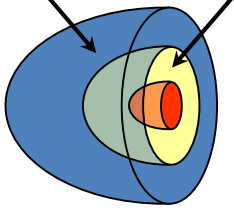
Interstaller ices
H_2O, CH_3OH, NH_3, CO_2, CH_2O…



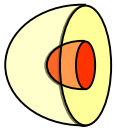
High energy processes
Heating

Volatil Organic Compounds (VOC)

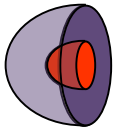
Refractory compounds



High energy processes
Heating



Alterations



Refractory organic residue

Evolution of interstellar icy grains
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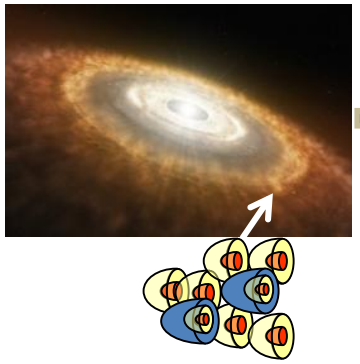
Molecular Cloud

T=10 K

Protostar

Protoplanetary disk



Planetesimal formation

Planetary system formation

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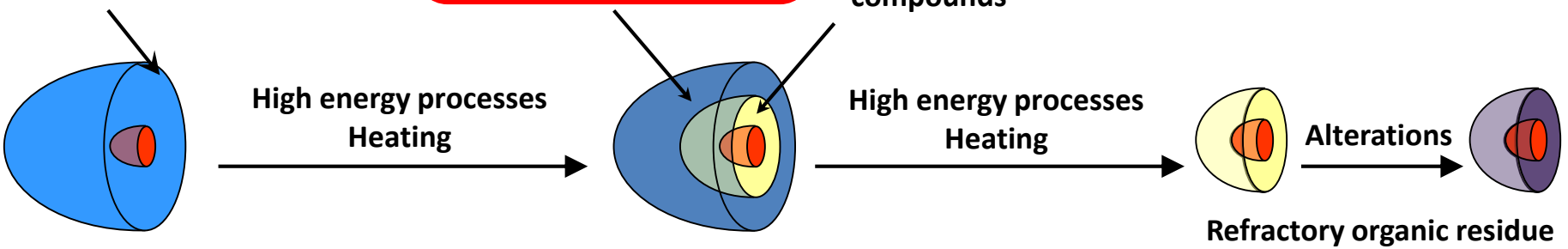
VAHIIA Project

Volatil Organic Compounds (VOC)

Interstaller ices H_2O, CH_3OH, NH_3, CO_2, CH_2O…

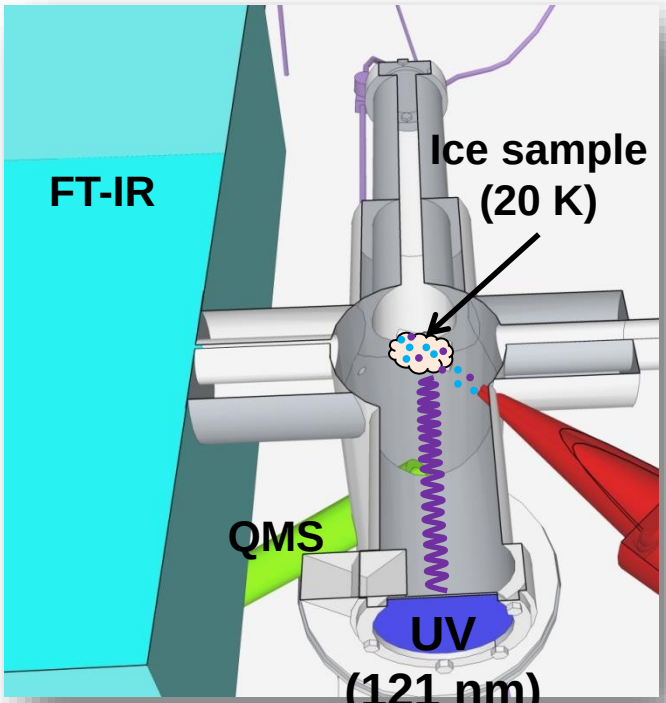
Refractory compounds



Principle of the VAHIIA device
Recovery and analysis of VOC by GC-MS

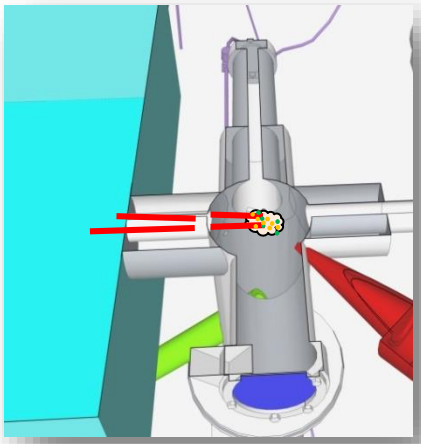
ANR-12-JS08-0001
2012-2015

Vacuum chamber (10^{-9} mbar)



GC-MS

FTIR

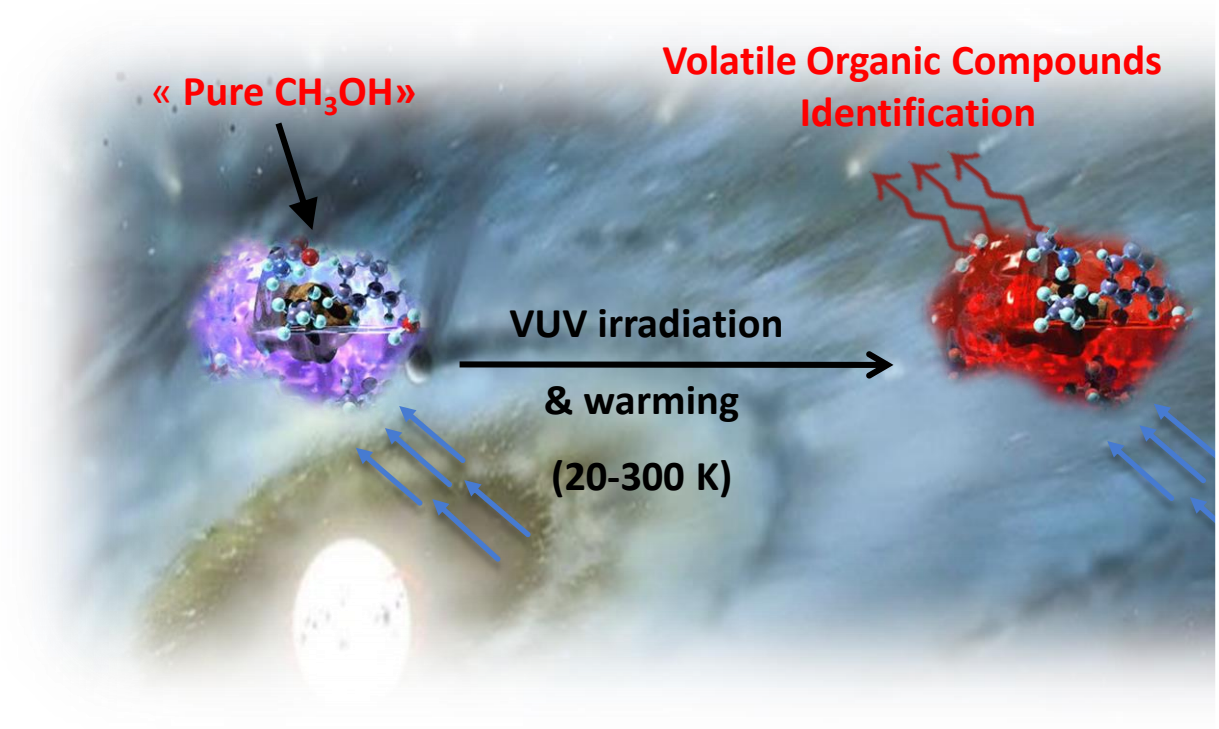


Ice formation in simulated conditions

http://piim.univ-amu.fr/Projet-VAHIIA-Volatile-Analyses

Abou Mrad et al., Anal. Chem., 2014,86,8391

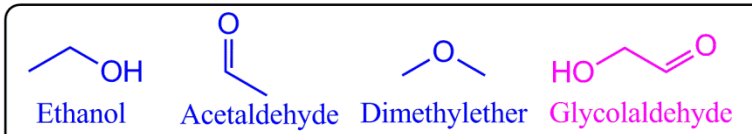
Methanol CH_3OH
An abondant source of reduces carbon in interstellar and cometary ices



Methanol CH_3OH
Analysis with the VAHIIA system – products identified

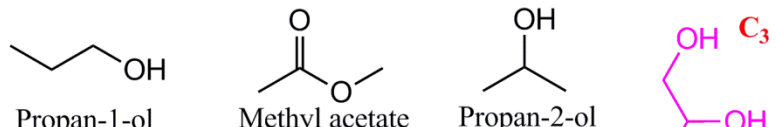
C_1
- CO — Carbon monoxide
- CO_2 — Carbon dioxide
- CH_2O — Formaldehyde
- HCOOH — Formic acid
- CH_4 — Methane

C_2



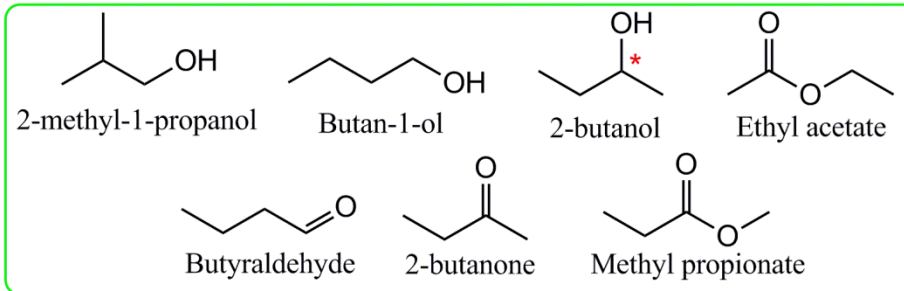
Ethanol, Acetaldehyde, Dimethylether, Glycolaldehyde, Acetic acid, Methyl formate, C_2H_6 Ethane, Ethylene glycol

C_3



Propan-1-ol, Methyl acetate, Propan-2-ol, Propionaldehyde, Dimethoxymethane, Acetone, Glycerol

C_4



2-methyl-1-propanol, Butan-1-ol, 2-butanol, Ethyl acetate, Butyraldehyde, 2-butanone, Methyl propionate

35 molecules identified

Gerakines et al., A&A, 1996, 312, 289

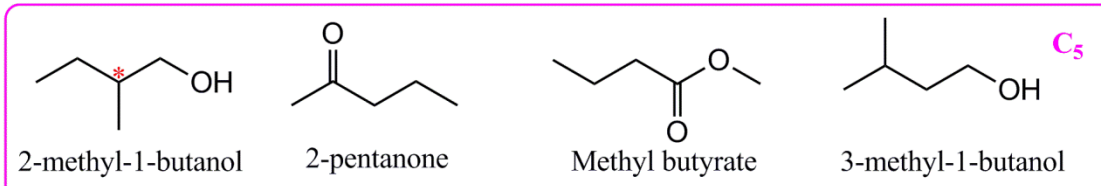
Oberg et al., A&A, 2009, 504, 891

Henderson et al., ApJ, 2015, 800, 66

Maity et al., PCCP, 2015, 17, 3081

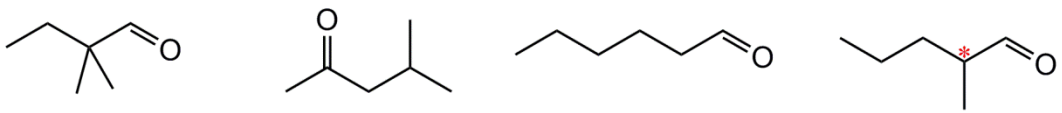
Kaiser, Angew. Chem., 2015, 54, 195

C_5



2-methyl-1-butanol, 2-pentanone, Methyl butyrate, 3-methyl-1-butanol, Pentanal, 3-methyl-2-butanol, 2-2-dimethyl propanol, 2-methyl butyraldehyde

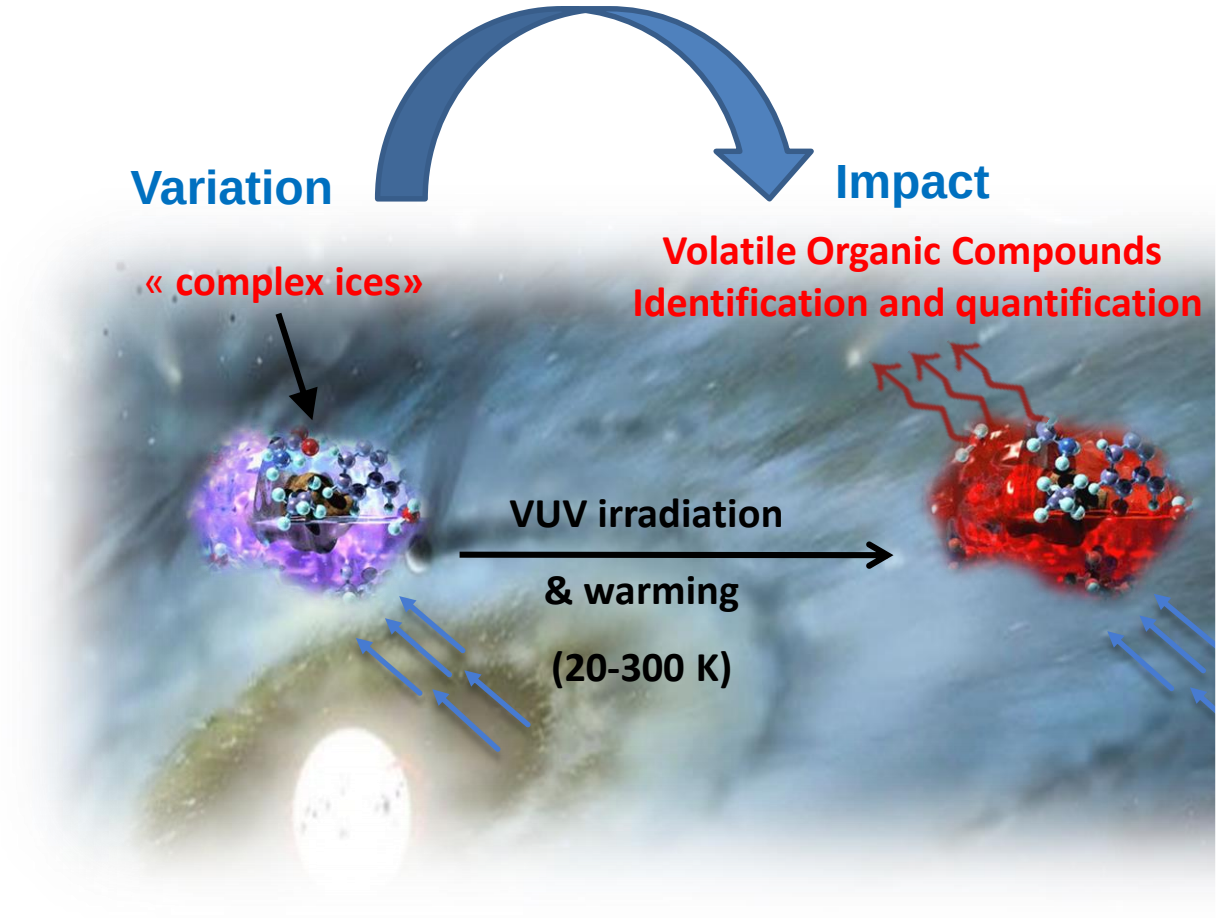
C_6



2,2-dimethyl butanal, 4-methyl-2-pentanone, Hexanal, 2-methyl pentanal

Abou Mrad et al., MNRAS, 2016, 458,1234

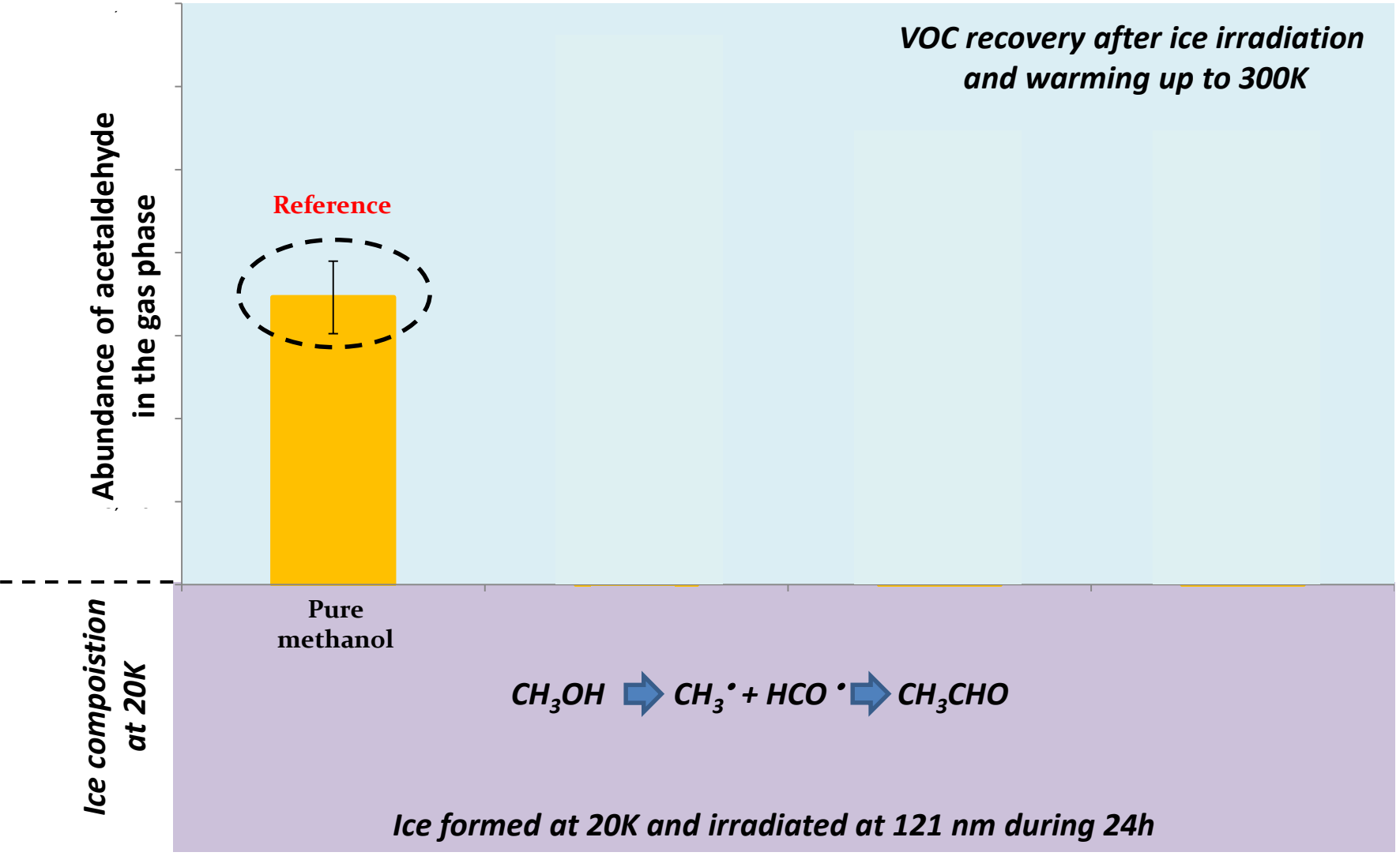
Complex ices
Impact of the ice composition on VOC abundances detected in the gas phase



Complex ices
Impact of the ice composition on VOC abundances detected in the gas phase

Abou Mrad et al., ApJ, 2017, 846, 124

VOC example: Acetaldehyde



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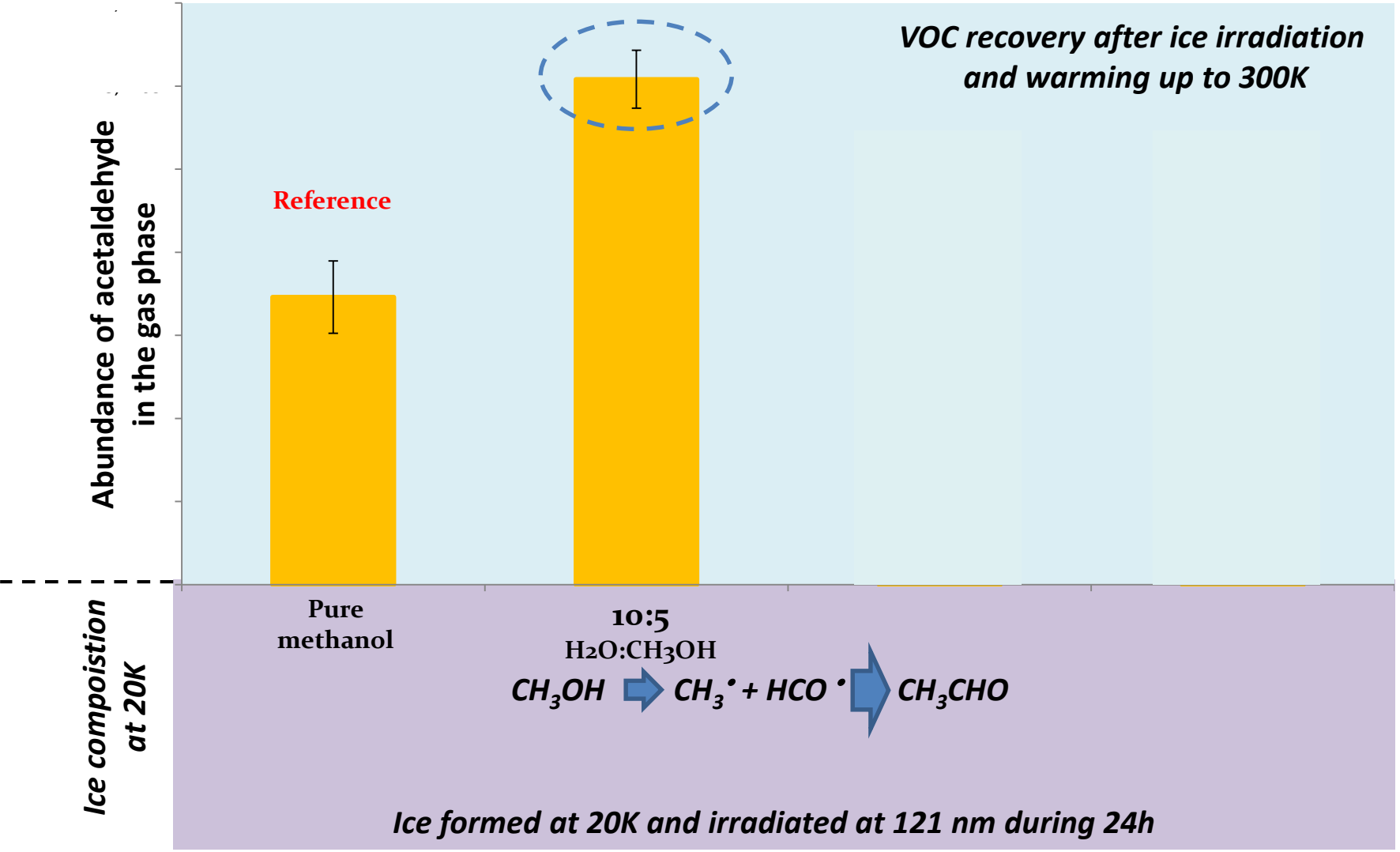

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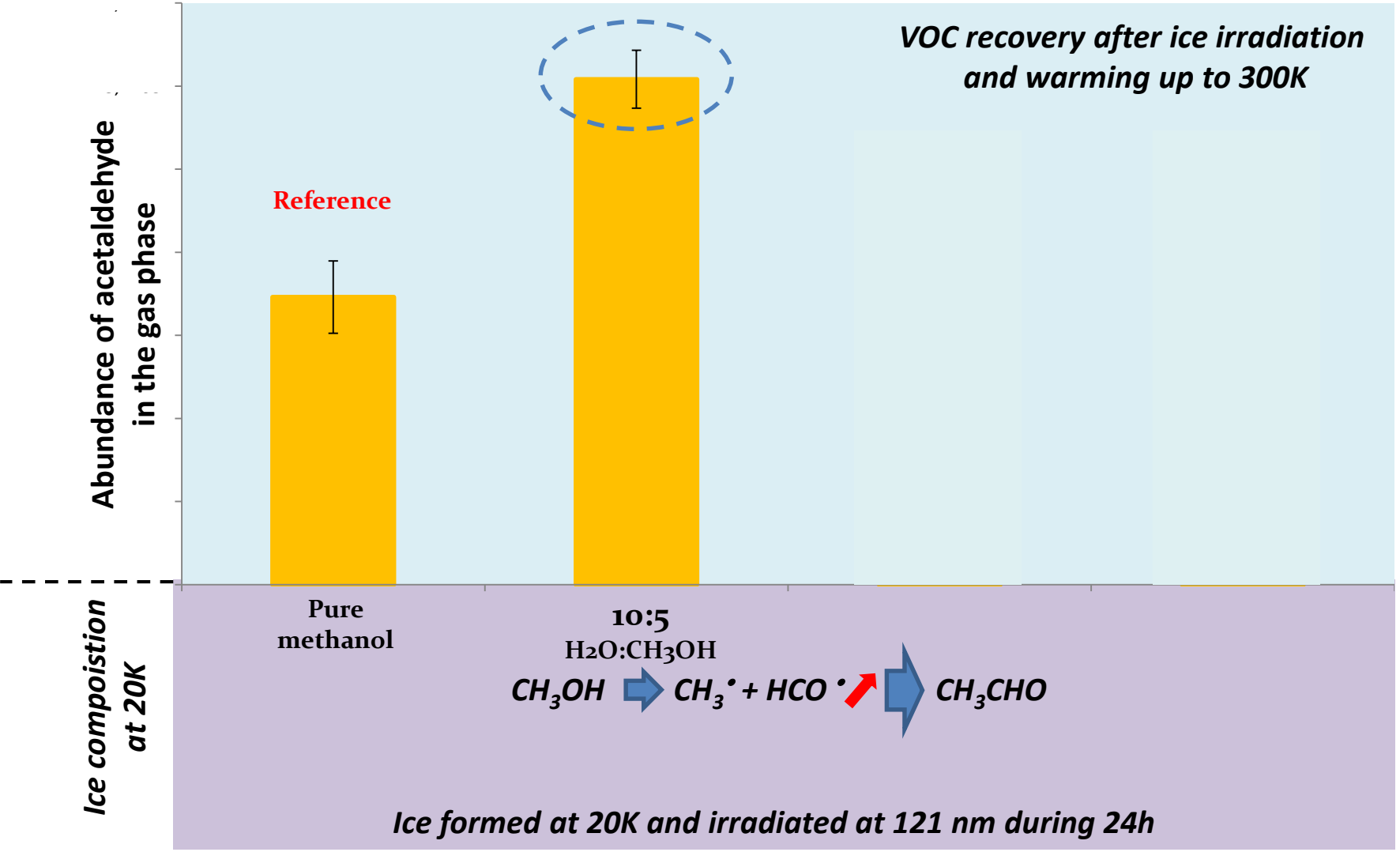

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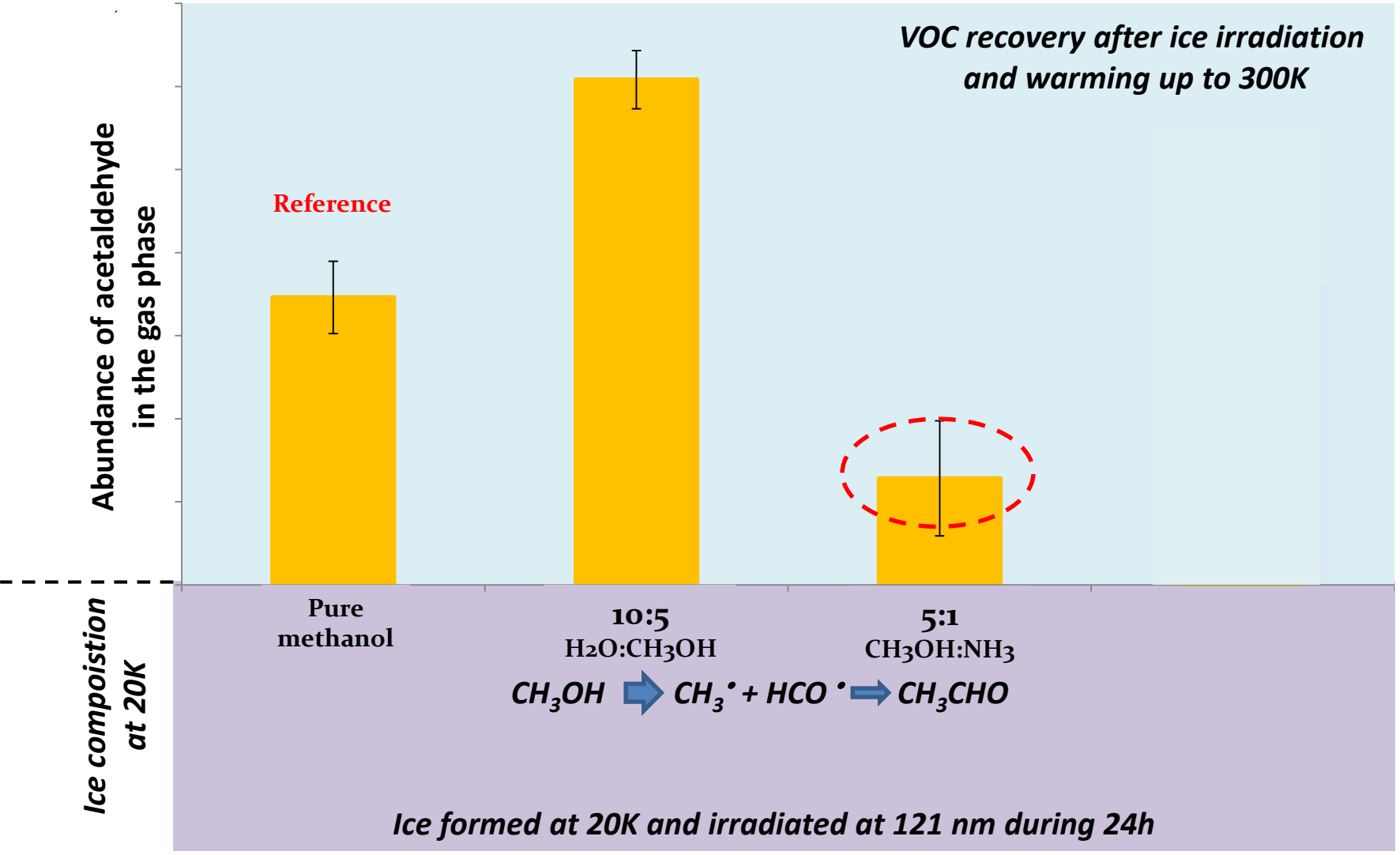

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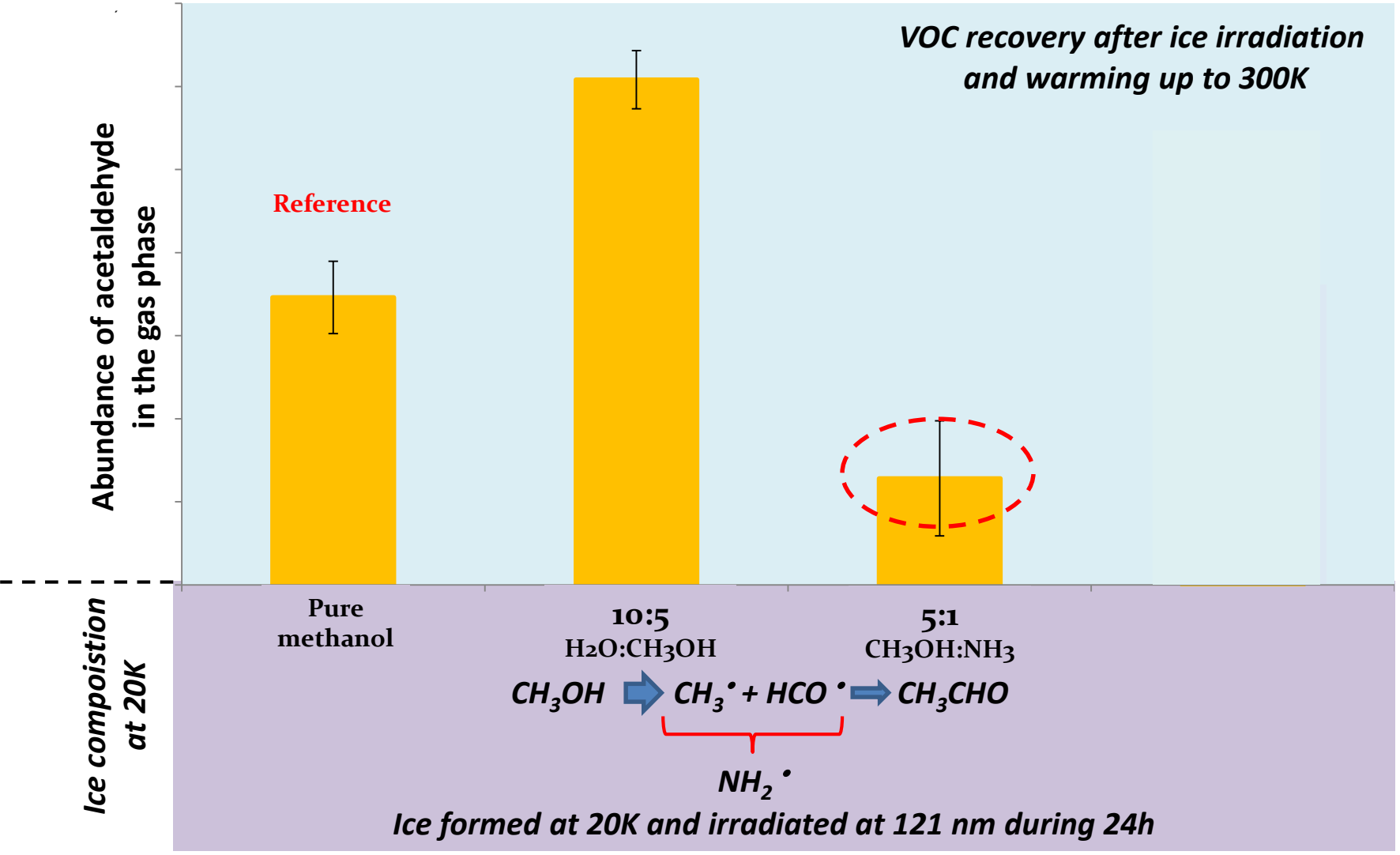

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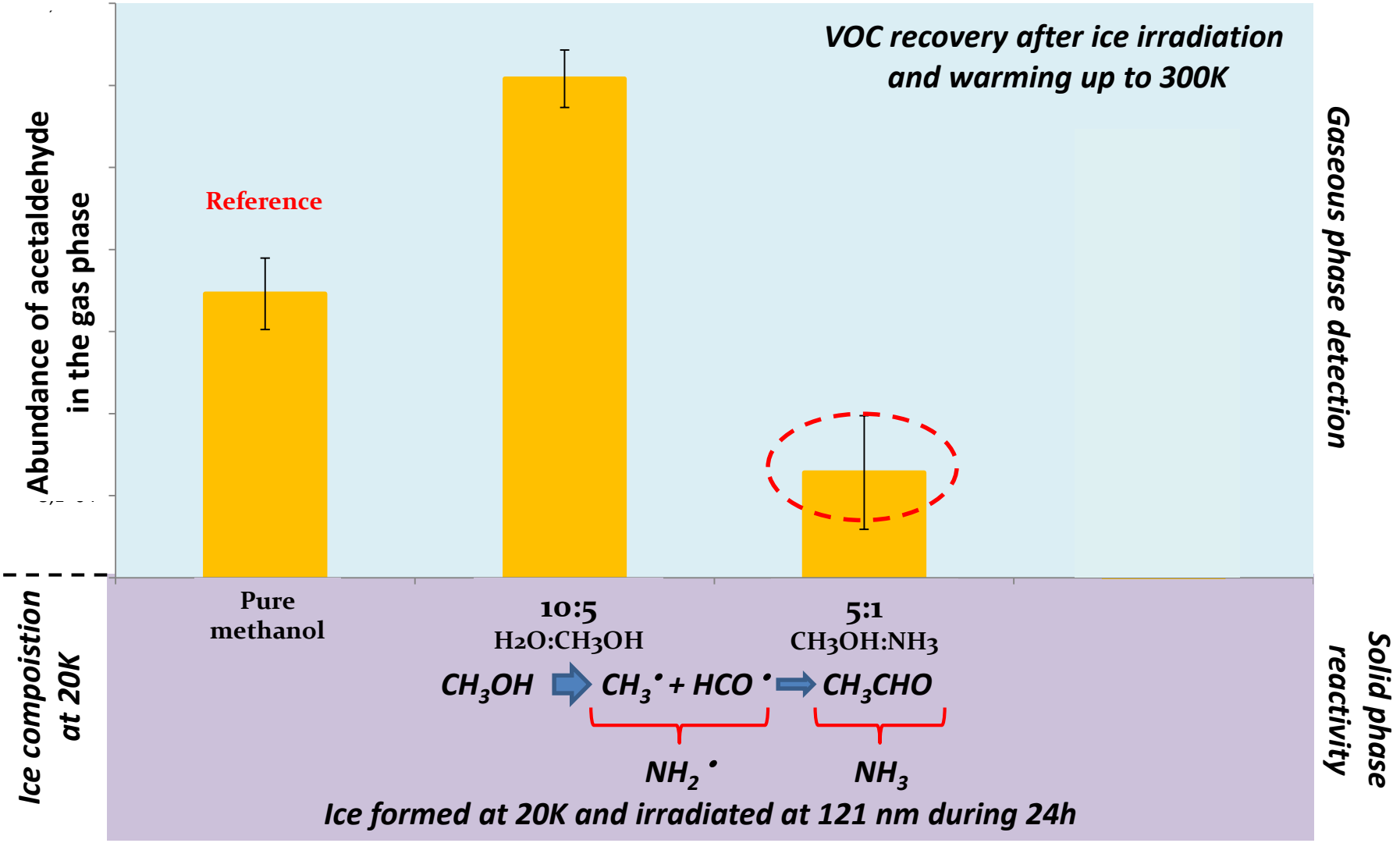

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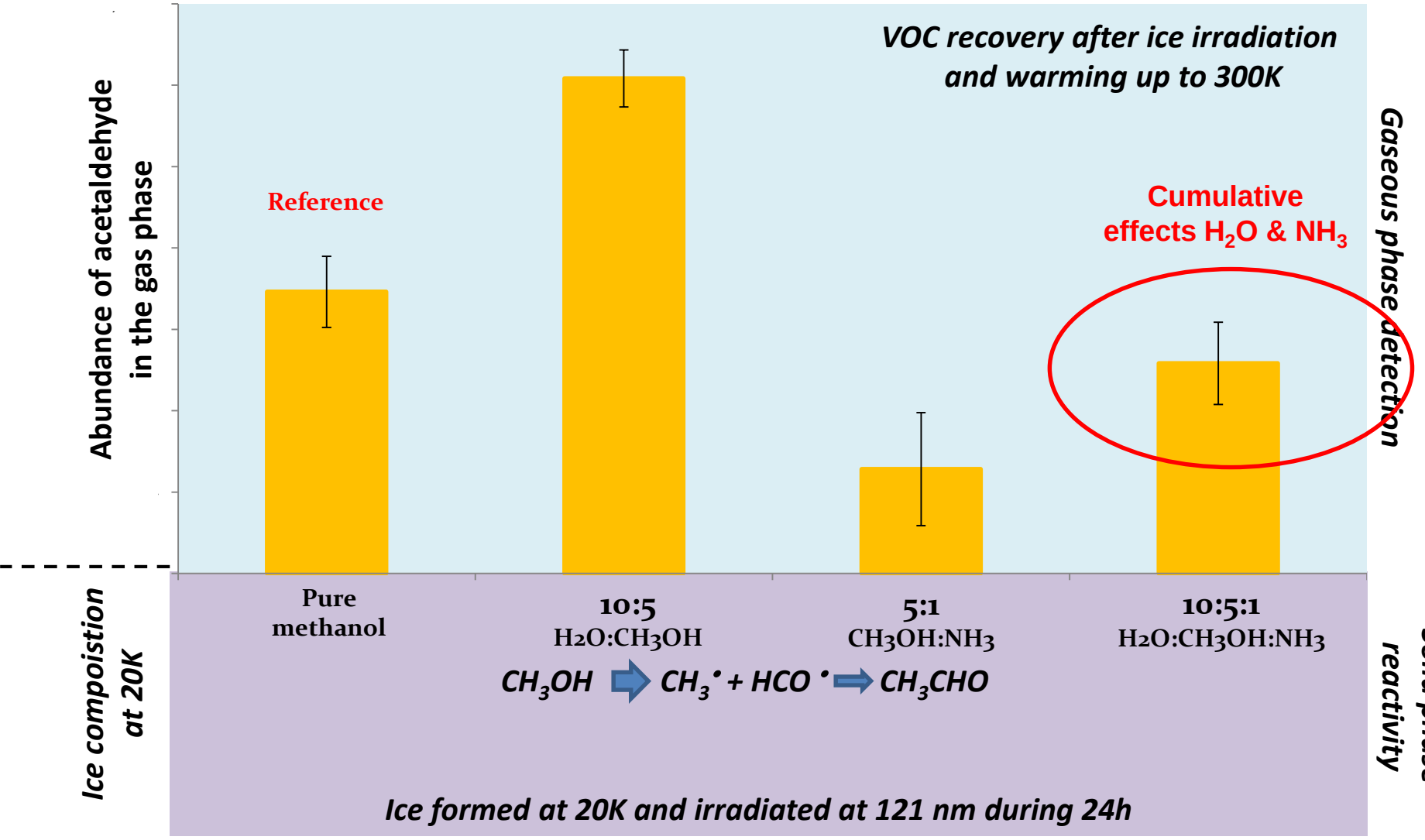
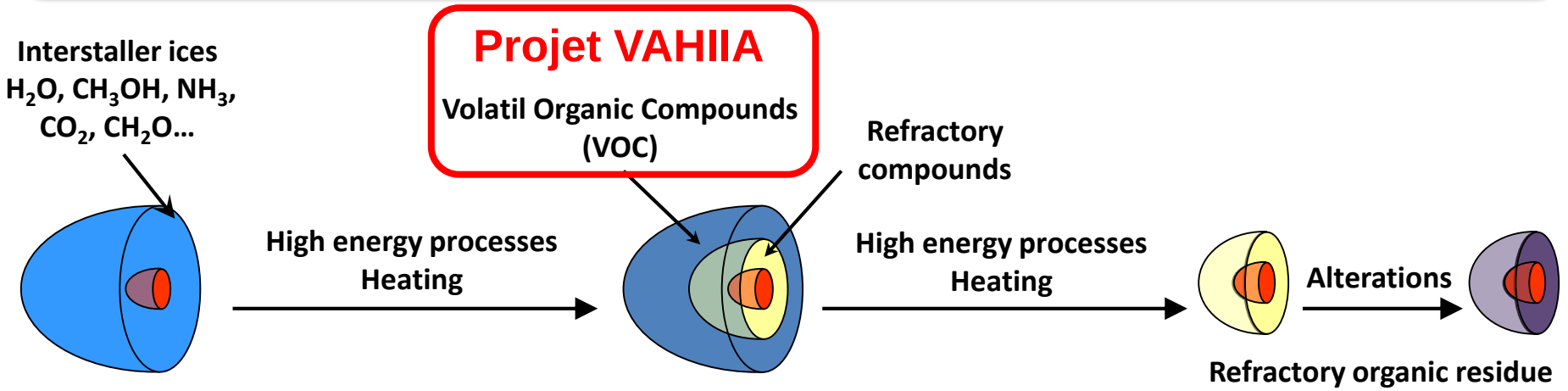


Evolution of interstellar icy grains
Toward the formation of complex organic matter in interplanetary bodies



Chemistry in diluted environment
20 K – 150 K

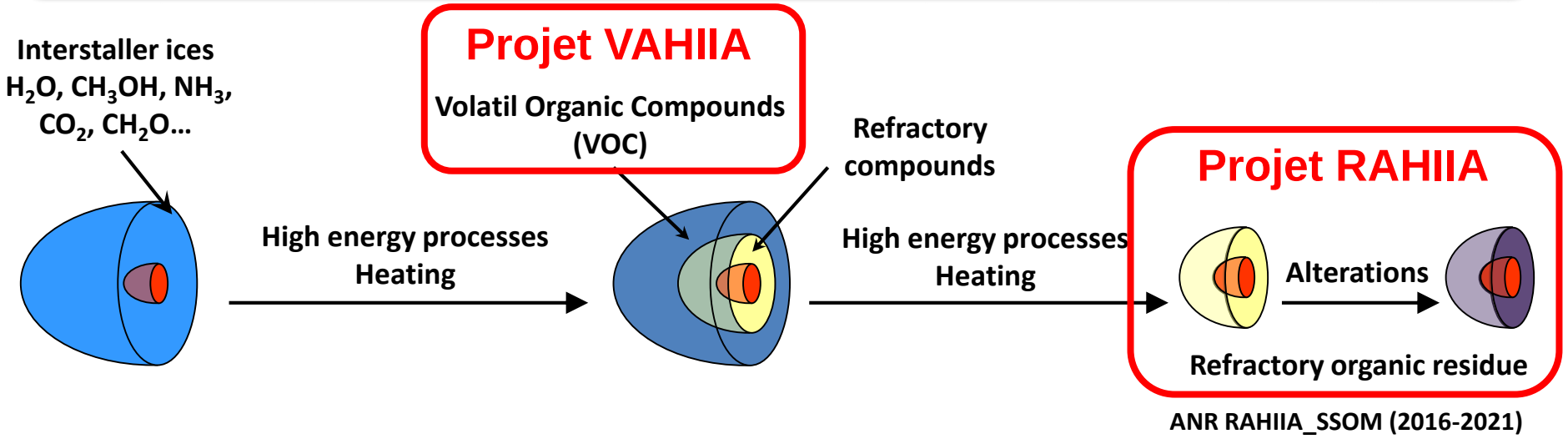
Radical and Thermal reactivities in water ice

Formation of small complex organic molecules

Water matrix restructuration and water desorption
150 K – 185 K

① Main desorption of VOCs

Evolution of interstellar icy grains
Toward the formation of complex organic matter in interplanetary bodies



ANR RAHIIA_SSOM (2016-2021)

Chemistry in diluted environment
20 K – 150 K

Radical and Thermal reactivities in water ice

Formation of small complex organic molecules

Water matrix restructuration and water desorption
150 K – 185 K

① Main desorption of VOCs

② Some VOCs trapped and react in the water matrix

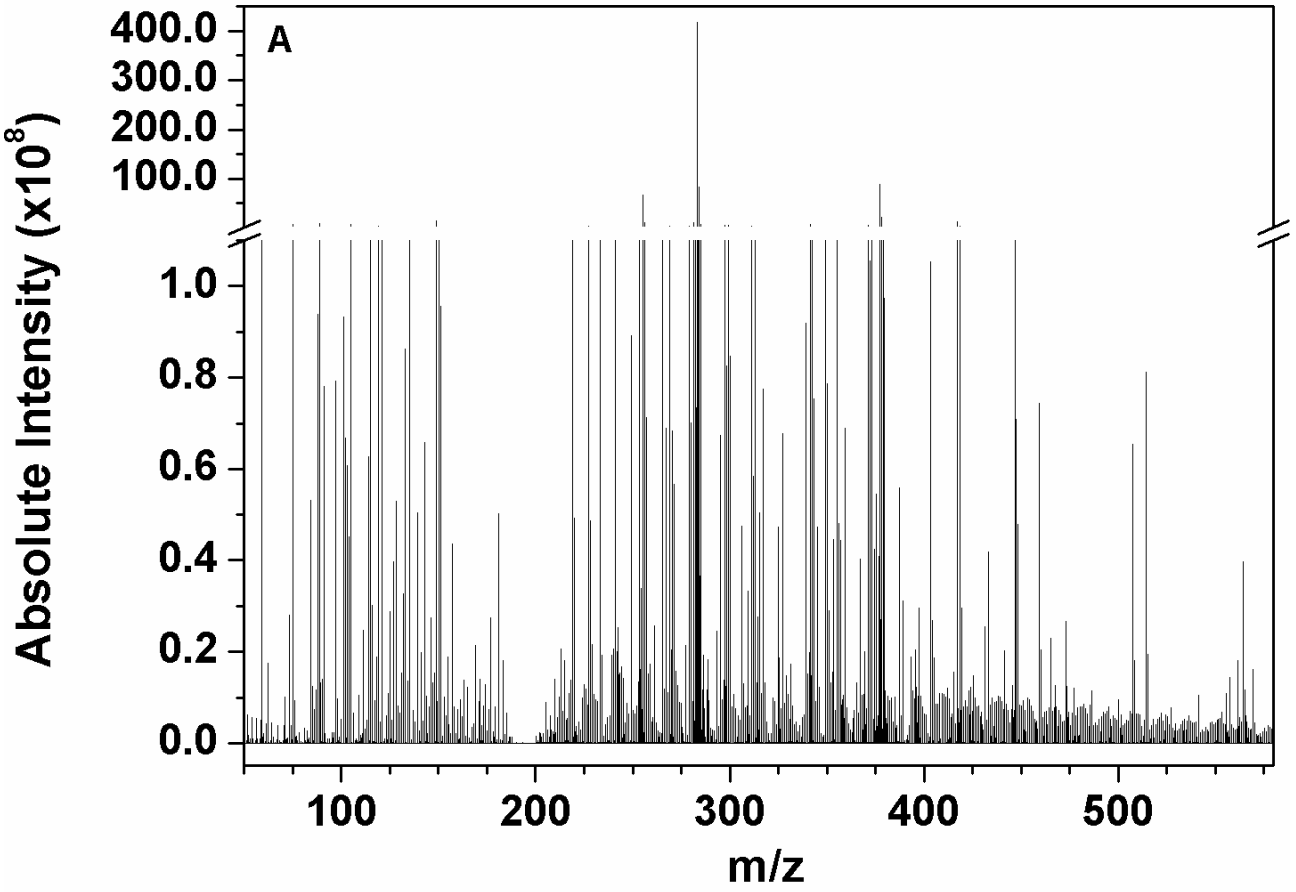
Chemistry in concentrated environment
> 185 K

Reactivity in absence of water

Formation of « macromolecules »

VHRMS (orbitrap) analyses of organic residues ($H_2O/NH_3/CH_3OH$ =3/1/1)

Collaboration with R. Thissen (IPAG, Grenoble, France) and P. de Marcellus, L. d'Hendecourt (IAS, Paris, France)



Negative ESI mode = $[M-H]^-$ analysis

Molecules with proton donnor chemical functions (e.g. carboxylic acid –COOH)

Danger et al., 2013, Geochim.Cosmochim.Acta, 118 , 184/ Danger et al., 2016, Geochim.Cosmochim.Acta, 189 , 184

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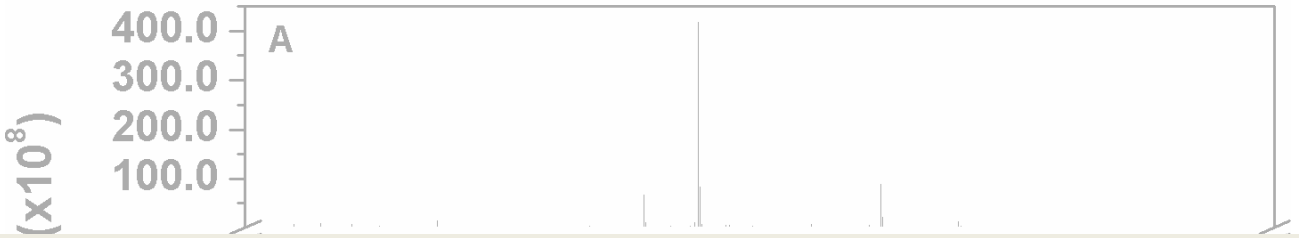


From an ice uniquely formed of H_2O:CH_3OH:NH_3
VUV + warming
=
Thousand of molecules with masses
up to 4,000 Da -> macromolecules
=
Complex and rich chemistry
=
Important molecular diversity

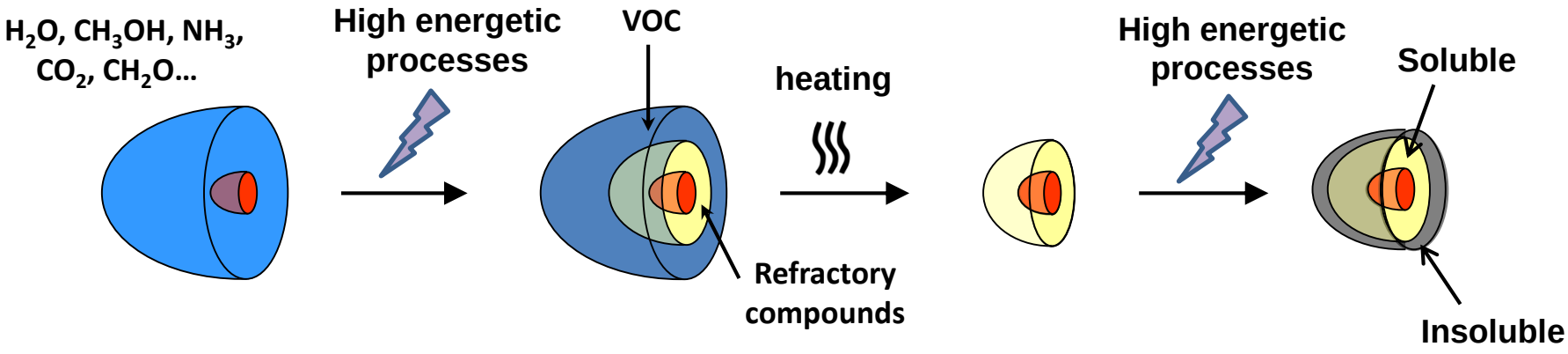
m/z

Negative ESI mode = $[M-H]^-$ analysis
Molecules with proton donnor chemical functions (e.g. carboxylic acid –COOH)

Danger et al., 2013, Geochim.Cosmochim.Acta, 118 , 184/ Danger et al., 2016, Geochim.Cosmochim.Acta, 189 , 184

Evolution of interstellar icy grains toward the formation of complex organic molecules in interplanetary objects

Primary processing



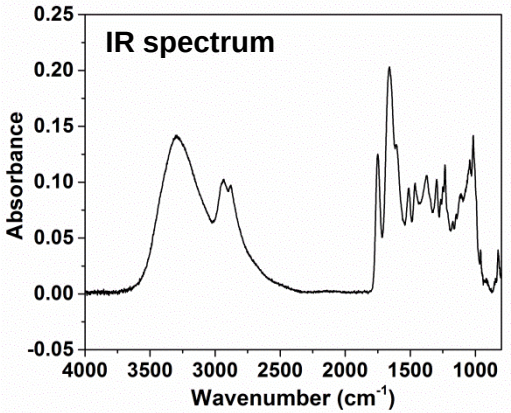
Evolution of interstellar ices: Formation of complex organic molecules

Collaboration with P. de Marcellus, L. d'Hendecourt and R. Brunetto (IAS, Paris, France)

A scenario from extraterrestrial ices to soluble and insoluble materials

Residue (soluble)

300 K



de Marcellus et al., 2017, MNRAS, 464, 114

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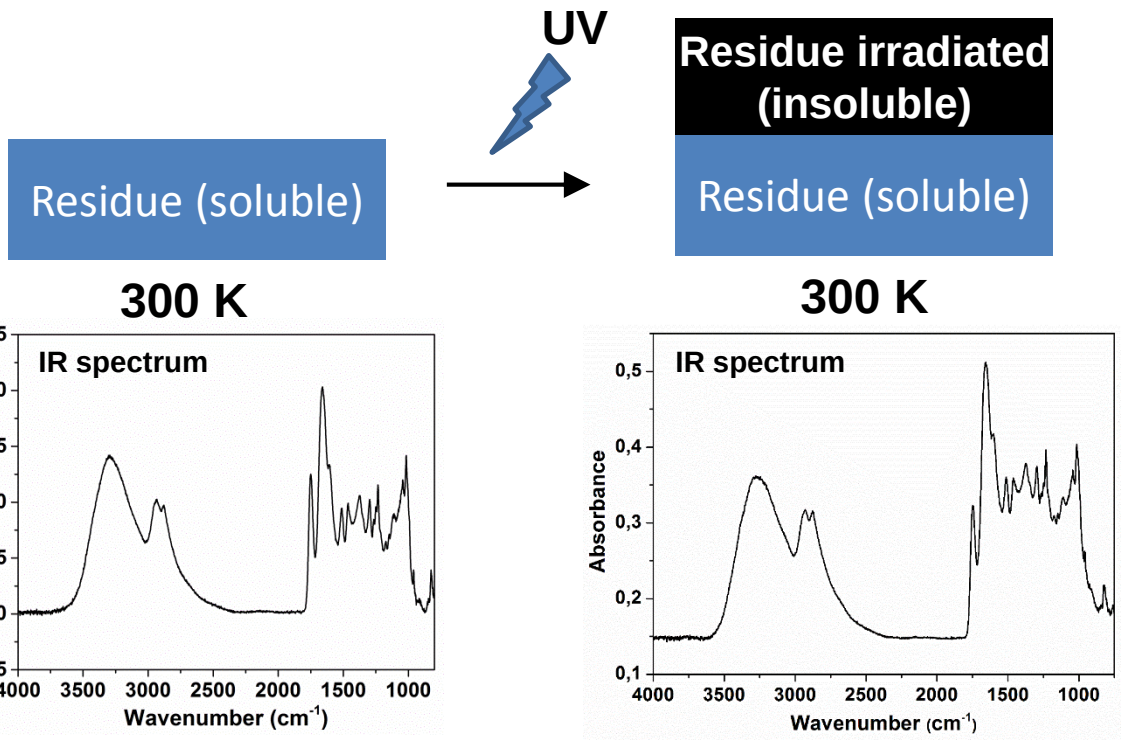

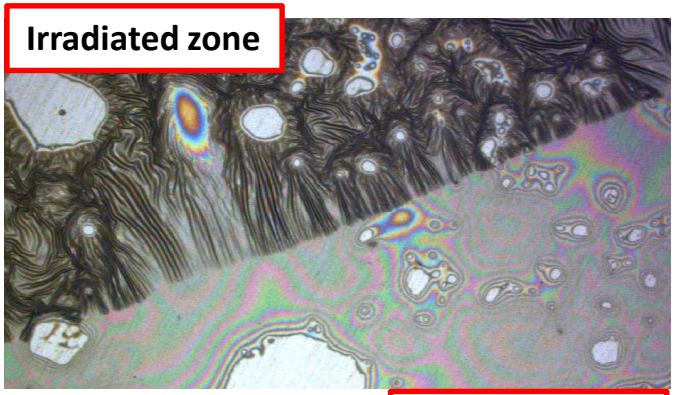

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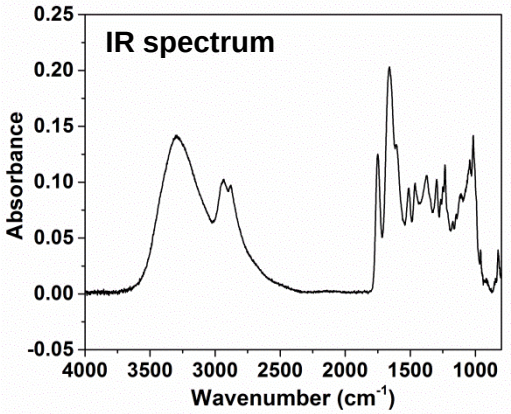
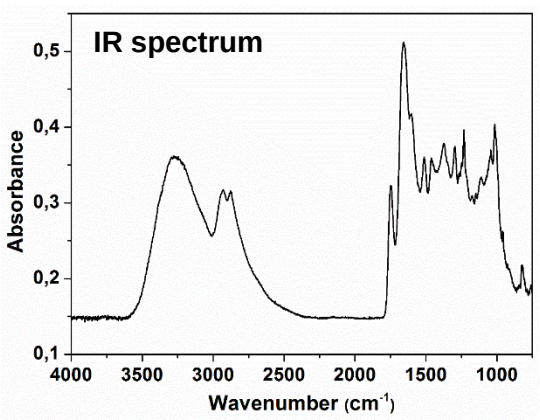
A scenario from extraterrestrial ices to soluble and insoluble materials

Residue (soluble) —UV→ Residue irradiated (insoluble) + Residue (soluble) —H_2O, 14h→ Irradiated residue (insoluble)

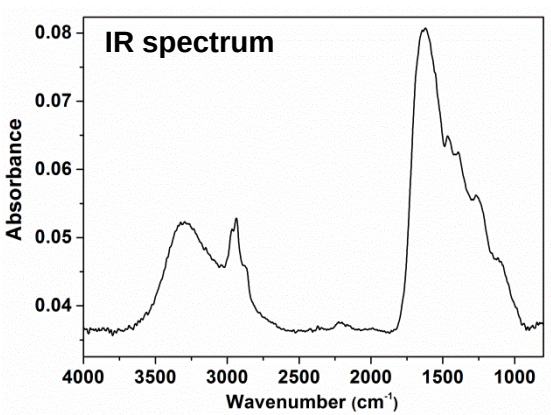
300 K

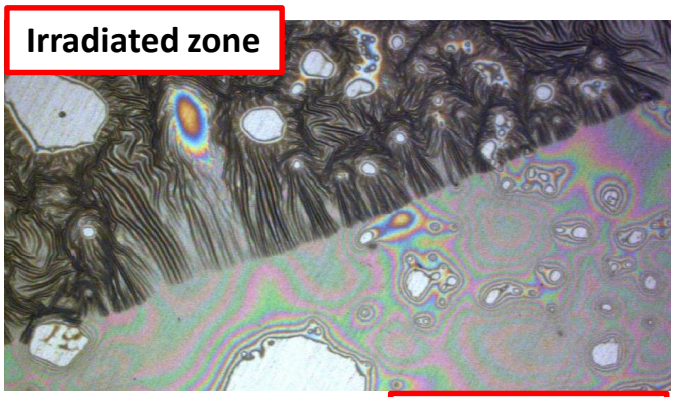


300 K



300 K

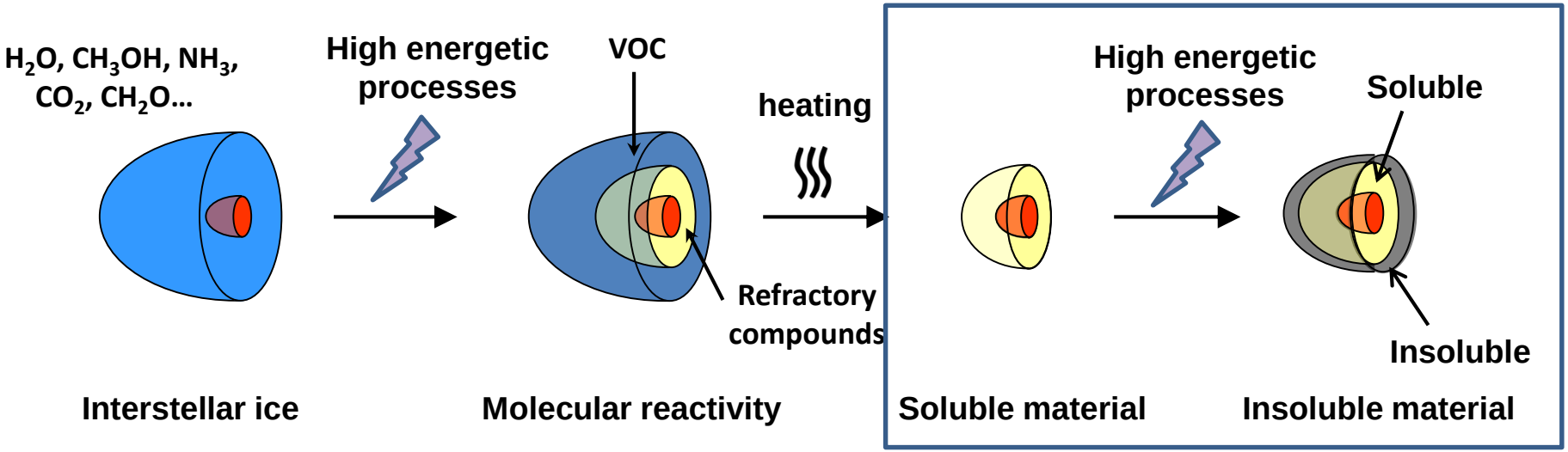




de Marcellus et al., 2017, MNRAS, 464, 114

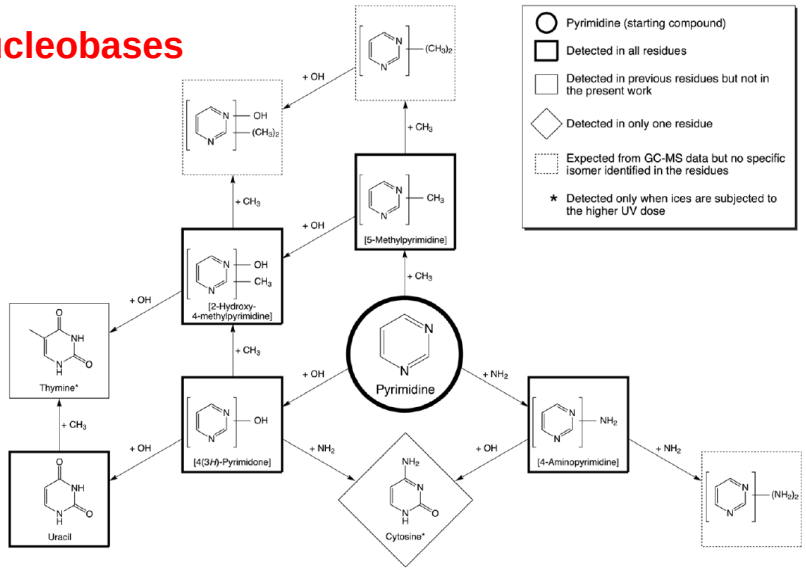
Evolution of interstellar icy grains toward the formation of complex organic molecules in interplanetary objects

Primary processing



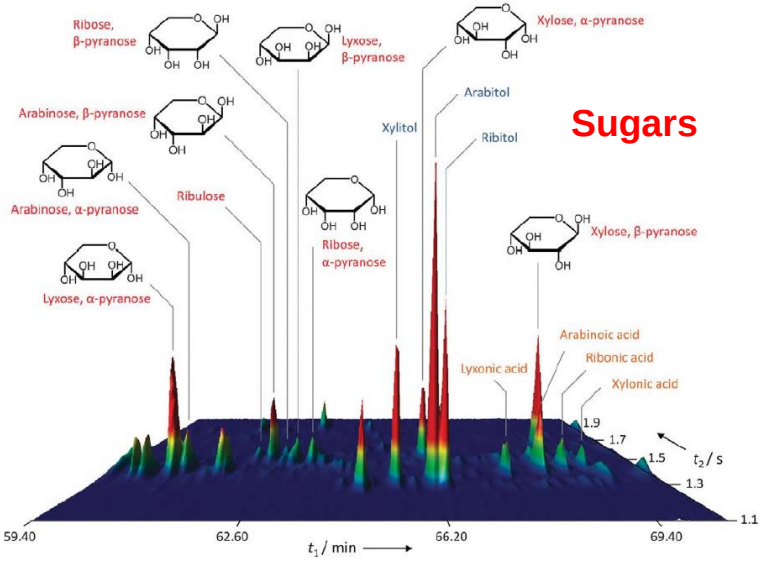
Evolution of interstellar icy grains toward the formation of molecules for prebiotic chemistry

Nucleobases



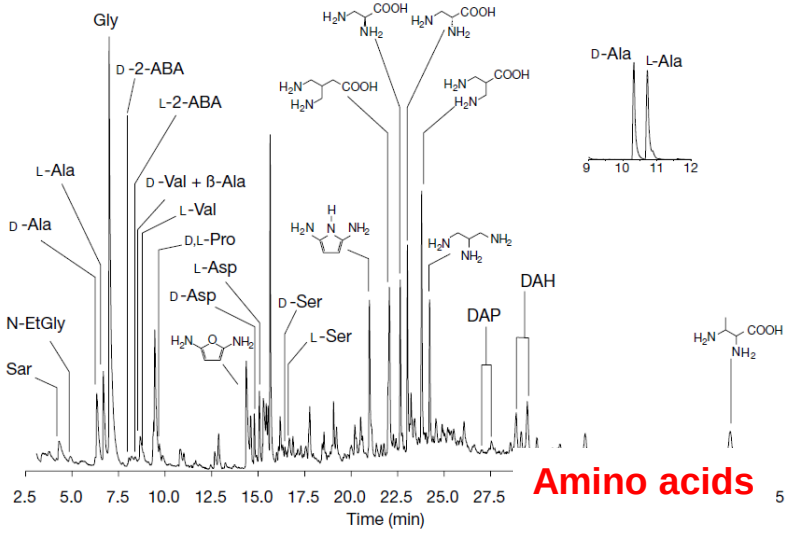
Nuevo et al., 2014, ApJ, 793,125

Sugars



Meinert et al., 2016, Science, 352,208

Amino acids



Munoz-Caro et al., 2002, Nature, 416, 403

Dipeptides

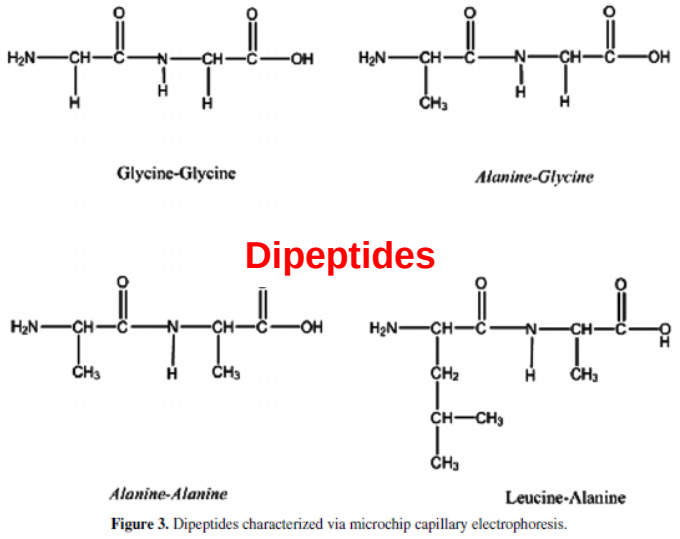


Figure 3. Dipeptides characterized via microchip capillary electrophoresis.

Kaiser et al., 2013, ApJ, 765, 111

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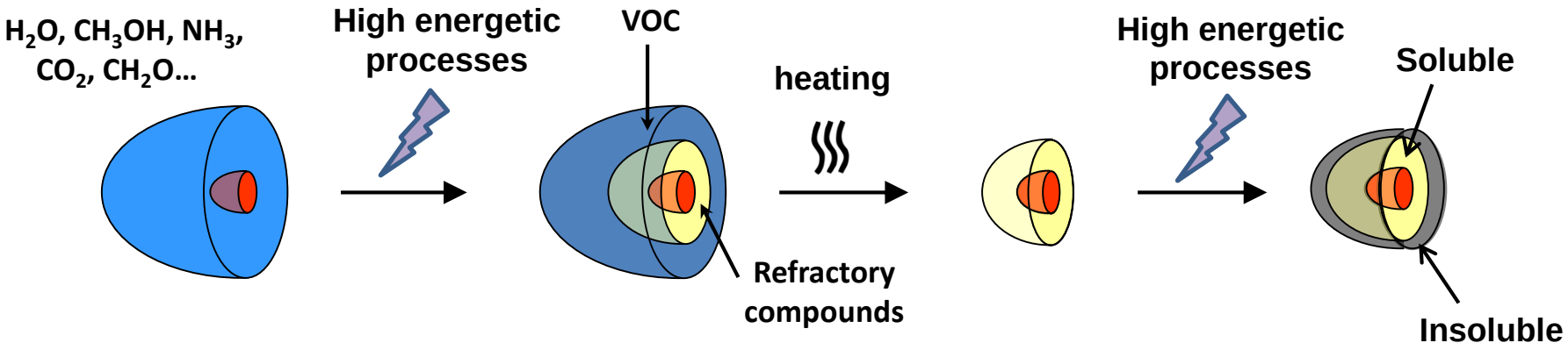
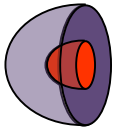
Primary processing



Formation of interplanetary bodies

Secondary processing



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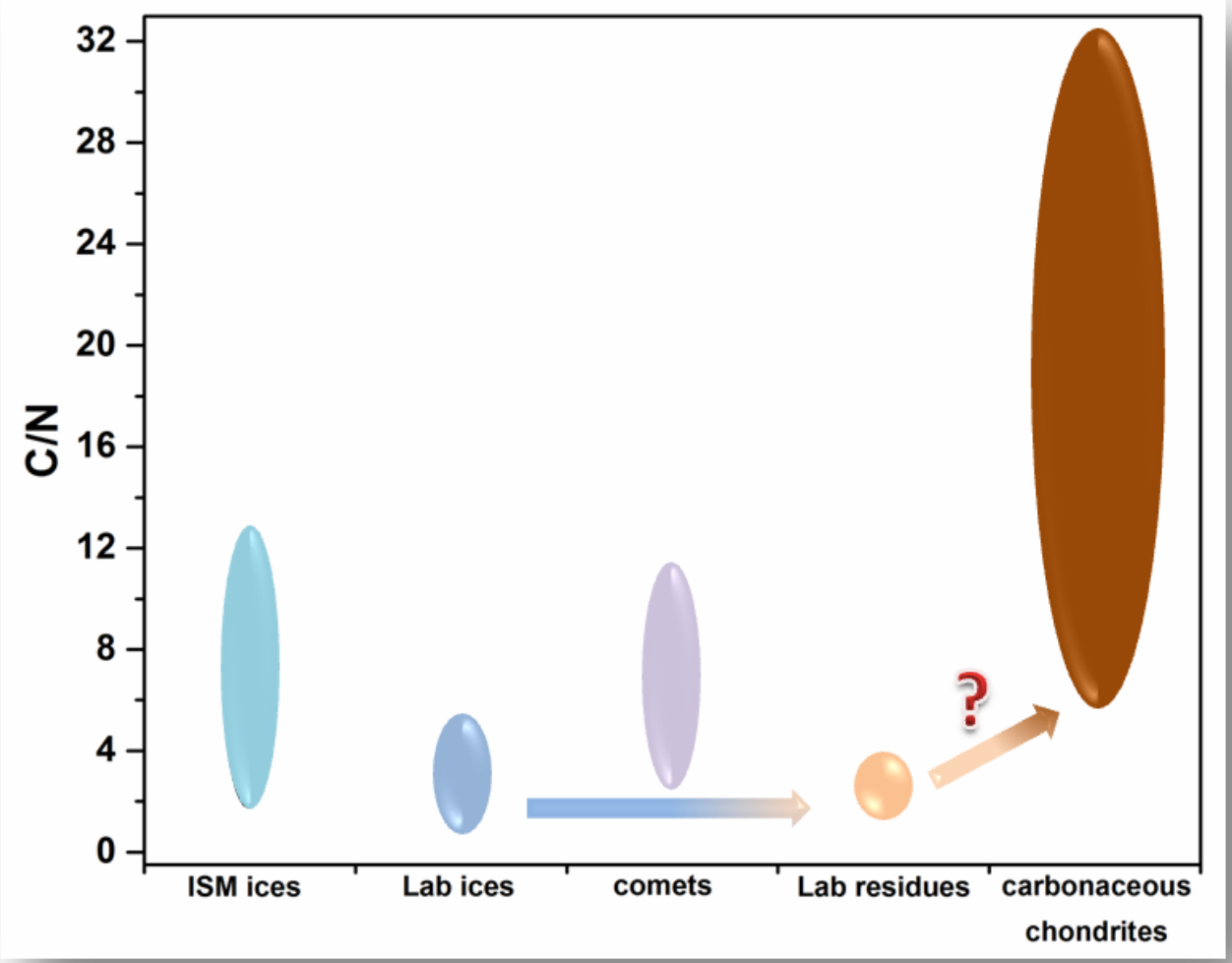
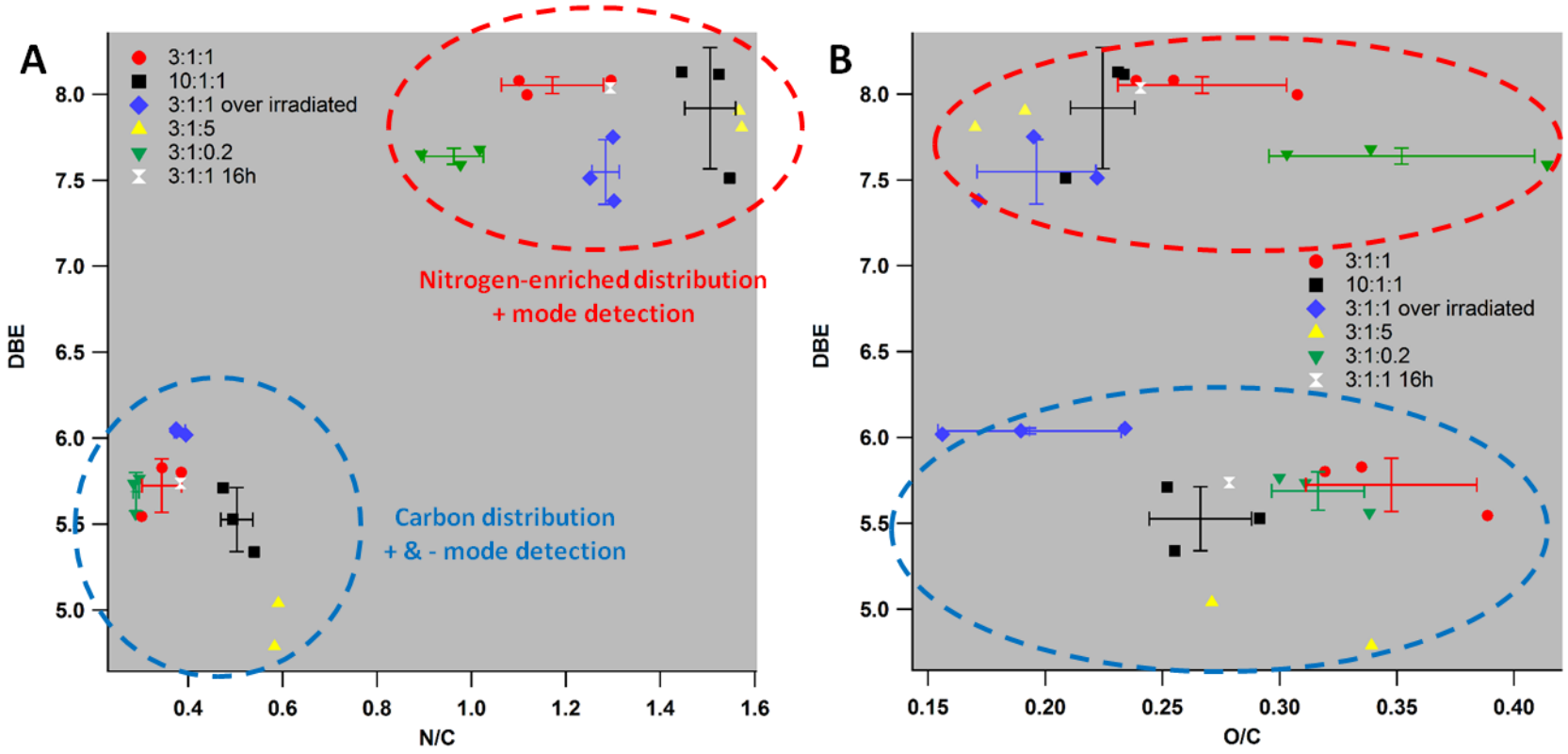


Bergin et al., 2015, PNAS, 112, 8965

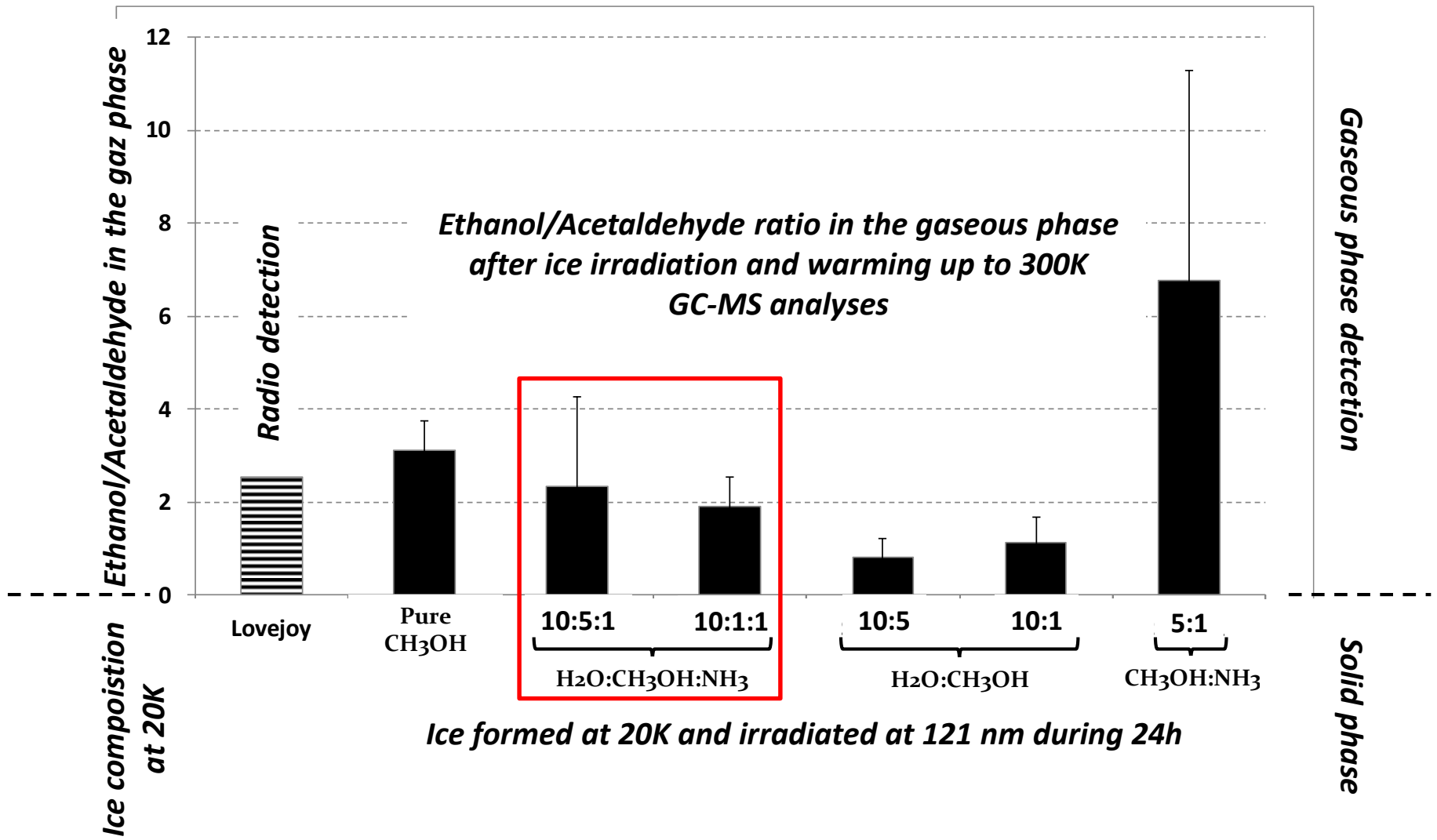
Fresneau et al., 2017, ApJ, 837, 168

Complex ices
Variability of residues

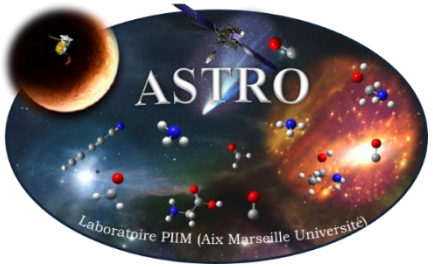


Fresneau et al., 2017, ApJ, 837, 168

Complex ices
Comparison to observations



Abou Mrad et al., ApJ, 2017, 846, 124



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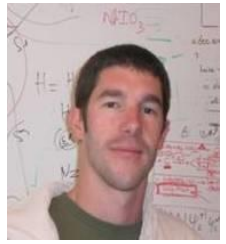
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