From Astrochemistry to Astrobiology?

A few selected papers on cosmic ices evolution

Louis L.S.d'Hendecourt[1,2]

[1]Team ASTRO-PIIM, [2]CNRS, Aix Marseille Université, France

2/6 Sept. 2019

Model Calculations of the Molecular Composition of Interstellar Grain Mantles

A. G. G. M. Tielens* and W. Hagen**
Laboratory Astrophysics Group, Rijksuniversiteit, 2300 RA Leiden, The Netherlands

Received February 1, accepted May 19, 1982

AGAIN!

Time dependent chemistry in dense molecular clouds

I. Grain surface reactions, gas/grain interactions and infrared spectroscopy

L.B. d'Hendecourt [1,2], L.J. Allamandola [1,3], and J.M. Greenberg [1]

[1] Laboratory Astrophysics, Huygens Laboratorium, Wassenaarseweg 78, NL-2300 RA Leiden, The Netherlands
[2] Groupe de Physique des Solides de l'ENS, T23, 4 Place Jussieu, F-75251 Paris Cedex 05, France
[3] NRC Senior Associate, NASA Ames Research Center, Mail Stop 245/6, Moffett Field, CA 94035, USA

Received June 21, 1984; accepted May 21, 1985

Time-dependent chemistry in dense molecular clouds

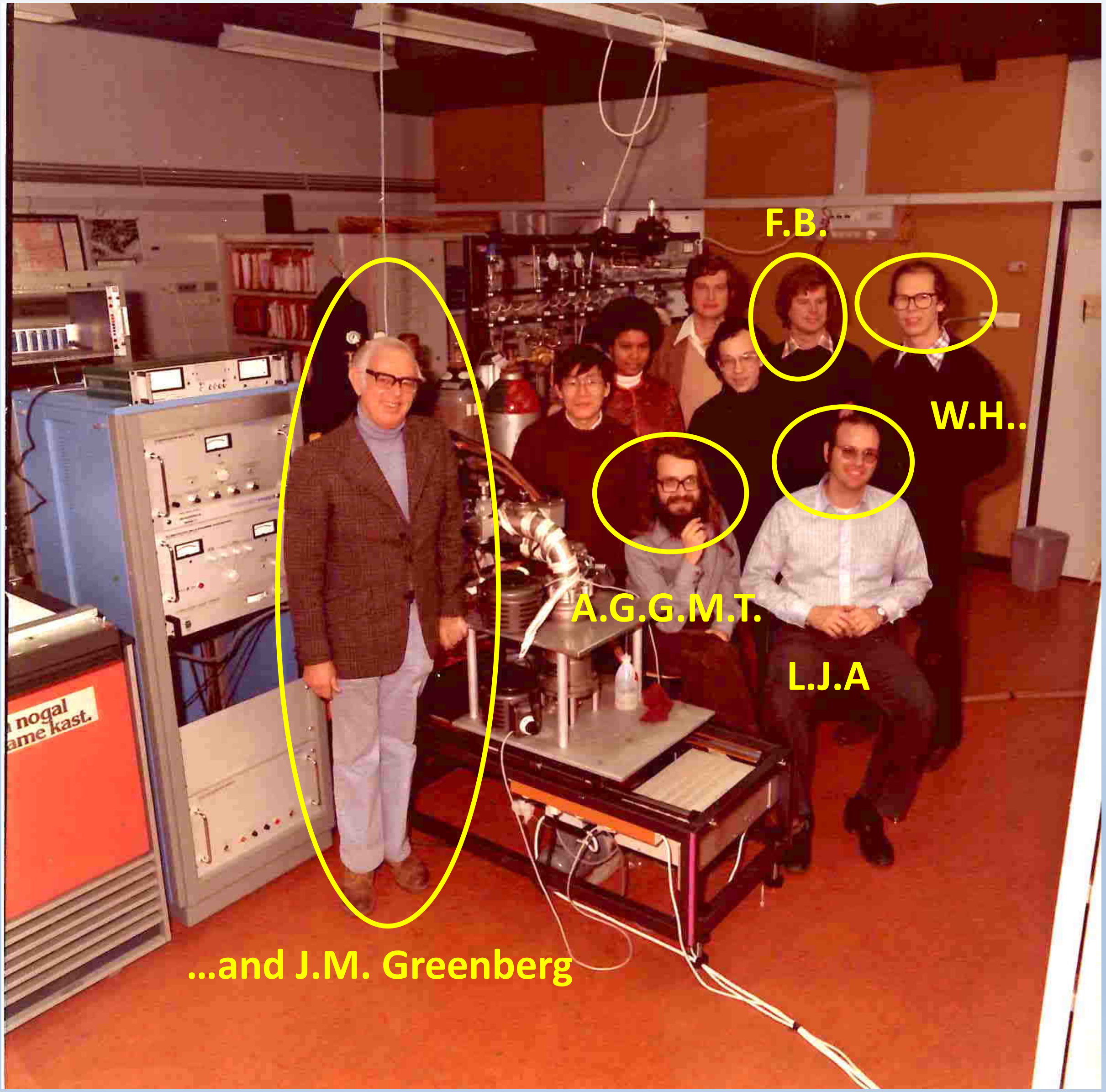
II. Ultraviolet photoprocessing and infrared spectroscopy of grain mantles

L.B. d'Hendecourt [1,2], L.J. Allamandola [1,3], R.J.A. Grim [1], and J.M. Greenberg [1]

[1] Laboratory Astrophysics, Huygens Laboratorium, Wassenaarseweg 78, NL-2300 RA Leiden, The Netherlands
[2] Groupe de Physique des Solides de l'E.N.S., T23, 4 Place Jussieu, F-75251 Paris Cedex 05, France
[3] NRC Senior Research Associate, NASA Ames Research Center, Mail Stop 245/6, Moffett Field CA 94035, USA

Received May 17, accepted September 16, 1985

Revisiting History? the Greenberg's group (1977)



Courtesy Lou Allamandola (08/2019)

From Astrochemistry to Astrobiology?

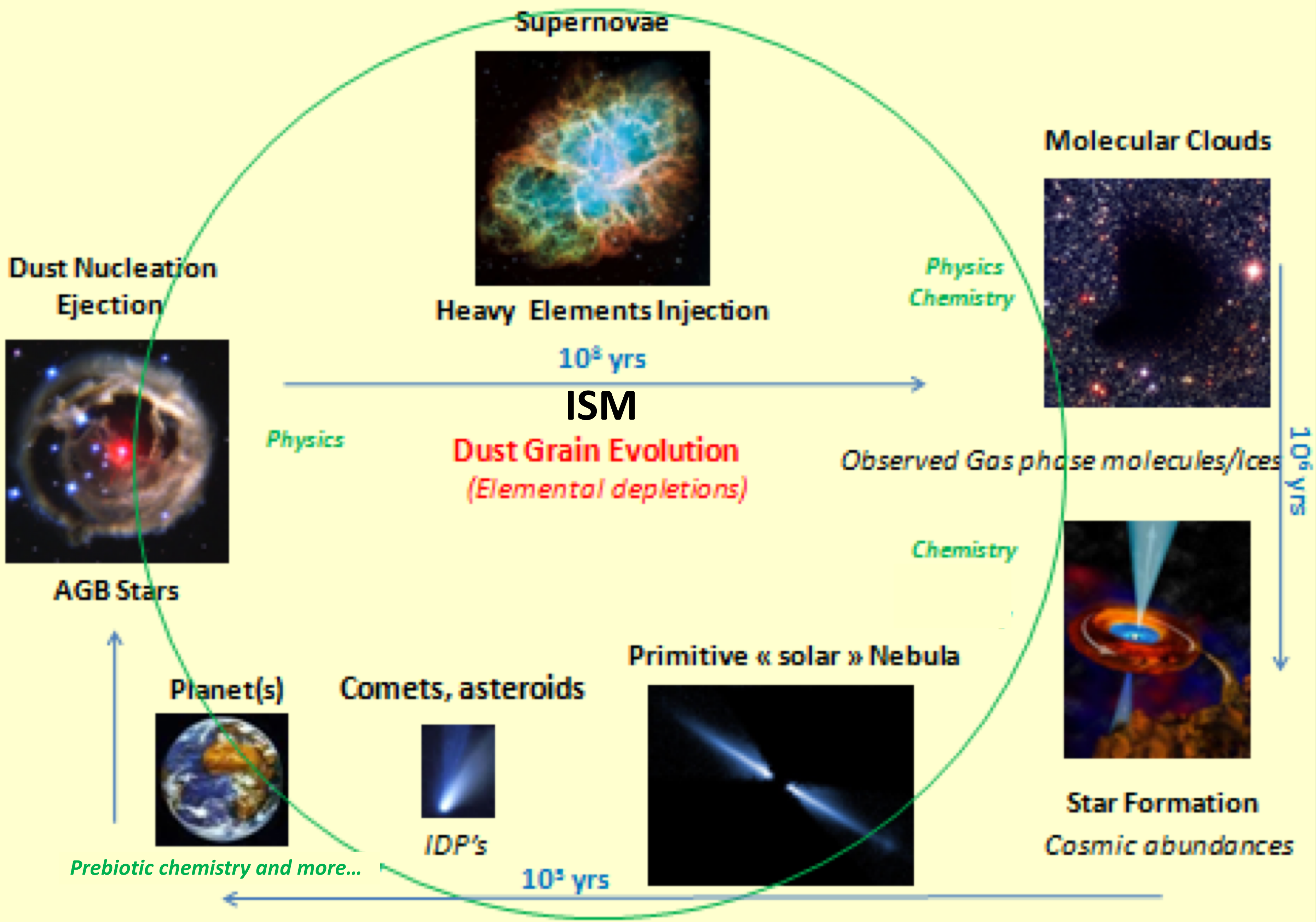
A few selected papers on cosmic ices evolution

Louis L.S.d'Hendecourt[1,2]

[1]Team ASTRO-PIIM, [2]CNRS, Aix Marseille Université, France

2/6 Sept. 2019

THE CYCLE OF SOLID STATE MATTER IN THE GALAXY



Molecules detected in the ISM gas (2010)

2 atomes	3 atomes	4 atomes	5 atomes	6 atomes	7 atomes	8 atomes	9 atomes	10 à 13 atomes
H_2	H_2O	NH_3	CH_4	CH_3OH	CH_2CHOH	H_2C_6	$(CH_3)_2O$	$(CH_3)_2CO$
CO	H_2S	H_2CO	SiH_4	CH_3SH	c-C_2H_4O	$HCOOCH_3$	CH_3CH_2CN	$HOCH_2CH_2OH$
CSi	HCN	H_2CS	CH_2NH	C_2H_4	$HCOCH_3$	CH_2OHCHO	CH_3CH_2OH	CH_3CH_2CHO
CP	HNC	C_2H_2	NH_2CN	H_2C_4	CH_3CCH	CH_3C_3N	CH_3C_4H	CH_3C_5N
CS	CO_2	HNCO	CH_2CO	CH_3CN	CH_3NH_2	CH_3COOH	HC_7N	HC_9N
NO	SO_2	HNCS	HCOOH	CH_3NC	CH_2CHCN	CH_2CHCHO	C_8H	CH_3C_6H
NS	MgCN	H_3O^+	HC_3N	NH_2CHO	HC_5N	CH_2CCHCN	C_8H^-	C_2H_5OCHO
SO	MgNC	SiC_3	HC_2NC	HC_2CHO	C_6H	C_7H	CH_3CONH_2	C_6H_6
HCl	NaCN	C_3S	c-C_3H_2	HC_3NH^+	C_6H^-	NH_2CH_2CN	CH_2CHCH_3	C_3H_7CN
NaCl	N_2O	H_2CN	l-C_3H_2	HC_4N				$HC_{11}N$
KCl	NH_2	c-C_3H	CH_2CN	C_5N				
AlCl	OCS	l-C_3H	H_2COH^+	C_5H				
AlF	CH_2	HCCN	C_4Si	H_2C_4				
PN	HCO	CH_3	C_5	C_5N^-				
SiN	C_3	C_2CN	HNC_3	c-H_2C_3O				
SiO	C_2H	C_3O	C_4H					
SiS	C_2O	$HCNH^+$	C_4H^-					
NH	C_2S	$HOCO^+$	CNCHO					
OH	AlNC	C_3N^-						
C_2	HNO	HCNO						
CN	SiCN	HSCN						
HF	N_2H^+							
FeO	SiNC							
LiH	c-SiC_2							
CH	HCO^+							
CH^+	HOC^+							
CO^+	HCS^+							
SO^+	H_3^+							
SH	OCN^-							
O_2	HCP							
N_2	CCP							
CF^+								
PO								
AlO								

Organic molecules dominate

Inorganic molecules with heavy atoms are mostly **« circumstellar »**

Grains as refractory **minerals**, covalent bonds, **out** of the gas phase and of chemistry **(surfaces)**

Limited complexity due to the nature of gas phase reactions as compared to solid phase ones

Fast decrease in abundances of large species

In an H-rich medium, atoms like O, C, N will easily make simple hydrides like H_2O, CH_4, NH_3 and **in presence of cold surfaces** give **ICES** **(Oort and van de Hulst, BAN, 1946)**

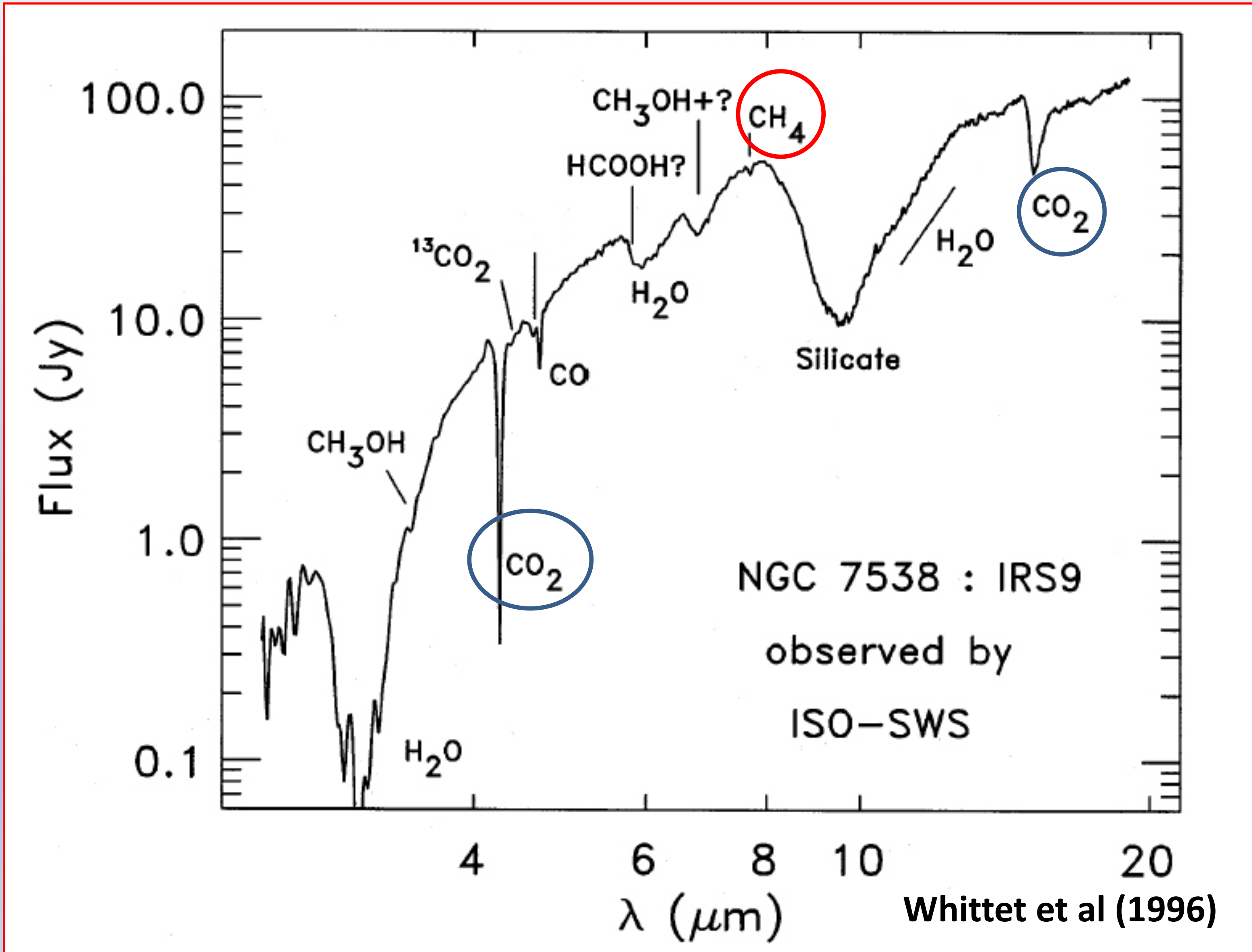
Interstellar Ices

Observed (much later!) toward embedded infrared souces (protostars) within collapsing molecular clouds, forming disks, stars, planets and debris (asteroids, comets,dust)

Gas phase ion-molecule reactions (and others) will provide for CO and its derivatives (HCO, H_2CO…) and go to **ICES**

Ices: the most abundant and universal molecular material

First detection for (solid) CH_4 and solid CO_2?



Whittet et al (1996)

although for CH_4…and for CO_2…

THE ASTROPHYSICAL JOURNAL, 376:556–560, 1991 August 1

DISCOVERY OF INTERSTELLAR METHANE: OBSERVATIONS OF GASEOUS AND SOLID CH_4 ABSORPTION TOWARD YOUNG STARS IN MOLECULAR CLOUDS

J. H. LACY,[1,5] J. S. CARR,[2,5] NEAL J. EVANS II,[1,5] F. BAAS,[3,5] J. M. ACHTERMANN,[1,5] AND J. F. ARENS[4]
Received 1990 November 26; accepted 1991 January 28

'…The total abundance (predominantly in the solid phase) is 1 to 4% of total CO (predominantly gaseous). This high fraction of CH_4 in the solid quggests that it Is made on the grains… ' (Oort and Van de Hulst hydrides)

The discovery of interstellar carbon dioxide

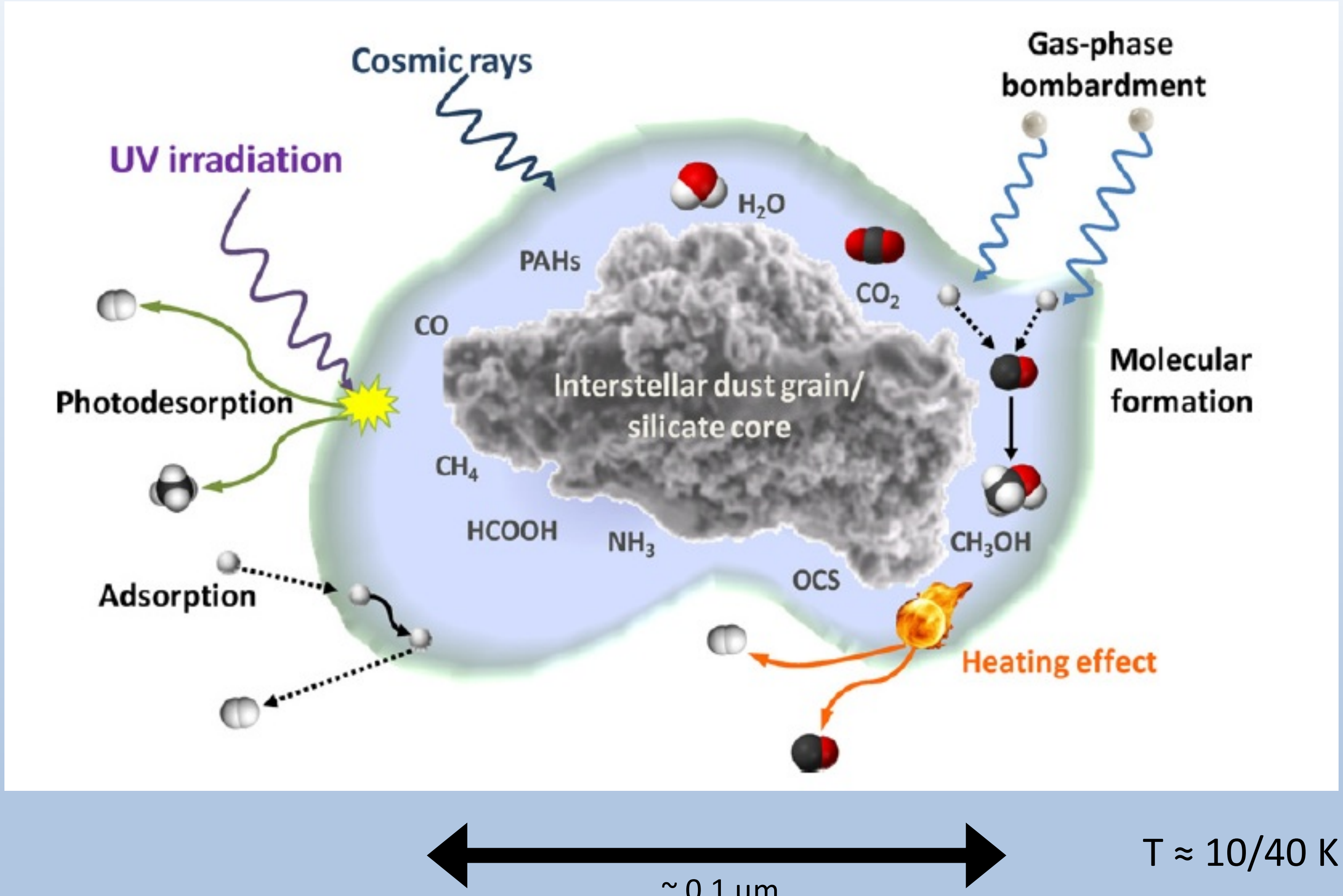
L.B. d'Hendecourt[1] and M. Jourdain de Muizon[2,3]

[1] Groupe de Physique des Solides, Université de Paris 7, Tour 23, 4 Place Jussieu, F–75251 Paris Cedex 05, France
[2] Sterrewacht Leiden, Postbus 9513, NL–2300 RA Leiden, The Netherlands
[3] Observatoire de Paris, Section de Meudon, F–92190 Meudon, France

Received July 25; accepted August 18, 1989

'…This detection of solid CO_2 is a confirmation of the presence of UV irradiation of these ices… '

Dust grain: a simple view



T ≈ 10/40 K

Adapted from **Greenberg's** model (1974) by Meinert et al., Phys Life Rev (2011)

→ Surface and **solid-state - bulk** chemistry

Organic Synthesis via Irradiation and Warming of Ice Grains in the Solar Nebula

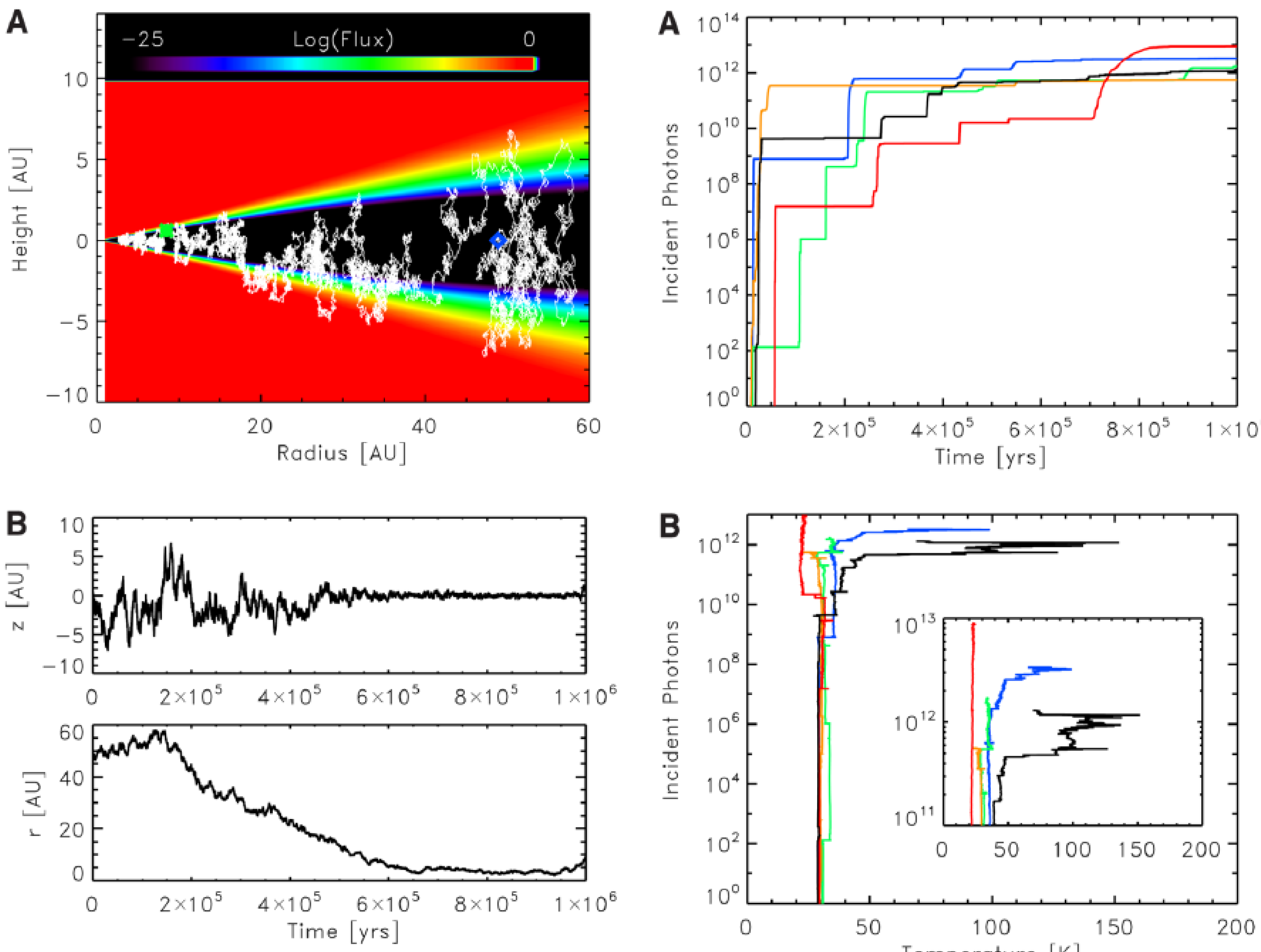
Fred J. Ciesla[1*] and Scott A. Sandford[2]

[1]Department of the Geophysical Sciences, University of Chicago, 5734 South Ellis Avenue, IL 60430, USA.
[2]NASA Ames Research Center, MS 245-6, Moffett Field, CA 94035, USA.

*To whom correspondence should be addressed. E-mail: fciesla@uchicago.edu

Complex organic compounds, including many important to life on Earth, are commonly found in meteoritic and cometary samples, though their origins remain a mystery. We examined whether such molecules could be produced within the solar nebula by tracking the dynamical evolution of ice grains in the nebula and recording the environments they were exposed to. We found that icy grains originating in the outer disk, where temperatures were <30 K, experienced UV irradiation exposures and thermal warming similar to that which has been shown to produce complex organics in laboratory experiments. These results imply that organic compounds are natural byproducts of protoplanetary disk evolution and should be important ingredients in the formation of all planetary systems, including our own.

Sciencexpress / http://www.sciencemag.org/content/early/recent / 29 March 2012 / Page 4/ 10.1126/science.1217291

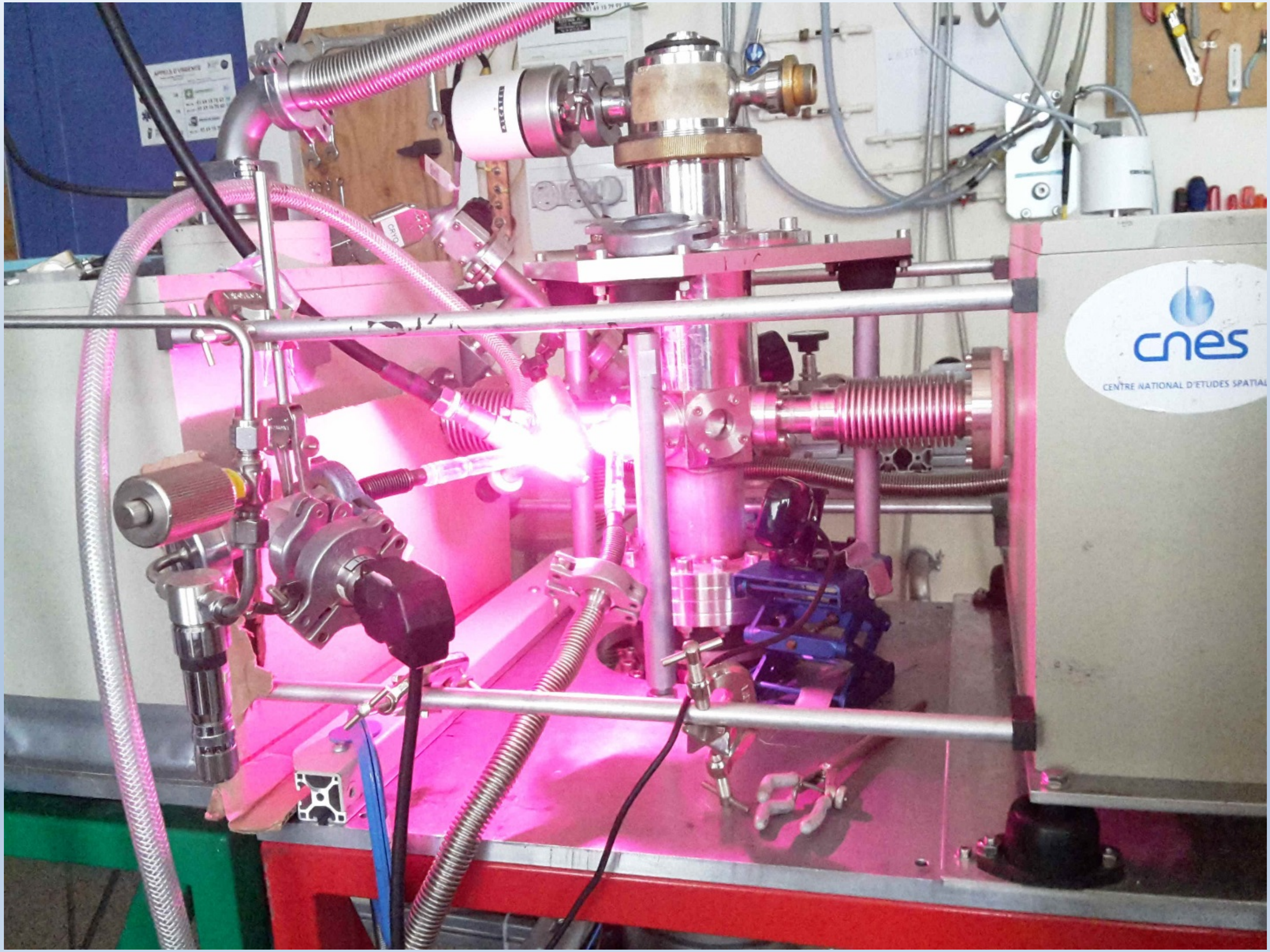


A
−25
Log(Flux)
0
Height [AU]
Radius [AU]
A
Incident Photons
Time [yrs]
B
z [AU]
r [AU]
Time [yrs]
B
Incident Photons
Temperature [K]

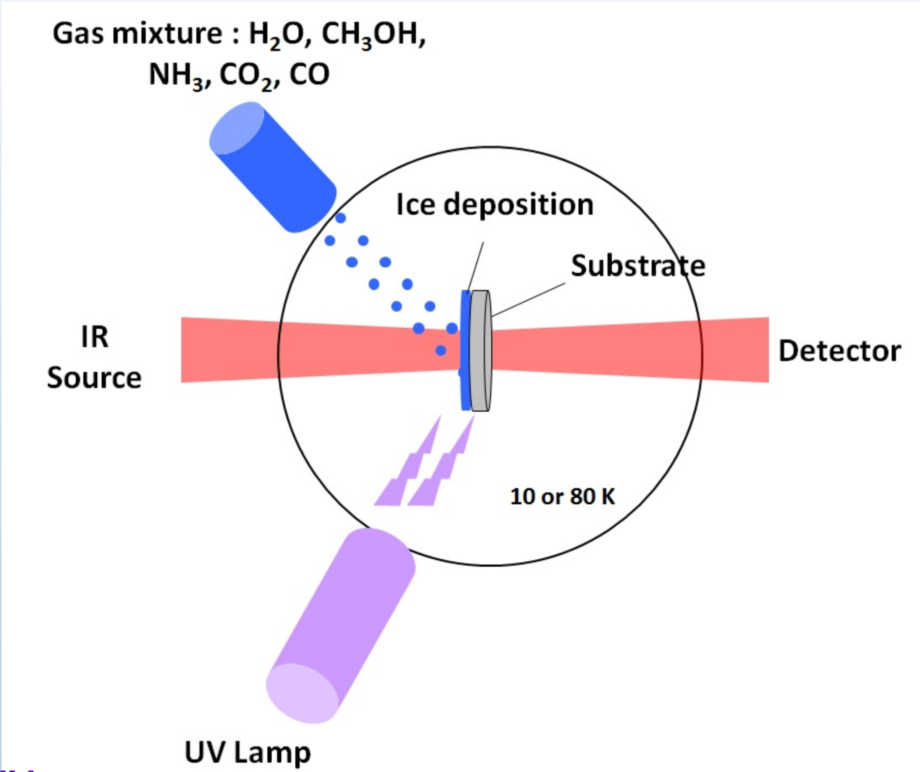

Labo


Astro

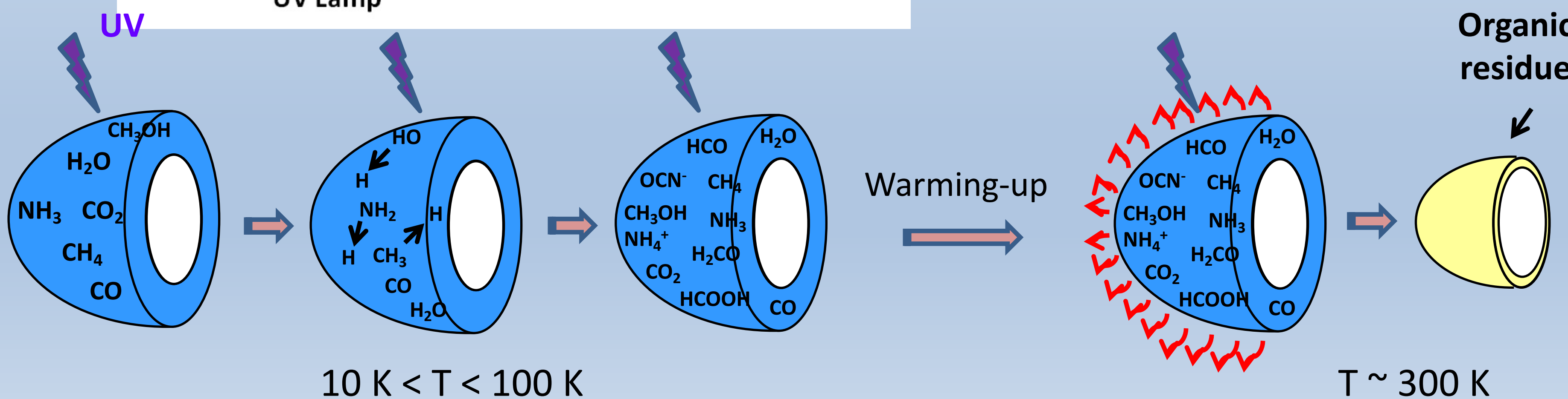
MICMOC: Matière Interstellaire et Cométaire, Molécules Organiques Complexes



Schematics of the MICMOC experiment



- Duration : 24 to 96h
- Monitoring of the quality of the mixture and its photochemical evolution by FT-IR (astro-observable)



Radical-induced chemistry from VUV photolysis of interstellar ice analogues containing formaldehyde

Teddy Butscher, Fabrice Duvernay, Grégoire Danger, and Thierry Chiavassa

PIIM, UMR 7345, Aix-Marseille Université, Avenue Escadrille Normandie-Niemen, 13397 Marseille, France
e-mail: fabrice.duvernay@univ-amu.fr

Received 5 February 2016 / Accepted 16 June 2016

ν (cm^{-1}) ^{12}C	^{13}C	Mode	A ($cm\ molec^{-1}$)	Molecule	Ref
2343	2275	ν(CO)	7.6×10^{-17}	CO_2	[a]
2136	2087	ν(CO)	1.1×10^{-17}	CO	[b]
1846	1804	ν(C = O)	2.1×10^{-17}	HCO	[c]
1751	1721	ν(C = O)	2.6×10^{-17}	GA	[d]
1217	1205	??		POM	[e]
1109	1095	ν(C–O)	9.7×10^{-18}	POM	[e]
1075	1058	ν(C–O)	3.9×10^{-18}	EG	[d]
1046	xx	ν(C–O)	3.9×10^{-18}	EG	[d]
1027	1006	ν(C–O)	1.8×10^{-17}	CH_3OH	[f]
991	970	ν(C–O)	–	POM	[e]
945	919	ν(C–O)	3.0×10^{-17}[g]	POM	[e]
912	887	ν(C–O)	3.0×10^{-17}[g]	POM	[e]

VUV irradiation of H_2CO at 15 K: molecules identified in the infrared

A&A 494, 109–115 (2009)
DOI: 10.1051/0004-6361:200810309

Astronomy & Astrophysics

A tracer of organic matter of prebiotic interest in space, made from UV and thermal processing of ice mantles

G. M. Muñoz Caro[1] and E. Dartois[2]

CHEMICAL REVIEWS

Review

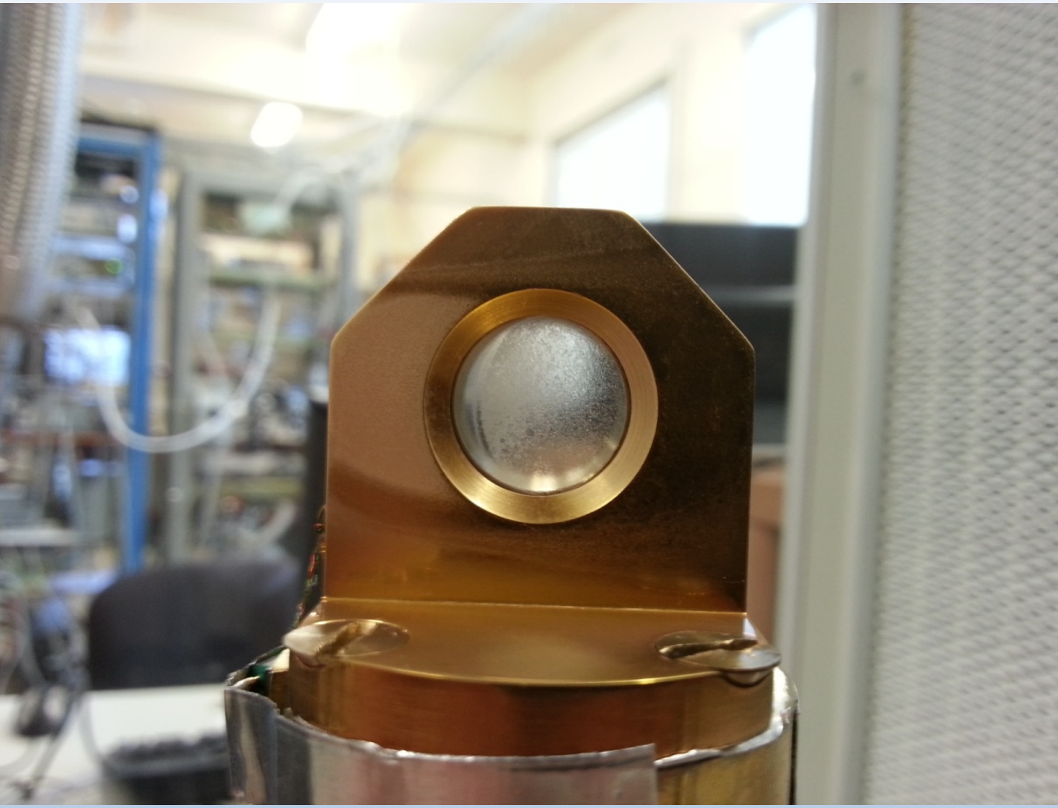
pubs.acs.org/CR

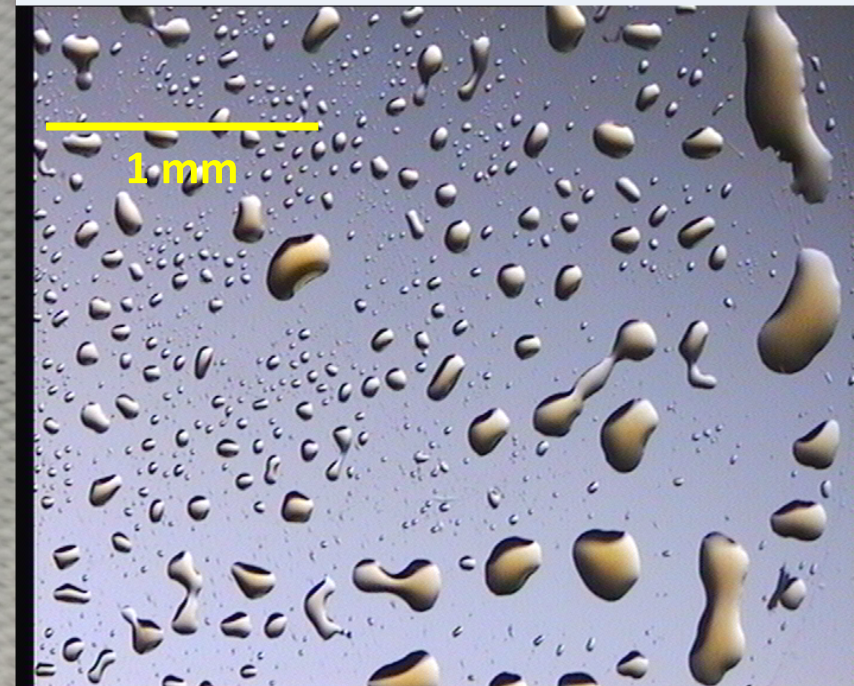
Photochemistry and Astrochemistry: Photochemical Pathways to Interstellar Complex Organic Molecules

Karin I. Öberg*

Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, Massachusetts 02138, United States

The organic residue at 300 K



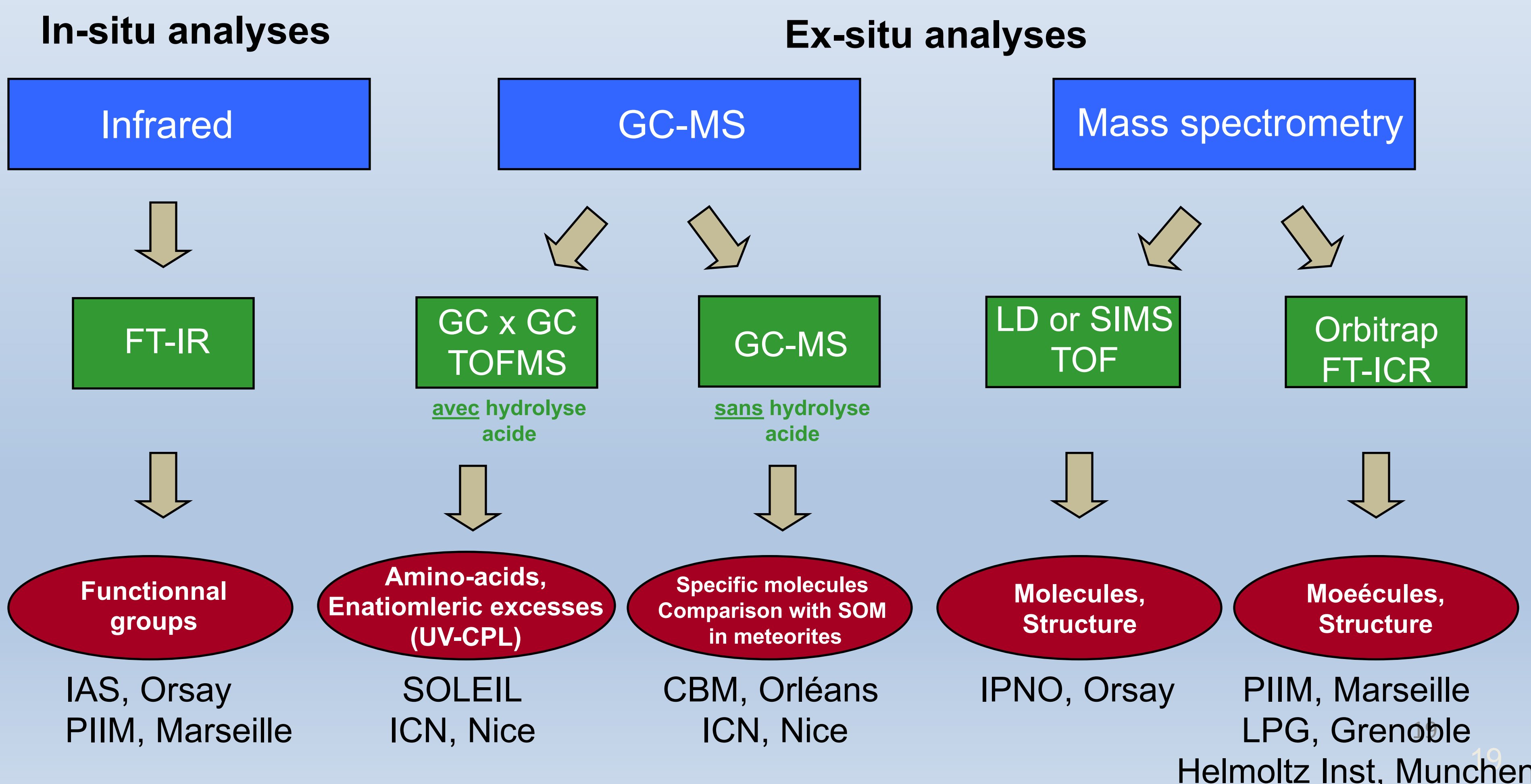


Microscope (visible) X60 (P. Modica, IAS)

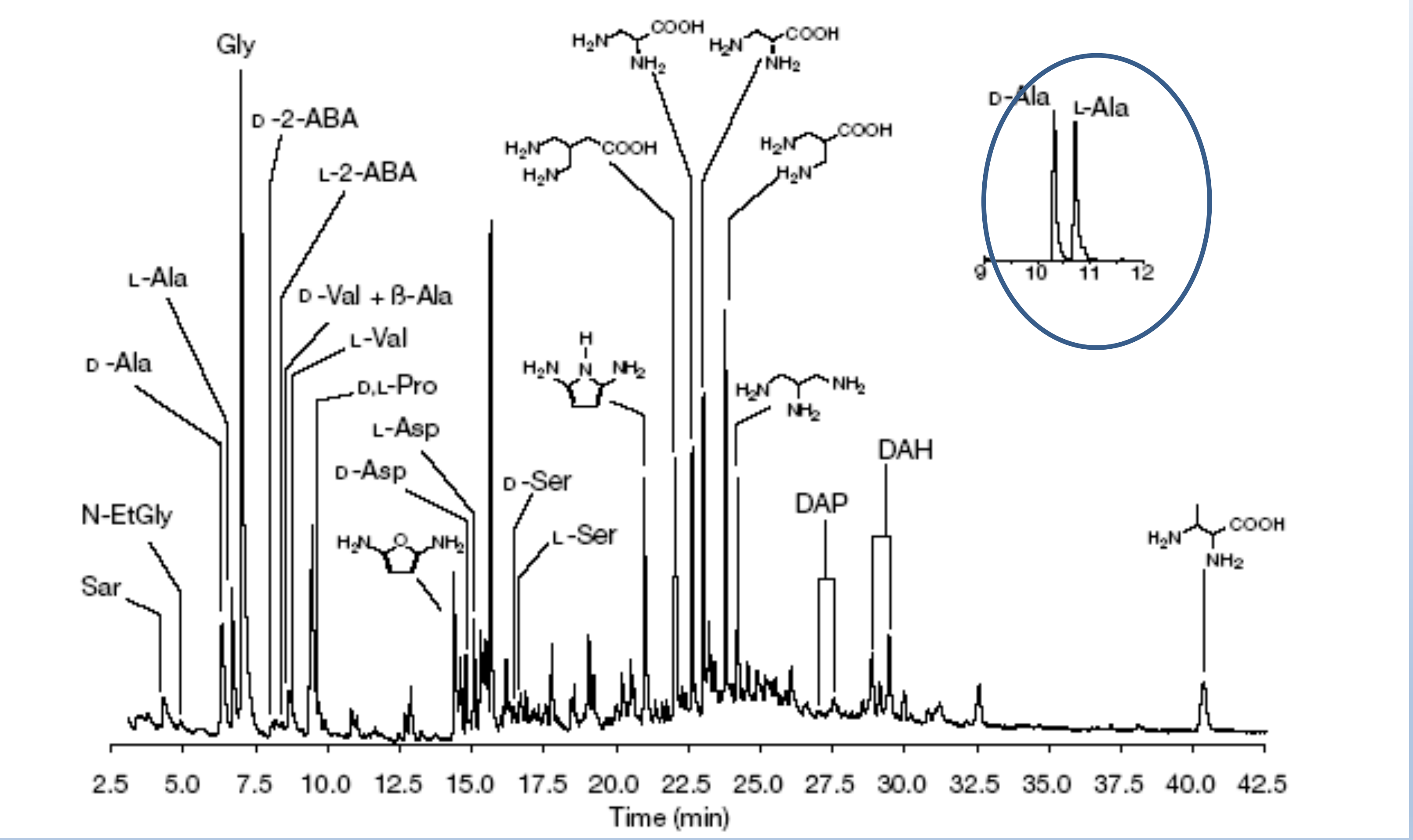
- totally **soluble** in usual solvents (water, methanol)
- 50 to 300 µg in each experiment (1 week to 1 month)
- Macromolecular material *(Danger et al., GCA, 2013)* as free molecules up to 4000 uma in the soluble part

The « new » tools of Astrochemistry: analytical chemistry

A scientific/technical interdiscilinary challenge

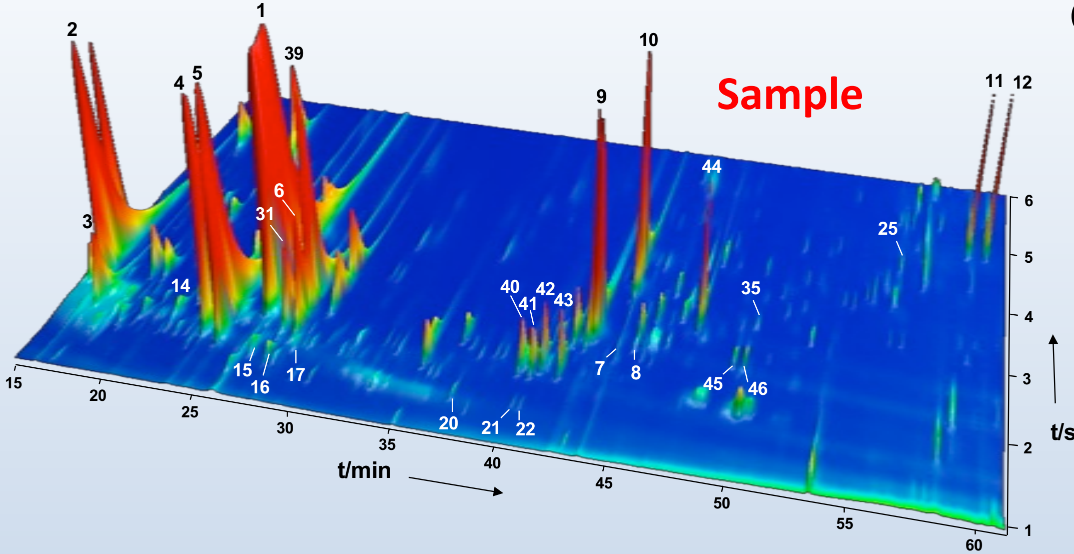


Detection of numerous amino acids (chiral molecules) in the acid hydrolysis of organic residues



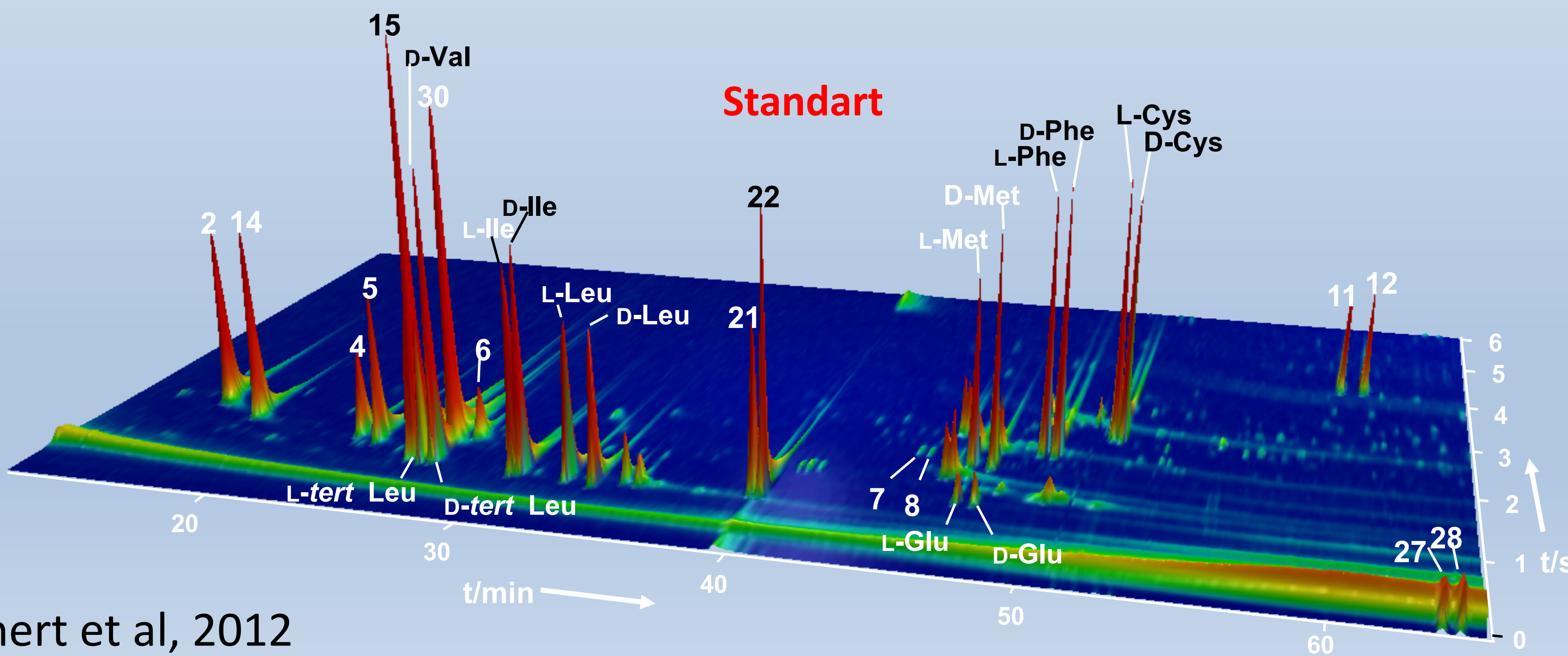
Munoz-Caro et al, 2003,
see also Bernstein et al, 2003, Nuevo et al,2006, 2008, Meinert et al, 2012

GCxGC-MS of the organic residue



20 amino acids
(up to 6 C atoms)
+
6 di-amino acids
+
~ 10 'unknown' species

Targeted search for amino acids



Meinert et al, 2012

CHEMPLUSCHEM

ChemPlusChem 2012, 77, 186 – 191

Targeted Molecules search: amino acids

DOI: 10.1002/cplu.201100048

N-(2-Aminoethyl)glycine and Amino Acids from Interstellar Ice Analogues

Cornelia Meinert,*[a] Jean-Jacques Filippi,[a] Pierre de Marcellus,[b] Louis Le Sergeant d'Hendecourt,[b] and Uwe J. Meierhenrich*[a]

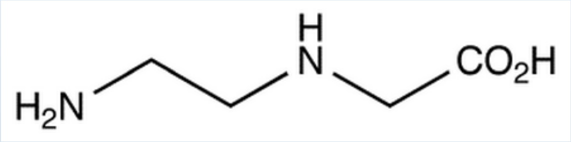
Glycine
Sarcosine
N-Methyl-D,L-alanine
α-L-Alanine
α-D-Alanine
β-Alanine
L-Serine[f]
D-Serine[f]
D,L-Amino (methylamino) acetic acid
N-Aminomethyl glycine
L-2,3-Diaminopropanoic acid
D-2,3-Diamino-propanoic acid
Triaminopropane
N-Ethylglycine
L-2-Aminobutyric acid
D-2-Aminobutyric acid
D,L-3-Aminoisobutyric acid
L-3-Aminobutyric acid
D-3-Aminobutyric acid
4-Aminobutyric acid
L-Aspartic acid
D-Aspartic acid
L-Pyroglutamic acid[h]
D-Pyroglutamic acid[h]
N-(2-aminoethyl) glycine
3-Amino-2-(aminomethyl) propionic acid[i]
L-2,4-Diaminobutyric acid[i]
D-2,4-Diaminobutyric acid[i]
Glycine-glycine[i]
D,L-Proline
L-Norvaline
D-Norvaline
Aminomethyl butanoic acid[k]
5-Aminovaleric acid
D,L-Hydroxyproline
L-Aminomethyl pentanoic acid[l]
D-Aminomethyl pentanoic acid[l]
Aminomethyl pentanoic acid[l]
Unidentified

N-(2-Aminoethyl)glycine and D,L-2,4-diamino-butyric acid may be involved in PNA prior to RNA world.

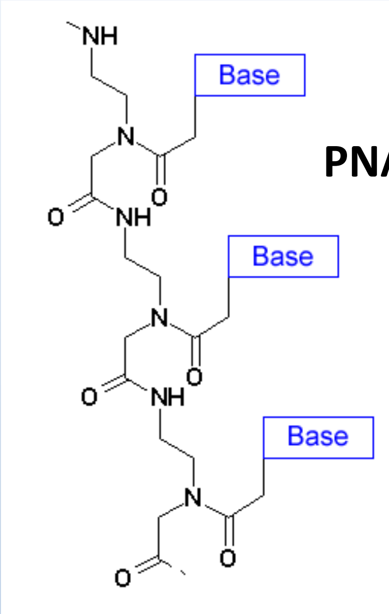
Numerous «prebiotic» molecules

- About 30 **amino** and **di-amino acids**

N-(2-aminoethyl)glycine



Meinert et al., ChemPlusChem, 77, 186 (2012)

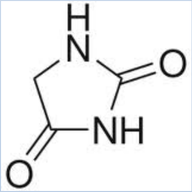


PNA

Nielsen, OLEB (1993)

- Important **intermediates/precursors**

Hydantoin



(Formation of poly- and oligo-peptides)

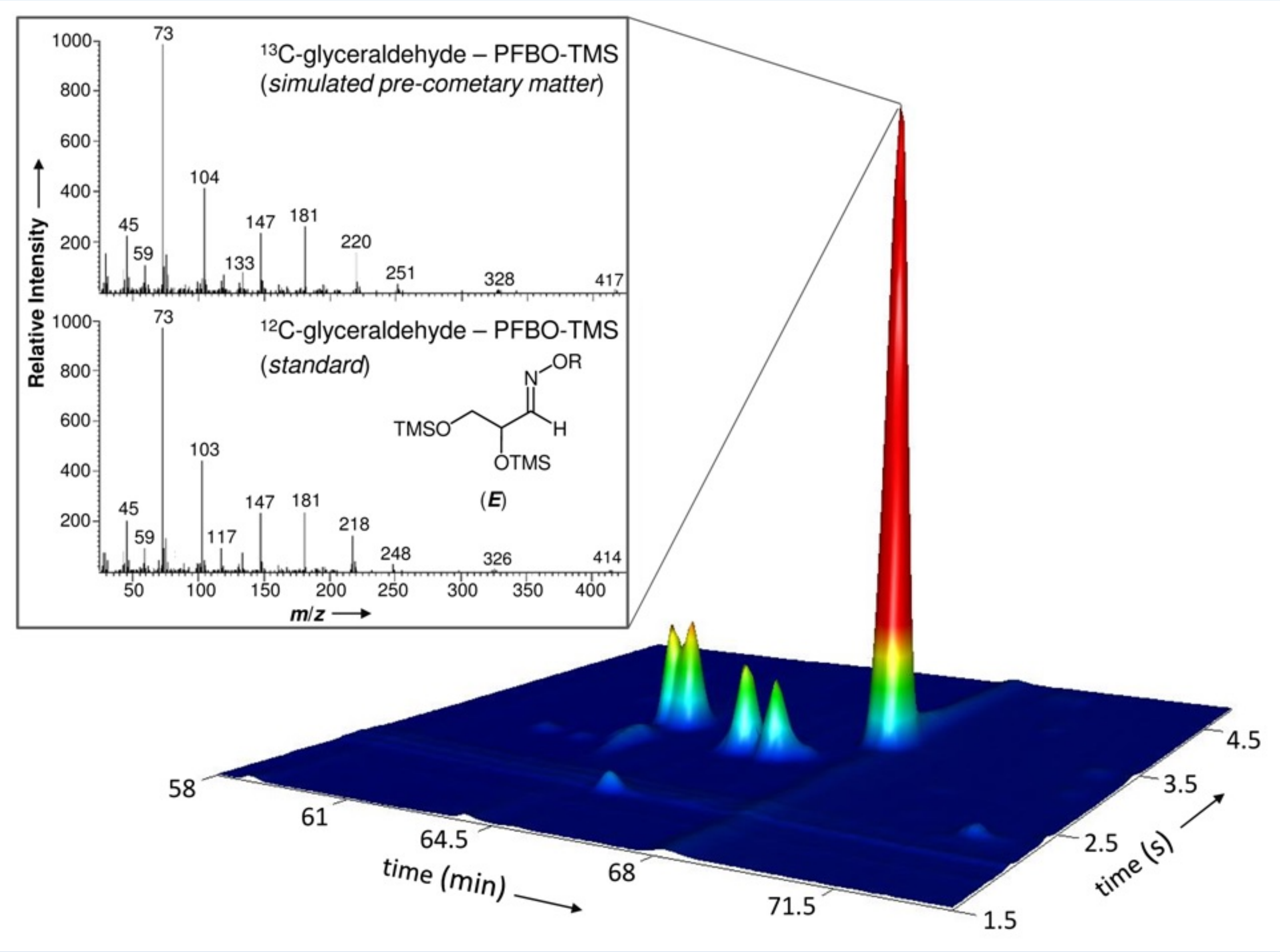
de Marcellus et al., Astrobiology, 11, 847 (2011)

Follow-up work

➔ Analogue of **soluble organic matter (SOM)** of meteorites (carbonaceous chondrites) and **comets** (ROSETTA)? Precursor of **insoluble organic matter (IOM) ?** (*de Marcellus et al, MNRAS, 2017*)

➔ **Search for sugars**

Targeted molecules: glycolaldehyde and glyceraldehyde



de Marcellus, Meinert et al, PNAS, *112 , 965 (2015)*

Aldehydes identified into the residues

Table 1. Aldehydes and sugar-related molecules identified in simulated precometary organic residues

#C[a]	Compound	R_{t1}[b] [min]	R_{t2}[c] [sec]	[$M^{+\bullet}$]	MS fragmentation/^{13}C sample	MS fragmentation/^{12}C standard
1	Formaldehyde	17.08	1.80	226[d]		
2	(*Z*)-Acetaldehyde	20.35	1.94	241[d]		
	(*E*)-Acetaldehyde	21.20	1.92	241[d]		
	(*Z*)-Glycolaldehyde	41.81	2.24	329[e]		
	(*E*)-Glycolaldehyde	42.14	2.32	329[e]		
	(*Z*)-Glyoxal	72.12	5.21	450[f]		
	(*E*)-Glyoxal	74.54	5.14	450[f]		
3	(*Z*)-Propanal	25.49	1.94	256[d]		
	(*E*)-Propanal	25.99	1.94	256[d]		
	(E,*Z*)-Propenal	25.98	2.20	254[d]		
	(*E,Z*)-Propenal	26.66	2.33	254[d]		
	(*Z*) Lactaldehyde	46.39	2.54	344[e]		
	(*E*) Lactaldehyde	46.81	2.54	344[e]		
	(*Z*) Glyceraldehyde	51.47	2.55	431[g]	417,	3, 73
	(*E*) Glyceraldehyde	52.89	2.44	431[g]	417,	3, 73
	(*Z*)-Methylglyoxal	71.12	3.84	465[f]		
	(*E*)-Methylglyoxal	74.54	4.14	465[f]		
4	(*Z*) Butyraldehyde	31.65	1.99	271[d]		
	(*E*) Butyraldehyde	31.74	2.04	271[d]		

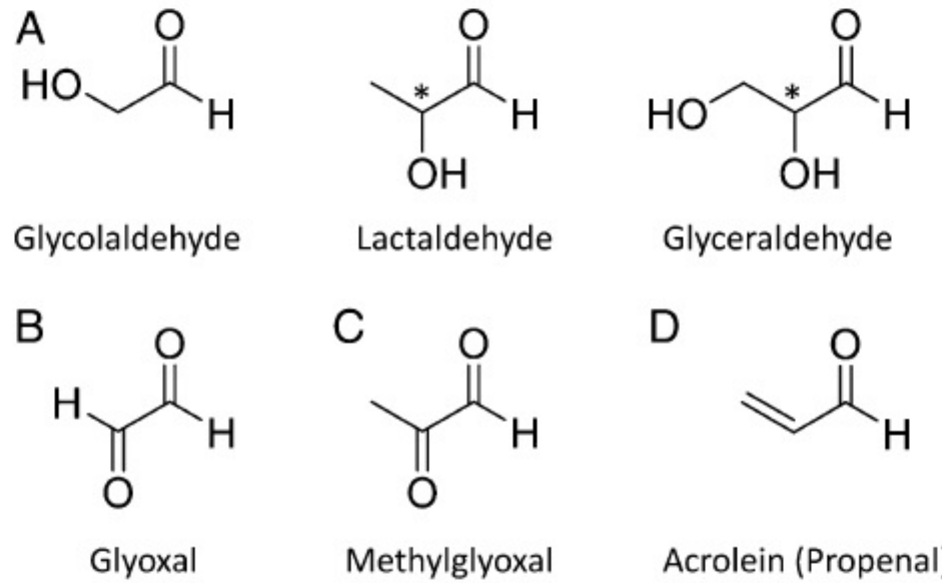


Fig. 1. Selected aldehydes identified at room temperature in simulated precometary organic residues: (*A*) hydroxyaldehydes, (*B*) dialdehyde, (*C*) ketoaldehyde, and (*D*) an unsaturated aldehyde.

Data were obtained from a VUV-irradiated ice mixture at 78 K containing water, ^{13}C-labeled methanol, and ammonia, H_2O:$^{13}CH_3OH$:NH_3, in molar composition of 12:3.5:1. After water extraction of the residue at room temperature, the aldehydes were derivatized to form 1-(*O*-pentafluorobenzyl) oxime derivatives and identified by enantioselective GC×GC–TOFMS analysis.

[a]Quantity of carbon atoms. [b]GC×GC retention time, first dimension. [c]GC×GC retention time, second dimension. [d]Molecular ion *m/z* value of 1-(*O*-pentafluorobenzyl) oxime (PFBO) derivatives. [e]Molecular ion *m/z* value of PFBO trimethylsilyl ether derivatives. [f]Molecular ion *m/z* value of di-PFBO derivatives. [g]Molecular ion *m/z* value of PFBO-bis(trimethylsilyl) ether derivatives. [h]McLafferty rearrangement.

Detection of ribose in organic residues

RESEARCH

REPORT

ASTROCHEMISTRY

Ribose and related sugars from ultraviolet irradiation of interstellar ice analogs

Cornelia Meinert,[1*] Iuliia Myrgorodska,[1,2] Pierre de Marcellus,[3] Thomas Buhse,[4] Laurent Nahon,[2] Soeren V. Hoffmann,[5] Louis Le Sergeant d'Hendecourt,[3] Uwe J. Meierhenrich[1*]

Meinert et al, Science, **352** (2016)

ARTICLE

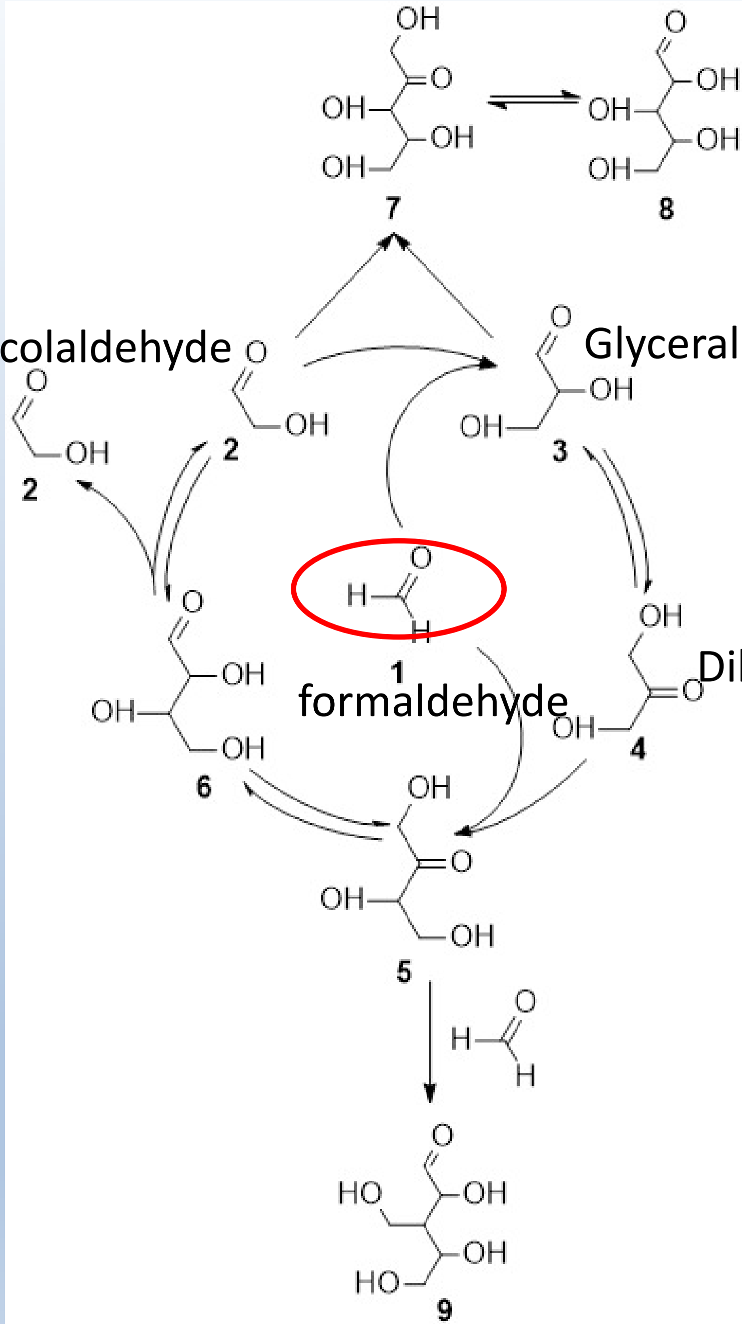
https://doi.org/10.1038/s41467-018-07693-x OPEN

Deoxyribose and deoxysugar derivatives from photoprocessed astrophysical ice analogues and comparison to meteorites

Michel Nuevo[1,2], George Cooper[3] & Scott A. Sandford[1]

Table 1 Deoxysugar derivatives identified in the ice photolysis residues (regular and ^{13}C-labeled)

Compounds[a]	Formulas	R_t (min)[b]	Abundances in residues[c] (pmol)	Detected in meteorites?
Deoxysugars				
2-Deoxyribose	$C_5H_{10}O_4$	61.2, 61.4	217–3855	Undetermined[k]
2-Deoxyxylose[d]	$C_5H_{10}O_4$	57.0, 57.3	373–3636[e]	Undetermined[k]
Deoxysugar alcohols				
1,2-Propanediol[f]	$C_3H_8O_2$	9.9	≥8–375	Yes[l,m]
1,3-Propanediol[f,g]	$C_3H_8O_2$	36.9	≥19–27	No
2-Methyl-1,3-propanediol[g,h]	$C_4H_{10}O_2$	38.7	≤1038–3354[h]	No
2-(Hydroxymethyl)-1,3-propanediol	$C_4H_{10}O_3$	30.9	n.d.	Yes[l]
1,2,3-Butanetriol	$C_4H_{10}O_3$	14.5	6–39	No
1,2,4-Butanetriol	$C_4H_{10}O_3$	32.2	35–50	Yes[l]
Deoxysugar acids				
3,4-Dihydroxybutyric acid[i,j]	$C_4H_8O_4$	16.5	—	Yes[n]
Sugars				
Ribose	$C_5H_{10}O_5$	64.7, 65.0	237–2467	No



Aldopentoses :
threose, arabinose, lyxose) ➔ different nucleic acids

Formose-like autocatalytic reaction ?

Non-directed and natural reaction (MIS, comets)
as proposed by the MICMOC simulation

The Astrophysical Journal, 793:125 (7pp), 2014 October 1 doi:10.1088/0004-637X/793/2/125

THE PHOTOCHEMISTRY OF PYRIMIDINE IN REALISTIC ASTROPHYSICAL ICES AND THE PRODUCTION OF NUCLEOBASES

Michel Nuevo[1,2], Christopher K. Materese[1,3], and Scott A. Sandford[1]
[1] NASA Ames Research Center, MS 245–6, Moffett Field, CA 94035, USA; michel.nuevo-1@nasa.gov
[2] BAER Institute, 625 2nd Street, Suite 209, Petaluma, CA 94952, USA
[3] Oak Ridge Associated Universities, PO Box 117, MS 36, Oak Ridge, TN 37831, USA
Received 2014 June 17; accepted 2014 August 4; published 2014 September 15

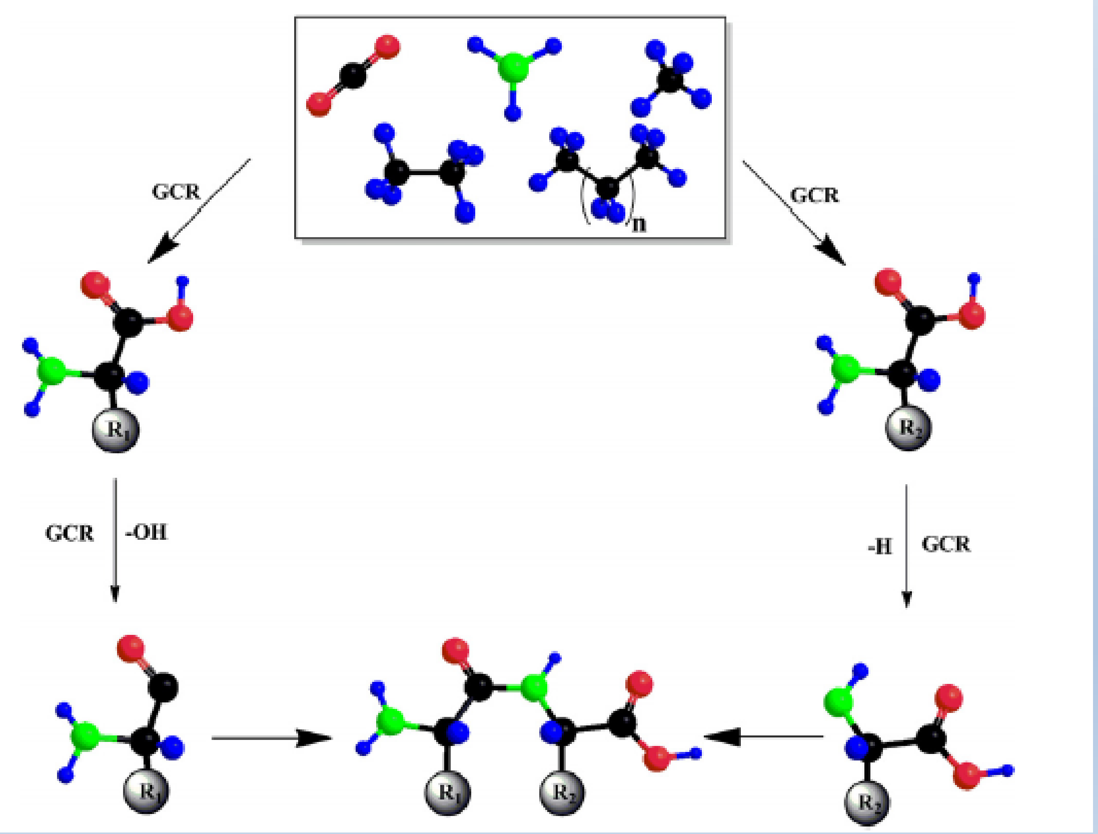
The Astrophysical Journal, 864:44 (6pp), 2018 September 1 https://doi.org/10.3847/1538-4357/aad328

The Photochemistry of Purine in Ice Analogs Relevant to Dense Interstellar Clouds

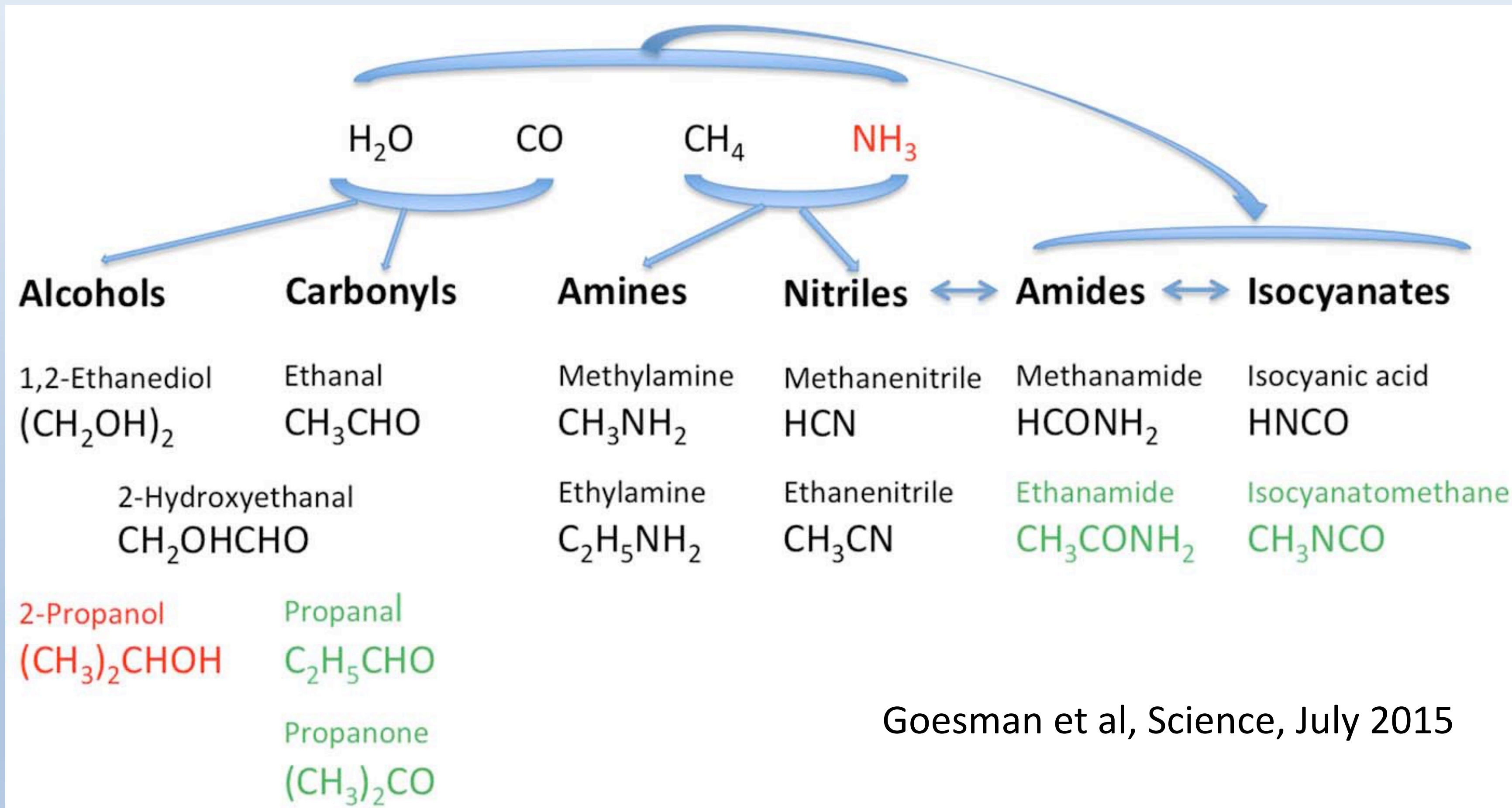
Christopher K. Materese[1,2], Michel Nuevo[1,2], Brittiana L. McDowell[3], Christina E. Buffo[4], and Scott A. Sandford[1]
[1] NASA Ames Research Center, Space Science and Astrobiology Division, MS 245-6, Moffett Field, CA 94035, USA; Scott.A.Sandford@nasa.gov
[2] Bay Area Environmental Research Institute, NASA Research Park, MS 18-4, Moffett Field, CA 94035, USA
[3] Langston University, 701 Sammy Davis Jr. Dr., Langston, OK 73050, USA
[4] Wellesley College, 106 Central St., Wellesley, MA 02481, USA
Received 2018 May 25; revised 2018 July 10; accepted 2018 July 10; published 2018 August 29

ON THE FORMATION OF DIPEPTIDES IN INTERSTELLAR MODEL ICES

R. I. Kaiser[1], A. M. Stockton[2,3], Y. S. Kim[1], E. C. Jensen[2], and R. A. Mathies[2]
[1] Department of Chemistry, University of Hawaii at Manoa, Honolulu, HI 96822, USA
[2] Department of Chemistry, University of California, Berkeley, CA 94720, USA
[3] Jet Propulsion Laboratory, Pasadena, CA 01109, USA
Received 2012 October 10; accepted 2013 January 7; published 2013 February 25



Molecule detections from COSAC experiment (GC- MS on board Philae



Note: most (if not all) of these molecules are present in our residues (or similar ones)

Low depletion of phosphorus in ISM leads to the detection of phosphine (PH_3) in 61p

RESEARCH ARTICLE

SPACE SCIENCES

Prebiotic chemicals—amino acid and phosphorus—in the coma of comet 67P/Churyumov-Gerasimenko

10.1126/sciadv.1600285

Kathrin Altwegg,[1,2*] Hans Balsiger,[1] Akiva Bar-Nun,[3] Jean-Jacques Berthelier,[4] Andre Bieler,[1,5] Peter Bochsler,[1] Christelle Briois,[6] Ursina Calmonte,[1] Michael R. Combi,[5] Hervé Cottin,[7] Johan De Keyser,[8] Frederik Dhooghe,[8] Bjorn Fiethe,[9] Stephen A. Fuselier,[10] Sébastien Gasc,[1] Tamas I. Gombosi,[5] Kenneth C. Hansen,[5] Myrtha Haessig,[1,10] Annette Jäckel,[1] Ernest Kopp,[1] Axel Korth,[11] Lena Le Roy,[2] Urs Mall,[11] Bernard Marty,[12] Olivier Mousis,[13] Tobias Owen,[14] Henri Rème,[15,16] Martin Rubin,[1] Thierry Sémon,[1] Chia-Yu Tzou,[1] James Hunter Waite,[10] Peter Wurz[1]

THE ASTROPHYSICAL JOURNAL, 819:97 (15pp), 2016 March 10 doi:10.3847/0004-637X/819/2/97

PROBING THE CARBON–PHOSPHORUS BOND COUPLING IN LOW-TEMPERATURE PHOSPHINE (PH_3)–METHANE (CH_4) INTERSTELLAR ICE ANALOGUES

ANDREW M. TURNER[1,2], MATTHEW J. ABPLANALP[1,2], AND RALF I. KAISER[1,2]
[1] W. M. Keck Research Laboratory in Astrochemistry, University of Hawaii at Manoa, Honolulu, HI 96822, USA
[2] Department of Chemistry, University of Hawaii at Manoa, Honolulu, HI 96822, USA
Received 2015 October 28; accepted 2016 February 2; published 2016 March 2

ARTICLE

DOI: 10.1038/s41467-018-06415-7 OPEN

An interstellar synthesis of phosphorus oxoacids

Andrew M. Turner[1,2], Alexandre Bergantini[1,2], Matthew J. Abplanalp[1,2], Cheng Zhu[1,2], Sándor Góbi[1,2], Bing-Jian Sun[3], Kang-Heng Chao[3], Agnes H.H. Chang[3], Cornelia Meinert[4] & Ralf I. Kaiser[1,2]

JOURNAL OF INTERDISCIPLINARY METHODOLOGIES AND ISSUES IN SCIENCE

Interstellar ices: a possible scenario for symmetry breaking of extraterrestrial chiral organic molecules of prebiotic interest

Louis L.S. d'HENDECOURT*[1,2], Paola MODICA[3], Cornelia MEINERT[4], Laurent NAHON[5], Uwe J. MEIERHENRICH[4]

Enantiomeric excesses produced in some amino acids by irradiation of IS ices analogues with UV – CPL light from the synchrotron SOLEIL

IR-CPL observed in many protostellar regions such as Orion-KL (see Kwon et al, 2016, 2018

Link with e.e's observed in meteorites? (Meierhenrich et al, 2015

Comparaison SOM in the lab/meteorites as « Paris »?

Laboratory

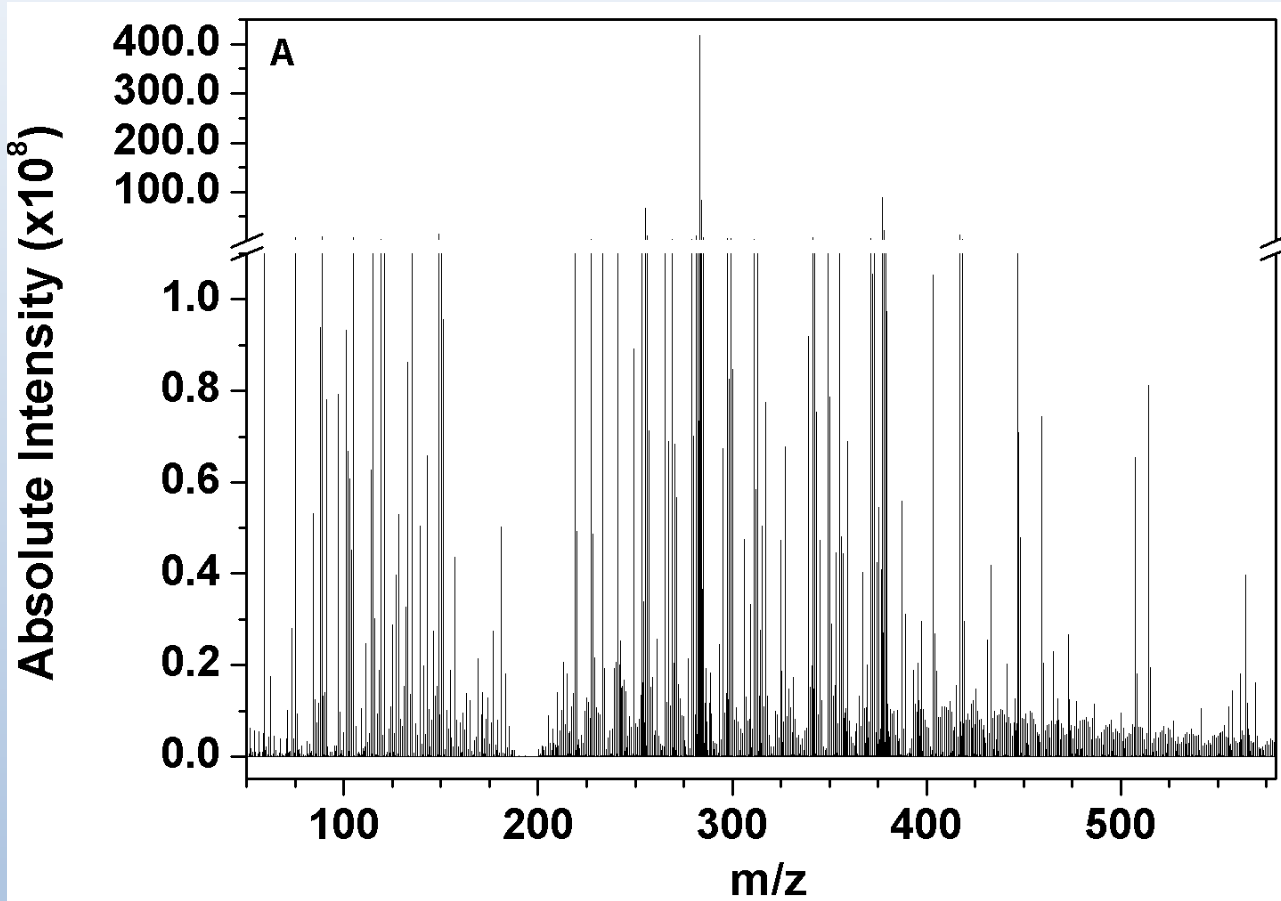
« Paris »
Carbonaceous chondites CM2.7/.8

?

Amino acids distribution as a tracer of aqueous alteration
(Modica, Martins et al, ApJ 2019

Amino acids and hydrocarbons
Martins et al, 2015

Non-targeted searches:
VHRMS (orbitrap) analyses of soluble organic residues

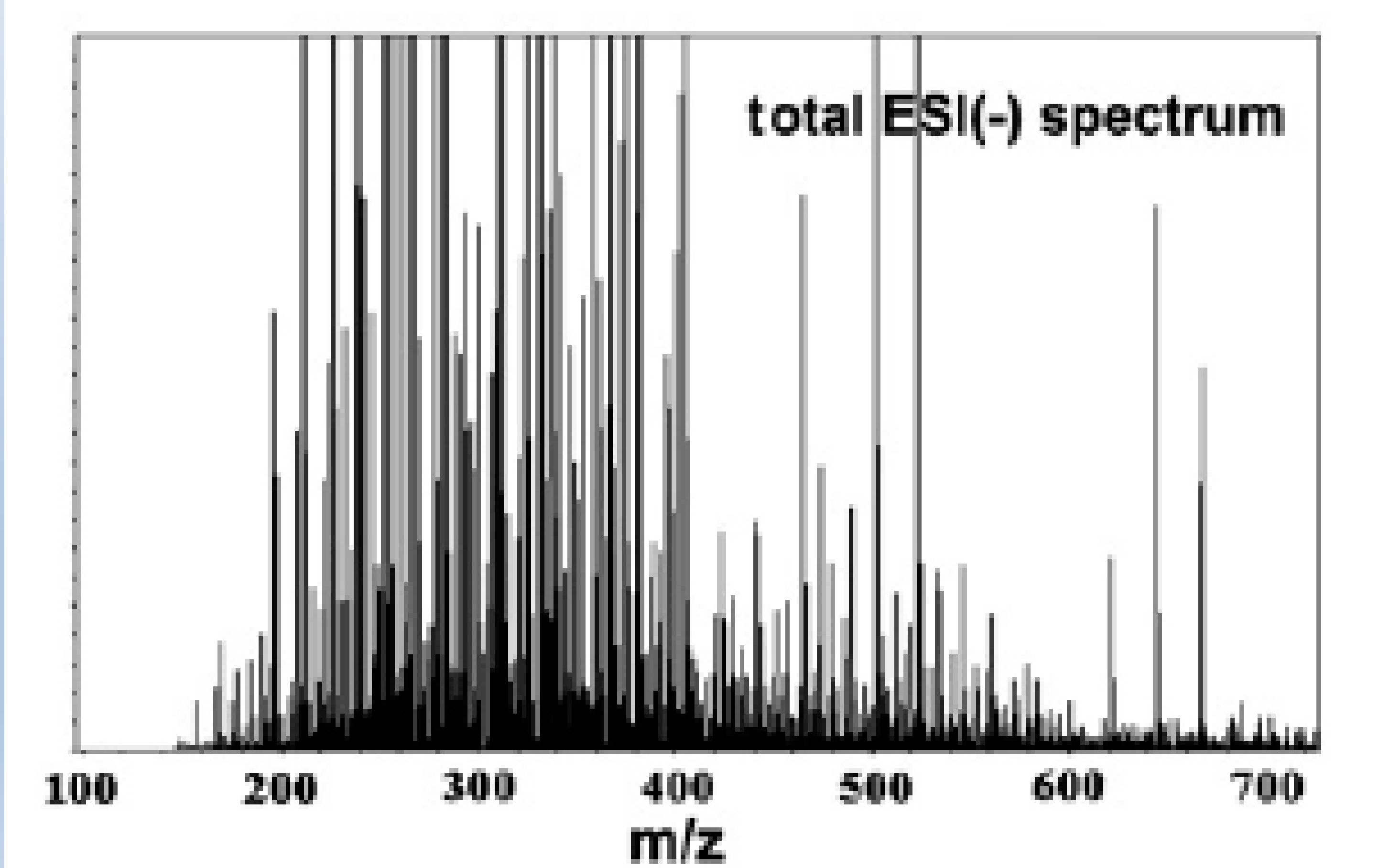


Negative ESI mode = $[M-H]^-$ analysis
Molecules with proton donor chemical functions (e.g. carboxylic acid –COOH)
up to 4000 uma!

Danger et al., 2013, 2016, GCA, **118** , 184; **189**, 184, Schmitt-Kopplin et al, 2010, Murchison

High molecular diversity of extraterrestrial organic matter in Murchison meteorite revealed 40 years after its fall

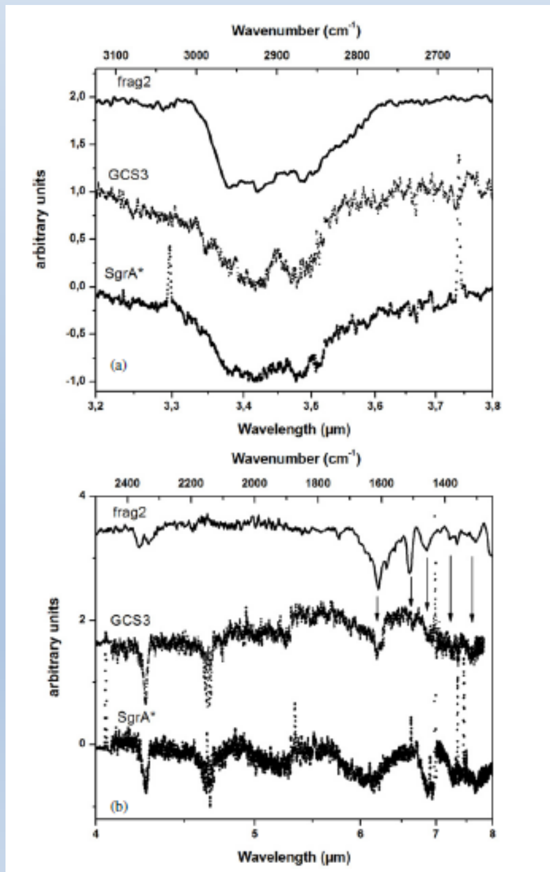
Philippe Schmitt-Kopplin[a,1,2], Zelimir Gabelica[b,1], Régis D. Gougeon[c,1], Agnes Fekete[a], Basem Kanawati[a], Mourad Harir[a], Istvan Gebefuegi[a], Gerhard Eckel[d], and Norbert Hertkorn[a,1]



The Astrophysical Journal, 756:154 (7pp), 2012 September 10 doi:10.1088/0004-637X/756/2/154

HYDROCARBON MATERIALS OF LIKELY INTERSTELLAR ORIGIN FROM THE PARIS METEORITE

S. Merouane[1], Z. Djouadi[1], L. Le Sergeant d'Hendecourt[1], B. Zanda[2], and J. Borg[1]
[1] Institut d'Astrophysique Spatiale, CNRS, UMR-8617, Université Paris Sud, bâtiment 121, F-91405 Orsay Cedex, France;
sihane.merouane@ias.u-psud.fr, zahia.djouadi@ias.u-psud.fr
[2] Muséum National d'Histoire Naturelle, CNRS, 61 rue Buffon, F-75005 Paris, France
Received 2012 May 25; accepted 2012 July 17; published 2012 August 24



Micro IR Spectroscopie sur la ligne SMIS-SOLEIL

Mid-infrared Peaks Obtained in the "Excavated" Grains (see Figure 3) between 1150 and 4000 cm^{-1} and their Possible Assignment According to Ehrenfreund et al. (1991), Socrates (2001), Matrajt et al. (2004), and Berné et al. (2011)

Peak Value in cm^{-1}	Peak Value in μm	Possible Assignment
1182	8.13	C–H bending mode
1255	7.97	C–O stretching in an ester
1462	6.84	C–H bending mode
1512	6.61	C=C aromatic stretching
1583	6.32	Carboxylic acids
1740	5.75	C=O in ketone
2850	3.51	Symmetric stretching mode of the CH_2 group in the alphatic hydrocarbon
2867	3.49	Symmetric stretching mode of the CH_3 group in the alphatic hydrocarbon
2923	3.42	Asymmetric stretching mode of the CH_2 group in the alphatic hydrocarbon
2954	3.38	Asymmetric stretching mode of the CH_3 group in the alphatic hydrocarbon
3385	2.95	O–H from adsorbed water
3050, 1610, 1305, 1150	3.27, 6.21, 7.66, 8.69	Polycyclic aromatic hydrocarbons (PAH)[a]

Note. [a] The 11.2 μm band usually observed in PAH cannot be identified in our samples because of the presence of silicates in this wavelength range.

Processus dans le MIS? Photo/thermochemie des glaces

A search for the origin of life

From G. Danger, HDR, 2017

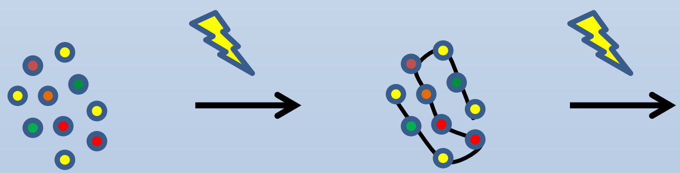
Origin of life

Only in specific environment

Prebiotic chemistry | **Biochemistry**

Prebiotic chemistry: How form complex structures in molecular terms or chemical networks.
How can evolve these chemical networks toward biochemical network (chemical evolution, selectivity, replication…).

1- Building blocks from extraterrestrial and planetary reservoir.



Molecular replicators and networks

2- Free low entropy energy (UV-Vis photons, Pascal, 2017) + liquid water

3- Self-organization of organic matter and emergence of far from equilibrium chemical systems (minimal life?)

Pascal R., *J.Syst.Chem.*, **3** (2012) 3

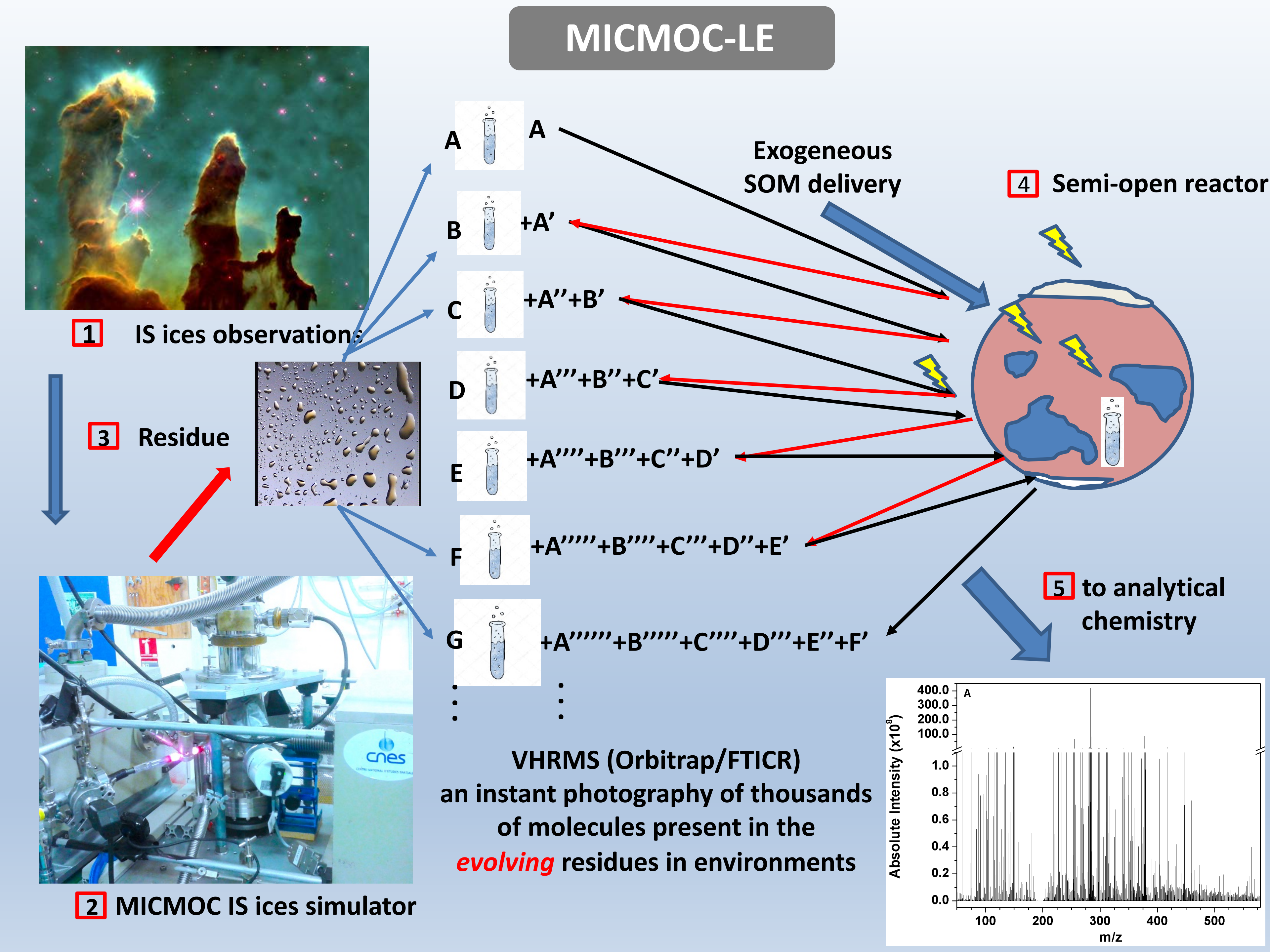
Pross A., *J.Syst.Chem.*, **2** (2011) 1-14

Pross et al., *Open Biology*, **3** (2013) 120190

Chemical evolution and selectivity

MICMOC-LE
far from equilibrium chemistry

A semi-open
reactor for prebiotic chemical evolution
in a « natural » environment



MICMOC-LE
1 IS ices observations
3 Residue
2 MICMOC IS ices simulator
A
B
C
D
E
F
G
A
+A'
+A''+B'
+A'''+B''+C'
+A''''+B'''+C''+D'
+A'''''+B''''+C'''+D''+E'
+A''''''+B'''''+C''''+D'''+E''+F'
Exogeneous
SOM delivery
4 Semi-open reactor
5 to analytical
chemistry
VHRMS (Orbitrap/FTICR)
an instant photography of thousands
of molecules present in the
evolving residues in environments
A
Absolute Intensity (x10^8)
400.0
300.0
200.0
100.0
1.0
0.8
0.6
0.4
0.2
0.0
100
200
300
400
500
m/z

MICMOC-LE is a systemic (holistic) experimental approach

toward the exponential build-up of chemical replicators (DKS stability)

allowing for a strong chemical selectivity imposed by the environment,

a proto - Darwinian evolution at the chemical level

possibility to work backwards at each step (reductionist approach)

Ultimate goals

to define a phase space-like conditions for emergence of true prebiotic and biochemical systems that will apply to primitive Earth, Mars, icy satellites, exoplanets…and define:

Habitability at the emergence of life = Chemicability for self-replication

As early as 1967 (!) with the Spiegelman's monster…

AN EXTRACELLULAR DARWINIAN EXPERIMENT WITH A SELF-DUPLICATING NUCLEIC ACID MOLECULE*

BY D. R. MILLS,† R. L. PETERSON, AND S. SPIEGELMAN

DEPARTMENT OF MICROBIOLOGY, UNIVERSITY OF ILLINOIS, URBANA

Communicated May 18, 1967

…and in 2018:

ARTICLE

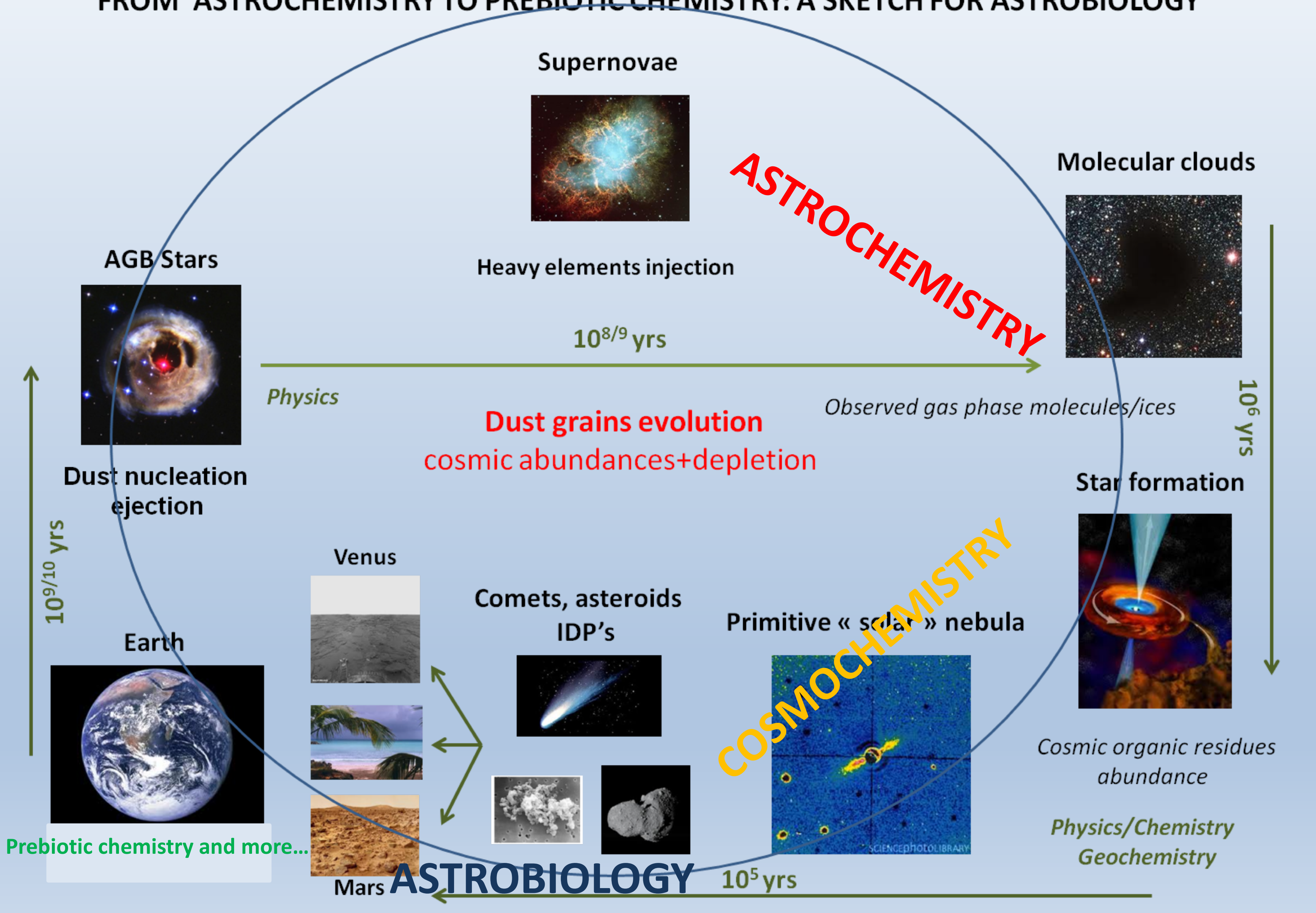
DOI: 10.1038/s41467-018-04488-y OPEN

Self-selection of dissipative assemblies driven by primitive chemical reaction networks

Marta Tena-Solsona[1,2], Caren Wanzke[1], Benedikt Riess[1], Andreas R. Bausch[3] & Job Boekhoven[1,2]

Determinism and contingency

FROM ASTROCHEMISTRY TO PREBIOTIC CHEMISTRY: A SKETCH FOR ASTROBIOLOGY



Thank You !