The Miller & Urey Experiment Shaping a Life-friendly Universe

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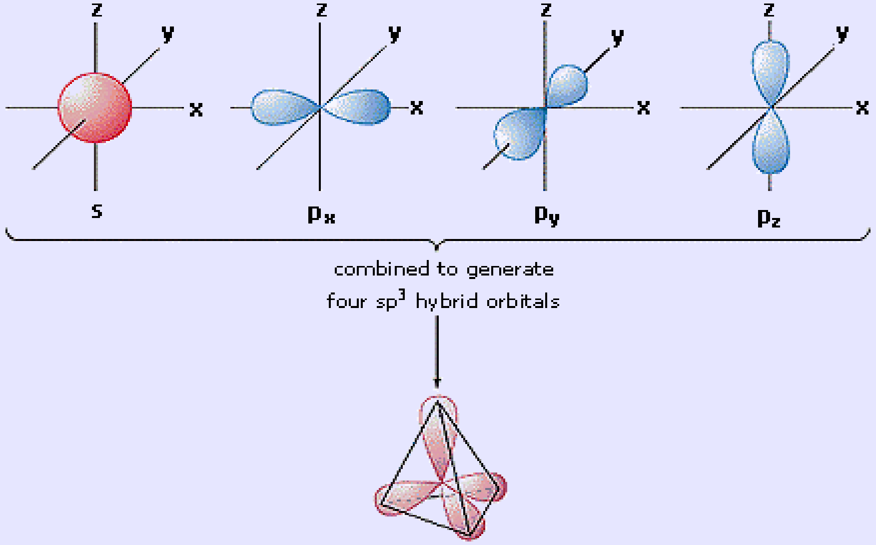
WHY carbon ??

carbon's hybrid orbitals = geometrical asymmetries



Carbon valence electrons: displaced in a tetrahedron geometry

⇨ covalent bonds to escape the XYZ 90° monotonous angles ⇨

⇨ asymmetrical chemical structures.

Structural variety = richer information

but other elements contribute to complexity…

nitrogen = asymmetric bonds with charge displacements

Nitrogen is more electronegative than C and H so ⇨ asymmetries

oxygen ⇨ induces charges dynamics

Oxygen is also very electronegative so ⇨

⇨ nitrogen- and oxygen-harboring compounds are very polar e.g. water

hydrogen = keeps reagents reduced

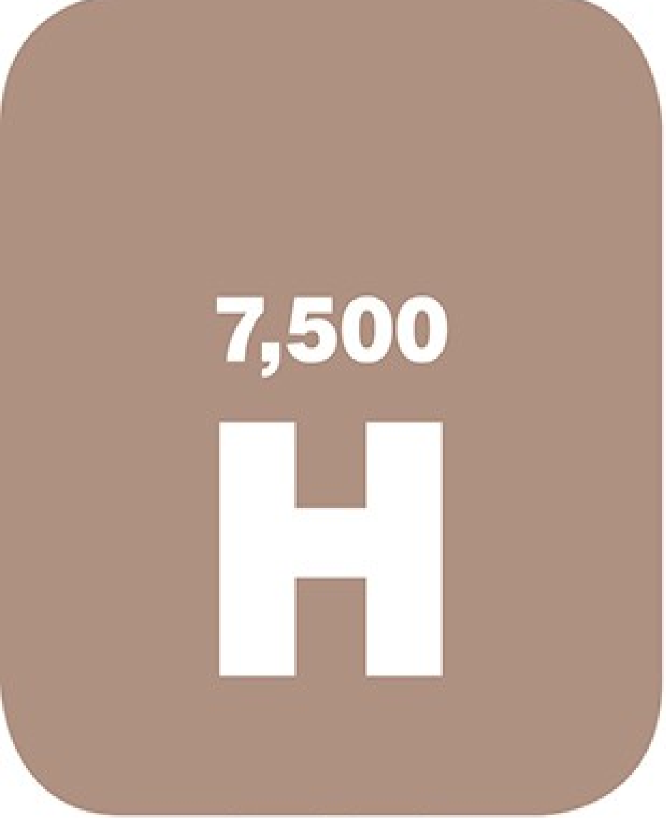
Hydrogen functions as a “bonding buffer” ⇨
⇨ reagents keeped in reduced form.

Whenever a reagent reacts with other compound ⇨ a proton is released when the covalent bonding is formed.

RELATIVE ABUNDANCES (% TOTAL)

EARTH		HUMAN BODY		SUN	
O	47.00	H	63.00	H	71.00
Si	28.00	O	25.50	He	27.10
Al	7.90	C	9.50	O	0.97
Fe	4.50	N	1.40	C	0.40
Ca	3.50	Ca	0.31	N	0.10
Na	2.50	P	0.22	Si	0.10
K	2.50	Cl	0.08	Mg	0.08
Mg	2.20	K	0.06	Ne	0.06
Ti	0.50	S	0.05	Fe	0.01
H	0.20	Na	0.03	S	0.04
C	0.20	Mg	0.01		

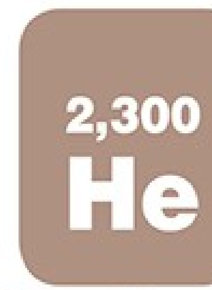
The chemical elements present in your body today were formed inside stars !!!



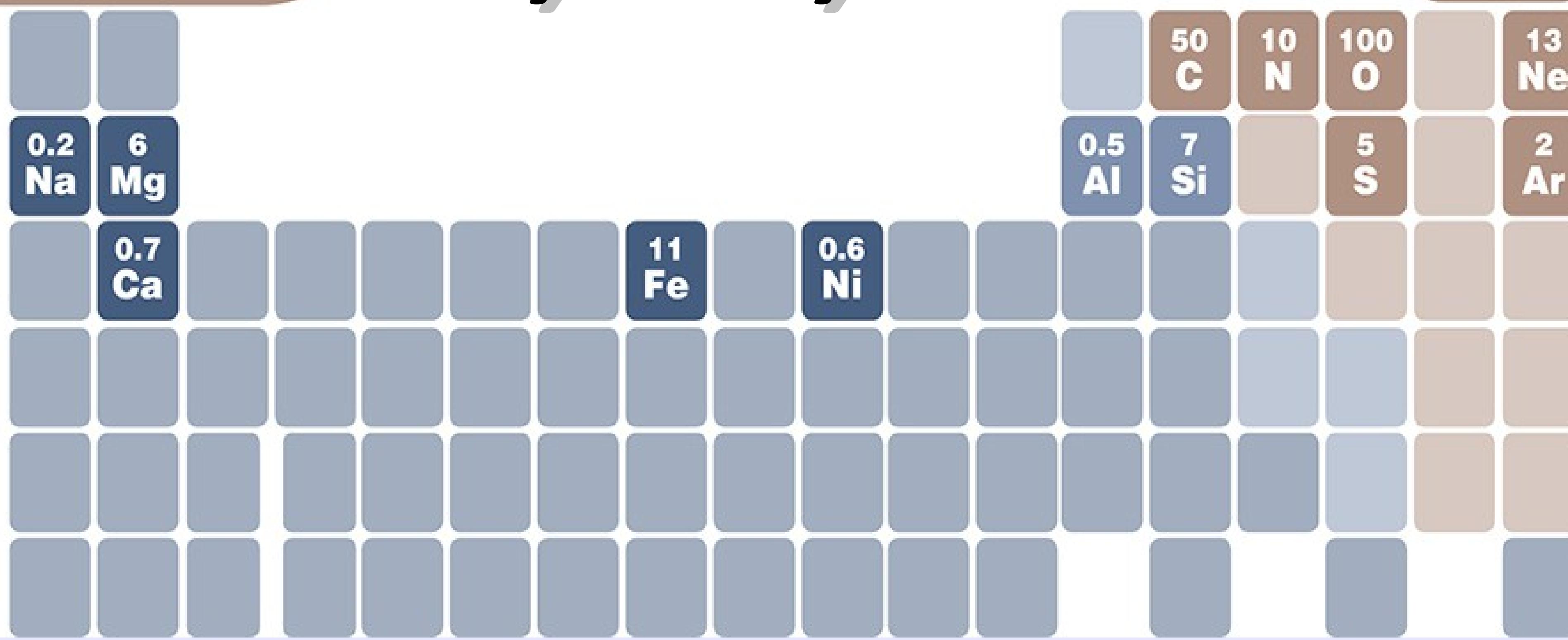
Basic chemistry,
from simple to complex

life as we know it = life as we CHON it

ABUNDANCES (1)



H, O, C



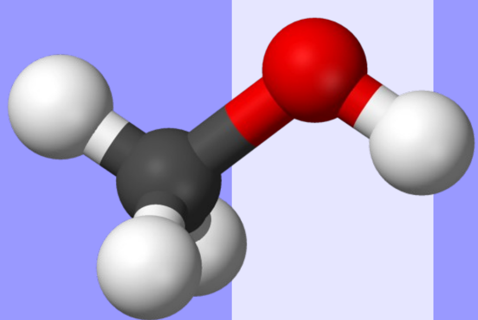
Basic chemistry,
from simple to complex

Two-element primary compounds:

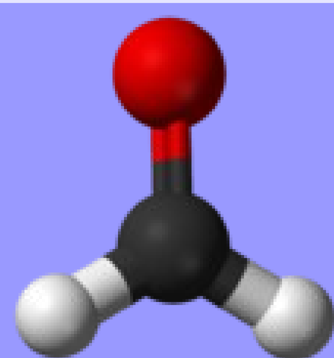
H_2O CO CH_4

Three-element pre-biotic compounds:

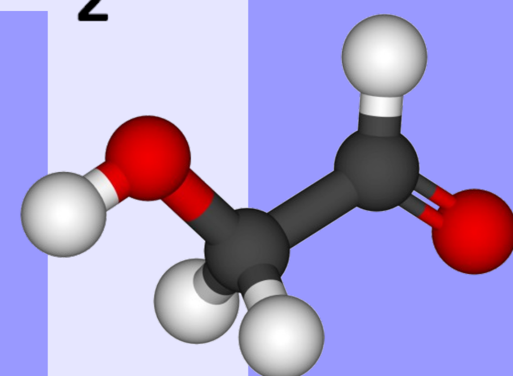
CH_3OH $HCOH$ $H_2COH\text{-}CHO$



methanol



formaldehyde

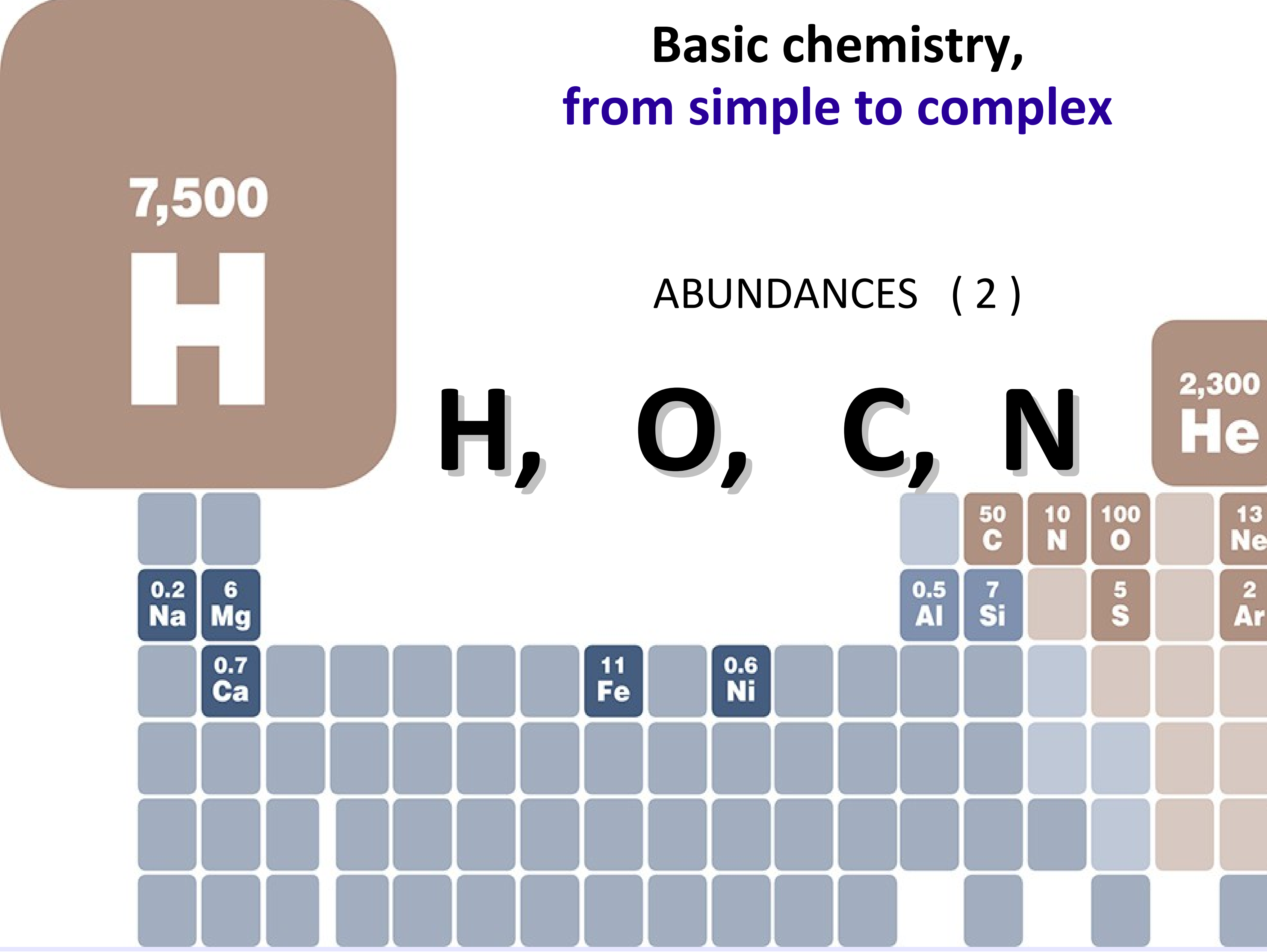


glycoaldehyde

Basic chemistry,
from simple to complex

ABUNDANCES (2)

H, O, C, N



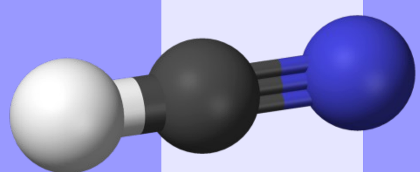
Basic chemistry,
from simple to complex

Two-element primary compounds:

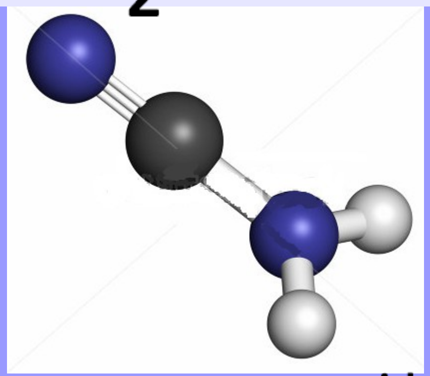
H_2O CO CH_4 NH_3

Three-element pre-biotic compounds:

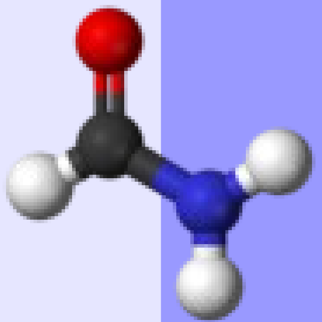
HCN **H_2NCN** **$COHNH_2$**



hydrogen cyanide



cyanamide

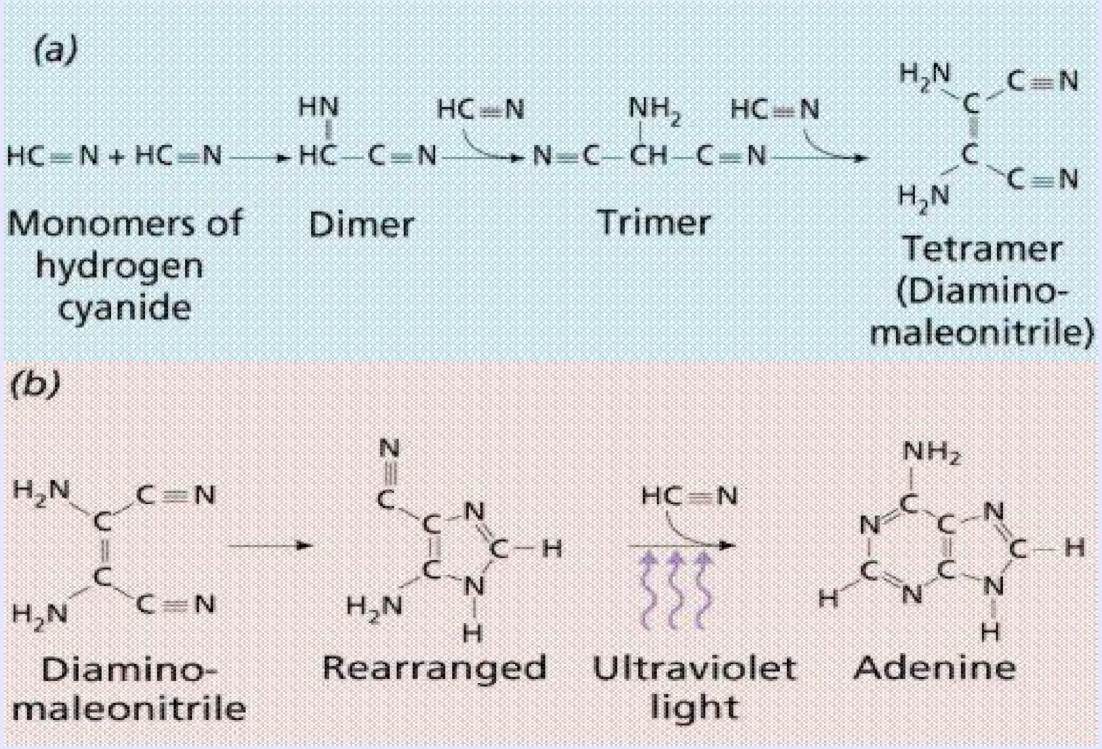


formamide

From simple to complex …

Primitive abiogenic reactions supposed to have generated life building blocks

$[HCN]_8$ ⇨ purine (DNA nucleobase)

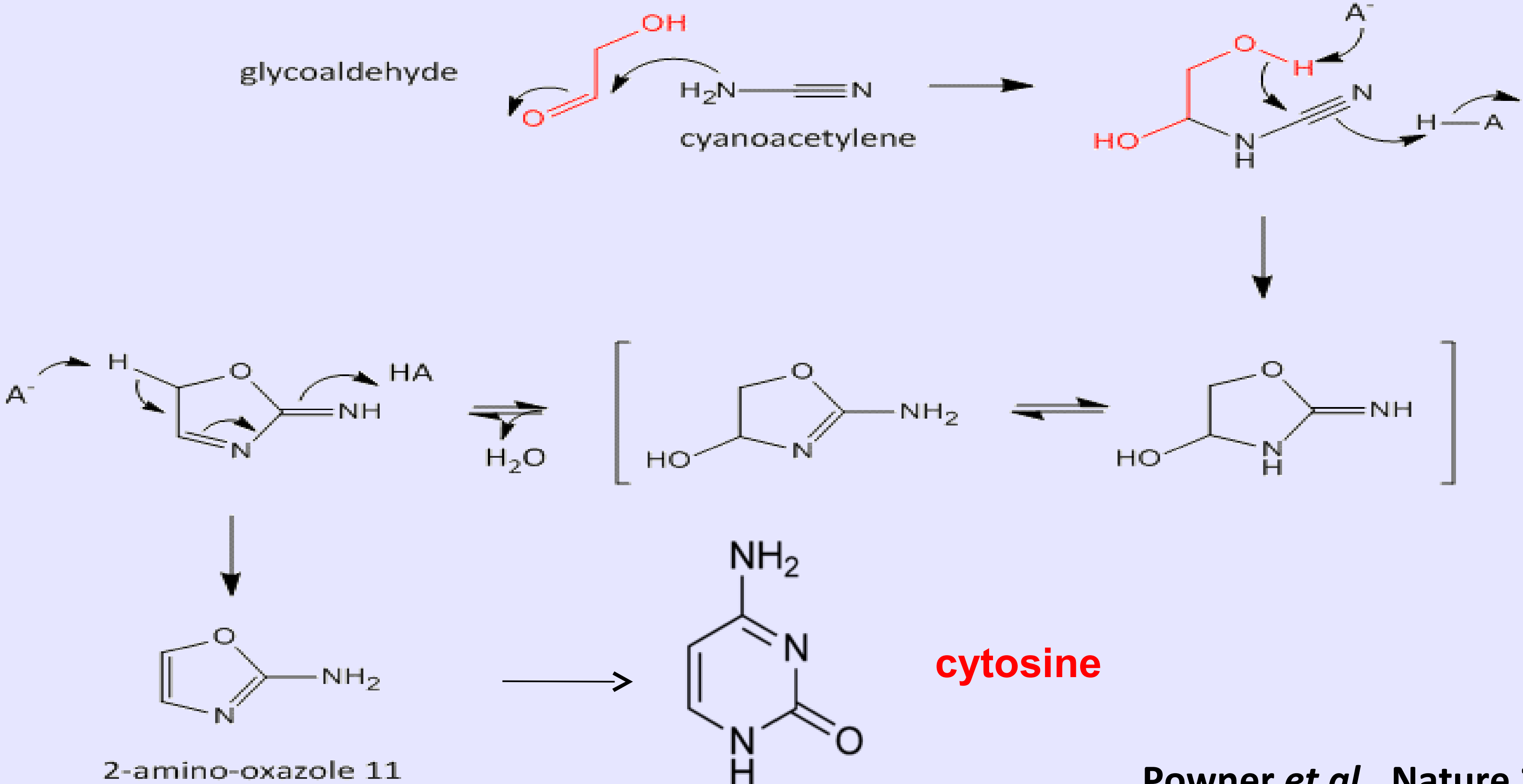


Saladino et al., 2004

From simple to complex …

Primitive abiogenic reactions supposed to have generated life building blocks

[?] ⇨ pyrimidine (DNA nucleobase)

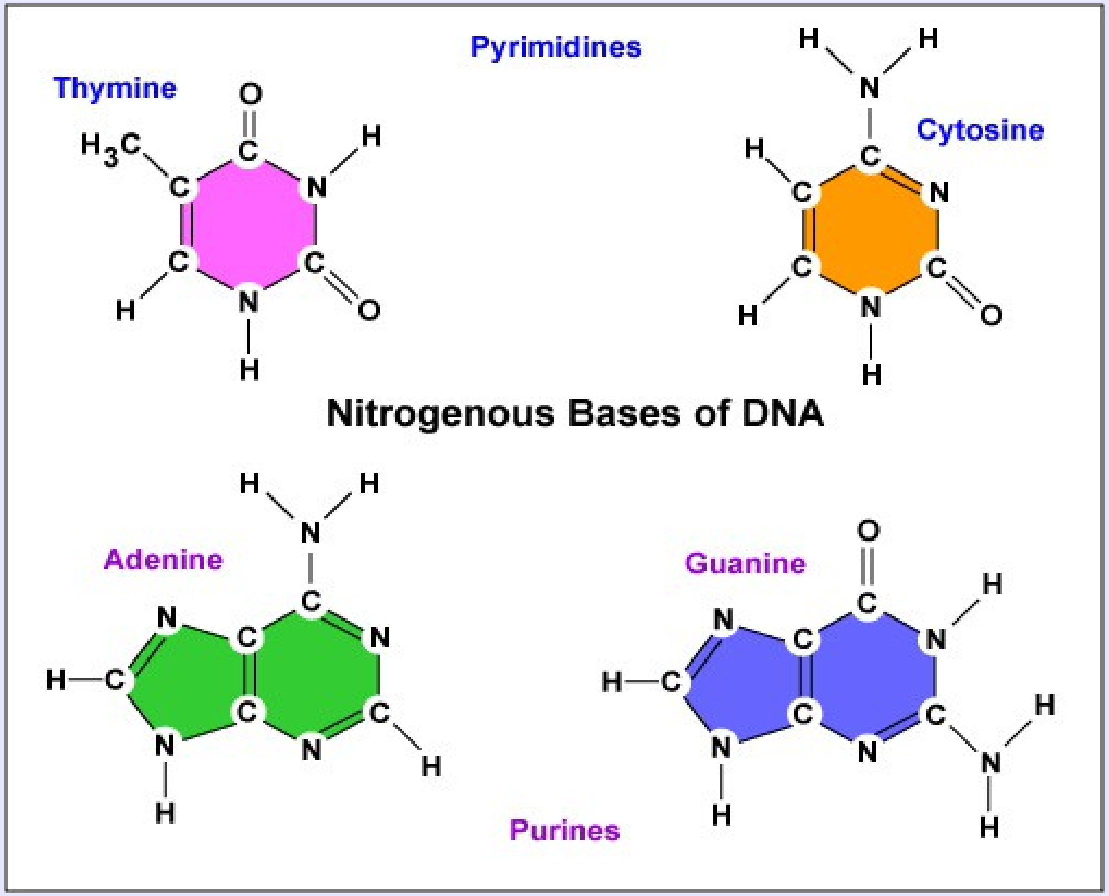


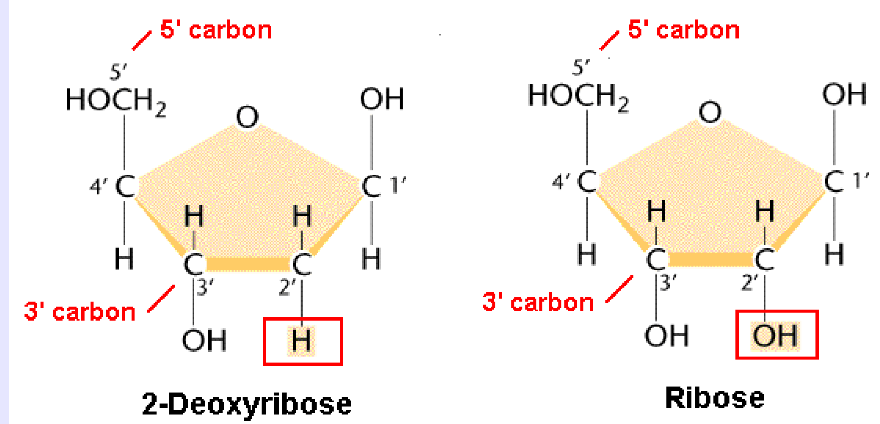
cytosine

Powner *et al.*, Nature 2009

$H2O$, $CH4$, CO, $NH3$ ⇨ prebiotic compounds ⇨

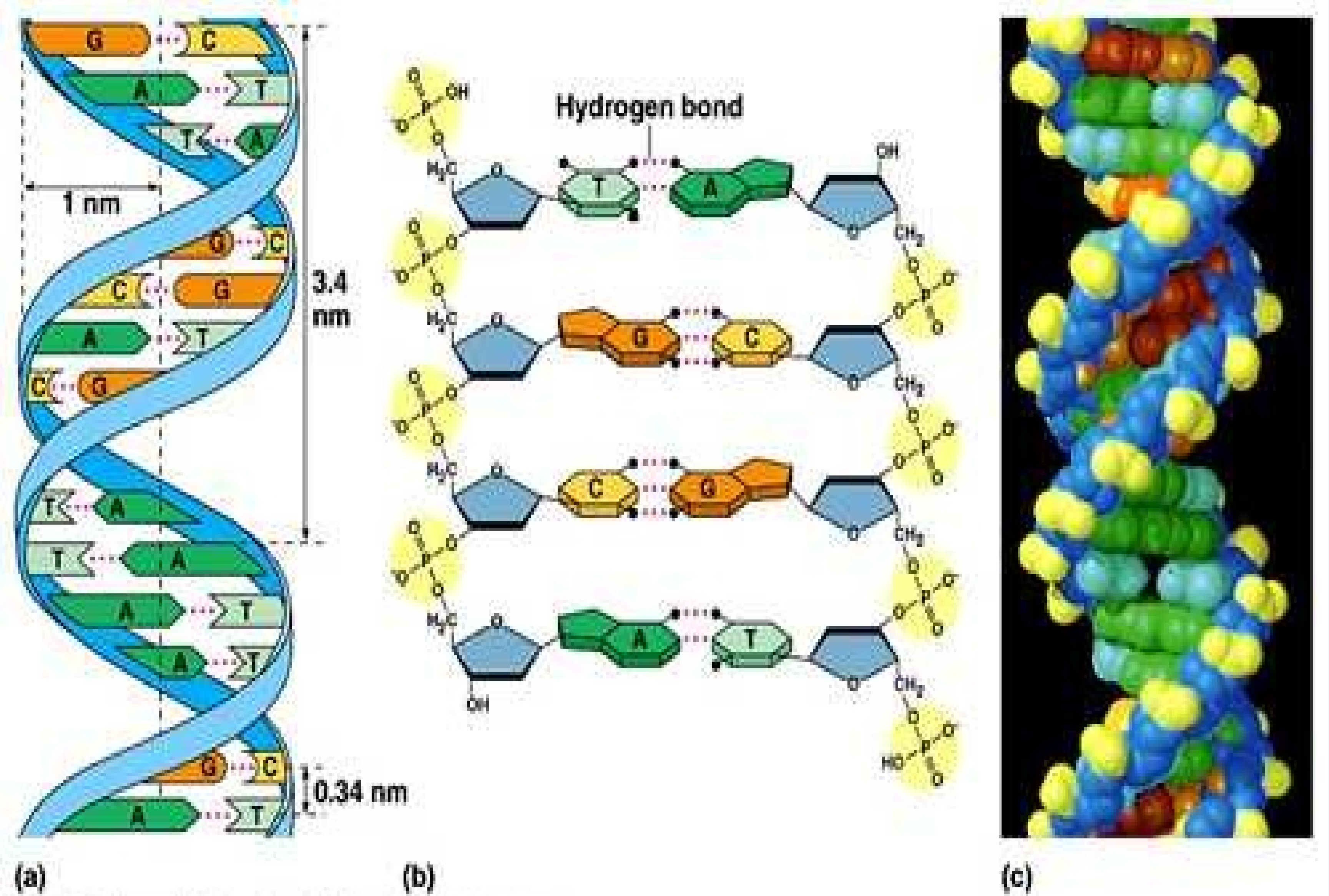
⇨ LIFE BUILDING BLOCKS, NUCLEOBASES, SUGARS, AMINOACIDS.





(Klug & Cummings 1997)

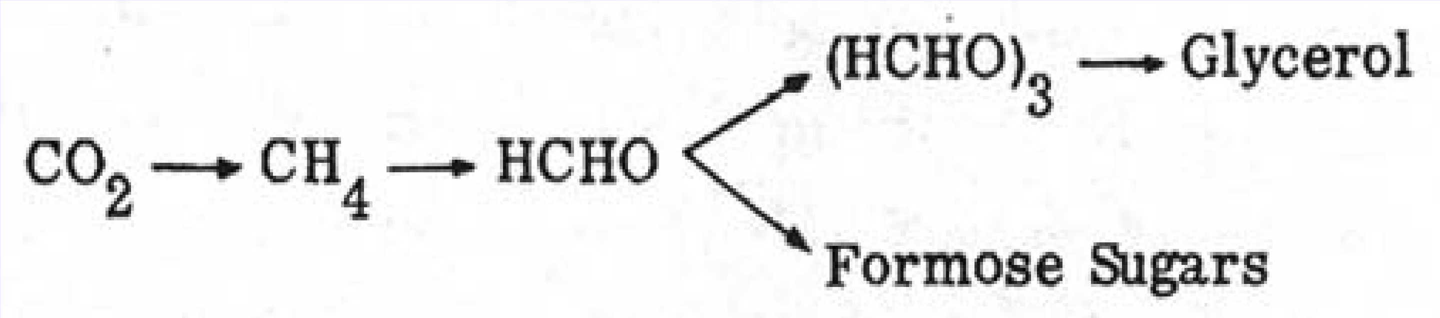
DNA complex structure



From simple to complex ...

Primitive abiogenic reactions supposed to have generated life building blocks

HCHO ⇨ simple sugars (energy feeding compounds)
formaldehyde



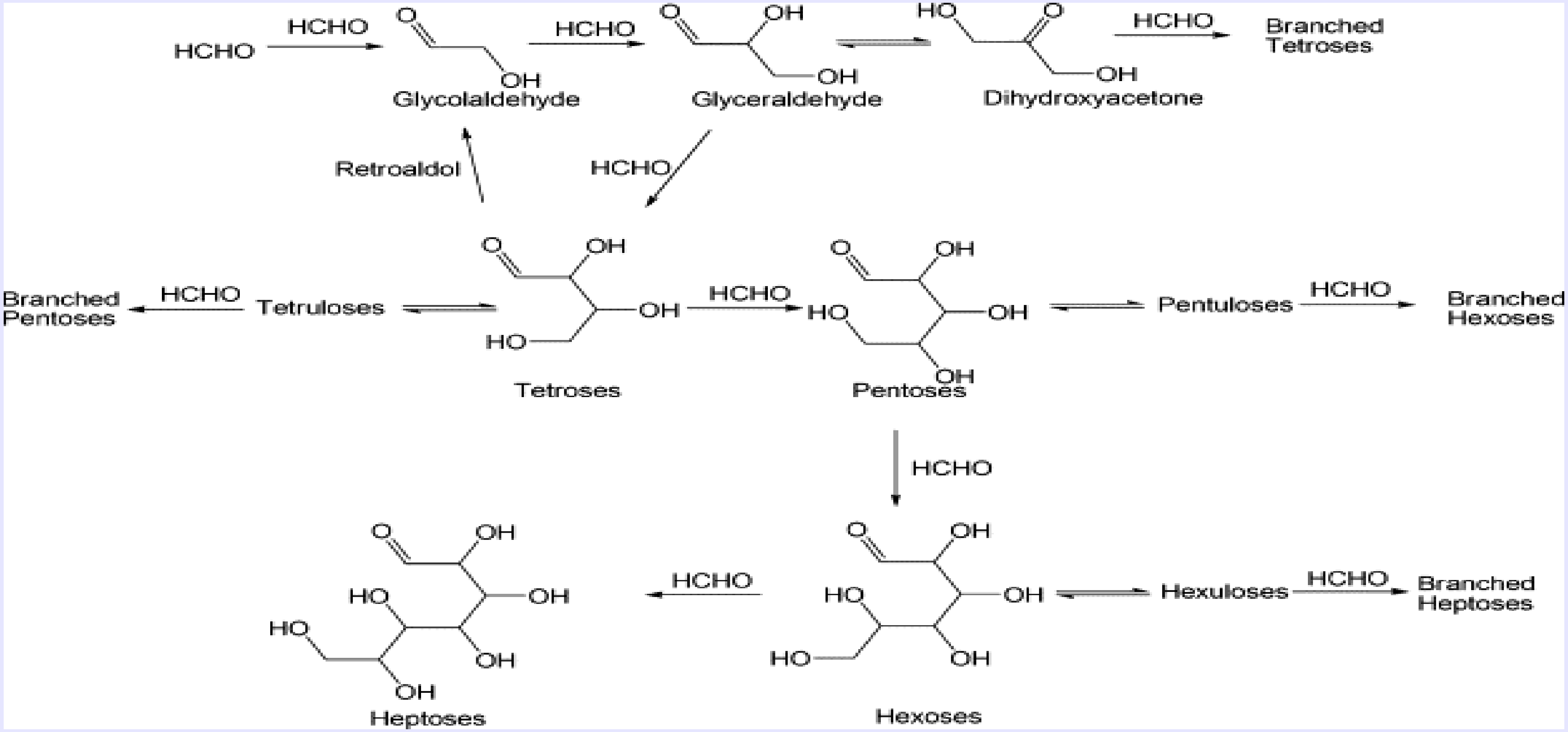
Prebiotic synthesis of simple sugars by an interstellar formose reaction.
Jalbout AF. Orig Life Evol Biosph, 2008, 38(6):489-497

Sugar synthesis from a gas-phase formose reaction. Jalbout AF, Abrell L, Adamowicz L, Polt R, Apponi AJ, Ziurys LM. Astrobiology, 2007, 7(3):433-442.

From simple to complex …

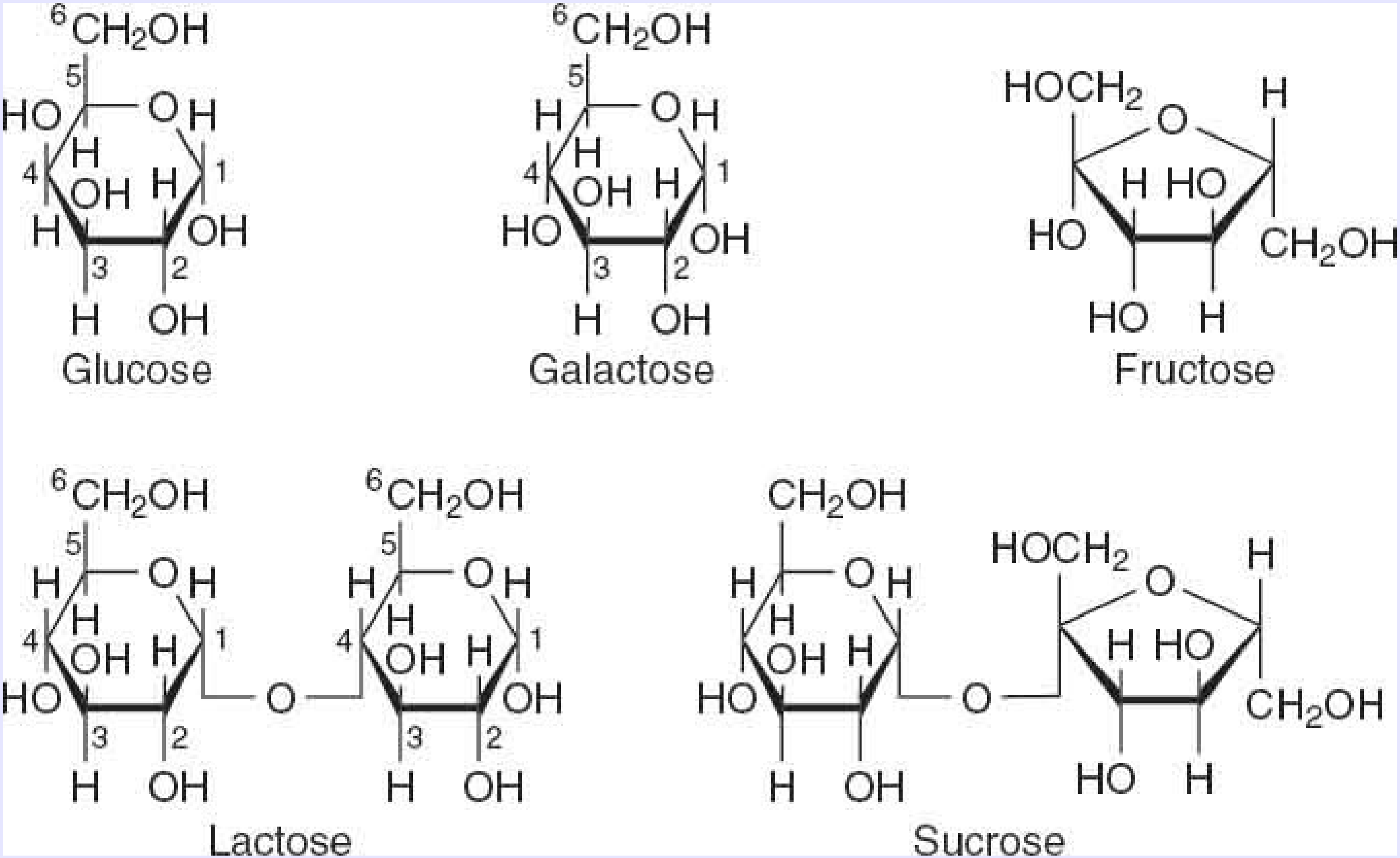
Primitive abiogenic reactions supposed to have generated life building blocks

HCHO ⇨ simple sugars ⇨ complex sugars



Sugars play a fundamental role in the energetic metabolism of every living being.

Chemical structures of compounds belonging to the hexose sugars



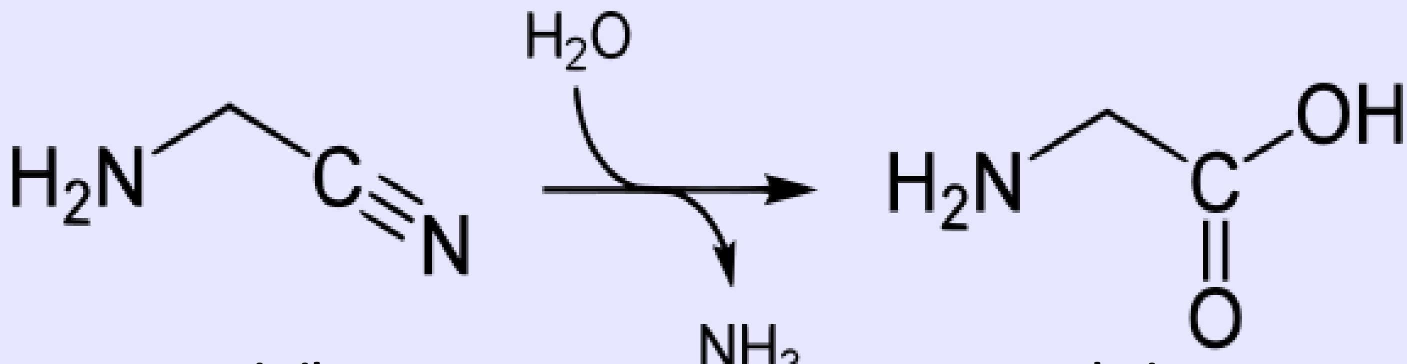
From simple to complex …

Primitive abiogenic reactions supposed to have generated life building blocks

HCHO + HCN ⇨ simple aminoacids

$$HCOH + HCN + NH_3 \rightarrow C_2H_4N_2 + H_2O$$

(acetonitrile)

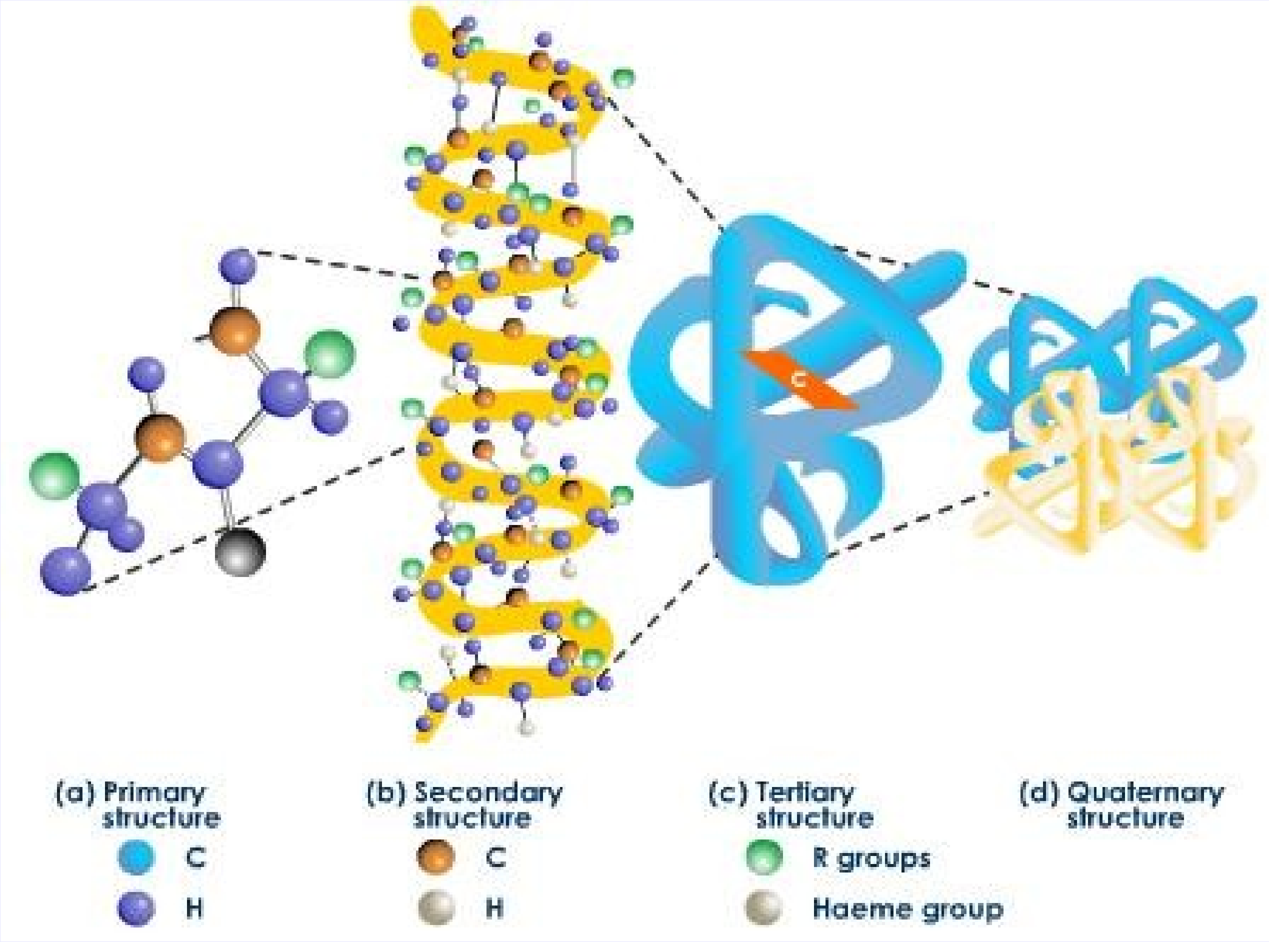


acetonitrile **glycine**

S Miller and James Cleaves II, The prebiotic chemistry on Primitive Earth

From simple to complex ...

Primitive abiogenic reactions supposed to have generated life building blocks:



aminoacids & proteins

Reaction chanels from CO/CO_2 on grain surfaces generating main pre-biotic compounds

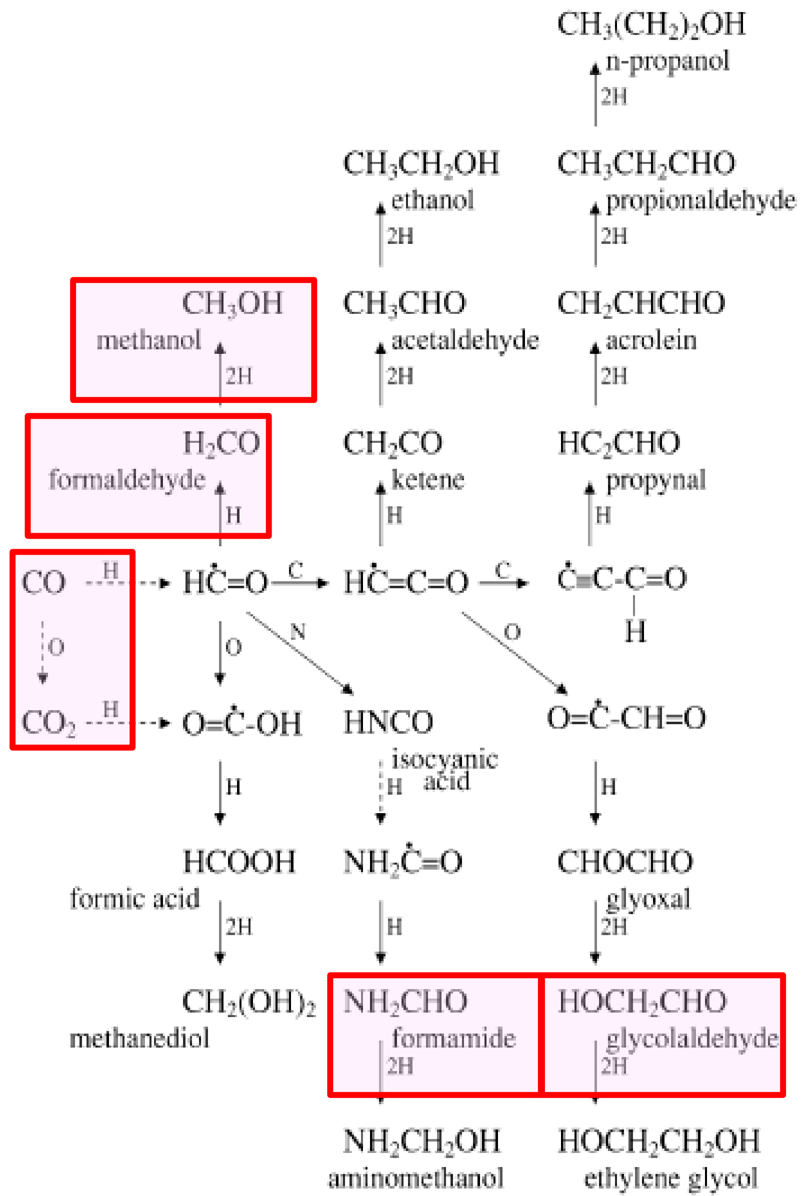
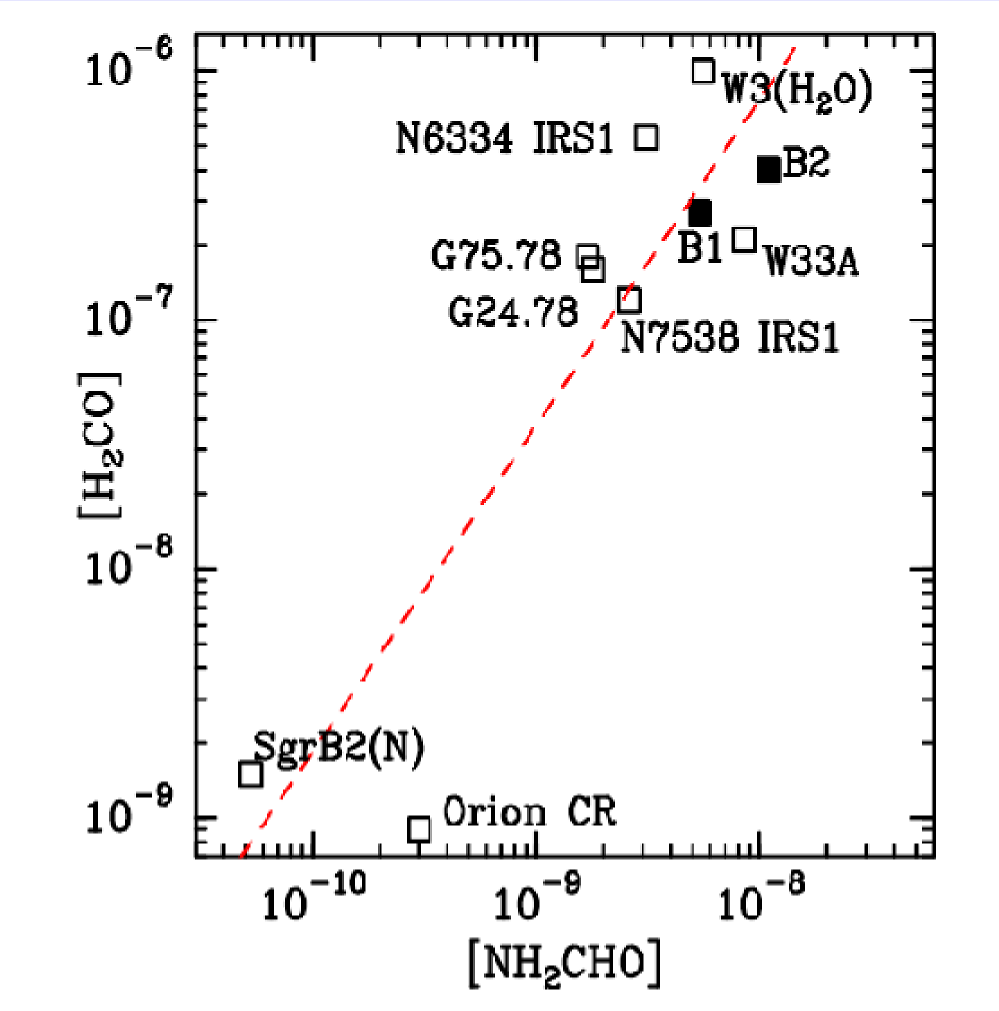


Fig. 1 Grain-surface atom addition reactions starting from CO as proposed by Charnley et al. (2001). Figure adapted from Charnley and Rodgers (2005)

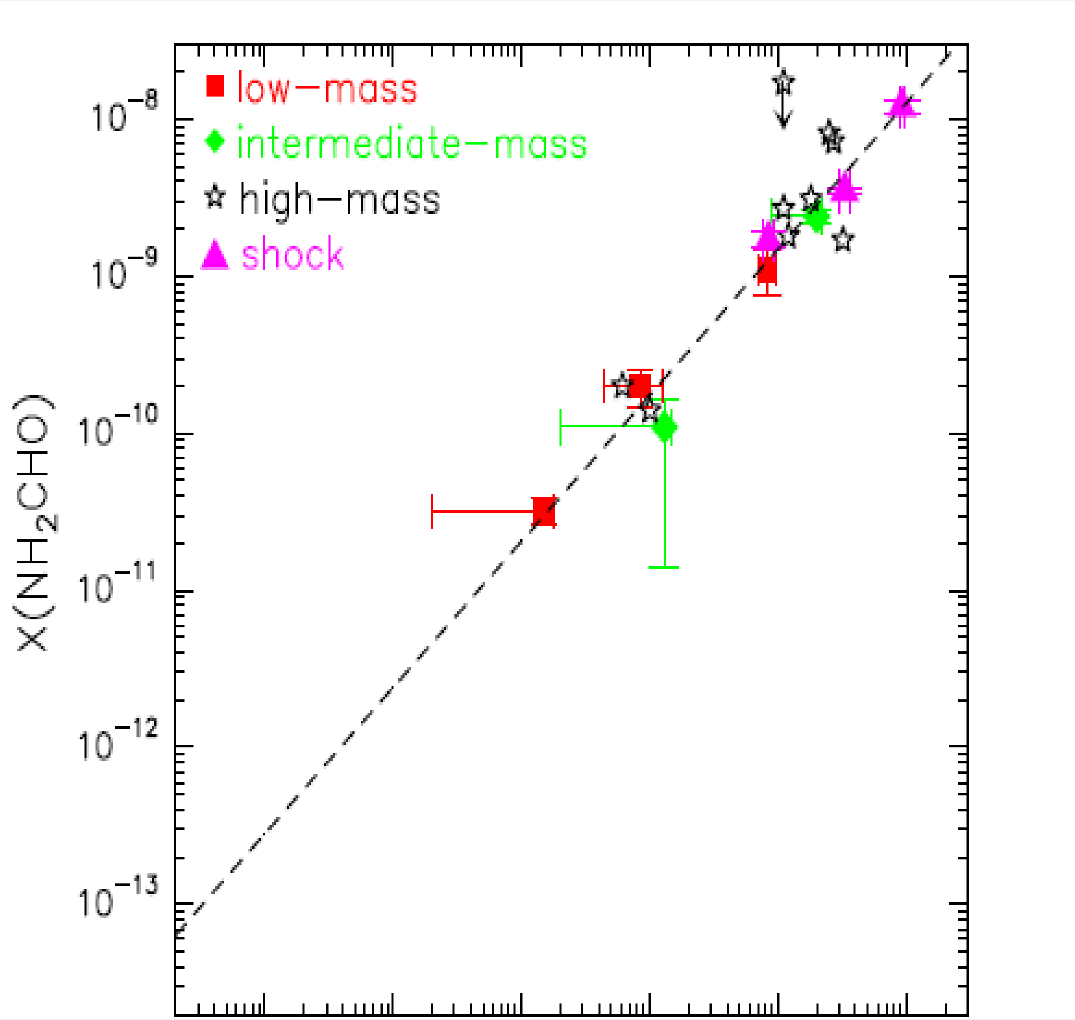
Table 1 Interstellar ice feature inventory with respect to H_2O ice towards dark clouds, low- and high-mass YSOs

Species	λ (μm)	Dark cloud (Elias 16)	L-m YSO (HH 46)	H-m YSO (W33A)
H_2O	3.05	100	100	100
CO	4.67	26[a]	20[b]	8.1[c]
CO_2	4.27	24[d]	21.6[e]	14.1[e]
HCOOH	5.85	≤1.4[f]	2.7[f]	5.2[f]
H_2CO	3.47, 3.54	...	6.0[f]	3.1[c]
CH_3OH	3.08	<2.3[f]	6.1[g]	14.7[f]
NH_3	2.96	≤8[d]	6.1[g]	15[c]
NH_4^+	6.85	5.2[f,i]	6.3[f,i]	8.1[f,i]
CH_4	3.32	<3[d]	5.0[h]	1.5[c]
OCN^-	4.62	<2.3[d]	≤0.6[j]	1.9[j]
OCS	4.92	<0.27[c]	<0.04[k]	0.2[c]

Ioppolo et al. (2011)



Mendoza et al. (2014)



X(HNCO)

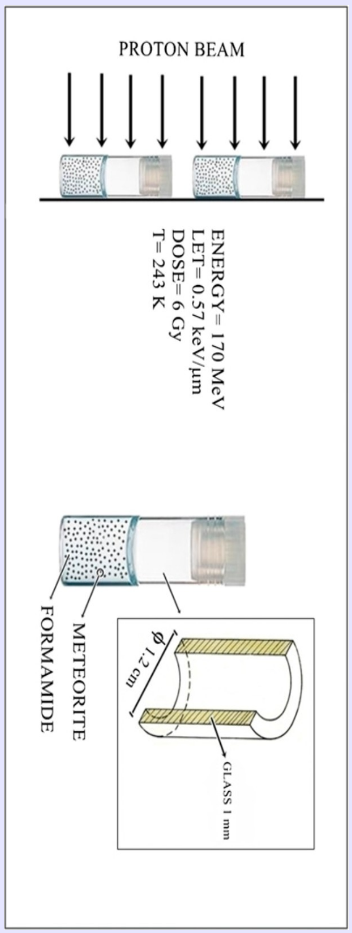
López-Sepulcre et al. (2015)

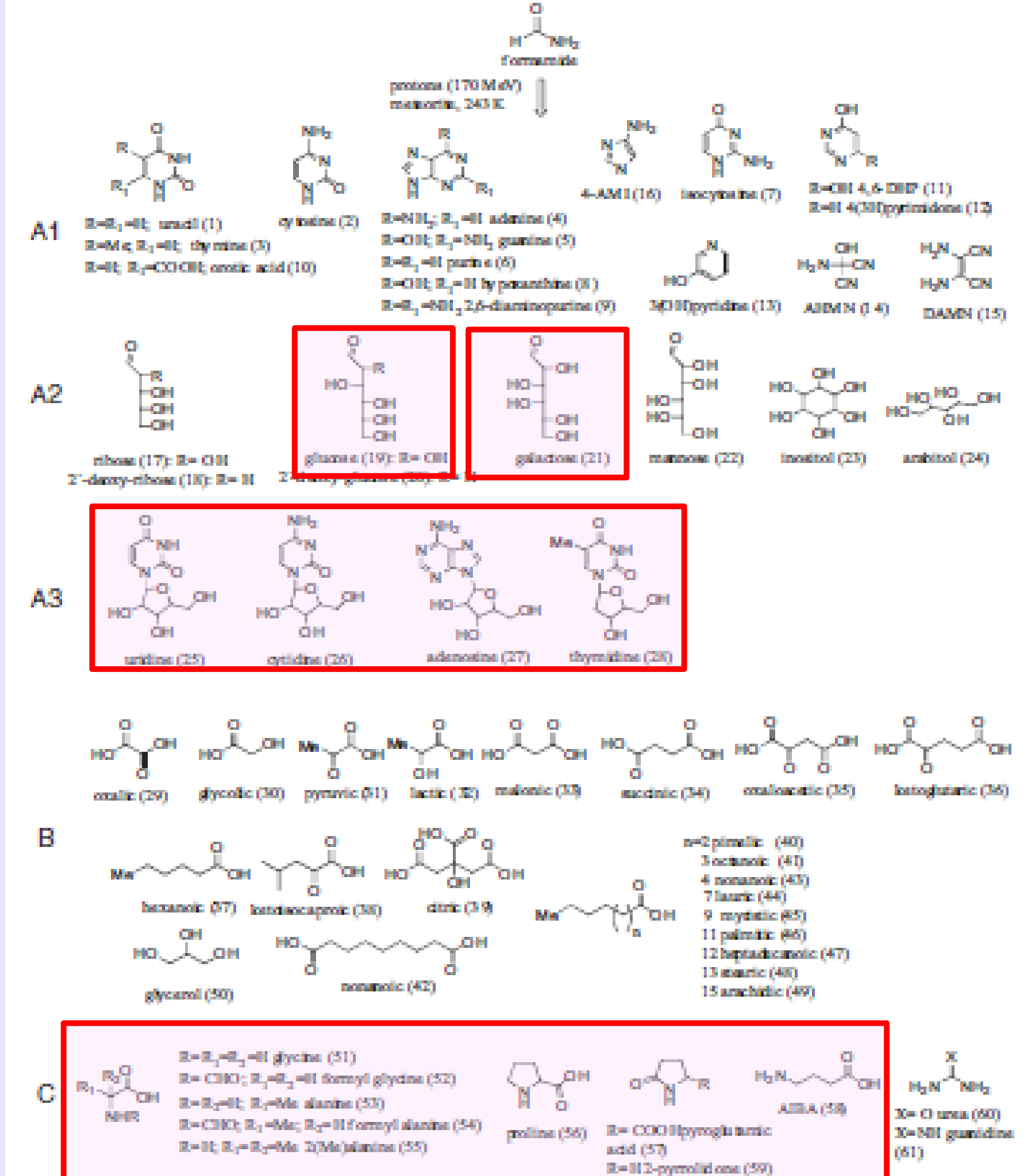
$HNCO + H \rightarrow NH_2CO$

$NH_2CO + H \rightarrow NH_2CHO$

Lots of building blocks formed through meteoritic-catalyzed synthesis from formamide under proton irradiation

Saladino et al. (2015)





sugars

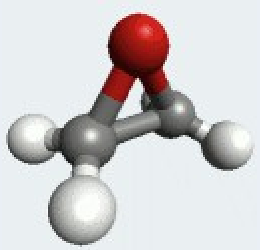
nucleobases

aminoacids

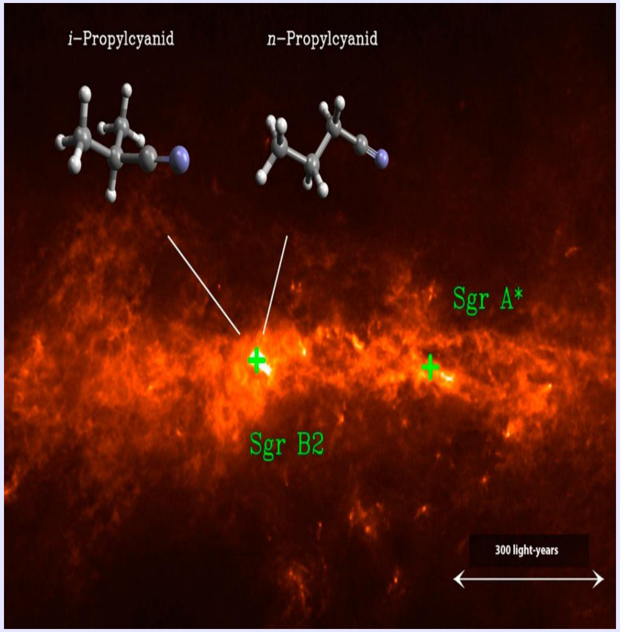
The Cologne Database of detected molecules

Molecules in the Interstellar Medium or Circumstellar Shells (as of 06/2016)

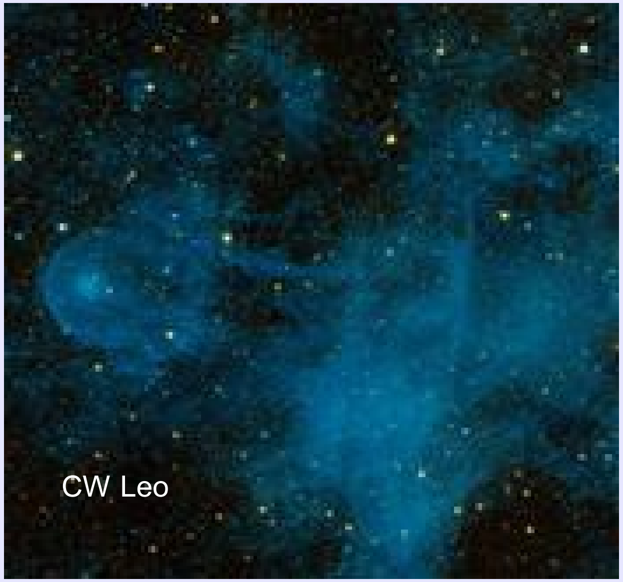
2 atoms	3 atoms	4 atoms	5 atoms	6 atoms	7 atoms	8 atoms	9 atoms	10 atoms	11 atoms	12 atoms	>12 atoms
H_2	C_3 *	c-C_3H	C_5 *	C_5H	C_6H	CH_3C_3N	CH_3C_4H	CH_3C_5N	HC_9N	c-C_6H_6 *	$HC_{11}N$
AlF	C_2H	l-C_3H	C_4H	l-H_2C_4	CH_2CHCN	$HC(O)OCH_3$	CH_3CH_2CN	$(CH_3)_2CO$	CH_3C_6H	n-C_3H_7CN	C_{60} *
AlCl	C_2O	C_3N	C_4Si	C_2H_4*	CH_3C_2H	CH_3COOH	$(CH_3)_2O$	$(CH_2OH)_2$	C_2H_5OCHO	i-C_3H_7CN	C_{70} *
C_2**	C_2S	C_3O	l-C_3H_2	CH_3CN	HC_5N	C_7H	CH_3CH_2OH	CH_3CH_2CHO	$CH_3OC(O)CH_3$	$C_2H_5OCH_3$?	C_{60}^+ *
CH	CH_2	C_3S	c-C_3H_2	CH_3NC	CH_3CHO	C_6H_2	HC_7N	CH_3CHCH_2O 2016			
CH^+	HCN	C_2H_2*	H_2CCN	CH_3OH	CH_3NH_2	CH_2OHCHO	C_8H				
CN	HCO	NH_3	CH_4 *	CH_3SH	c-C_2H_4O	l-HC_6H *	$CH_3C(O)NH_2$				
CO	HCO^+	HCCN	HC_3N	HC_3NH^+	H_2CCHOH	CH_2CHCHO (?)	C_8H^-				
CO^+	HCS^+	$HCNH^+$	HC_2NC	HC_2CHO	C_6H^-	CH_2CCHCN	C_3H_6				
CP	HOC^+	HNCO	HCOOH	NH_2CHO	CH_3NCO 2015	H_2NCH_2CN	CH_3CH_2SH (?)				
SiC	H_2O	HNCS	H_2CNH	C_5N		CH_3CHNH					
HCl	H_2S	$HOCO^+$	H_2C_2O	l-HC_4H *							
KCl	HNC	H_2CO	H_2NCN	l-HC_4N							
NH	HNO	H_2CN	HNC_3	c-H_2C_3O							
NO	MgCN	H_2CS	SiH_4 *	H_2CCNH (?)							
NS	MgNC	H_3O^+	H_2COH^+	C_5N^-							
NaCl	N_2H^+	c-SiC_3	C_4H^-	HNCHCN							
OH	N_2O	CH_3 *	HC(O)CN								
PN	NaCN	C_3N^-	HNCNH								



Organics everywhere !



c-H2C3O, H2NCH2CN, NH, C3, C**2**H, H2C, HNC, HCO+, NH2, HCCN, HCNO, HOCN, NH3, c-C3H2, H2CCN, CH3CN, H2C2CHO, c-C2H4O, CH3CHO, HCONH2, HC2nN, CH3C2N, C2H3CN, H2COHCHO, HCOOCH3, CH3COOH, CH2CHCHO, CH3CHNH, H2NCH2CN, (NH2)2CO, HCOOCH3, C2H5CN, CH3CONH2, C2H5OH, (CH3)2CO ...



CN, C3, C2H, HNC, c-C3H2, CH3OH, C2CH3CN, C7H, HC5N, *l*-C3H, c-C3H, C2H2, C2H4, H2CCN, *l*-H2C4, CH2CHCN, HC2H, HC2nH, HNC, HCCN, H2C2O, C5H, C6H, C2H5CN, HCNO, NH3, C5, C4H, CH3CN, C5N, CH3CHO, CH8

Mapping the presence of organics with ALMA

Walsh et al. Ap J 823, L10 (May, 2016)

a

Detection of gas-phase methanol in the TW Hydrae with ALMA

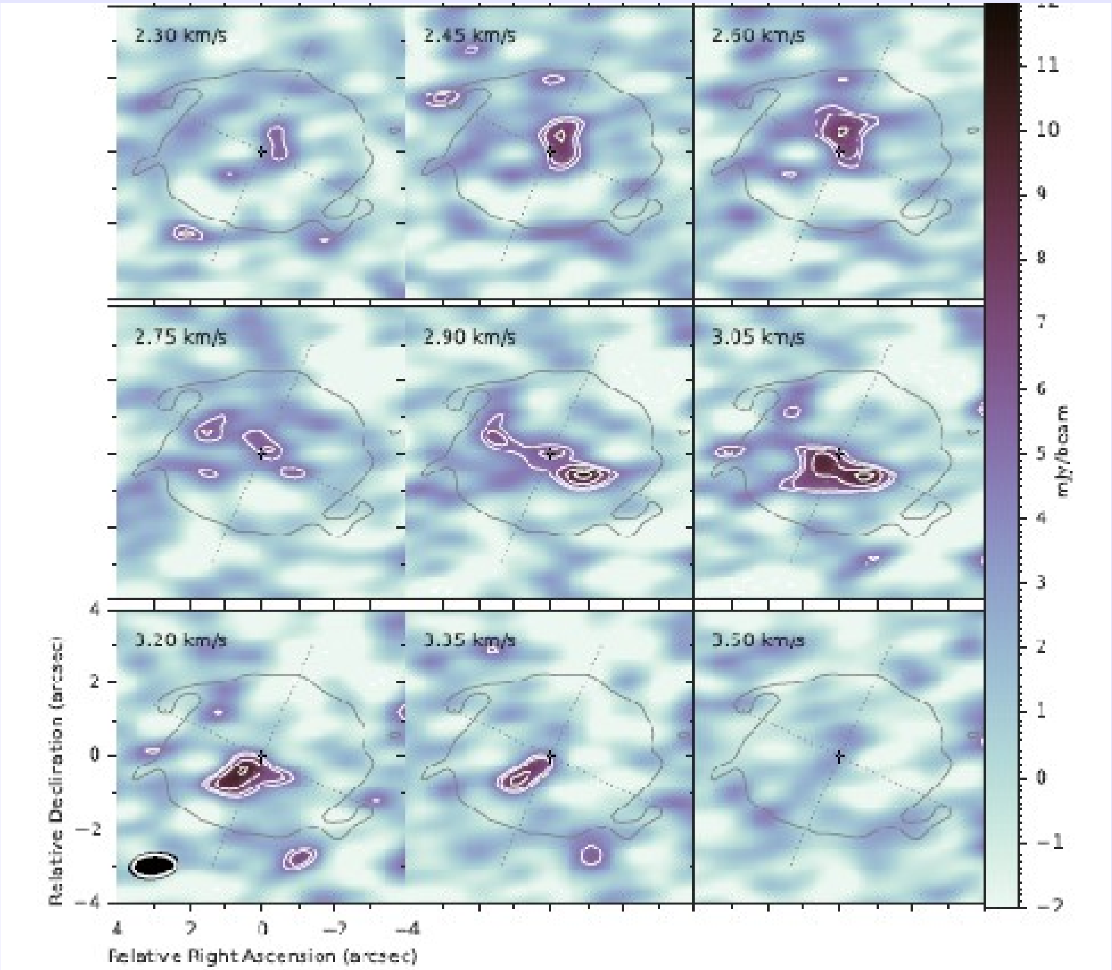


Fig. 1— Channel maps for the stacked observed B7 CH_3OH line emission. The white contours show the 2.5, 3.0, 4.0 and 5.0σ levels for the CH_3OH data and the gray contour shows the 3σ extent of the 317 GHz continuum. The black cross denotes the stellar position, and the dashed gray lines show the disk major and minor axes. The synthesised beams for the continuum (open ellipse) and line (filled ellipse) emission are shown in the bottom-left panel.

MILLER & UREY REACTIONS IN THE UNIVERSE !

),

"All the world began with a *yes*. One molecule said *yes* to another molecule and life was born...

[...] Make no mistake, I only achieve simplicity with enormous effort."

Clarice Lispector
"The Hour of the Star"

Abstract

The atomic composition of the present Universe is largely dominated by hydrogen and helium that were formed in the Big Bang. Heavier elements form through nucleosynthesis inside stars and in Supernovae explosions. From those, a rich chemistry comes out in particular in astrophysical locations as molecular clouds and the interstellar gas. Therewith, simpler elements recombine in successive reaction paths, generating two-, three- and even four-atom compounds. Hydrogen, carbon, oxygen and nitrogen easily react forming H_2O, NH_3, CO, CH_4, and CO_2. From these simple molecules, more complex organics such as formaldehyde (HCOH), hydrogen cyanide (HCN), methanol (CH2OH), formic acid (HCOOH) and glycoaldehyde (HCOH2) are shown to appear driven by proper catalysis, as it was successfully showed in several Miller & Urey-like laboratory experiments. This contribution is intended to feed evidence on how those robust prebiotic reactions could have shaped a life-friendly Universe, providing solid arguments for future observations and science development.