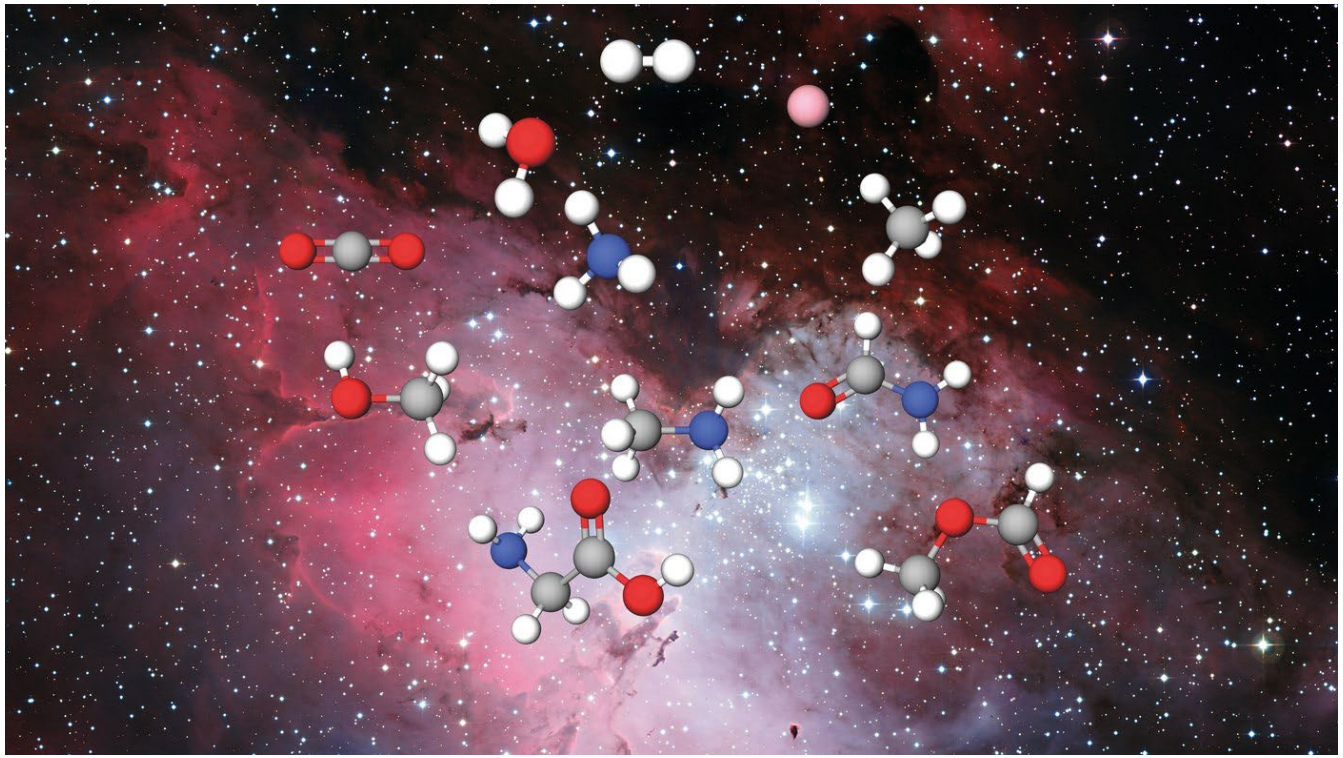
Exploring Prebiotic Chemistry in Cosmic Ice Analogues through Laboratory Studies



Tushar Suhasaria, MPIA

Perspectives of Planet and Star formation, 25th June, 2026

Acknowledgements & Collaborations

Our group:

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Thomas Henning

Collaborator:

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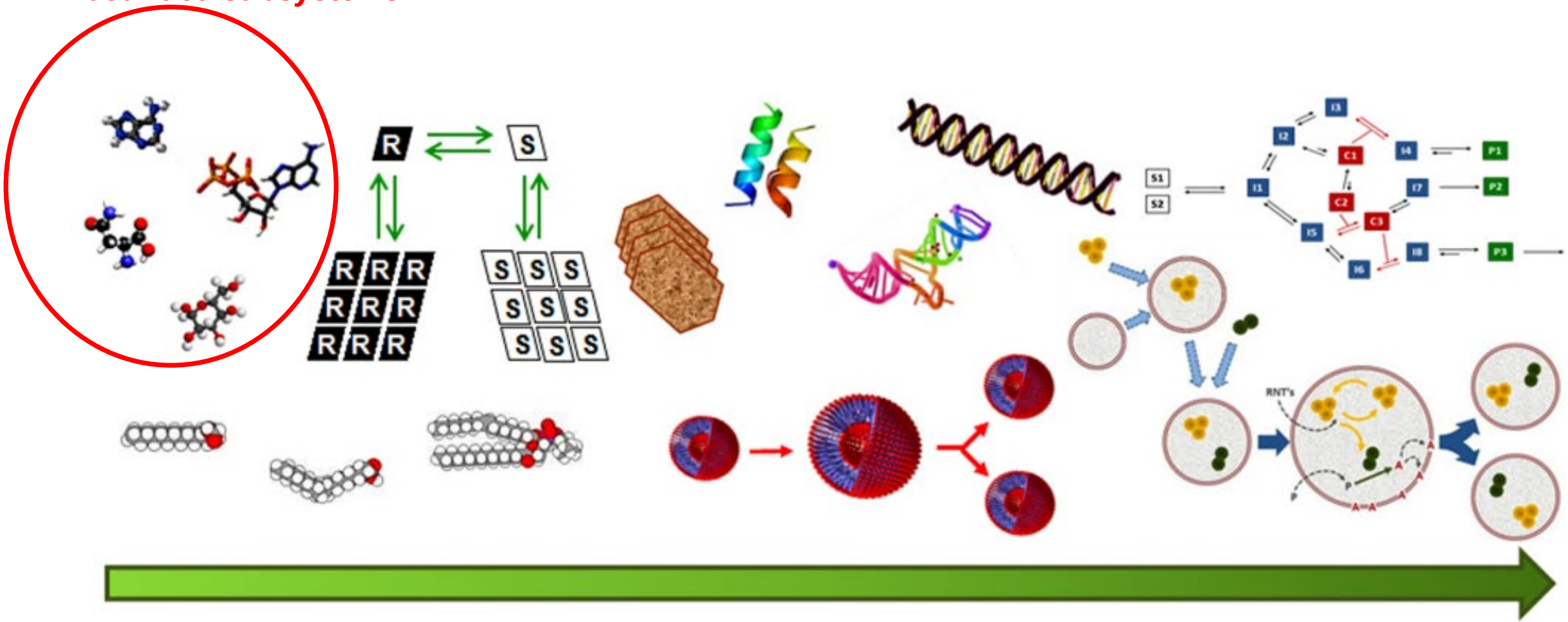
Oliver Trapp
Nico Ueberschaar

Prebiotic components for Origin of Life

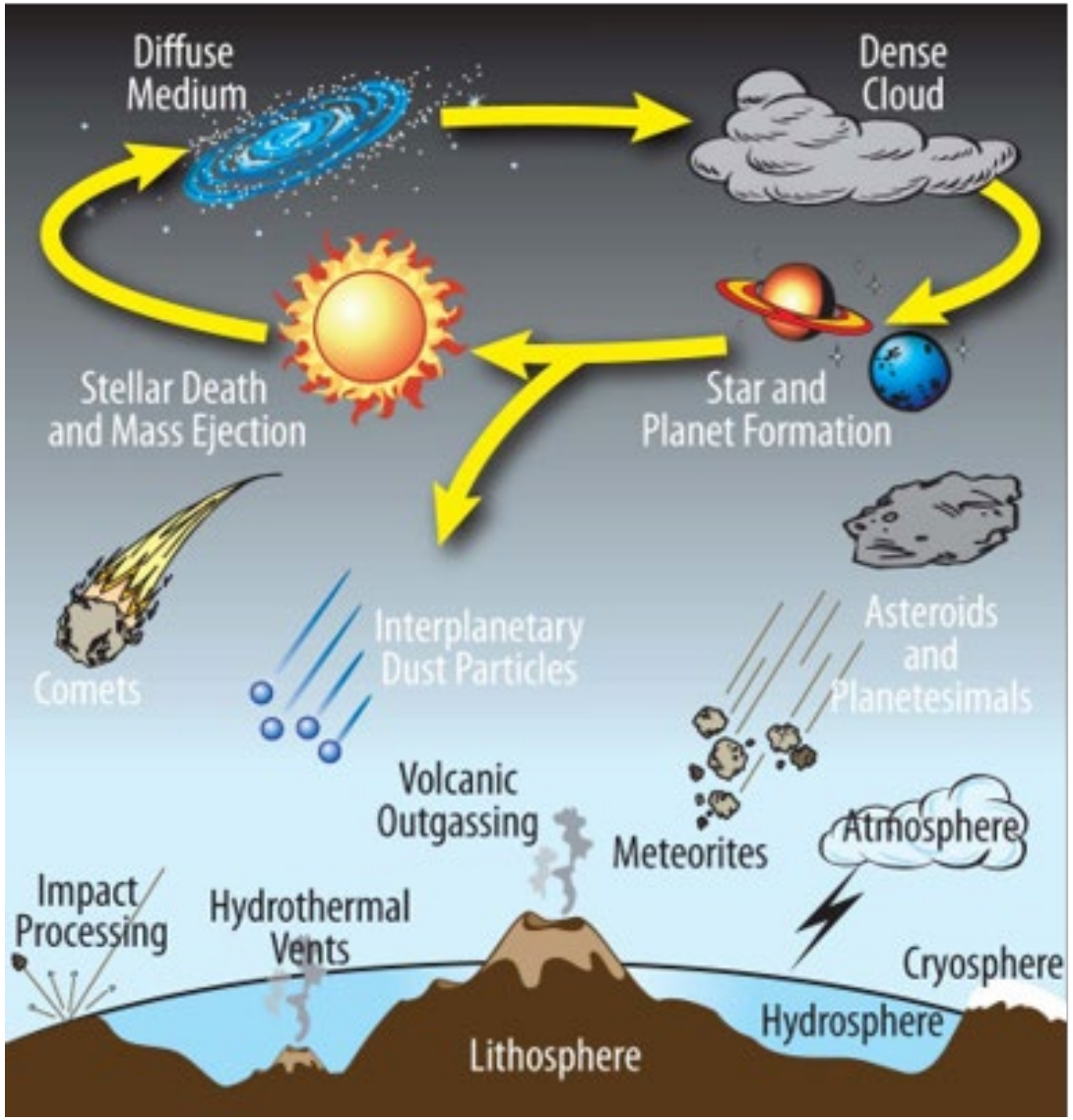
Precursor components progressively turning to Primordial metabolic, self-replicating, and membrane bounded subsystems

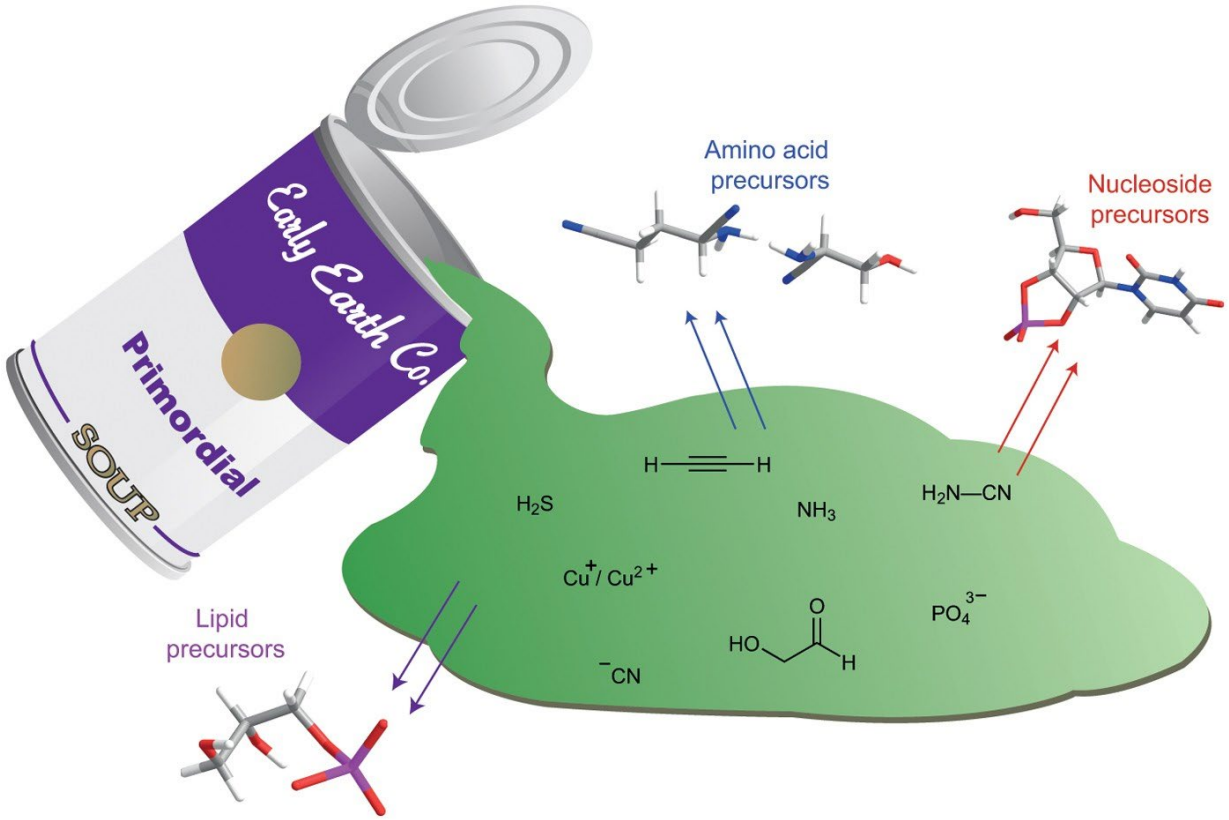


Increasing chemical complexity

Ruiz-mirazo 2014

Motivation: From molecular cloud to life on Earth





Deamer+2002, Bracher 2015

Prebiotic formation in ice analogues and detection in meteorite analysis

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] Søren V. Hoffmann,[5] Louis Le Sergeant d'Hendecourt,[3] Uwe J. Meierhenrich[1*]

Amino acids from ultraviolet irradiation of interstellar ice analogues

G. M. Muñoz Caro*, U. J. Meierhenrich†‡, W. A. Schutte*, B. Barbier†, A. Arcones Segovia*, H. Rosenbauer§, W. H.-P. Thiemann‡, A. Brack† & J. M. Greenberg*

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]

Racemic amino acids from the ultraviolet photolysis of interstellar ice analogues

Max P. Bernstein*†, Jason P. Dworkin*†, Scott A. Sandford†, George W. Cooper† & Louis J. Allamandola†

Carbonaceous meteorites as a source of sugar-related organic compounds for the early Earth

George Cooper*, Novelle Kimmich*, Warren Belisle*, Josh Sarinana*, Katrina Brabham* & Laurence Garrel†

The amino acid and hydrocarbon contents of the Paris meteorite: Insights into the most primitive CM chondrite

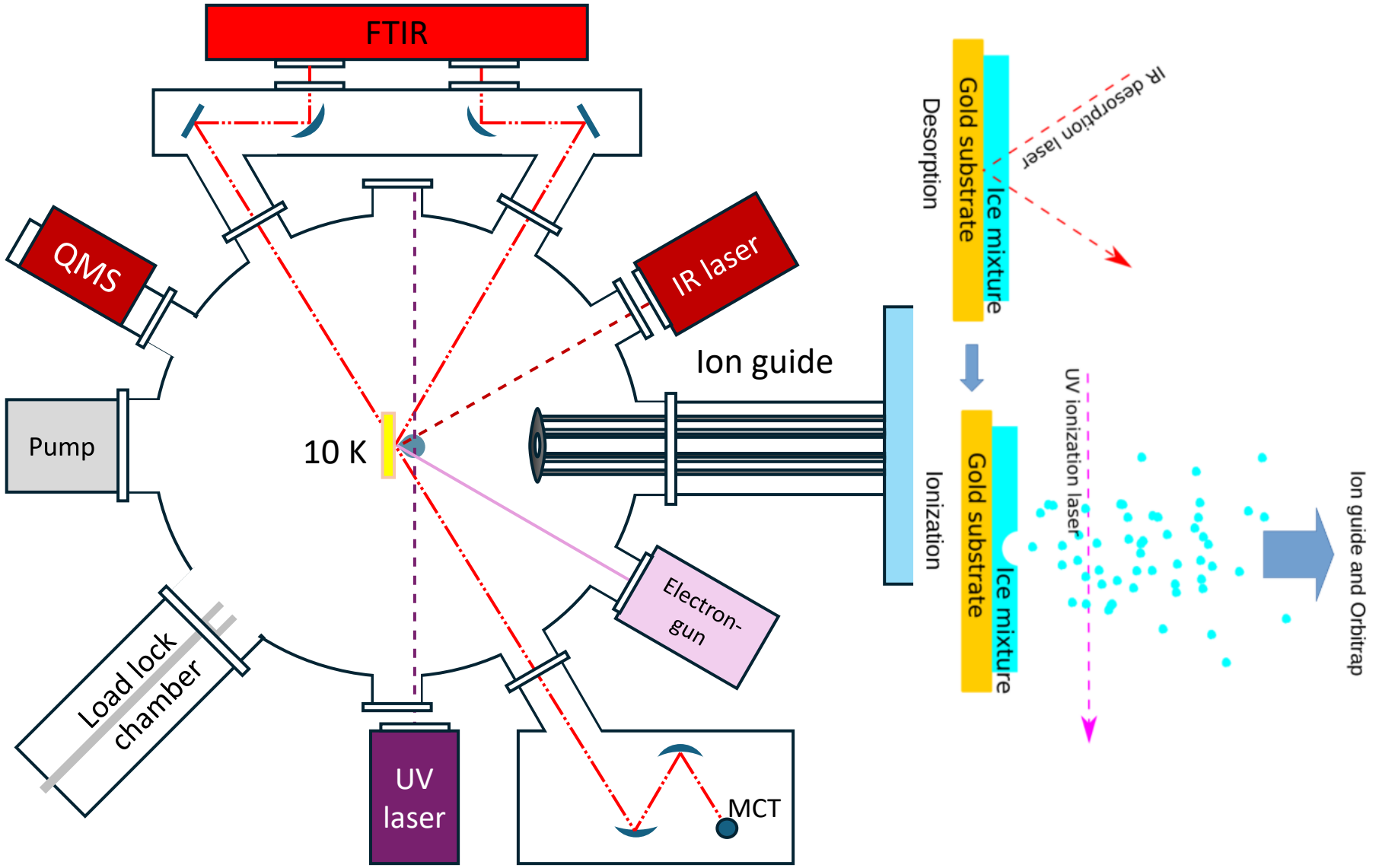
Zita MARTINS[1*], Paola MODICA[2], Brigitte ZANDA[3], and Louis Le Sergeant D'HENDECOURT[2]

Meinert+2016, Nuevo+2018, Munoz Caro+2002, Bernstein+2002, Cooper+2002, Martins+2015

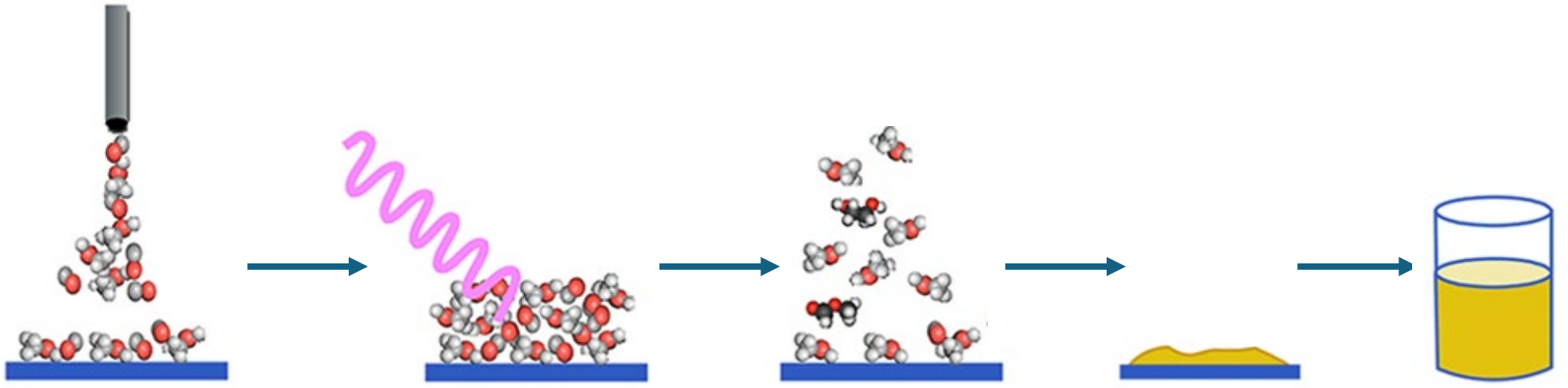
Perspectives

- Are prebiotics really formed at 10 K? Can we detect them at that temperature in energetic processing experiment?
- What are the roles of the underlying grain surface in the ice chemistry?
- Are these process stochastic or is there a specific route?
- Which molecules or combination can enhance prebiotic formation?
- Starting point simple icy mantles or intermediates? How is formation of prebiotic influenced?

Simulate the space environment in Origins Lab



Wet chemical analysis



Deposition & Characterization

FTIR

Irradiation & Product analysis

FTIR

Warm-Up to 300 K

QMS

Residue

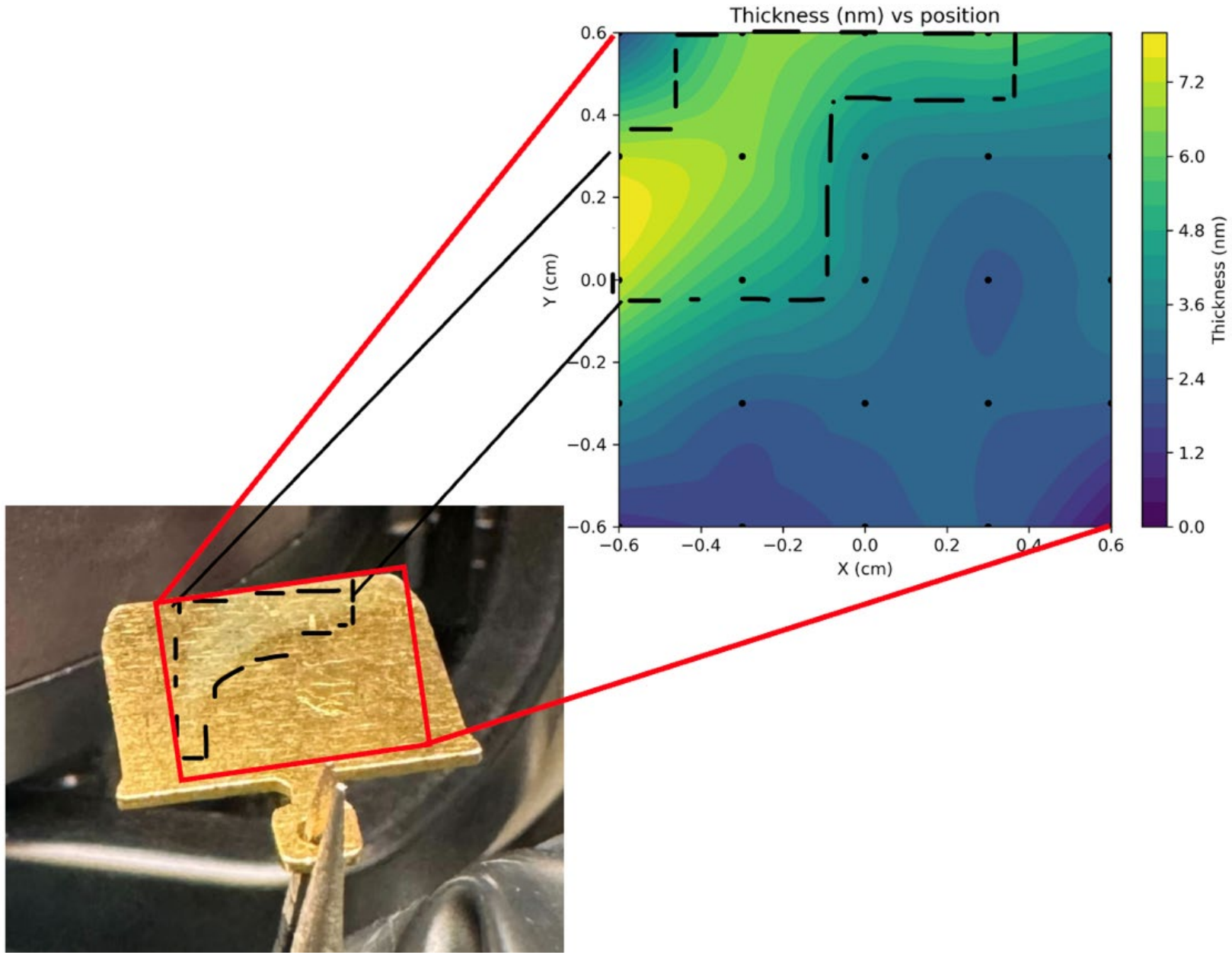
FTIR

Solvation

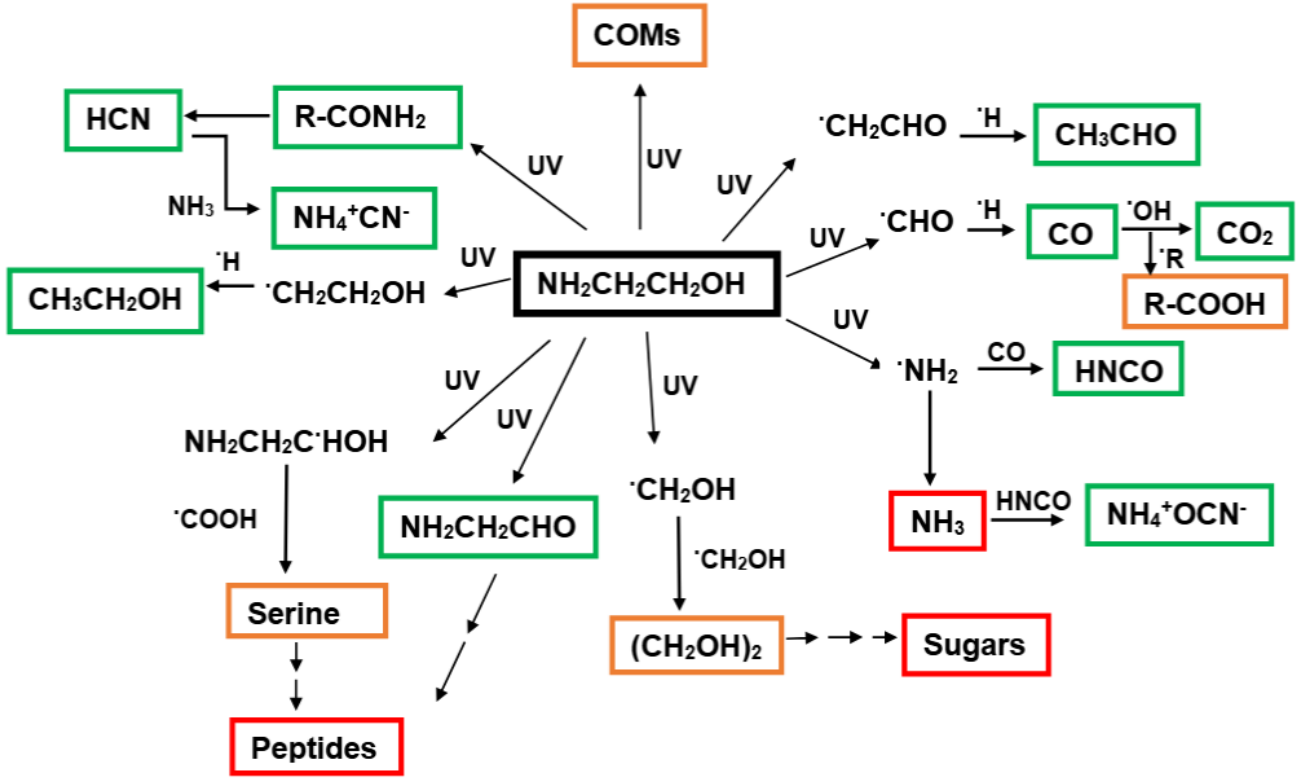
Chromatography

Wet chemical analysis

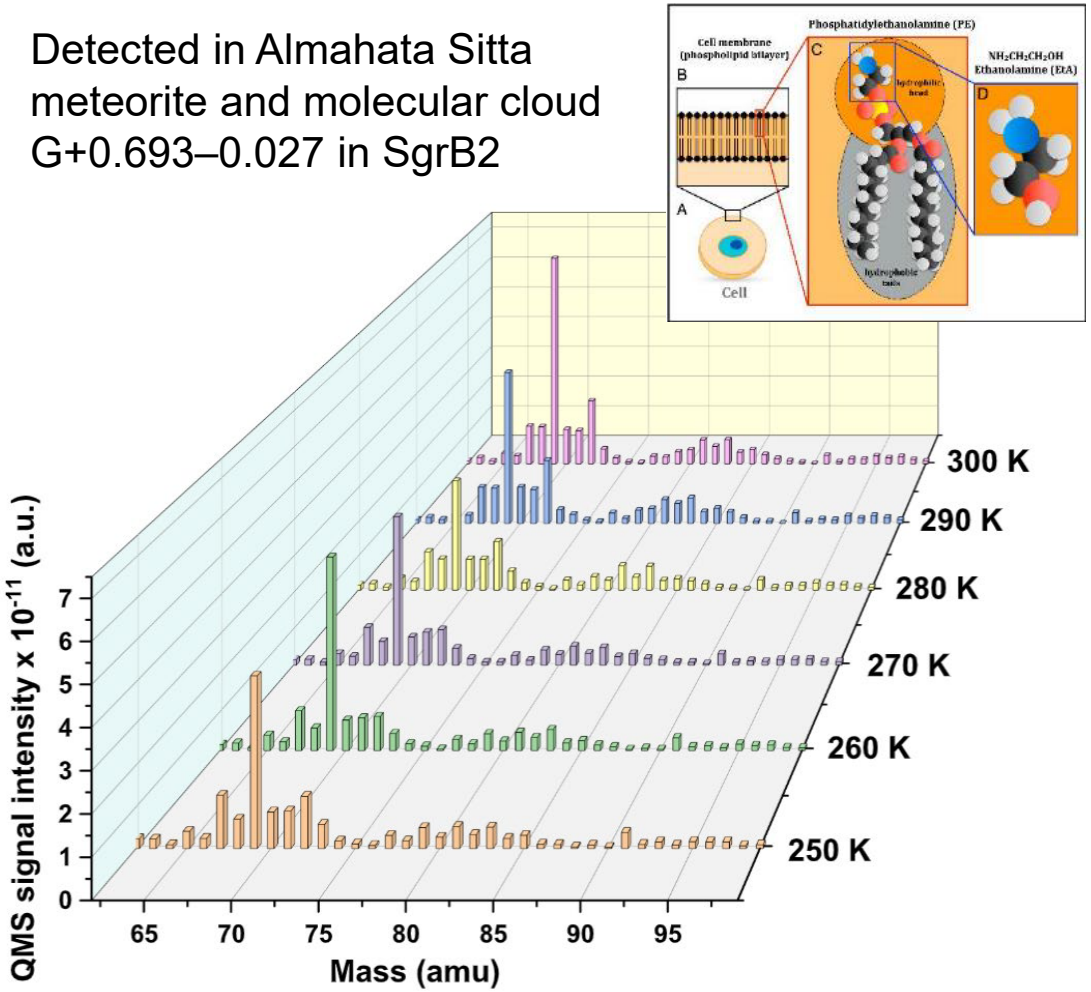
High res Mass Spectrometer


Thickness (nm) vs position
Y (cm)
X (cm)
Thickness (nm)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
7.2
6.0
4.8
3.6
2.4
1.2
0.0

Ly-α processing of solid EA: potential precursors to sugar and peptide derivatives



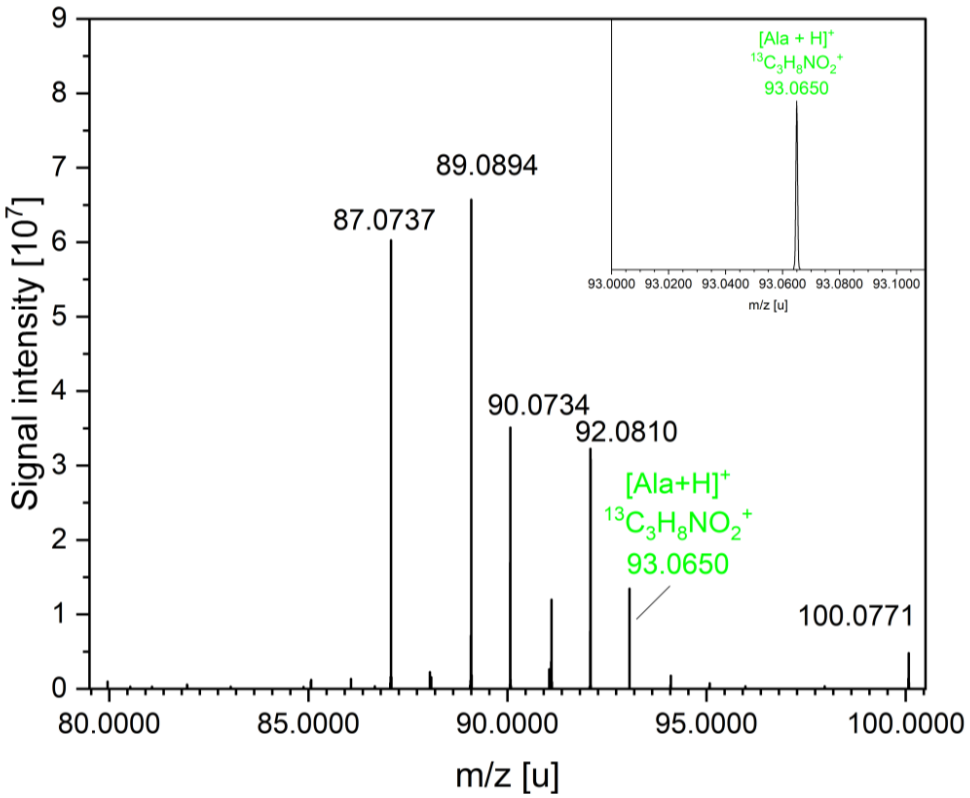
Detected in Almahata Sitta meteorite and molecular cloud G+0.693–0.027 in SgrB2



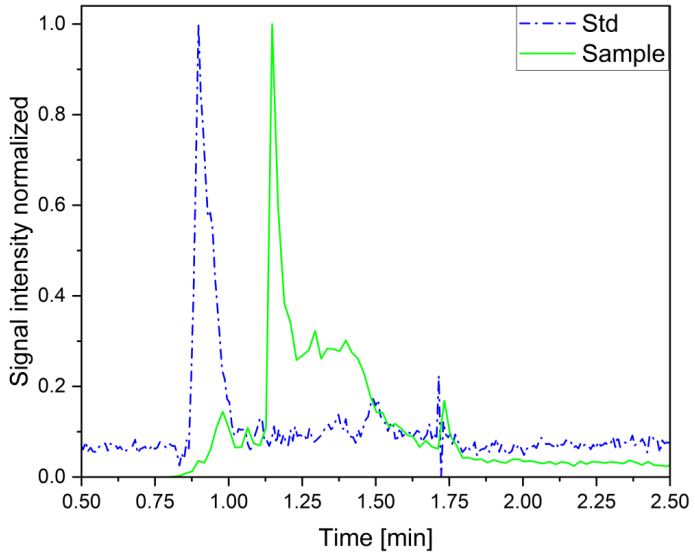
Used IR and Mass spectra for analysis

Rivilla+2021, Zhang+2024, Suhasaria+2025

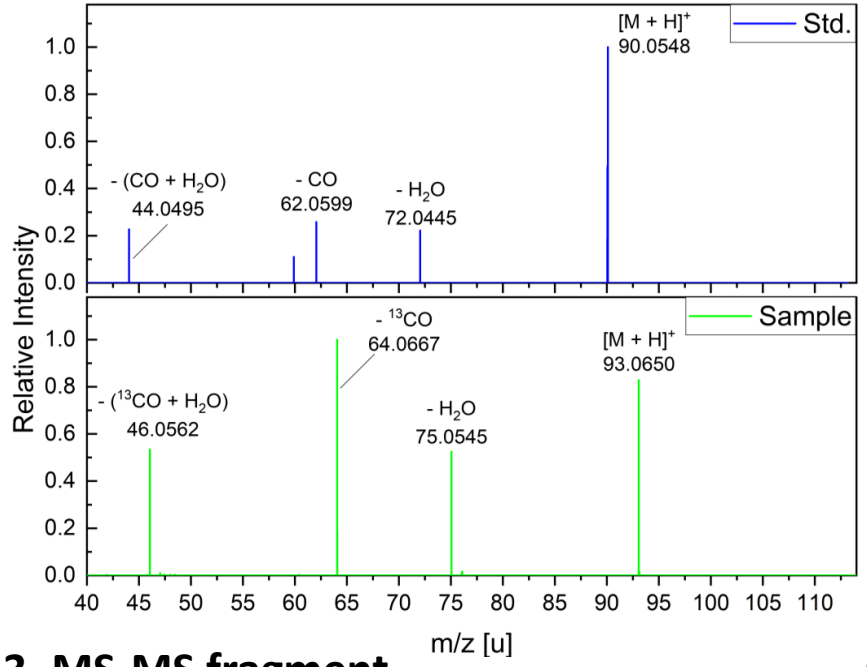
Amino acid/dipeptide synthesis in ice analogues



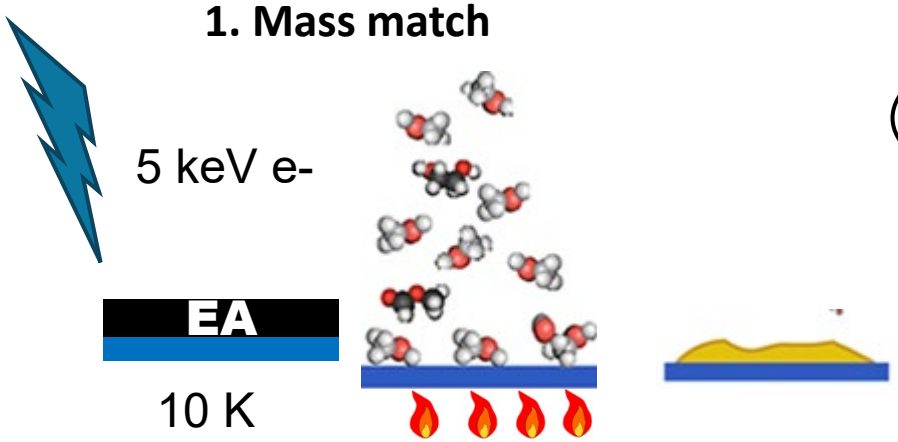
1. Mass match



2. RT match



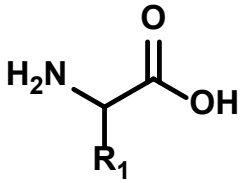
3. MS-MS fragment

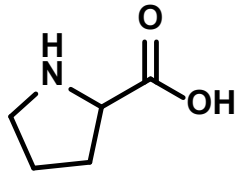


Alanine

Amino acid/dipeptide synthesis in ice analogues

Amino acids

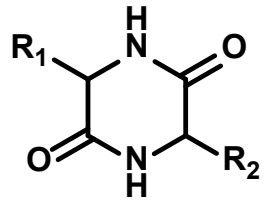




1. R_1 = CH_3 (Ala)
2. R_1 = C_3H_7 (Val)
3.* R_1 = C_4H_9 (Leu/Ile)
4. R_1 = C_2H_5O (Thr)
5.* R_1 = C_3H_6NO (Gln)

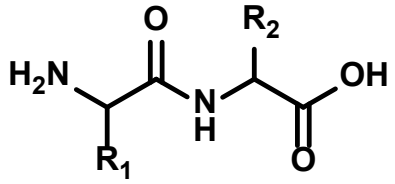
6. Pro

Cyclic dipeptides

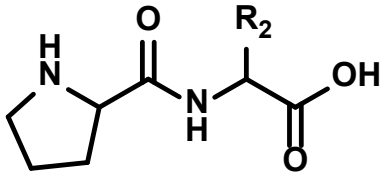


1.* R_1 = H (Gly) - R_2 = H (Gly)
2. R_1 = H (Gly) - R_2 = CH_3 (Ala)

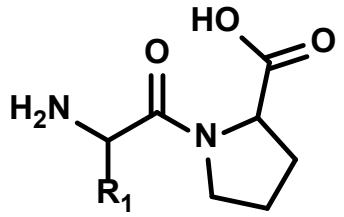
Dipeptides



1.* R_1 = CH_3 (Ala) - R_2 = H (Gly)
2. R_1 = CH_3 (Ala) - R_2 = C_3H_7 (Val)
3. R_1 = C_4H_9 (Leu) - R_2 = H (Gly)



4. Pro - R_2 = H (Gly)
5. Pro - R_2 = CH_3 (Ala)



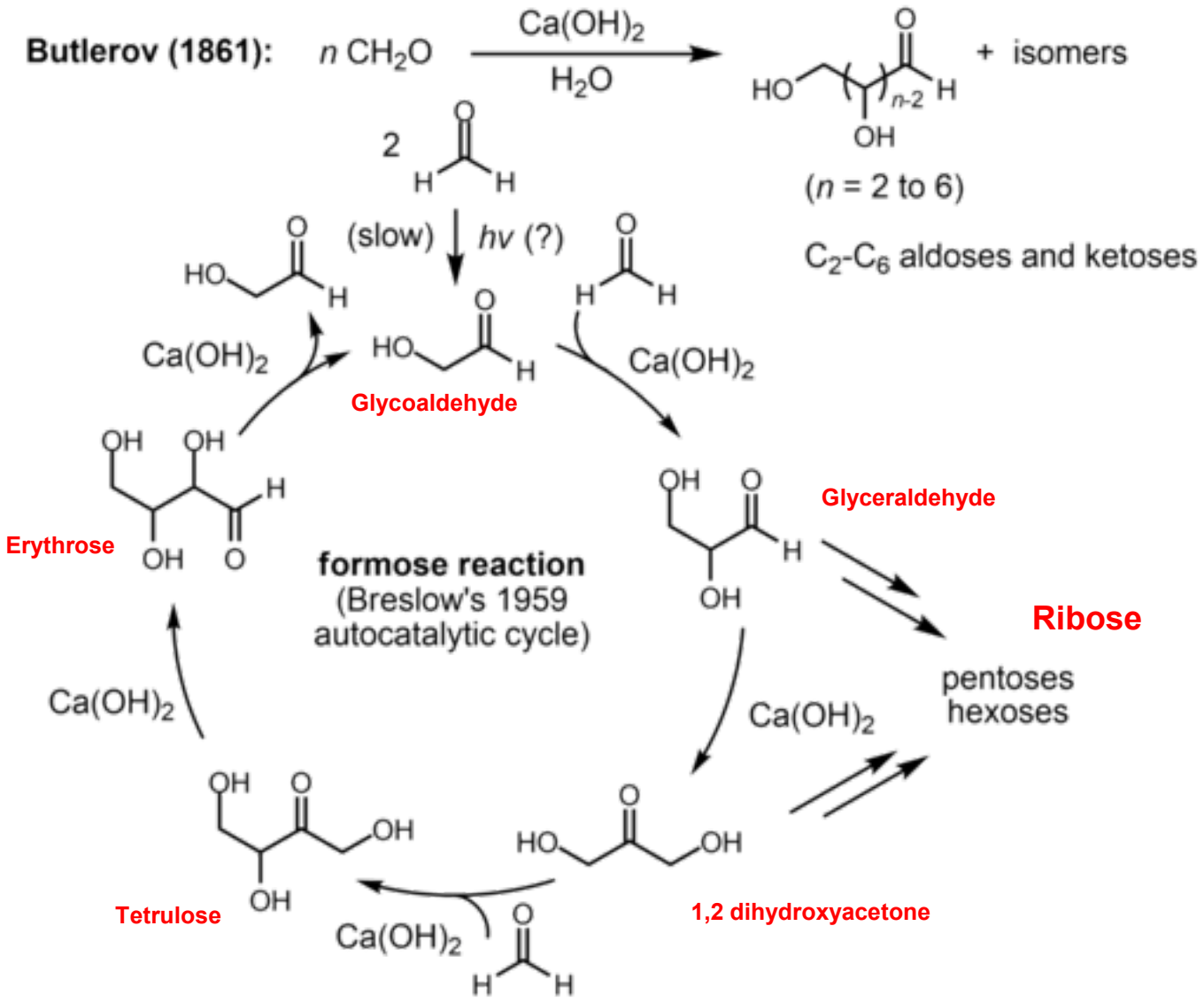
6. R_1 = CH_3 (Ala) - Pro

*tentative; Blue = New detections

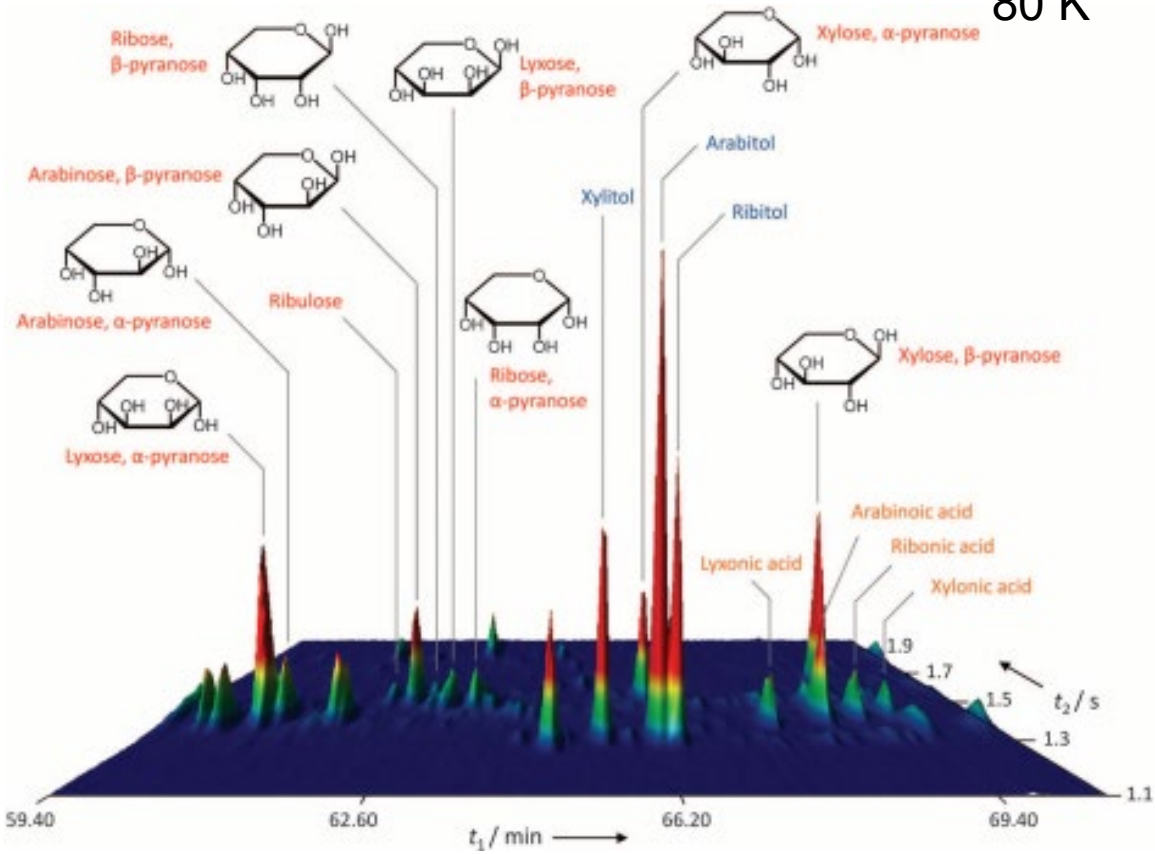
Catalytic effect in sugar synthesis

10.2 eV photons

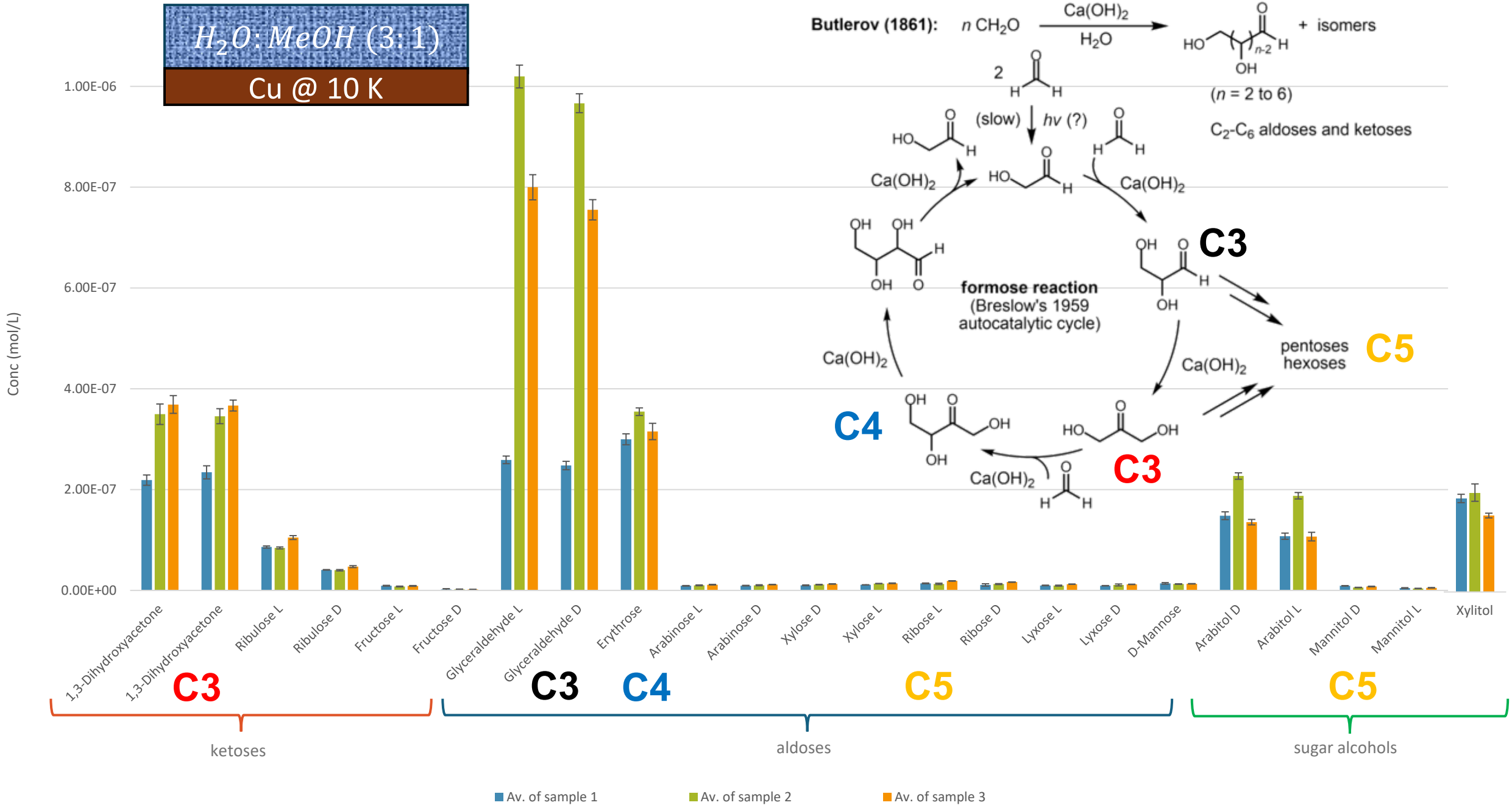
H_2O:CH_3OH:NH_3



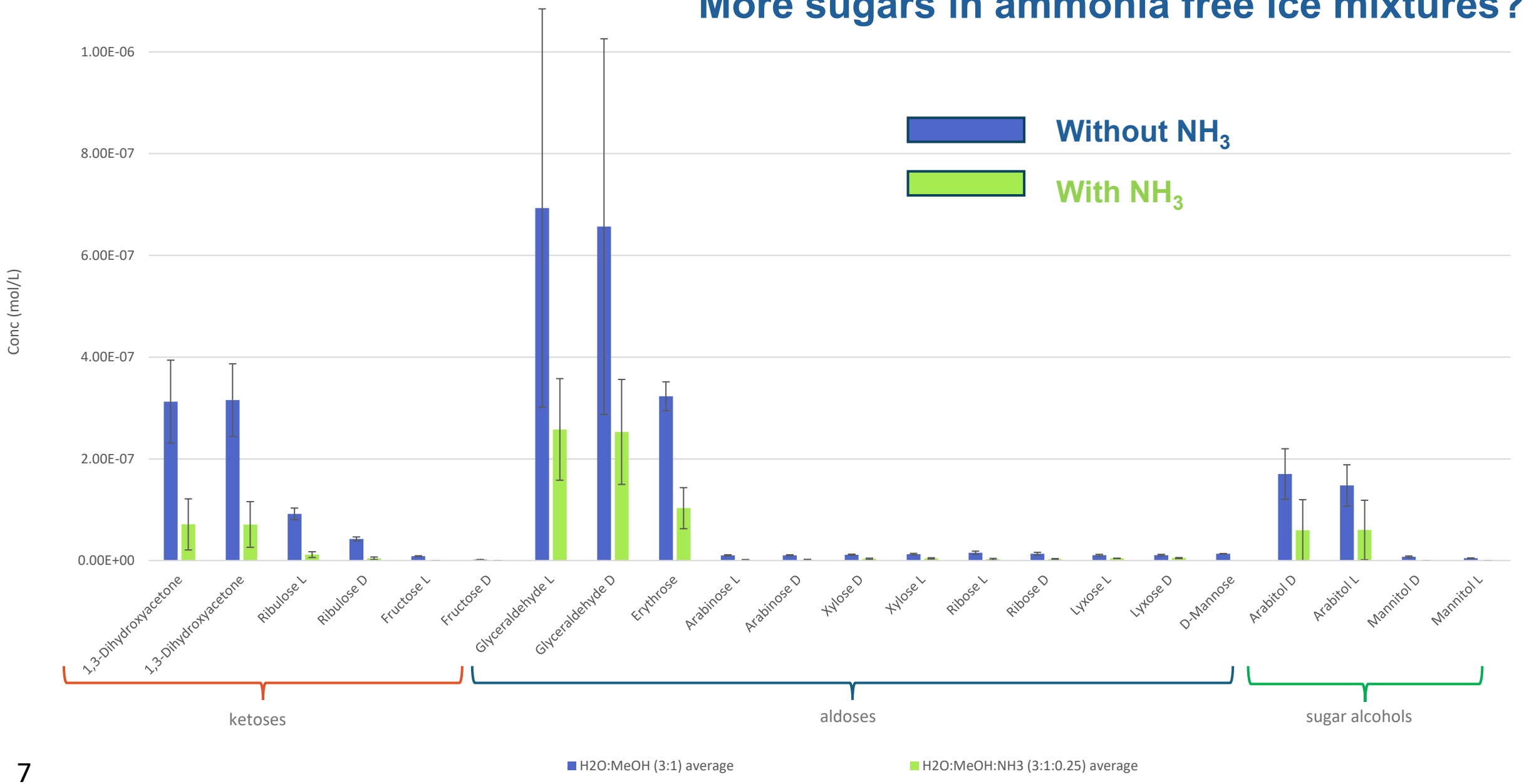
80 K



Meinert+ 2016


$H_2O:MeOH$ (3:1)
Cu @ 10 K
Butlerov (1861): n CH2O Ca(OH)2 H2O + isomers
(n = 2 to 6)
C2-C6 aldoses and ketoses
(slow) hv (?)
Ca(OH)2
formose reaction
(Breslow's 1959 autocatalytic cycle)
C3
C4
C5
pentoses
hexoses
Conc (mol/L)
1.00E-06
8.00E-07
6.00E-07
4.00E-07
2.00E-07
0.00E+00
1,3-Dihydroxyacetone
1,3-Dihydroxyacetone
Ribulose L
Ribulose D
Fructose L
Fructose D
Glyceraldehyde L
Glyceraldehyde D
Erythrose
Arabinose L
Arabinose D
Xylose D
Xylose L
Ribose L
Ribose D
Lyxose L
Lyxose D
D-Mannose
Arabitol D
Arabitol L
Mannitol D
Mannitol L
Xylitol
C3
C3
C4
C5
C5
ketoses
aldoses
sugar alcohols
Av. of sample 1
Av. of sample 2
Av. of sample 3

More sugars in ammonia free ice mixtures?



Prebiotic components: summary & conclusion

	Sugars, sugaracids	Amino acids, peptides
Starting ice analog	Water:methanol with/without ammonia	Ethanolamine
Analysis	Derivitization	Direct analysis
Results	Quantitative analysis, Stereochemistry	Unambiguous qualitative identification

- The presence of NH_3 likely causes competition between nitrogen-containing compound formation (amino acids) and sugar formation in terms of available carbons
- We can detect amino acids without extra derivitization step and also inspite of using very high energy the fragile amino acids and simple peptides survive