Astrobiology with ALMA: Searching for Prebiotic Compounds in Protoplanetary Disks

Claudia Lage[1], Eduardo Janot-Pacheco[2], Philippe Bendjoya[3], Olga Suarez[3], Martine Adrian-Scotto[3], Bruno Lopez[3], Alex Carciofi[2], Armando Domiciano[3]

Looking forward understand life's cosmic origin with ALMA

- exoplanetary formation *vs.* ASTROBIOLOGICALLY IMPORTANT exoplanets formation

- better resolution in defining molecular mapping and complexity for different stars' ages

- **complex biomolecules: how to observe them ?**

RELATIVE ABUNDANCE (% 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

Two-element pre-biotic compounds:

CH_4 CO H_2O NH_3

Three-element pre-biotic compounds:

HCO^- HCN

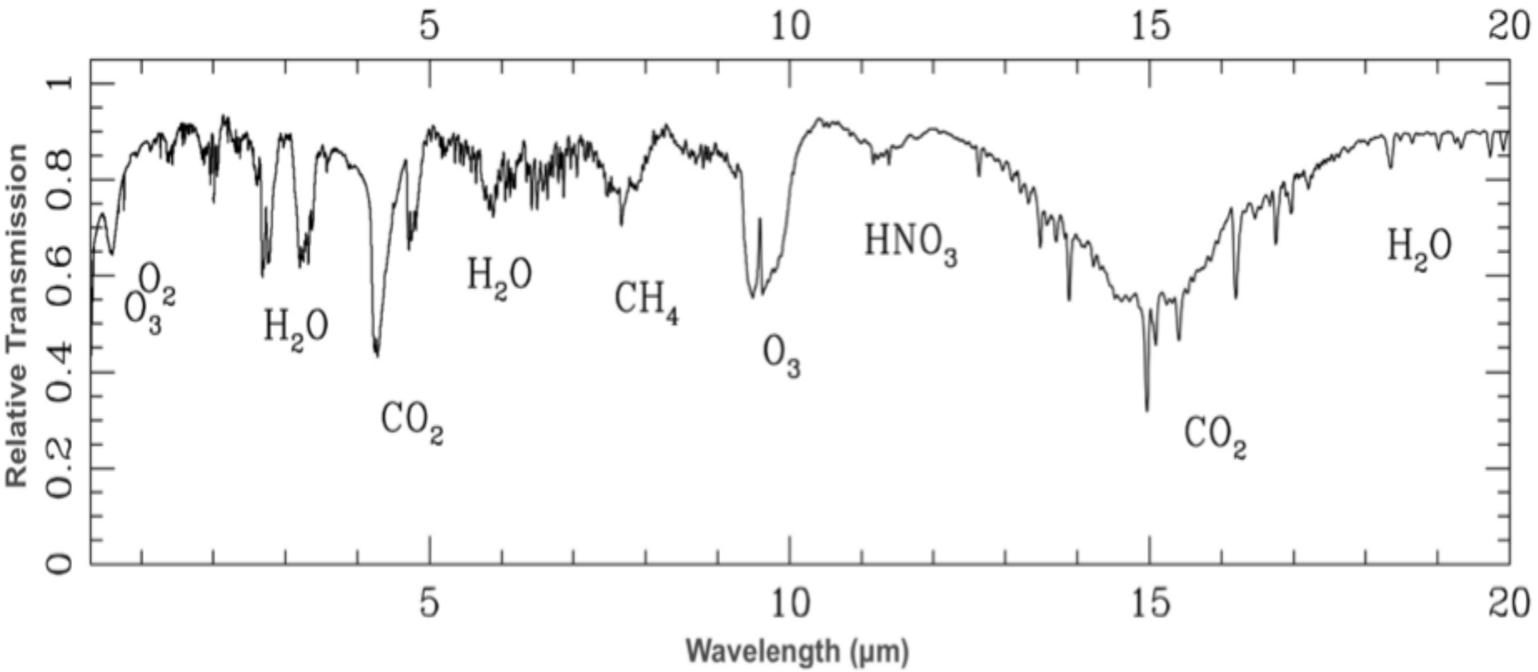
(formaldehyde) (hydrogen cyanide)

AMINO ACID	MURCHISON METEORITE	DISCHARGE EXPERIMENT
GLYCINE	• • • •	• • • •
ALANINE	• • • •	• • • •
α-AMINO-*N*-BUTYRIC ACID	• • •	• • • •
α-AMINOISOBUTYRIC ACID	• • • •	• •
VALINE	• • •	• •
NORVALINE	• • •	• • •
ISOVALINE	• •	• •
PROLINE	• • •	•
PIPECOLIC ACID	•	•
ASPARTIC ACID	• • •	• • •
GLUTAMIC ACID	• • •	• •
β-ALANINE	• •	• •
β-AMINO-*N*-BUTYRIC ACID	•	•
β-AMINOISOBUTYRIC ACID	•	•
γ-AMINOBUTYRIC ACID	•	• •
SARCOSINE	• •	• • •
N-ETHYLGLYCINE	• •	• • •
N-METHYLALANINE	• •	• •

Proc Natl Acad Sci USA, 1972, 69(4): 809–811. Nonprotein Amino Acids from Spark Discharges and Their Comparison with the Murchison Meteorite Amino Acids, Yecheskel Wolman, William J. Haverland, and Stanley L. Miller

What to tr@ck ? (a real highway to follow !)

- particular spectral signatures of simple biogenic C,O,N compounds, together (ex. Earth IR spectrum);



Life building blocks – who are they ?

Sugars → energy source

Nucleobases → DNA, RNA

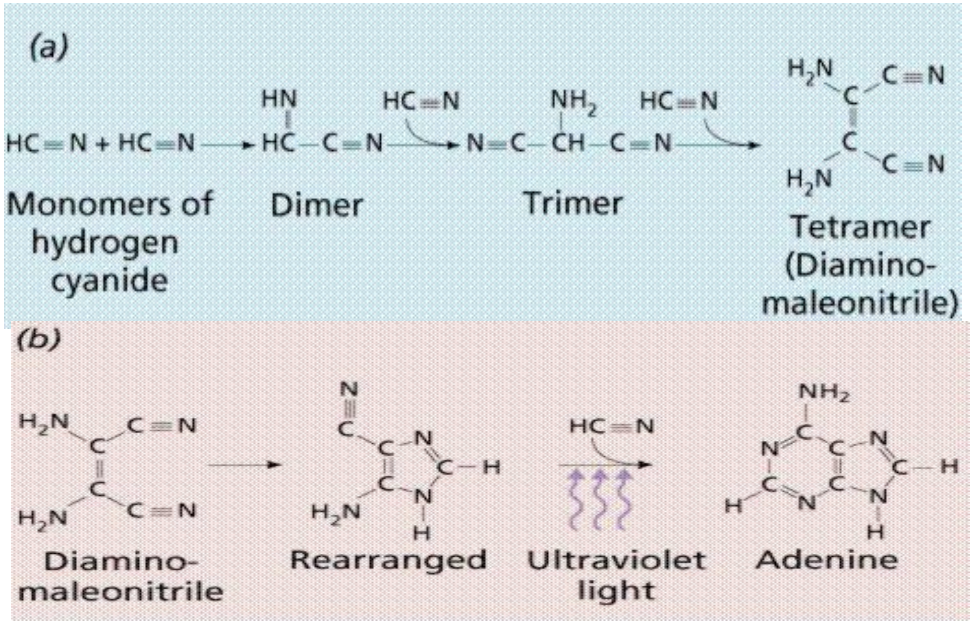
Aminoacids → proteins

Lipids → membranes

From simple to complex ...

Primitive abiogenic reactions supposed to have generated life building blocks

$[HCN]_8$ = purines (DNA nucleobases)

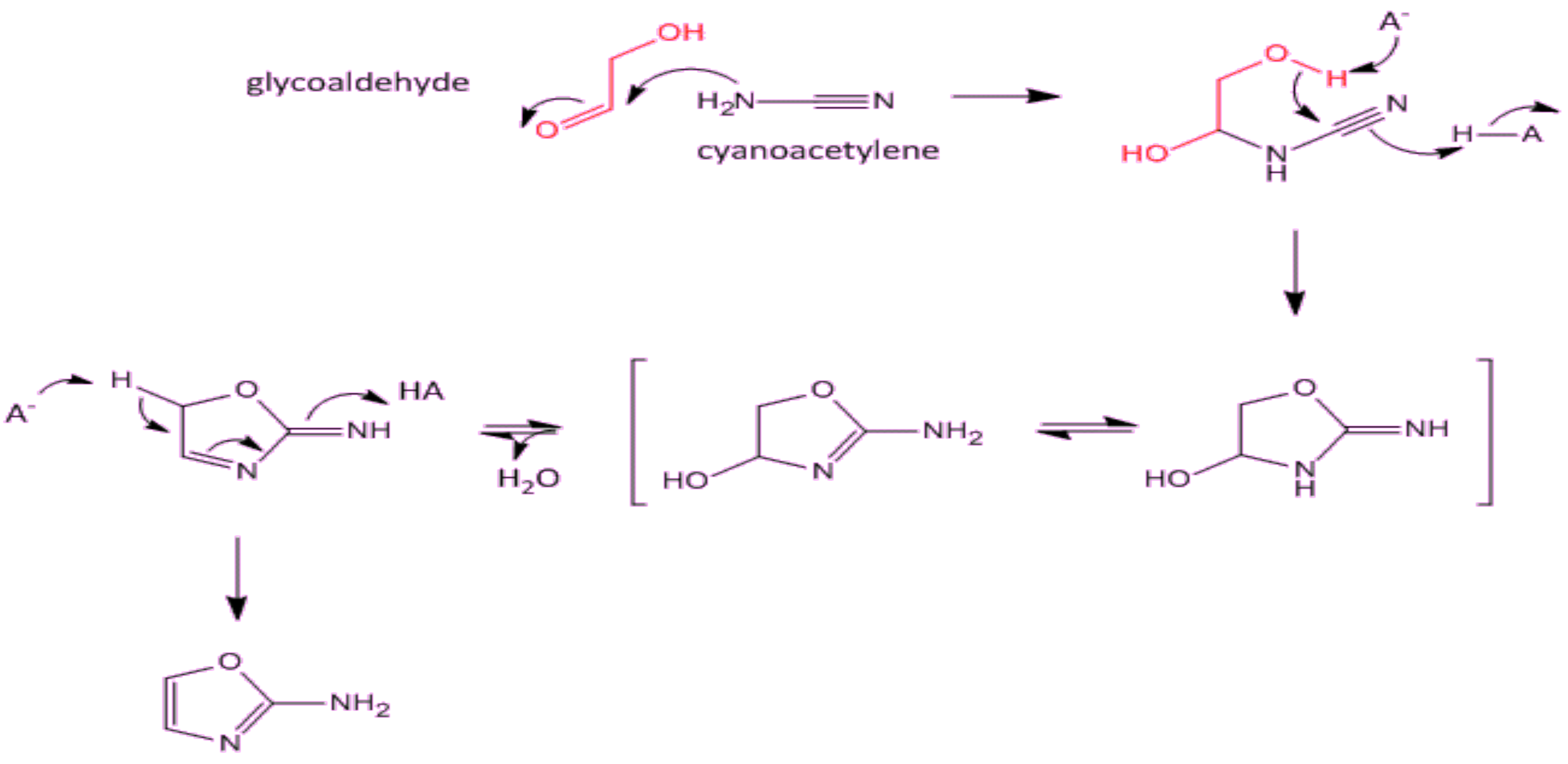


Saladino et al., 2004

From simple to complex ...

Primitive abiogenic reactions supposed to have generated life building blocks

[?] = pyrimidines (DNA nucleobase)



2-amino-oxazole 11

Powner *et al.*, Nature 2009

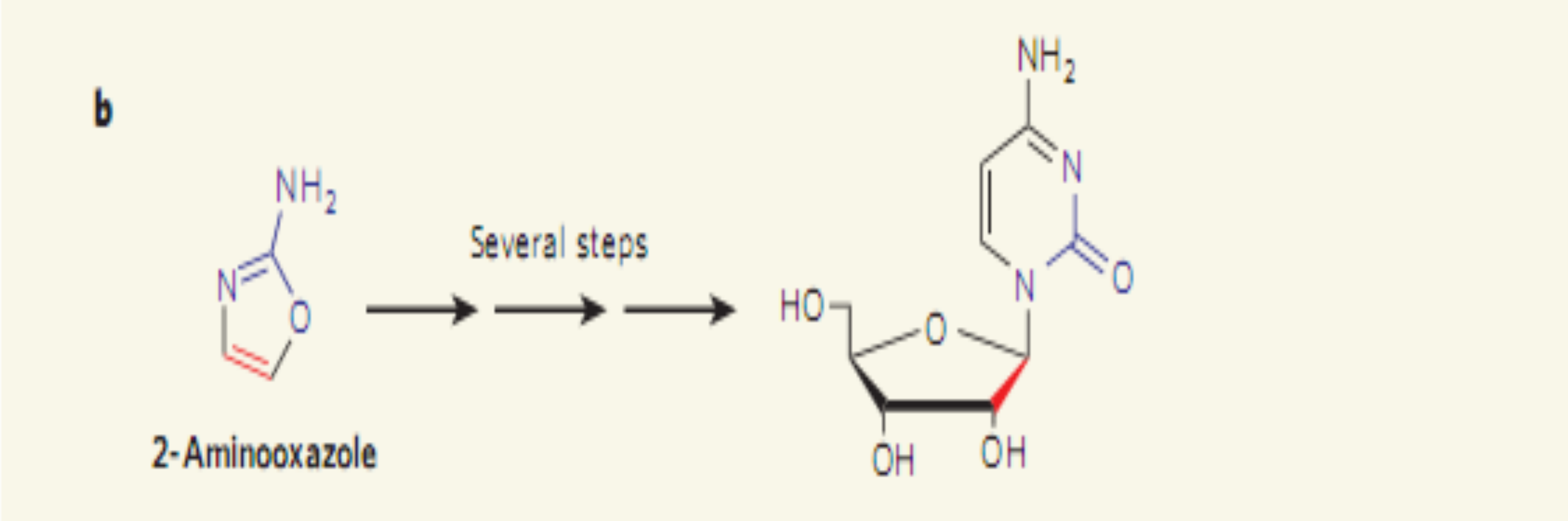
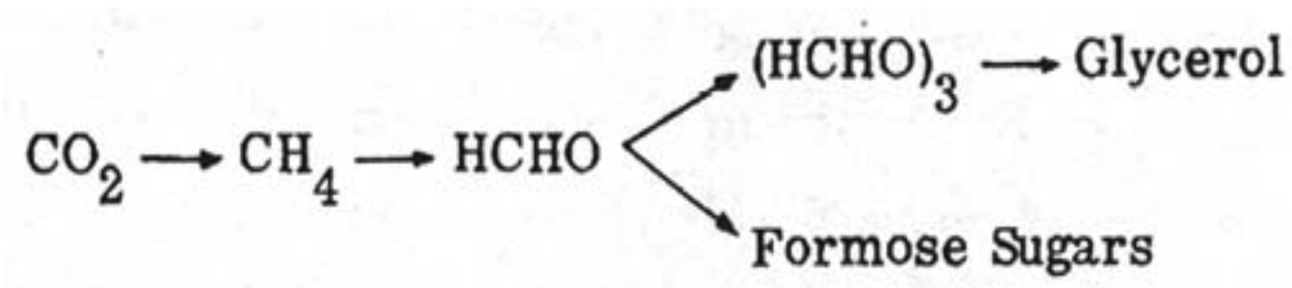


Figure 1 | Theories of prebiotic syntheses of pyrimidine ribonucleotides. The idea that RNA might have formed spontaneously on early Earth has inspired a search for feasible prebiotic syntheses of ribonucleotides, the building blocks of RNA. **a**, The traditional view is that the ribose sugar and nucleobase components of ribonucleotides formed separately, and then combined. But no plausible reactions have been found in which the two components could have joined together. **b**, Powner *et al.*[2] show that a single 2-aminooxazole intermediate could have contributed atoms to both the sugar and nucleobase portions of pyrimidine ribonucleotides, so that components did not have to form separately. For a more detailed overview of the pathways depicted here, see Figure 1 on page 239.

From simple to complex …

Primitive abiogenic reactions supposed to have generated life building blocks

HCHO = simple sugars



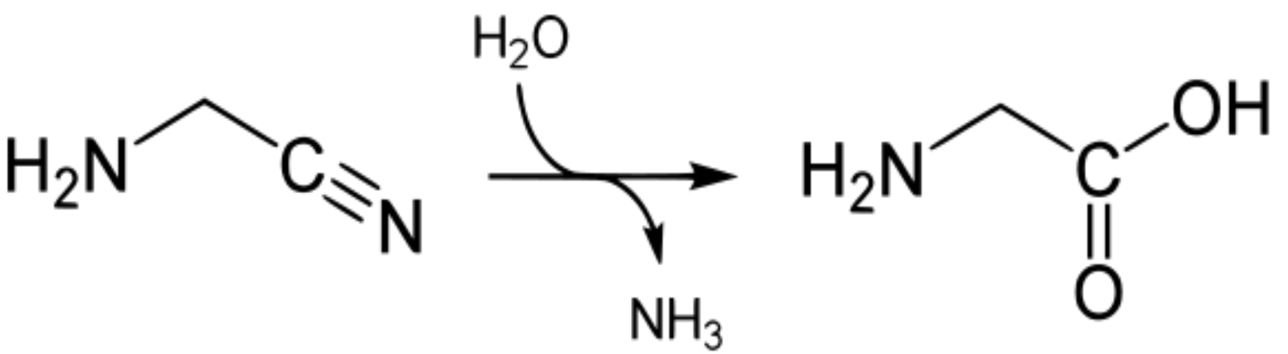
Prebiotic synthesis of simple sugars by an interstellar formose reaction. Jalbout AF. Orig Life Evol Biosph, 2008, 38(6):489-497

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 + HCN = simple aminoacids

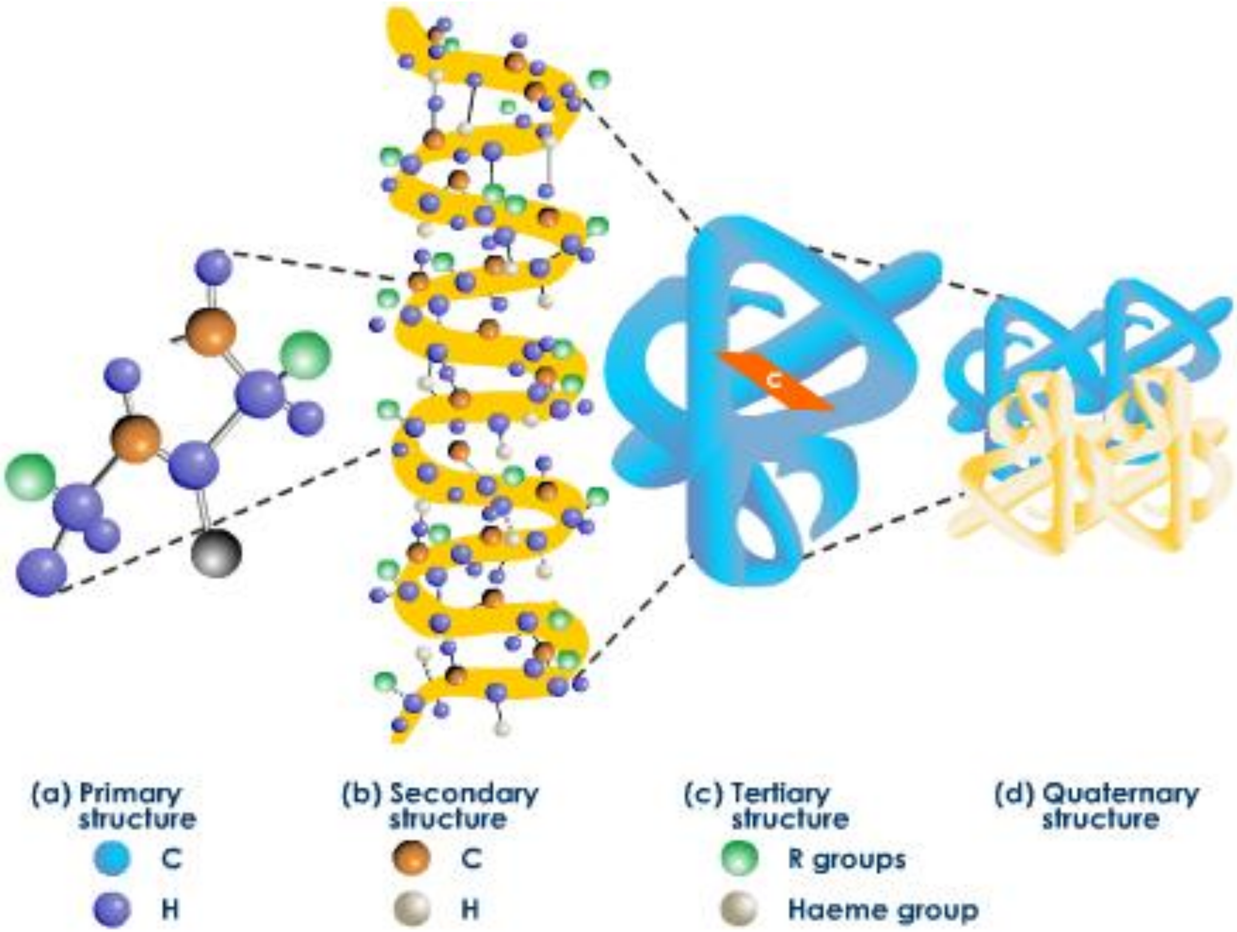


acetonitrile **glycine**

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



Evidence for life on Earth before 3,800 million years ago

S. J. Mojzsis*, G. Arrhenius*, K. D. McKeegan†, T. M. Harrison†, A. P. Nutman‡ & C. R. L. Friend§

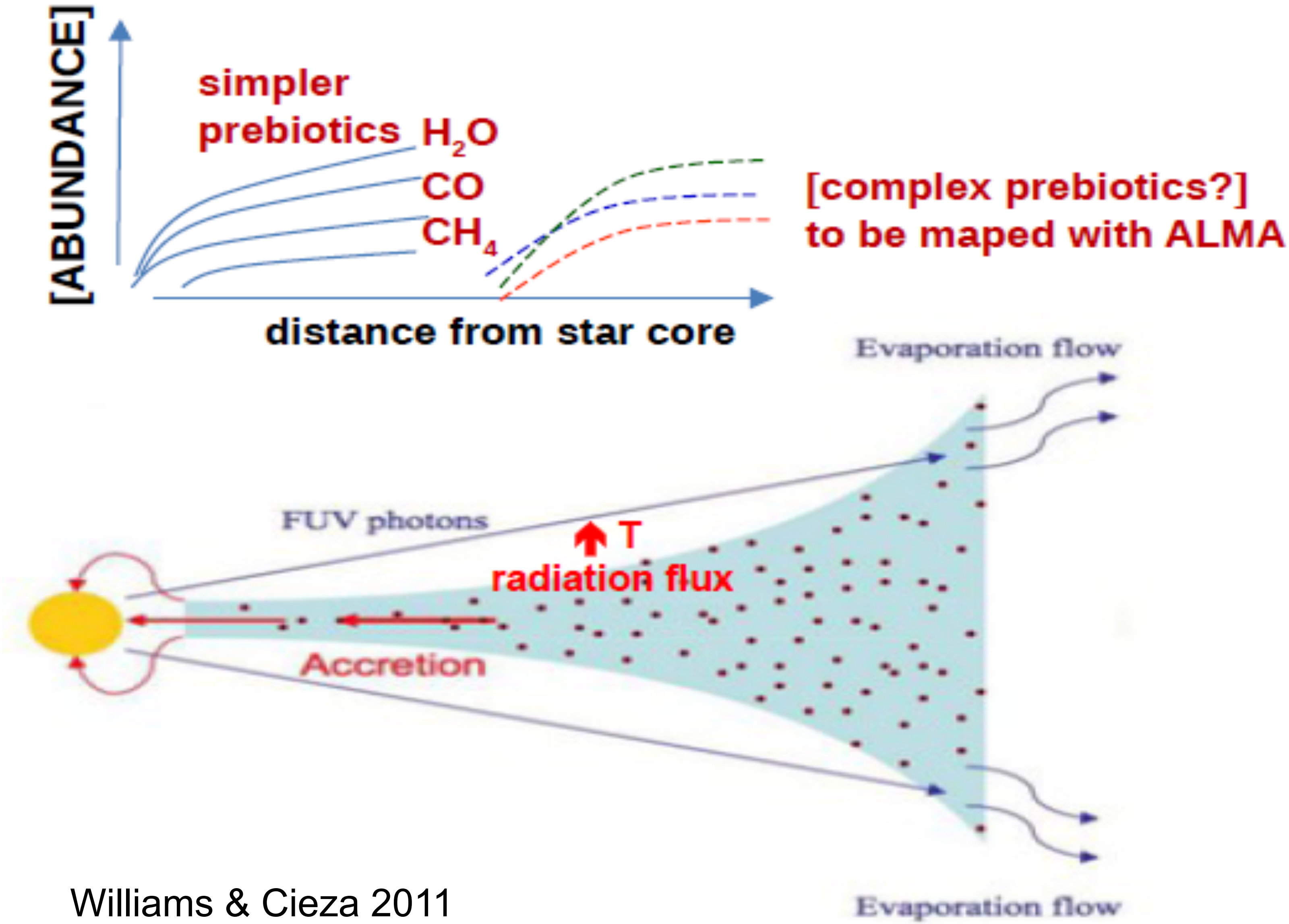
* Scripps Institution of Oceanography, University of California San Diego, La Jolla, California 92093-0220, USA
† W.M. Keck Foundation Center for Isotope Geochemistry, Department of Earth and Space Sciences, University of California Los Angeles, Los Angeles, California 90095-1567, USA
‡ Research School of Earth Sciences, The Australian National University, Canberra, A.C.T. 0200, Australia
§ Department of Geology and Cartography, Oxford Brookes University, Headington, Oxford OX3 0BP, UK

It is unknown when life first appeared on Earth. The earliest known microfossils (~3,500 Myr before present) are structurally complex, and if it is assumed that the associated organisms required a long time to develop this degree of complexity, then the existence of life much earlier than this can be argued[1,2]. But the known examples of crustal rocks older than ~3,500 Myr have experienced intense metamorphism, which would have obliterated any fragile microfossils contained therein. It is therefore necessary to search for geochemical evidence of past biotic activity that has been preserved within minerals that are resistant to metamorphism. Here we report ion-microprobe measurements of the carbon-isotope composition of carbonaceous inclusions within grains of apatite (basic calcium phosphate) from the oldest known sediment sequences—a ~3,800-Myr-old banded iron formation from the Isua supracrustal belt, West Greenland[3–5], and a similar formation from the nearby Akilia island that is possibly older than 3,850 Myr (ref. 3). The carbon in the carbonaceous inclusions is isotopically light, indicative of biological activity; no known abiotic process can explain the data. Unless some unknown abiotic process exists which is able both to create such isotopically light carbon and then selectively incorporate it into apatite grains, our results provide evidence for the emergence of life on Earth by at least 3,800 Myr before present.

... now you can sleep with this challenge on your bedside table....

NATURE · VOL 384 · 7 NOVEMBER 1996

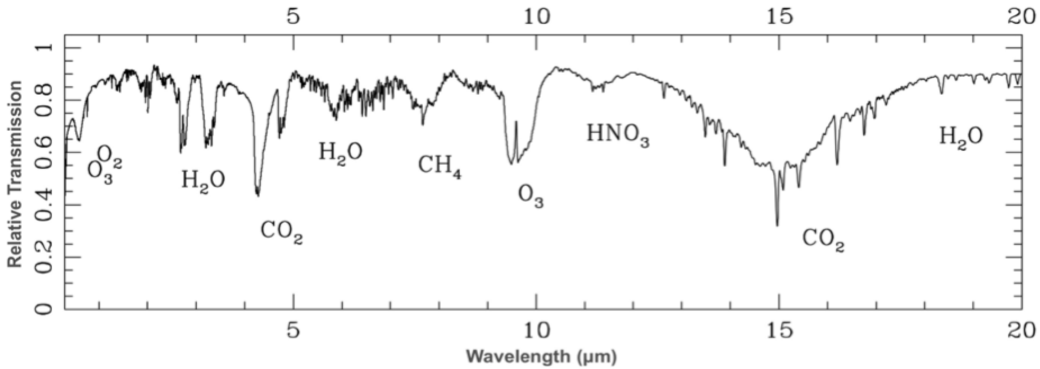
Astrobiology with ALMA



Williams & Cieza 2011

Life ELSEWHERE...
setting points:

CHON ✓



☞☞ **spontaneously formed complex organics**

(simple, together → complex)

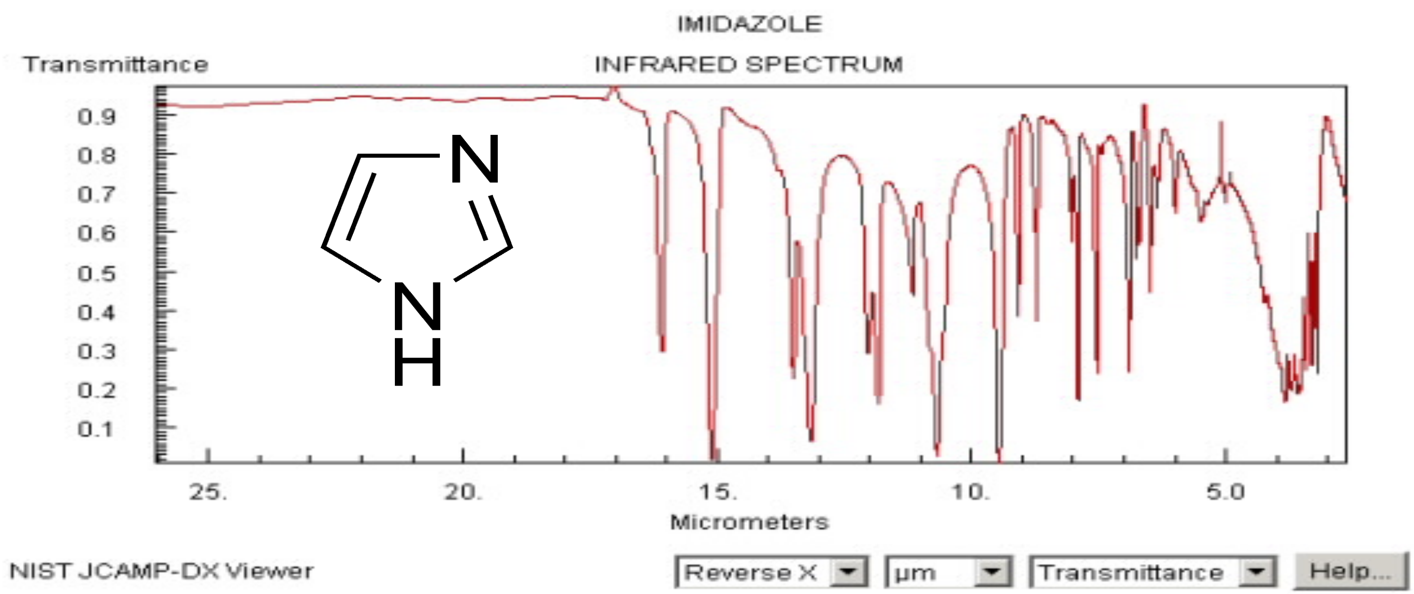
complex biomolecules: HOW to unequivocally detect ??

The quest for detection/identification of complex biomolecules

SOME SPECTRAL DATA !!!!

NIST database, http://www.nist.gov/srd/nist35.htm

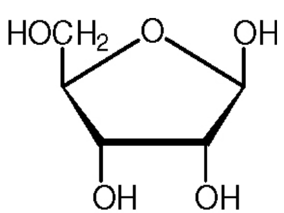
Imidazole - C3H4N2 — 8.0; 9.45; 10.65; 11.15; 11.85; 12.05; 13.2; 13.5; 15.1; 16.1 µm



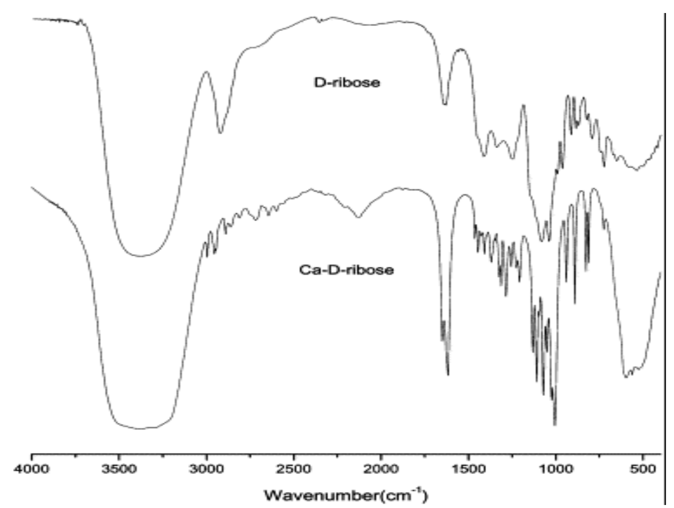
D-Ribose - C5H10O5 –

TRANSITION BANDS IN IR RANGE, but

NO KNOWN SPECTRUM IN RADIO

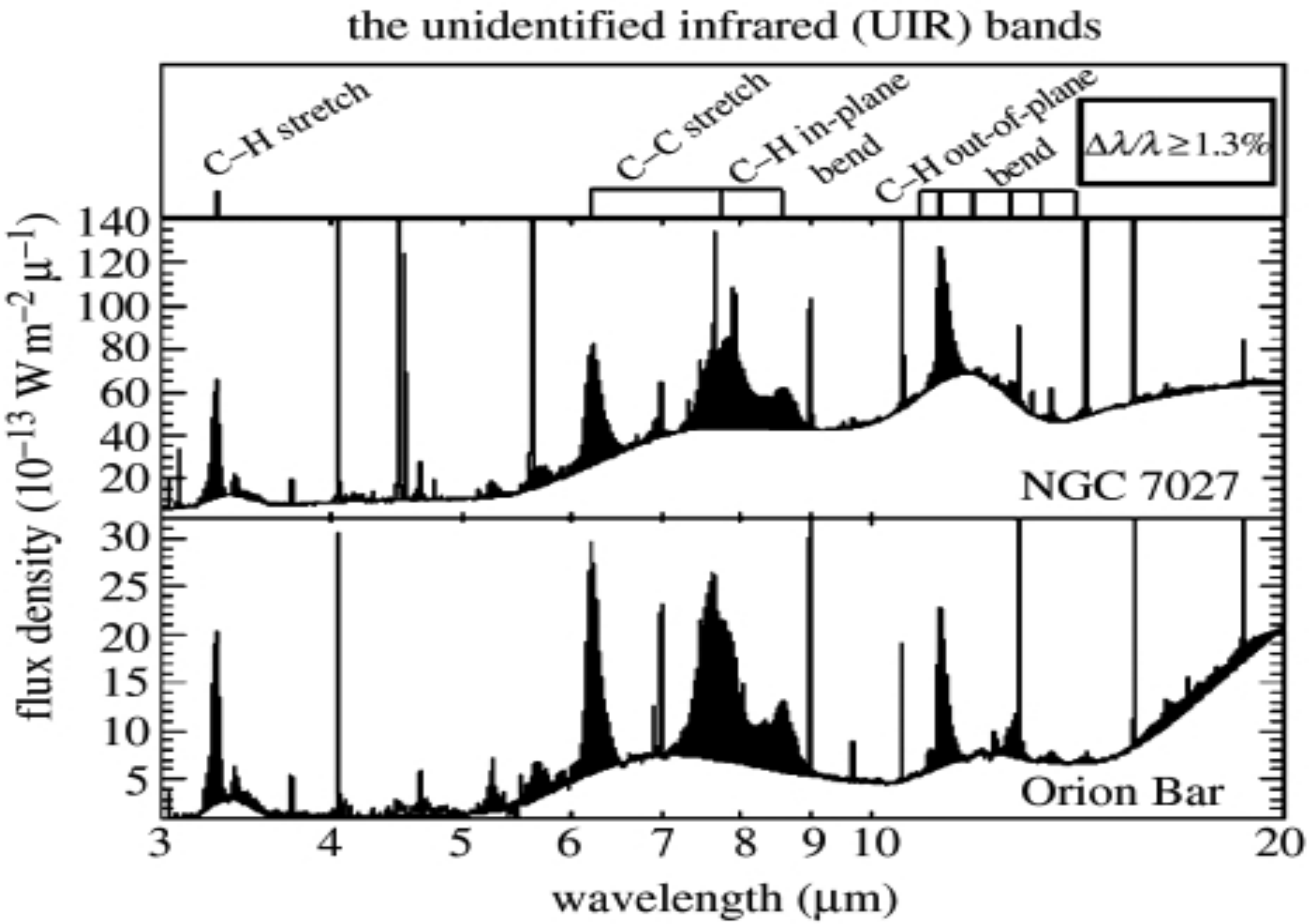


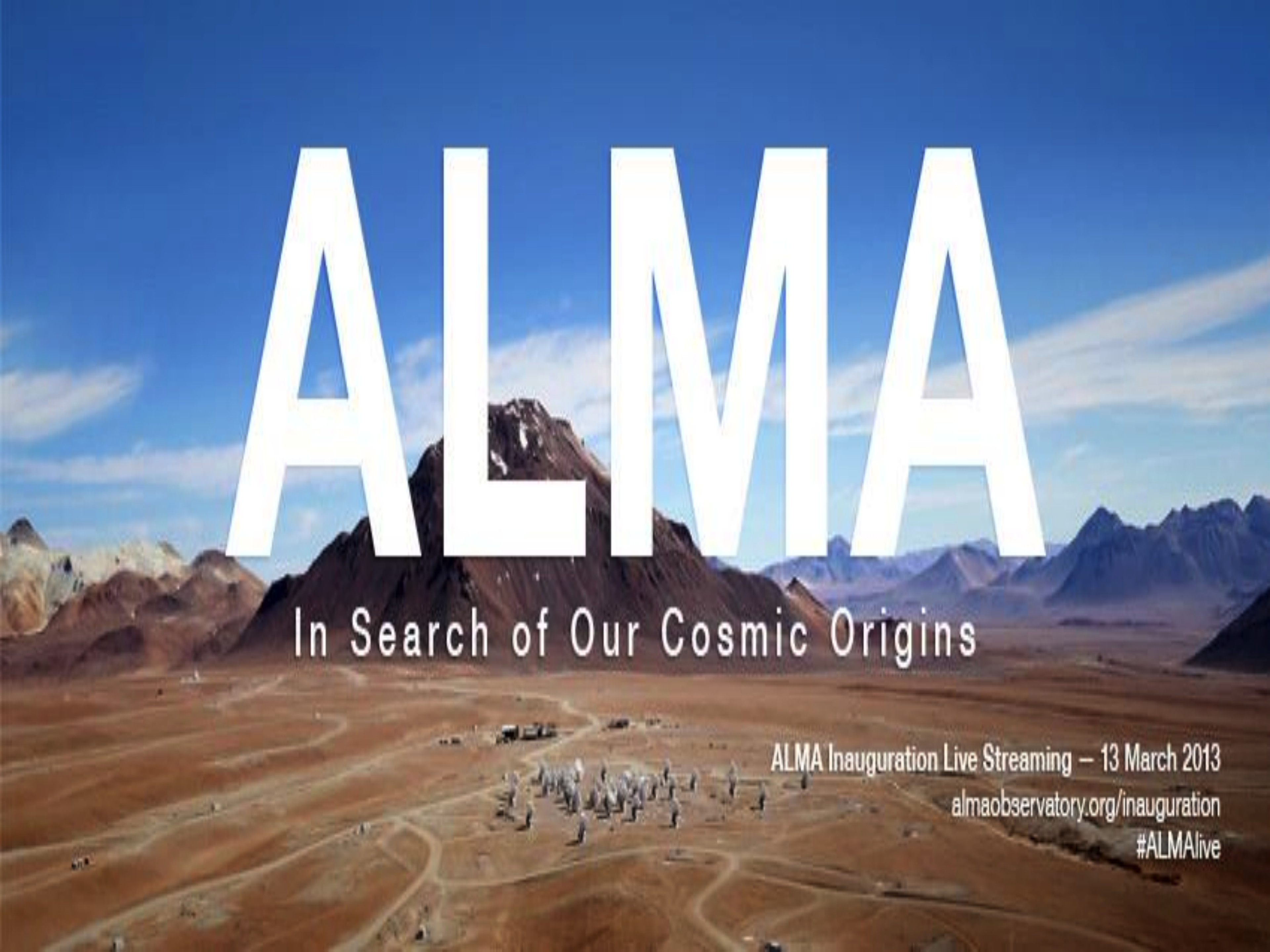
(backbone sugar in RNA)



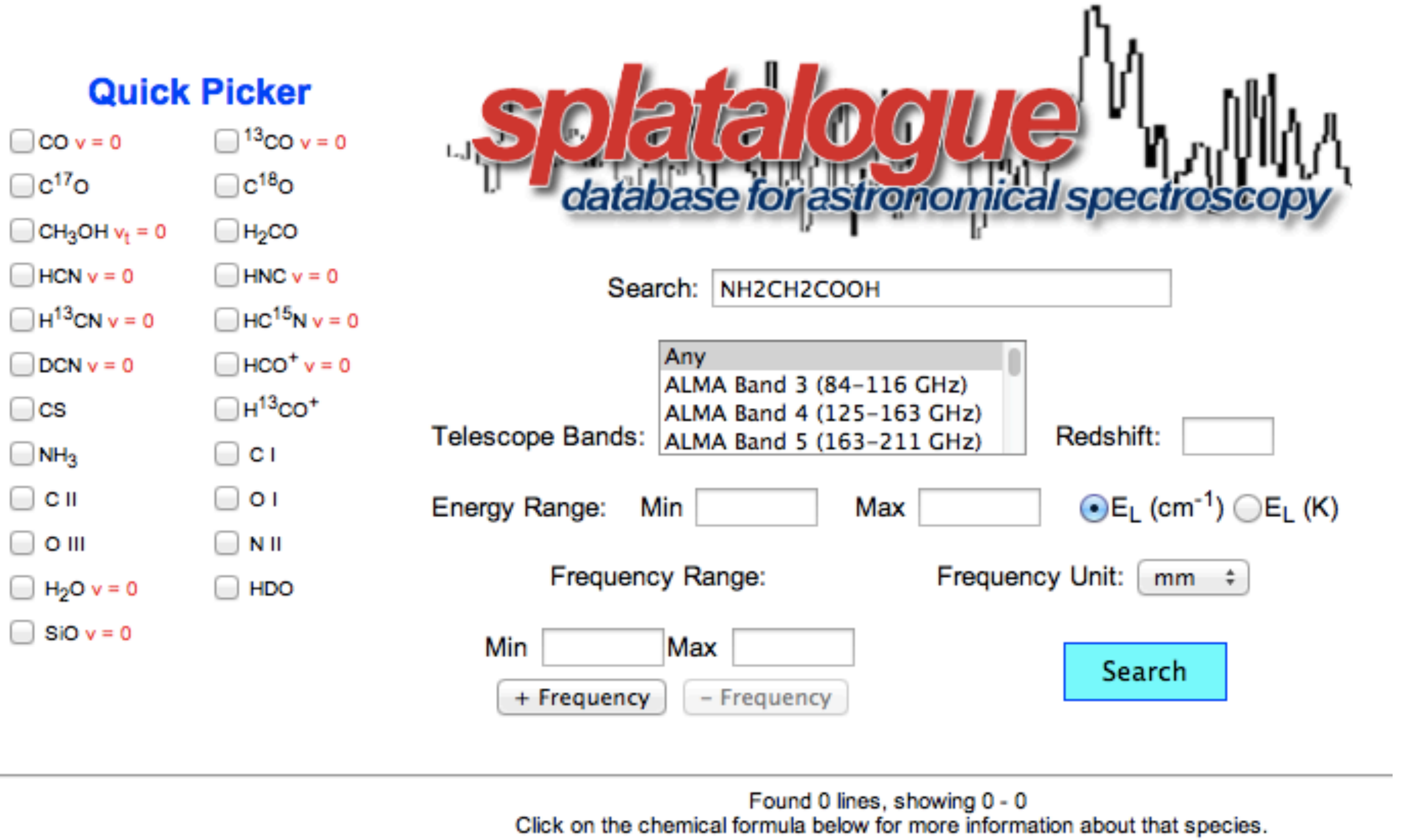
Yan Lu et al., J. Inorg. Biochem. 2003

THE SPECTRAL FOREST !!




ALMA
In Search of Our Cosmic Origins
ALMA Inauguration Live Streaming – 13 March 2013
almaobservatory.org/inauguration
#ALMAlive

ALMA & radio spectral database: 0 lines for simpler aminoacid glycine



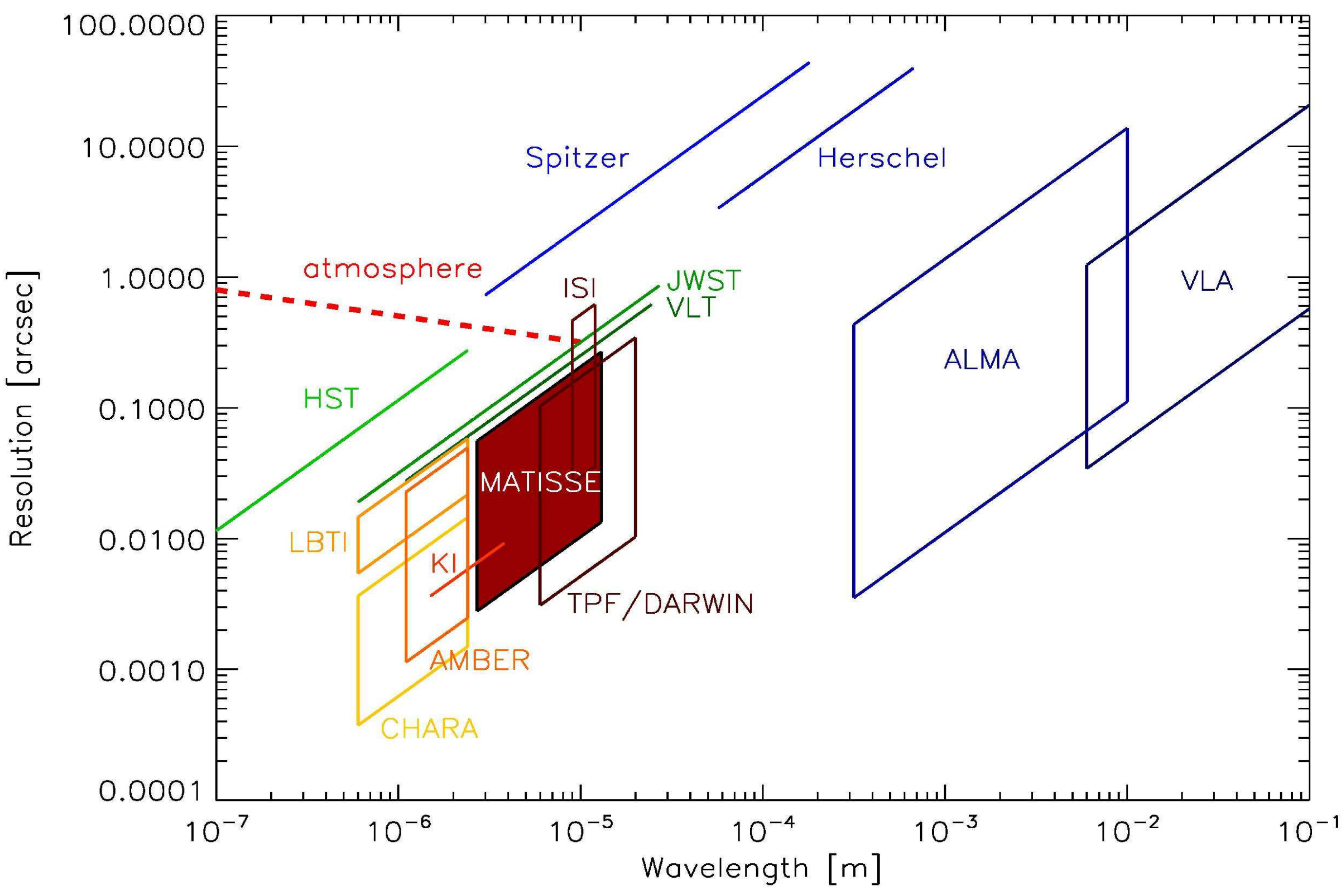
MATISSE (the Multi AperTure mid-Infrared SpectroScopic Experiment)

VLT-MATISSE (mid-IR SpectroScopic Interferometer)

Baseline Specification

Requirement
Optical Throughput 15% (goal 25%) in L and N band
Wavelength coverage L, M and N band
Spectral Resolution 20< R <1000 in L band, 20 < R <550 in M band and 20 < R < 250 in N band
Field of View n/a
Spatial Sampling n/a
Interferometric Contrast 0.6 (goal 0.75) in L and N band
Observing modes High Sensitivity (HighSens) and Simultaneous Photometry (SiPhot)

Comparison between VLT-MATISSE and ALMA

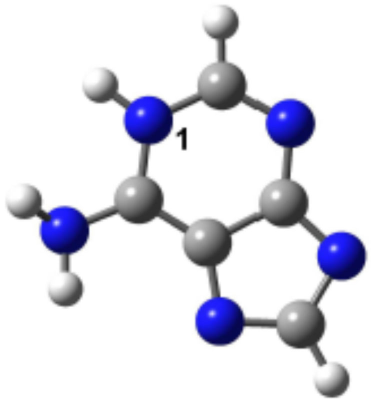


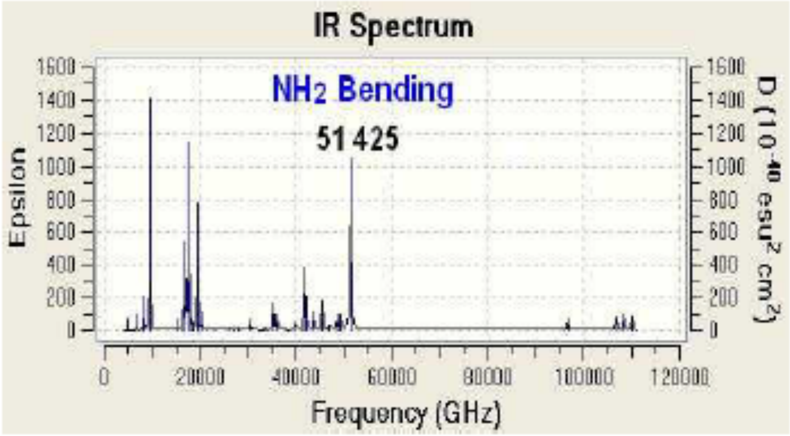
Modeling IR spectra of key biomolecules

- to start with feasible model *vs* experimental correlations
- modelization under different T, P parameters

Adenine (15 atoms)

Molecular structures for possible tautomers / 39 vibration modes





1H-amino-adenine : E = -467.301 kcal.mol^{-1}

μ = 8.3776 D

Take-away conclusions in the search for life elsewhere:

- **define key biomolecules which detection could be better ascribed to the existence of complex chemical pathways**
- **seek for representative spectral bands to define spectral signatures of complex biomolecules**
- **modelization of radio signatures to match radio observations of potentially astrobiologically important targets → ALMA !!!**
- **complimentary IR / radio observations for better tracking of molecular complexity ("life" ??)**
- **astrochemists needed !**

AstroBio Science Team:

UFRJ
Universidade Federal do Rio de Janeiro

Claudia Lage

USP

Eduardo Janot-Pacheco

Alex Carciofi

Observatoire de la CÔTE d'AZUR

Philippe Bendjoya

Olga Suarez

Bruno Lopez

Martine Adrian-Scotto

Armando Domiciano

Université Nice SOPHIA ANTIPOLIS

cnrs advancing the frontiers

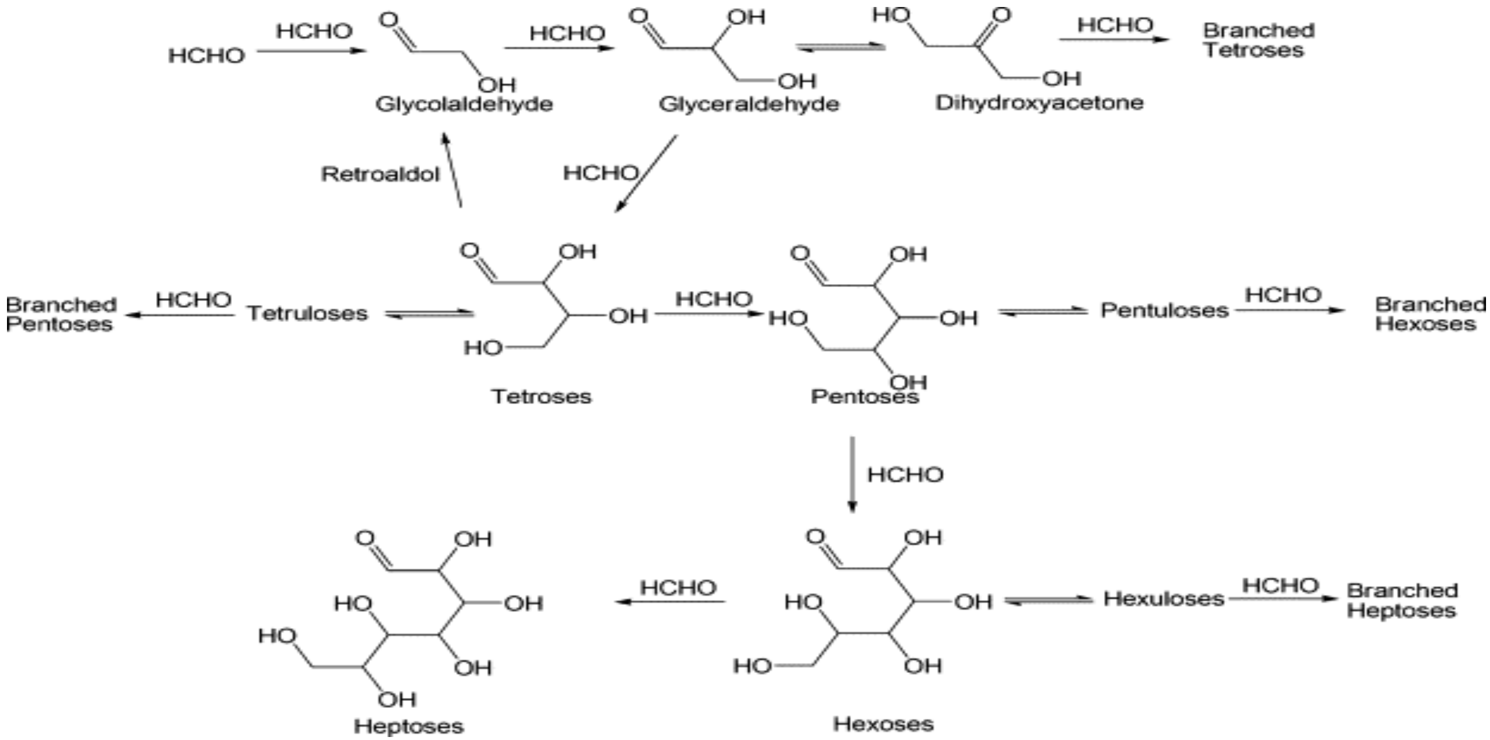
INEspaço
Instituto Nacional de Estudos do Espaço


let's dive in science now !!
thank you !!

From simple to complex ...

Primitive abiogenic reactions supposed to have generated life building blocks

HCHO = simple sugars = complex sugars



H. James Cleaves II, The prebiotic geochemistry of formaldehyde, Precambrian Research, 2008, 164(3-4):111–118