Biodiversities and habitability

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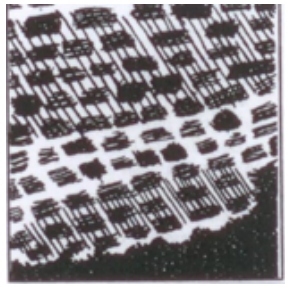
The cell is considered as the smallest living unit

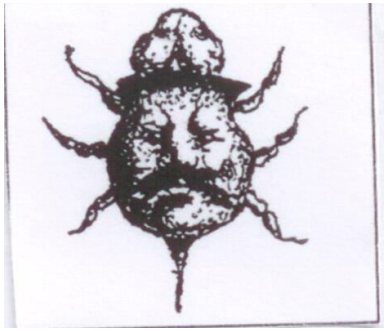
All living organisms, known are composed of cells (Theodor Schwann 1810-1882)

Discovered by Robert Hooke in the 17th century (*Cella* « small rooms » from microscope observations of cells in thin slices of cork)



This discovery was followed by all sorts of surprising, microscopic « living » shapes … approved by the Academy of Sciences …

Louis Joblot (1718)



Unicity of the living cell

Compartment limited by a membrane

Large compartment containing smaller ones

A single compartment

Eucarya

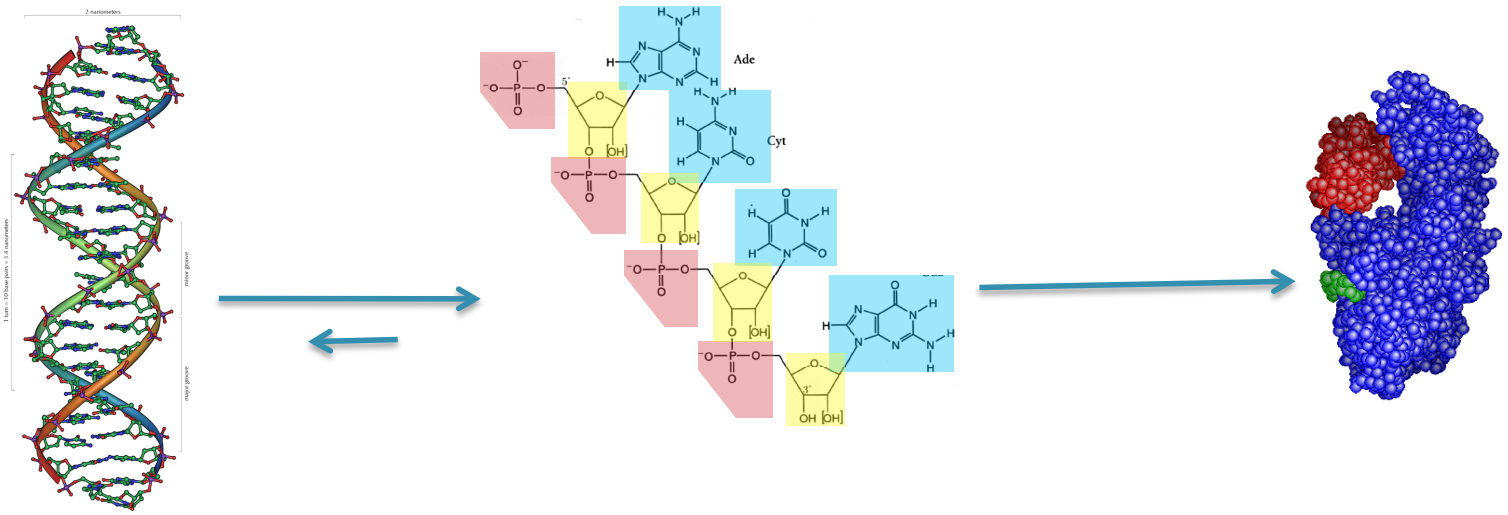
Archae / Eubacteria

The metabolism (change) → the circulation of **matter** (C, H, O, N, P etc.) and **energy** leading to the biological functions of DNA, RNA and Proteins

Unicity: The central dogma of molecular biology

The expression of the basic biochemical framework driven by DNA-RNA-Proteins

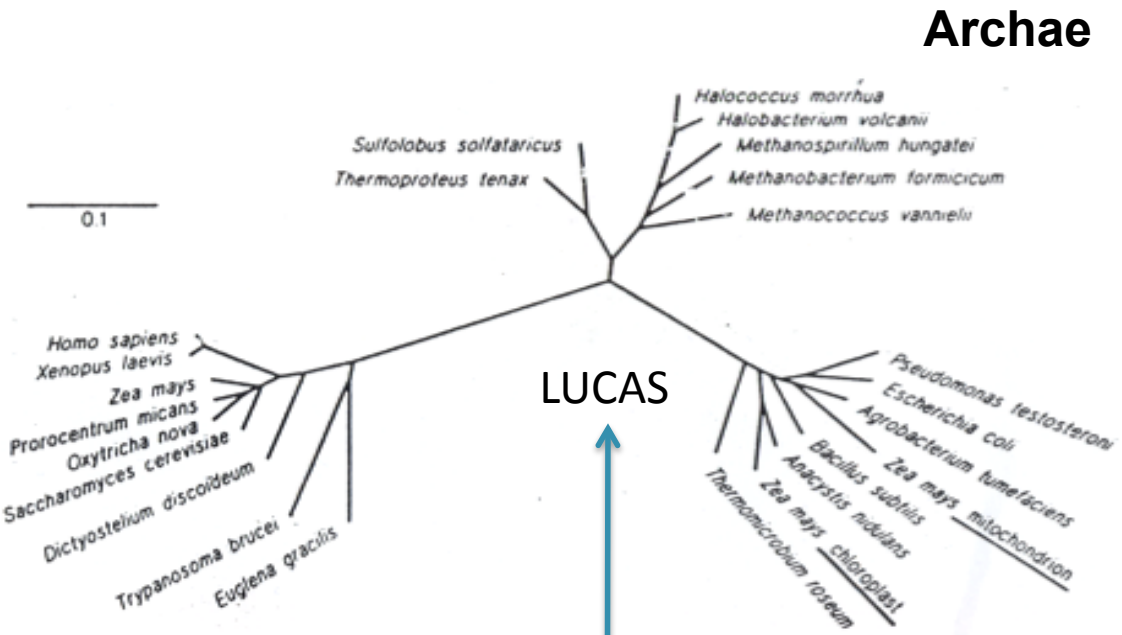
All living cells perform the same type of metabolism (**unicity**) whatever their **diversity**



DNA RNA Protein- enzyme

Biodiversity

Unicity exists in the 3 domains of life which are very **diverse**



viruses and viroids ?

Origins of life

More than 99% bacteria are unknown

Microbial biomass represent more than the half of terrestrial biomass
ex: Procchlorococcus marinus (cyanobacteria living in the plancton: 10 to 100 millions of cells/l of sea water. 30% of marine primary production)

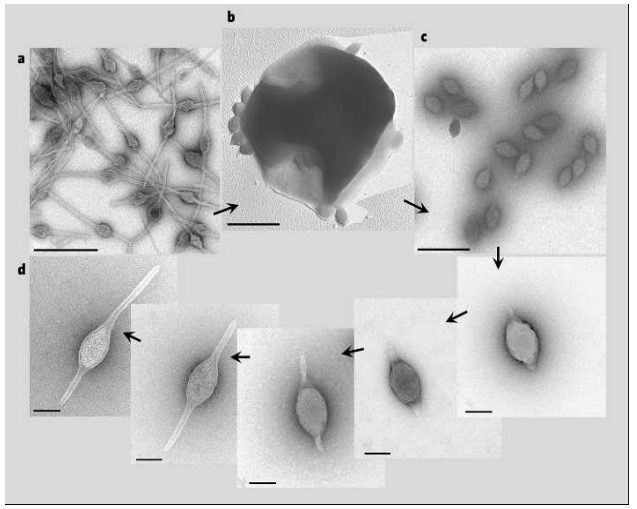
Habitats	Number of bacteria	% cultivable
soil	10^{10} - 10^{13} / kg	0,01 - 0,1
Rivers, lakes	10^{9} - 10^{10} / l	0,01 - 0,1
Oceans (surface)	10^{7} - 10^{9} / l	0,001 - 0,1
Oceans (depth)	10^{7} - 10^{8} / l	ND
Oceans (sediments)	10^{9} - 10^{12} / l	< 1 %

From Suttle, 2005. *Nature. Patel et al., 2007, Fuhrman Nat Protoc.*

Viruses : DNA or RNA

- Boundaries virus/cell become more and more blurred
- A diversity higher than the combined 3 domains of life.
- Some are capable, to produce, outside the host, appendix of 800 amino acids
- Parasitism is not the prerogative of viruses alone (found for some bacteria)

·Mimivirus (Didier Raoult) present numerous genes - no homologs in the 3 domains of life .
Some researchers propose a separate origin ---> fourth branch in the tree of life : Girus (Giant Virus)?



Some viruses are changing their morpholgy-shape outside cellular context (Archael virus ATV) (Acidianus two-tailed virus) (*Haring et al, Nature 2005)*

Viruses

The most important biomass of the *ocean* : 10^{30} viruses in the ocean.
10^{6} -10^{9} viruses/ml.

Biomass virus ocean : 200 Mt (= 75 millions of blue wales)

Viral diversity is very high : several hundred thousand species!

Ocean viruses end to end = the radius of the 60 closest galaxies

More viruses than human cells in our body.

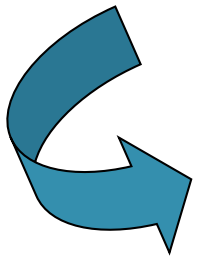
Are we humans-assemblies-of-cells that
permit the survival of millions of viruses?

From Suttle, 2005. *Nature. Patel et al., 2007, Fuhrman Nat Protoc.*

Biodiversity is not linked to the *number of species*

Biodiversity exists at all levels

Diversity of clades
Diversity of shapes
Diversity of sizes
Diversity of colors
Diversity of behaviors
Diversity of life cycles,
Diversity of the type of cells (ex: extremophiles…)
Etc.



To-day, one speaks of

BiodiversitieS

Diversity of the metabolism

With respect to the source of carbon and energy :

Carbon source	**inorganic** (CO_2) : **autotrophs** use minerals **organic** (sugars, lipids) : **heterotrophs** use organic compounds
Energy source	**phototrophs** use **light** **chimiotrophs** use **chemical** compounds

All combinations of these 2 sources exist among bacteria. Eucarya are limited to photo-autotrophs (plants) and chemo-heterotrophs (animals).

Elysia Chlorotica : a photosynthetic sea ***slug***

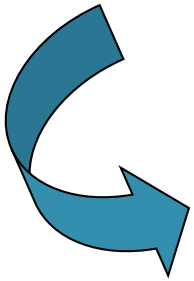
Diversity of media

Bacteria and viruses are omnipresent, numerous and frequently live in unfriendly conditions

				Min.	Opt.	Max.
Temp.	high	thermophile	*Pyrolobus fumarii*	90°C	106°C	113°C
	low	psychrophile	*Polaromonas vacuolata*	0°C	4°C	12°C
pH	acid	acidophile	*Picrophilus oshimae*	0,06	0,7 (60°C)	4
	alcalin	alcalinophile	*Natrialba magadii*	8,5	9	12
pressure	high	barophile	MT41 (Mariana Trench) 11033 m (depth)	500 atm	700 atm 4°C	> 1000 atm
salt	high	halophile	*Halobacterium salinarum*	15 %	25 %	32 % (saturation)

The living is everywhere, in the smallest most remote nook of the Earth, in the heart of rocks, and including the hundreds of species that inhabit our digestive tube.

… we only know **1%** of the species living to-day that themselves represent **1/1000** of the living organisms that have existed since 3,45 Ga.



This underscores the **weakness of concepts and generalisations**… that surround the notions of the living, of **biomarkers**, biosignatures and of the definitions of life (over 200 definitions are known) etc.

Taken as a whole, all the data lead us to ask

What does Earth Life Need?

Physical conditions

- Temperature, <-10° C --> 120° C
- Pressure: < 10^{-3} MPa -->10^{3} MPa

Chemical conditions

- Carbon sources: CO_2 (most biomass), organics
- N, P, minerals.
- Electron donors (food): Reduced carbon (many organisms), H_2S, H_2 (methanogens), Fe(II).
- Terminal electron acceptors: O_2, SO_4^{2-}, Fe(III), organics, CO_2 (methanogens, $H_2 + CO_2$ ---> CH_4)
- Chemical disequilibrium

Liquid H_2O

In these physical and chemical conditions,

——> **Earth is an "habitable" zone**

Do these specific conditions occur everywhere in the Solar System? And beyond, on exoplanets?

Adapted from N. Pace

Origins of life on Earth → the passage between minerals to organics

non-living to living

From a prebiotic world
to simple biology

- Organics
- Minerals
- Liquid Water

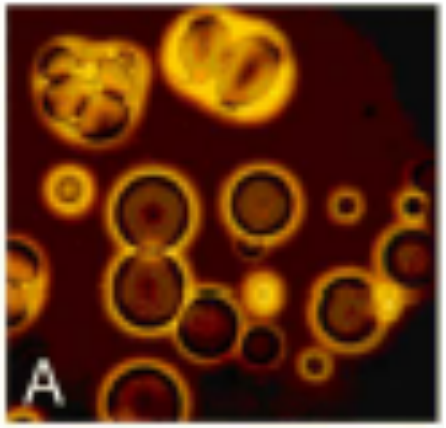
Impact theory

Synthesis of building blocks of life from space.
Amino acids, nitrogenous bases (A,U,G,C,T), sugars would have been brought by **meteorites**

—> primitive soup of biological monomers.

Carbonaceous **meteorites** contain a wide range of **extraterrestrial nucleobases that are the building blocks of DNA and RNA.**

Callahan M. et al. *PNAS* 2011

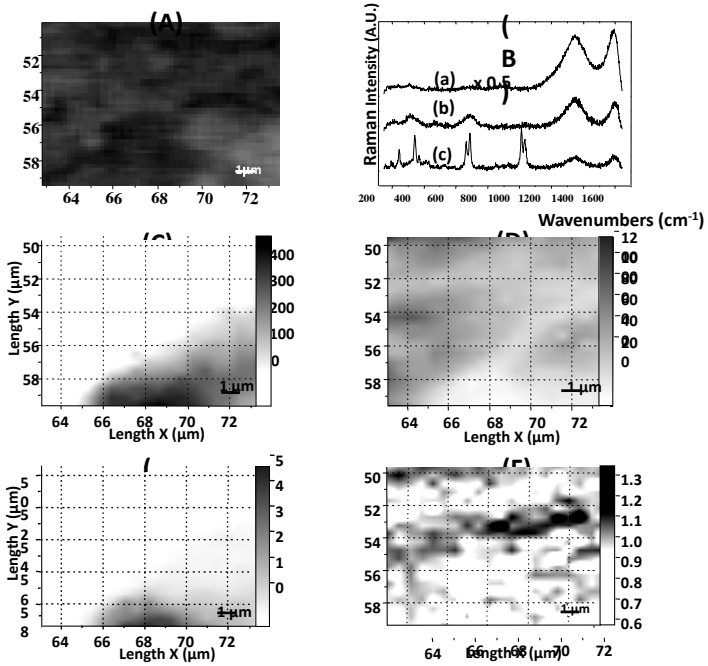


Membrane-like vesicles. Deamer, 1986

Amphiphilic compounds from the Murchison meteorite ($C_{8\text{-}11}$ carboxylic acid + polycyclic hydrocarbon derivatives)

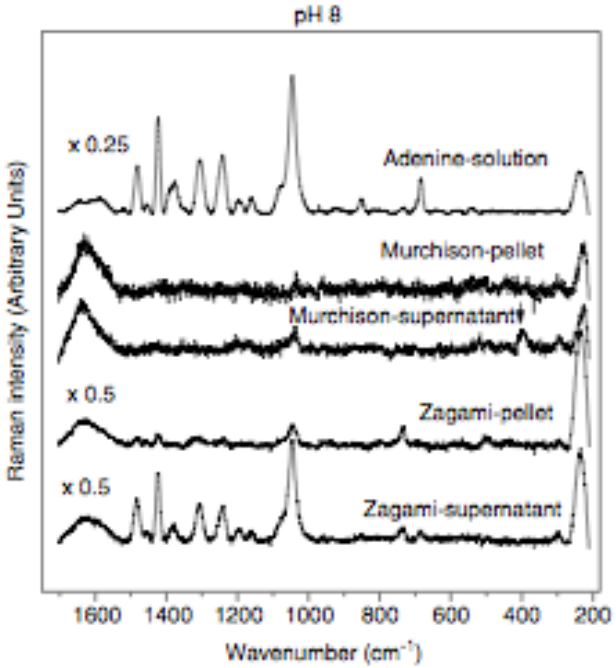
Distribution of **carbonaceous matter** in the **Murchison** meteorite investigated by Raman imaging

Two-dimensional distribution of graphitised carbon, amorphous carbonaceous matter and minerals obtained on 100μm² maps.



ElAmri, Maurel, Sagon, Baron (2005) Spectrochimica Acta, 61

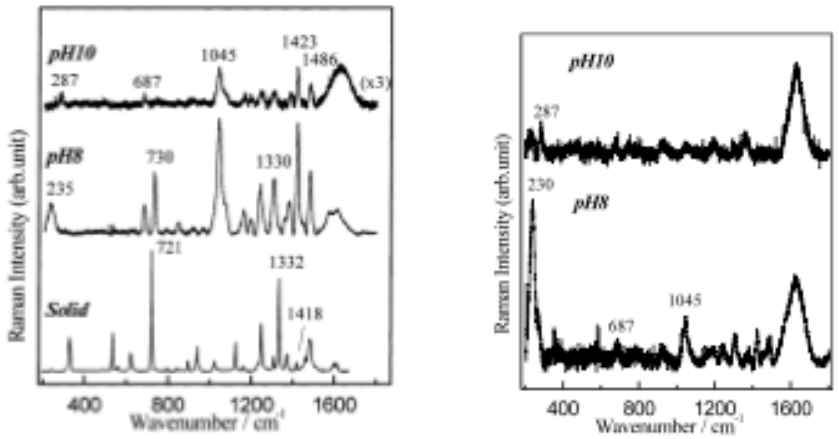
Adenine (A) is more strongly bound to the **Murchison** meteorite, that contains bioorganic matter, than to the silica mineral **Zagami** meteorite.



ElAmri, Baron, Maurel (2004) J. Raman Spectrosc.

Subpicomole molecules of biological interest in and on meteorites using Raman spectroscopy

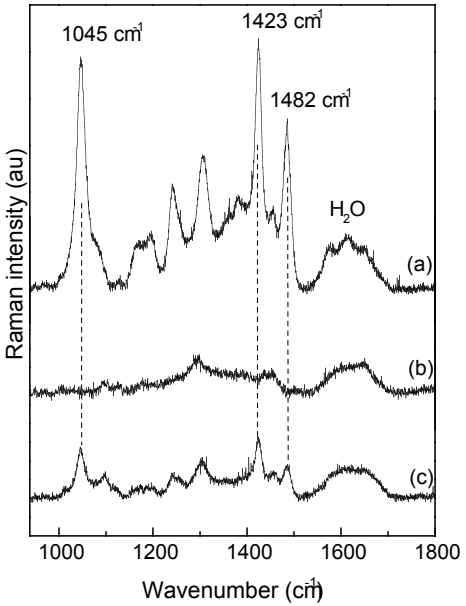
Subpicomole detections of **Adenine** and **RNA** in mineral samples by Surface-enhanced Raman spectroscopy (SERS)



A combination of SERS effect and Raman microscopy is essential for an optimal detection up to 10^{-3} picomoles

El Amri, Baron, Maurel (2003) Spectrochimica Acta, 59.

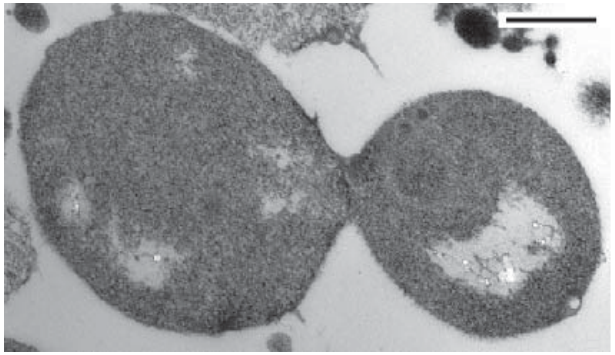
SERS are used to monitor and quantify the catalysis of RNA ribozyme cleavage in **real time**



Percot, Lecomte, Vergne, Maurel (2009) Biopolymers, 91,5.

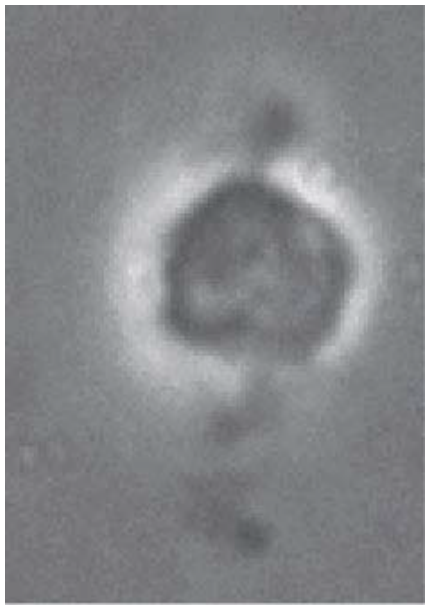
Fission and association

imaging of L-forms

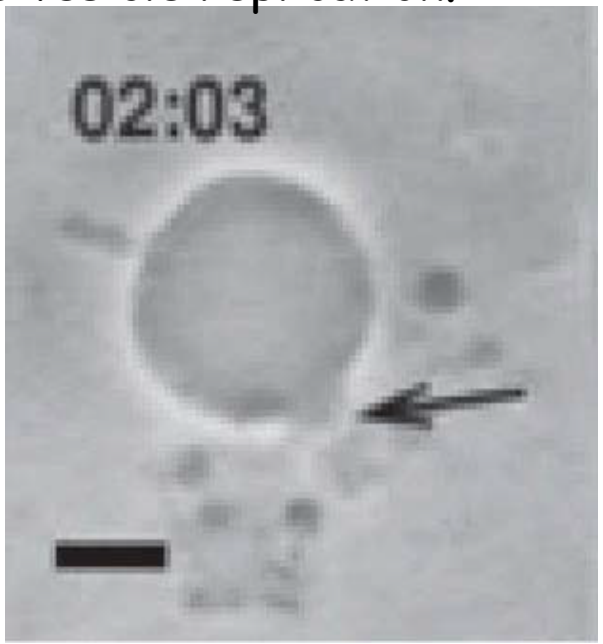


Errington, Nature, 2009

L-form proliferation and its similarity to ***in vitro*** vesicle replication.



B. subtilis L-form surrounded by recently generated progeny blebs



In vitro proliferation **abiotic lipid vesicles**

Errington, 2013

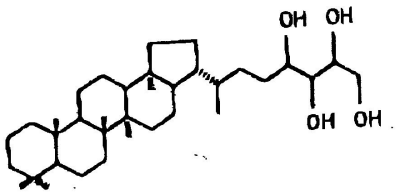
identification of life : biomarkers

« Biomarkers » of Life that are searched for elsewhere, in space, on meteorites and on mineral surfaces

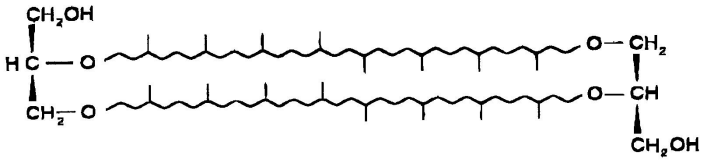
- building blocks
  - amino acids
  - nitrogenous bases (A,U,G,C,T..)
  - sugars etc.

- macromolecules → • DNA, RNA (remains of early life?…), carbon chains, etc.

Potential biomarkers on Mars



Hopanoids

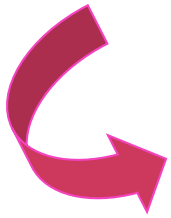


isoprenoids

Hopanoids and Isoprenoids cannot be formed via abiotic pathways

stellar radiation + O_2 + => ? life ?

- No oxygen (O_2) at the origins of life. (O_2) appeared around 2Ga.
- The presence of oxygen in a planetary environment linked to bio-photosynthetic activity?



a major problem for biologists, given the sophistication of photosynthesis in present-day cells (requires pigments, photosystems, enzymes, etc.)

The basic question is:

- If life were to again take the path it followed for 4 Gy ago,

no one can certify that it would take the same path.

- if life exists - or existed elsewhere - benefiting from the same initial planetary conditions as on Earth, it most likely does not have the same history, hence the same characteristics.

Thus, how can we possibly recognize and/or identify something that we are unable to conceptualize ?

Origins and evolution of life on Earth

Living *is not - all or nothing - but - more or less*

From non living to living: something gradual that can be passed over several dimensions.

One can live in various ways :

Proto-living systems = stable things

Neonts
Progenies
Vario-replicators
Metabolic replicators
Simple replicators
Coupled replicators
Metabolisers
Photo-reactors
Linked metabolisers
Hydrothermal synthetizers

Can we extrapolate ?

life elsewhere ----→ starting from conditions of this or that chemistry

Malaterre; Maurel in http://www.bio-conferences.org/articles/bioconf/abs/2015/01/bioconf-origins2015_00001/bioconf-origins2015_00001.html

Conventionally, the circumstellar habitable zone (HZ) is considered as a region where liquid water could be stable on the surface of a planet.

1 Are there other fluids than water for an appropriate chemistry ?

One must consider the nature of the liquid system in which chemistry arises.
A non-water (bio)chemistry might be envisaged

- Ammoniachemistry from internal oceans of the Galilean satellites and silicon (??) chemistry in liquid nitrogen have been proposed as speculative approaches .

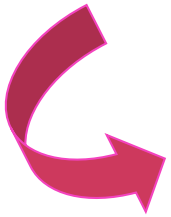
2 Fluids are always equated with liquid.
But dense gases near their critical point (liquid and its vapor can coexist) could also provide the dense mobile environment in which chemistry could occur

- There exist supercritical fluids (SCFs) that are good solvents.
ex: Super critical carbon dioxide is a good solvent in industrial applications

From W. Bains

C, H, O, N « builders » ?
… might be unnecessarily narrow

Is life based around carbon, hydrogen, oxygen and nitrogen the only plausible chemistry?



Is the terrestrial biochemistry of nucleic acids, proteins and sugars « universal »?

Complex macromolecules could be built to capture matter and energy.
The self-sustained pattern could be replicated, amplified to give birth to something « liveable » .
Ex: the entropically disfavoured assembly reaction driven by iterative freeze-thaw cycles, even in the absence of external activation chemistry (Mutschler et al, 2015).

Do alternative forms of chemistry exist?

What about Sulfur chemistry, H_2S versus H_2O etc. ?

Another idea related to the « artificial life » would be simulation that entails replacing matter and energy by information.

Can one conceive a kind of metabolome solely based on information?

Now that on the planet Earth robolution is advancing, can we conceive that this might occur elsewhere or may have occured elsewhere without human design?

Can we recognize this as something atypically « living »

According to Frye, from a strictly materialistic point of view,
no barriers exist
between the non living and the living.

One can consider a diversity that would be unique to every planetary environment, different physical and chemical conditions adapted to different levels, different scales, different dimensions, different durations of « life », different kinetics of reactions etc.

Which of these observations is the odd one out?

What goes without saying does not interest Science;
its rather the problem of common sense
(Gaston Bachelard)

Anomaly constitutes the « driving force » that operates in « scientific revolutions » (Thomas Kuhn)

*

The best available strategy to discover the forms of life (on Earth and) elsewhere is to search for anomalies.