

# Have we found Life?

28/08/2014  
Banyuls-sur-Mer: Origin, Evolution and Future of the Biosphere

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## Content

2

- Introduction
  - Nasa Mission, State of the art
- Hypothesis
- Flow Chart
  - Phylogenetic Relationship
  - Chemical Characterisation
  - Chemical Metabolism
  - Thermodynamic Metabolism
  - Evolution
- Discussion
- Conclusion

## Introduction


3



## What are Nanobacteria?

4


- Hallmark of nanobacteria is thick coat of apatite
- Culturable in cell-free media
- Can replicate and incorporate radiolabeled uridine



Urbano & Urbano, 2007, PLoS Pathog

## What are Nanobacteria? 5

- Nanobacteria are capable of:
  - Infecting & Damaging other beings
  
- Have been reported to be present in
  - Animal blood
  - Human blood
  - Bile
  - Australian sandstones
  - In the stratosphere
  - In meteorites
  - ...




[www.nature.com](http://www.nature.com)

Urbano & Urbano, 2007, PLoS Pathog

## A Definition of Life 6

„Life is a self-sustained chemical system capable of undergoing Darwinian evolution.“



- Nasa Definition of Life

Joyce, 1994, Origins of Life: the Central Concepts

## Asteroid Redirect Mission 7

- Main Segments of the mission
  - 1) Identify
  - 2) Redirect
  - 3) Explore

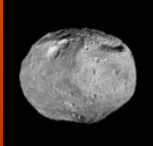


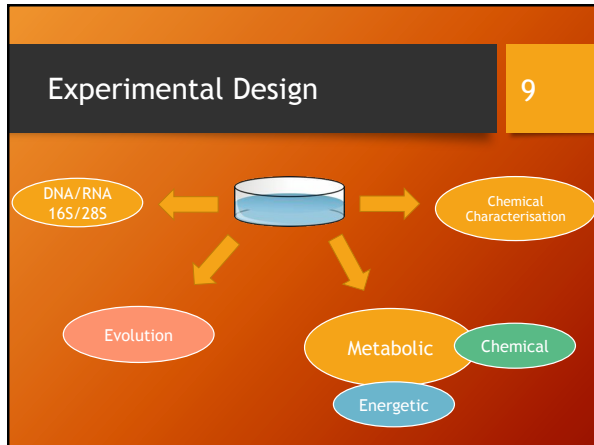


http://www.nasa.gov

## Hypothetical Starting Point 8

- NASA found an interesting sample on one of their asteroids
  
- Sample seems to be some sort of microscopic life
  
- We can cultivate it under laboratory conditions





### Phylogenetic Relationship? 10

- Sequencing preserved genomic regions
  - For identification
  - For establishing phylogenetic relationships
- Markers
  - 16S (prokaryotes)
  - 18S (eukaryotes)
  - ITS (fungi)

A phylogenetic tree diagram showing relationships between various species, with a scale bar of 0.1 divergence per site. Source: Pace, 1997.

### Biomolecules 11

Three 3D molecular models: DNA (double helix), RNA (single helix), and Proteins (folded chain).

DNA      RNA      Proteins

Wikipedia.org

### Analytical Methods 12

Three images illustrating analytical methods: a fluorescence plate, a test tube with purple liquid, and a mass spectrometer.

Fluorescence      Colorimetry      Mass spectrometry

Wikipedia.org

## Chemical Metabolism

13

Environmental composition is key  
Carbon labelling

### Why?

- CO<sub>2</sub> is a by-product of glycolysis
- Other metabolic products such as ATP and NADPH are more difficult to measure
- It gives a strong idea into other cellular metabolic pathways



## Experimental Set Up

14



Krieg et al., 2003, J. Biochem. Biophys. Methods, 58(2)

- 1) Culture cellular monolayer in flask
- 2) Scintillation pad saturated with aminoethanol
- 3) Syringe filled with radiolabelled compound
- 4) Needle used to inject the culture flask
- 5) Incubate, and add 1ml 5N sulfuric acid
- 6) Place back in incubator for 30mins
- 7) Remove filter paper containing <sup>14</sup>C CO<sub>2</sub> and analyse using a liquid scintillation counter

## Protocols

15

- During counting, normalisation must be done to cellular mass by determining the cell aliquot protein content
- Other chemicals can be added to the scintillation paper such as methane to trap other gases and measure other forms of metabolism

## Controls


16

- Positive control= *Listeria monocytogenes* (a facultative anaerobe)
- Negative control= Heat treated *Listeria monocytogenes* (autoclave, highly heat sensitive)



## Thermodynamic Approach 17

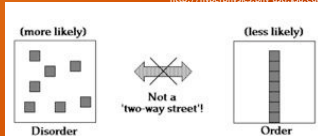
- The Second Law of Thermodynamics states that *entropy and disorder shall always increase (in natural, irreversible process) [...] . Living systems "violate" the Second Law, by developing well-ordered systems (themselves) out of relatively chaotic systems (their food).*



<http://www.scientificamerican.com>

## How Can We Measure Entropy? 18

- We can't. We can calculate it.
- Probability - useful only for ideal gas particles.




<http://hyperphysics.phy-astr.gsu.edu>

$S = k_B \cdot \ln(W)$

$\delta Q = T \cdot dS$

## Solution 19

- Measure work done by the system - energy exchanged with the environment
- Measure ability to keep low entropy of the system.




<http://www.fnal.gov>

Top-left: a low-entropy painting by Piet Mondrian. Bottom-right: a high-entropy painting by Jackson Pollock.

## Living ≠ Dead ? 20

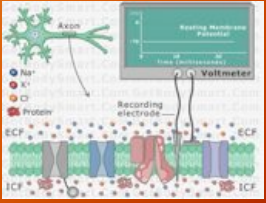
- Is death the opposite of life? How can we say if something is alive for sure?



[tumblr.com](http://tumblr.com)

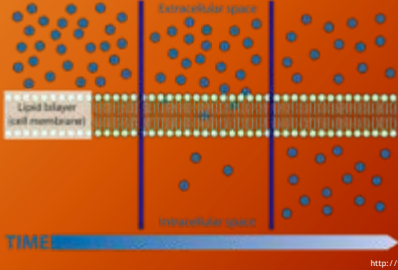
## Performing the Test 21

- Sampling during even periods of time



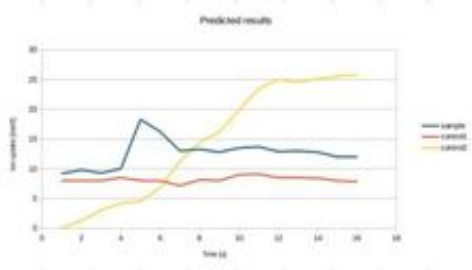
- Negative control: lipid vesicles in ionic solution
- Positive control: *E. coli* culture in ionic solution

## Principle of the Measurement 22



<http://www.biologyguide.net>

## Results 23



## Evolution 24

**NASA definition of life:**  
 "Life is a self-sustained chemical system capable of undergoing Darwinian evolution"  
 (Joyce, 1994)

**Wikipedia definition of evolution:**  
 "Evolution is the change in the inherited characteristics of biological populations over successive generations."  
 (<http://en.wikipedia.org/wiki/Evolution>)

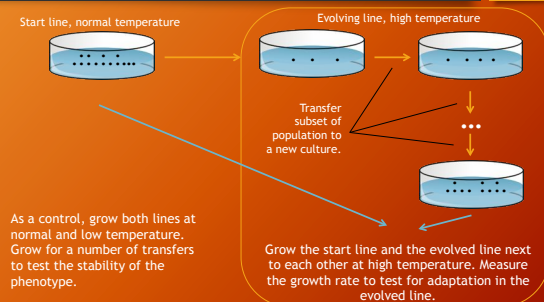
## Testing Adaptation

25

- Adaptation to new environments can be measured as a proxy of evolution
- By comparing for instance growth rate of an adapted strain, and an ancestral nonadapted strain adaptation and evolution can be inferred

## Experimental Setup

26



## Discussion

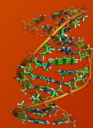
27

- Essentialist definition  
 “The activity of a highly ordered system of matter and energy characterized by complex cycles that maintain or gradually increase the order of the system through an exchange of energy with its environment”  
 (Shapiro and Feinberg, 1990)
- Descriptive definition  
 “Self-organization, growth, development, functionality, metabolism, adaptability, agency, reproduction, inheritance or susceptibility to death.”  
 (Ruiz-Mirazo *et al.*, 2002)
- Best integration of biology with physics and chemistry

## Discussion

28

- DNA as the only replication mechanism?
- Carbon-based chemistry?
- Long-timescale needed to test evolution
- Diachronic processes + synchronic processes



## Conclusion

29

- Metabolism (+) / Adaptation (-)
- Adaptation (+) / Metabolism (-)
  
- Rethink our procedures
- Rethink our definition
  
- More experimental efforts

## Questions?

30



Benner, 2010, Astrobiology, 10