#arseniclife, social media and open science

Rosie Redfield
Dept. of Zoology, UBC
NASA Sets News Conference on Astrobiology Discovery; Science Journal Has Embargoed Details Until 2 p.m. EST On Dec. 2

WASHINGTON -- NASA will hold a news conference at 2 p.m. EST on Thursday, Dec. 2, to discuss an astrobiology finding that will impact the search for evidence of extraterrestrial life.

The news conference will be held at the NASA Headquarters auditorium at 300 E St. SW, in Washington. It will be broadcast live on NASA Television and streamed on the agency’s website at http://www.nasa.gov.

Participants are:
- Mary Voytek, director, Astrobiology Program, NASA Headquarters, Washington
- Pamela Conrad, astrobiologist, NASA’s Goddard Space Flight Center, Greenbelt, Md.
- Steven Benner, distinguished fellow, Foundation for Applied Molecular Evolution, Gainesville, Fla.
- James Elser, professor, Arizona State University, Tempe

Media representatives may attend the conference or ask questions by phone or from participating NASA locations. To obtain dial-in information, journalists must send their name, affiliation and telephone number to Steve Cole at stephen.e.cole@nasa.gov or call 202-358-0918 by noon Dec. 2.
[News] NASA Sets News Conference on Astrobiology Discovery: NASA will hold a news conference at 2 p.m. EST http://go.nasa.gov/ghgV4


Greetings, Earthlings. Sorry to make you wait to talk NASA, but... http://bit.ly/gRLCLO

I'm sad to quell some of the @kottke-induced excitement about possible extraterrestrial life. I've seen the Science paper. It's not that.

A Bacterium That Can Grow by Using Arsenic Instead of Phosphorus


1NASA Astrobiology Institute, USA. 2U.S. Geological Survey, Menlo Park, CA, USA. 3School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA. 4Lawrence Livermore National Laboratory, Livermore, CA, USA. 5Department of Biological Sciences, Duquesne University, Pittsburgh, PA, USA. 6Stanford Synchrotron Radiation Lightsource, Menlo Park, CA, USA. 7BEYOND: Center for Fundamental Concepts in Science, Arizona State University, Tempe, AZ, USA. 8Department of Chemistry, Arizona State University, Tempe, AZ, USA.

Life is mostly composed of the elements carbon, hydrogen, nitrogen, oxygen, sulfur and phosphorus. Although these six elements make up nucleic acids, proteins and lipids and thus the bulk of living matter, it is theoretically possible that some other elements in the periodic table could serve the same functions. Here we describe a bacterium, strain GFAJ-1 of the Halomonadaceae, isolated from Mono Lake, CA, which substitutes arsenic for phosphorus to sustain its growth. Our data show evidence for arsenate in macromolecules that normally contain phosphate, most notably nucleic acids and proteins. Exchange of one of the major bio-elements may have profound evolutionary and geochemical significance.
NASA Discovers New Life! Arsenic

It's life, but not as we know it

By PAUL SUTHERLAND, Sun Spaceman
Published: 01 Dec 2010

HOPE of finding ET-style life on other worlds has got a massive boost after scientists discovered microbes in a deadly poisonous ARSENIC lake.

"Weird life": Clue to alien bacteria that can live on arsenic

By FIONA MACRAE
Last updated at 8:39 AM on 3rd December 2010

NASA has discovered alien life – but it is right here on Earth.

The announcement, at a press conference at the space agency's Jet Propulsion Laboratory, ended months of frenetic speculation that it was about to reveal the existence of alien bacteria that can live on arsenic.

While the truth – an 'alien' bacterium lurking deep within a Cali
ted lake – marked a huge breakthrough in the hunt for life beyond Earth, it will also raise new questions about the nature of life itself.

Two species of bacteria, isolated from the lake, can pull arsenic out of their environment and make DNA with it.

Geomicrobiologist Felisa Wolfe-Simon, collecting lake-bottom sediments in the shallow Mono Lake in California. Wolfe-Simon cultured the arsenic-utilizing organisms from this lake.
Their Astrobiology Program wants to understand how life can originate and what forms it can take.

What were the researchers looking for?

A form of life that uses arsenic in place of phosphorus.

Why was NASA funding them?

Their Astrobiology Program wants to understand how life can originate and what forms it can take.
Did nature also choose arsenic?

Felisa Wolfe-Simon

All known life requires phosphorus
Arsenic is chemically similar.

We hypothesize that ancient biochemical systems...
could have used arsenate in the equivalent biochemical role.

Such organisms may even persist on Earth today, undetected, in unusual niches.

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doi:10.1017/S14735550408004394 © Cambridge University Press 2009
The Shadow Biosphere

- Bacteria
- Archaea
- Eukaryotes

Origin of life

Shadow biosphere?
NASA gave Wolfe-Simon a fellowship to search for arsenic-using members of the Shadow Biosphere in Mono Lake mud (200 µM AsO$_4$)
She added Mono Lake sediment to a culture medium containing \( \text{AsO}_4 \) rather than \( \text{PO}_4 \).

Cells eventually grew, even in 40 mM \( \text{AsO}_4 \).
Fig. 2 NanoSIMS analyses of GFAJ-1: extracted DNA and whole-cells elemental ratio maps.

Fig. 3 X-ray analysis of GFAJ-1 +As/-P described similarity of As coordinated like P in DNA. (A) EXAFS comparisons of the Fourier transformed data for As in model environments and GFAJ-1 (washed and fixed, collected on whole cells).

F Wolfe-Simon et al. Science 2011 ;332:1163-1166
Chemical clarification:

Structure of normal DNA

BACKBONES (the sides of the ladder)

Chains of alternating sugar and phosphate molecules (the newly discovered bacteria contain arsenate in place of phosphate)

BASE PAIRS (the rungs of the ladder)

Combinations of four types of molecules (adenine, thymine, guanine and cytosine)
Here's a detailed review of the new paper from NASA claiming to have isolated a bacterium that substitutes arsenic for phosphorus on its macromolecules and metabolites. (Wolfe-Simon et al. 2010, A Bacterium That Can Grow by Using Arsenic Instead of Phosphorus.) NASA's shameful analysis of the alleged bacteria in the Mars meteorite made me very suspicious of their microbiology, an attitude that's only strengthened by my reading of this paper. Basically, it doesn't present ANY convincing evidence that arsenic has been incorporated into DNA (or any other biological molecule).

What did the authors actually do? They took sediment from Mono Lake in California, a very salty and alkaline lake containing 88 mg of phosphate and 17 mg of arsenic per liter. They put the sediment into a similarly alkaline and hypersaline defined medium containing 10 mM glucose as a carbon source, 0.8 mM NH4SO4 as a nitrogen and sulfur source, and a full assortment of

Poisoned Debate Encircles a Microbe Study’s Result

By DENNIS OVERBYE  
Published: December 13, 2010

The announcement that NASA experimenters had found a bacterium that seems to be able to subsist on arsenic in place of phosphorus — an element until now deemed essential for life — set off a cascading storm of criticism on the Internet, first about alleged errors and sloppiness in the paper published in Science by Felisa Wolfe-Simon and her colleagues, and then about their and NASA’s refusal to address the criticisms.

The result has been a stormy brew of debate.

Doubts Brew About NASA’s New Arsenic Life

"This Paper Should Not Have Been Published"

Scientists see fatal flaws in the NASA study of arsenic-based life.

By Carl Zimmer


On Thursday, Dec. 2, Rosie Redfield sat down a new paper called "A Bacterium That Can Gr Using Arsenic Instead of Phosphorus." Despite innocuous title, the paper had great ambitions: living thing that scientists have ever studied |

[DOI:10.1126/science.1138696]
The -P growth medium had contaminating PO\textsubscript{4}, but nobody knew how much

<table>
<thead>
<tr>
<th>MEDIA</th>
<th>PO\textsubscript{4} (µM)</th>
<th>Should be</th>
</tr>
</thead>
<tbody>
<tr>
<td>-P/-As media (-vitamins, -arsenic, -phosphate, -glucose) 5 Apr 2010 batch</td>
<td>3.7</td>
<td>0</td>
</tr>
<tr>
<td>-P/-As media (-vitamins, -arsenate -phosphate, -glucose) 11 June 201 batch</td>
<td>&lt;0.3</td>
<td>0</td>
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<tr>
<td>-P/+As media (+vitamins, +10 mM glucose, +arsenate) 29 July 2010 batch</td>
<td>2.9</td>
<td>0</td>
</tr>
<tr>
<td>-P/+As media (+ vitamins, +10 mM glucose, +arsenate) 5 Apr 2010 batch</td>
<td>2.7</td>
<td>0</td>
</tr>
<tr>
<td>+P/-As media (+ vitamins, +10 mM glucose, +phosphate) 5 Apr 2010 batch</td>
<td>2,003</td>
<td>1500</td>
</tr>
<tr>
<td>cell wash solution -P/-As media (-vitamins, -arsenic, -phosphate, -glucose, -trace metals), 3 July 2010 batch</td>
<td>7.4\textsuperscript{a}</td>
<td>0</td>
</tr>
</tbody>
</table>
Most $-P +As$ preps had enough $PO_4$ for the observed growth.

The amount of phosphate in the ‘no-phosphate’ culture medium:

$$\frac{3 \text{ \mu M} P}{6.02 \times 10^{23} \text{ P per mol}} \times \frac{1 \text{ DNA-P}}{10 \text{ atoms P}} \times \frac{1 \text{ bp}}{2 \text{ DNA-p}} \times \frac{1 \text{ genome}}{3.8 \times 10^6 \text{ bp}} \times \frac{3.1 \times 10^{-6} \text{ mol P}}{10^3 \text{ ml}} = 2.47 \times 10^7 \text{ genomes per ml}$$

The number of cells that could be made using this phosphate:

$$\frac{2.47 \times 10^7 \text{ cells per ml}}{5 \times 10^8 \text{ cells ml}^{-1} \text{ time}} = 2.47 \times 10^7 \text{ cells per ml}$$
Maybe the arsenate was just carried along with the dirty DNA sample

“NanoSIMS analyses. Individual cells and DNA in high purity agarose gel sections were analyzed for As and P abundance by high-resolution secondary ion mass spectrometry.”

Problem 1:
The DNA was not well purified before being loaded in the gel.

Problem 2:
The DNA was not purified from the gel before analysis.

The As in the gel slices may not have been part of the DNA.
Chemical consideration: As-DNA bonds are unstable
WASHINGTON -- NASA will hold a news conference at 2 p.m. EST on Thursday, Dec. 2, to discuss an astrobiology finding that will impact the search for evidence of extraterrestrial life. Astrobiology is the study of the origin, evolution, distribution and future of life in the universe.

NASA spokesman Dwayne Brown (Dec. 6, quoted by CBC News):

Wolfe-Simon will not be responding to individual criticisms, as the agency doesn't feel it is appropriate to debate the science using the media and bloggers. Instead, it believes that should be done in scientific publications.

Felisa Wolfe-Simon (Dec. 7, quoted by Carl Zimmer):

Any discourse will have to be peer-reviewed in the same manner as our paper was, and go through a vetting process so that all discussion is properly moderated.
My Letter to Science

By Rosie Redfield on Wednesday, December 08, 2010

SteveF  December 8, 2010 9:27 AM

There seems to be a lack of references to back up a number of your statements in this letter. Perhaps this concern reflects my considerable lack of expertise in the subject and the things you mention are so

Anonymous  December 8, 2010 8:45 AM

I'd reword this opening paragraph. It's sort of confusing because you say they eliminated contamination in their materials but not in their assayed materials. Should reword this sentence so it doesn't start with "And because". No correction can be made for the agarose contribution to the total carbon because the levels of DNA and agarose in the gel slice are unknown yaddaydaddayadda.
Response to Comments on “A Bacterium That Can Grow Using Arsenic Instead of Phosphorus”

Felisa Wolfe-Simon,¹,²*† Jodi Switzer Blum,² Thomas R. Kulp,² Gwyneth W. Gordon,³ Shelley E. Hoeft,² Jennifer Pett-Ridge,⁴ John F. Stolz,⁵ Samuel M. Webb,⁶ Peter K. Weber,⁴ Paul C. W. Davies,¹,⁷ Ariel D. Anbar,³,⁸ Ronald S. Oremland²

Concerns have been raised about our recent study suggesting that arsenic (As) substitutes for phosphorus in major biomolecules of a bacterium that tolerates extreme As concentrations. We welcome the opportunity to better explain our methods and results and to consider alternative interpretations. We maintain that our interpretation of As substitution, based on multiple congruent lines of evidence, is viable.
The flawed evidence for arsenic in DNA is overwhelmed by the ‘prior-knowledge’ obstacles.

Nevertheless, the blogosphere, the twitterverse, and the mainstream media all agreed: ‘Someone should put the claims to an experimental test!’
In at the deep end

By Rosie Redfield on Wednesday, August 02, 2006

Ideally I would begin this blog with an overview of all our research, explaining our big goals and the various approaches we're taking to them. But a thorough overview would be enough work that I'm likely to put off doing it. So instead I'm just going to jump right into posting about current research projects, and fill in the background as I go.

The CRP-S manuscript:

This manuscript describes a PhD student's work on the specialized CRP-binding sites that control transcription of competence genes in H. influenzae. We keep thinking that it's at the 'nearly finished' stage, but we keep finding ways to substantially improve it. It's now a fine manuscript showing the following:

First, that the genes that are regulated by CRP-S sites in H. influenzae are present in a much wider group of bacteria (the gamma-proteobacteria). This is important because most of these bacteria have not been shown to be competent.
The minimal experiments needed to test the #arseniclife claims:

1. Get GFAJ-1 cells from authors; check identity by 16S sequencing
2. Measure growth (# of cells/ml) in AML-60 medium ±PO$_4$ and ±AsO$_4$
3. Thoroughly purify DNA from cells grown ±AsO$_4$; check stability
4. Assay DNA for arsenic (send DNA to collaborators with expertise)

Blog about every step...
Collaborators (at Princeton):

Joshua D. Rabinowitz  
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Marshall Louis Reaves  
mreaves at princeton.edu

Leonid Kruglyak  
@leonidkruglyak  
Professor of Genomics and Evolutionary Biology. Lapsed physicist. Math and statistics junkie. Occasional mountaineer  
Princeton, NJ  
http://www.princeton.edu/genomics/kruglyak/
GFAJ-1 (no real progress to report)
By Rosie Redfield on Wednesday, July 06, 2011
I'm now using the medium exactly as specified, but the cells still aren't growing consistently. They also form variable numbers and sizes of Tween 20-resistant clumps.

Yes, that last experiment was grasping at straws...
By Rosie Redfield on Tuesday, October 11, 2011

DNA! Lots and lots of lovely GFAJ-1 DNA!
By Rosie Redfield on Friday, November 18, 2011
GFAJ-1 DNA

DNA chromatography-mass spectrometry

Liquid chromatography-mass spectrometry

Arsenate is here

blank

wash

-As -P

-As +P

+As +P

+As -P
The manuscript is available on the arXiv server. The paper is ‘in press’ at Science.

In early July I gave a big public outreach talk at the big joint Evolution meeting. Here’s a slide I showed.

Science had embargoed it until July 26...
Some journals use ‘press embargos’ to control how research is publicized.

**Journalists** get advance copies of papers, on condition that they don’t publish anything until the paper appears in the journal.

**Authors** are instructed not to speak to the press except under this condition.

*Your cooperation protects you from problems that may jeopardize your paper’s publication.*
FAIL

Lead author

FAIL

Senior author (her supervisor)

FAIL

Other authors

FAIL

Reviewers

FAIL

Editors of Science

FAIL

NASA

FAIL
But science (the process) worked well.
Credits and Inspirations

• **Pedro Beltrao**: His blog post about open science started me blogging.

• **Sunita Sinha** (my lab RA): She did the 16S rDNA sequencing and helped write the paper.

• **Leonid Kruglyak, Josh Rabinowitz** and especially **Marshall Reaves**: They did the arsenate analysis and helped write the paper.

• **Canadian Institutes for Health Research**: They paid for the arsenate and Sunita’s time.

• **Science (the journal)**: They gave us an easy target and then a hospitable environment for rebutting it.