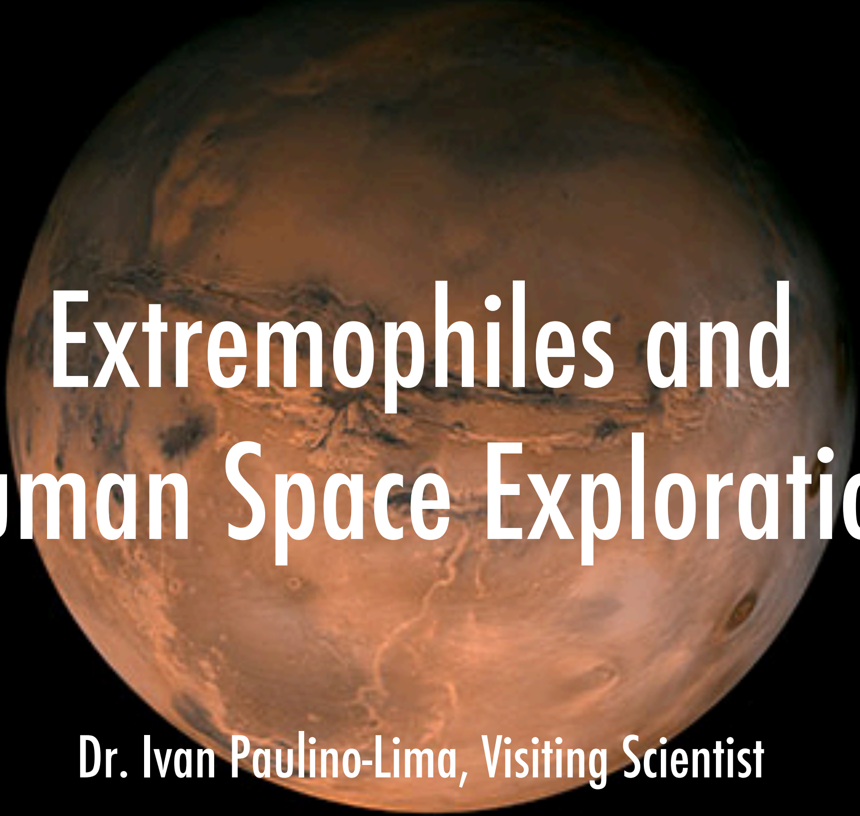


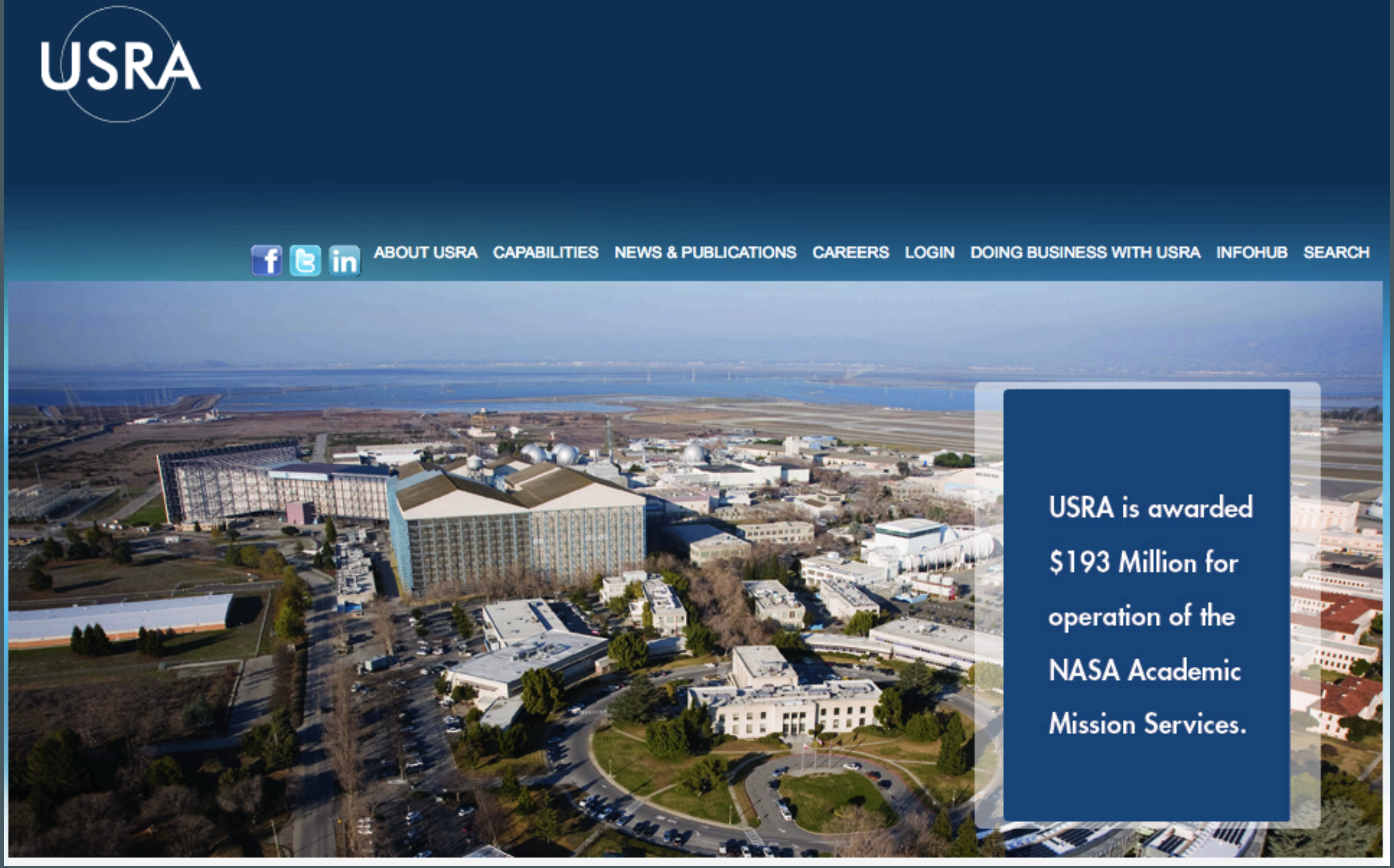
Extremophiles and Human Space Exploration

Dr. Ivan Paulino-Lima, Visiting Scientist

USRA Universities Space Research Association
Established in 1969

Who we are

- Internationally recognized scientific investigators
- Advancing space & aeronautics
- Partnering with academia, government and industry
- Providing customers with intellectual and scientific leadership
- Serving the public good
- Advocates for space-related public policy
- Representing scientific excellence verified by independent science councils
- Advancing STEM by leveraging space S&T
- Developing pipeline of science talent from early career to senior scientists



http://www.usra.edu/

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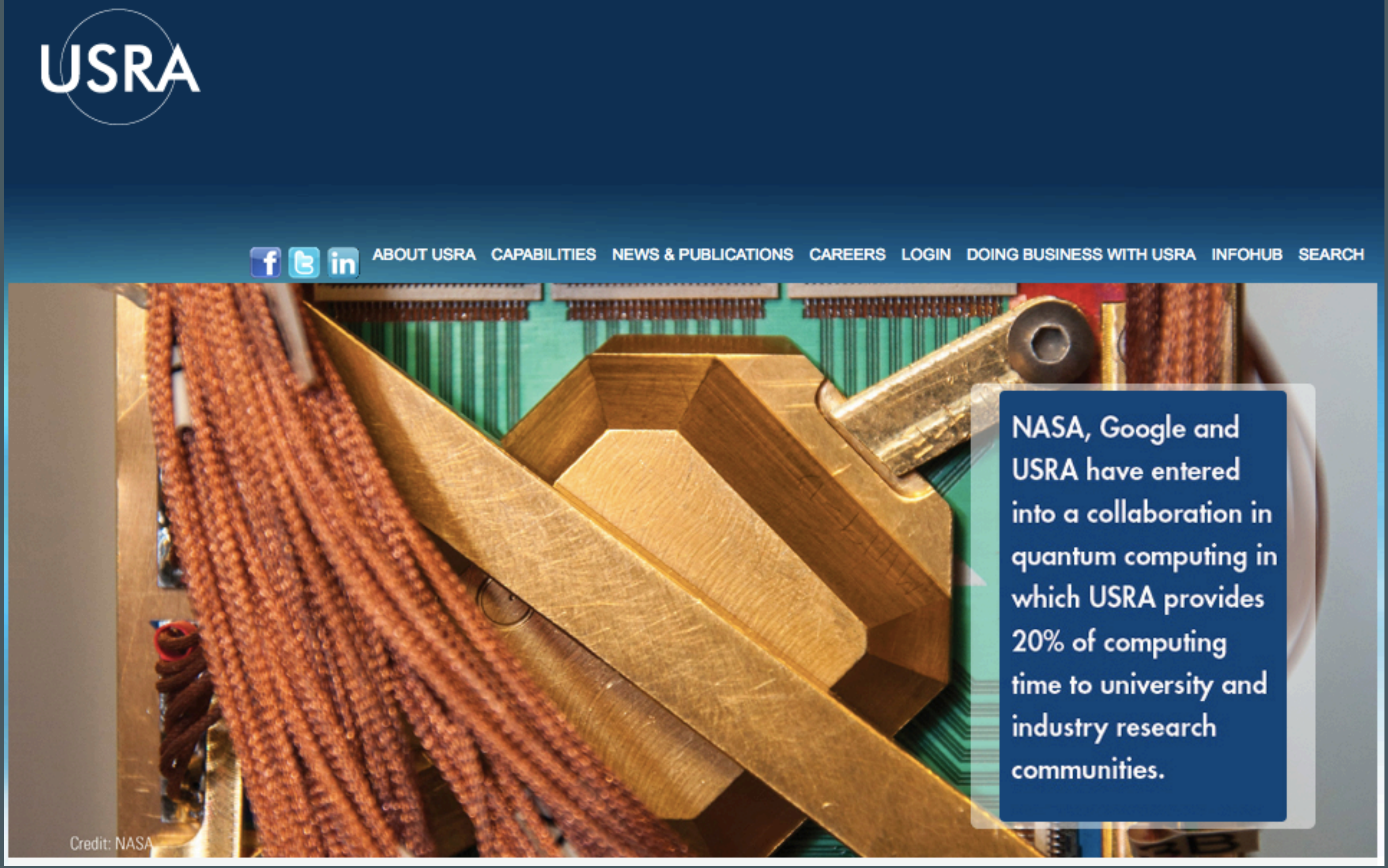

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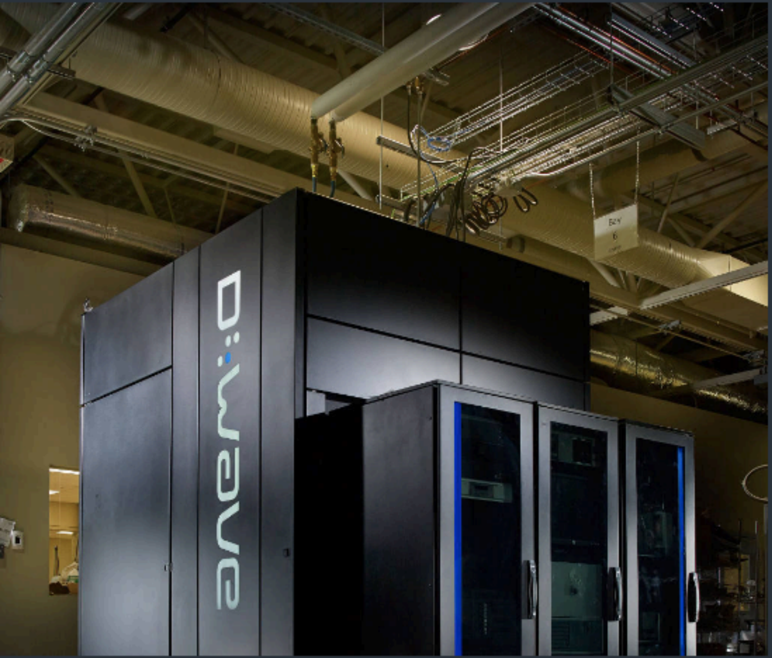
http://www.riacs.edu/

RIACS

MENU



QUANTUM COMPUTING

USRA, NASA, and Google have established a joint Quantum Artificial Intelligence Laboratory (QuAIL), with 20% of Computing Time available to the University and Industry Research Communities.

USRA manages the QuAIL Science Operations to engage the broader research community, and manages the technical operations of a D-Wave 2X™ system located at NASA's Ames Research Center.

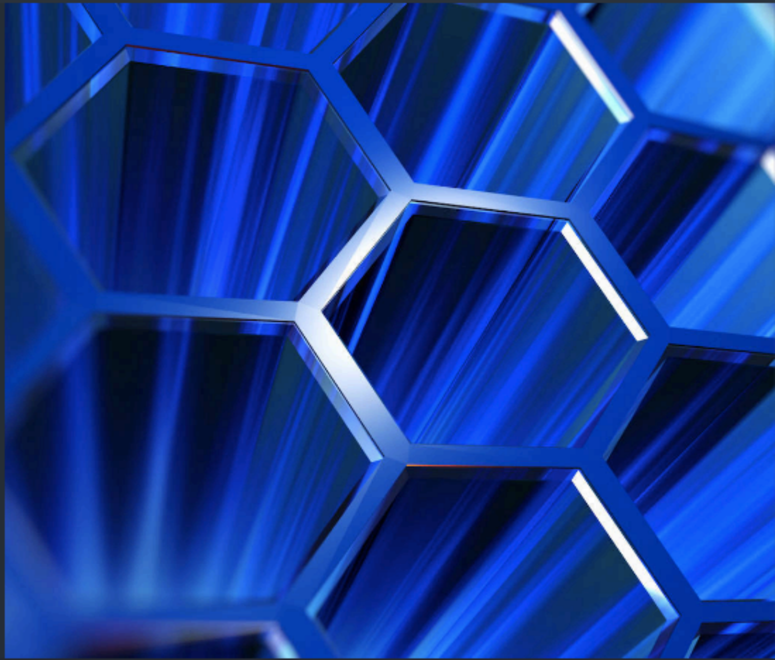
Research includes fundamental research in quantum physics and computer science, as well as applied research exploring application of quantum computing to various domains including planning and scheduling and fault management for various space and aeronautics applications.

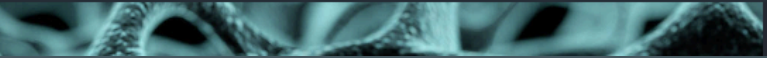
http://www.riacs.edu/

CLOUD COMPUTING

USRA has partnered with the NASA Headquarters Office of the Chief Information Officer (OCIO) to support various data needs in NASA through the research and development of a novel Model-Based Cloud Computing Service.

The service enables rapid provisioning of model-based applications including support for data integration and data analytics, and is being used by various NASA programs including the International Space Station (ISS) Extravehicular Activity (EVA) Office.





http://www.riacs.edu/

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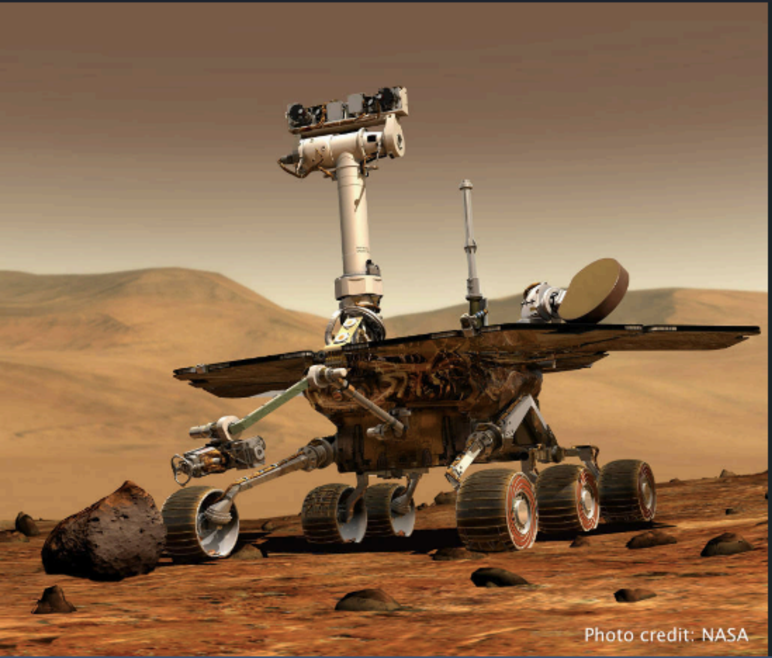


Photo credit: NASA

ARTIFICIAL INTELLIGENCE AND ROBOTICS

USRA has partnered with the Intelligent Systems Division at NASA's Ames Research Center to conduct collaborative research on AI and Robotics.

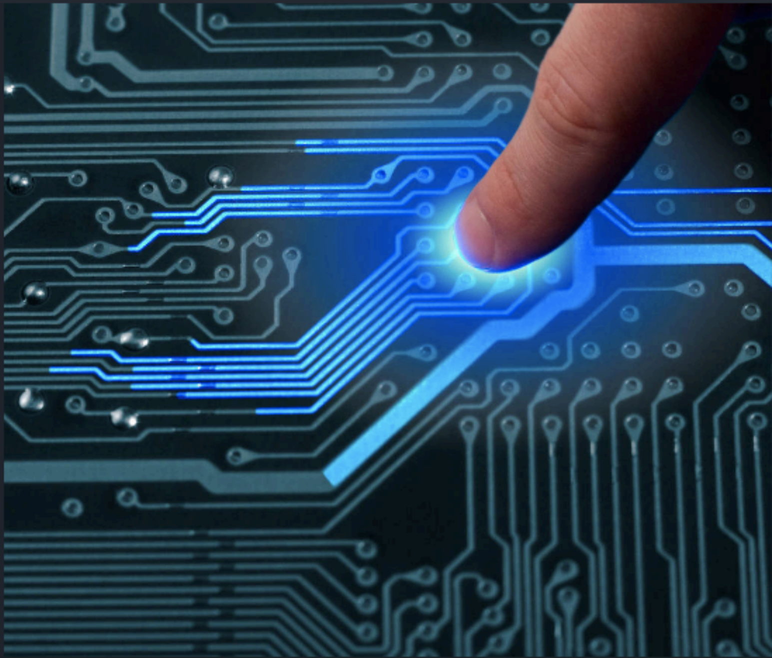
Current projects include research on planning and scheduling, as well as application of technologies from the mobile phone industry for intelligent systems. For example, this includes collaboration on the SPHERES Smartphone Project, which is part of the NASA Human Exploration Telerobotics Mission.

http://www.riacs.edu/

NANOTECHNOLOGY

USRA has partnered with the Center for Nanotechnology at NASA's Ames Research Center, to develop state-of-the art technologies on the atomic scale including sensors and electronics that utilize nano-scale components.

USRA scientists lead development of a novel additive manufacturing approach for creating electronic circuitry and sensors using nano-particles, and a novel approach for creating nano-scale vacuum channel transistors and other nano-scale electronics.



http://www.riacs.edu/

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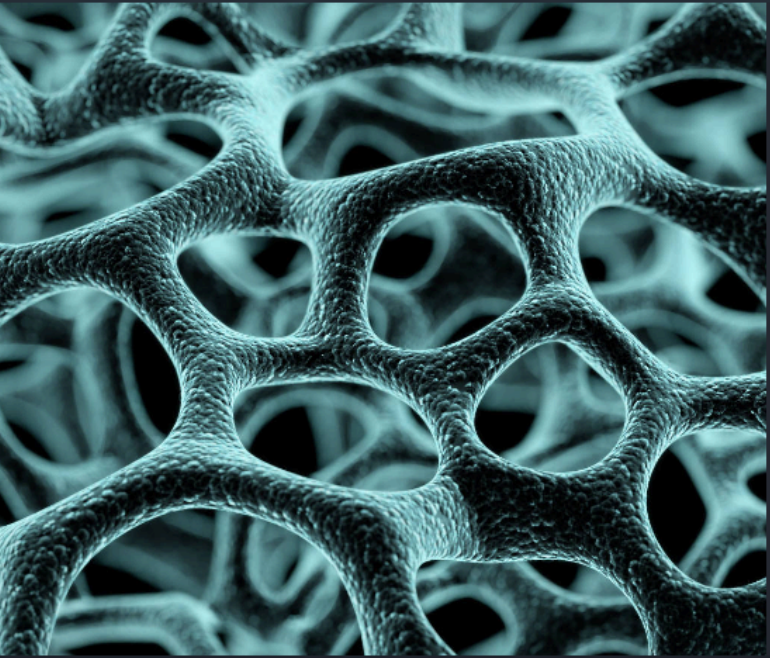
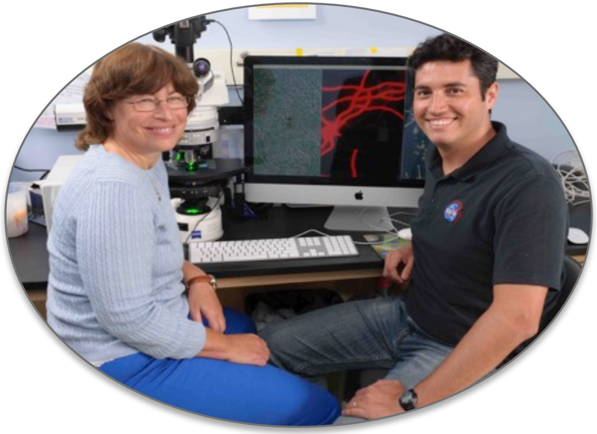


SYNTHETIC BIOLOGY

USRA has partnered with the Synthetic Biology Lab at NASA's Ames Research Center, to conduct collaborative research in synthetic biology focusing on application for human space exploration and astrobiology. The goal is to harness engineered biological systems to further space exploration and science, to search for life beyond Earth, and to improve life on Earth.

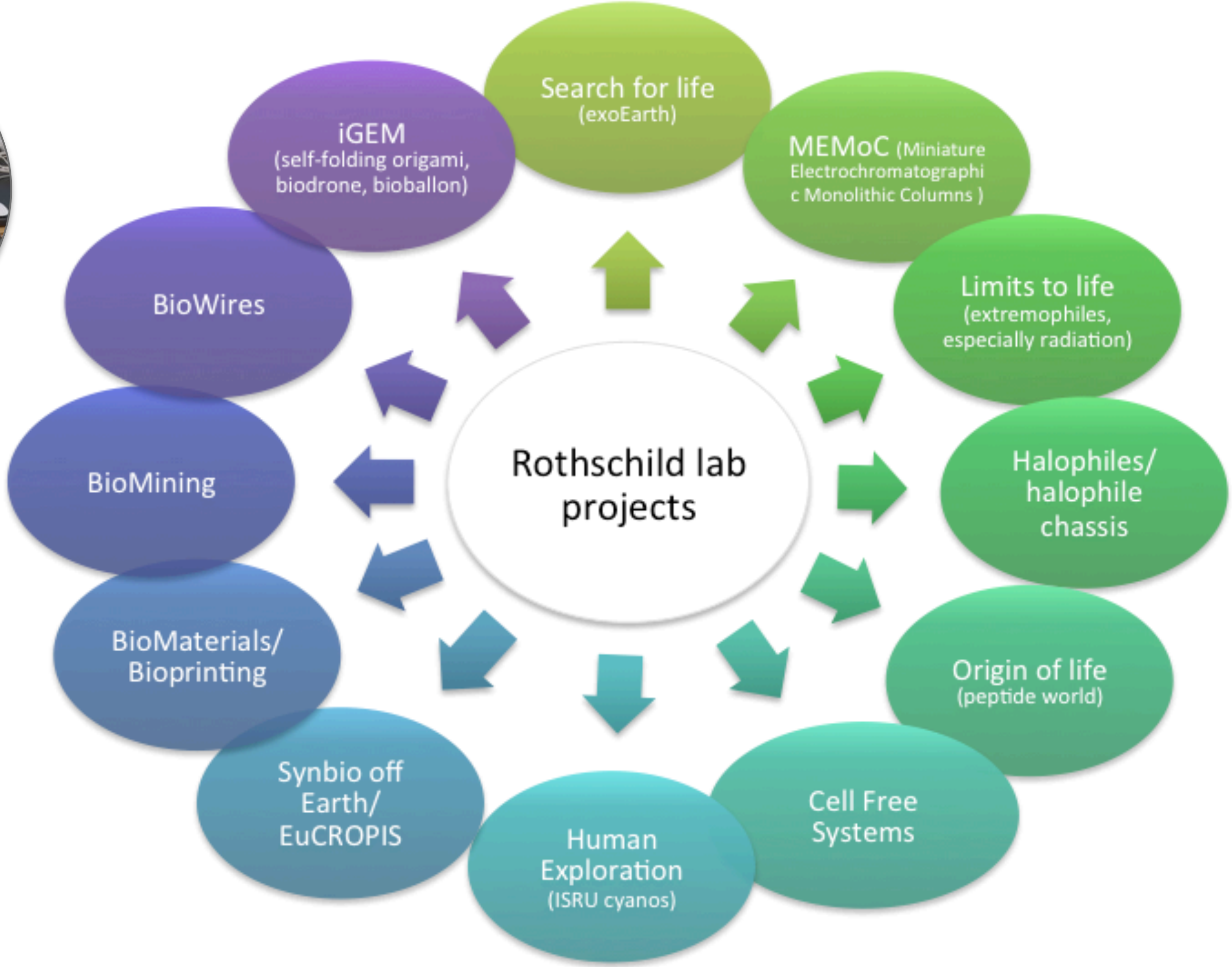
Research is accomplished through lab and field work including instrument development, as well as missions such as the Eu:CROPIS mission which is planned to demonstrate synthetic biology technology in space.

http://www.riacs.edu/



Dr. Ivan Paulino-Lima

- Development, delivery and ground controls for the PowerCell payload on the DLR Eu:CROPIS mission
- Continuation of my NPP work



PowerCells on Eu:CROPIS: A demonstration of synthetic biology technology and biology in space

Eu:CROPIS: A DLR satellite mission scheduled to launch in March 2017

Euglena

Combined

Regenerative

Organic Food

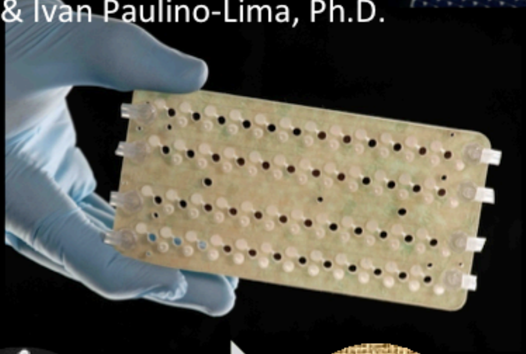
Production

In

Space

PI: Lynn J. Rothschild, Ph.D.

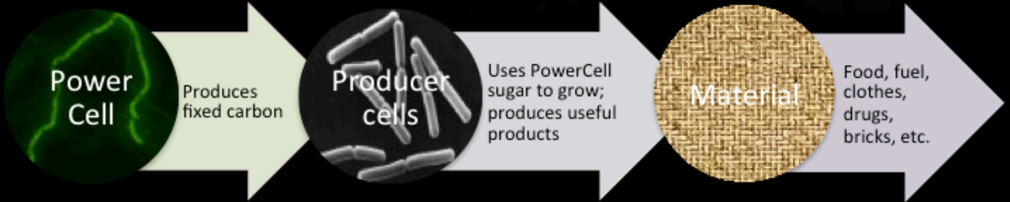
Biology: Ryan Kent, Griffin McCutcheon, Evie Pless & Ivan Paulino-Lima, Ph.D.

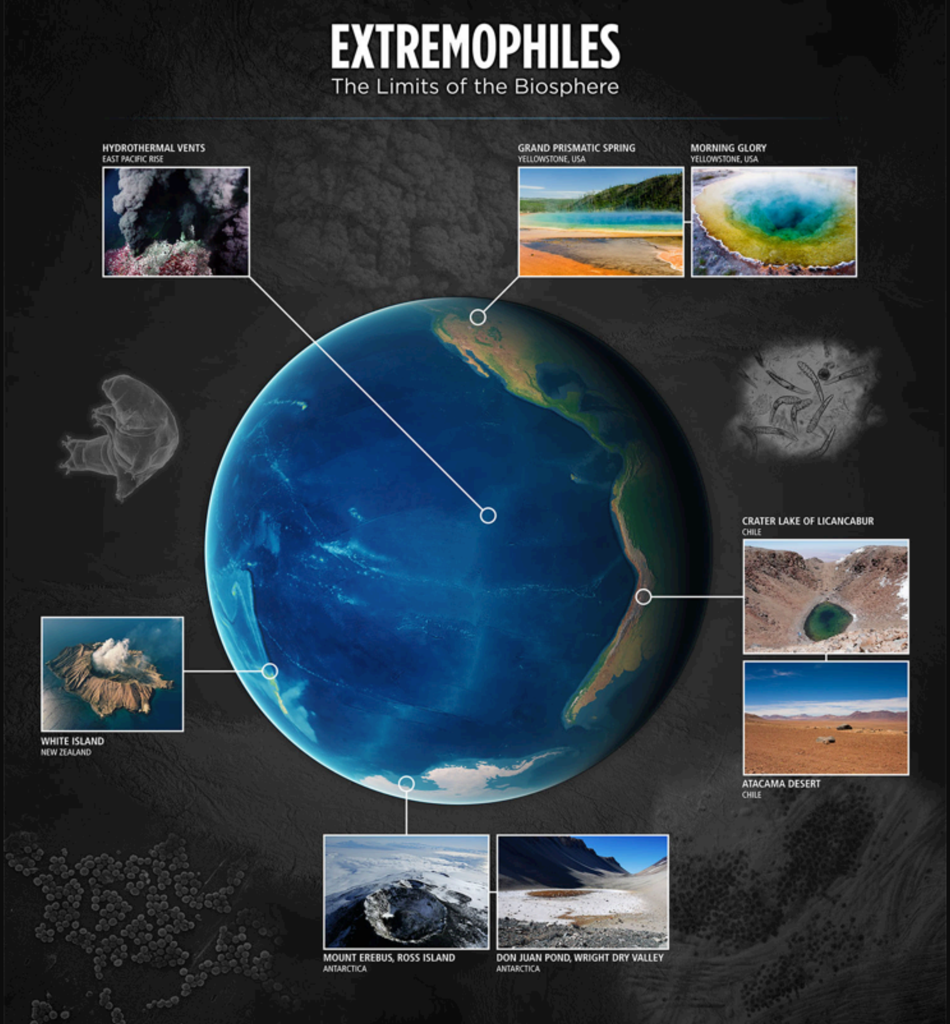


How does variable gravity impact synthetic biology?

PowerCell:

- Genetic competency
- Transformation
- Protein production





http://globaia.org/portfolio/diagrams-and-graphics/

National Aeronautics and Space Administration

ASTROBIOLOGY STRATEGY

www.nasa.gov

TABLE 3-1. Extremophile and tolerance tables.

The Limits of Known Life on Earth*			
Factor		**Environment/Source**	**Limits**
High Temperature		Submarine Hydrothermal Vents	110 to 121°C
Low Temperature		Ice	-17 to -20°C
Alkaline Systems		Soda Lakes	pH > 11
Acidic Systems		Volcanic Springs, Acid Mine Drainage	pH -0.06 to 1.0
Ionizing Radiation		Cosmic Rays, X-rays, Radioactive Decay	1,500 to 6,000 Gy
UV Radiation		Sunlight	5,000 J/m^2
High Pressure		Mariana Trench	1,100 bars
Salinity		Low Temperature Systems	$\alpha H_2 0 \sim 0.6$
Desiccation		Atacama Desert (Chile), McMurdo Dry Valleys (Antarctica)	~60% relative humidity

https://astrobiology.nasa.gov/

Extremophiles**			
Factor	**Class**	**Defining Growth Condition**	**Example Organisms**
High Temperature	Hyperthermophile Thermophile	> 80°C 60 to 80°C	*Pyrolobus fumarii*
Low Temperature	Psychrophile	< 15°C	*Synechococcus lividis*
High pH	Alkaliphile	pH > 9	*Psychrobacter, Vibrio, Anthrobacter*
Low pH	Acidophile	pH < 5 (typically much less)	*Natronobacterium, Bacillus, Clostridium paradoxum*
Radiation	–	High ionizing and UV radiation	*Deinococcus radiodurans, Rubrobacter, Pyrococcus furiosus*
High Pressure	Barophile Piezophile	High weight High pressure	Unknown *Pyrococcus* sp.
Salinity	Halophile	2 to 5 M NaC1	*Halobacteriaceae, Dunaliella salina*
Low Nutrients	Oligotroph	e.g., <1 mg L^{-1} dissolved organic carbon	*Sphingomonas alaskensis, Caulobacter* spp.
Oxygen Tension	Anaerobe Microaerophile	Cannot tolerate O_2 Tolerates some O_2	*Methanococcus jannaschii* *Clostridium*
Chemical Extremes	–	Tolerates high concentrations of metal (e.g., Cu, As, Cd, Zn)	*Ferroplasma acidarmanus* *Ralstonia* sp. CH34

* Table adapted from Marion et al. 2003. Reprinted with permission from Elsevier.

** Table adapted from Mancinelli and Rothschild 2001. Reprinted with permission from Macmillan Publishers Ltd.

https://astrobiology.nasa.gov/

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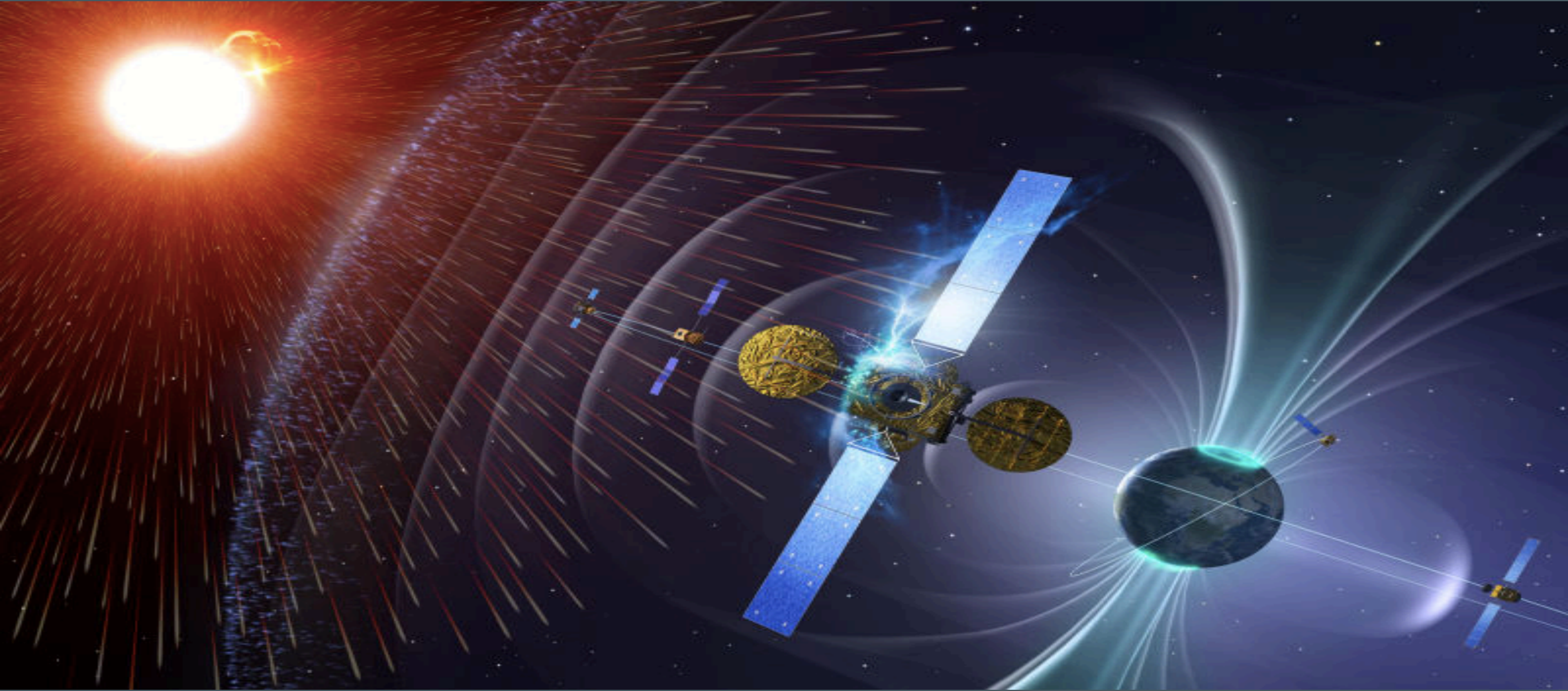
* Table adapted from Marion et al. 2003. Reprinted with permission from Elsevier.

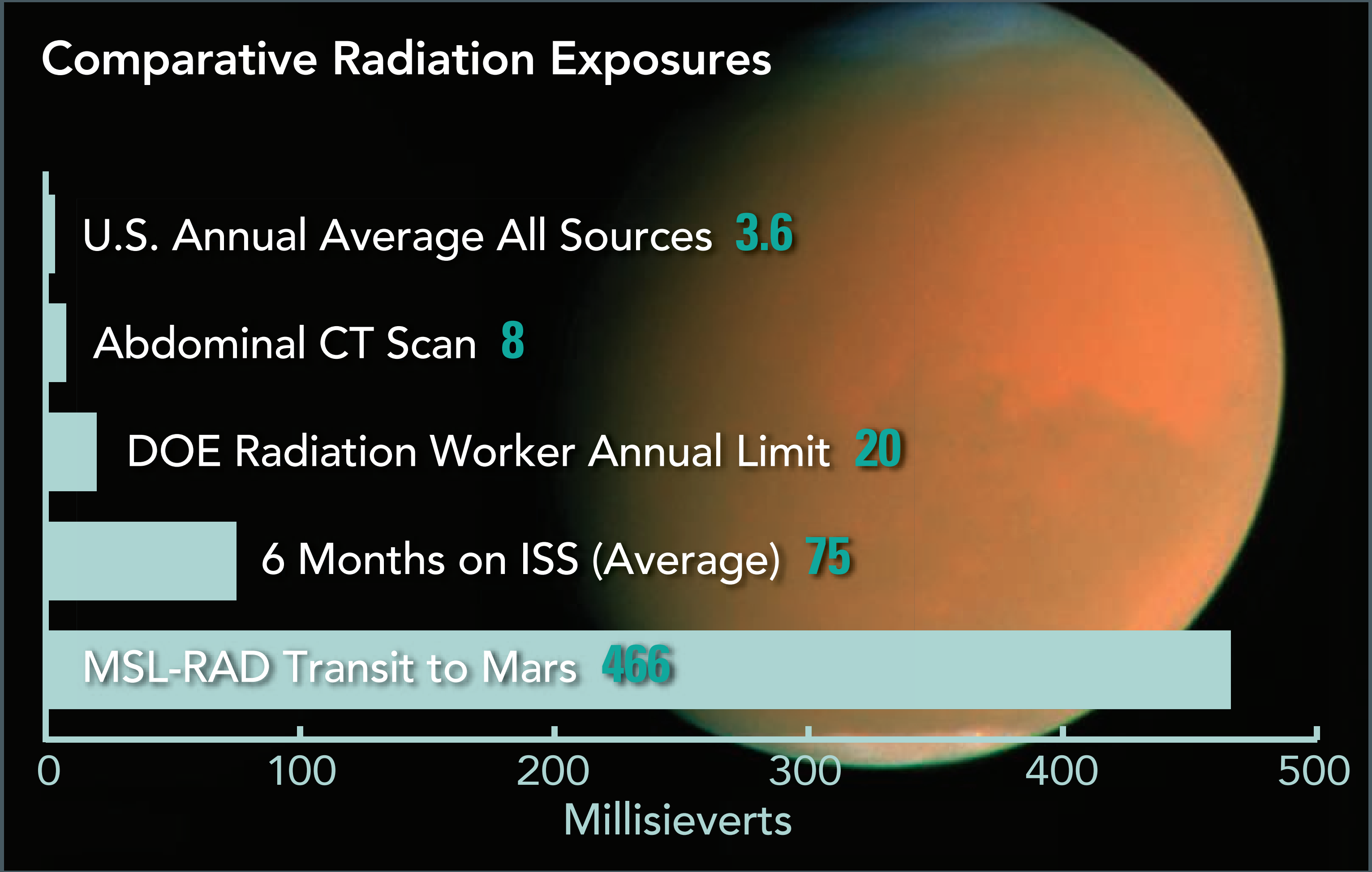
** Table adapted from Mancinelli and Rothschild 2001. Reprinted with permission from Macmillan Publishers Ltd.

https://astrobiology.nasa.gov/

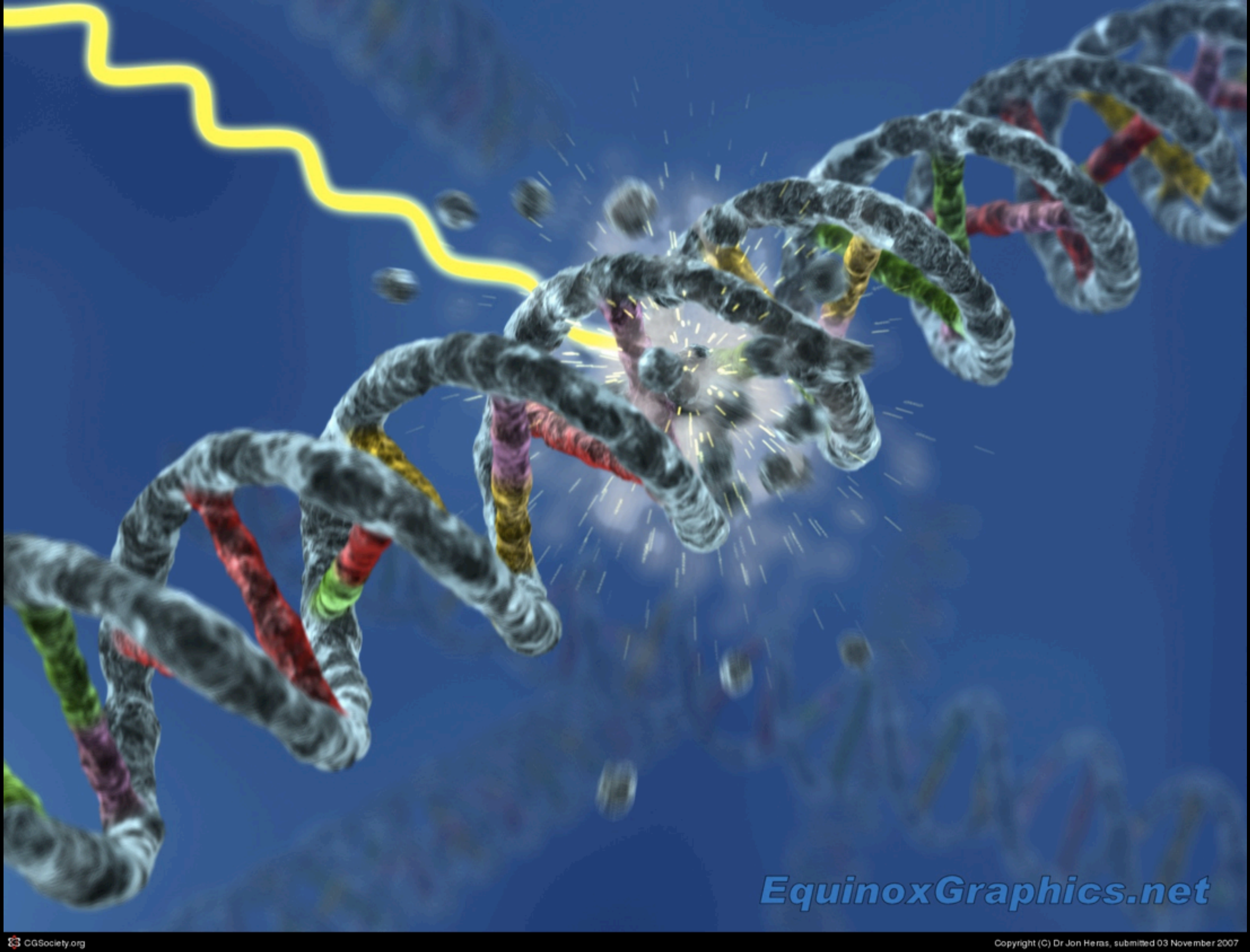
Why the study of radiation and its effects in materials and biology is important?



http://www.esa.int/Our_Activities/Space_Engineering_Technology/Proba_Missions/Detecting_radiation



Kerr, R A. (2013) Science, 340 (6136), 1031.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The Nobel Prize in Chemistry 2015
Tomas Lindahl, Paul Modrich, Aziz Sancar

Share this: 1.7K

The Nobel Prize in Chemistry 2015

Photo: Cancer Research UK

Tomas Lindahl

Prize share: 1/3

Photo: K. Wolf/AP Images for HHMI

Paul Modrich

Prize share: 1/3

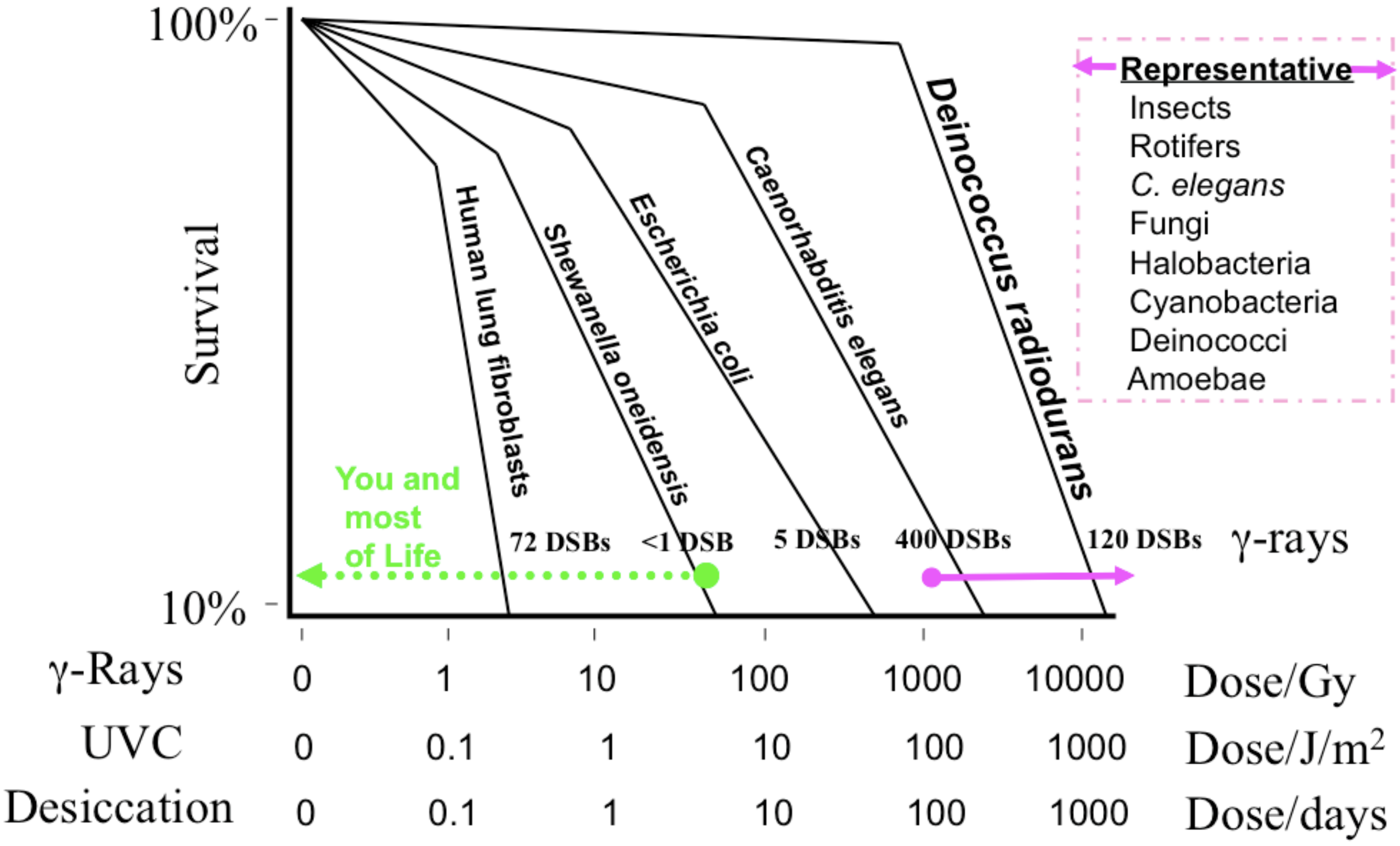
Photo: M. Englund, UNC-School of Medicine

Aziz Sancar

Prize share: 1/3

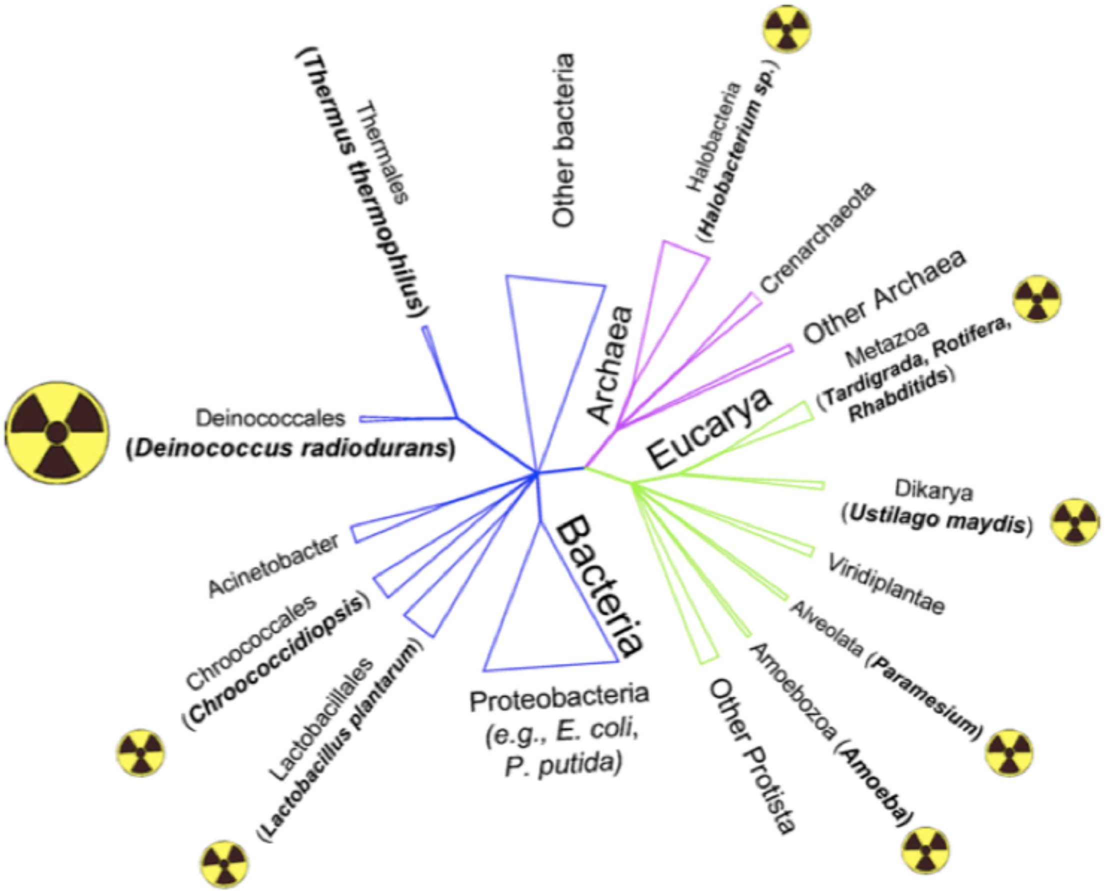
The Nobel Prize in Chemistry 2015 was awarded jointly to Tomas Lindahl, Paul Modrich and Aziz Sancar *"for mechanistic studies of DNA repair"*.

Survival Curves and DSBs



https://www.usuhs.edu/sites/default/files/media/path-deinococcus/ppt/mcbdalyusushow.ppt

Radiation-resistant representatives



Daly, M. DNA Repair 11, 12-21 (2012)

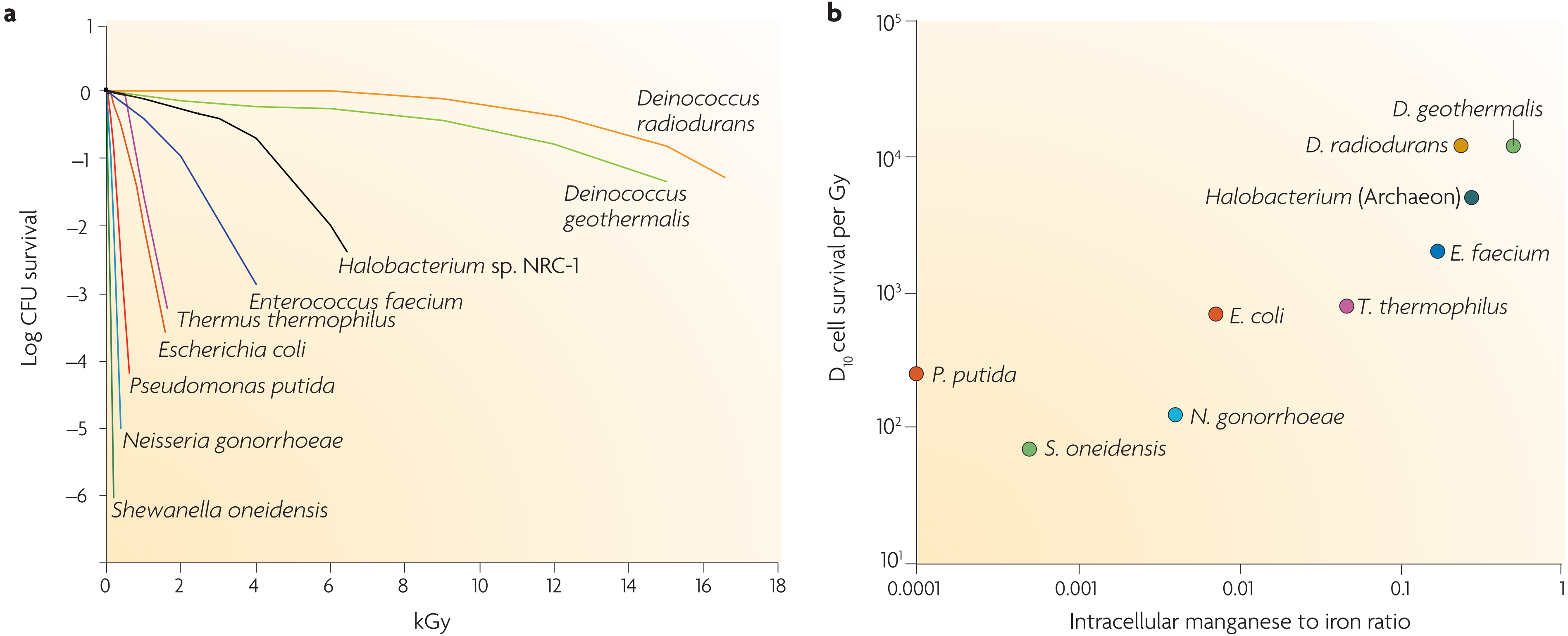


Figure 1 | **Relationship between survival following exposure to ionizing radiation and intracellular manganese and iron contents. a** | Ionizing

Daly, M. Nature Reviews Microbiology, 7, 237-245 (2009)

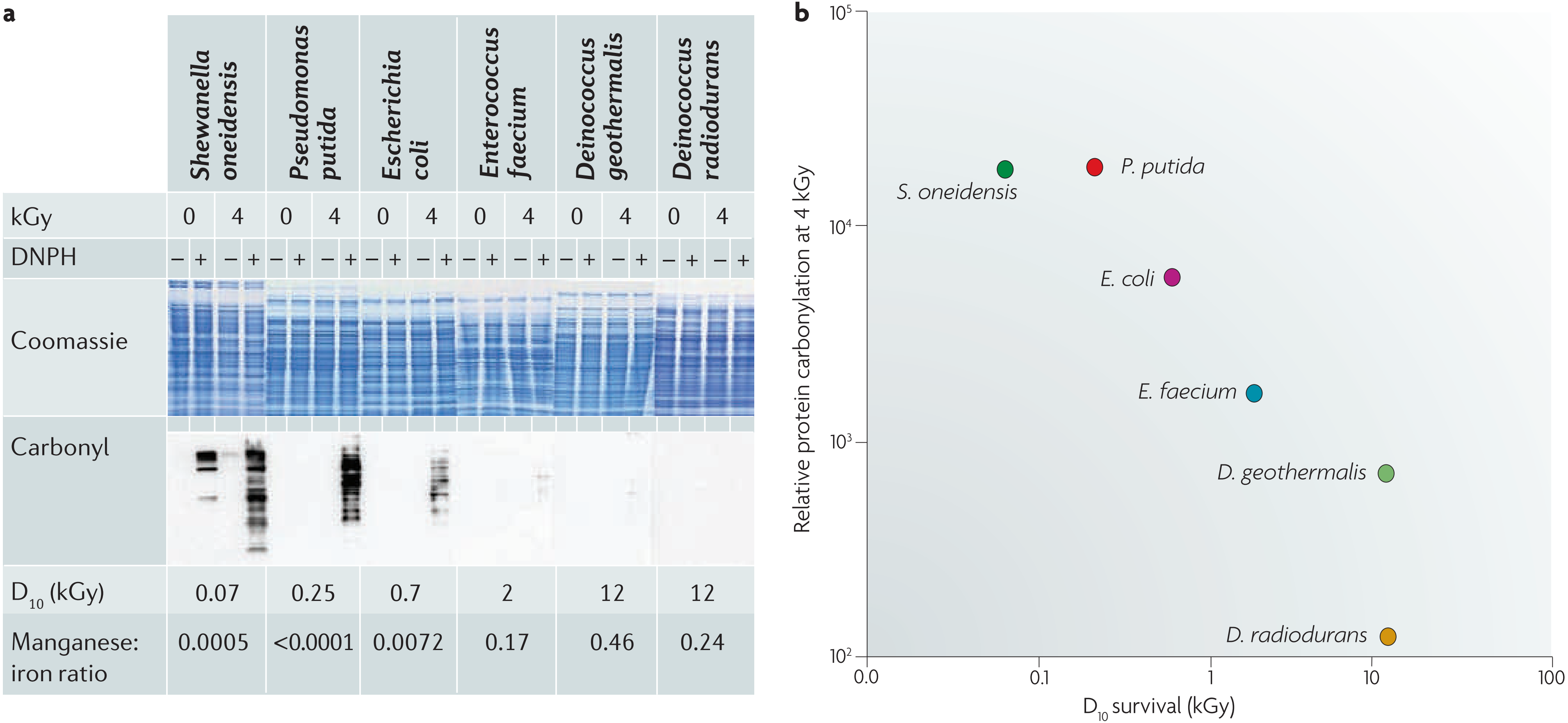
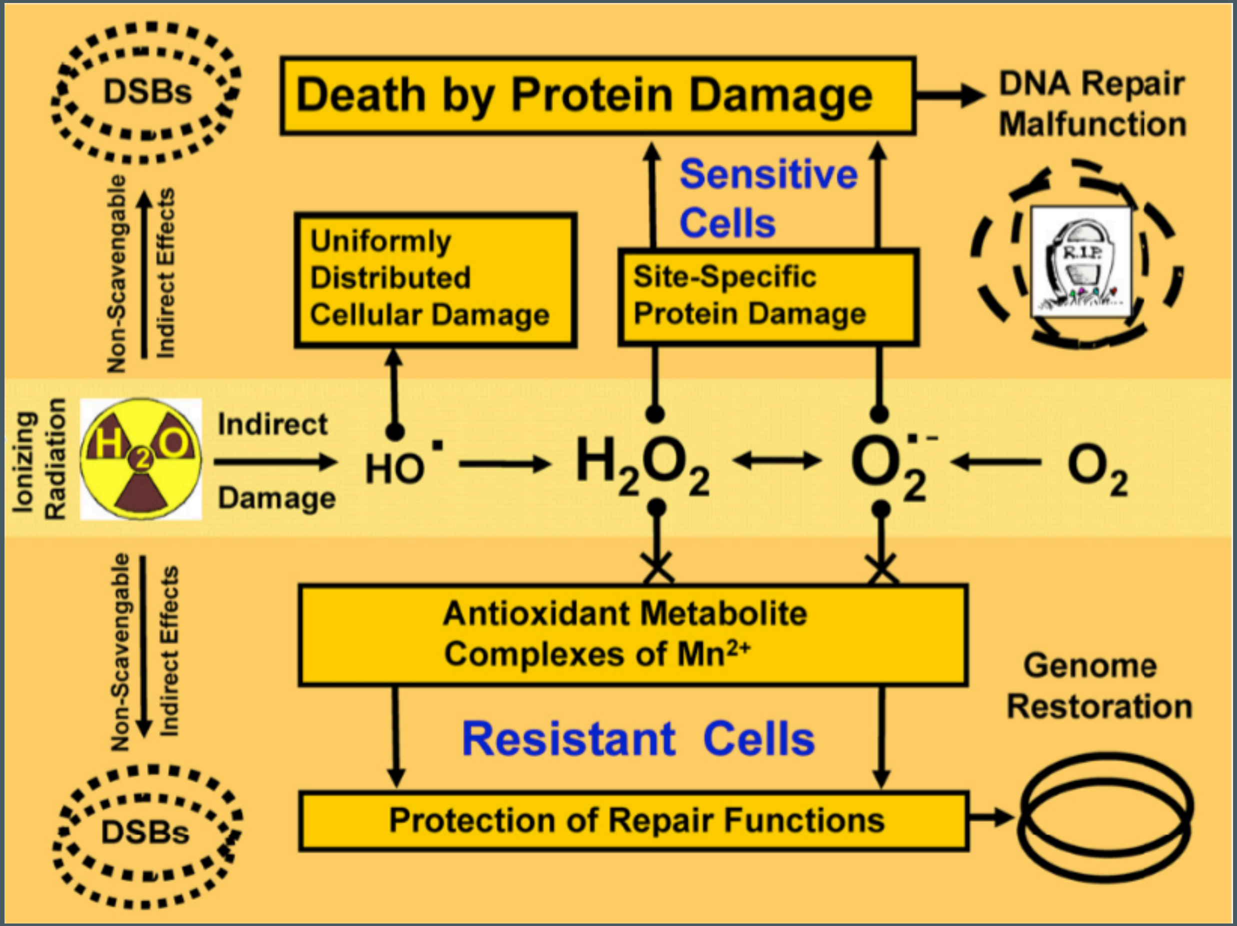


Figure 2 | ***In vivo* ionizing radiation-induced oxidative protein damage.**

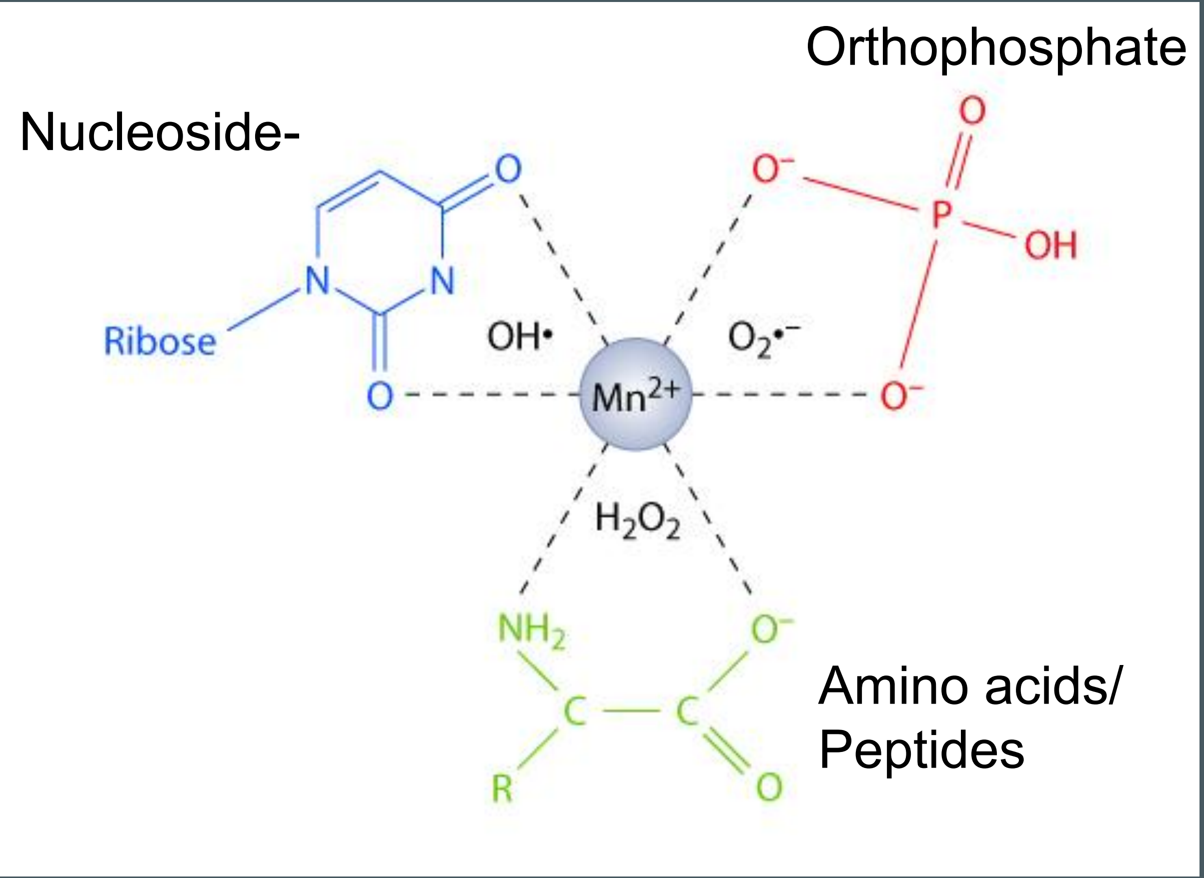
Daly, M. Nature Reviews Microbiology, 7, 237-245 (2009)

Cell death by protein damage after gamma irradiation



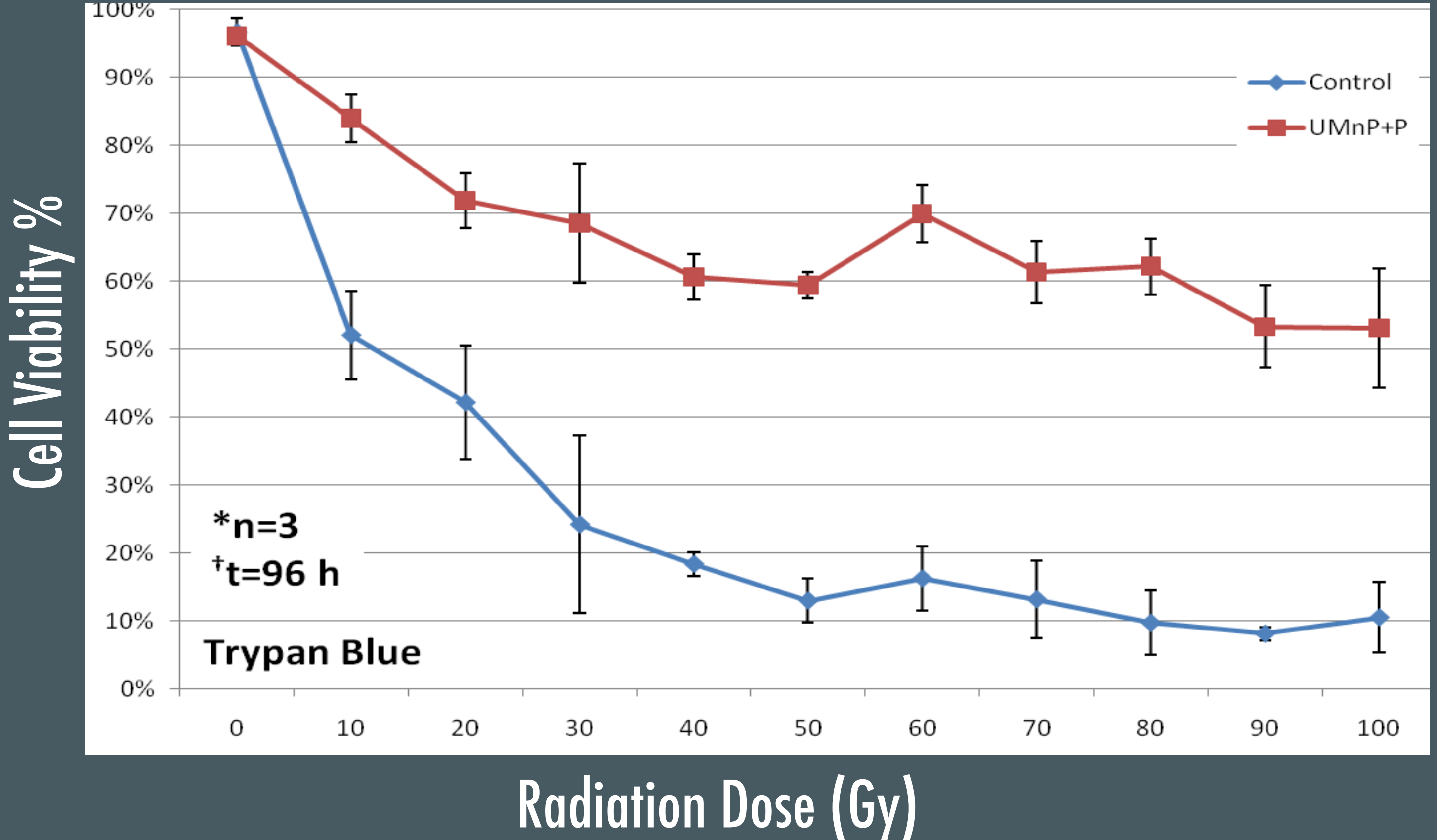
(Daly, M. DNA Repair, 11, 12-21, 2012)

Putative *D. radiodurans* Mn^{2+} Complexes



https://www.usuhs.edu/sites/default/files/media/path-deinococcus/ppt/mcbdalyusushow.ppt

Ex Vivo Radioprotective Effects of Reconstituted *D. radiodurans* Mn-Peptide Complexes on Human Cells



https://www.usuhs.edu/sites/default/files/media/path-deinococcus/ppt/mcbdalyusushow.ppt

Is *D. radiodurans* the last frontier of radiation resistance?

Other organisms:

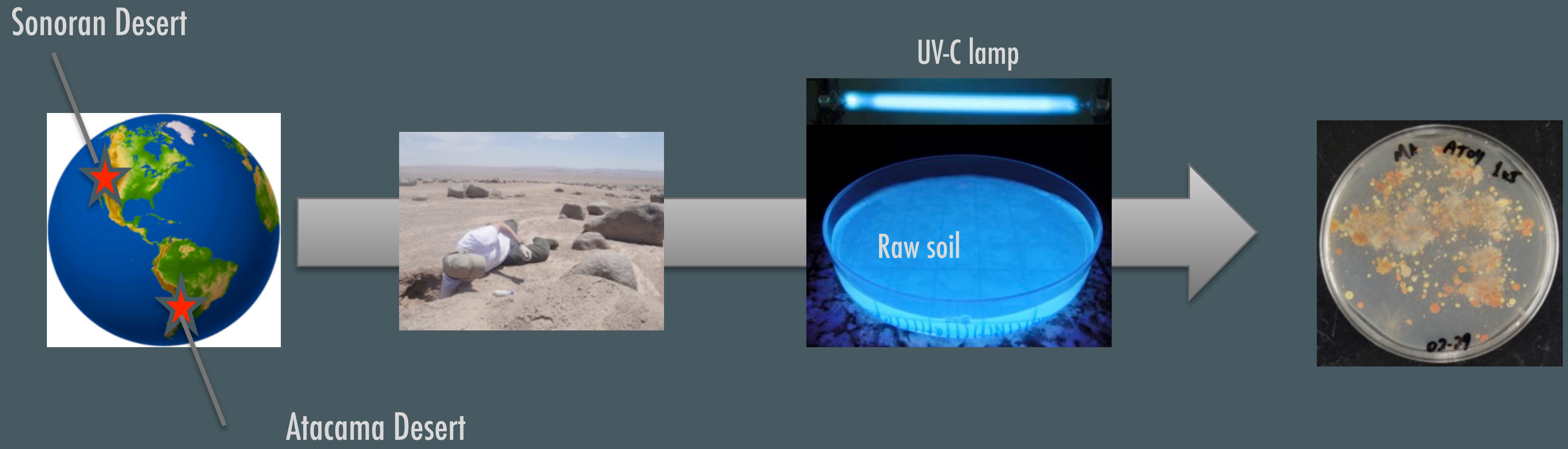
- Accumulate higher levels of Mn;
- May have a more efficient DNA repair tool set;
- May produce antioxidant secondary metabolites;


ARC02
ARC01
ARC03
ARC05
ARC04
California
Artillery Peak, Arizona
Arizona
© 2012 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2012 TerraMetrics
© 2012 Cnes/Spot Image
35°07'12.72" N 114°36'02.91" W elev 3312 ft
Cordillera Oriental Mountains
La Paz
Bolivia
The Andes
AT02
AT01
AT03
AT04
AT05
Chile
© 2012 MapLink/Tele At

Field sites

METHODS

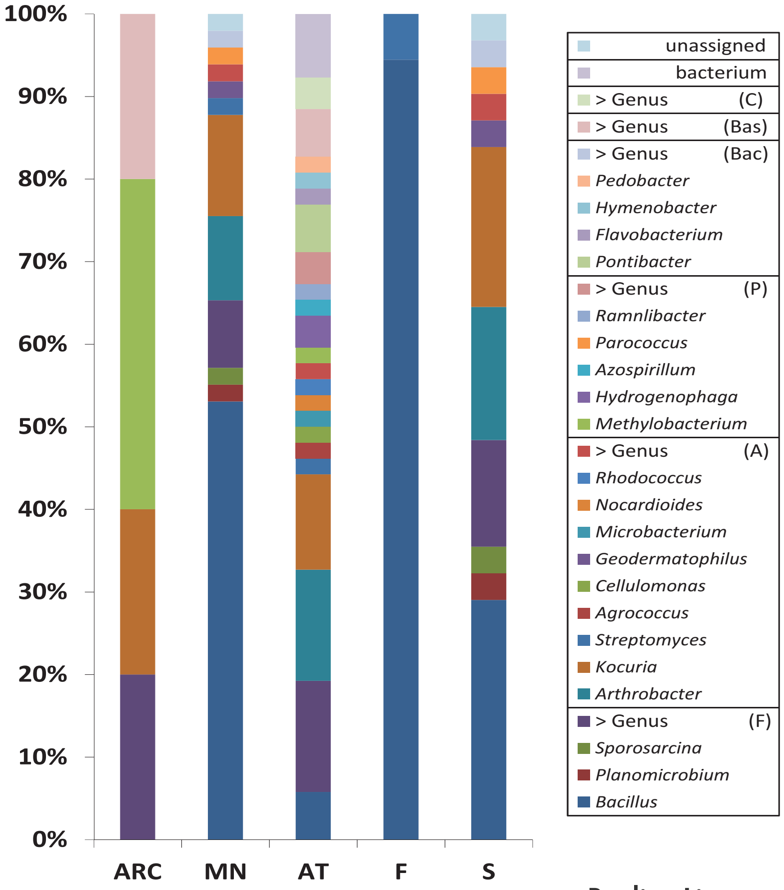
- Selection and identification of (106) morphotypes from 25 soil samples

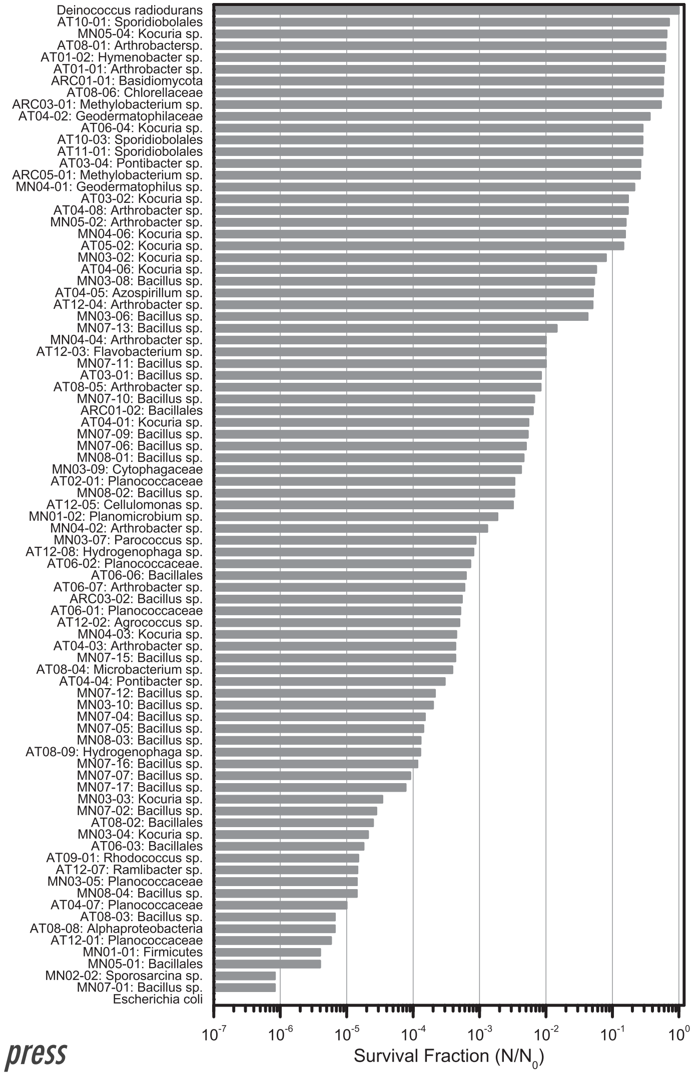


- Survival curves to UV-C irradiation using germicidal lamp
- Extracellular and Intracellular Mn/Fe ratio through ICP-MS
- Optical and Electron Microscopy

RESULTS

High diversity of radiation resistant isolates

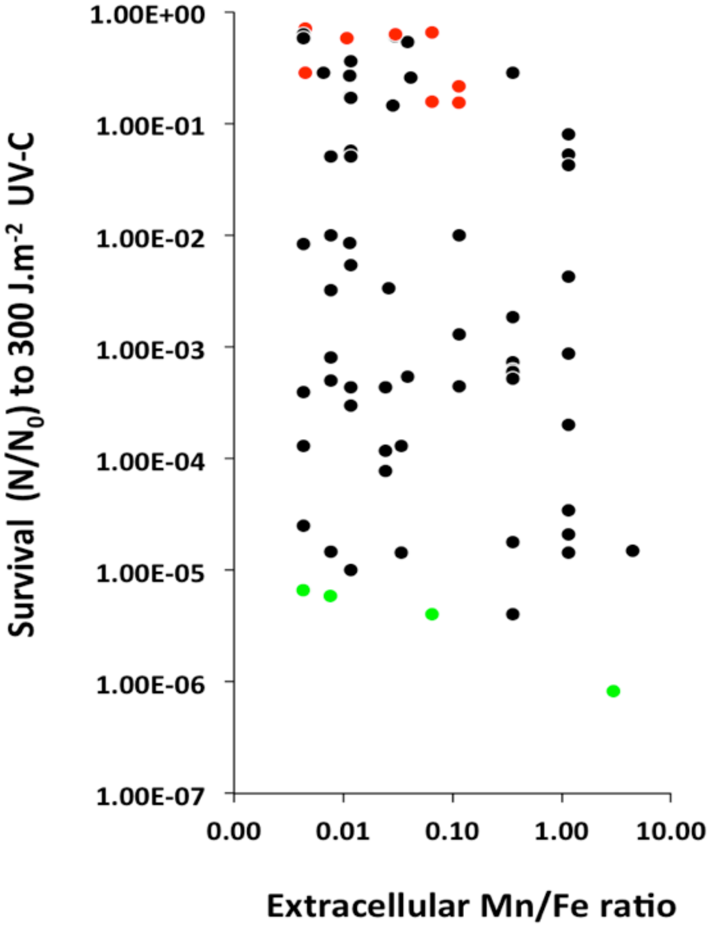




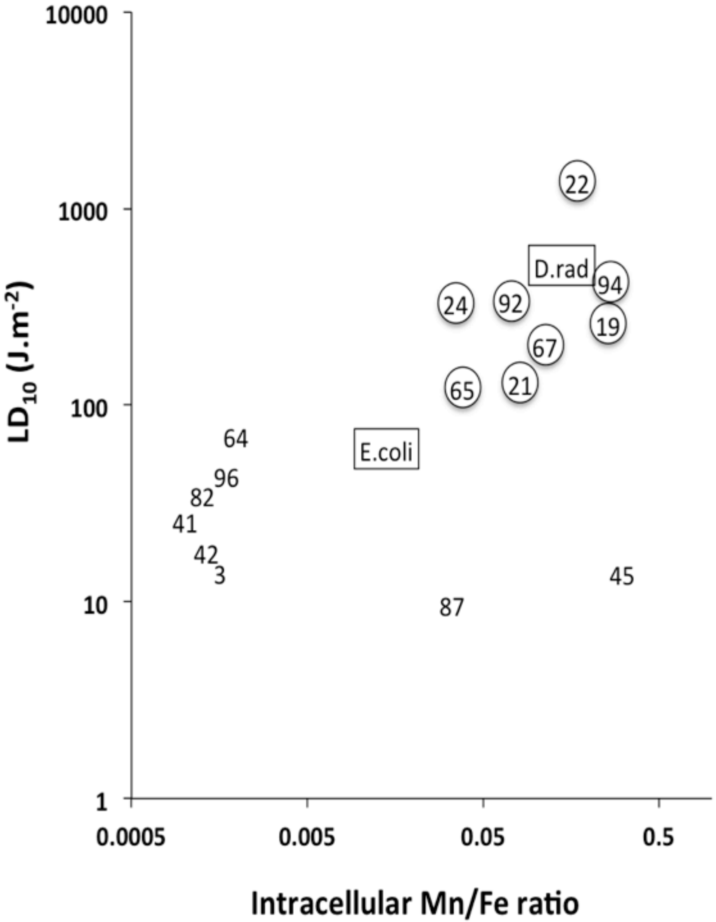
300 J/m^2 UV-C irradiation

Paulino-Lima et al. (2016) *in press*

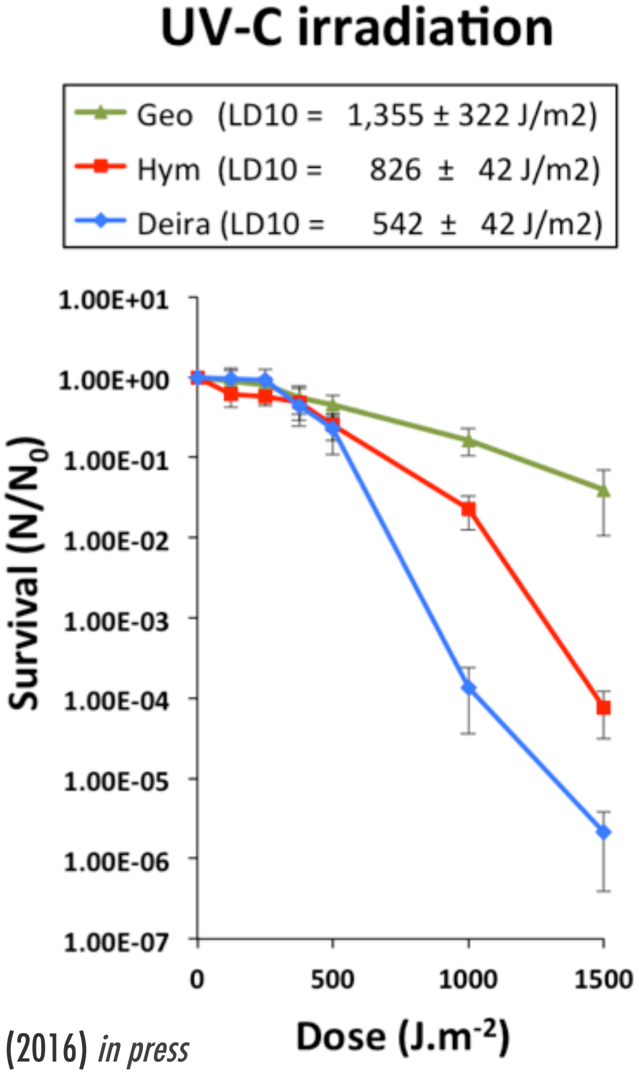
EXTRACELLULAR Mn/Fe RATIO VERSUS SURVIVAL

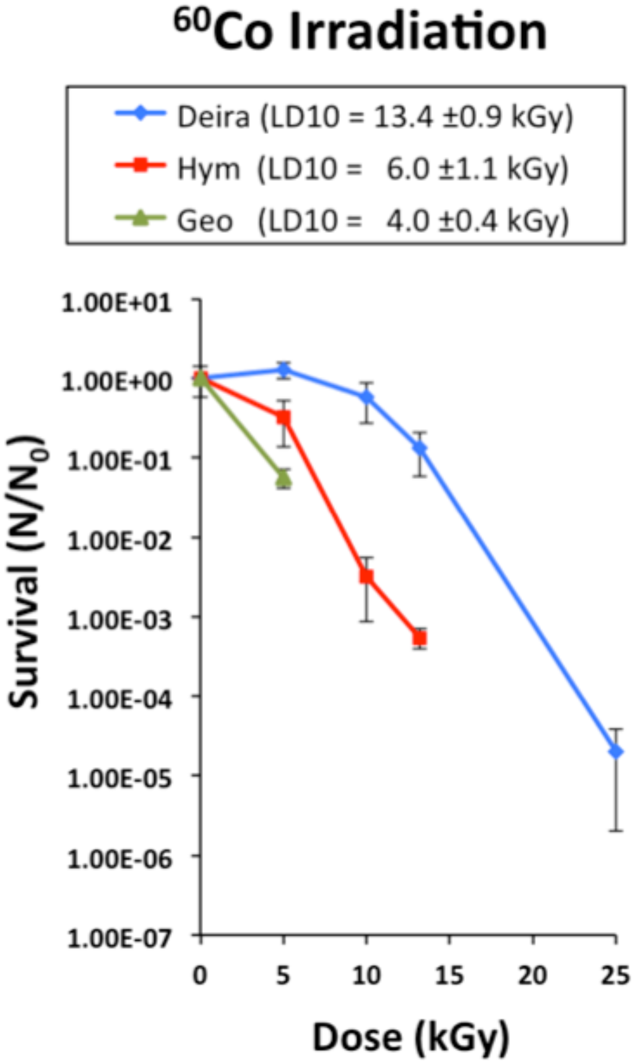


INTRACELLULAR Mn/Fe RATIO VERSUS SURVIVAL

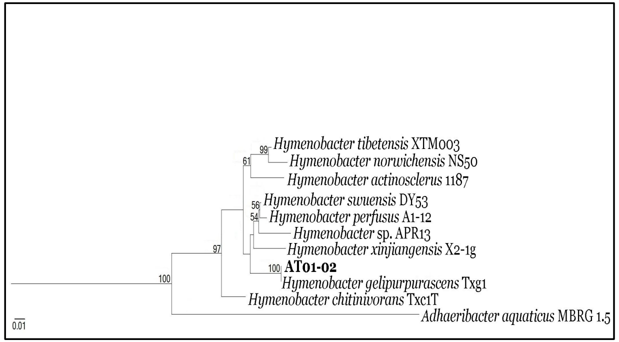


Paulino-Lima et al. (2016) *in press*





Paulino-Lima et al. (2016) *in press*



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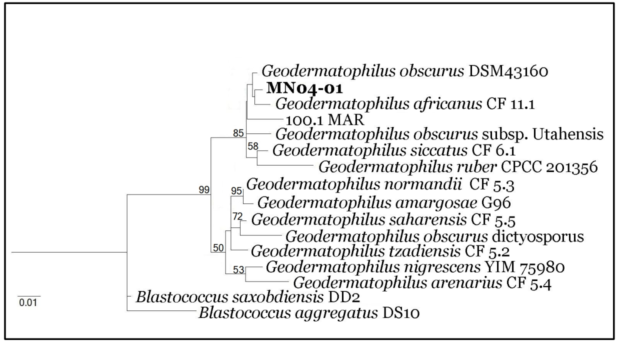

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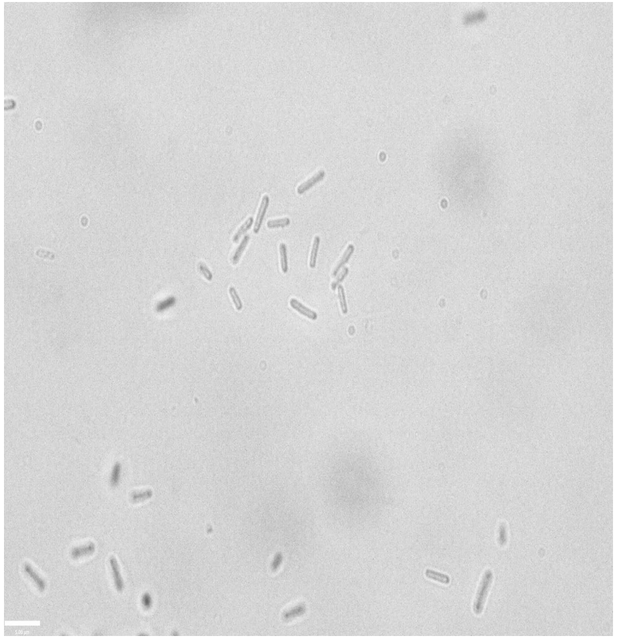
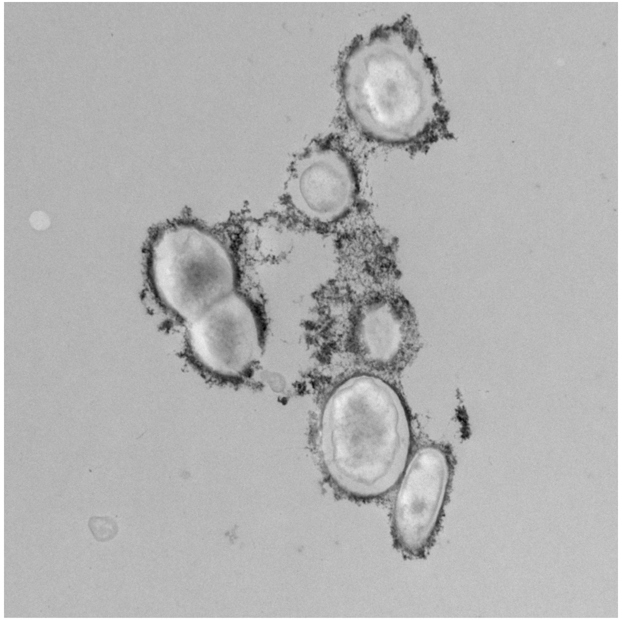


C

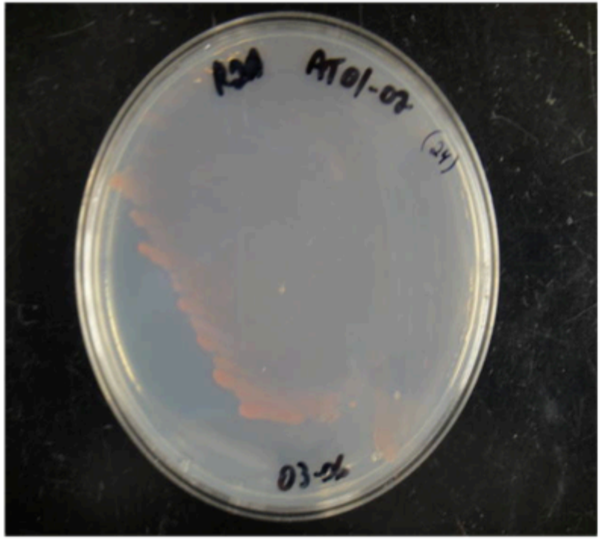


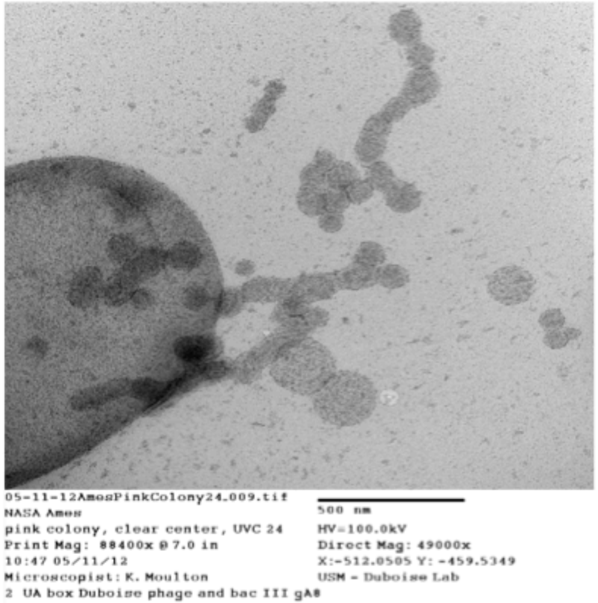
D

TEM Dec 2014014.tif
Geodermatophilus sp.

500 nm

Hymenobacter sp. strain AT01-02





- ★ Isolated from the hyperarid core of the Atacama Desert
- ★ Presence of virus-like particles
- ★ Red pigmented
- ★ Highly resistant to UV-C light

AMERICAN SOCIETY FOR MICROBIOLOGY genomeAnnouncements

Draft Genome Sequence of *Hymenobacter* sp. Strain AT01-02, Isolated from a Surface Soil Sample in the Atacama Desert, Chile

Anders Cai Holm Hansen,[a] Ivan Glaucio Paulino-Lima,[b] Kosuke Fujishima,[c] Lynn Justine Rothschild,[d] Peter Ruhdal Jensen[a]

Microbial Biotechnology & Biorefining, National Food Institute, Technical University of Denmark, Lyngby, Denmark[a]; NASA Postdoctoral Program Fellow, NASA Ames Research Center, Moffett Field, California, USA[b]; University Affiliated Research Center, NASA Ames Research Center, Moffett Field, California, USA[c]; NASA Ames Research Center, Moffett Field, California, USA[d]

Here, we report the 5.09-Mb draft genome sequence of *Hymenobacter* sp. strain AT01-02, which was isolated from a surface soil sample in the Atacama Desert, Chile. The isolate is extremely resistant to UV-C radiation and is able to accumulate high intracellular levels of Mn/Fe.

Received 11 December 2015 **Accepted** 21 December 2015 **Published** 11 February 2016

Citation Holm Hansen AC, Paulino-Lima IG, Fujishima K, Rothschild LJ, Jensen PR. 2016. Draft genome sequence of *Hymenobacter* sp. strain AT01-02, isolated from a surface soil sample in the Atacama Desert, Chile. Genome Announc 4(1):e01701-15. doi:10.1128/genomeA.01701-15.

Address correspondence to Anders Cai Holm Hansen, achh@food.dtu.dk.

Hymenobacter sp. strain AT01-02, isolated from the Atacama Desert, Chile, is a Gram-negative pink-pigmented bacterium that thrives in an extremely dry environment, where it is exposed to large temperature variations and high levels of solar UV radiation (1, 2). Several *Hymenobacter* spp. were reported to be radiation resistant (3–6), and isolate AT01-02 is more resistant than *Deinococcus radiodurans* to UV-C irradiation, being able to accumulate high intracellular levels of Mn/Fe (our unpublished data).

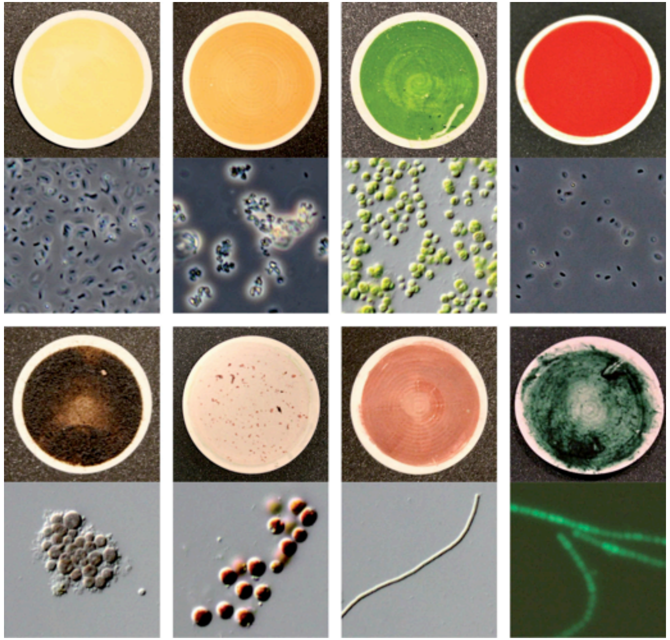
xenobiotic biodegradation and metabolism, 43 genes related to DNA replication and repair (UvrABC system, *recA*, and MutS), and 29 genes related to membrane transport (including 16 ABC transporters, 11 secretory systems, and 2 manganese transporters of the natural resistance-associated macrophage protein [NRAMP] family). Similar to what was reported recently for a different *Hymenobacter* isolate (7), we found 4 teichoic and 3 lipoteichoic biosynthesis genes, which are characteristically present

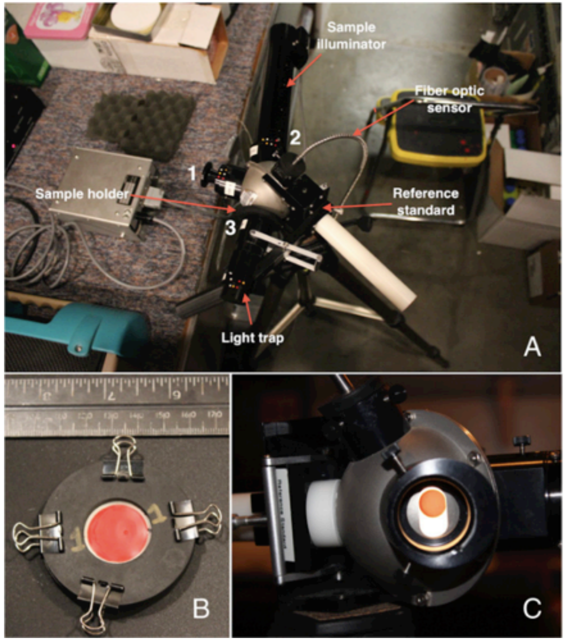
Surface biosignatures of exo-Earths: Remote detection of extraterrestrial life

Siddharth Hegde[a,1], Ivan G. Paulino-Lima[b], Ryan Kent[c], Lisa Kaltenegger[a,d], and Lynn Rothschild[e]

[a]Max Planck Institute for Astronomy, Heidelberg 69117, Germany; [b]National Aeronautics and Space Administration Postdoctoral Program Fellow, National Aeronautics and Space Administration Ames Research Center, Moffett Field, CA 94035; [c]University of California, Santa Cruz University Affiliated Research Center, National Aeronautics and Space Administration Ames Research Center, Moffett Field, CA 94035; [d]Institute for Pale Blue Dots, Department of Astronomy, Cornell University, Ithaca, NY 14853; and [e]National Aeronautics and Space Administration Ames Research Center, Moffett Field, CA 94035

Edited by Neta A. Bahcall, Princeton University, Princeton, NJ, and approved February 2, 2015 (received for review November 5, 2014)





Geodermatophilus sp._KM349882

Sample name: *Geodermatophilus* sp.

Accession number for 16S rRNA partial gene sequence: KM349882

Classification: Bacteria; Actinobacteria; Actinobacteridae; Actinomycetales; Frankineae; Geodermatophilaceae; Geodermatophilus

Metabolism: Heterotrophic

Origin: Sonoran desert, AZ, USA

Isolation: Ivan P. Lima (NPP at NASA Ames, CA, USA)

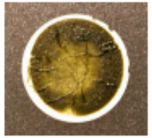
Sample concentration: 6.02×10^6 cells/ml

Sample count on filter substrate: $1.80 \pm 0.12 \times 10^7$ cells

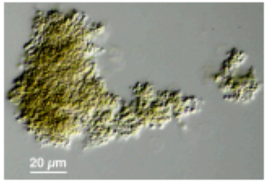
Laboratory growth conditions: 30 °C, 180 rpm, 1 week

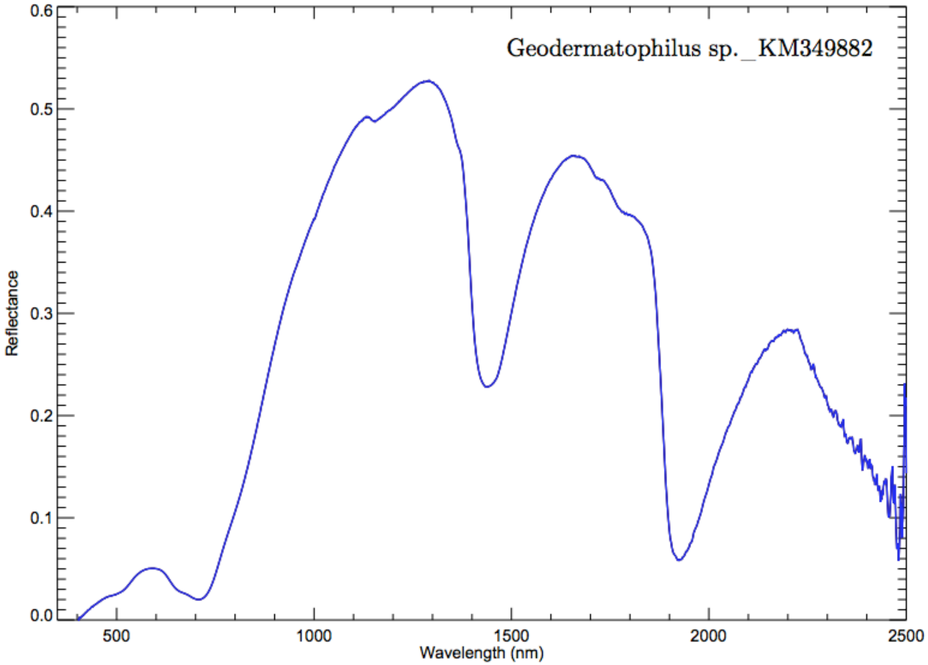
Culture medium: Reasoner's 2A (R2A)

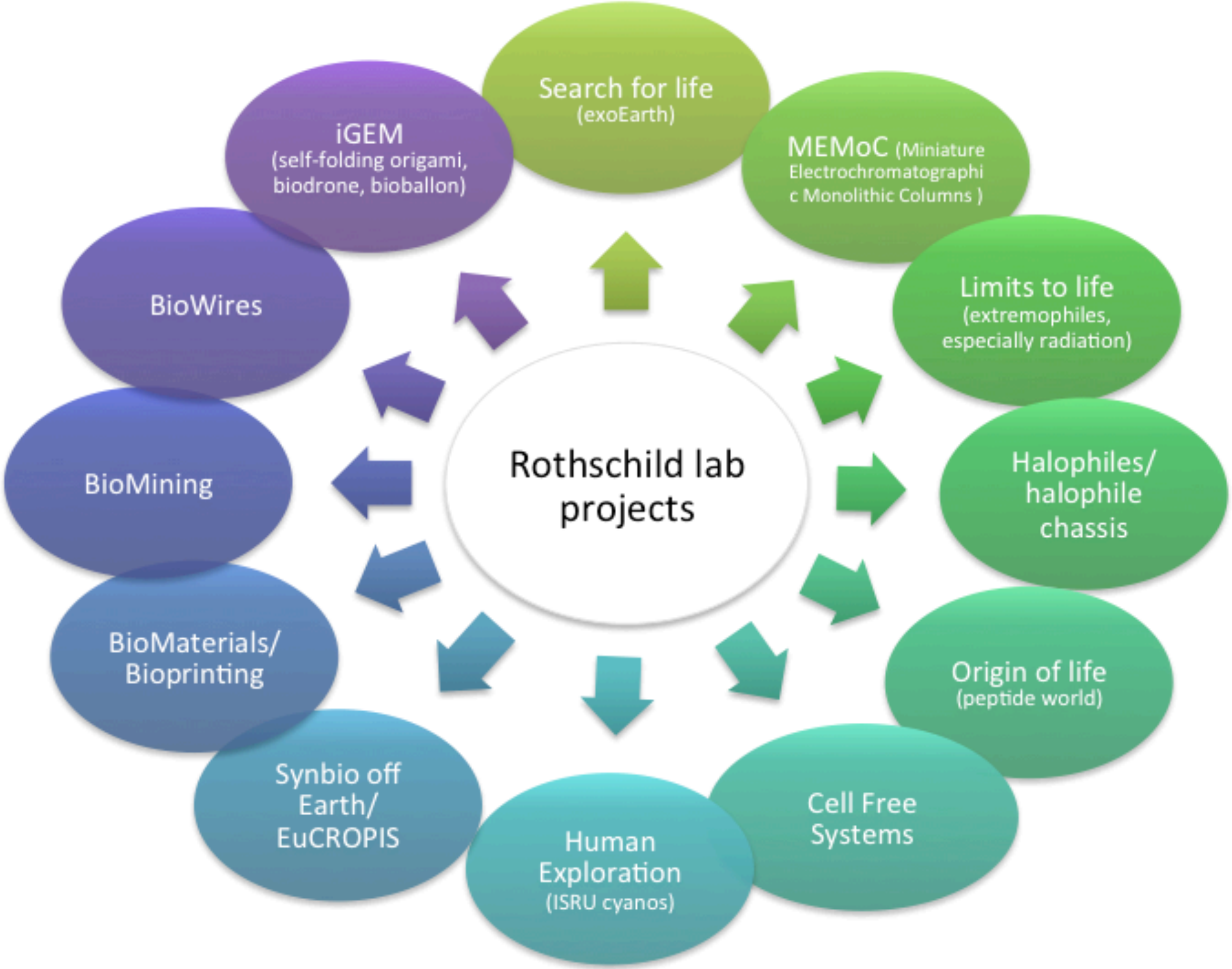
Sample photograph:



Sample micrograph:






Rothschild lab projects
Search for life (exoEarth)
MEMoC (Miniature Electrochromatographic Monolithic Columns)
Limits to life (extremophiles, especially radiation)
Halophiles/ halophile chassis
Origin of life (peptide world)
Cell Free Systems
Human Exploration (ISRU cyanos)
Synbio off Earth/ EuCROPIS
BioMaterials/ Bioprinting
BioMining
BioWires
iGEM (self-folding origami, biodrone, bioballon)

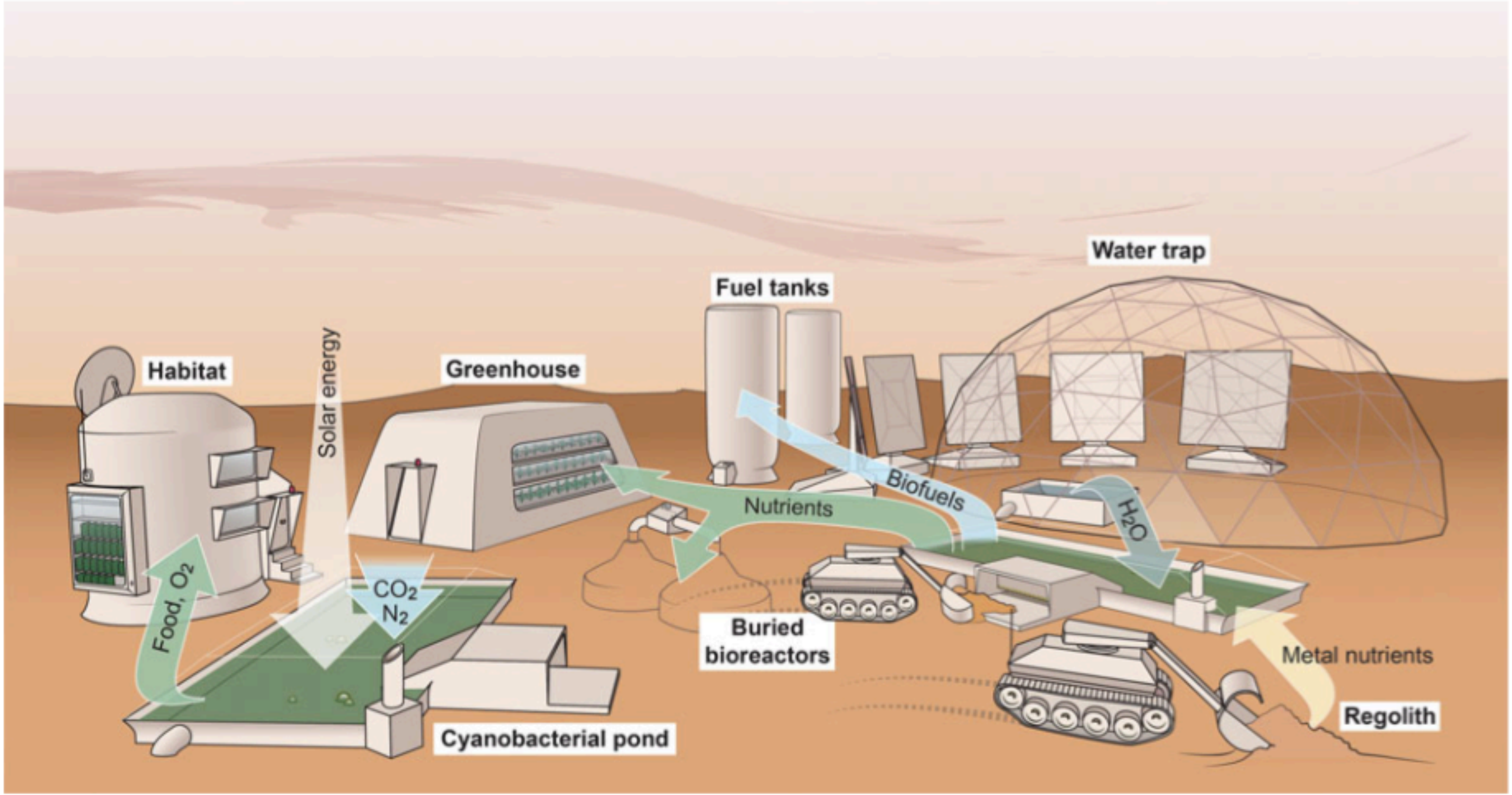


Fig. 1. Artist's rendering of a cyanobacterium-based biological life-support system on Mars. Figure design: Cyprien Verseux and Sean McMahon (Yale University). Layout: Sean McMahon.

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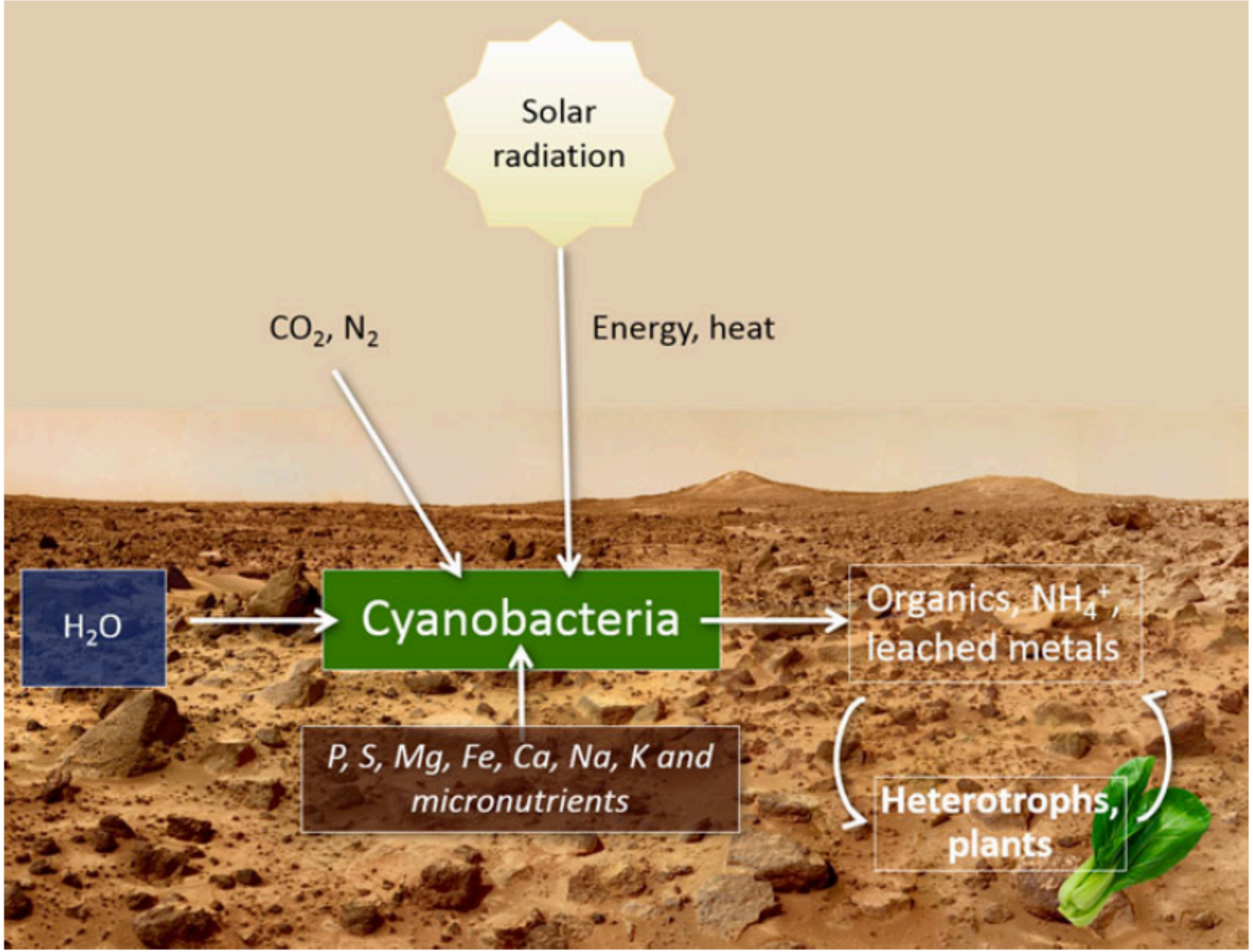

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MARS
#JOURNEYTOMARS
http://www.nasa.gov/social/journeytomars-social/

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Fabio Rodrigues, University of São Paulo, Brazil

Gabriel Guarany, University of São Paulo, Brazil

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Thank you !