LENRs: radiation-free ultralow energy neutron reactions

Can microorganisms use LENRs to shift isotopes & transmute elements?

Microbial radiation resistance, biotransmutation of chemical elements, and time around the dawn of life on planet Earth

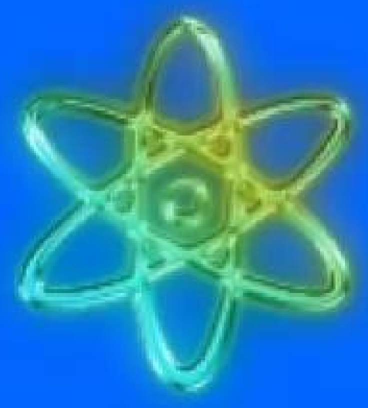
Multi-species communities of microorganisms will expend energy to assimilate and process heavy elements like Cesium, Gold, and Uranium that -- now -- play no obvious roles in growth or metabolism. Credible experimental data suggests some bacteria are shifting isotope ratios and possibly even transmuting certain elements. How and why are microbes doing this? LENRs may explain how, but why?

Lewis Larsen

President and CEO

Lattice Energy LLC

March 26, 2019



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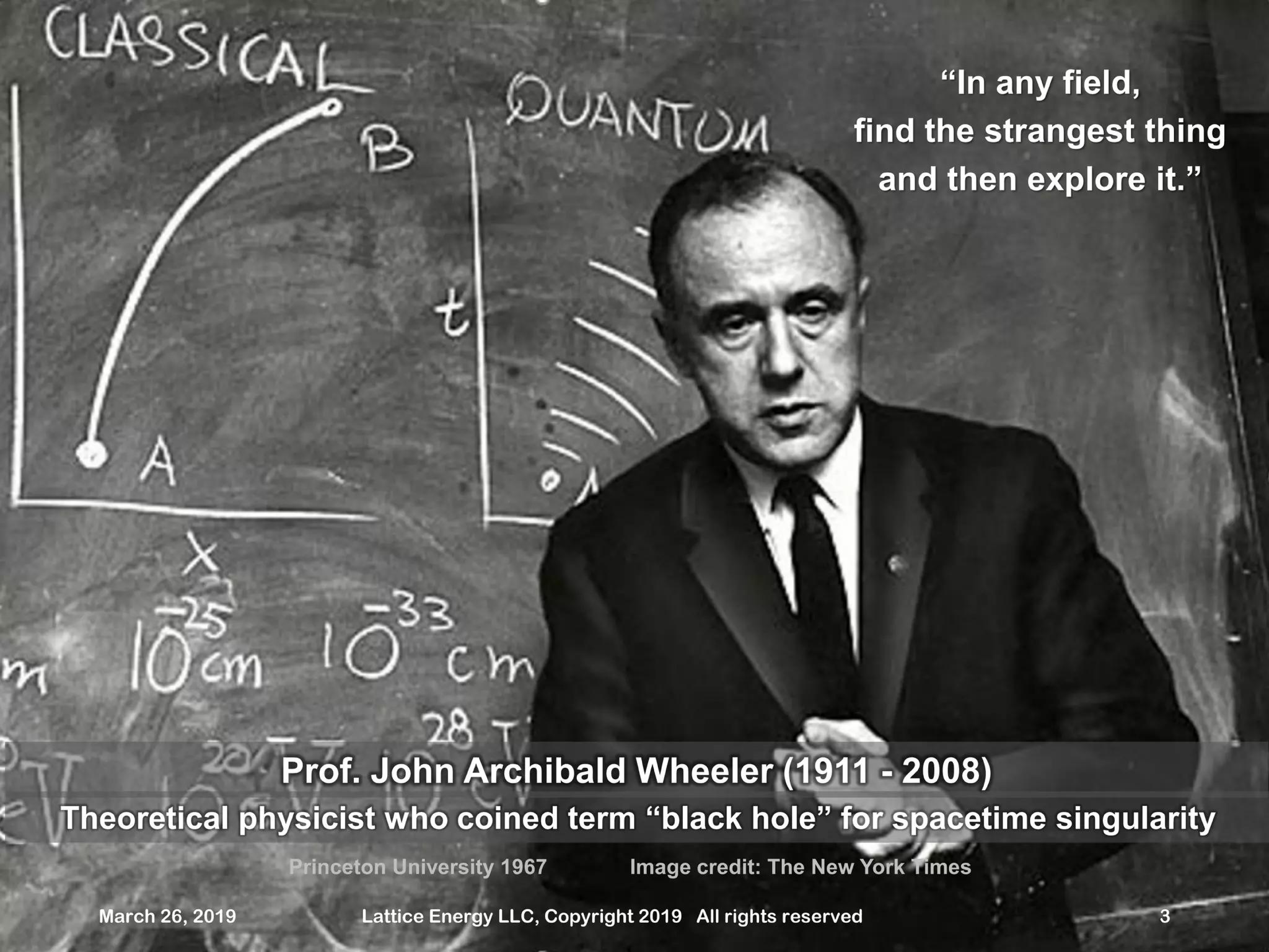
Summary

- Credible experimental data suggests some microbes can transmute certain elements via LENRs. However, much more experimentation will be required to decisively demonstrate that microorganisms can truly transmute chemical elements at will and determine which species of microbes have such capabilities. LENRs may not be all that uncommon out in Nature; if so, there will be major implications for geochemistry, isotope geology, and nuclear waste remediation
- LENRs can mimic isotopic effects of mass-dependent and mass-independent chemical fractionation. Elements and isotopes conserve their mass-balances in purely chemical systems; that is not necessarily true if LENRs are also occurring in same systems. Accurate measurement of total mass balances for all chemical species may be needed to discriminate between chemical and nuclear processes
- ULE neutron-catalyzed transmutation is not energetically practical for more-abundant chemical elements found in living systems such as Carbon. However, transmutation could potentially be an energetically feasible and advantageous capability that could enable some fortunate microbes to produce life-critical, low-abundance catalytic active site metals that are unavailable in local environments
- Japanese government-funded project with Mitsubishi Heavy Industries, Toyota, Nissan, and four universities is developing abiotic LENRs for power generation. Recently reported outstanding heat production results at working temperatures and pressures far lower than those found in many undersea hydrothermal vents



"In any field, find the strangest thing and then explore it."

Prof. John Archibald Wheeler (1911 - 2008)

Theoretical physicist who coined term "black hole" for spacetime singularity

Princeton University 1967 Image credit: The New York Times

Decay rate anomaly is explained if bacteria transmuted ^{137}Cs

Korean scientists observed ^{137}Cs decay rate anomaly with mixed bacteria

LENRs: radiation-free ultralow energy neutron reactions

Bacteria may be using LENRs to alter isotopes and transmute elements

Korean scientists used experimental mixtures of bacteria to reduce the concentration of radioactive Cesium-137 present in aqueous solutions irradiated with light at 12-hour intervals, shaken, and incubated at 25^{o} C

During experiments, and compared to controls, measured gamma radiation for flasks containing bacteria decreased at vastly higher rates than would be expected for 'normal' rate of Cs-137 β-decay: is radioactive Cesium actually being transmuted into heavier Cs isotopes and other elements by living bacteria?

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February 21, 2019

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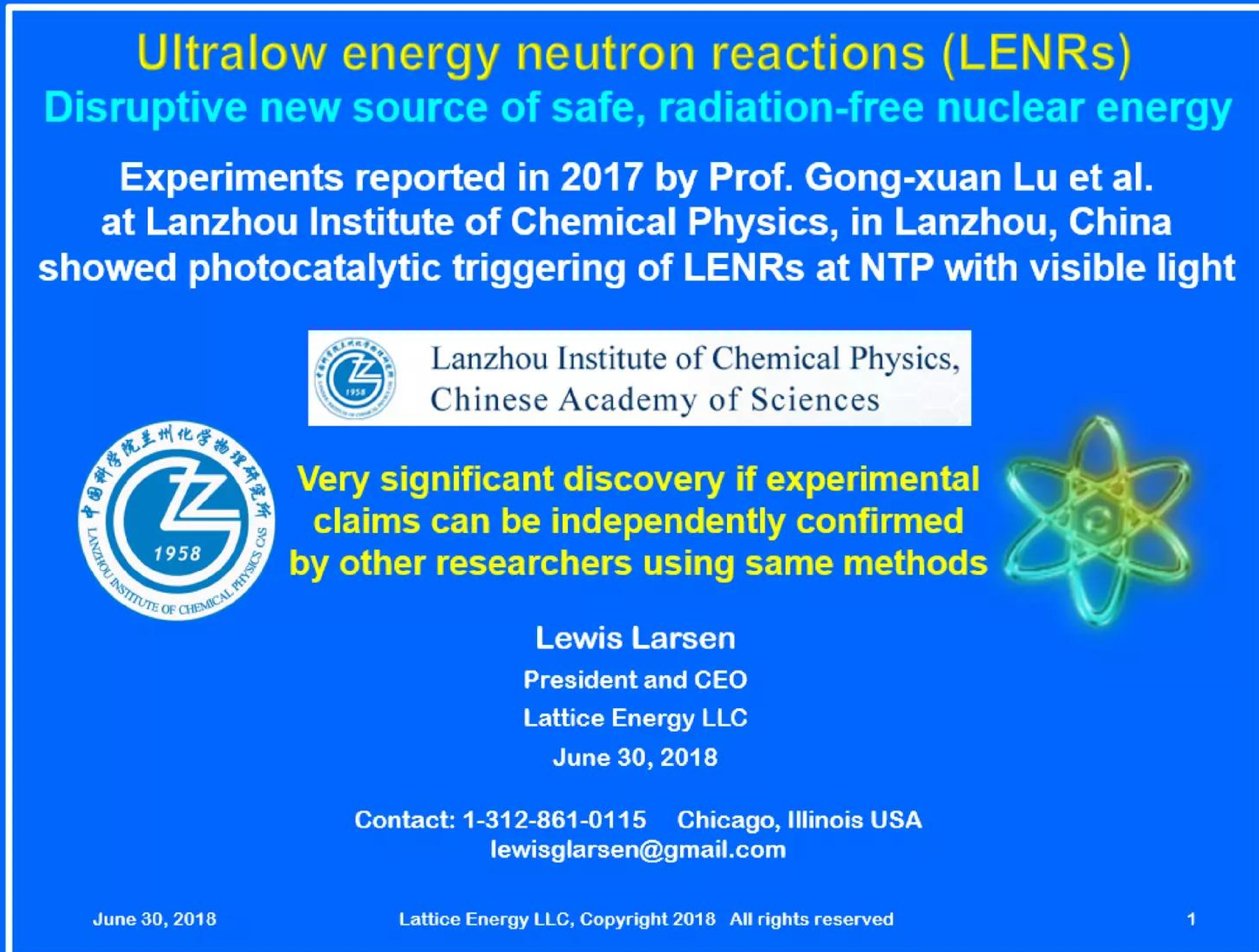
https://www.slideshare.net/lewisglarsen/lattice-energy-llc-korean-scientists-use-bacteria-to-reduce-concentration-of-radioactive-cesium137-in-aqueous-solutions-feb-21-2019

Researchers claimed abiotic LENRs triggered by visible light

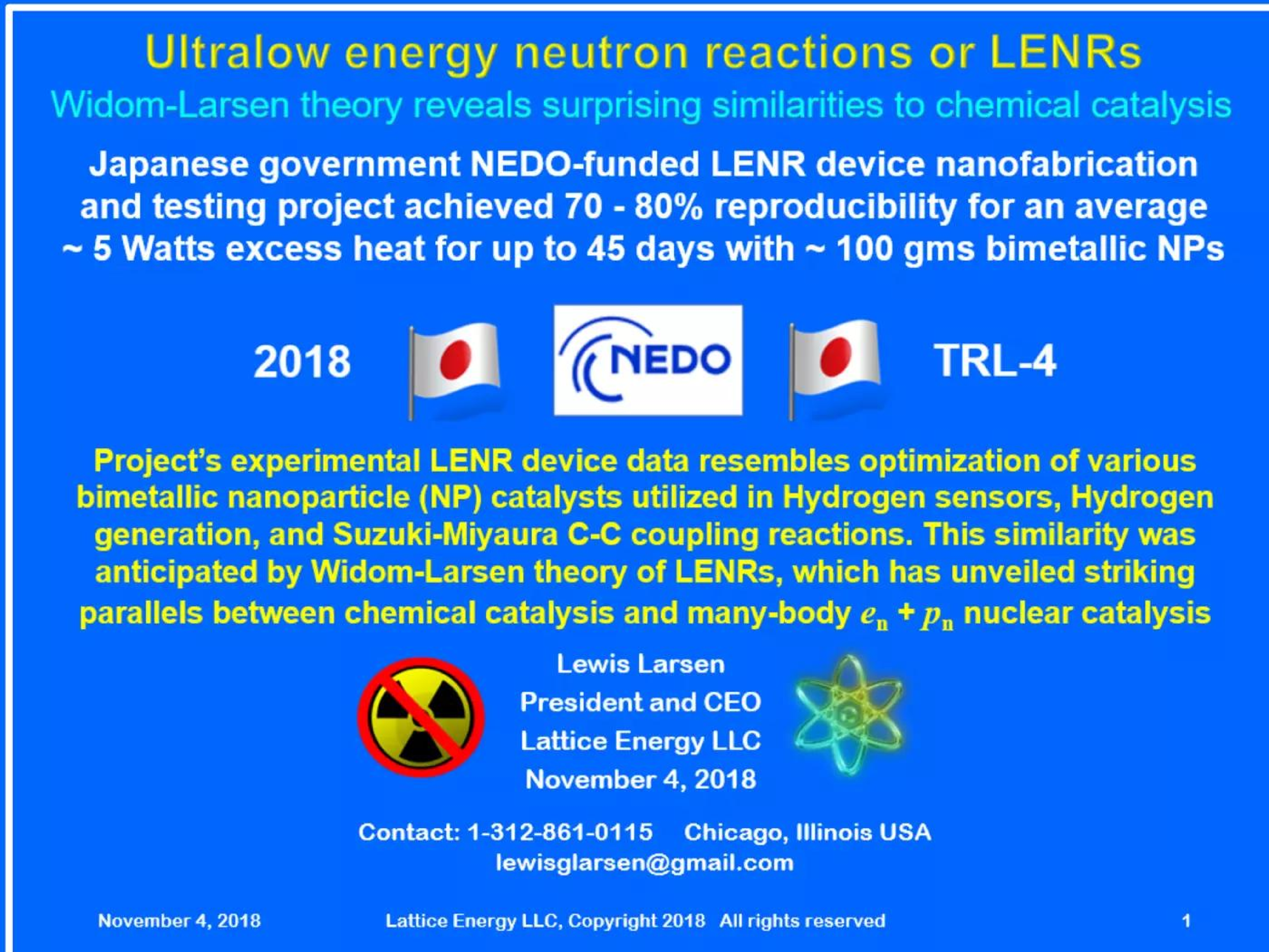
Produced Deuterium & Helium and transmuted Potassium into Calcium



https://www.slideshare.net/lewisglarsen/lattice-energy-llc-chinese-chemists-report-photochemical-triggering-of-lenrs-at-ntp-in-aqueous-cells-by-irradiation-with-visible-light-june-30-2018

Japanese are developing abiotic LENRs for power generation

Data reveals surprising similarities between LENRs & chemical catalysis



https://www.slideshare.net/lewisglarsen/lattice-energy-llc-widomlarsen-theory-reveals-surprising-similarities-and-connections-between-lenrs-and-chemical-catalysis-nov-4-2018

Possibility that bacteria are capable of transmuting elements

Paradigm shift in thinking that many scientists are very averse to believe

- Most recent thread of experimental mass-spectroscopy evidence dates back to Vysotskii & Kornilova (book published by Mir Publishing House – Moscow, 2003). Using Mossbauer spectroscopy, their data was credible; indicated mixed bacterial cultures could transmute Manganese into Iron. Their proposed theory for the process invoked "cold fusion" and was not believable. As a result, their otherwise good data was generally ignored
- V. Vysotskii & A. Kornilova's experimental data found in Chapter 4 of 2003 book indicated that laboratory cultures with *Deinococcus radiodurans* M-1 and *Bacillus subtilis* GSY-228 were able to synthesize elemental Iron (Fe – four stable isotopes) from Manganese (Mn - one stable isotope) present in Iron-free culture medium. In 2010, their 2003 book was republished with permission by the Pentagon Press (India) under a new title, "Nuclear transmutation of stable and radioactive isotopes in biological systems"
- In 2011, scientists at India's Indira Gandhi Centre for Atomic Research (IGCAR) claimed they essentially repeated Vysotskii & Kornilova's earlier Mn → Fe transmutation results. To date, R. George et al. have been unable get their paper titled "Microbial catalyst transmutation of stable isotopes (Mn-55 to Fe-57) by biogranules" published in respected first-tier journal. Mainstream journals have been extremely reluctant to publish such work

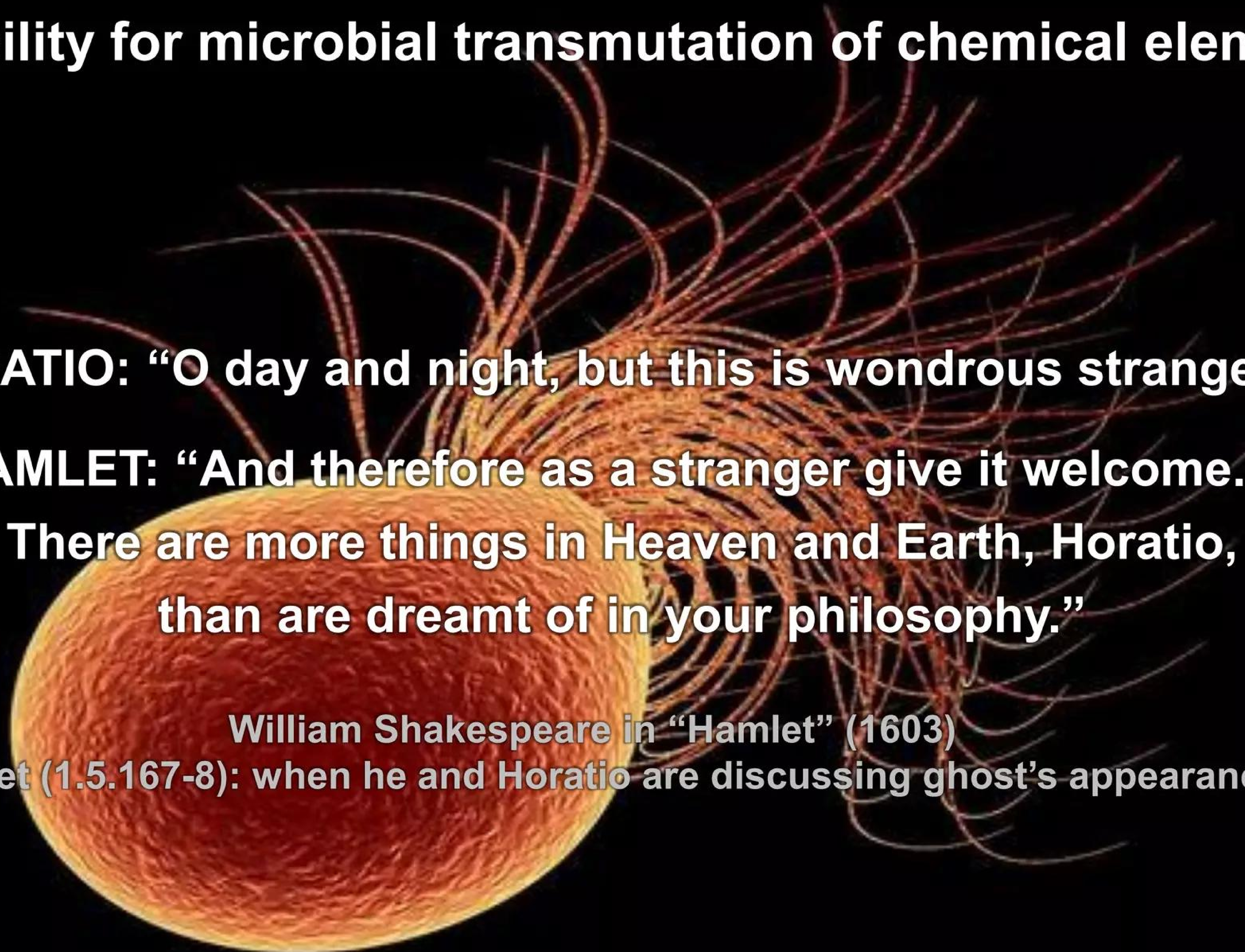
LENRs are a conceptual paradigm shift in nuclear science

Radiation-free transmutation of chemical elements under mild conditions

NTP (per NIST) = normal temperature and pressure: about 20 ºC and 1 atmosphere

At center of 30-year battle swirling around ultralow energy neutron reactions (LENRs) is a revolutionary, still ongoing paradigm shift in nuclear thinking *a la* Thomas Kuhn. Advent of LENRs has caused ongoing controversy and consternation within the global nuclear community because long-venerated sacred cows are being gored. With many-body 'green' LENRs, hard-radiation-free nucleosynthesis and transmutation of elements without long-lived radioactive wastes can occur in condensed matter systems under comparatively mild, NTP-like macroscopic temperatures and pressures. Existence of LENRs is thus heretical and anathema to many nuclear physicists still mired in tight grip of presently dominant, 70-year-old conceptual paradigm. This older, widely accepted, now-erroneous paradigm posits nucleosynthetic processes can *only* occur in super-hot stellar plasmas, manmade or natural fission reactors, man-made 150 million ºC fusion reactors like the ITER D+T Tokamak, explosions of nuclear weapons, and/or particle accelerators --- all of which emit readily detected, deadly energetic gamma and/or neutron radiation.

Possibility for microbial transmutation of chemical elements



HORATIO: "O day and night, but this is wondrous strange!"

HAMLET: "And therefore as a stranger give it welcome.
There are more things in Heaven and Earth, Horatio,
than are dreamt of in your philosophy."

William Shakespeare in "Hamlet" (1603)
Hamlet (1.5.167-8): when he and Horatio are discussing ghost's appearance

BIO PRO Baden-Württemberg GmbH

"Extremophile microorganisms know how to survive; the photo shows a deep sea bacterium, highly sought after by scientists." (Photo: Karl Johaentges)

Contents

Note: purplish-colored hyperlinks in PowerPoint are 'live'. Double-clicking on link uploads referenced source document into another window of Internet browser

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LENRs occur at very moderate temperatures and pressures

Can transmute dangerous radioactive isotopes into other stable elements

Fission and fusion → ‘Greening’ of nuclear technology → Safe green LENRs

Laura 13

No deadly MeV-energy gamma radiation

No dangerous energetic neutron radiation

Insignificant production of radioactive waste

Vastly higher energies vs. chemical processes

Revolutionary, no CO_2 , and environmentally green

Is fully explained by physics of Widom-Larsen theory

Image credit: co-author Domenico Pacifici
“Nanoscale plasmonic interferometers for multispectral, high-throughput biochemical sensing”
J. Feng et al., *Nano Letters* pp. 602 - 609 (2012)

Three nuclear technologies: fission, fusion, and LENRs (new)

Fission and fission both produce deadly radiation and radioactive wastes

LENRs are greener than fission and fusion because no deadly radiation or wastes

TRL = technology readiness level   MeV = Megaelectron Volt = 1 million (10^6) eV

Nuclear process	Energetic MeV gamma γ radiation?	Energetic MeV neutron radiation?	Long-lived radioactive waste products?	Basic description of nuclear process	Energy release in MeVs Chemical only produces eVs
Fission: TRL 9^+ $Uranium^{235}$	Yes	Yes	Yes	Heavy Uranium-235 nuclei capture neutrons; shatter into many lighter elements	~ 200 MeV many different end-products
Fusion: TRL $4^{+\ 2019}$ ITER D+T reactor in $France^{2025}$	Yes All fusion	Yes For D+T	No Induced	Gigantic temperatures enable two light ionized nuclei to smash together and then fuse into heavier chemical elements	Depending on specific fusion reaction, value ranges from ~ 3 to ~ 24 MeV
LENRs: TRL 4 In 2019, Japanese project had best-ever excess heat	No Heavy electrons convert γ rays to IR	No ~All ULE neutrons captured locally	No Neutron-rich LENR products decay fast	Input energy creates ultra low energy neutrons (via $e + p$ reaction) that capture on target atoms. Gammas from neutron captures are converted into infrared; very neutron-rich products decay into stable elements	Depending on targets and subsequent reactions as well as decays, values range from ~ 0.1 MeV up to ~ 22 MeV

IR = infrared (heat)

Electroweak ULE neutron production in Widom-Larsen theory

Protons or deuterons can react directly with electrons to make neutrons

Input energy required to trigger many-body $e_n + p_n$ reactions in LENR active sites

Input energy boosts electric fields >10^{11} V/m

Collective many-body quantum effects: many SP electrons each transfer little bits of energy to a much smaller number of *sp* electrons also bathed in same nuclear-strength local electric field ≥ 1.4 x 10^{11} V/m

Heavy-mass e^{-*} electrons react directly with protons

Quantum electrodynamics (QED): smaller number of electrons that absorb energy directly from local electric field will increase their effective masses (m = E/c^2) above key thresholds β_0 where they can react directly with a proton (or deuteron) → neutron and neutrino

Input energy

$$\text{Energy}_{\text{E-field}} + e^-_{n\ SP} \rightarrow e^{-*}_{n\ SP} + p^+_n \rightarrow n^0_{ule} + \nu_e$$

ν_e neutrinos: ghostly unreactive particles that fly-off into space; n^0 neutrons capture on nearby atoms

Induces safe hard-radiation-free nuclear transmutation processes

Neutrons + atomic nuclei → heavier elements + decay products

Neutron capture $$n + (Z, A) \rightarrow (Z, A+1)$$

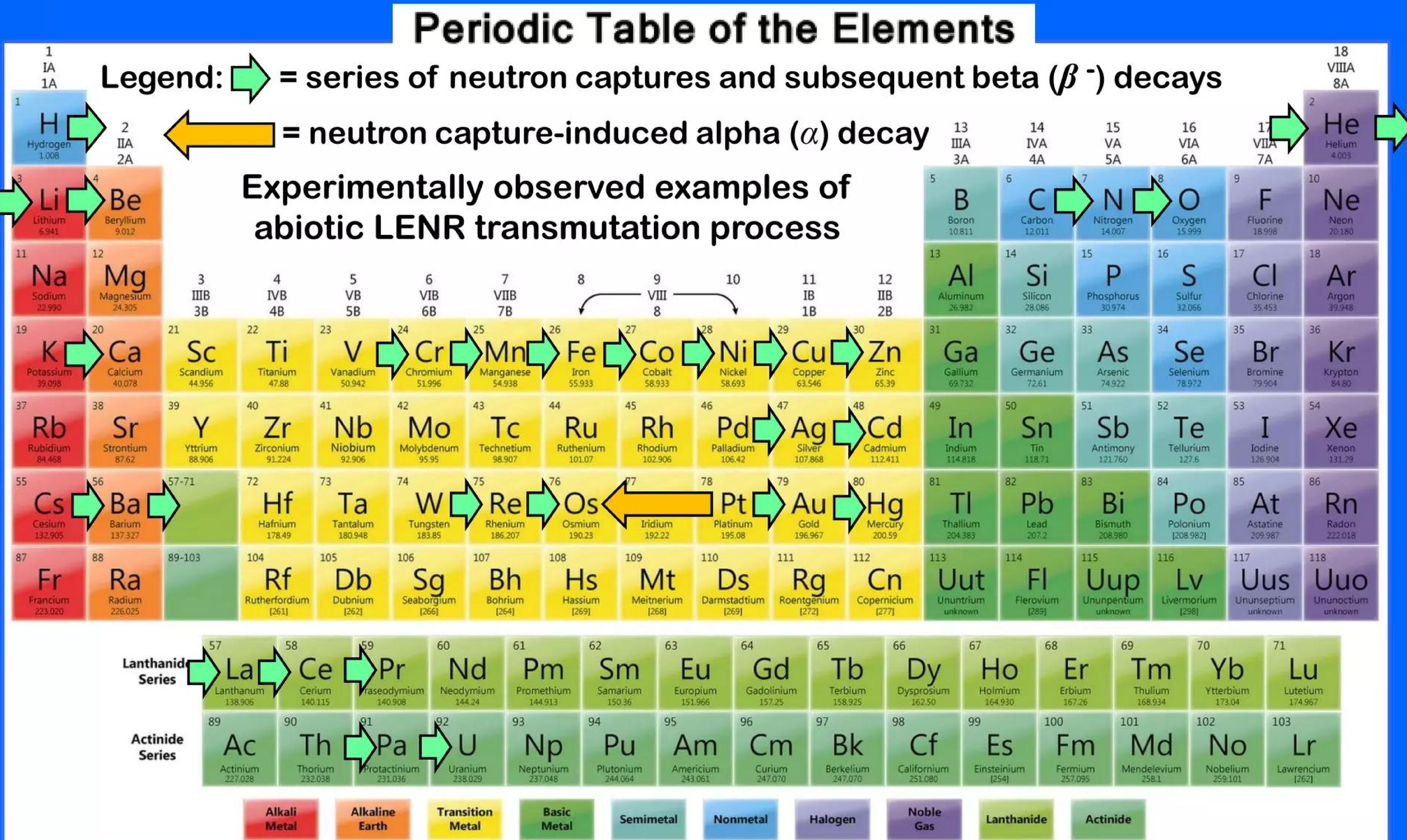
Beta decay $$(Z, A+1) \rightarrow (Z+1, A+1) + e^-_\beta + \bar{\nu}_e$$

Neutron capture-driven transmutation of isotopes and elements

Neutron captures & β^- decays go from left-to-right along rows

Alpha decays induced by neutron capture go from right-to-left along rows

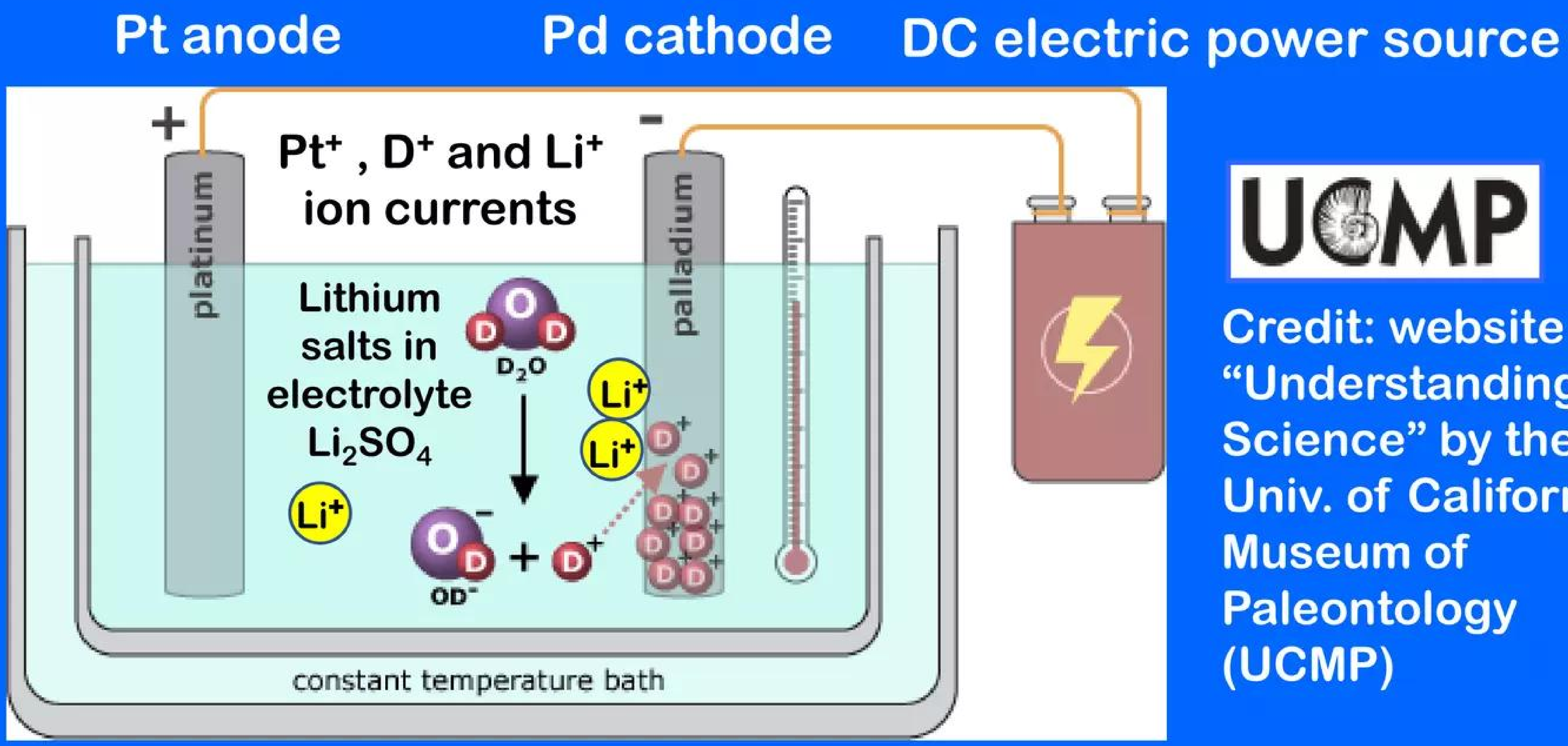
Alpha-decay process produces Helium-4 (^4He) which is a noble monatomic gas



LENRs in electrochemical cells at room temps and pressures

Platinum anode, Palladium cathode, Lithium salts and aqueous electrolyte

Analogous to when charging Lithium-ion batteries; LENR electrolytic cells typically have DC input current that provides the energy required to create neutrons via Widom-Larsen theory's 'green' electroweak $e_n + p_n$ reaction



Credit: website "Understanding Science" by the Univ. of California Museum of Paleontology (UCMP)

Above is a conceptual schematic for an aqueous D_2O heavy-water electrolytic chemical cell used in many LENR experiments; typically use < 10V DC power supply as electrical input energy source. Using modern mass spectroscopy for post-experiment analyses of cathode materials, LENR researchers have carefully documented and reported the production (via LENR transmutation) of minute amounts of many different elements and isotopically shifted stable isotopes on cathode surfaces in such cells. In some cases, ultralow energy neutron fluxes were $>10^{10}$ cm^2/sec which then created a broad array of stable LENR transmutation products over the course of several weeks of electrolysis

External input energy required to produce neutrons via *e* + *p*

Electron or ion currents; E-M photon fluxes; or organized magnetic fields

Input energy required to produce neutrons: to create non-equilibrium conditions that enable nuclear-strength local E-fields which produce populations of heavy-mass e^{-*} electrons that react with many-body surface patches of p^+, d^+, or t^+ to produce neutrons via $e^{-*} + p^+ \rightarrow 1\, n$ or $e^{-*} + d^+ \rightarrow 2\, n$, $e^{-*} + t^+ \rightarrow 3\, n$ (energy cost = 0.78 MeV/neutron for H; 0.39 for D; 0.26 for T); includes (can combine sources):

- Electrical currents - i.e., an electron 'beam' of one sort or another can serve as a source of input energy for producing neutrons via *e* + *p* electroweak reaction
- Ion currents - passing across a surface or an interface where SP electrons reside (i.e., an ion beam that can be comprised of protons, deuterons, tritons, and/or other types of charged ions); one method used for inputting energy is a d^+ ion flux caused by imposing a modest 1 atm pressure gradient (Iwamura et al. 2002)
- Incoherent and coherent electromagnetic (E-M) photon fluxes - incoherent E-M radiation inside resonant electromagnetic cavities or from external light sources; with proper momentum coupling, SP electrons can also be directly energized with coherent laser beams comprised of E-M photons at resonant wavelengths
- Organized magnetic fields with cylindrical geometries - many-body collective magnetic LENR regime with direct acceleration of particles operates at very high electron/proton currents; includes organized and so-called dusty plasmas; scales-up to stellar flux tubes on stars with dimensions measured in kilometers

W-L theory explains absence of energetic gamma radiation

Heavy-mass electrons in LENR active sites convert gammas into infrared

"Apparatus and method for absorption of incident gamma radiation and its conversion to outgoing radiation at less penetrating, lower energies and frequencies"

https://www.slideshare.net/lewisglarsen/us-patent-7893414-b2

U.S. Patent #7,893,414 B2
Inventors: Lewis Larsen, Allan Widom
Issued: February 22, 2011
Assignee: Lattice Energy LLC

Unreacted heavy electrons naturally present in nm- to μ-scale LENR active sites (in which ultralow energy neutrons are produced) will automatically and directly convert deadly MeV-energy gamma photon radiation produced locally by ULE neutron captures or nuclear decays into benign infrared (IR) photons (heat) that can be harvested to provide motive power or electricity. Absence of deadly energetic gamma and neutron radiation emissions from active sites enables LENRs to be safe and green, unlike nuclear fission and fusion processes

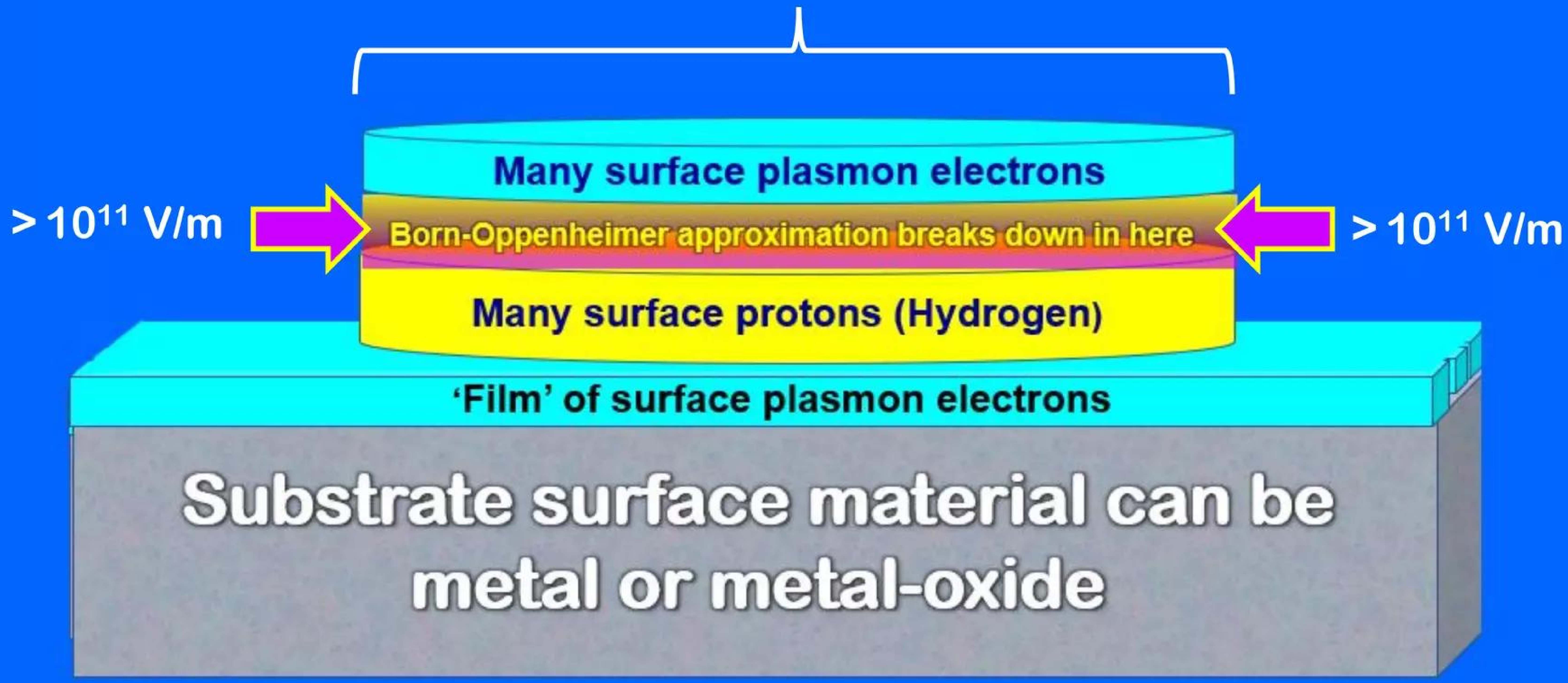
Widom-Larsen theory specifies details of LENR active sites

Much is known about their characteristics in non-living abiotic systems

High electric fields > 1.4 x 10^{11} V/m occur where Born-Oppenheimer breaks down

IDEALIZED AND NOT TO SCALE

Single nascent LENR active site; sizes range from ~ 2 nm up to 100 - 200 microns



Many-body SP electron + proton subsystems shown above form one Widom-Larsen active site on a planar surface; active sites can also form on surfaces of nanoparticles or at various types of interfaces

Key steps in Widom-Larsen theory of LENR active sites

5-step process occurs in active sites over est. ~ 300 - 400 nanoseconds

W-L theory can explain why energetic neutron & gamma radiation are not emitted

1. Collectively oscillating, quantum mechanically entangled, many-body ‘patches’ of Hydrogen (+-charged protons or deuterons) will form spontaneously on fully loaded hydride surfaces & at certain interfaces: e.g. metal/oxide, gas/oxide, etc.

2. Born-Oppenheimer approximation spontaneously breaks down, allows E-M coupling between local surface plasmon electrons and protons within patches; application of input energy creates nuclear-strength local electric fields $\geq$ 1.4 x 10^{11} V/m - increases effective masses of surface plasmon electrons in patches

3. Heavy-mass surface plasmon electrons formed in many-body patches can then react directly with electromagnetically interacting protons; process creates neutrons and neutrinos via a many-body collective electroweak $e_n + p_n$ reaction

4. Neutrons collectively created in patches have ultralow kinetic energies and are all absorbed locally by nearby atoms – fluxes of energetic neutrons will not be emitted externally. Any locally produced or incident gammas will get converted directly into safe infrared photons (IR heat) by unreacted heavy electrons (Lattice patent US# 7,893,414 B2) - no deadly energetic gamma radiation will be emitted

5. Transmutation of elements and reworking of surfaces by active sites then begins

Before W-L $e + p$ thought to occur only in stellar explosions

Simple two-body reaction requires 10 billion degrees Kelvin inside stars

W-L theory: many-body collective quantum effects allow $e_n + p_n$ to occur on Earth

LENRs resemble enzymes in that temperature for $e_n + p_n$ reaction is radically decreased

Crab nebula: expanding gas cloud of huge supernova explosion of a star that was observed by many Chinese astronomers in 1054 A.D.

"Ultra low momentum neutron catalyzed nuclear reactions on metallic hydride surfaces"
A. Widom and L. Larsen *EPJC* (2006)

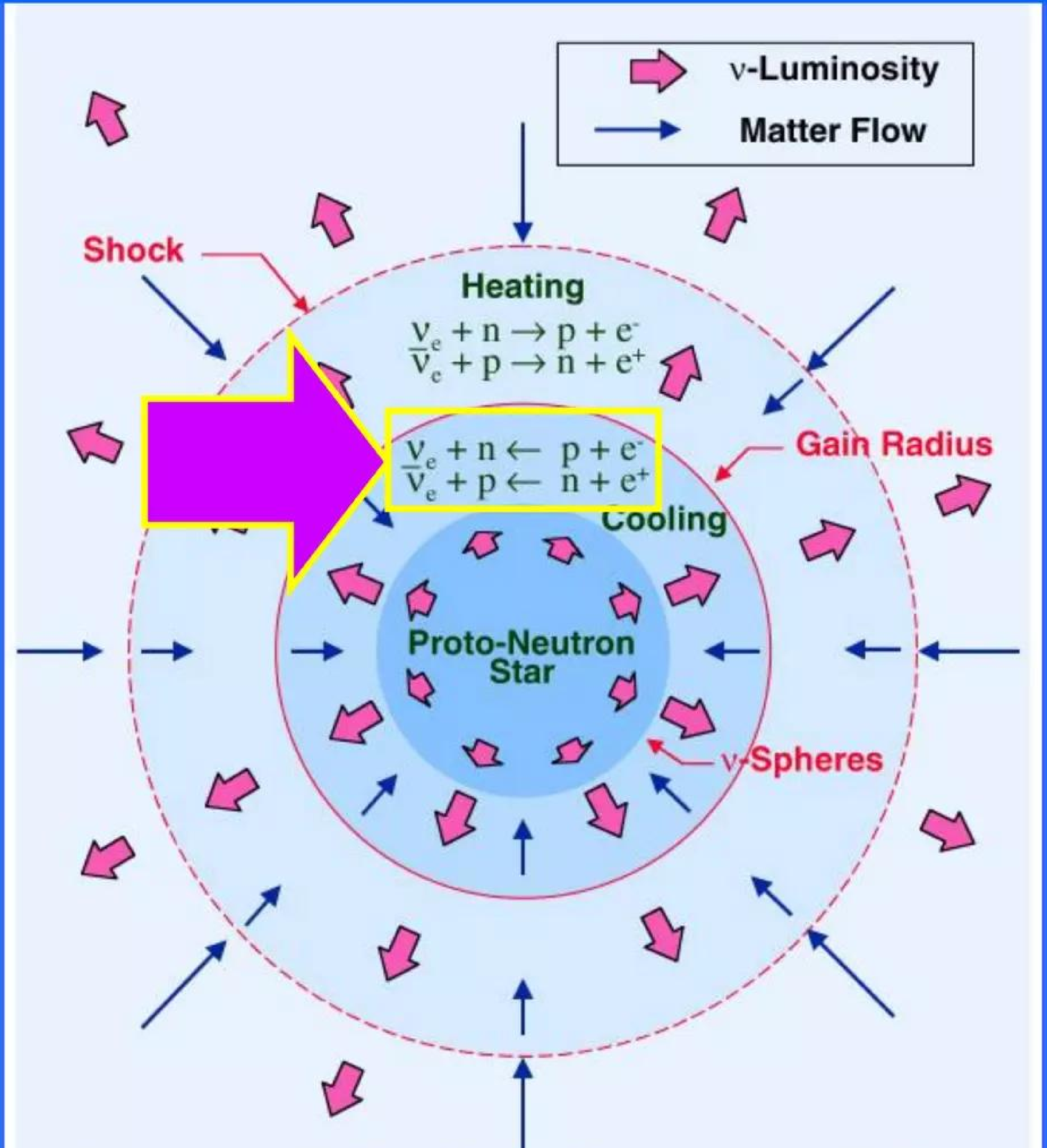


Image credit: TeraScale Supernova Initiative

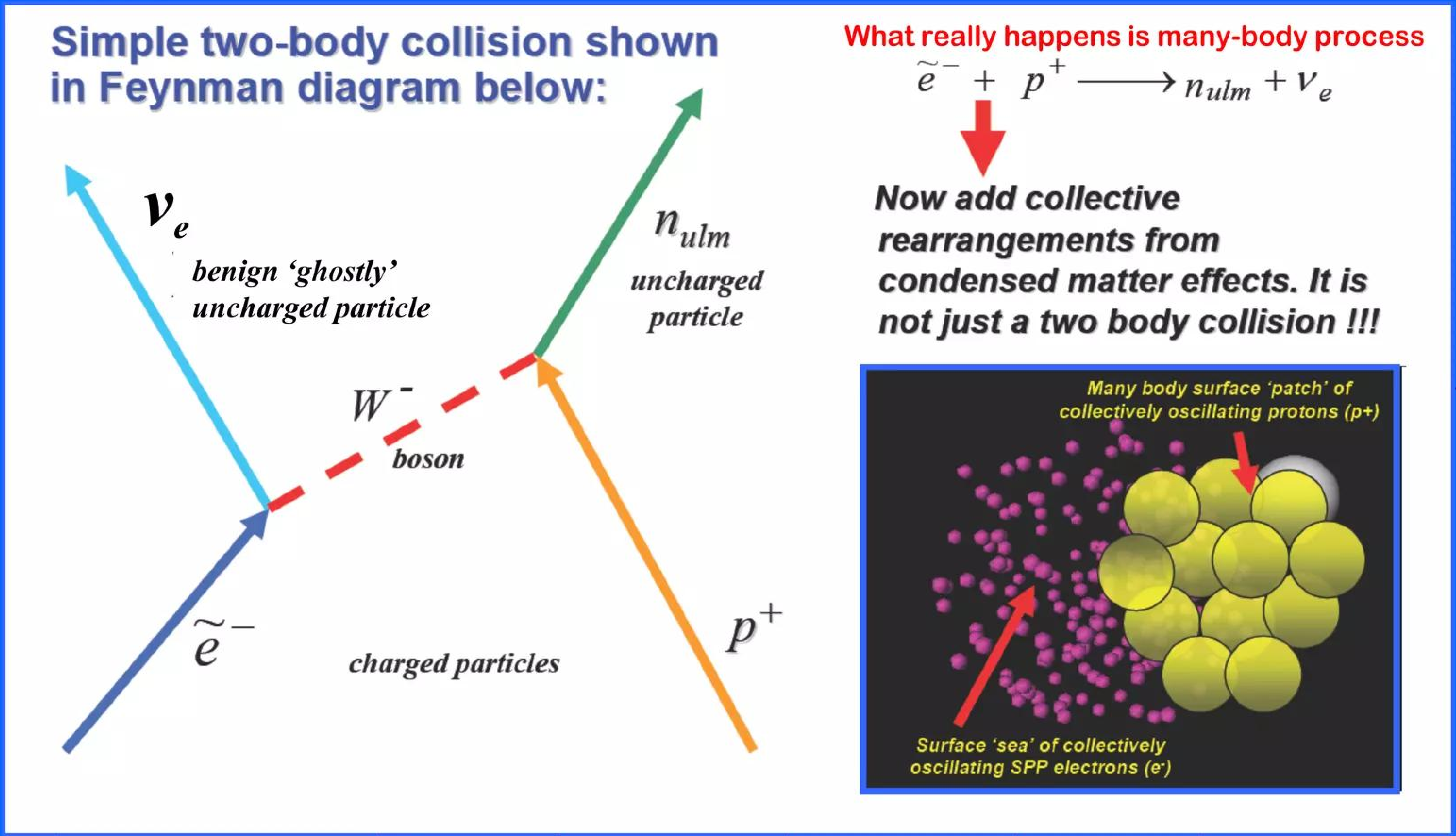
Many-body collective quantum effects are crucial to LENRs

Diagram shows two-body e^- + p^+ reaction - what happens is many-body

Many-body collective effects involve quantum entanglement of particles

What occurs is many-body reaction between Q-M entangled electrons and protons

LENR reaction is more accurately written as: $e_n + p_n \rightarrow n_{ule} + \nu_e$



Many-body collective quantum effects are crucial for LENRs

Enable LENR transmutation reactions at moderate temps & pressures

Many-body collective

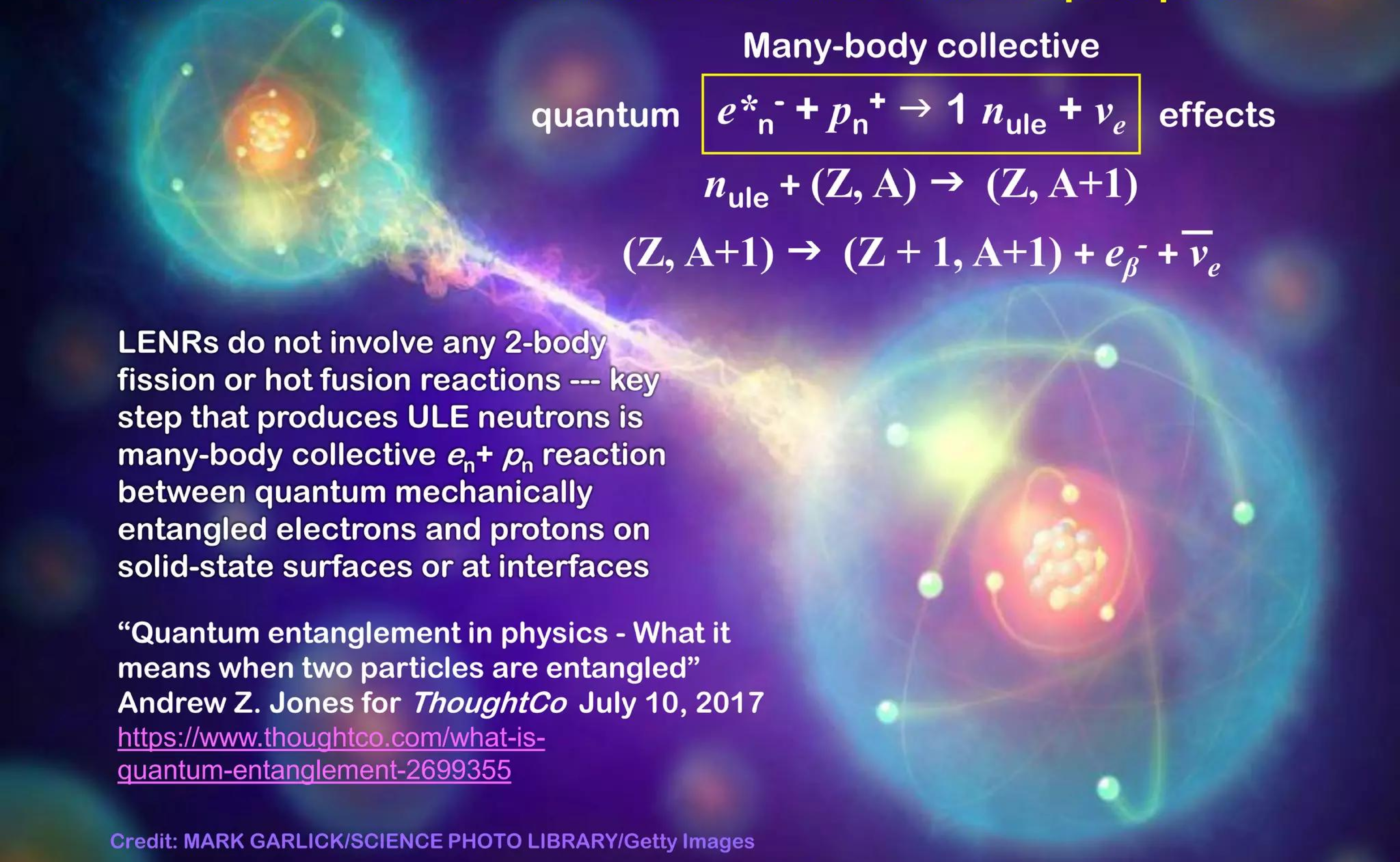
quantum $e^{*}_{n}{}^{-} + p_{n}{}^{+} \rightarrow 1\ n_{ule} + \nu_{e}$ effects

$$n_{ule} + (Z, A) \rightarrow (Z, A+1)$$

$$(Z, A+1) \rightarrow (Z+1, A+1) + e_{\beta}^{-} + \overline{\nu}_{e}$$

LENRs do not involve any 2-body fission or hot fusion reactions --- key step that produces ULE neutrons is many-body collective $e_n + p_n$ reaction between quantum mechanically entangled electrons and protons on solid-state surfaces or at interfaces

"Quantum entanglement in physics - What it means when two particles are entangled" Andrew Z. Jones for *ThoughtCo* July 10, 2017 https://www.thoughtco.com/what-is-quantum-entanglement-2699355

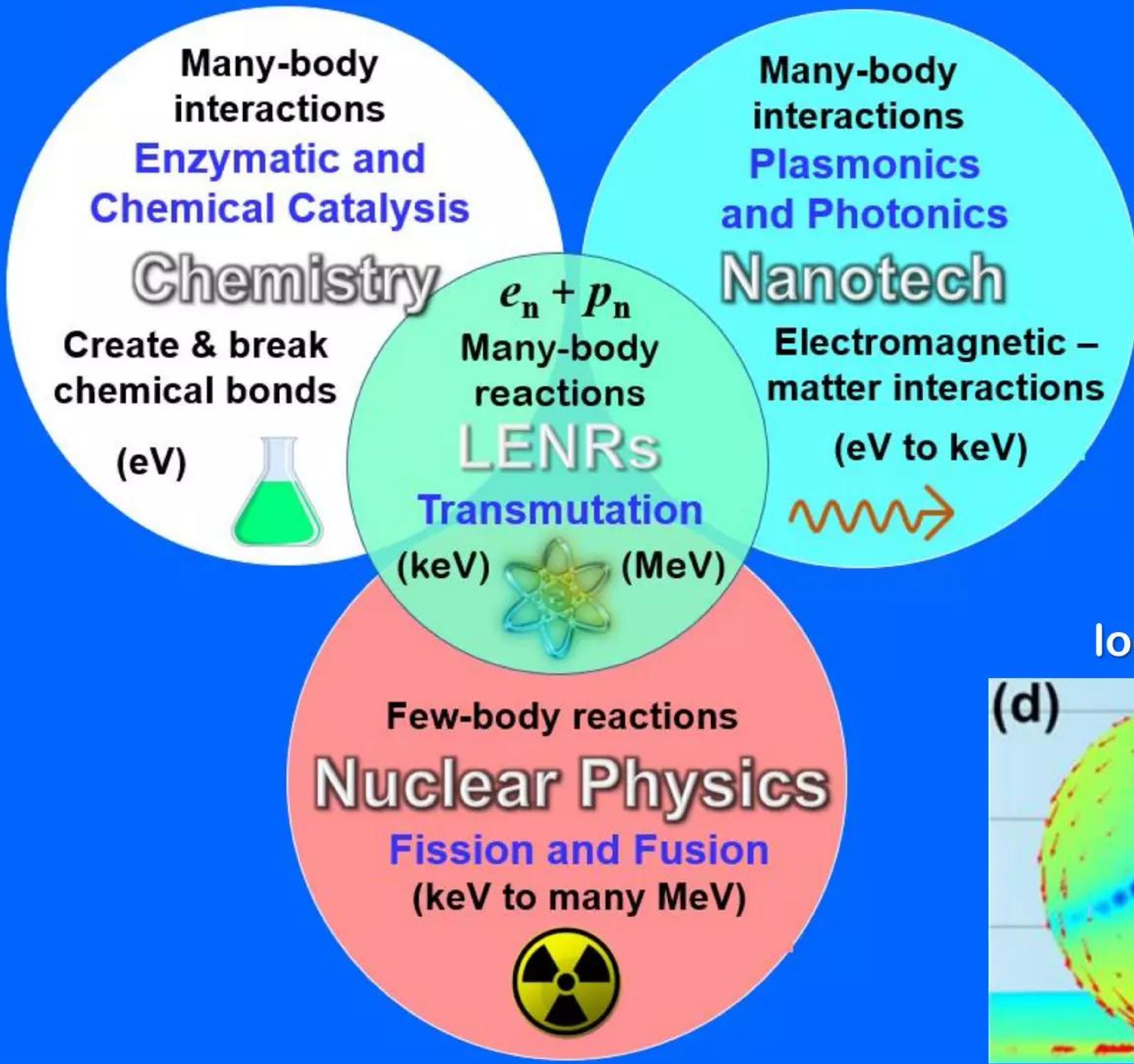


Credit: MARK GARLICK/SCIENCE PHOTO LIBRARY/Getty Images

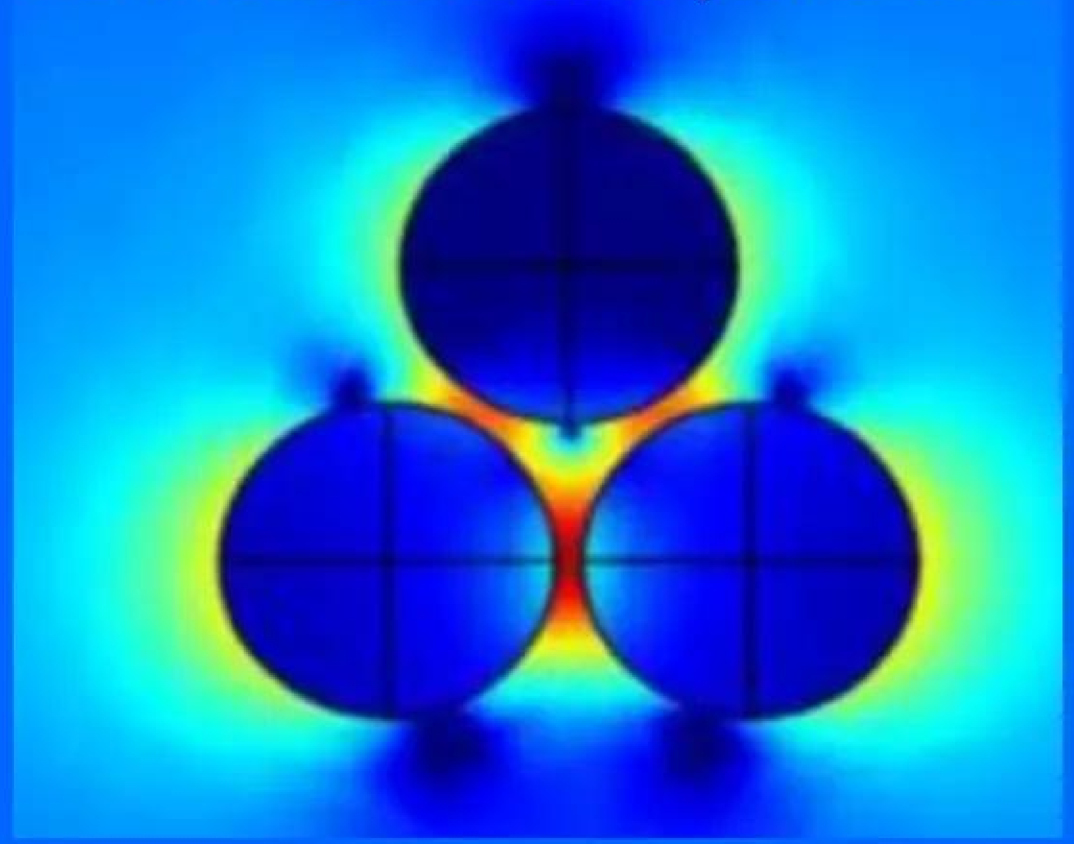
Radiation-free LENRs are not as exotic as one might assume

Widom-Larsen theory: LENR physics, nanotech & chemistry interrelated

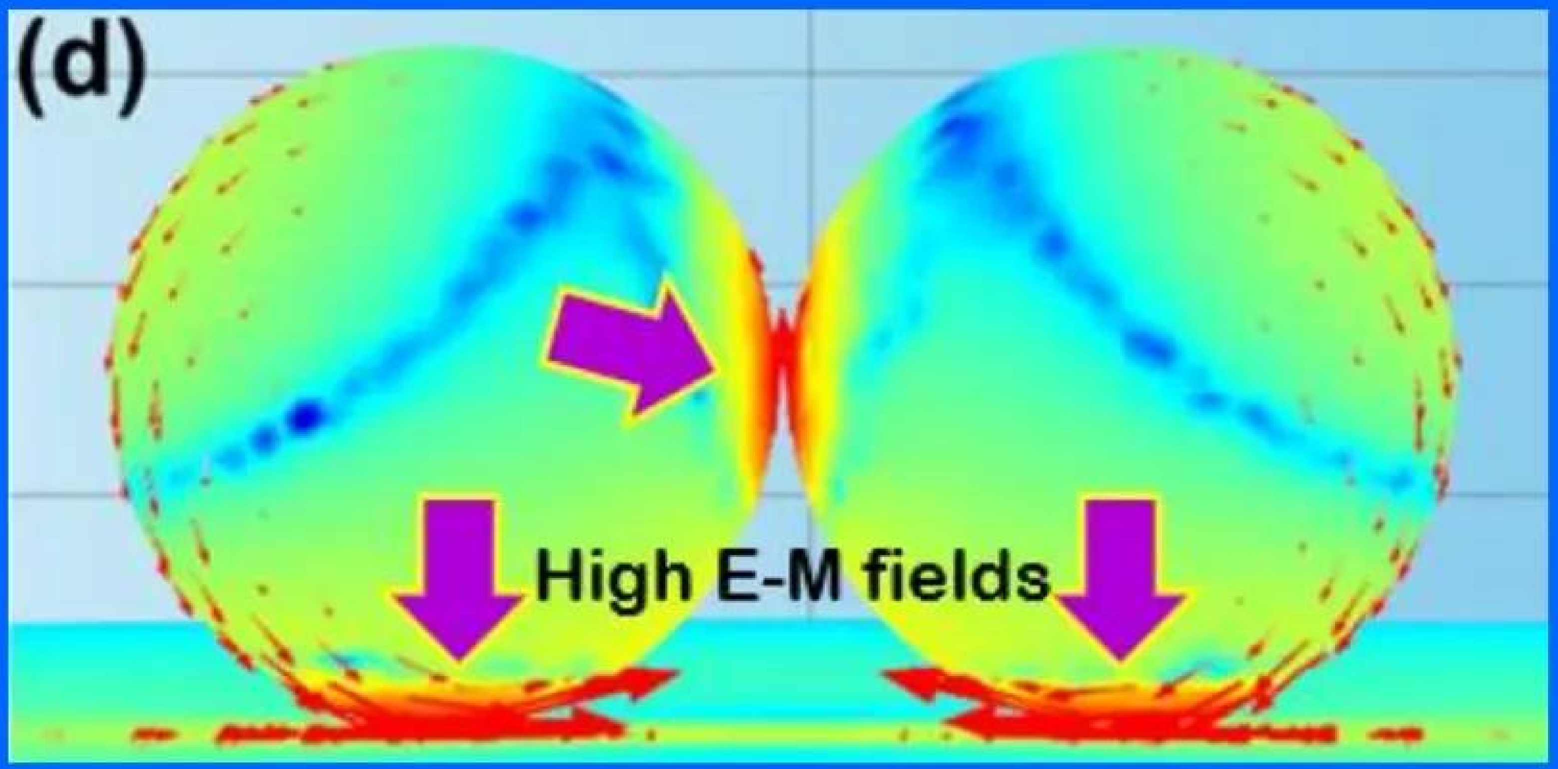
Leverage W-L theory & nanotech know-how to accelerate LENR development



Electric field strengths on surfaces of nanoparticles



$e_n + p_n$ reaction requires local E-fields ≥ 1.4 x 10^{11} V/m



Important papers by Fried & Boxer about enzymatic catalysis

Experiments measured electric > fields 10^{10} V/m in enzyme active sites

Electric field strength is key contributor to catalytic abilities of many enzymes

"Electric fields and enzyme catalysis"

S. Fried and S. Boxer in *Annual Review of Biochemistry* 86 pp. 387 - 415 (2017)

https://docs.wixstatic.com/ugd/4006c9_4bd285496dab421080e63a577b3a1928.pdf

https://docs.wixstatic.com/ugd/4006c9_57d9b28edb084f6a887b247a8dd2399f.pdf

Abstract: "What happens inside an enzyme's active site to allow slow and difficult chemical reactions to occur so rapidly? This question has occupied biochemists' attention for a long time. Computer models of increasing sophistication have predicted an important role for electrostatic interactions in enzymatic reactions, yet this hypothesis has proved vexingly difficult to test experimentally. Recent experiments utilizing … vibrational Stark effect make it possible to measure … electric field a substrate molecule experiences when bound inside its enzyme's active site. These experiments have provided compelling evidence supporting a major electrostatic contribution to enzymatic catalysis … we review these results and develop a simple model for electrostatic catalysis that enables us to incorporate disparate concepts introduced by many investigators to describe how enzymes work into a more unified framework stressing the importance of electric fields at the active site."

Fried & Boxer "Electric fields and enzyme catalysis" (2017)

Quote from paper: "Electrostatic catalysis is pervasive in enzymology"

> "Support … notion that electrostatic catalysis is a key strategy enzymes use. Appreciating the centrality of electrostatic catalysis has enabled us to incorporate disparate concepts, such as geometric discrimination and distal binding interactions, into a unified framework …"

Summary points:

1. "Noncovalent interactions between a given molecule and its environment (including H-bonds) can be expressed and quantified in terms of the electric field the environment exerts on the molecule."
2. "Electric field created by an environment can be experimentally measured through … vibrational Stark effect, which maps … frequencies of vibrational probes to the electric field experienced by that vibration."
3. "A chemical reaction can be catalyzed by an electric field if … reactant's charge configuration (dipole moment) changes upon passing to a transition state. If the dipole moment increases (decreases) in magnitude, an electric field of greater (smaller) magnitude will accelerate the reaction; if the dipole reorients, an electric field aligned with the transition state's dipole orientation will accelerate the reaction.
4. "Electrostatic catalysis is pervasive in enzymology because most chemical reactions in biology involve charge rearrangements."

Electric field strength determines chemical vs. LENR process

N_2 bond is broken at ~1.0 x 10^{11} V/m; threshold for LENRs ≥ 1.4 x 10^{11} V/m

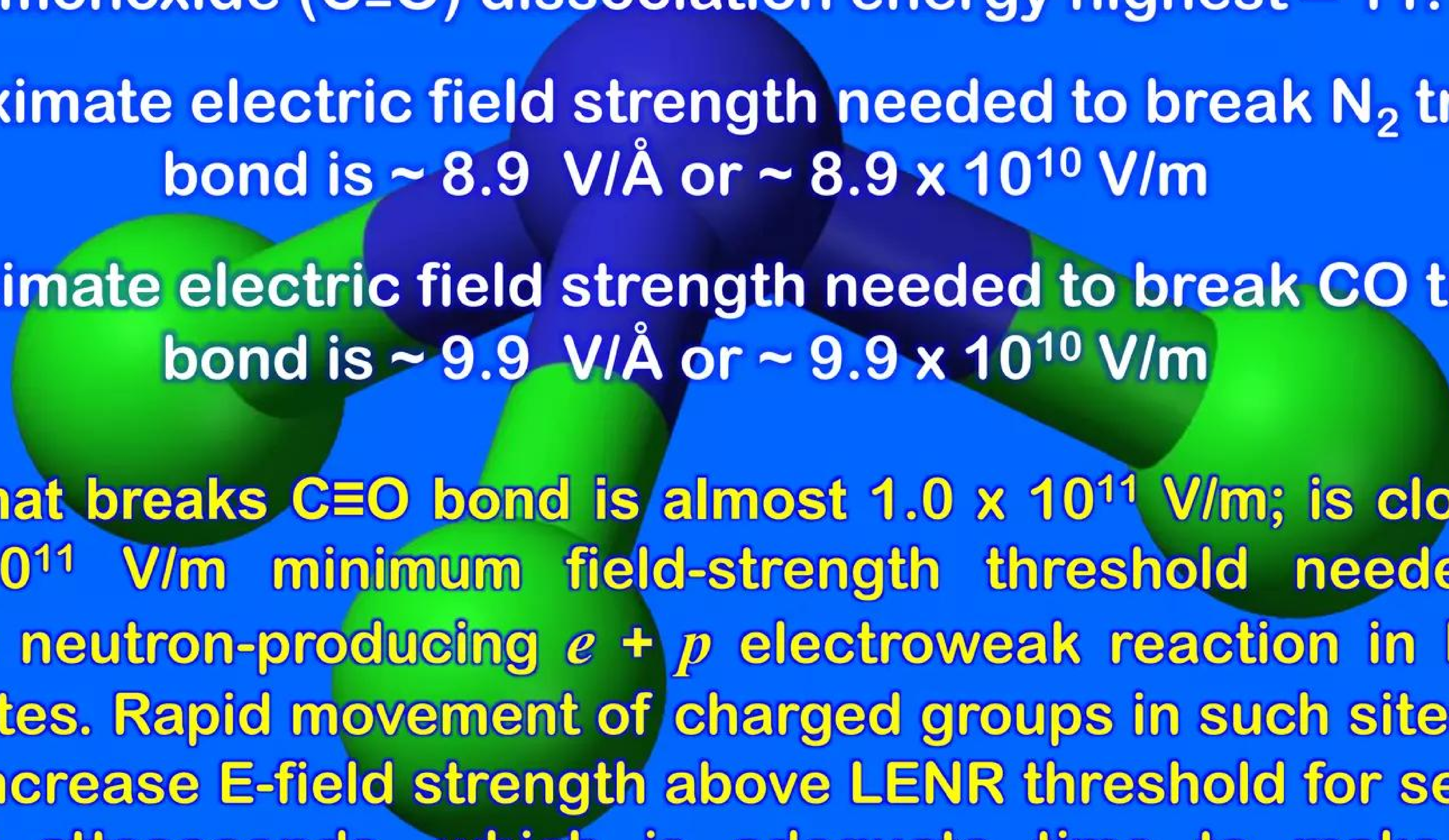
Nitrogen (N≡N) molecule's triple bond is 2^{nd} strongest chemical bond in Nature with dissociation energy of 9.79 eV

Carbon monoxide (C≡O) dissociation energy highest = 11.16 eV

Approximate electric field strength needed to break N_2 triple bond is ~ 8.9 V/Å or ~ 8.9 x 10^{10} V/m

Approximate electric field strength needed to break CO triple bond is ~ 9.9 V/Å or ~ 9.9 x 10^{10} V/m

E-field that breaks C≡O bond is almost 1.0 x 10^{11} V/m; is close to 1.4 x 10^{11} V/m minimum field-strength threshold needed to catalyze neutron-producing $e + p$ electroweak reaction in LENR active sites. Rapid movement of charged groups in such sites can locally increase E-field strength above LENR threshold for several hundred attoseconds, which is adequate time to make ULE neutrons. ULE neutron captures only require 10s of picoseconds.



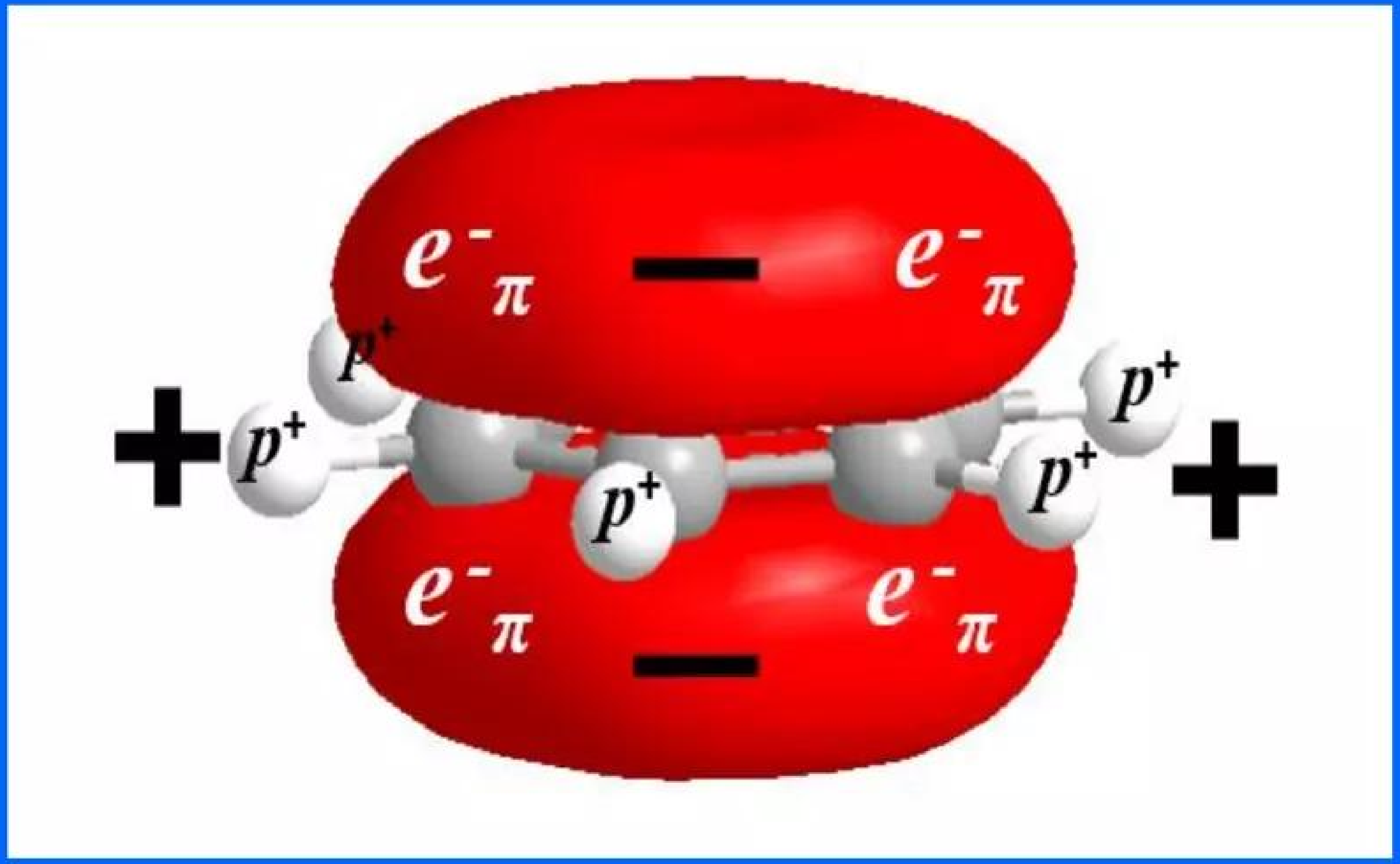
Ammonia molecule in background (NH_3)

Lattice extended Widom-Larsen theory to aromatic rings

Carbon aromatic rings can function as 2 nm molecular LENR active sites

Lattice's conjecture (2009) that π electrons on aromatic rings can behave like the functional equivalents of surface plasmons on metals was finally confirmed by A. Manjavacas et al. (2013)

Red indicates many-body π electron clouds on both sides of Carbon aromatic ring



Only tiny fraction of total number of π electrons are shown in this graphic

- Delocalized clouds of π electrons situated above and below 6-Carbon aromatic ring structures are in very close physical proximity to protons (hydrogen atoms), all oscillate collectively, and are mutually Q-M entangled (Manjavacas et al. 2013)
- Protons that are also attached to an aromatic ring's Carbon atoms oscillate collectively and are Q-M entangled with each other (was first observed and reported by Chatzidimitriou-Dreismann, 2005)

Lattice extended Widom-Larsen theory to aromatic rings

Carbon aromatic rings can function as 2 nm molecular LENR active sites

- Local breakdown of Born-Oppenheimer approximation occurs on aromatic ring structures; this enables electromagnetic (EM) coupling and energy transfers between collectively oscillating π electrons and nearby protons (H) on aromatic ring; during E-M energy input, very high fluctuating local electric fields are created in vicinity of the ring
- When aromatic structures are adsorbed onto the surface of metallic substrate, ring will spontaneously orient itself as it approaches so that ~flat ring plane of the aromatic molecule ends-up ~parallel to the substrate surface. Born-Oppenheimer approximation also breaks down at such locations, enabling further E-M coupling and energy transfers between Carbon-ring π electrons and 'thin-film' of surface plasmon electrons on substrate surfaces (S. Jenkins, *Proc. Royal Soc*. 465, 2009). Surface plasmons absorb and transport E-M energy
- Dynamics very much analogous to manner in which LENR active sites function on loaded metallic hydride surfaces. Molecular aromatic ring structure becomes functional analogue of a many-body LENR active site in which ULE neutrons are produced collectively via electroweak $e + p$ reaction; neutrons will tend to capture on nearby ring Carbons; same thing for multi-ring polycyclic aromatic hydrocarbons (PAHs)

Widom-Larsen theory specifies details of LENR active sites

Bacterial LENR active sites: key requirements and likely locations in cells

- Widom-Larsen theory of LENRs posits that safe ULE neutron-producing, $e + p$ reaction is many-body collective process between quantum mechanically entangled protons (Hydrogen) and electrons in nm- μ-scale active sites where local electric field strength must exceed key threshold of ~1.4 x 10^{11} V/m for > 100 - 200 attoseconds
- While LENR active sites in biological systems are expected to differ from those that form spontaneously in abiotic condensed matter systems, they must still fulfill all the basic requirements noted above
- In what types of locations might such requirements be satisfied in bacteria? Four possibilities are apparent: (1) in or near active sites of enzymes in which msec-time-averaged E-fields are already known to exceed 10^{10} V/m; (2) on or near outer membrane surfaces, perhaps in close proximity to trans-membrane p^+ (H^+) proton pumps; (3) on or near mitochondrial membranes; and (4) inside, on surfaces of, or near points of attachment for modified pili (e.g. *Geobacter*) or extensions of outer cell wall membranes (e.g. *Shewanella*) --- both of which are called "nanowires" --- that carry electrical currents. They can connect bacteria to substrates or interconnect multiple species of many bacterial in cooperative energy transfer & sharing networks

Widom-Larsen theory specifies details of LENR active sites

Bacterial LENR active sites: key requirements and likely locations in cells

- Biological LENR active sites would have high concentrations of Q-M entangled protons (Hydrogen) & electrons (reactants for *e* + *p* reaction) in close proximity to each other in small regions where local injection of energy and/or rapid motion of charged groups operate to briefly increase local electric field strength above key 1.4 x 10^{11} V/m. Since produced neutrons have ultralow energy, intended 'targets' for neutron capture must be positioned inside or very close to active sites

- Many-body collective *e* + *p* reaction is endothermic; requires input energy equivalent to ~1.2 million ATP molecules per neutron. It is energetically 'expensive' to operate LENR transmutation networks; seems likely that bacteria would probably only do it for good reasons, whatever those might be. External light sources could provide bacteria with needed input energy; G. Lu et al (Lanzhou Institute of Chemical Physics, China 2016) claimed abiotic LENRs were triggered with light from a 300 Watt Xenon lamp. Electric currents can provide input energy for LENRs; remarkable types of "electric bacteria" recently discovered

- Widom-Larsen theory extends to aromatic molecules; that being the case, one might reasonably expect that aromatic groups are likely to be located in or near LENR active sites found in biological systems

Early 1970s Larsen in PhD program on theoretical biophysics

After beginning to write thesis had to drop-out due to cuts in AEC funding

1973: sketched ideas about energy maximization hypothesis in unpublished paper

Theorized abstractly: G = spatial subvolume containing discrete living components L_j

E_i = the energy category, i

$\xi_i = \xi_i(x,y,z,t)$, the energy vector of the category E_i

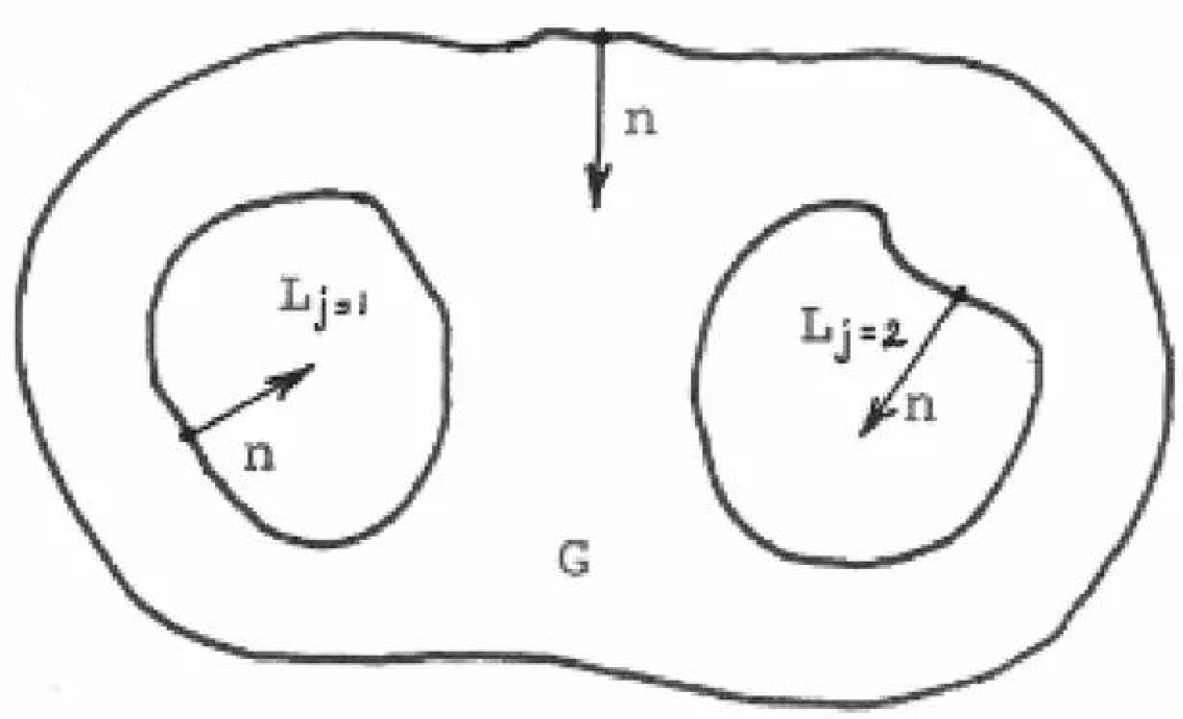
$\xi_i = \rho_{E_i} \cdot v_{E_i}$ with $c^2 \geq v_{E_i}^2 \geq 0$

ρ_{E_i} = density of E_i at time t

v_{E_i} = velocity vector of E_i at time t

c = velocity of light

We shall also adopt the convention that the surfaces of G and L are to be taken in a positive orientation, that is, with the unit normal vector n pointing inward. Graphically,



thus,

$\xi_i \cdot n > 0$ implies a flow of E_i into G or into L_j

$\xi_i \cdot n < 0$ implies a flow of E_i out of G or out of L_j

1973: living systems evolve to maximize value of ϕ over time

Predicts: photosynthesis will evolve and exploit peak in solar energy flow

Is life multiparametric spacetime worm that maximizes its share of energy flows?

$\int_{t_0}^{t_n}\iint_S {}^{+}\xi_i \cdot n \, da \, dt$ = total positive flow of the category E_i across the surface of G or L_j over the time-interval (t_0, t_n)

$\int_{t_0}^{t_n}\iint_S {}^{-}\xi_i \cdot n \, da \, dt$ = total negative flow of the category E_i across the surface of G or L_j over the time-interval (t_0, t_n)

Note that:

$$\left(\int_{t_0}^{t_n}\iint_S {}^{+}\xi_i \cdot n \, da \, dt\right) + \left(\int_{t_0}^{t_n}\iint_S {}^{-}\xi_i \cdot n \, da \, dt\right) = \int_{t_0}^{t_n}\iint_S \xi_i \cdot n \, da \, dt$$

$\int_{t_0}^{t_n}\iint_S \xi_i \cdot n \, da \, dt$ = total flow of the category E_i across the surface of G or L_j over the time-interval (t_0, t_n)

${}^{+}\Sigma\Sigma F_{L_j}$ = with respect to all components L_j (for all $j = 1,2,3,\ldots,m$), with respect to all categories of energy E_i ($i = 1,2,3,\ldots,n$), the total positive flow across the surface of L over the time-interval (t_0, t_n).

(2.04) $${}^{+}\Sigma\Sigma F_{L_j} = \sum_{j=1}^{m}\left(\sum_{i=1}^{n}\left(\int_{t_0}^{t_n}\iint_{S_{L_j}} {}^{+}\xi_i \cdot n \, da dt\right)\right)$$

ϕ is defined as,

(2.07) $$\phi = \frac{\sum_{j=1}^{m}\left(\sum_{i=1}^{n}\left(\int_{t_0}^{t_n}\iint_{S_{L_j}} {}^{+}\xi_i \cdot n \, da dt\right)\right)}{\sum_{i=1}^{n}\left(\int_{t_0}^{t_n}\iint_{S_G} {}^{+}\xi_i \cdot n \, da dt\right)}$$

and Property 1.0 is, formally,

(2.08) $$\max \phi = \max \frac{\sum_{j=1}^{m}\left(\sum_{i=1}^{n}\left(\int_{t_0}^{t_n}\iint_{S_{L_j}} {}^{+}\xi_i \cdot n \, da dt\right)\right)}{\sum_{i=1}^{n}\left(\int_{t_0}^{t_n}\iint_{S_G} {}^{+}\xi_i \cdot n \, da dt\right)}$$

Property 1.0 implies that, for two consecutive, sufficiently-long time-intervals, $\Delta t_2 = (t_0, t_n)$, and $\Delta t_1 = (2t_0 - t_n, t_0)$,

(2.09) $$\phi_{\Delta t_1} < \phi_{\Delta t_2}$$

1973: living systems evolve to maximize value of Φ over time

Maximization occurs within multiplicity of different constraints on system

Living systems arose in vicinity of nonequilibrium energy flows in environment

- Per I. Prigogine, living organisms are far-from-equilibrium quantum dissipative systems. They extract energy from their environment to maintain structural integrity, grow, and multiply, thus expanding their occupied territory in spacetime
- On Earth, life likely first arose in very close proximity to variety of different types of available energy flows, namely: (1) thermal (heat); (2) chemical - molecules, molecular bonds, and electrons; (3) electromagnetic - (a) radiation emitted from Sun, (b) natural electric currents; and (4) various types of radiation emitted during decay of unstable, radioactive isotopes of elements in the Periodic Table
- Early life likely also arose in close proximity to 2-D interfaces (e.g. gas-liquid; gas-solid; solid-liquid) and surfaces where reduced dimensionality helps enable chemical, electronic, or nuclear processes that are improbable in 3 dimensions: e.g. Born-Oppenheimer approximation breakdown on surfaces critical to LENRs
- Living organisms intrinsically rely upon and utilize many-body collective quantum mechanical effects on many length-scales ranging from *nm*-scale molecules up to μ-scales for entire cells; will very rarely operate like far simpler, few-body systems
- Maximization of Φ is not an emergent property of individual organisms, single species, or even species ensembles; most likely operant and measurable at level of multiple phyla, biomes, or entire planetary biosphere. Not monotonic process

Higher temperatures will increase rates of chemical reactions

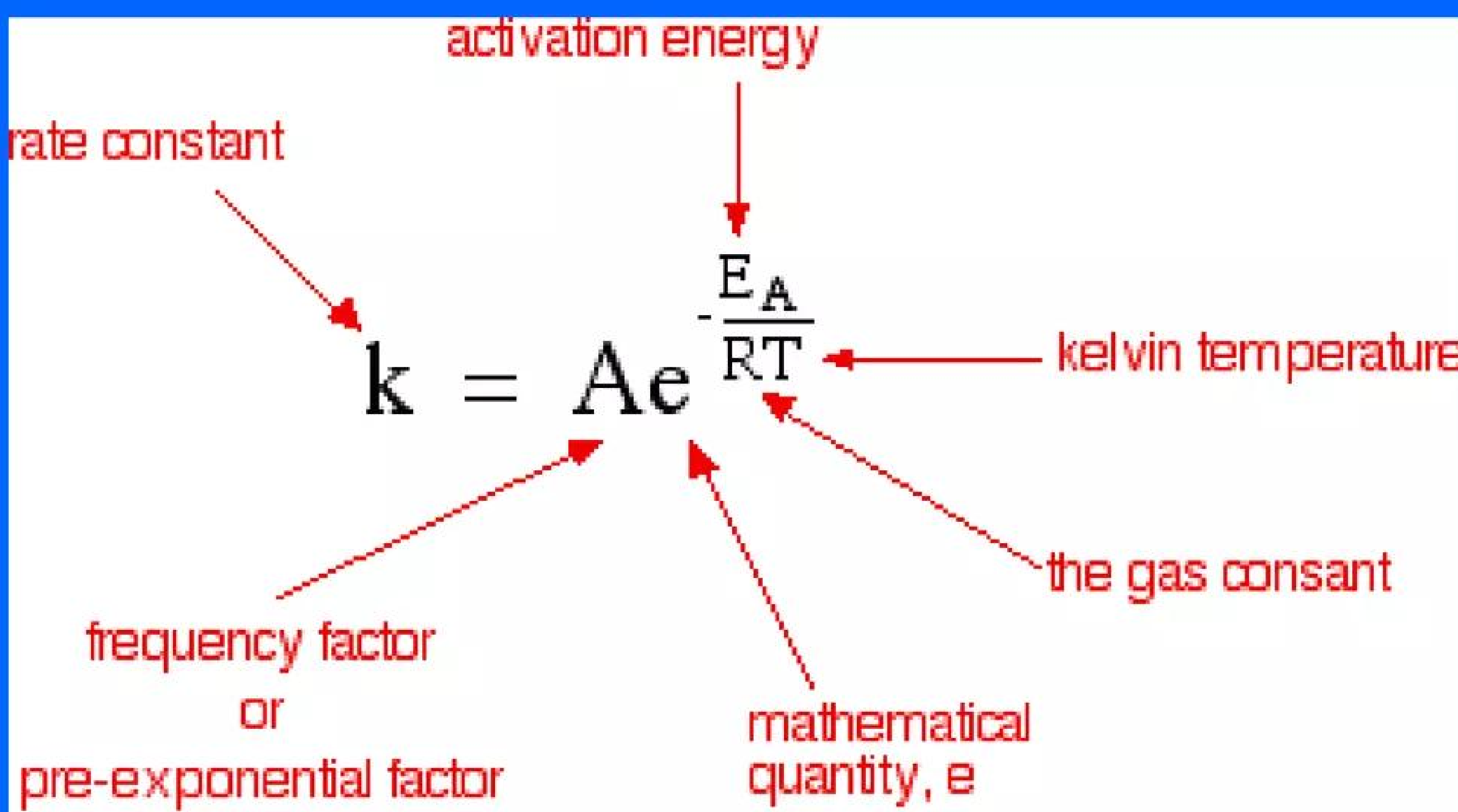
Microbes utilize higher temps and catalysts (enzymes) to maximize *Φ*

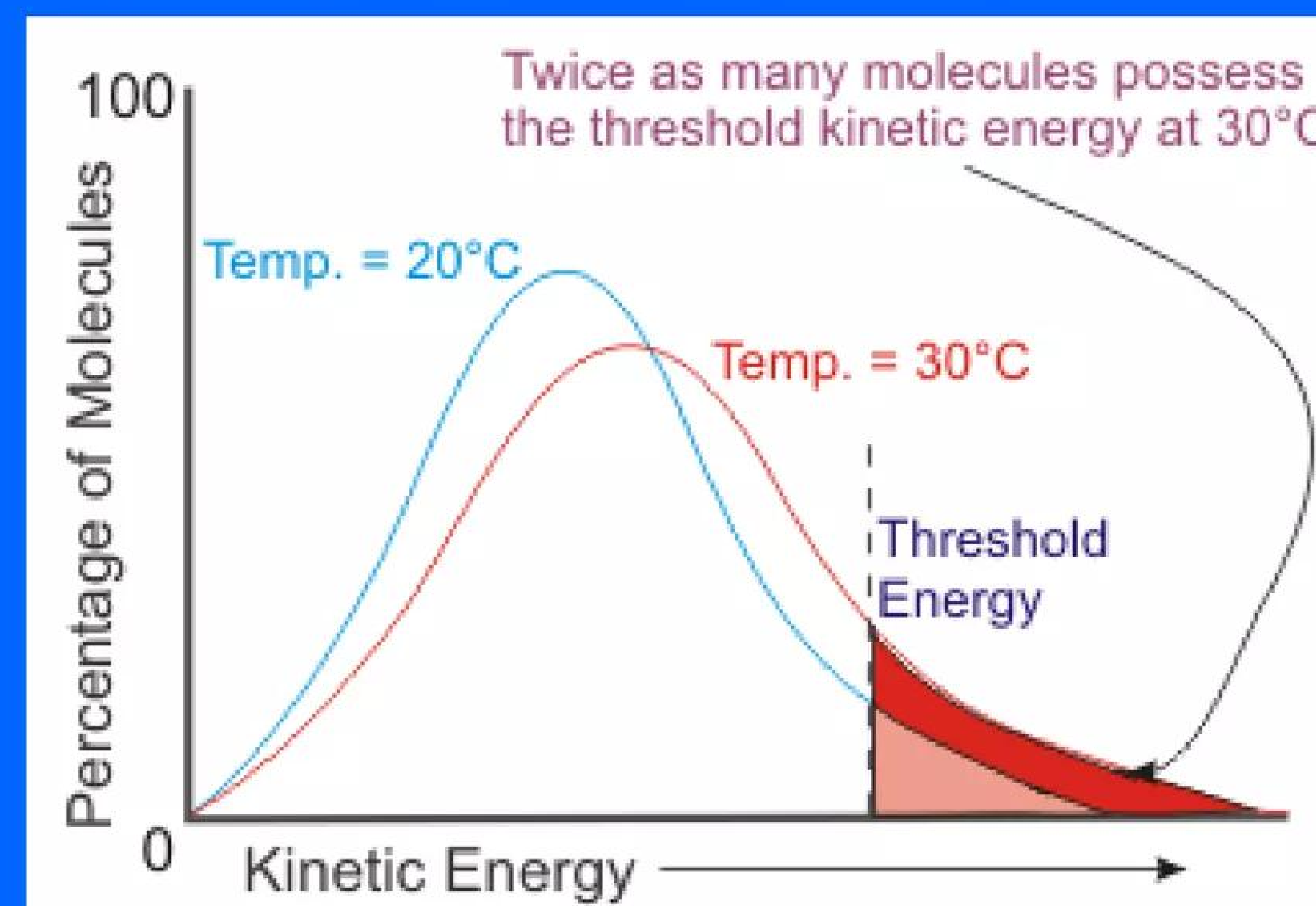
Metallic catalysts and enzymes work to reduce activation (= threshold) energy

Early microbial life had far less well-developed enzymatic capabilities compared to modern organisms. Thus, they probably exploited natural heat sources and locally available catalytic metals to increase rates of chemical reactions that support metabolism and growth. In early Archaean, microbes likely adapted to use energy from surface hydrothermal vents and hot springs and telluric currents; those living in weathered soils or crustal rocks away from hydrothermal vents or hot springs likely used heat and telluric currents created by deposits of radioactive elements

Arrhenius equation: reaction rate increases with T

More molecules react at higher temp (T)





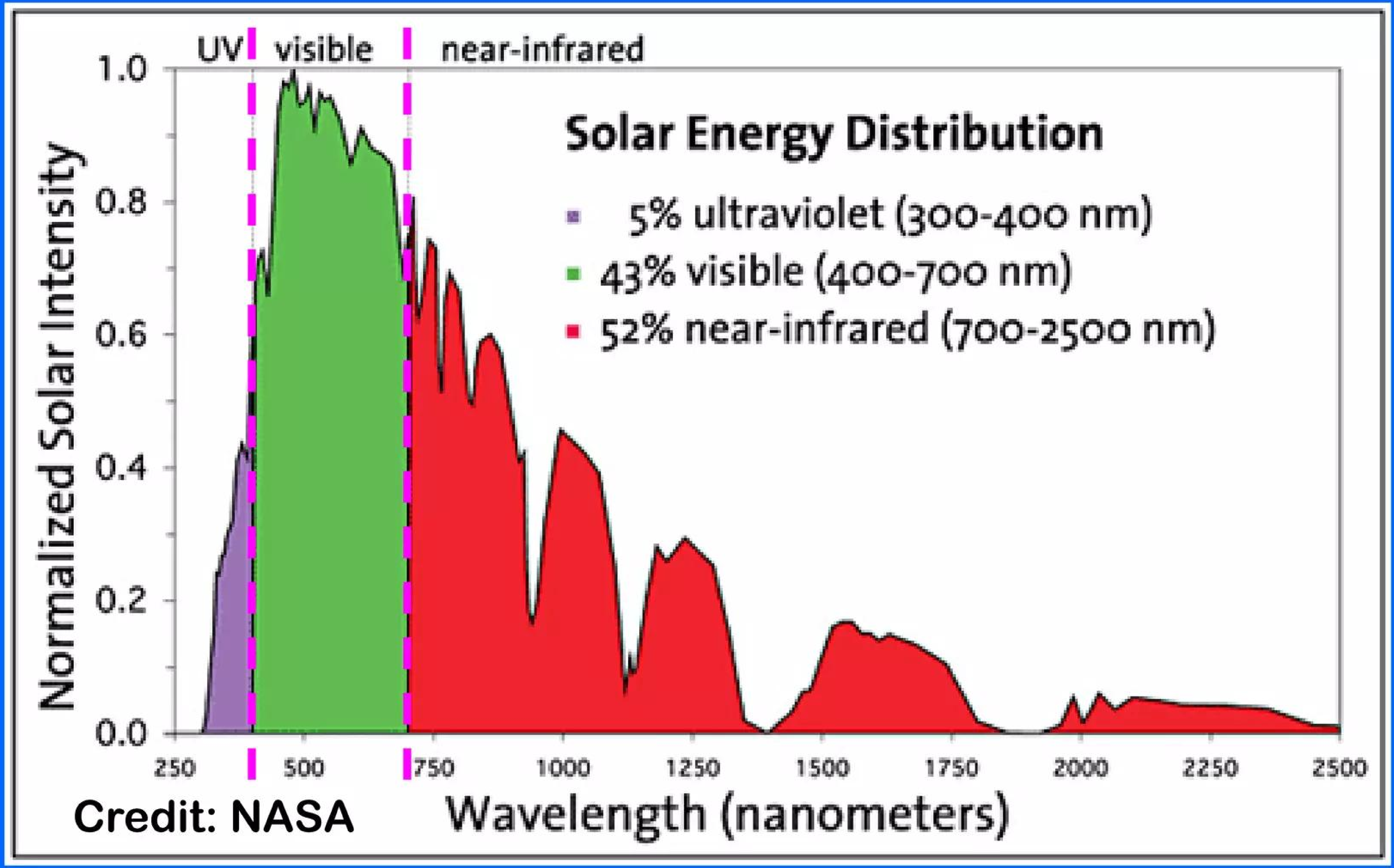
https://www.cdli.ca/sampleResources/chem3202/unit01_org01_ilo03/b_activity.html

https://www.chemguide.co.uk/physical/basicrates/arrhenius.html

Peak in Sun's energy flow to Earth is located in visible region

Visible spectrum from 400 - 700 nm comprises ~ 43% of solar energy flow

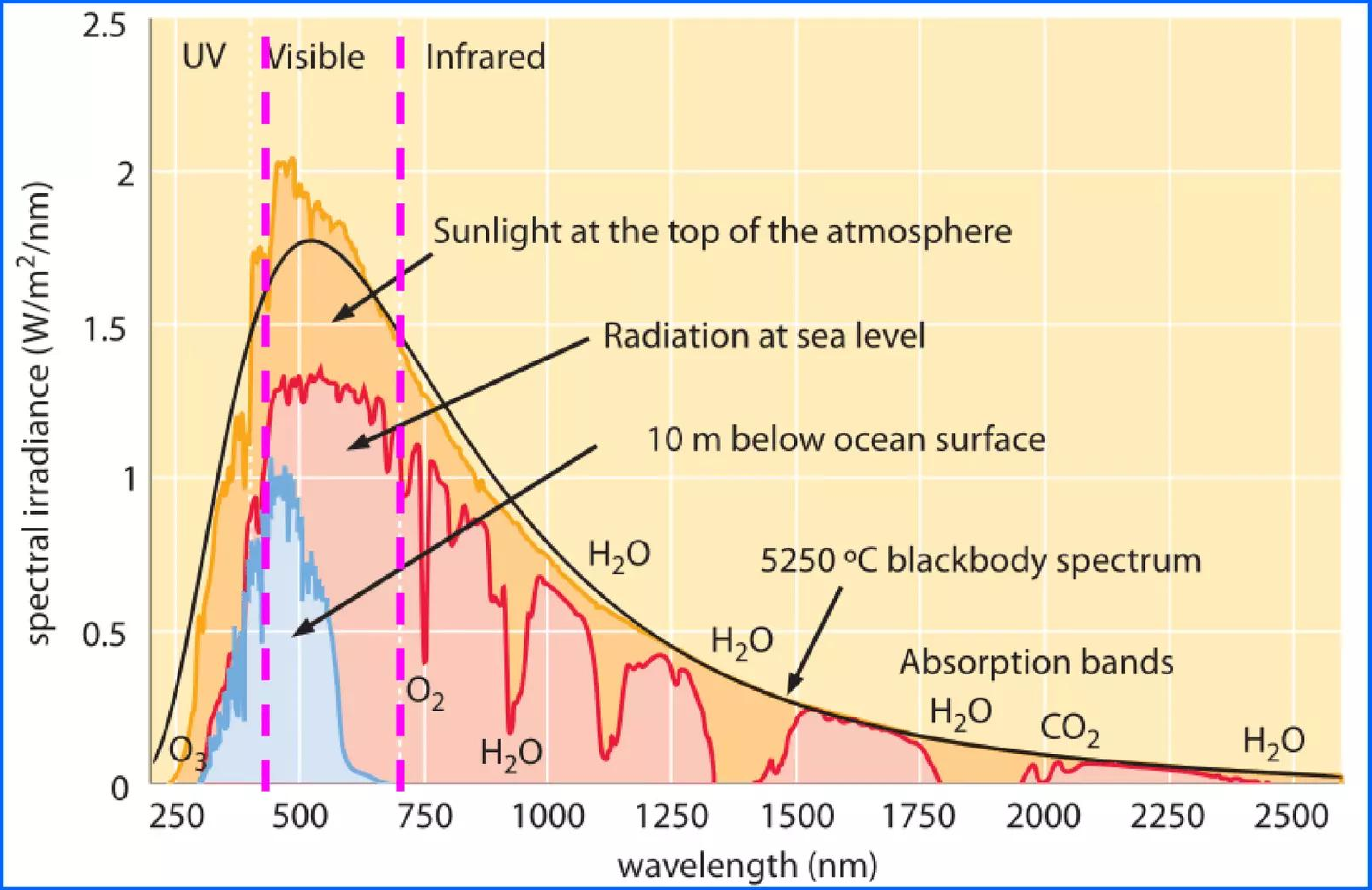
Chart shows net solar energy distribution incident on Earth's surface at sea level



More about flow of electromagnetic energy from Sun to Earth

Incident solar radiation at sea level also shown in chart on previous slide

Major reduction in available solar energy at ocean depths exceeding 10 meters



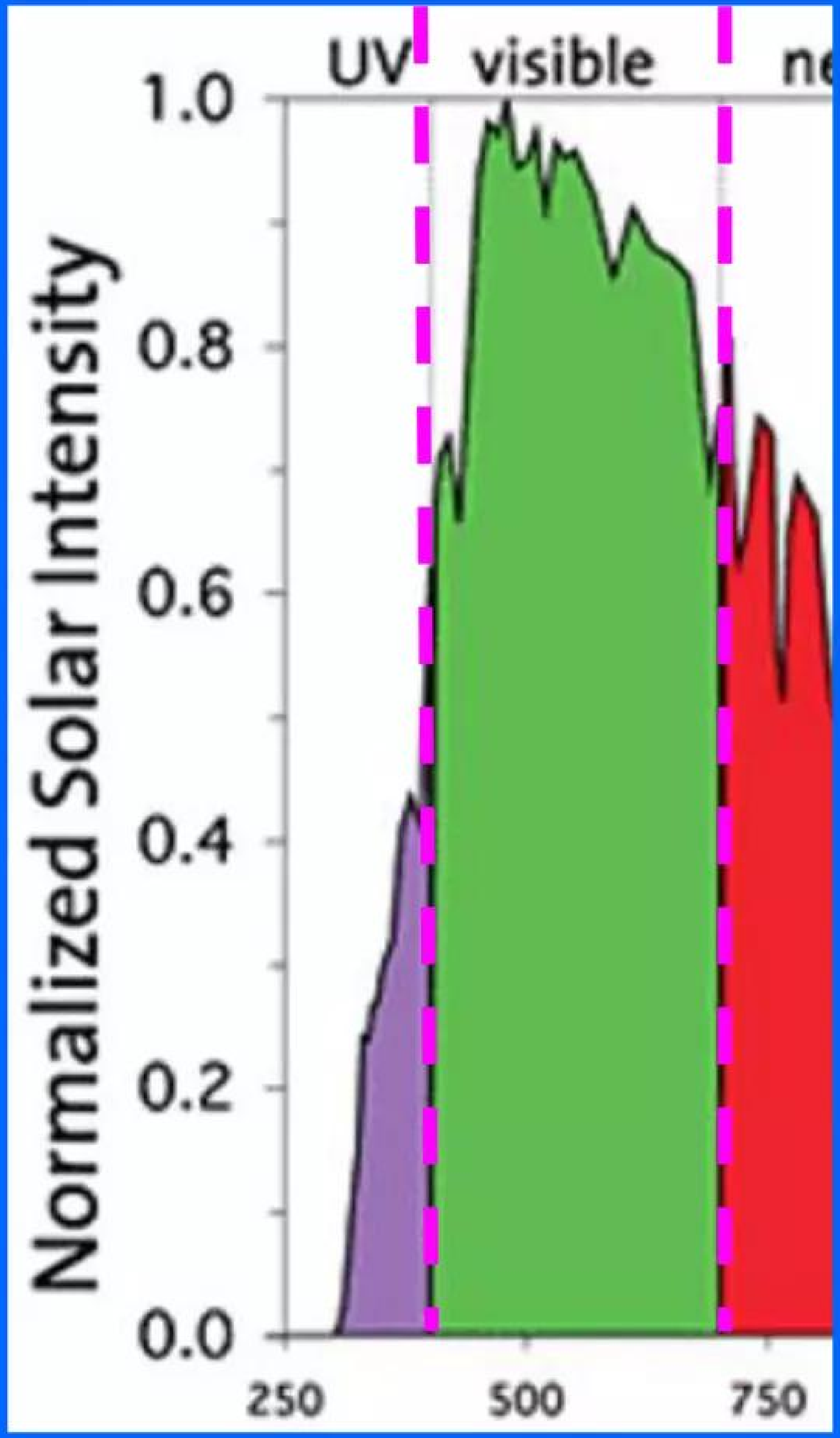
http://book.bionumbers.org/how-much-energy-is-carried-by-photons-used-in-photosynthesis/

Absorption peaks in pigments consistent with maximizing *Φ*

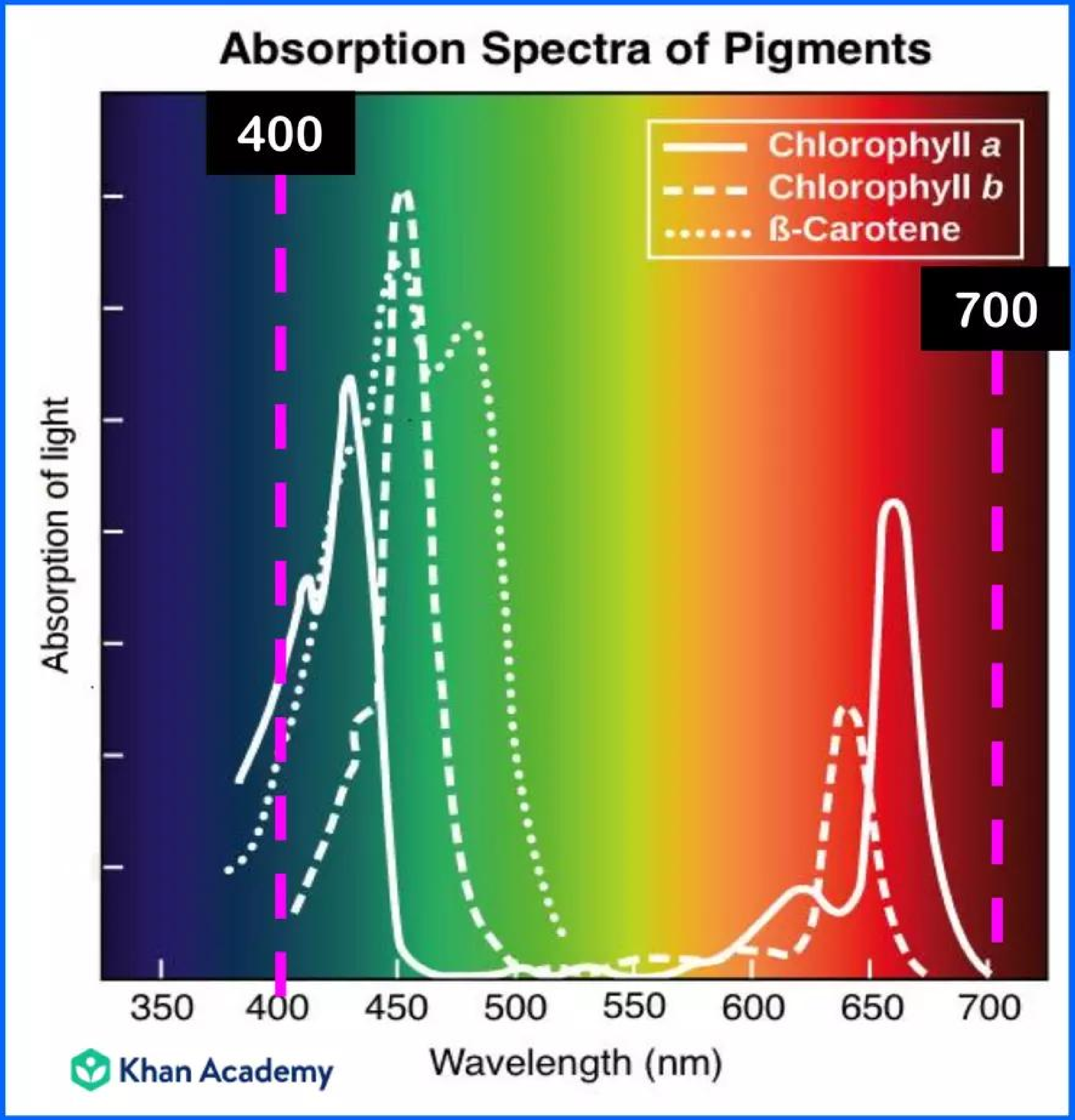
Evolution of pigments with such absorption peaks not a random accident

Photosynthetic plants have largest biomass because exploit peak in solar energy

Solar energy peak: 400 - 700 nm



Peaks in absorption spectra of pigments

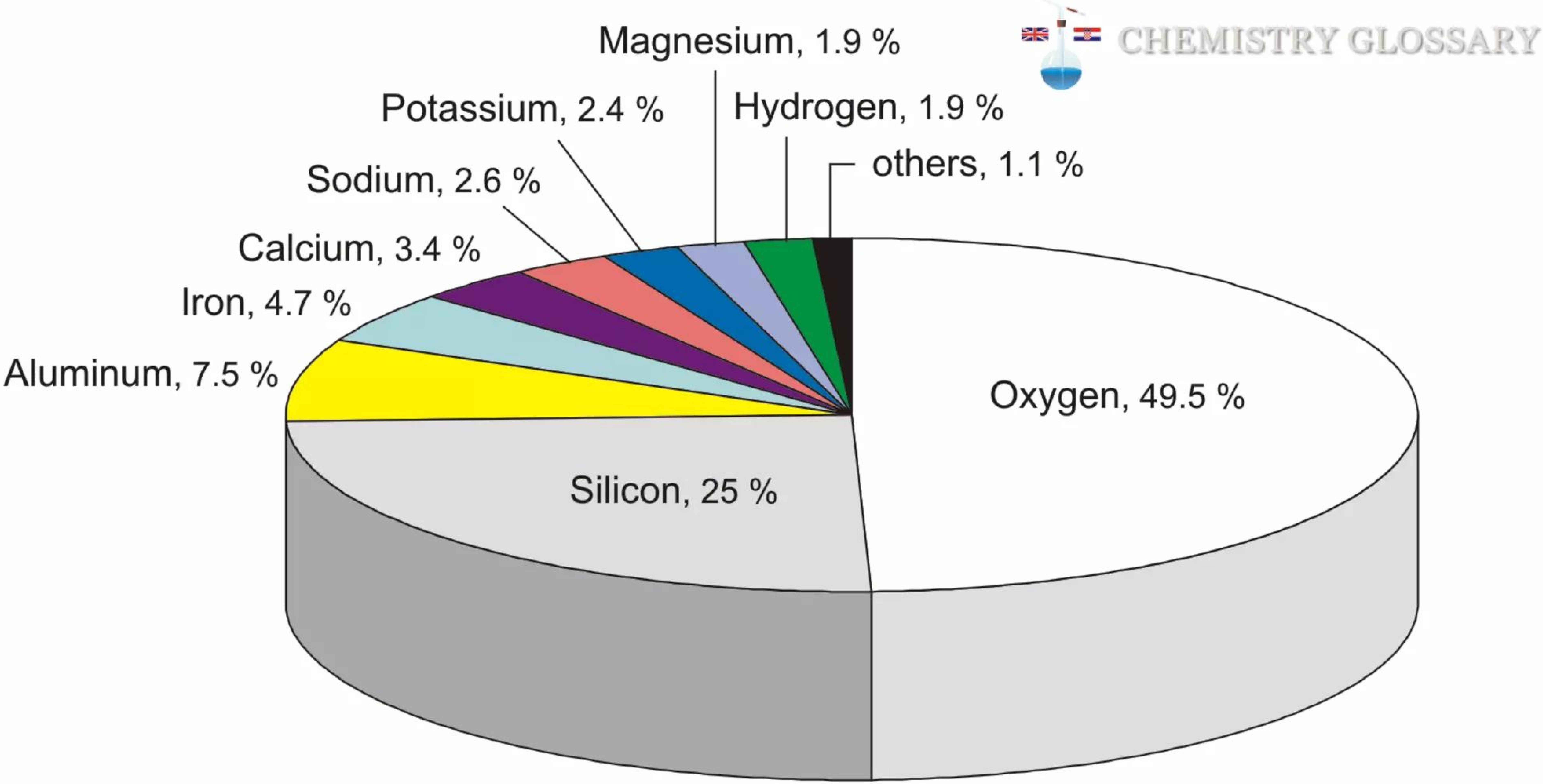


https://www.khanacademy.org/science/biology/photosynthesis-in-plants/the-light-dependent-reactions-of-photosynthesis/a/light-and-photosynthetic-pigments

% abundances of elements now present in our Earth's crust

Carbon - the essential building block of life - is minor (under others 1.1%)

9 elements are ~99 % of crust's present composition: O, Si, Al, Fe, Ca, Na, K, Mg, H



E. Generalic, https://glossary.periodni.com/glossary.php?en=abundance+of+elements

Chemical elements found in biological systems on Earth

Outside of Fe, Ca, K, Mg, active site metals have tiny crustal abundances

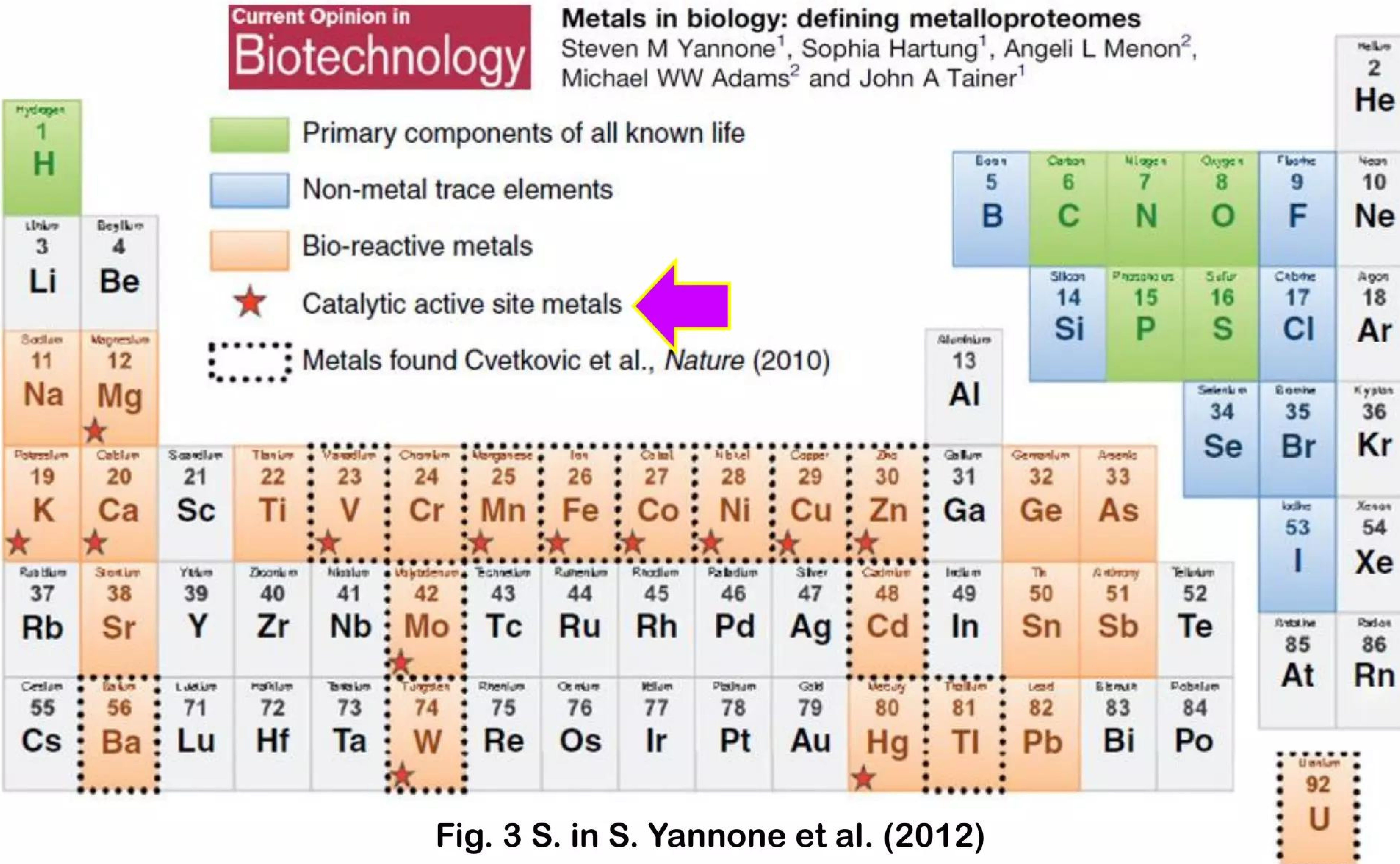


Fig. 3 S. in S. Yannone et al. (2012)

Metalloproteins play key roles in crucial biological processes

"All known living systems have exploited … unique properties of metals"

"Metals in biology: defining metalloproteomes"

S. Yannone et al. *Current Opinion in Biotechnology* 23 pp. 89 - 95 (2012)

https://www.academia.edu/14926962/Metals_in_biology_defining_metalloproteomes

From closing remarks: "Citation of metalloprotein studies has grown steadily and increased ten-fold over the past twenty years reaching nearly 2500 citations last year. Recent findings have revealed that the sum of these works and our current knowledge is probably limited to far less than half of the metalloproteins that exist. Among known metalloprotein functions are vital roles in the fundamental processes of photosynthesis, electron transport, nitrogen fixation, and oxygen transport in vertebrates among many others. The discovery of such a large number of uncharacterized metalloproteins holds enormous potential for uncovering new biochemistries and novel evolutionary solutions to basic biochemical reactions … All known living systems have exploited the unique chemical and physical properties of metals to maintain homeostasis and facilitate life in even the most extreme environments. Considering the ubiquity and indispensable nature of metals to all life, any such 'systems view' will be severely lacking without consideration of metal requirements, balance, flux, and functions. As the newer metal-technologies mature to meet established technologies, our ability to rapidly identify and characterize novel metalloproteins, metal folds, and define metal usage in biological systems will be dramatically expanded."

Abundances of chemical elements in ‘higher’ mammal’s body

Nearly total overlap with elements found in ‘lowly’ Archaea and Bacteria

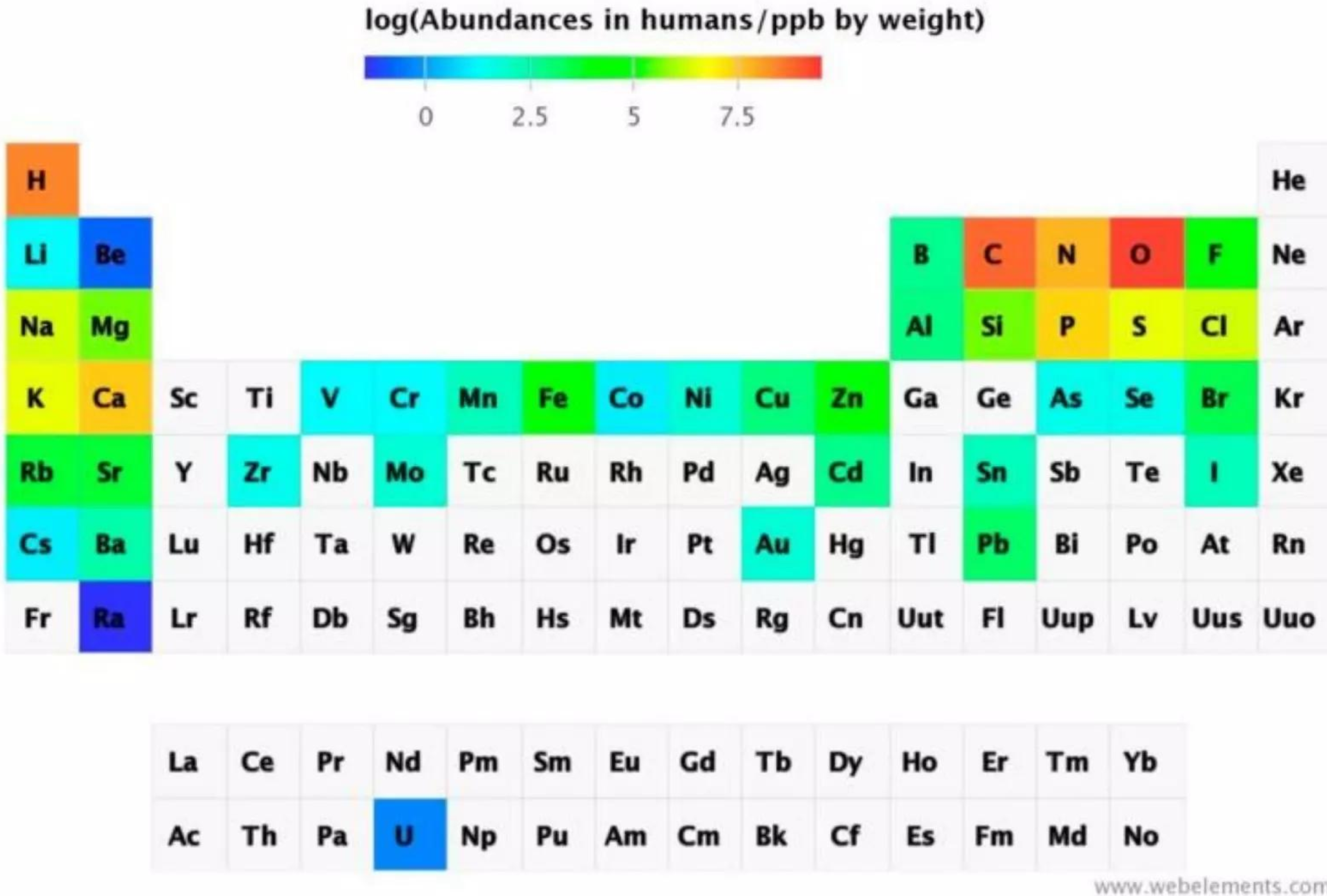


Fig. 3 in: “The metals in the biological Periodic System of the Elements: concepts and conjectures”
W. Maret *International Journal of Molecular Sciences* 17 pp. 66 - 73 (2015)

Metals in cytoplasmic metalloproteins of *Pyrococcus furiosis*

Note: "Metalloproteins have key roles in most biological processes"

"Microbial metalloproteomes are largely uncharacterized"
A. Cvetkovic et al. *Nature* 466 pp. 779 - 782 (2010)
https://www.researchgate.net/publication/45272220_Microbial_metalloproteomes_are_largely_uncharacterized

From Abstract: "Metal ion cofactors afford proteins virtually unlimited catalytic potential, enable electron transfer reactions and have a great impact on protein stability. Consequently, metalloproteins have key roles in most biological processes, including respiration (Iron and Copper), photosynthesis (Manganese) and drug metabolism (Iron). Yet, predicting from genome sequence numbers and types of metal an organism assimilates from its environment or uses in its metalloproteome is currently impossible because metal coordination sites are diverse and poorly recognized. We present here a robust, metal-based approach to determine all metals an organism assimilates and identify its metalloproteins on a genome-wide scale … [We] characterize cytoplasmic metalloproteins from an exemplary microorganism (*Pyrococcus furiosus*)."

Metals in cytoplasmic metalloproteins of *Pyrococcus furiosis*

Metalloproteomes "more extensive & diverse than previously recognized"

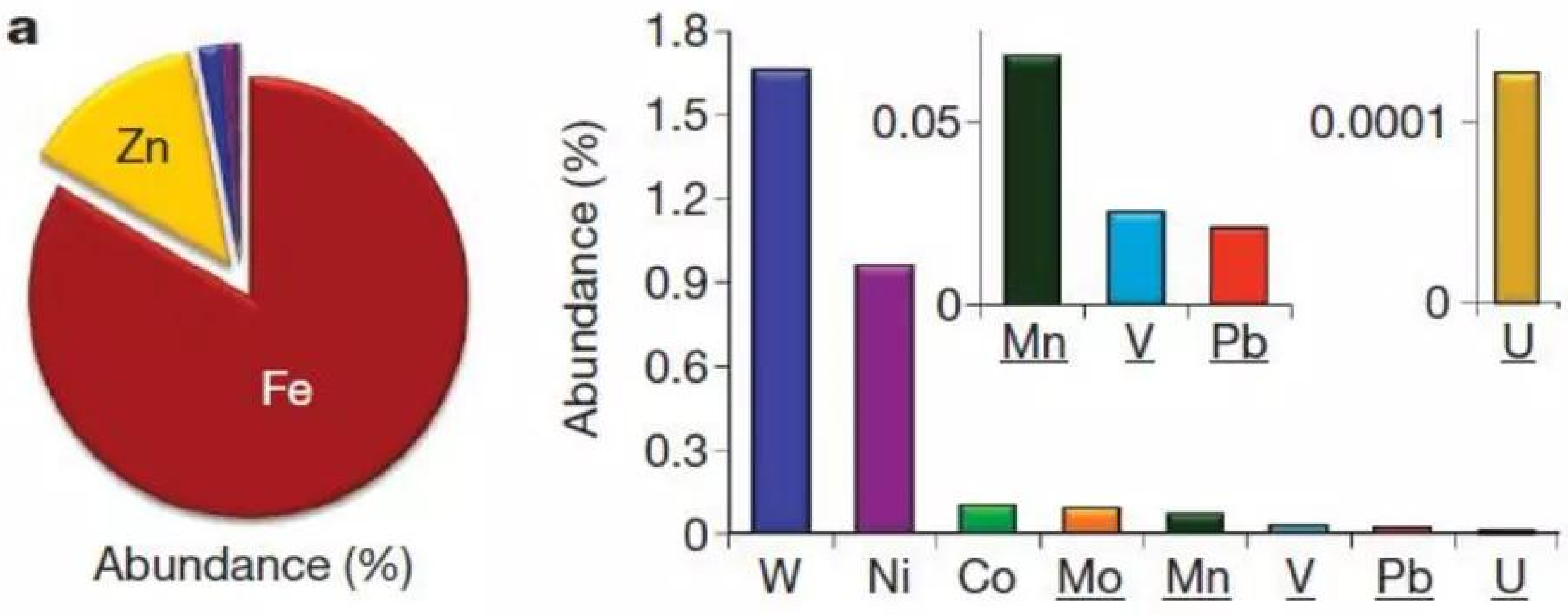
"Microbial metalloproteomes are largely uncharacterized"
A. Cvetkovic et al. *Nature* 466 pp. 779 - 782 (2010)
https://www.researchgate.net/publication/45272220_Microbial_metalloproteomes_are_largely_uncharacterized

From Abstract: "Of 343 metal peaks in [C1] chromatography fractions, 158 did not match any predicted metalloprotein. Unassigned peaks included metals known to be used (Cobalt, Iron, Nickel, Tungsten and Zinc; 83 peaks) plus metals the organism was not thought to assimilate (Lead, Manganese, Molybdenum, Uranium and Vanadium; 75 peaks). Purification of eight of 158 unexpected metal peaks yielded four novel Nickel- and Molybdenum-containing proteins, whereas four purified proteins contained sub-stoichiometric amounts of misincorporated Lead and Uranium. Analyses of two additional microorganisms (*Escherichia coli* and *Sulfolobus solfataricus*) revealed species specific assimilation of yet more unexpected metals. Metalloproteomes are therefore much more extensive and diverse than previously recognized, and promise to provide key insights for cell biology, microbial growth and toxicity mechanisms."

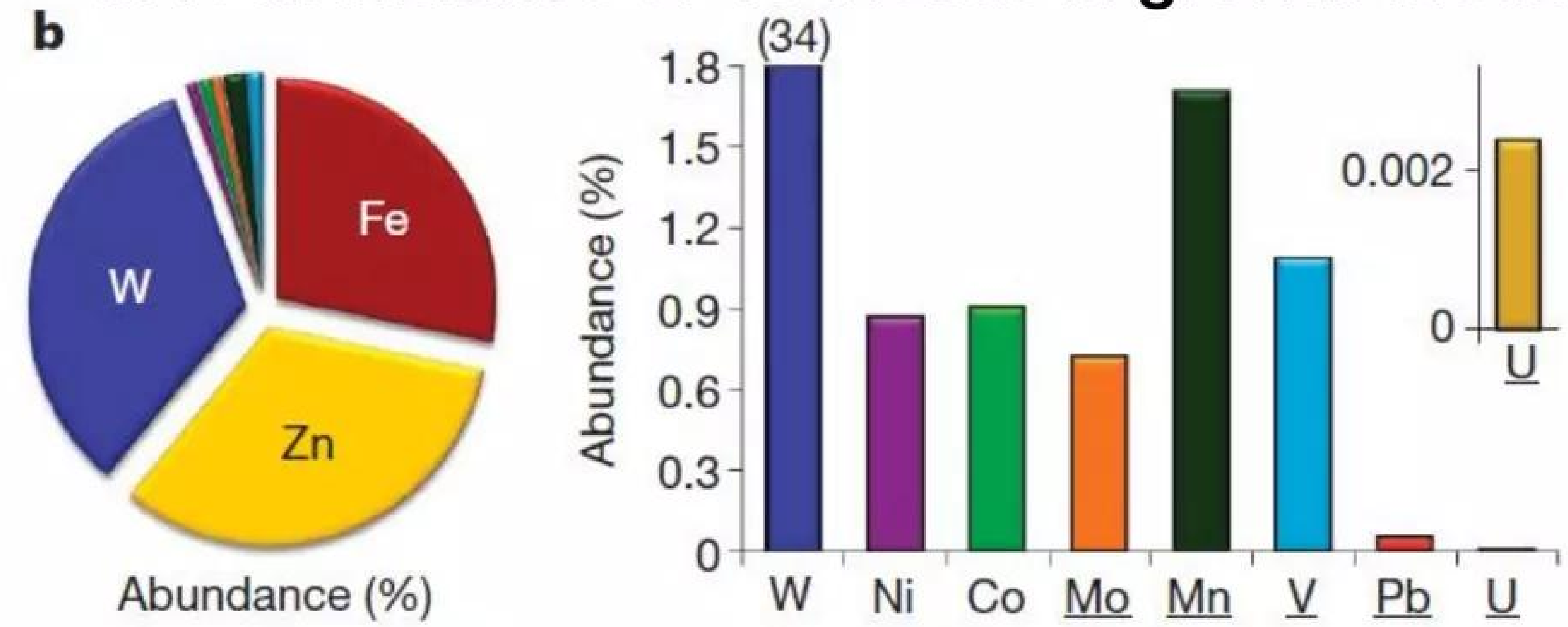
Metals in cytoplasmic metalloproteins of *Pyrococcus furiosis*

Some have large difference between abundance in bacterium vs. medium

a. % abundance of 10 metals in bacterium



b. % abundance of 10 metals in growth medium



c. number of assigned and unassigned peaks by metal

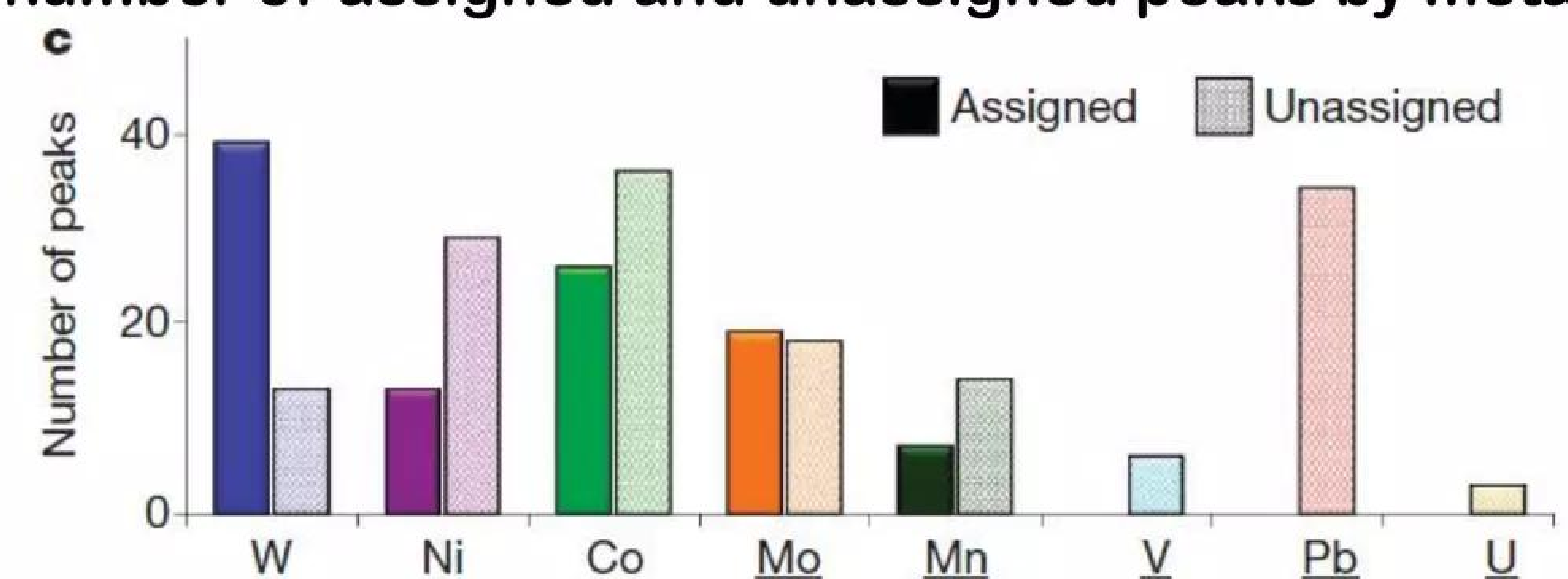


Fig. 1 in A. Cvetkovic et al. (2010): "Metal assimilation by *P. furiosus* and unassigned metal peaks. a–c, Relative amounts (percentage on a molar basis) of the ten metals present as peaks in C1 chromatography fractions (a) and those ten metals in the growth medium (b), and number of metal peaks in C2 chromatography fractions that can be assigned (solid bars) or cannot be assigned (shaded bars) to a protein with an InterPro-Metal (IPM) hit for that metal (c). values for Uranium are from C1 column. Order of metals in bar graphs reflects their abundance in C1 fractions (W content is 34% in medium) and data for Fe and Zn are omitted for clarity. Metals that *P. furiosus* was not known to use are underlined (see Supplementary Tables 3 and 5)."

Metals in cytoplasmic metalloproteins of *Pyrococcus furiosis*

Note: "3.1. The microbial metalloproteome has been largely unexplored"

"Microbial metalloproteomics"
P-L. Hagedoorn *Proteomes* 3 pp. 424 - 439 (2015)
https://www.mdpi.com/2227-7382/3/4/424

From paper: "Metalloproteomic research on hyperthermophilic archaeon *Pyrococcus furiosus* revealed … metalloproteome appeared to be largely unexplored. Uncharacterized metalloproteins were discovered and unanticipated metals such as Pb, U and V were detected in protein samples … incorporation of Pd and U was found to be substoichiometric (e.g., 0.01 U atom per ferritin monomer), of which the biological relevance still needs to be established."

"*Pyrococcus furiosus* has unique property that it is dependent on Tungsten for growth on carbohydrates. This is due to the presence of five Tungsten containing enzymes. The two metals Tungsten and Molybdenum are chemically remarkably similar, as a consequence of the Lanthanide contraction. Also, biochemistry of Tungsten and Molybdenum is entangled. Nature uses similar enzymes, cofactors and transport systems for both metals. *P. furiosus* is able to distinguish between Tungsten and Molybdenum, and has a very strong preference for Tungsten over Molybdenum, even in the presence of a 1000-fold excess of Molybdenum."

Medium-sized E. coli bacterial cell composed of ~ 10^{10} atoms

Many catalytic active site metals present in very small numbers %-wise

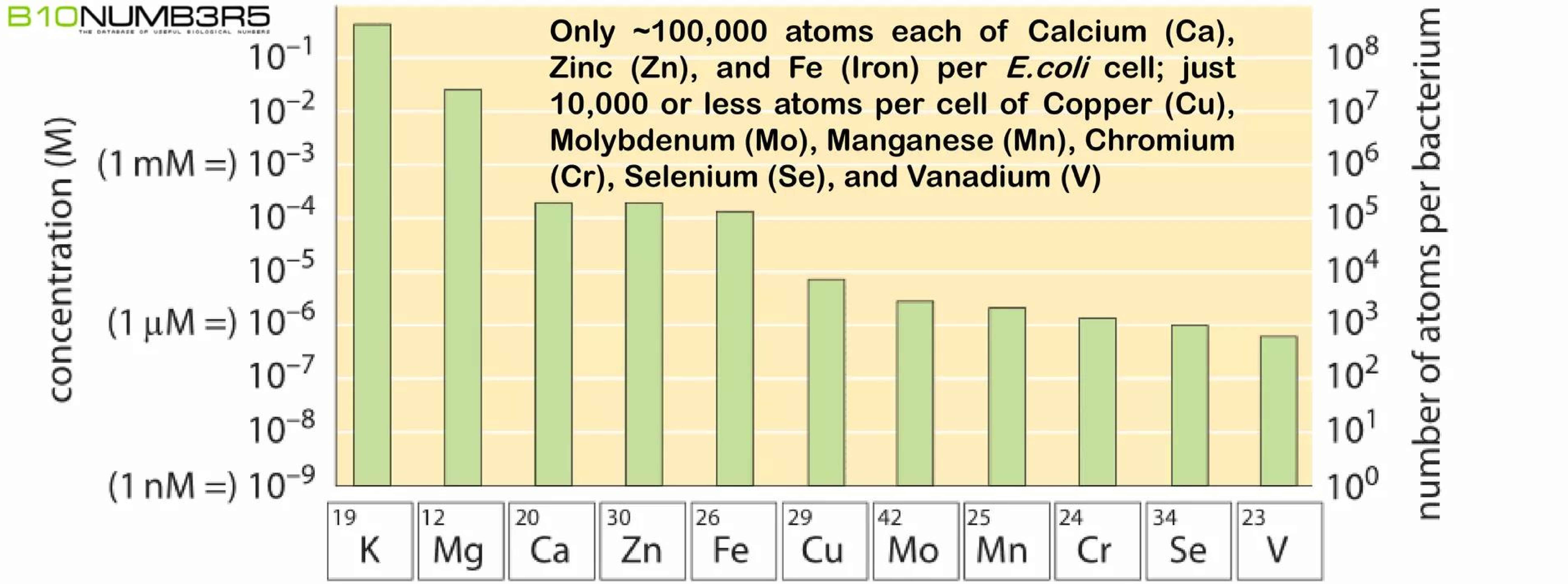
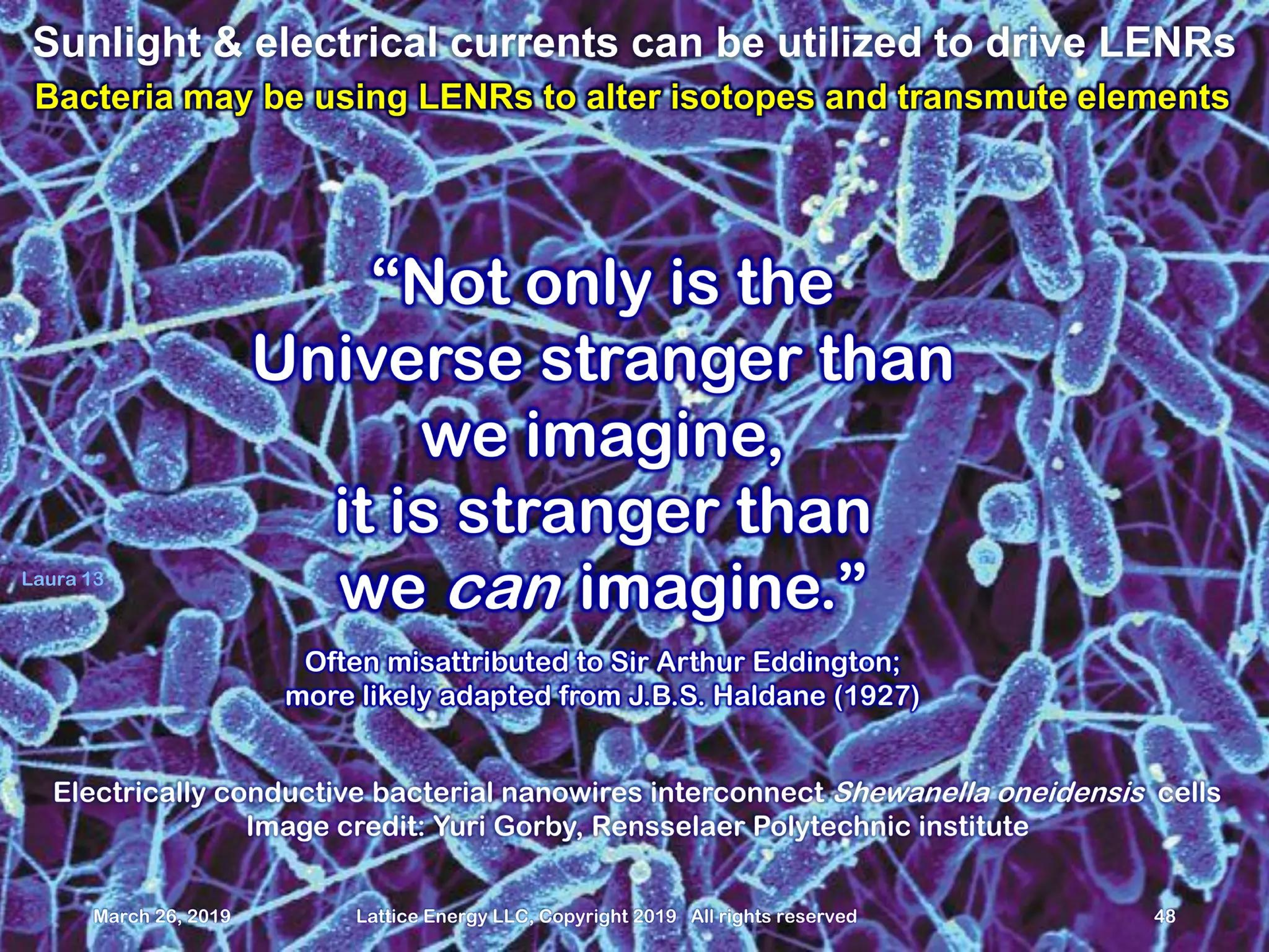


Figure 2: "Metal content of *E. coli* cells grown in LB and glucose minimal medium as determined by mass spectrometry. The *E. coli* metallome, i.e., the total metal content of the cell, is represented in terms of both concentrations and atoms per cell (grown in minimal medium) for each metal ion. The shown values are the mean of three independent measurements; error bars are small on this log scale and are not shown. (Adapted from C. E. Outten, *Science*, 292:2488, 2001)"

http://book.bionumbers.org/what-quantities-of-nutrients-need-to-be-supplied-in-growth-media/



Sunlight & electrical currents can be utilized to drive LENRs

Bacteria may be using LENRs to alter isotopes and transmute elements

Laura 13

"Not only is the Universe stranger than we imagine, it is stranger than we *can* imagine."

Often misattributed to Sir Arthur Eddington;
more likely adapted from J.B.S. Haldane (1927)

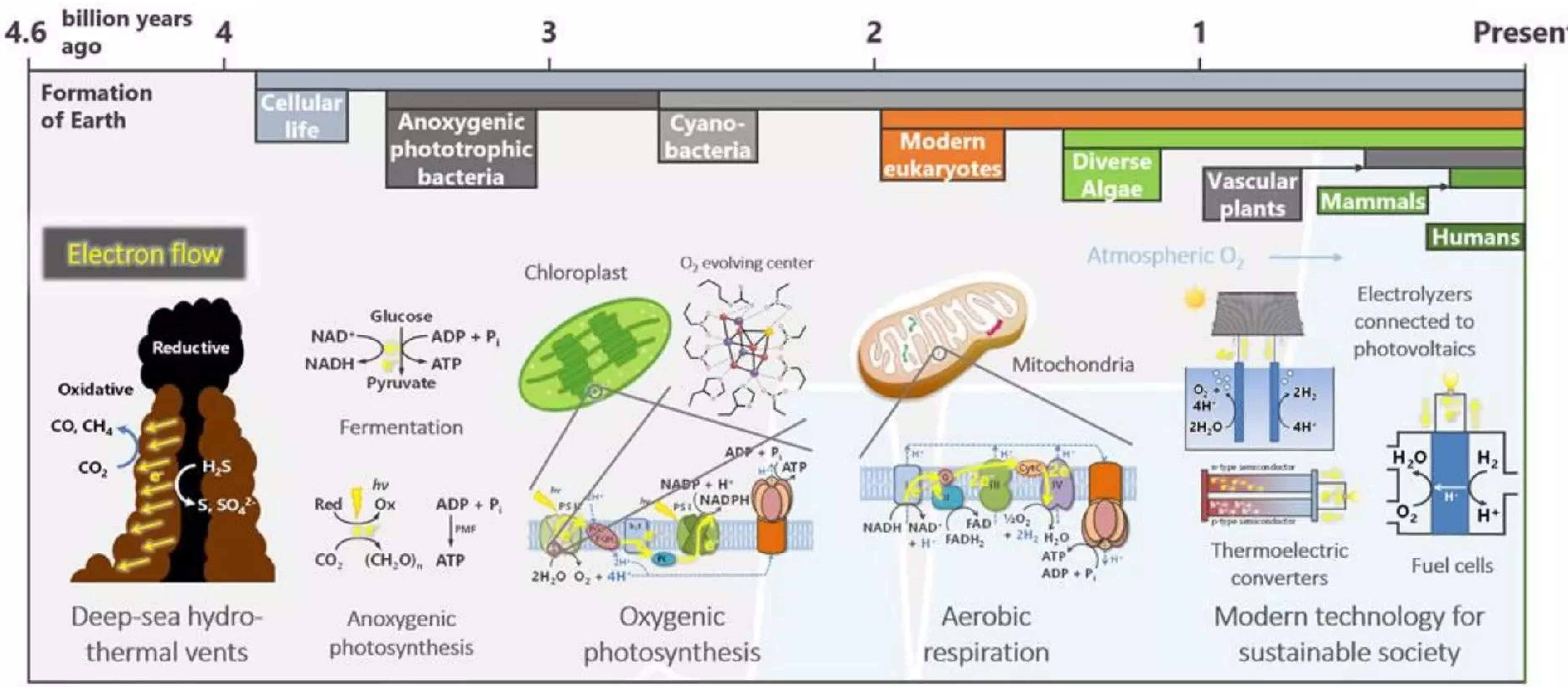
Electrically conductive bacterial nanowires interconnect *Shewanella oneidensis* cells
Image credit: Yuri Gorby, Rensselaer Polytechnic institute

Riken: brief history of life from 4.6 billion years ago to today

2010: proposed electricity generation in deep sea hydrothermal vents

Are vents "giant electrochemical fuel cells" powered by magmatic activity?

RIKEN CSRS Center for Sustainable Resource Science RIKEN



Riken studies "Giant electro ecosystems in a deep hydrothermal environment"

http://www.csrs.riken.jp/en/interview/nakamura/index.html

Sun's radiation is largest energy source for Earth's biosphere

Geothermal energy for driving chemosynthesis only ~.03% of Sun's

Size of Sun's energy flow is why photosynthetic plants have largest biomass

- "Earth's internal heat budget is fundamental to thermal history of the Earth ... flow of heat from Earth's interior to surface is estimated at 47 ± 2 terawatts (TW) and comes from two main sources in roughly equal amounts: radiogenic heat produced by radioactive decay of isotopes in mantle and crust, and primordial heat left over from formation of the Earth."
- "Earth's internal heat powers most geological processes and drives plate tectonics. Despite its geological significance, this heat energy coming from Earth's interior is actually only 0.03% of Earth's total energy budget at [Earth's] surface, which is dominated by 173,000 TW of incoming solar radiation ... insolation that eventually, after reflection, reaches the surface penetrates only several tens of centimeters on daily cycle and only several tens of meters on the annual cycle. This renders solar radiation minimally relevant for internal processes."

Source: Wikipedia

https://en.wikipedia.org/wiki/Earth%27s_internal_heat_budget

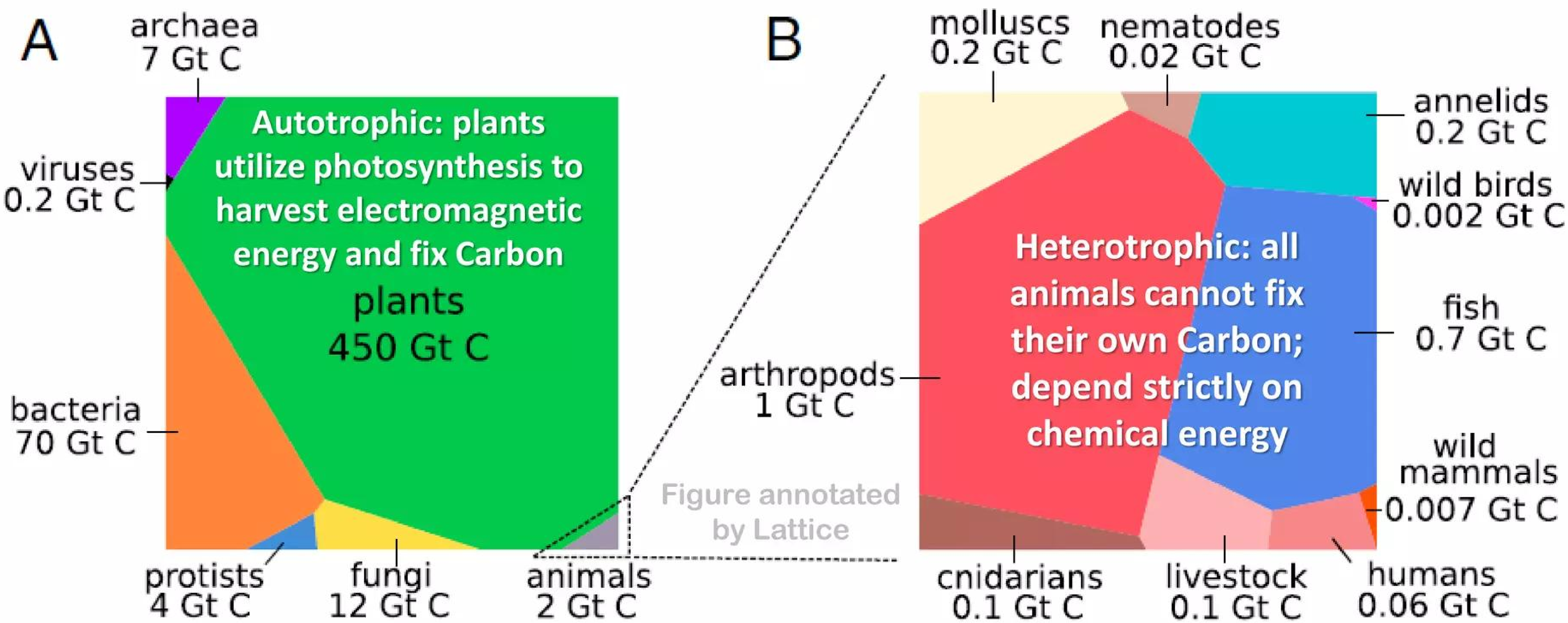
Microorganisms today: 41x greater total biomass vs. animals

Microbes now = 14.9% of global biomass; plants = 82.5%; animals = 0.36%

Earth formed 4.5 billion years ago; life began 3.8 - 4.3 BYA; first animals 1.5 BYA

Bacteria ruled the biosphere for 2.5 billion years before 'higher' life evolved

Fig. 1. "Graphical representation of the global biomass distribution by taxa"



The biomass distribution on Earth"

Yinon M. Bar-On et al *PNAS* 115 pp. 6506 - 6511 (2018)

https://www.pnas.org/content/115/25/6506

Dec. 2018 reported new data from deep drilling in Earth's crust

Estimated Deep Life biomass = 15 - 23 Gt; below Bar-on et al. value (2018)

Deep Carbon Observatory

A global community of more than 1000 scientists on a ten-year quest to understand the quantities, movements, forms, and origins of carbon inside Earth.

Drilled, sampled, and analyzed microbes found in deep habitats; max. depth 2.5 km under sea floor and 5 km under continents; used state-of-the-art sampling methods

Deep life is dominated by Archaea and Bacteria; discovered *Geogemma barossii* that survives and grows at 121 C (~250º F) and immense pressures. Estimated that ~70% of all Archaea and Bacteria presently living are underground and out-of-sight

Maximum depths at which life was detected are 5 km beneath continental crust and 10.5 km under ocean surface. Estimated Deep Biosphere has total volume of 2 - 2.3 billion cubic km – this value represents about 2x total volume of all Earth's oceans

Deep Life's genetic diversity is comparable to or exceeds that on Earth's surface; most species have never been cultured or characterized in labs. Estimated total biomass of Deep Life = 15 - 23 billion tons (Gt). While below Bar-on et al's estimate (2018), is equal to biomass of ~115 million Blue Whales, Earth's largest-ever animal

Microbes in deepest habitats are energy- and nutrient-constrained. Cell metabolic, growth, and division rates slow fantastically to survive: become "zombie bacteria"

https://deepcarbon.net/life-deep-earth-totals-15-23-billion-tonnes-carbon

Early Earth around LHB was inhospitable compared to today

Archaea & Bacteria dominated Earth's biosphere for over 2 billion years

- Toxic effects of external ionizing radiation and ingestion of heavy elements or radioactive isotopes are well-known in 'higher' organisms such as mammals like humans. However, it is questionable to assume that this longstanding dictum also applies to 'lower' microorganisms like Archaea and Bacteria: some species can readily survive and even thrive under incredible onslaughts of temperatures as high as ~250^{O} F and radiation doses that would be lethal to most 'higher' life forms

- Early in Earth's history, at or near dawn of life 3.8 - 4.3 billion years ago, ~3.9 BYA Earth endured the Late Heavy Bombardment (LHB) period when planet was pummeled by asteroids, some being as large as the state of Kansas. Then, early microorganisms' living conditions were vastly less hospitable than today's. During LHB, only survival deep underground was possible where temperatures did not exceed 230 degrees Fahrenheit. Earth's surface and outer crust then had much higher concentrations of radioactive elements like Uranium, Thorium, and Potassium. This allowed natural Uranium fission reactors like 17 found in Okla, Gabon to form occasionally; some were still operating as late as ~ 2.0 BYA

- After surviving or kickstarting by LHB, 'lowly' Archaea and Bacteria dominated Earth's biosphere for another ~2.5 billion years before 'higher' multicellular animals finally evolved and appeared at ~1.5 BYA. For over 2 billion years, natural selection and adaptation to many environments allowed microorganisms to flourish, speciate, develop greater capabilities for utilizing different forms of matter & energy, and expand into vast numbers of new habitat types and niches

Some features of early Archaean Earth are widely accepted

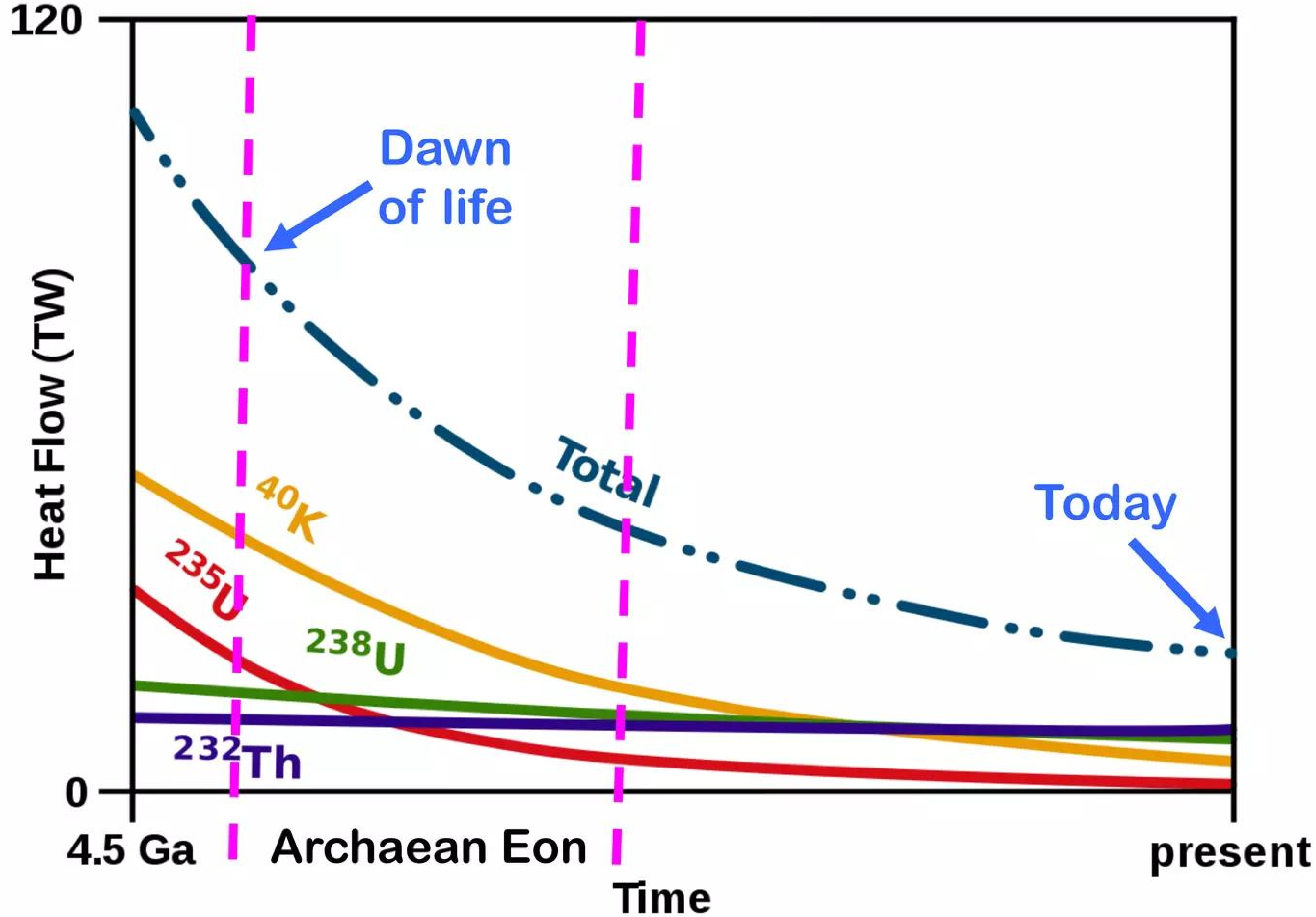
Microbes were primarily chemoautotrophic and/or electrolithoautotrophic

- Much controversy still remains about many important details of Earth's environment at dawn of life early in the Archaean Eon (from ~4.0 to 2.5 BYA)
- What is widely accepted about Archaean is: (1) Sun was ~25 - 30% less luminous than today; (2) atmosphere contained little or no free Oxygen (O_2) so present ozone shield didn't exist and ultraviolet (UV) radiation from the Sun was much more intense at Earth's surface vs. today; (3) biologically active oceans of liquid water were present on Earth; (4) volcanism was more intense because planet's internal heat flux was then nearly 3x higher than today – episodes of large, super-hot komatiite eruptions created dust clouds and huge lightning storms, likes of which no longer occur today; (5) much larger quantities of radioactive elements like Uranium, Thorium, and Potassium and their 'daughter' decay products were present on weathered surfaces, incorporated in crustal minerals, and in water-soluble compounds and; (6) ~2.5 BYA marked first availability of significant amounts of free Oxygen in biosphere produced by oxygenic photosynthesis in Cyanobacteria
- Lacking photosynthesis, most microbes were obligately chemoautotrophic and/or electrolithoautotrophic, obtaining chemical and/or electrical energy required for their existence from oxidation of electron donor molecules or natural electrodes that were present and accessible in local environments

Radioactive elements much more abundant in early Archaean

Living organisms encountered higher levels of ionizing radiation vs. today

"Evolution of Earth's radiogenic heat"



https://commons.wikimedia.org/wiki/File:Evolution_of_Earth%27s_radiogenic_heat.svg

Radiation resistance probably evolved early in Archaean eon

Strong selective pressures for adaptation to high-radiation environments

- **Early Earth near dawn of life was very radiation-rich environment. Island surfaces were raked by X-ray/ultraviolet (XUV) radiation emitted by young Sun and volcanic lightning discharges during eruptions. Weathered surface soils and crust held much higher concentrations of radioactive elements that emit ionizing radiation comprised of energetic gamma-ray photons and charged alpha (α) and beta (β) particles that heat nearby environment and break chemical bonds by scattering off local materials and/or molecules**

- **Compared to today, young Sun was ~10x more magnetically active and had enormous solar superflares of energetic charged particles, XUV, and gas that compressed Earth's magnetosphere and irradiated its atmosphere and surface. Recent detection of superflare in young star like the early Sun that was *10 billion times more powerful* than any ever observed on the Sun ("The JCMT transient survey: an extraordinary submillimeter flare in the T Tauri binary system JW 566" S. Mairs et al *The Astrophysical Journal* 871 Jan. 23, 2019 https://iopscience.iop.org/article/10.3847/1538-4357/aaf3b1/meta)**

- **Early Archaean island surfaces: very energy-rich but dangerous places with many radiation hazards. Greater abundance of radioactive isotopes in crust also meant never total escape from some radiation, even deep underground. Consequently, there were very strong selective pressures for life to develop multiple types of mechanisms that enabled resistance to ionizing radiation**

Volcanic islands were only land above water in early Archaean

Ultrahot Komatiite eruptions accompanied by enormous volcanic lightning

"Exposed areas above sea level on Earth >3.5 Gyr ago: implications for prebiotic and biotic chemistry" J. Bada & J. Korenaga *Life* 8 pp. 55 - 64 (2018)

https://www.mdpi.com/2075-1729/8/4/55

Excerpt from Abstract: "On the Earth >3.5 Gyr ago there would have likely been no exposed continental crust above sea level … only land areas that protruded out of the oceans would have been associated with hotspot volcanic islands, such as the Hawaiian island chain today. On these long-lived islands, in association with reduced gas-rich eruptions accompanied by intense volcanic lightning, prebiotic reagents would have been produced that accumulated in warm or cool little ponds and lakes on the volcano flanks. During seasonal wet–dry cycles, molecules with increasing complexity could have been produced. These islands would have thus been the most likely places for chemical evolution and the processes associated with the origin of life. The islands would eventually be eroded away and their chemical evolution products would have been released into the oceans where Darwinian evolution ultimately produced the biochemistry associated with all life on Earth today."

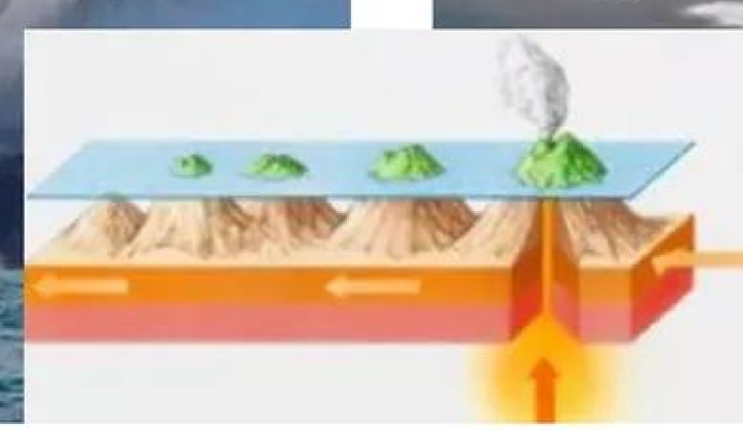
Volcanic islands were only land above water in early Archaean

Before plate tectonics: today's hydrothermal vent systems not yet formed

Hunga Tonga-Hunga Ha'apai is like hotspot islands that dotted early Archaean seas

Large underwater volcano created a new island in the South Pacific named Hunga Tonga-Hunga Ha'apai. This barren, bone-colored island was formed after a submarine volcano in the Kingdom of Tonga erupted in 2014, sending huge amounts steam, ash, and rock 30,000 feet into the air. By time volcanic activity had subsided in January 2015, new island had been created with its tallest peak 120-meters above sea level

Hunga Tonga-Hunga Ha'apai in 2014

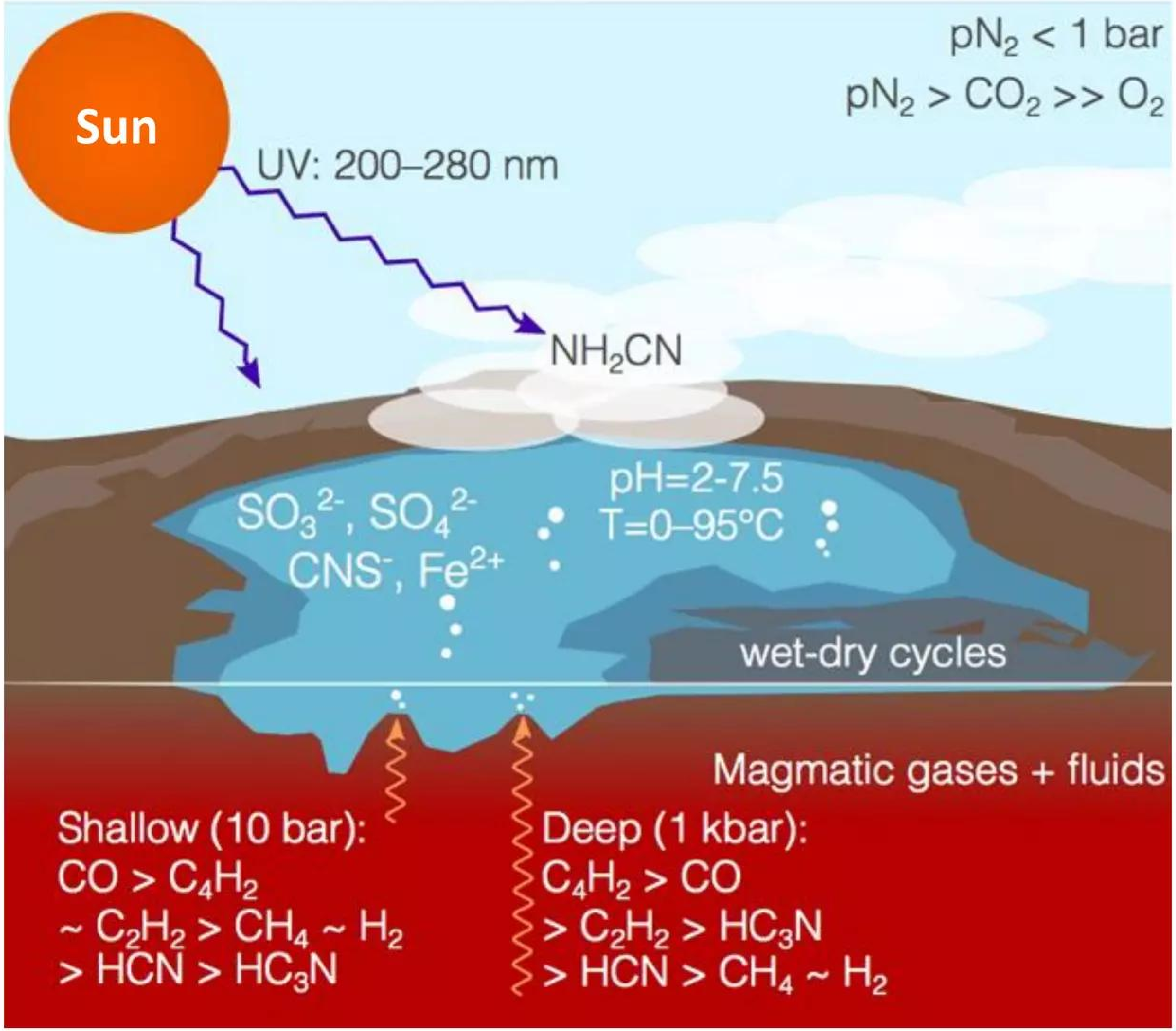


Same volcanic island in February 2015

Archaean islands had surface and undersea hydrothermal vents

Aboveground surfaces exposed to atmosphere also likely had hot springs

Figure 3 from P. Rimmer & O. Shorttle *Life* 9 pp. 12 - 31 (2019)



Archaean islands had surface and undersea hydrothermal vents

Aboveground surfaces exposed to atmosphere also likely had hot springs

"Origin of life's building blocks in Carbon- and Nitrogen-rich surface hydrothermal vents" P. Rimmer & O. Shorttle *Life* 9 pp. 12 - 31 (2019)

https://www.mdpi.com/2075-1729/9/1/12/pdf

Excerpt from Abstract: "There are two dominant and contrasting classes of origin of life scenarios: those predicting that life emerged in submarine hydrothermal systems, where chemical disequilibrium can provide an energy source for nascent life; and those predicting that life emerged within subaerial environments, where UV catalysis of reactions may occur to form the building blocks of life. Here, we describe a prebiotically plausible environment that draws on the strengths of both scenarios: surface hydrothermal vents. We show how key feedstock molecules for prebiotic chemistry can be produced in abundance in shallow and surficial hydrothermal systems. We calculate the chemistry of volcanic gases feeding these vents over a range of pressures and basalt C/N/O contents. If ultra-reducing carbon-rich nitrogen-rich gases interact with subsurface water at a volcanic vent they result in 1 mM to 1 M concentrations of diacetylene, acetylene, cyanoacetylene, hydrogen cyanide, bisulfite, hydrogen sulfide and soluble iron in vent water."

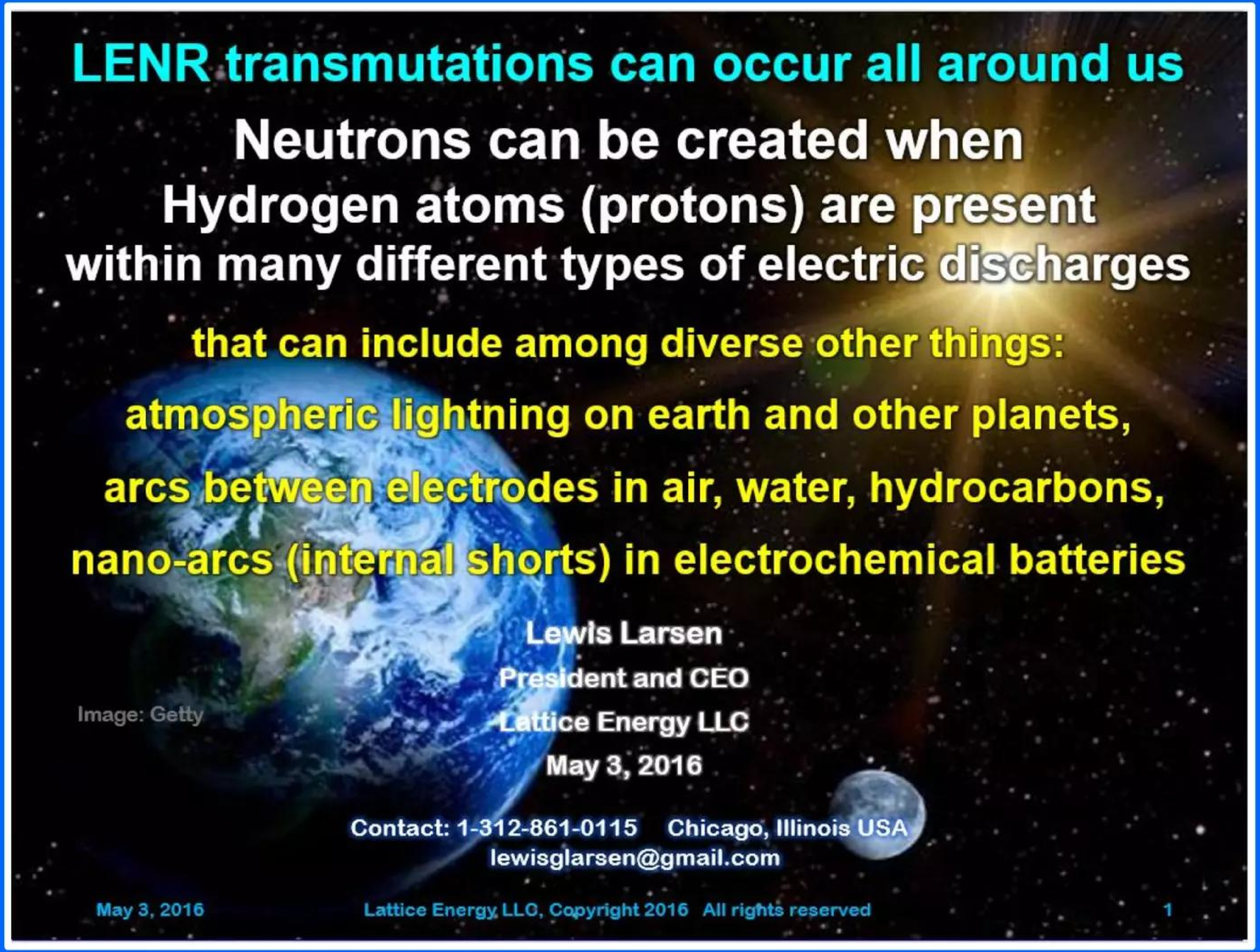
Archaean eruptions: much stronger volcanic lightning vs. today

33% of the lightning discharges impacted on islands' above-water surfaces

Volcanic dust lightning during major eruption in Eyjafjallajökull, Iceland (2010)

Neutron production can occur in natural lightning discharges

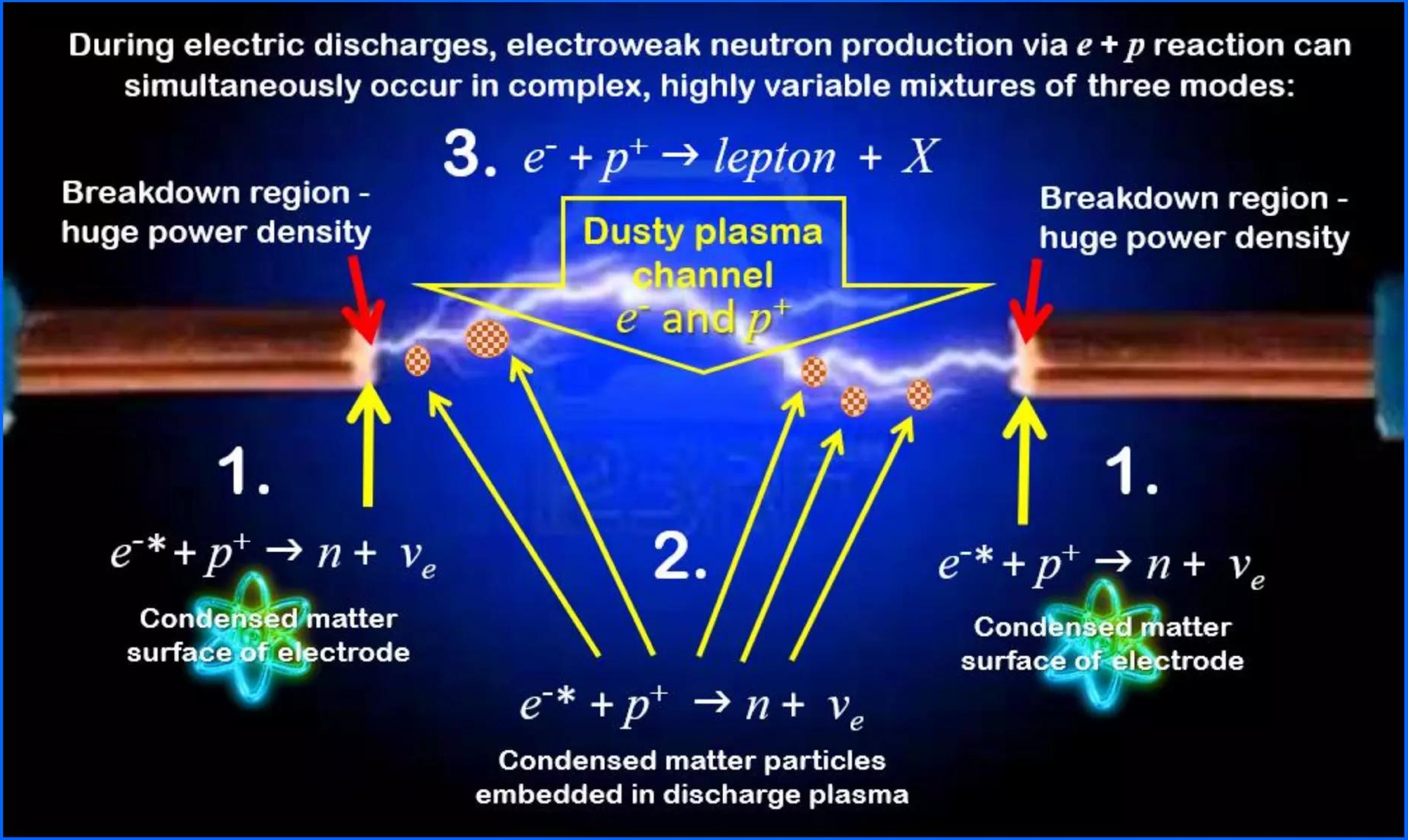
Magnetic analogue of Widom-Larsen theory provides mechanism for $e + p$



http://www.slideshare.net/lewisglarsen/lattice-energy-llc-neutron-production-and-nucleosynthesis-in-electric-discharges-from-lightning-bolts-to-batteries-may-3-2016

Neutron production can occur in during electrical discharges

Widom-Larsen theory posits three modes for *e* + *p* reaction in such arcs



1.3 billion Volt lightning discharge observed by researchers

Atmospheric lightning discharges in Archaean more violent than today

physicsworld

"Billion-volt thunderstorm studied using muons"
Physics World March 26, 2019

atmosphere

https://physicsworld.com/a/billion-volt-thunderstorm-studied-using-muons/

"Measurement of the electrical properties of a thundercloud through muon imaging by the GRAPES-3 experiment"
B. Hariharan et al. *Physical Review Letters* 122 105101 (2019)

https://arxiv.org/pdf/1903.09801.pdf

From *PhysicsWorld:* "Thundercloud with a record-breaking voltage of 1.3 GV has been observed by physicists in India and Japan … [they] Sunil Gupta at the Tata Institute of Fundamental Research in Mumbai and colleagues calculated the voltage from changes in the intensity of atmospheric muons detected by the GRAPES-3 muon telescope … existence of such high voltages could explain the origin of the mysterious, high-energy gamma-ray flashes, which are occasionally seen in cloud tops during thunderstorms … team modelled a thundercloud as a colossal parallel-plate capacitor– with plates representing positively- and negatively-charged cloud layers that are separated by several kilometres. Using this model … they concluded that a voltage of 1.3 GV had developed between cloud layers – confirming [Charles] Wilson's prediction [in 1925].

Lightning strikes change rock surfaces and heat local matter

Discharges create temporary electric ground currents in vicinity of strikes

"Mineralogical and compositional features of rock fulgurites: a record of lightning effects on granite" C. Elmi et al *American Mineralogist* 102 pp. 1470 - 1481 (2017)

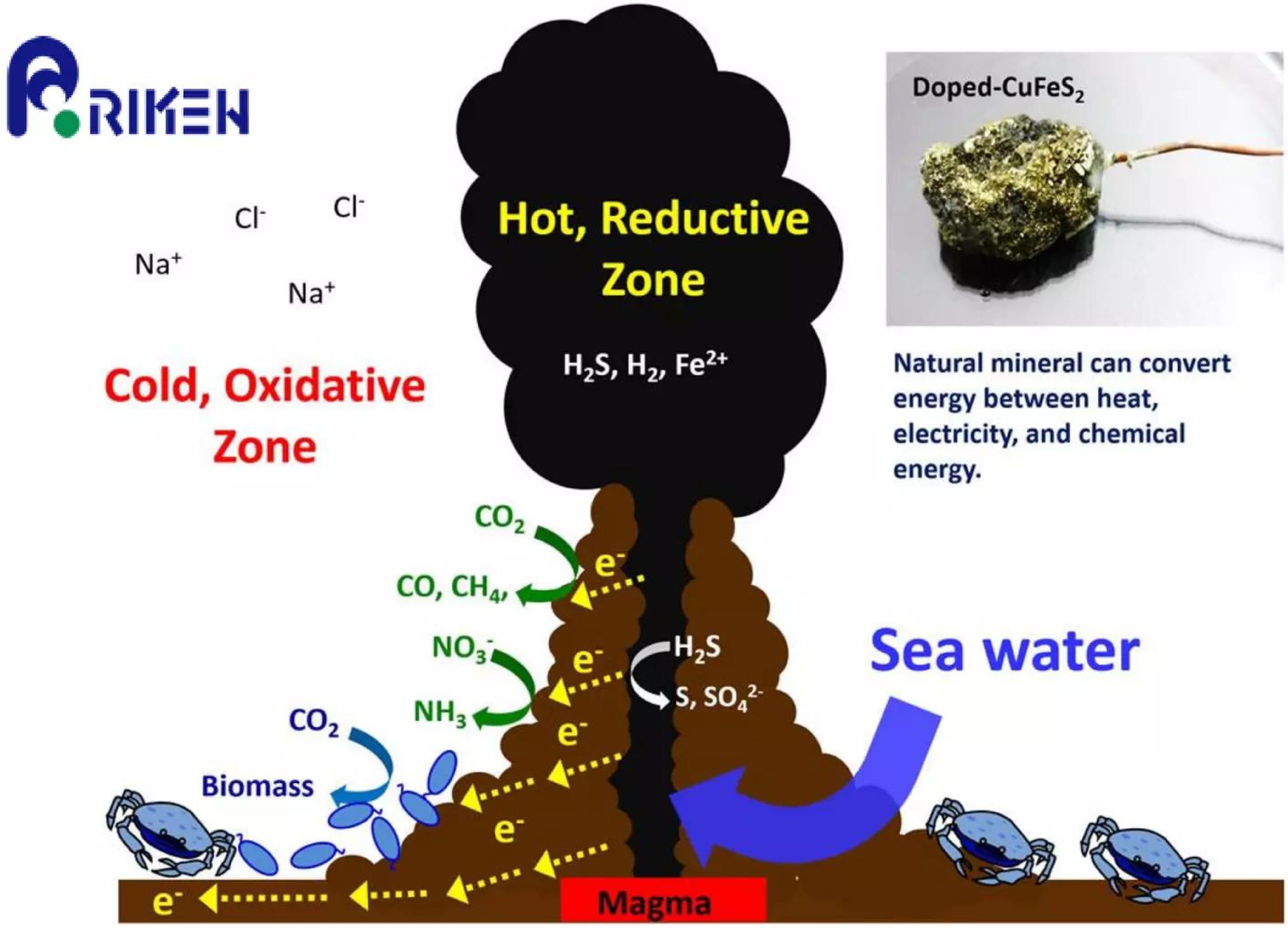
https://www.researchgate.net/publication/318118302_Mineralogical_and_compositional_features_of_rock_fulgurites_A_record_of_lightning_effects_on_granite

- "Fulgurites are a naturally occurring glass formed when sand, rock, or soil is struck by atmospheric electrical discharges (lightning). The aim of this paper is to provide insights into the conditions occurring in rocks during the lightning strike."
- "Powder diffraction data for fulgurite reveal presence of Cristobalite and Quartz crystals in a glass matrix, suggesting … temperature exceeded ~1700 °C at near atmospheric conditions."
- "Idealized physical model reveals that while lightning strike only lasts about 50 ms, high electrical current, up to 10 kA, easily generates enough heat to burn surficial organic matter … model treats lightning as a point source, yielding an electrical field strength in the vicinity of the lightning strike of more than 10^{11} V/m. This value exceeds the breakdown electrical field strength for burnt organic material on surface, and resulting temperature is >10^5 °C … Thickness of rock fulgurite [is ~] 10 μm … rock fulgurite mass formed per strike ranges from a few hundred grams to about 30 kg." [n.b. ~10^{11} V/m = threshold for neutron production]
- "Thus, lightning affects significant portion of rocks exposed at Earth's surface."

Archaean life utilized chemical and electrical energy sources

Surface & underwater hydrothermal vents could provide electric currents

Fig.2 "Chimney: giant electrochemical fuel cell sustained by magmatic activity?"



http://www.csrs.riken.jp/en/interview/nakamura/index.html

Electric currents are present in undersea hydrothermal vents

Microbes can collect electrical energy & utilize it for metabolism & growth

"From chemolithoautotrophs to electrolithoautotrophs: CO_2 fixation by Fe(II)-oxidizing bacteria coupled with direct uptake of electrons from solid electron sources"
T. Ishii et al *Frontiers in Microbiology* 6 pp. 994 - 1003 (2015)
https://www.frontiersin.org/articles/10.3389/fmicb.2015.00994/full

"Electrical current generation across a Black Smoker chimney"
R. Nakamura et al *Angewandte Chemie* International Edition 49 pp. 7692-7694 (2010)
https://onlinelibrary.wiley.com/doi/abs/10.1002/anie.201003311

2015 paper: **"Until recently, all the microbial components at vent systems have been assumed to be fostered by the primary production of chemolithoautotrophs; however, both the laboratory and on-site studies demonstrated electrical current generation at vent systems and have suggested that a portion of microbial Carbon assimilation is stimulated by the direct uptake of electrons from electrically conductive minerals. Here we show that chemolithoautotrophic Fe(II)-oxidizing bacterium, *Acidithiobacillus ferrooxidans*, switches the electron source for Carbon assimilation from diffusible Fe^{2+} ions to an electrode under the condition that electrical current is the only source of energy and electrons … [this] supports our hypothesis (Nakamura et al., 2010; Yamamoto et al., 2013) … [about] the possibility of electrons to be a primary energy source for deep- sea hydrothermal ecosystems."**

Deformation-induced electric currents in Earth's rocky crust

Cartwright-Taylor's thesis results support some aspects of Freund's work

"Deformation-induced electric currents in Marble under simulated crustal conditions: non-extensivity, superstatistical mechanics and implications for earthquake hazard"
Alexis Cartwright-Taylor Ph.D. thesis University College London (409 pages - March 2015)
http://discovery.ucl.ac.uk/1471386/1/AlexisCartwright-Taylor_PhDThesis_Full.pdf

- **"Thesis investigates electric current signals generated spontaneously in specimens of Carrara marble during deformation under crustal conditions … Approach … combines rock deformation experiments and statistical modelling … examine how these electric currents evolve with deformation at laboratory scale and make several original discoveries regarding their behaviour."**
- **"Small (nanoAmpere) electric currents *are* generated and sustained during deformation under all conditions tested. Spontaneous electric current flow in dry samples is seen only in region of permanent deformation and is due to presence of localised electric dipoles. This current flow is correlated to damage induced by microcracking, with a contribution from other intermittent ductile mechanisms. Current and charge densities are consistent with proposed models of crack separation charging and migrating charged edge dislocations … onset of current flow occurs only after 10% reduction in P-wave velocity, implying that some degree of crack damage and/or crack connectivity is required before current will flow through the samples. Electric current evolution exhibits three separate time-scales of behaviour …"**

Deformation-induced electric currents in Earth's rocky crust

Charge from regions of deforming rocks adds to crustal telluric currents

"Deformation-induced electric currents in Marble under simulated crustal conditions: non-extensivity, superstatistical mechanics and implications for earthquake hazard"
Alexis Cartwright-Taylor Ph.D. thesis University College London (409 pages - March 2015)

"My findings support notion that electric currents in crust *can* be generated purely from deformation processes themselves. Scaling up laboratory results to large stressed rock volumes at shallow crustal pressures and constant crustal strain rates, deformation induced transient telluric current systems may be as large as 10^6 A[mperes], even accounting for > 99% dissipation, which corresponds to a huge accumulated net charge of 10^{22} C[oulombs]. This implies that a significant amount of charge from deforming tectonic regions contributes to Earth's telluric currents and electric field, although due to conduction away from stressed rock volume, it is unlikely that accumulated charge of this quantity would ever be measured in the field."

Also: "Superstatistical view of stress-induced electric current fluctuations in rocks"
A. Cartwright-Taylor, F. Vallianatos, and P. Sammonds
Physica A: Statistical Mechanics and its Applications 414 pp. 368 - 377 (2014)

https://www.sciencedirect.com/science/article/pii/S0378437114006487?via%3Dihub

Deformation-induced electric currents in Earth's rocky crust

Freund's contentious *p*-hole idea consistent with some experimental data

https://www.slideshare.net/lewisglarsen/lattice-energy-llc-lenrs-pholes-crustal-nucleosynthesis-seismicity-and-deep-biosphere-dec-22-2014

Hydrogen (protons) is readily available in Earth's rocky crust

Experiments revealed that crushed Andesite yielded 5 liters H_2/m^3 of rock

"Hydrogen in rocks: an energy source for deep microbial communities"
F. Freund et al. *Astrobiology* 2 pp. 83 - 92 (2002)
http://online.liebertpub.com/doi/abs/10.1089/153110702753621367

Excerpting from abstract: "To survive in deep subsurface environments, lithotrophic microbial communities require a sustainable energy source such as hydrogen … A more reliable and potentially more voluminous H_2 source exists in nominally anhydrous minerals of igneous and metamorphic rocks. Our experimental results indicate that H_2 molecules can be derived from small amounts of H_2O dissolved in minerals in the form of hydroxyl, OH, or $O_3Si{-}OH$, whenever such minerals crystallized are in an H_2O-laden environment. … H_2 molecules diffused out of the freshly fractured mineral surfaces. If such a mechanism occurred in natural settings, the entire rock column would become a volume source of H_2. Crushing experiments to facilitate the out-diffusion of H_2 were conducted with common crustal igneous rocks such as granite, andesite, and labradorite. At least 70 nmol of H_2/g diffused out of coarsely crushed andesite, equivalent at standard pressure and temperature to 5,000 cm^3 [5.0 Liters] of H_2/m^3 of rock. In the water-saturated, biologically relevant upper portion of the rock column, the diffusion of H_2 out of the minerals will be buffered by H_2 saturation of the intergranular water film."

Hydrogen (protons) is readily available in Earth's rocky crust

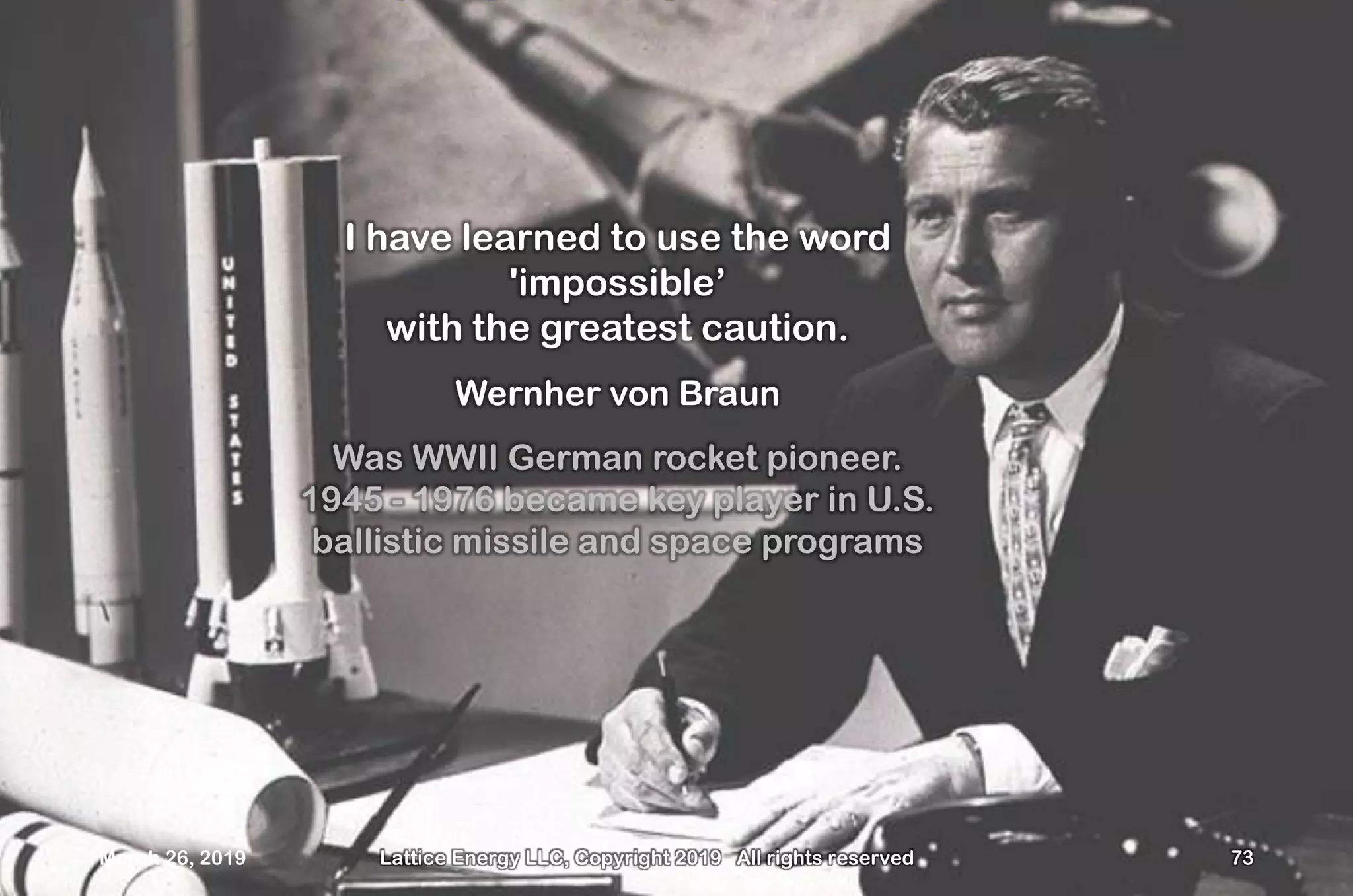
Precambrian rocks previously thought to contain negligible amounts of H_2

"The contribution of the Precambrian continental lithosphere to global H_2 production"
B. Lollar *et al. Nature* 516 pp. 379 - 382 (2014)
http://www.artsci.utoronto.ca/main/media-releases/a-w/nature.pdf

Quoting from paper: "Ancient saline fracture waters in Precambrian continental subsurface, with groundwater residence times ranging from millions to billions of years, provide a previously underestimated source of H_2 for the terrestrial deep biosphere. Until now, little of the information on H_2 in these settings, accessed via underground research laboratories and mines, has been incorporated into global geochemical and biogeochemical models ... Sites in Precambrian terrains globally have H_2 concentrations as high as those reported for Witwatersrand basin and for marine hydrothermal systems ... Drawing on this global data set, we provide, for the first time, estimates of global H_2 production for the Precambrian continental lithosphere that consider H_2 production from both radiolysis and hydration reactions ... Although total thickness of continental crust is between 30 km and 50 km, we based our estimate on a depth of 5 km ... estimated depth of the habitable zone ... we ... estimate of 0.78 - 1.8 $x10^{11}$ mol/yr H_2 from mafic/ultramafic Precambrian crust ... These findings all support major conclusion of this paper that H_2 production from Precambrian continental lithosphere, hitherto assumed to be negligible, is in fact an important source of H_2 production."

Many think nuclear transmutation by microbes is impossible

Widom-Larsen theory's rigorous physics provides plausible mechanism



I have learned to use the word 'impossible' with the greatest caution.

Wernher von Braun

Was WWII German rocket pioneer. 1945 - 1976 became key player in U.S. ballistic missile and space programs

Microbes evolved to utilize broad range of energy sources:

Chemical and/or electromagnetic (photons and electrical currents) energy

- Early in Archaean period, evolving microorganisms first became adept at utilizing chemical and electrical energy present in energy-rich volcanic island surface or near-surface habitats. Anoxygenic photosynthesis very likely developed sometime thereafter but well-before onset of widespread Oxygenic photosynthesis at 2.3 - 2.5 BYA
- It was long-known that various types of electrical (telluric) currents occur in Earth's rocky crust. Thanks to recent work of Freund and Cartwright-Taylor, it appears that deformation of Earth's crust may also create substantial amounts of telluric currents. Much of this electrical energy could be accessible to microbes living deep in rocks
- Relatively recently, microbiologists discovered various species of microbes that can survive on electricity as a sole energy source. Moreover, such "electric bacteria" appear to be ubiquitous in that researchers are finding them in increasing numbers of environments
- Since Hydrogen (protons) and electrical currents (electrons) are readily available to microbes living anywhere in and around the Earth, do plausible scenarios exist where it might be energetically workable and advantageous survival-wise for bacteria to utilize transmutation?

Are energetics of LENR transmutation workable for bacteria?

Transmutation very costly vs. chemical but maybe advantageous for metals

Energetic cost to produce 1 ULE neutron by reacting proton with an electron:

~ 0.78 MeV = 1.20 x 10^{-13} Joules

Energy released by hydrolysis of 1 molecule of ATP (Adenosine triphosphate):

~ 1.0 x 10^{-19} Joules

Number of ATP molecules that release equivalent total energy of 0.78 MeV:

~ 1.2 x 10^{6} ATP molecules or ~ 1.2 million ATPs per ULE neutron

In rapid growth a 1 μm^3 volume bacterium uses energy equivalent of (BioNumbers.org):

10^{10} to 10^{11} ATP molecules per hour (assumed division time = 1 hr.)

% of total energy use to create 1 neutron/hr. = ~1.2 x 10^{-4} - 1.2 x 10^{-5} or ~ .012 - .0012% / hr.

Discussion: ~18 ATPs needed for bacterium to fix Carbon from CO_2. LENRs would need one neutron to transmute stable Boron into stable Carbon (^{11}B + 1 n → ^{12}B; half-life = 20 μsec) which then β^- decays into stable ^{12}C (nat. abundance = 98.9%). LENR transmutation to obtain usable Carbon is clearly way too energetically expensive for bacteria; chemical Carbon fixation is vastly less costly. However, production of very low-abundance catalytic active site metals via transmutation could be a different situation. If bacterium's environment were 100% deficient in Fe but had abundant Mn, it could transmute Mn to Fe (^{55}Mn + 1 n → ^{56}Mn; half-life = 2.6 hrs) which β^- decays to ^{56}Fe (nat. abund.= 91.8%). Using LENRs to produce 100,000 vitally needed Fe atoms would cost 1-2% of total bacterial energy use: maybe advantageous trade-off?

http://book.bionumbers.org/what-is-the-power-consumption-of-a-cell/

Indira Gandhi Centre for Atomic Research (IGCAR India 2011)

Conducted experiments to evaluate earlier claims made by Vysotskii et al.

"IGCAR was established in the year 1971, under the Department of Atomic Energy, Government of India. The Centre is engaged in broad based multidisciplinary programme of scientific research and advanced engineering directed towards the development of Fast Breeder Reactor technology. Fast Breeder Test Reactor based on unique mixed Plutonium Uranium Carbide fuel, first of its kind in the world and KAMINI Reactor, the only operating Reactor in the World using U^{233} fuel are successfully operated. The design of 500 MWe Prototype Fast Breeder Reactor is completed and the construction is in progress."

http://www.igcar.gov.in/

Indira Gandhi Centre for Atomic Research (IGCAR India 2011)

Conducted experiments to evaluate earlier claims made by Vysotskii et al.

Microbial Catalyst Transmutation of stable isotope (Mn^{55} to Fe^{57}) by biogranules

Microbial Corrosion Programme,
Corrosion Science and Technology Division,
Indira Gandhi Centre for Atomic Research, Kalpakkam
rani@igcar.gov.in

IGCAR experiments used mixed laboratory bacterial cultures

Bacillus, *Pseudomonas*, and *Micrococcus* (different from Vysotskii et al.)

Development of biogranules

- Aerobic biogranules grown with laboratory strains (*Bacillus* sp., *Pseudomonas* sp., *Micrococcus* sp., *Flavobacterium* sp.) in 1 litre of synthetic waste water containing the following nutrients (mg):
- NH_4Cl 500, KH_2PO_4 250, K_2HPO_4 250, $MgSO_4.7H_2O$ 320, $FeCl_3$ 30, $NiSO_4$ 32, $CaCl_2$ 50, $Na_2BO_7.H_2O$ 5, $(NH_4)6Mo_7O_{24}.H_2O$ 14, $ZnCl_2$ 6, $CoCl_2.6H_2O$ 5, $CuCl_2.2H_2O$ 4, $MnCl_2.\ 4H_2O$ 5.
- Acetate / Glucose as carbon sources in separate flasks (750 mg/L). [Liu and Tay, 2002; Yang et al., 2004a]

28-Feb-11 3

Dr. Rani George et al. conducted experiments at IGCAR-India

Temp and duration: “All media flasks were incubated at 35^{o} C for 20 days”

Transmutation studies with granules

- MCT media were prepared with and without $MnSO_4$ in distilled water and 3 weeks old biogranules were inoculated in the sterile medium. Biogranules were also inoculated in sterile distilled water and uninoculated media were kept as control. All media flasks were incubated at 35°C for 20 days.
- After incubation, cultured media were filtered through 0.2 µm membrane and the filtrate was analyzed with ICP MS.

28-Feb-11 10

Experimental results R. George et al. reported at conference

ICP-MS showed Fe was only present at trace ppb in uninoculated medium

Transmutation studies with granules

- MCT medium was prepared with the chemicals dissolved in distilled water (Milli-Q) and ICP MS analysis was done for the presence of Fe.
- The analysis showed only traces of Fe (ppb level) in the uninoculated medium.

28-Feb-11 9

Experimental results R. George et al. reported at conference

Fe ~ absent in controls but ICP-MS showed significant Fe^{56} in Biogranules

Transmutation studies with granules

- Fe was not present in the controls (biogranules in water and uninoculated control media).
- ICP MS spectral peaks confirmed the presence of Fe^{56} in Biogranules inoculated Mn medium.

28-Feb-11 11

IGCAR data is consistent with Vysotskii et al.'s earlier results

If data correct could conclude LENR transmutation of Mn → Fe occurred

- IGCAR biotransmutation experiments were conducted under watchful eye of Centre's Director. Results appeared to confirm earlier claims about bacterial transmutation of Manganese (Mn) into Iron (Fe) published by Vysotskii et al
- In IGCAR experiments with mixed bacteria, significant amounts of Iron (Fe) were readily detected after 20 days of incubation. Anomaly: Fe was only present at barely detectable ppb trace levels when experiments first began at t_0. If (1) ICP-MS measurements were correct, and (2) there was no external contamination of growth media or analyzed filtrate with Fe, then one must explain how observed amounts of Fe were produced. In that case, and utilizing Widom-Larsen theory of LENRs in biological systems, one could conclude neutron-catalyzed transmutation of Mn → Fe had likely occurred
- IGCAR researchers unable to publish their results in first-tier journal. Editors and referees appear reluctant to facilitate publication of such data, even absent any obvious errors in experimental techniques or measurements
- While these IGCAR experiments are not definitive and were not published in a refereed journal, their data are consistent with earlier results of Vysotskii et al. and can be explained by LENR transmutation per Widom-Larsen theory

Certain bacteria can assimilate Uranium; Plutonium; Cesium

Recent experiments indicated possible biotransmutation of Cesium-137

- **Certain bacteria are known to assimilate heavy elements such as Uranium, Plutonium, Cesium, and Lead, among others. It is not clear why they have such a capability, when it may have been first developed, or exactly what they are doing chemically with these usually toxic elements. Surprisingly, some of these and other heavy or unusual elements have turned-up in ICP-MS metalloprotein assays**

- **Recent (K-J. Yum et al. 2019) experimental results with laboratory cultures of mixed bacteria indicate possible transmutation of radioactive Cesium (^{137}Cs). Transmutation is inferred from data reported by Korean government-supported researchers at conference; it shows apparent anomaly in nuclear β^- decay rate of ^{137}Cs. What they observed over time-duration of experiments was much larger decrease in concentration of ^{137}Cs in flasks (as indicated by measurements of ^{137}Cs 662 keV gamma emission) than could possibly be explained by known decay rate of that isotope. LENR transmutation of ^{137}Cs can explain these results**

- **In peer-reviewed paper (*Japanese Journal of Applied Physics* 2002), Mitsubishi Heavy Industries (MHI) has reported *abiotic* transmutation of stable Cesium (Cs) into stable Praseodymium (Pr) via permeation of pure D_2 gas through specially fabricated Pd/PdO thin-film heterostructures; confirmed by Toyota (*JJAP* 2013)**

- **Widom-Larsen theory of LENRs specifies possible Cesium-137 transmutation pathways in bacteria; these possibilities are outlined in three slides that follow**

Certain bacteria assimilate Cesium; why are they doing this?

Main Cesium isotopes found in the environment are shown in Table at left

Main Cesium isotopes found in Nature

Isotope			Decay	
	abun-dance	half-life ($t_{1/2}$)	mode	pro-duct
^{133}Cs	100%	stable		
^{134}Cs	trace	2.0648 y	ε	^{134}Xe
			β^-	^{134}Ba
^{135}Cs	trace	2.3×10^6 y	β^-	^{135}Ba
^{137}Cs	trace	30.17 y[1]	β^-	^{137}Ba

Source: Wikipedia

"Cesium has 40 known isotopes ... atomic masses of these isotopes range from 112 to 151. Only one isotope, ^{133}Cs, is stable ... longest-lived radioisotopes are ^{135}Cs with a half-life of 2.3 million years, ^{137}Cs with half-life of 30.1671 years and ^{134}Cs with half-life of 2.0652 years. All other isotopes have half-lives < 2 weeks, most under an hour."

Elements ordered by increasing atomic number

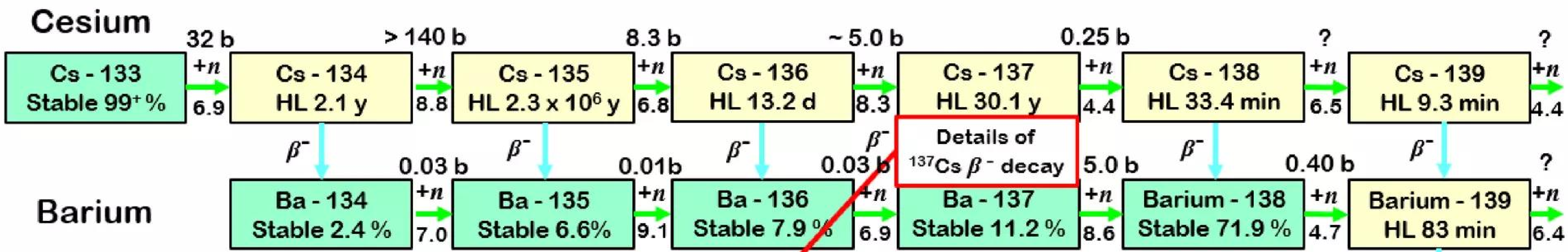
55	56	57	58	59
Cs	Ba	La	Ce	Pr
Cesium	Barium	Lanthanum	Cerium	Praseodymium

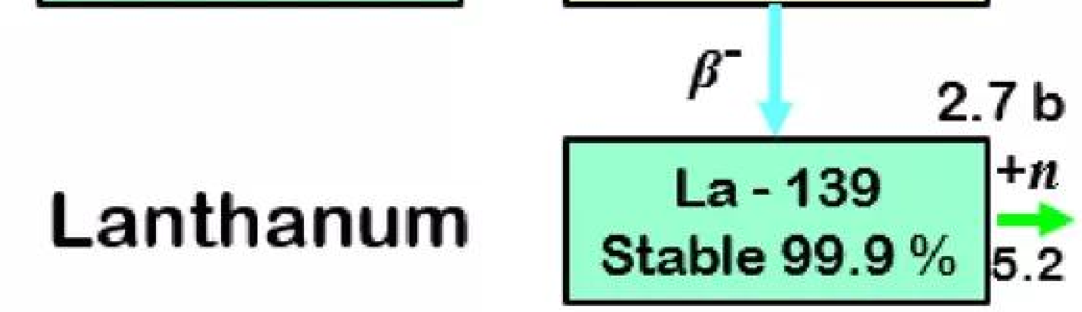
- **Neutron capture:** creates heavier, more neutron-rich isotopes of same chemical element; they may be stable or unstable
- **Beta-decay:** common decay for unstable neutron-rich isotopes of elements. It transmutes one element into a heavier element with higher (+1) atomic number
- **LENRs:** ULE neutron-catalyzed nuclear transmutation processes will commonly proceed from left-to-right along rows of the Periodic Table of chemical elements
- **Per Widom-Larsen theory:** LENRs create complex, branching networks of stable and unstable transmutation products

Bacterial transmutation of Cesium could use these pathways

Neutron-catalyzed LENR transmutation network starting with Cesium-133

Possible transmutation pathways according to Widom-Larsen theory of LENRs

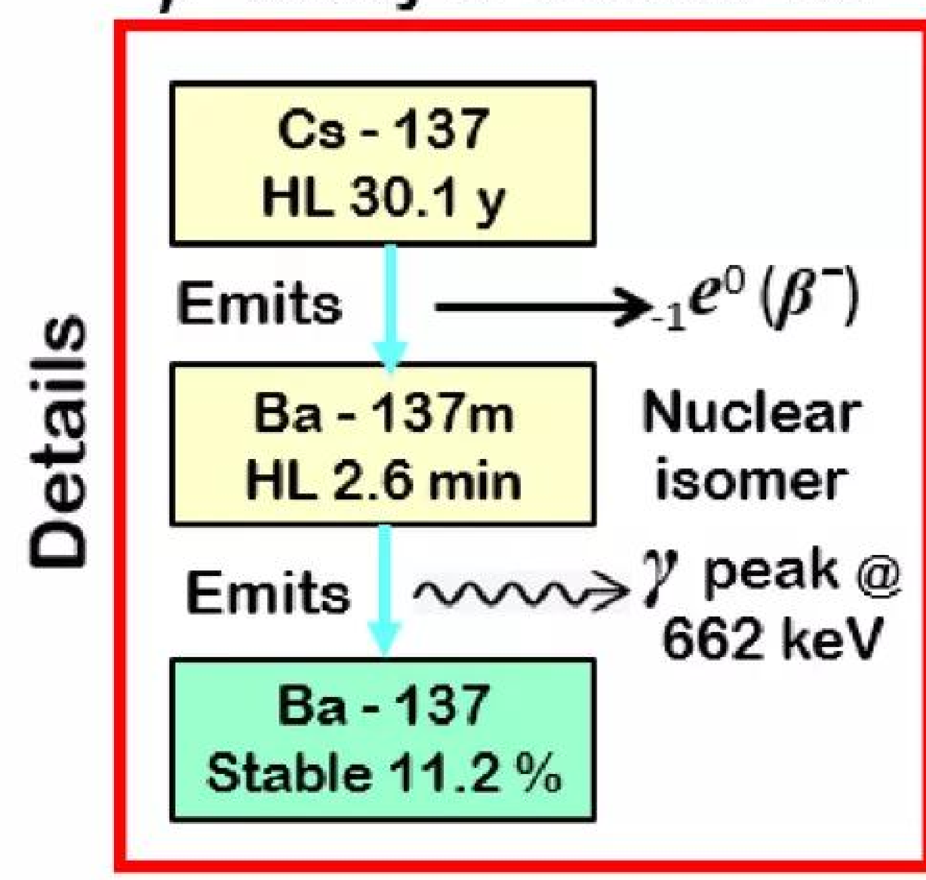




Latest capture data

Cesium Isotope	Thermal neutron capture cross section (barns)
Cs-133	32.0 b
Cs-134	> 140.0 b
Cs-135	8.3 b
Cs-136	~5.0 b
Cs-137	0.25 b

β^- decay of Cesium-137



Legend:

Stable isotopes are indicated with green boxes; natural abundance is listed in %

Unstable isotopes are indicated with yellow boxes; half-life is listed down below

ULE neutron captures (green arrows) go from left-to-right; Q-value (MeV) is number below green arrow and thermal neutron capture cross-section (b = barns) above it

Beta decays β^- (light blue arrows) point downward; isotope's decay energy (MeV unless otherwise noted) is to right of arrow

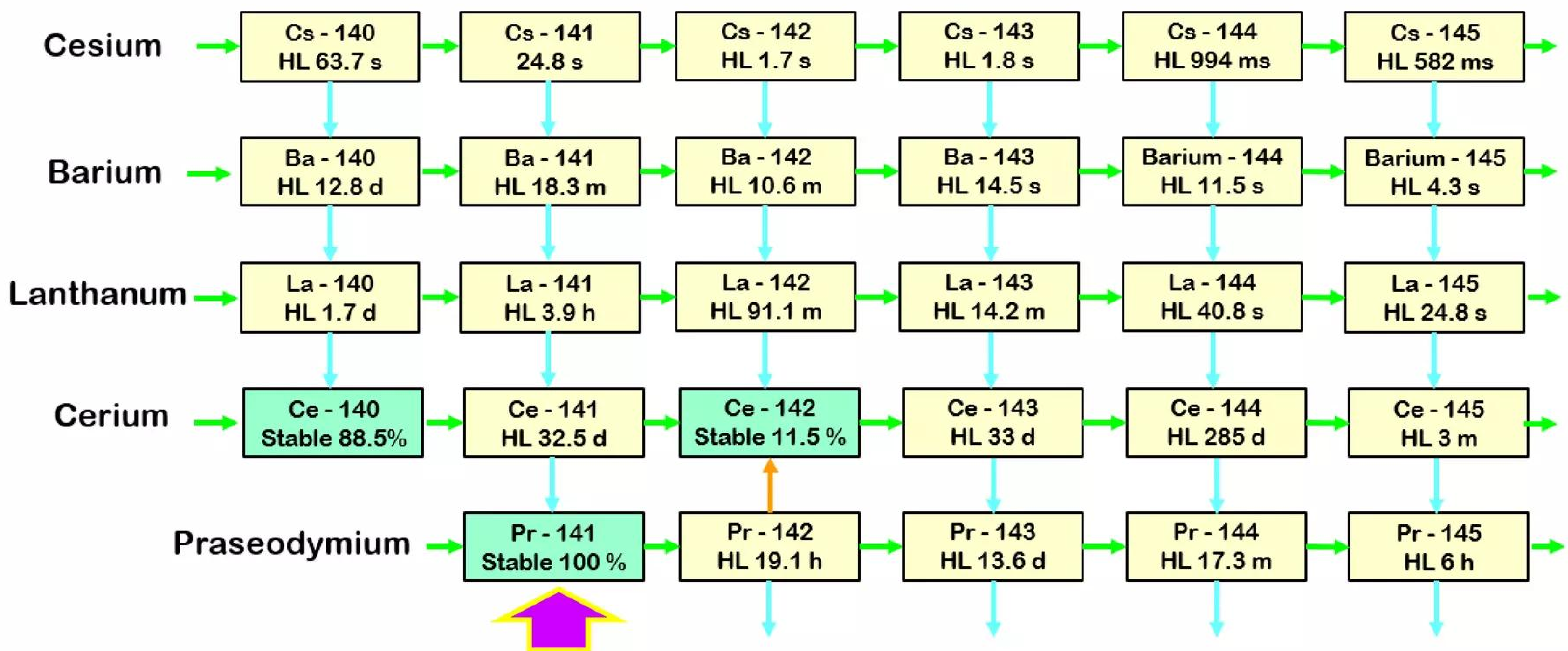
Electron capture (ε) is upward orange arrow

Energetic gammas not shown because from ~ 0.5 - 1.0 MeV up through ~ 10.0 - 11.0 MeV (boundaries vary depending on details) all gammas get converted directly into benign infrared photons (heat) by unreacted heavy-mass SP electrons per Widom-Larsen theory

Bacterial transmutation of Cesium could use these pathways

Neutron-catalyzed LENR transmutation network starting with Cesium-133

Possible transmutation pathways according to Widom-Larsen theory of LENRs



Key paper published by MHI researchers in *Japanese Journal of Applied Physics* (2002)

Abiotic LENRs 2002

MITSUBISHI HEAVY INDUSTRIES, LTD.
Our Technologies, Your Tomorrow

$$ {}^{133}_{55}Cs \rightarrow {}^{141}_{59}Pr $$

Implanted Cesium
↓
Praseodymium

https://www.lenr-canr.org/acrobat/IwamuraYelementalaa.pdf

Bacteria altered $^{238}U/^{235}U$ isotopic ratio in lab experiments

Explained their results with chemical fractionation; what if it was LENRs?

"Experimentally determined Uranium isotope fractionation during reduction of hexavalent U by bacteria and zero valent Iron"

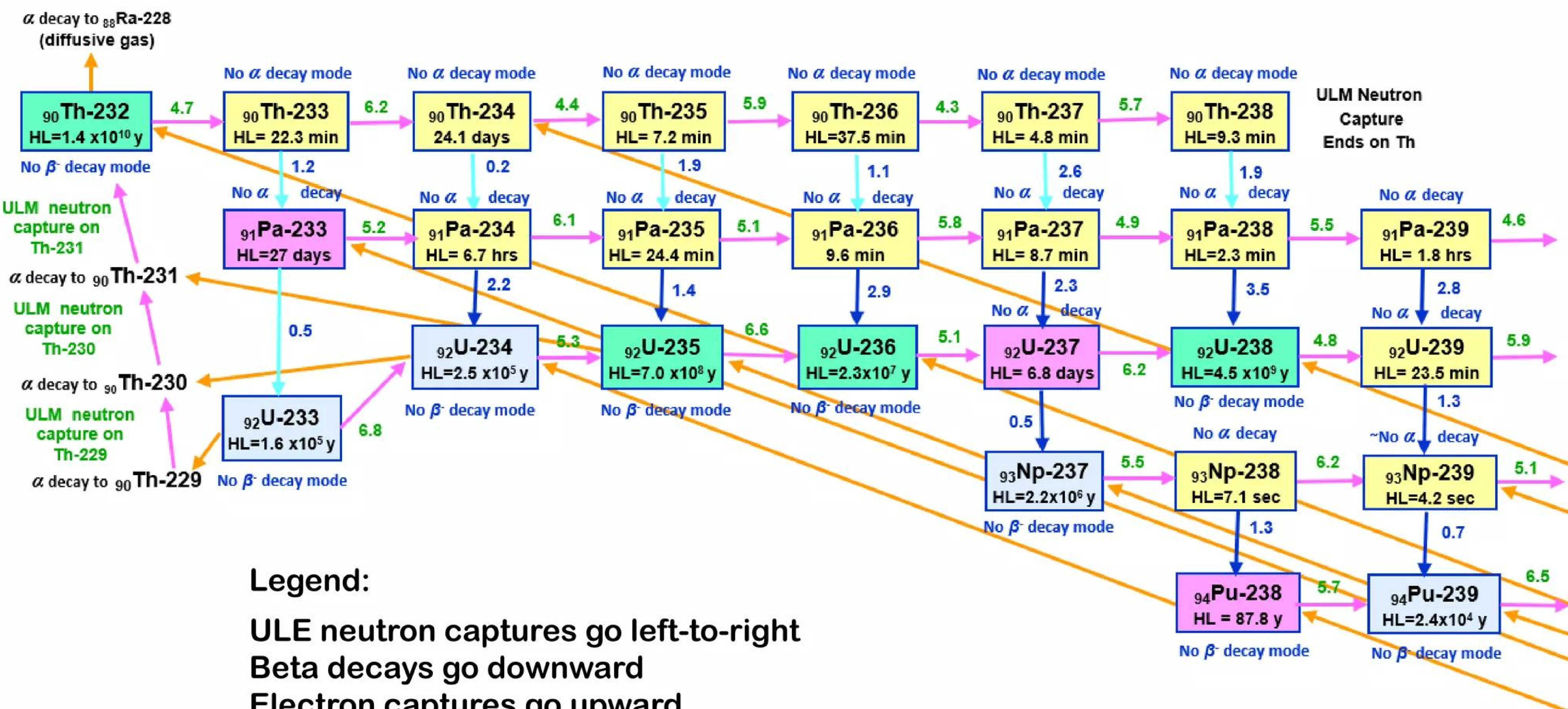
L. Rademacher et al. *Environmental Science & Technology* 40 pp. 6943 - 6948 (2006)

https://pubs.acs.org/doi/abs/10.1021/es0604360

- **Interestingly, LENR ULE neutron capture on Uranium isotopes present in Rademacher et al's bacterial cultures would have produced similar qualitative results with regard to causing increases in the $^{238}U/^{235}U$ ratio**
- **Upon exposure to ULE neutrons, Uranium-235 could have either undergone fission and/or radiatively captured ULE neutrons and then been transmuted into heavier unstable Uranium isotopes that decay into heavier transuranic elements. Observationally, water soluble Uranium-VI would 'disappear' from aqueous media. In any case, since neutron capture cross-section of ^{238}U is much smaller than ^{235}U, isotopically lighter ^{235}U will react with ULE neutrons at much higher rate than with ^{238}U, which will increase the $^{238}U/^{235}U$ ratio. Increases in $^{238}U/^{235}U$ occur in fuel cycle of ^{235}U fission reactors and were also observed in rock samples collected from 2 billion year-old, natural fission reactor discovered in an Okla, Gabon mine in 1972**

Bacterial transmutation of Uranium could use these pathways

Neutron-catalyzed LENR transmutation network starting with Thorium-232

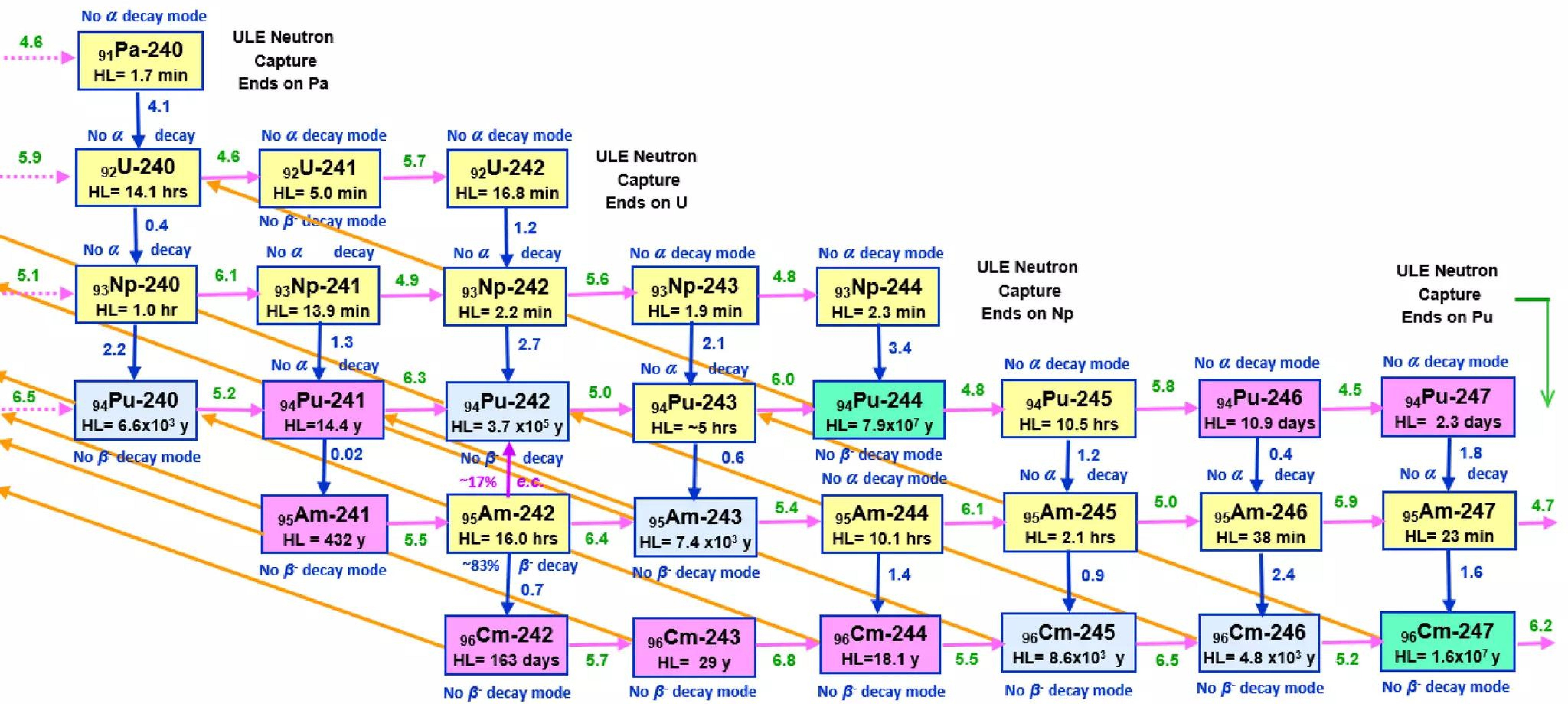


Legend:

ULE neutron captures go left-to-right
Beta decays go downward
Electron captures go upward
Alpha decays go right-to-left at ~45° angle

Bacterial transmutation of Uranium could use these pathways

Half-lives tend to decrease for progressively heavier transuranic elements



Abiotic Uranium catalyst discovered by Falcone et al. (2017)

Microbial Uranium: did Archaean bacteria once use it as active site metal?

"Nitrogen reduction and functionalization by a multimetallic Uranium nitride complex"

M. Falcone et. al. *Nature* 547 pp. 332 - 335 (20 July 2017)

https://www.nature.com/nature/journal/v547/n7663/full/nature23279.html

Complex 1 breaks N_2 bond; Complex 2 reacts with H_2 and/or H^+ to make NH_3

Complex 1 - nitrido —— 1 atm N_2 @ room temp ——→ **Complex 2 - hydrazido**

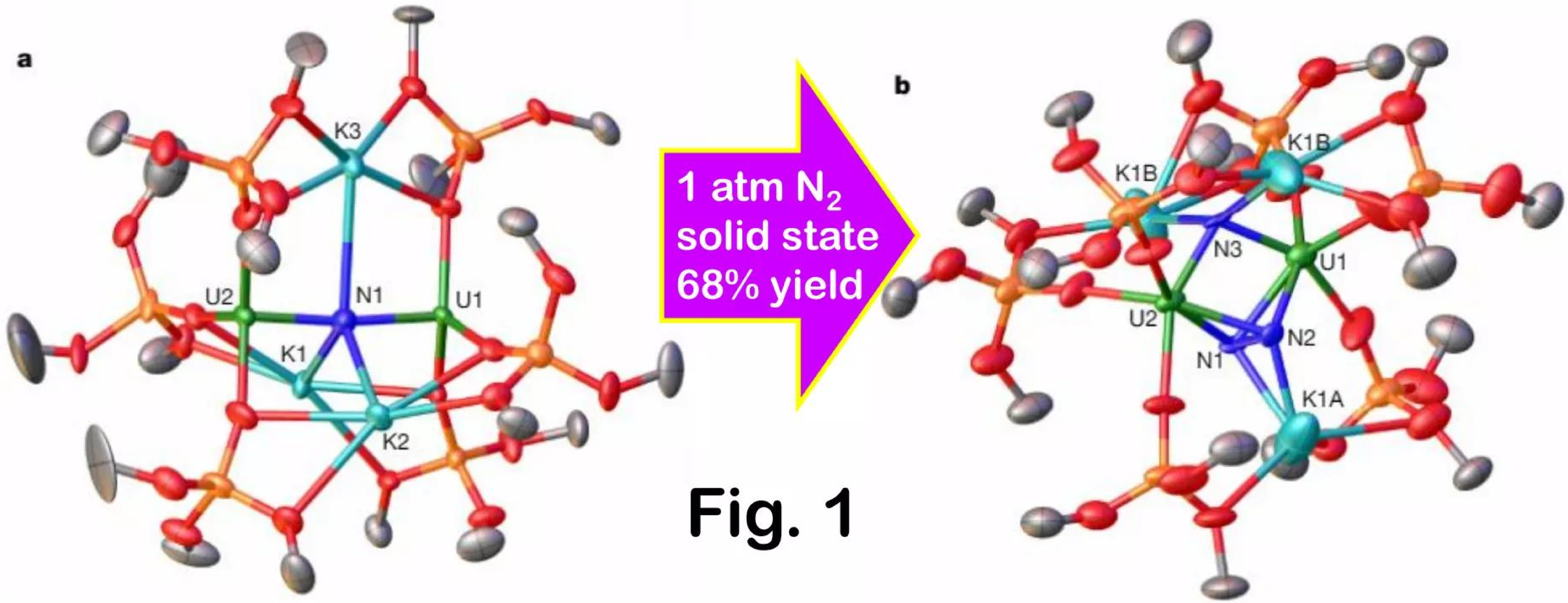


Fig. 1

Microbes have had long association with radioactive Uranium

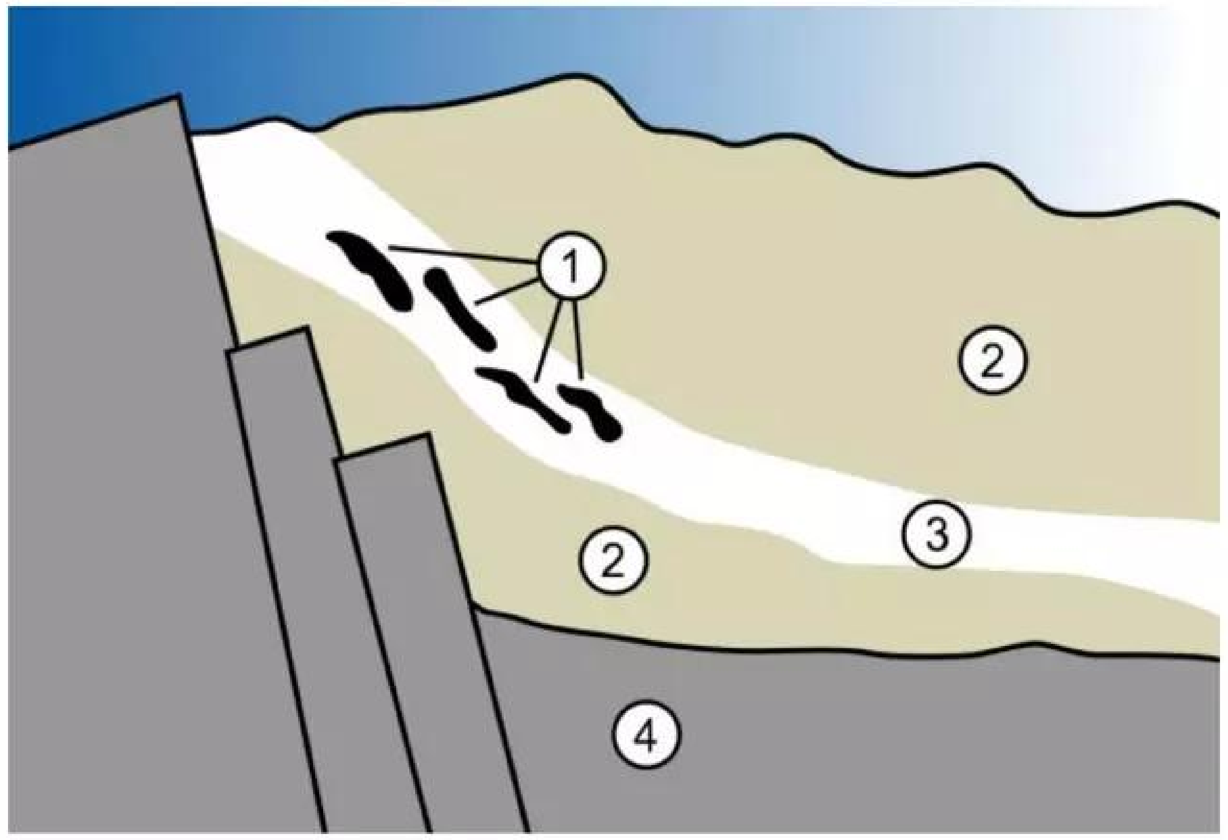
Multibillion year-old connection is mysterious and raises many questions

"Biogenic non-crystalline $U^{(IV)}$ revealed as major component in Uranium ore deposits" A. Bhattacharyya et al. *Nature Communications* 8 article 15538 (2017)

https://www.nature.com/articles/ncomms15538

"Here we show that non-crystalline $U^{(IV)}$ generated through biologically mediated $U^{(VI)}$ reduction is the predominant $U^{(IV)}$ species in an undisturbed U roll-front ore deposit in Wyoming, USA. Characterization of U species revealed that the majority (~58 - 89%) of U is bound as $U^{(IV)}$ to C-containing organic functional groups or inorganic carbonate, while Uraninite and $U^{(VI)}$ represent only minor components."

Roll-front geology of natural fission reactors found in Oklo, Gabon, Uranium deposit:



1. Nuclear reactor zones
2. Sandstone
3. Uranium ore layer
4. Granite

U-pond one of world's most radiologically contaminated sites

Anomaly: found 4x more ^{238}U than AEC records say was dumped in pond

"Ecological behavior of Plutonium and Americium in a freshwater ecosystem. Phase II. Implications of differences in transuranic isotopic ratios"
R. Emery & T. Garland Report: BNWL-1879 UC-48 (December 1974)
https://www.osti.gov/biblio/4218018

Per AEC records, 1400 kg of Uranium-238, 8.1 kg of weapons-grade Plutonium isotopes, plus unknown amounts of Americium and Thorium were discharged into U-pond. See 2nd paragraph on page 10. When Emery & Garland sampled site and analyzed their data, they found 4 times *more* ^{238}U than what had been dumped there. They remarked that "we have no explanation for this difference."

What were bacteria doing in the U-pond? Did they transmute Thorium into Uranium?

"The Atomic Pond: A radioactive wastewater collection site at Hanford comes to life"
Melvin R. Adams *Columbia* 24 (2010)
http://www.washingtonhistory.org/files/library/24-3_Adams.pdf

"During the operation of U–pond about 8.1 kg of Plutonium was released to the trenches leading to the pond. The bomb that destroyed Nagasaki in Japan during World War II was made with Plutonium from Hanford and contained 6.1 kg of Plutonium."

Summary

- Credible experimental data suggests some microbes can transmute certain elements via LENRs. However, much more experimentation will be required to decisively demonstrate that microorganisms can truly transmute chemical elements at will and determine which species of microbes have such capabilities. LENRs may not be all that uncommon out in Nature; if so, there will be major implications for geochemistry, isotope geology, and nuclear waste remediation
- LENRs can mimic isotopic effects of mass-dependent and mass-independent chemical fractionation. Elements and isotopes conserve their mass-balances in purely chemical systems; that is not necessarily true if LENRs are also occurring in same systems. Accurate measurement of total mass balances for all chemical species may be needed to discriminate between chemical and nuclear processes
- ULE neutron-catalyzed transmutation is not energetically practical for more-abundant chemical elements found in living systems such as Carbon. However, transmutation could potentially be an energetically feasible and advantageous capability that could enable some fortunate microbes to produce life-critical, low-abundance catalytic active site metals that are unavailable in local environments
- Japanese government-funded project with Mitsubishi Heavy Industries, Toyota, Nissan, and four universities is developing abiotic LENRs for power generation. Recently reported outstanding heat production results at working temperatures and pressures far lower than those found in many undersea hydrothermal vents

Key publications about Widom-Larsen theory of LENRs

"Ultra low momentum neutron catalyzed nuclear reactions on metallic hydride surfaces"
A. Widom and L. Larsen (author's copy)
European Physical Journal C - Particles and Fields 46 pp. 107 - 112 (2006)
http://www.slideshare.net/lewisglarsen/widom-and-larsen-ulm-neutron-catalyzed-lenrs-on-metallic-hydride-surfacesepjc-march-2006

"A primer for electro-weak induced low energy nuclear reactions"
Y. Srivastava, A. Widom, and L. Larsen (author's copy)
Pramana - Journal of Physics 75 pp. 617 - 637 (March 2010)
http://www.slideshare.net/lewisglarsen/srivastava-widom-and-larsenprimer-for-electroweak-induced-low-energy-nuclear-reactionspramana-oct-2010

"Theoretical Standard Model rates of proton to neutron conversions near metallic hydride surfaces"
A. Widom and L. Larsen
Cornell physics preprint arXiv:nucl-th/0608059v2 12 pages (2007)
http://arxiv.org/pdf/nucl-th/0608059v2.pdf

"Hacking the Atom" (Volume 1 - 484 pages) popular science book
Steven B. Krivit, Pacific Oaks Press, San Rafael, CA, September 11, 2016
Paperback US$16.00; hardcover US$48.00; Kindle US$3.99
https://www.amazon.com/dp/0996886451

Working with Lattice Energy LLC, Chicago, Illinois USA

Partnering on LENR commercialization and consulting on other subjects

1-312-861-0115   lewisglarsen@gmail.com

L. Larsen c.v.: http://www.slideshare.net/lewisglarsen/lewis-g-larsen-cv-june-2013

- We believe Lattice is the world-leader in proprietary knowledge about LENR device engineering required to develop high-performance, long lived, scalable power sources. Our published peer-reviewed theoretical papers rigorously explain the breakthrough device physics of LENR processes, including the absence of dangerous energetic neutron or gamma radiation and lack of long-lived radioactive waste production
- Lattice welcomes inquiries from large, established organizations that have an interest in discussing the possibility of becoming Lattice's strategic capital and/or technology development partner
- Lewis Larsen also independently engages in consulting on variety of subject areas that include: biological transmutation; Lithium-ion battery safety issues; long-term electricity grid reliability and resilience; and evaluating potential future impact of LENRs from long-term investment risk management perspective for certain types of large CAPEX projects

