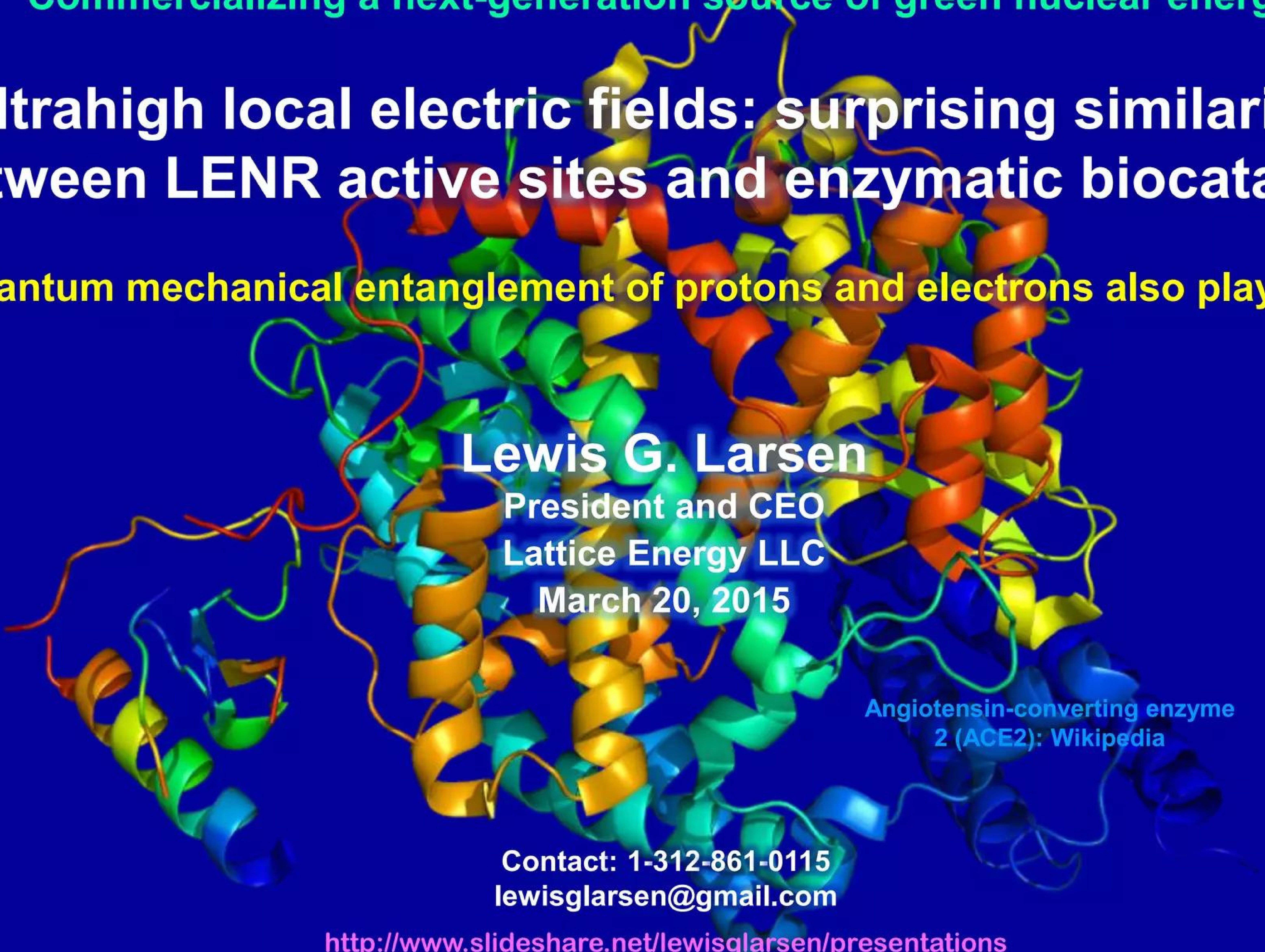
Lattice Energy LLC

Commercializing a next-generation source of green nuclear energy

Ultrahigh local electric fields: surprising similarities between LENR active sites and enzymatic biocatalysis

Quantum mechanical entanglement of protons and electrons also play roles



Angiotensin-converting enzyme 2 (ACE2): Wikipedia

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March 20, 2015

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http://www.slideshare.net/lewisglarsen/presentations

LENRs and enzymatic catalysis are similar in key ways

- ✓ Similar to what happens in stars, LENRs are neutron-induced nuclear transmutation reactions that produce heavier stable elements from neutron captures on lighter ones. Unlike stars and fission reactors, LENRs do not emit any deadly MeV radiation; they occur in laboratory devices as well as at low rates in Nature elsewhere on Earth

- ✓ In LENRs, star-like nucleosynthesis of elements occurs under mild macroscopic conditions; e.g. at as little as room temperature and atmospheric pressure. This enzyme-like feat is possible with electroweak catalysis that creates ultralow-energy neutrons via many-body collective quantum effects in a direct reaction: $e + p \rightarrow n + \nu_e$

- ✓ Peer reviewed Widom-Larsen theory of ultralow energy neutron reactions (LENRs) in condensed matter systems enables a clear understanding and provides detailed conceptual descriptions of *nm*- to *μ*-scale LENR active sites that form on surfaces, at certain types of interfaces, on hydrogenated Carbon aromatic rings, and even on graphene under particular sets of physical conditions specified in detail by theory

- ✓ W-L theory posits: mutual quantum-mechanical (Q-M) entanglement of many-body collections of charged particles (protons and electrons) and nuclear-strength local electric fields are crucial to operation of LENRs in condensed matter. Herein we will discuss how high electric fields and mesoscopic Q-M entanglement are also quite important in the operation of biological enzymes and that there are very surprising similarities between how LENR-active sites operate and enzymatic biocatalysis

Characteristics of LENR and chemical catalytic active sites

Parameter	Characteristics of catalytically active sites that greatly increase reaction rates		
Energy scale	Nuclear - keV up to multiple MeVs	Chemical - up to several eVs or thereabouts	
Type of system	Electroweak catalysis in condensed matter	Biological enzyme	Metallic industrial
Are extremely high local electric fields important?	Yes, it is crucial to electroweak catalysis of LENRs in condensed matter at ~STP	Yes, see Fried *et al*. *Science* (2014)	Sometimes
Are many-body collective effects important?	Yes, it is crucial to electroweak catalysis of LENRs in condensed matter at ~STP	Yes, see Herschlag *et al*., *Biochem*. (2013)	Sometimes
Is quantum mechanical entanglement of protons (Hydrogen) important?	Yes, adsorbed H in surface active sites and H on aromatic rings that rest on surfaces, including metals, fullerenes, graphene	Yes, see Wang *et al*. *PNAS* (2014)	Yes, H adsorbed on surfaces or at interfaces
Quantum mechanical entanglement of electrons?	Yes, amongst surface plasmons and π electrons found on aromatic rings	Yes, π electrons on Carbon aromatic rings	Yes, with surface plasmons
Any deadly MeV-energy gamma emissions?	None: heavy-mass electrons convert γ to safe infrared per US Patent #7,893,414 B2	None	None
Any deadly MeV-energy neutron emissions?	None: almost all are captured locally; see Widom & Larsen, *EPJC* (2006)	None	None
Extreme specificity for reactants and products?	Yes, $e + p$ or $e + d$ or $e + t$ → [1, 2, or 3] $n + \nu_e$ (neutron, neutrino)	Yes, extremely	Somewhat; can vary greatly
Is catalytically active site conserved and reusable?	No, exists for ~200 to 400 nanoseconds and then Q-M coherence thermally destroyed	Yes, essentially unchanged and viable	Mostly, for a while
Are species of chemical elements conserved in catalytic process?	No, relative isotopic ratios of stable elements can shift; species and quantities of chemical elements present can change	Yes, all species of chemical elements are fully conserved, i.e. do not change; when measurable, isotopic shifts should always mass-balance	

Contents

Key characteristics of catalysts for chemical reactions

Primarily increase reaction rates and reduce operating temperatures

Certain metallic elements, zeolites and biomolecular enzymes can be catalysts

- ✓ Enable a given chemical reaction to proceed at a substantially higher rate at a given temperature than if it were not being catalyzed
- ✓ Equivalently, enable high rates of a given chemical reaction to occur at substantially lower temperatures than would be the case if such a catalyst were absent from the system
- ✓ High specificity - catalytic activity is usually restricted to only certain species of reactants and end-products; reduces number of potential side-products and side-reactions for a given accelerated chemical reaction
- ✓ Certain metals, zeolites, and myriad of complex Carbon-based organic molecules called enzyme proteins can function as chemical catalysts
- ✓ Living organisms use enzymes to mediate and speed-up their many metabolic chemical processes and molecular biosynthetic reactions
- ✓ Many types of industrial chemical processes use abiotic metallic catalysts

Increasing temperature speeds-up chemical reactions

Chemical catalysts boost reaction rates by lowering activation energy

Many-body collective quantum effects can catalyze electroweak nuclear reactions

- ✓ As a very rough rule-of-thumb, for chemical reactions that would ordinarily occur at significant rates at room temperature of ~23° C, the observed reaction rate will approximately double (2x) for every additional ~10° C increase in temperature
- ✓ Raising temperatures will speed-up most chemical reaction rates by increasing numbers of input reactant molecules whose average kinetic energy is greater than the minimum activation energy that is needed to drive a given reaction to completion (found in the high-energy 'tail' of the Maxwell-Boltzmann distribution)
- ✓ Inorganic metallic elements that include among others, Nickel (Ni), Platinum (Pt), Palladium (Pd), can greatly boost rates of some chemical reactions and function as catalysts by substantially lowering the activation energy for certain reactions
- ✓ In course of evolution, living organisms gradually 'learned' how to greatly increase rates of chemical reactions and encoded that information within the collective genome in sequences that specify specialized macromolecules called enzymes; this key advance enabled biological systems to flourish at modest temperatures
- ✓ Akin to enzymes, herein we will see how Nature can utilize many-body collective quantum effects in condensed matter to vastly increase rates of an important type of electroweak neutron-producing reaction that enables variety of star-like nuclear transmutation processes to proceed at substantial rates at modest temperatures

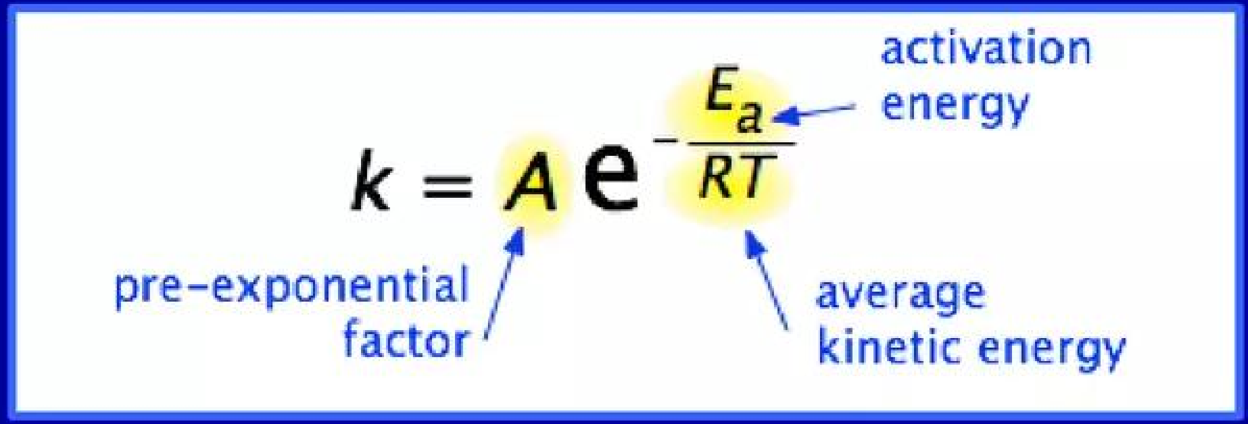
Enzymes and metals can catalyze chemical reactions

Enable huge increases in rates at lesser temperatures and pressures

Enzyme catalysis allows human metabolism to operate at 98º instead of 400º F

Arrhenius equation for reaction rate constant (*k*)

Enzymes reduce reactions’ activation energy



$$k = A e^{-\frac{E_a}{RT}}$$

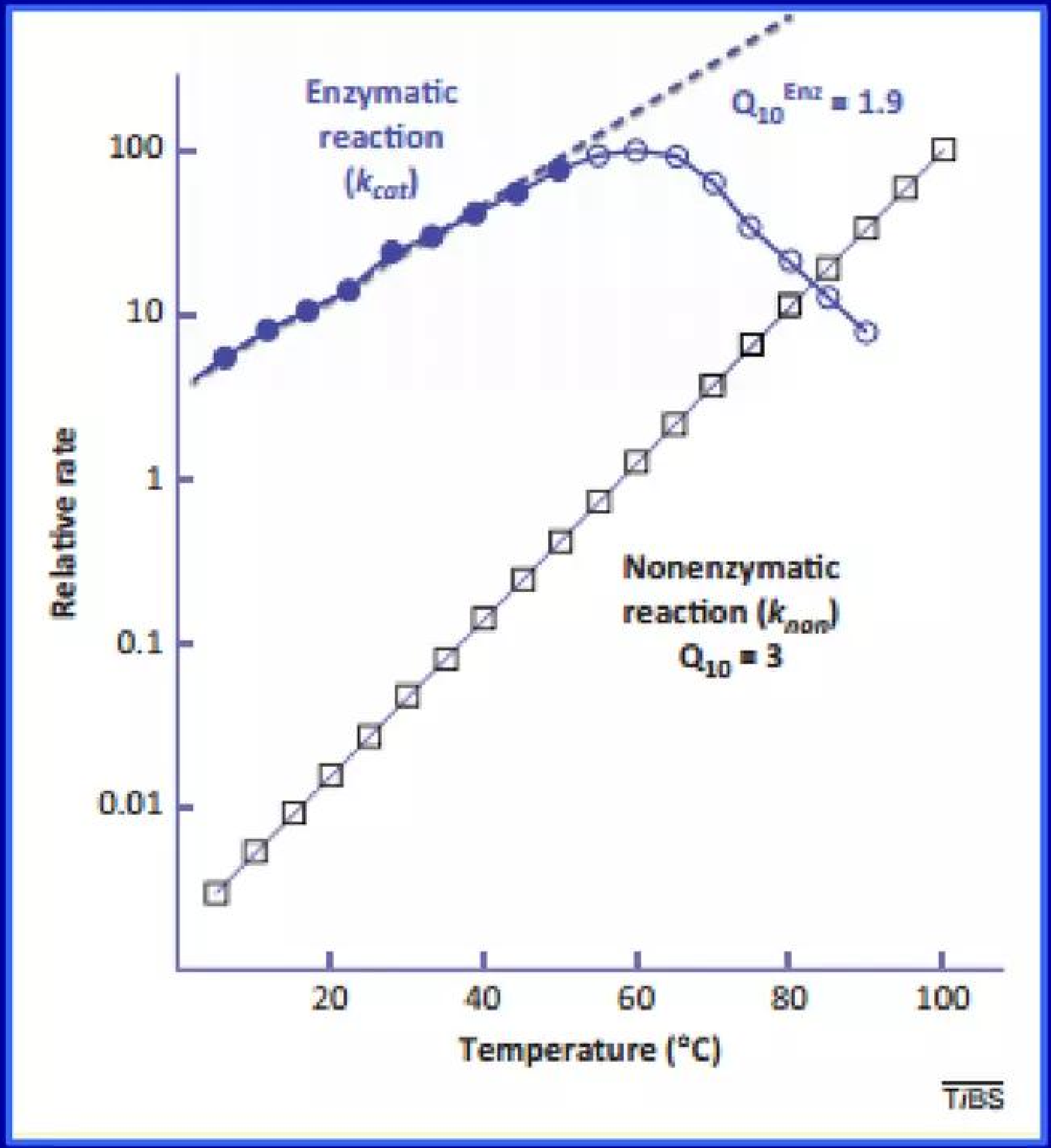
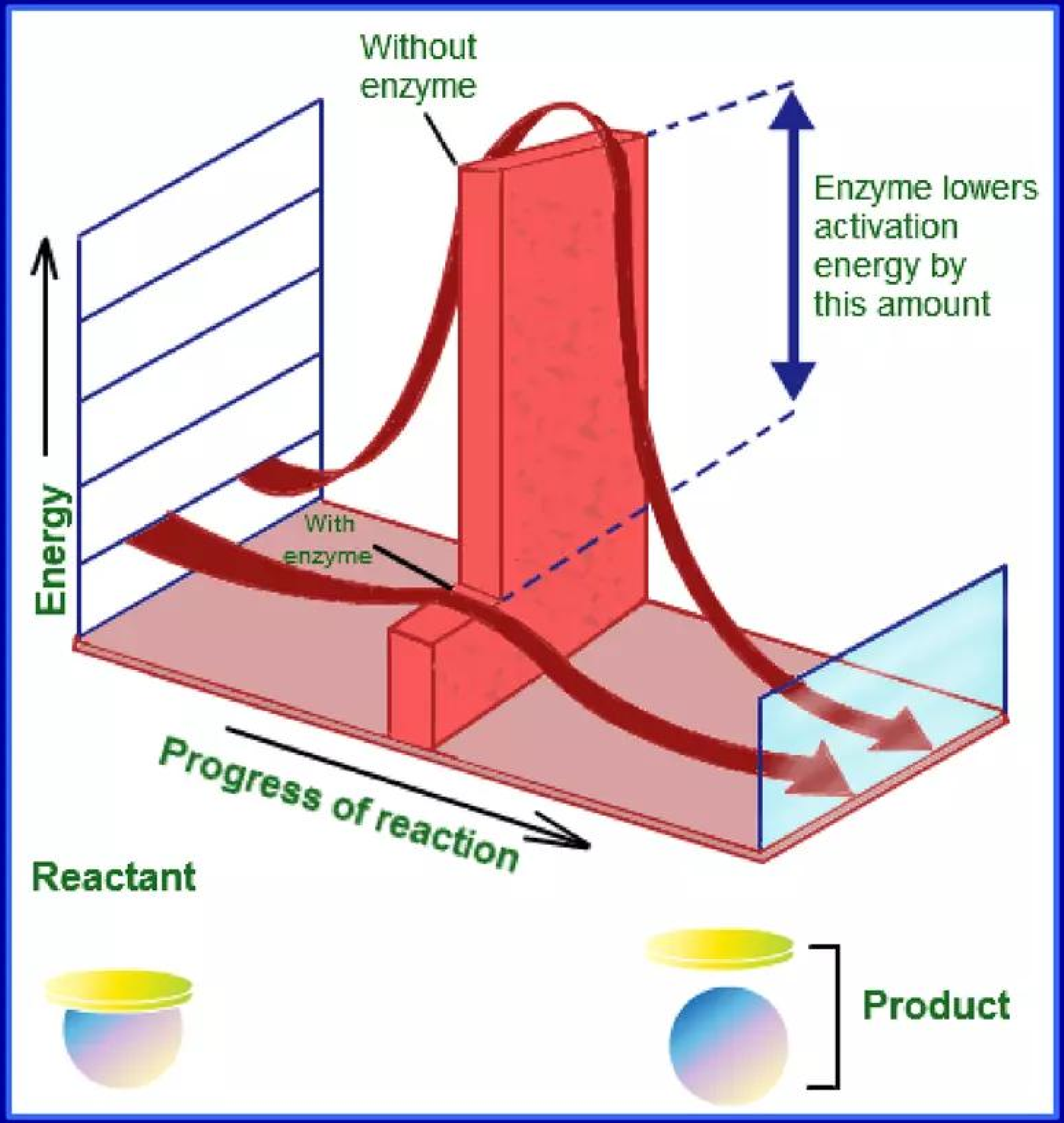


Fig. 1 in Elias *et al*. (2014) http://www.weizmann.ac.il/Biological_Chemistry/scientist/Tawfik/papers/%28115%29Elias_TiBS_%202014.pdf

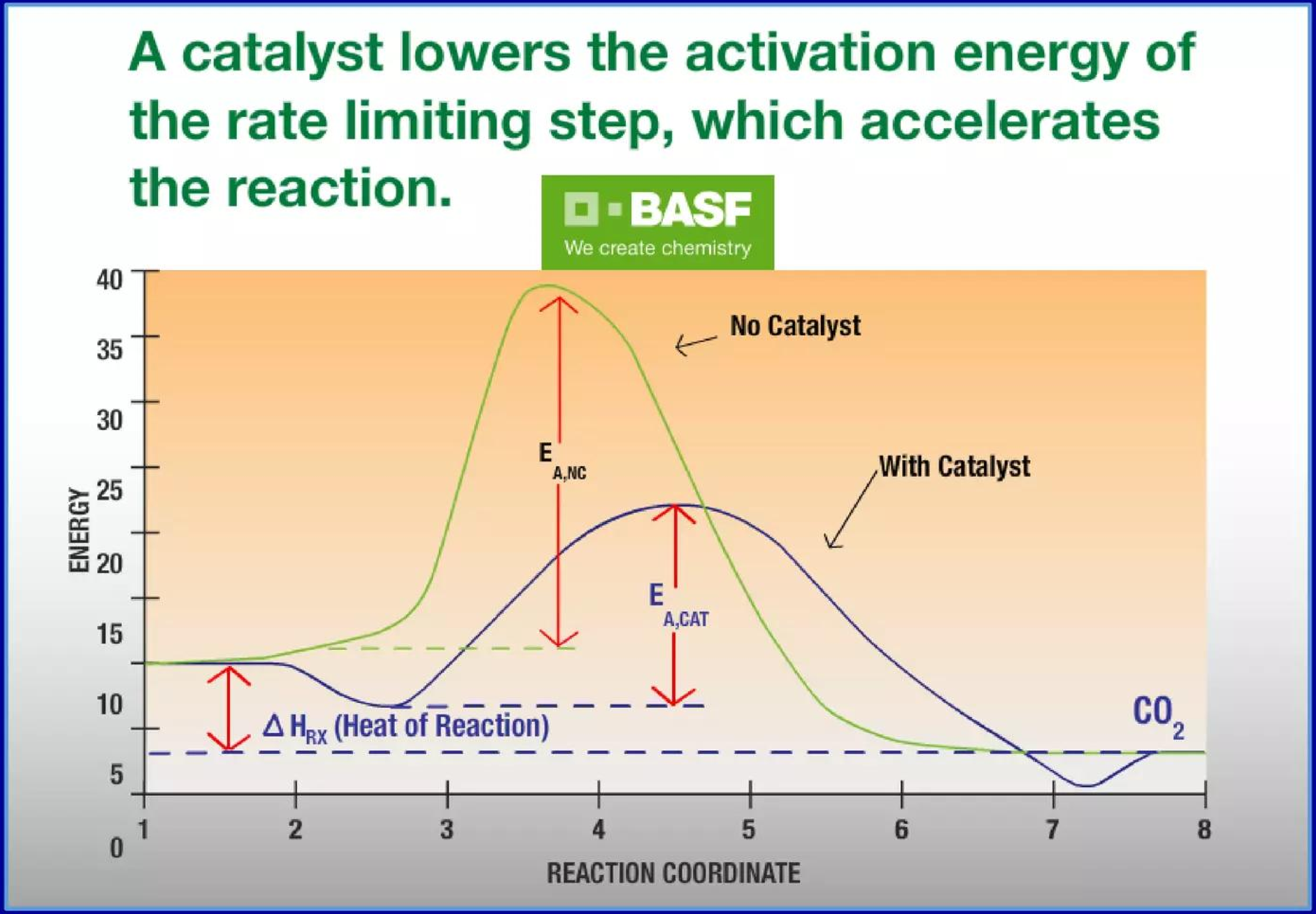


http://www.biologyquizon.com/2014/08/quiz-on-enzyme-kinetics.html

Enzymes and metals can catalyze chemical reactions

Enable vast increases in rates at lesser temperatures and pressures

Catalysts reduce amount of input energy required to drive reaction to completion



A catalyst lowers the activation energy of the rate limiting step, which accelerates the reaction.

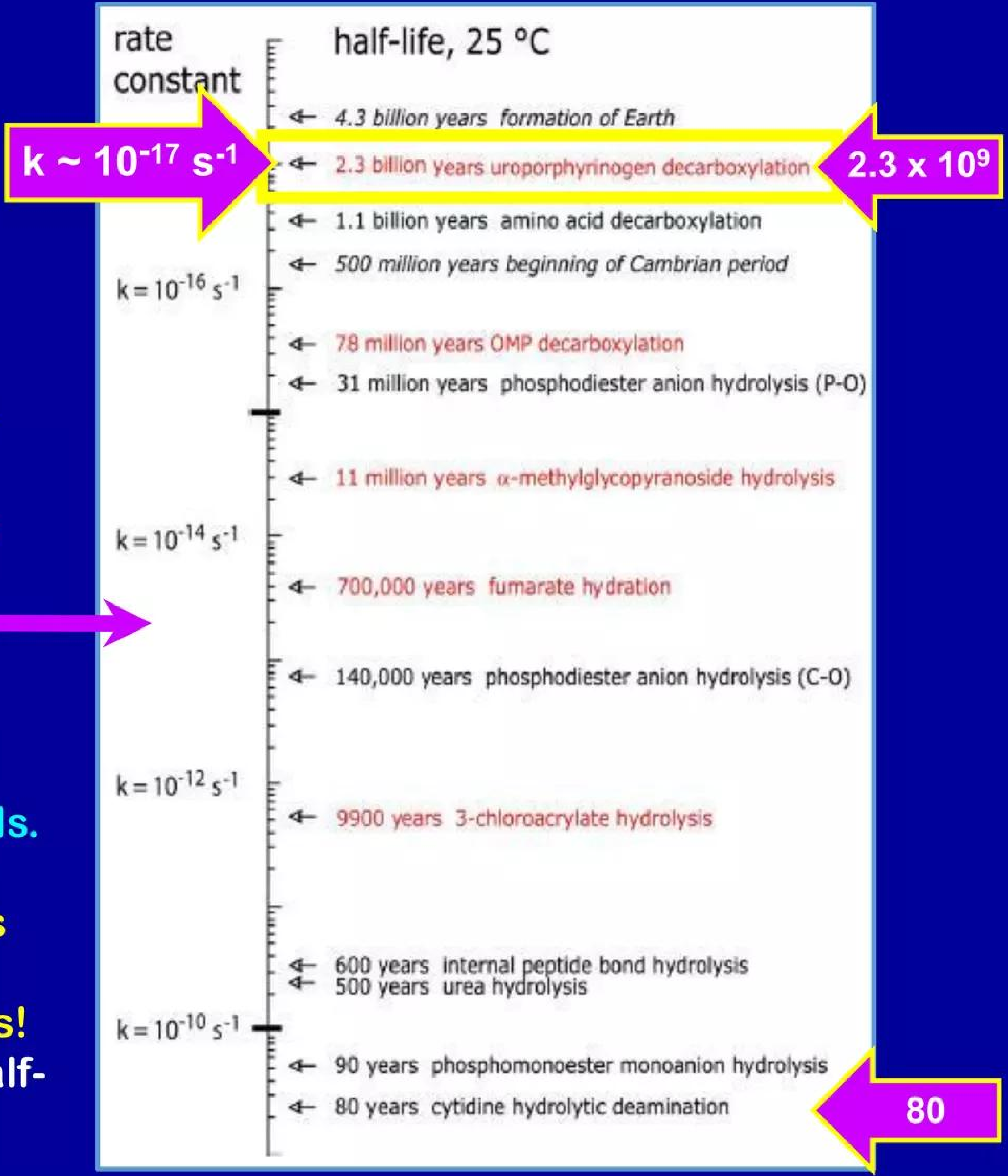
Credit: BASF

Enzymes increase rate constants of spontaneous reactions

A hypothetical reaction: A + B → C + D will proceed spontaneously with a finite rate constant if its Gibbs free energy ΔG is < 0

For selected biochemical reactions, chart to right shows how long (in years) it would require for 50% of the initial reactant(s) to *spontaneously* turn into products without *any* enzymatic catalysis, i.e. their "half-life" @ 25º C based on rate constants; this value ranges from 80 up to 2.3 billion years

"Lewis and Wolfenden (2008) studied a reaction catalyzed by uroporphyrinogen decarboxylase, an enzyme involved in the synthesis of porphyrins such as heme, the cofactor in hemoglobin, and the chlorophylls. They were were able to model the reaction and determine that the rate of spontaneous decarboxylation is 9.5×10^{-18} s^{-1}, which corresponds to a half-life of 2.3 billion years! [They] published a chart showing typical half-lives of spontaneous reactions." L. Moran



k ~ 10^{-17} s^{-1}

2.3×10^9

80

http://sandwalk.blogspot.com/2008/11/enzyme-efficiency-best-enzyme.html

Enzymes increase rate constant of biochemical reactions

Catalytic proficiency displays the multiple of uncatalyzed reaction rate

Maximum enzymatic proficiency is Uroporphyrinogen decarboxylase = 2.5 x 10^{24}

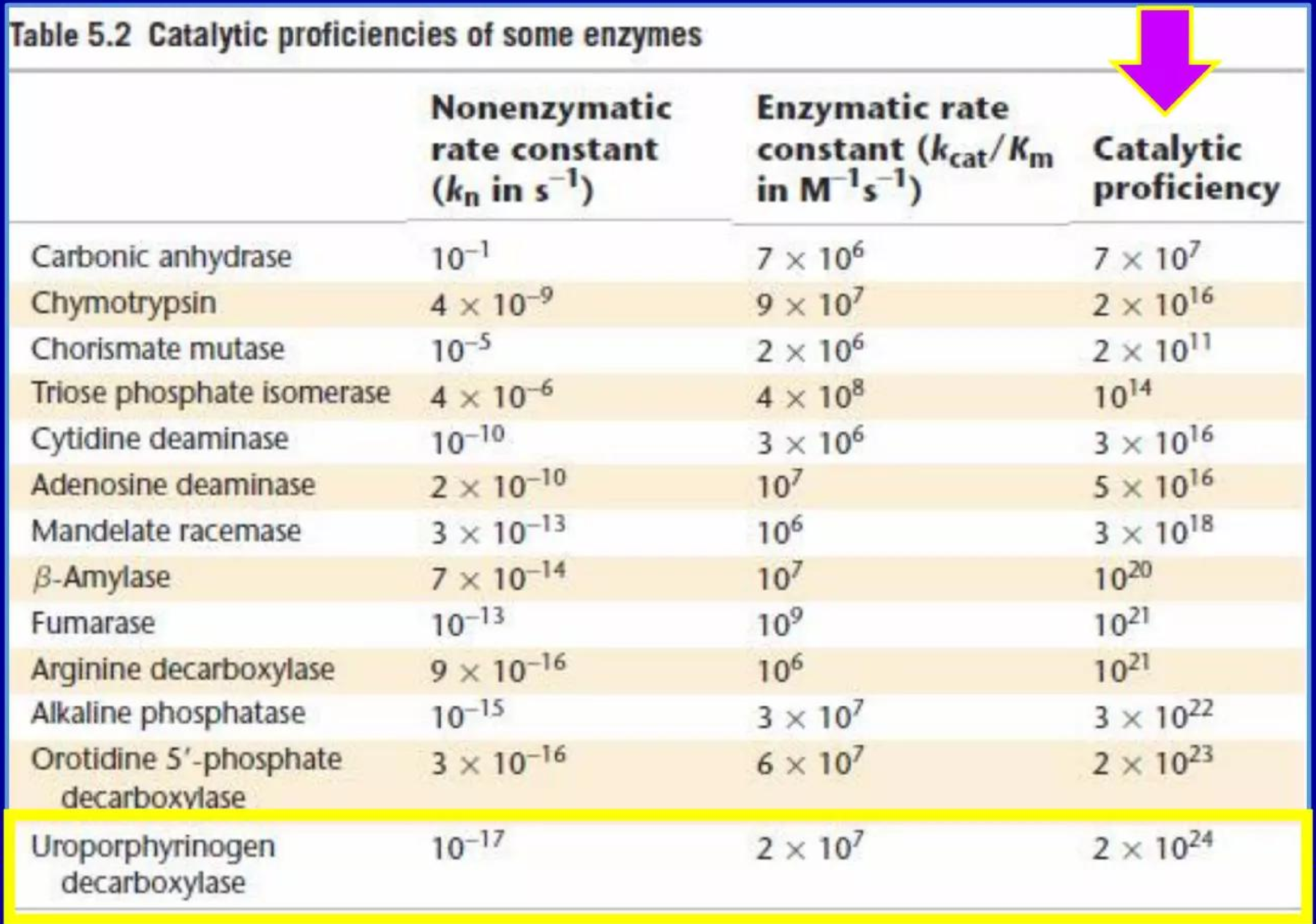


Table 5.2 Catalytic proficiencies of some enzymes

	Nonenzymatic rate constant (k_n in s^{-1})	Enzymatic rate constant (k_{cat}/K_m in $M^{-1}s^{-1}$)	Catalytic proficiency
Carbonic anhydrase	10^{-1}	7×10^{6}	7×10^{7}
Chymotrypsin	4×10^{-9}	9×10^{7}	2×10^{16}
Chorismate mutase	10^{-5}	2×10^{6}	2×10^{11}
Triose phosphate isomerase	4×10^{-6}	4×10^{8}	10^{14}
Cytidine deaminase	10^{-10}	3×10^{6}	3×10^{16}
Adenosine deaminase	2×10^{-10}	10^{7}	5×10^{16}
Mandelate racemase	3×10^{-13}	10^{6}	3×10^{18}
β-Amylase	7×10^{-14}	10^{7}	10^{20}
Fumarase	10^{-13}	10^{9}	10^{21}
Arginine decarboxylase	9×10^{-16}	10^{6}	10^{21}
Alkaline phosphatase	10^{-15}	3×10^{7}	3×10^{22}
Orotidine 5′-phosphate decarboxylase	3×10^{-16}	6×10^{7}	2×10^{23}
Uroporphyrinogen decarboxylase	10^{-17}	2×10^{7}	2×10^{24}

Source: "Principles of Biochemistry" (5th Edition) L. Moran *et al.*, Pearson (2011)

Enzymes speed-up chemical reactions at active sites

Key: geometry, conformation Δ, site chemical/electronic environments

First step: substrate binds to empty pocket of an active site on enzyme's surface

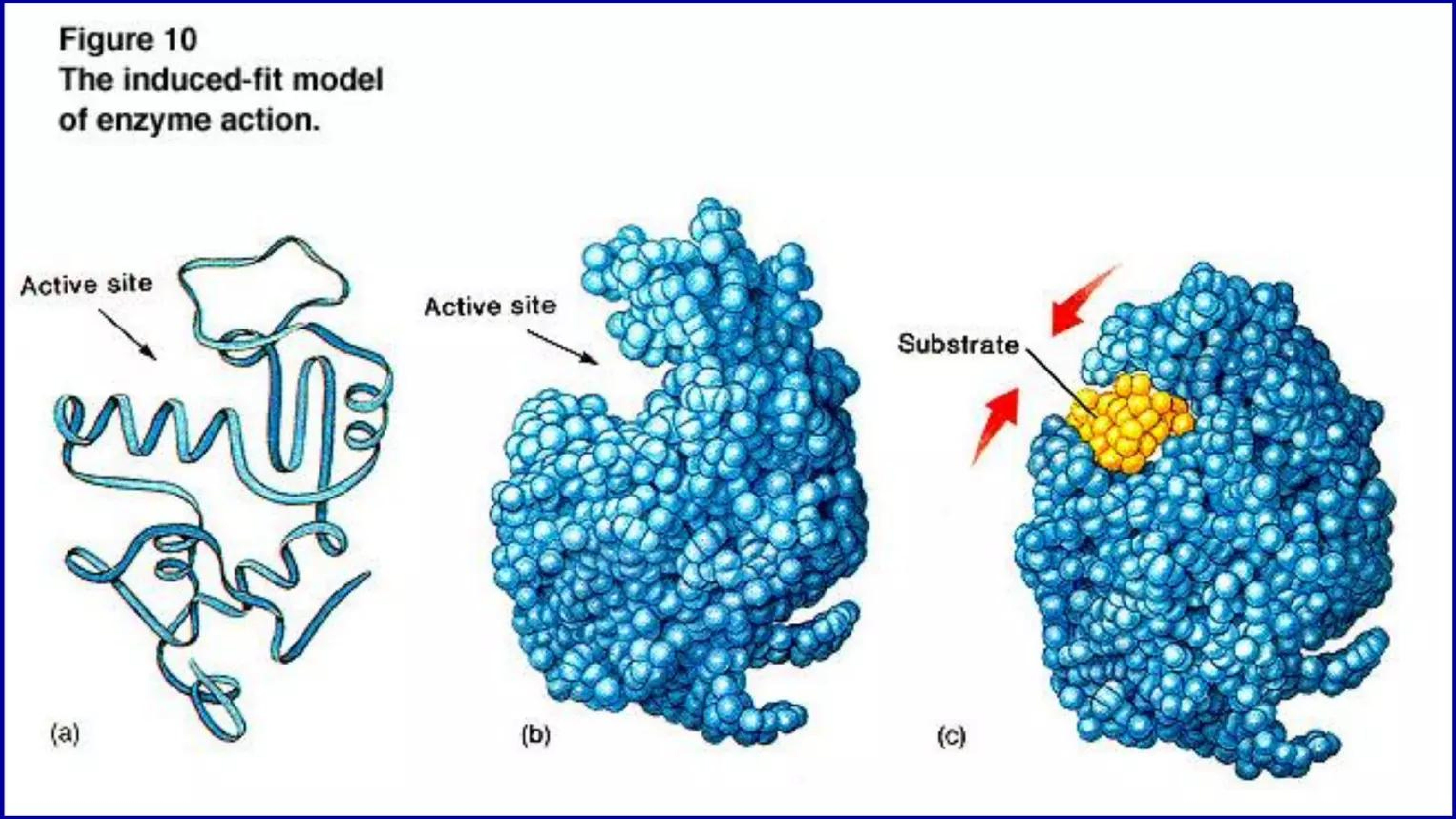


Figure 10
The induced-fit model of enzyme action.

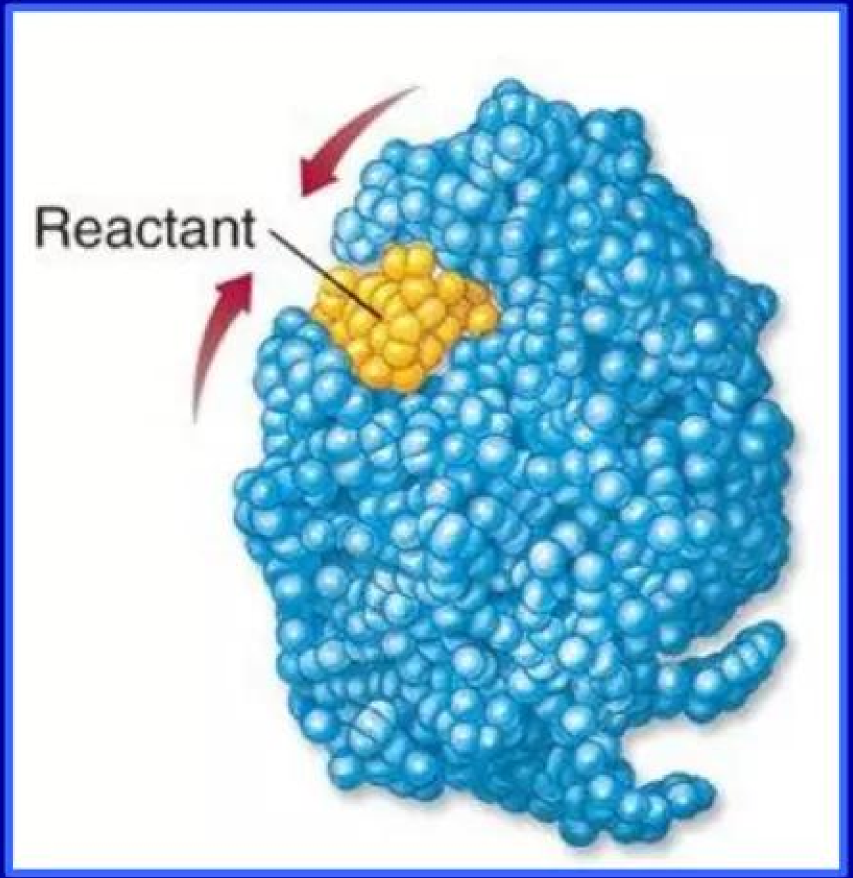
http://iws.collin.edu/biopage/faculty/mcculloch/1406/outlines/chapter%206/chap06.html

Biological enzymatic catalysis processes reactants

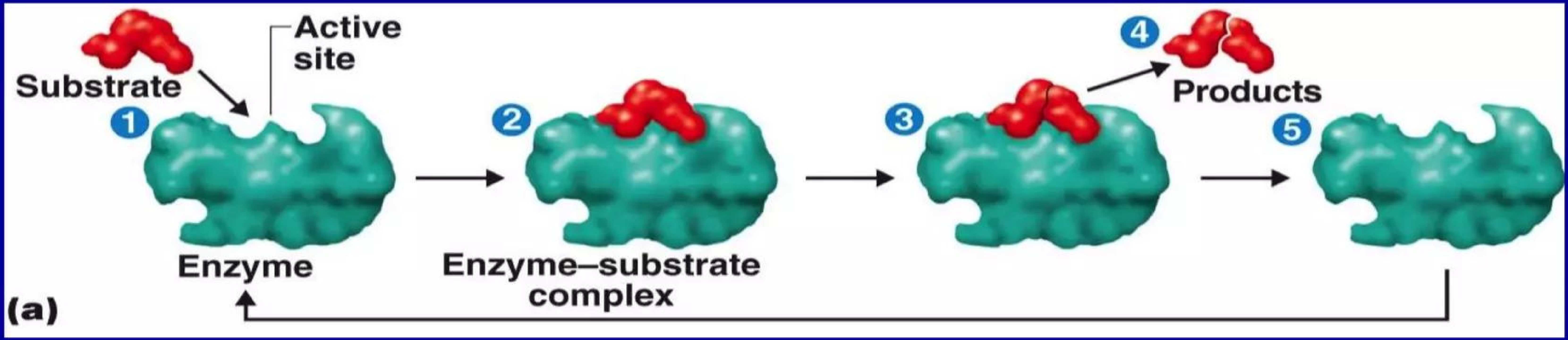
Enzymes have localized active sites where chemical reactions occur

Unique environments at active sites enormously increases the rate of reactions

1. Substrates bind to enzyme molecule very selectively by fitting into special active sites that are clefts or pockets in surface of enzyme molecule
2. Substrates undergo chemical reactions while substantially enveloped within active sites



3. Products of catalysis are released from active site into the local environment
4. Active site returns to its t_o initial state; enzyme is now ready to begin processing reactants again; enzyme molecule is ~ unchanged

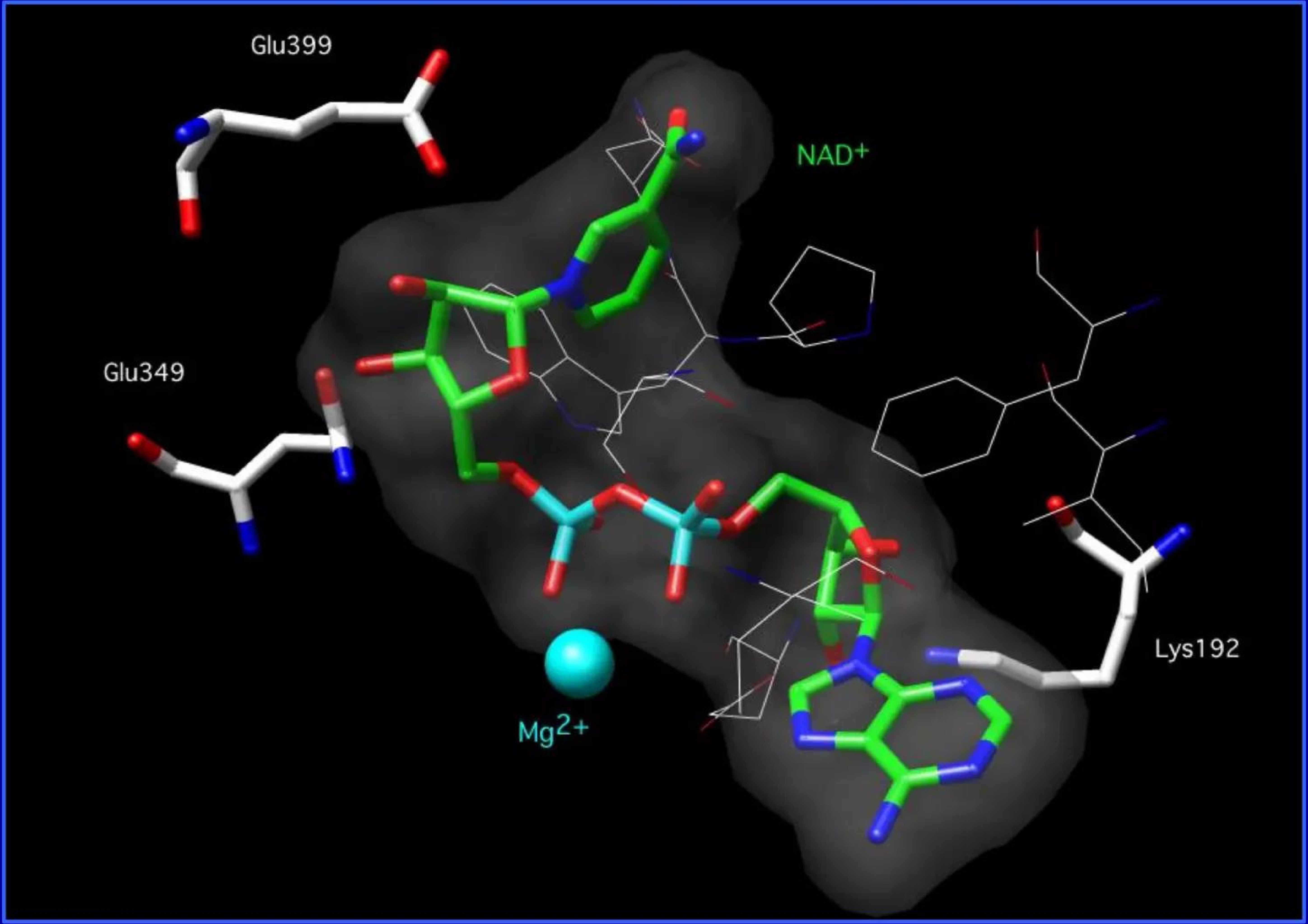


https://www.studyblue.com/notes/note/n/microbial-metabolism-/deck/10602

Details of active site in aldehyde dehydrogenase enzyme

Note geometry and positions of Mg^{2+} ion, aromatic rings and hydrogen

K487E mutant aldehyde dehydrogenase 2



Details of active site in histidinol phosphatase enzyme

Note geometry and positions of Zn^{2+} ions, aromatic rings and hydrogen

Length-scale of interactions among groups within active site is ~2 Angstroms (Å)

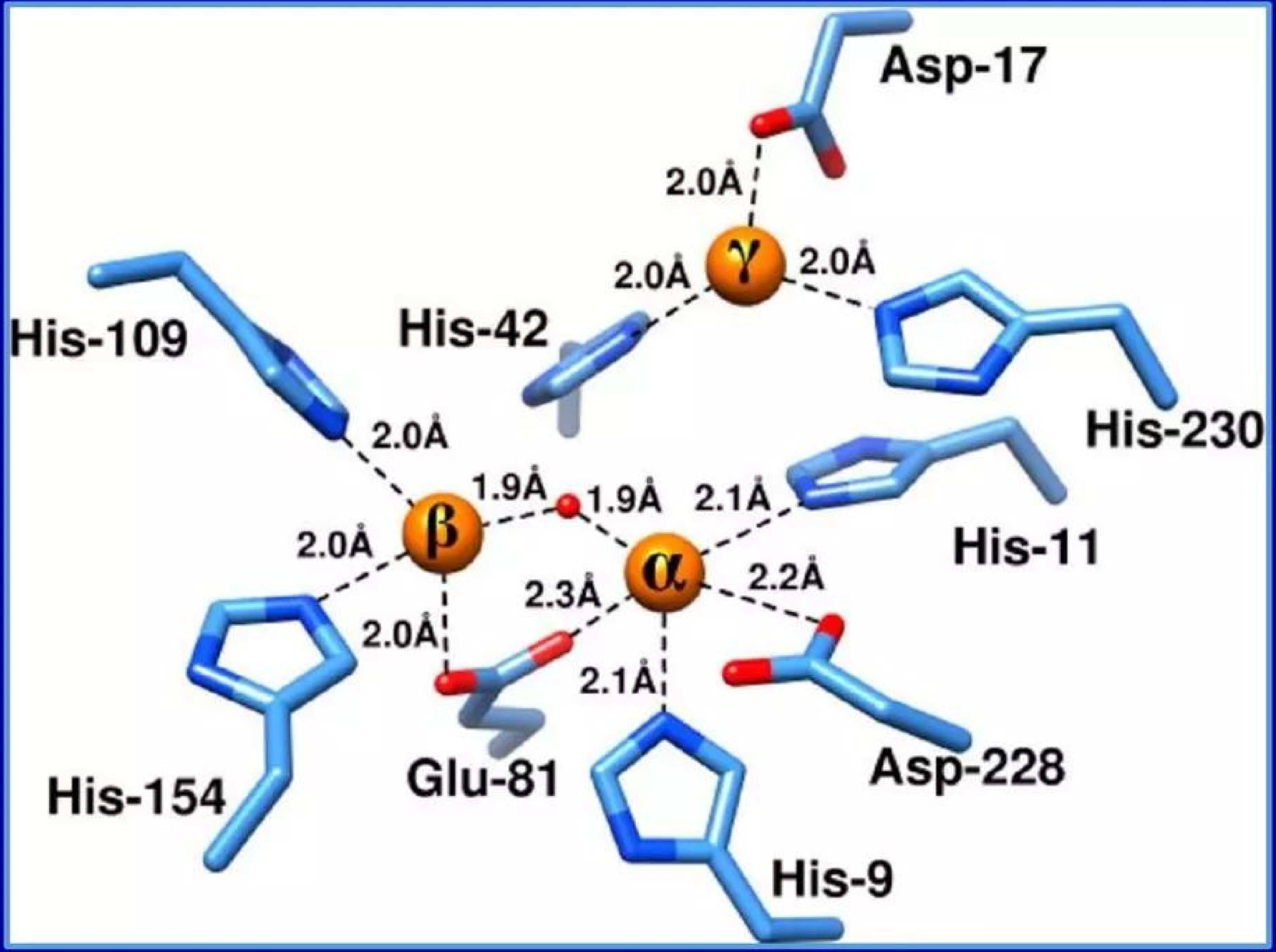


Figure 6. "Active site structure of HPP from L. lactis. The three Zn^{2+} ions in the active site are shown as orange spheres, and the enzyme residues serving as ligands to the metal ions are colored light blue."

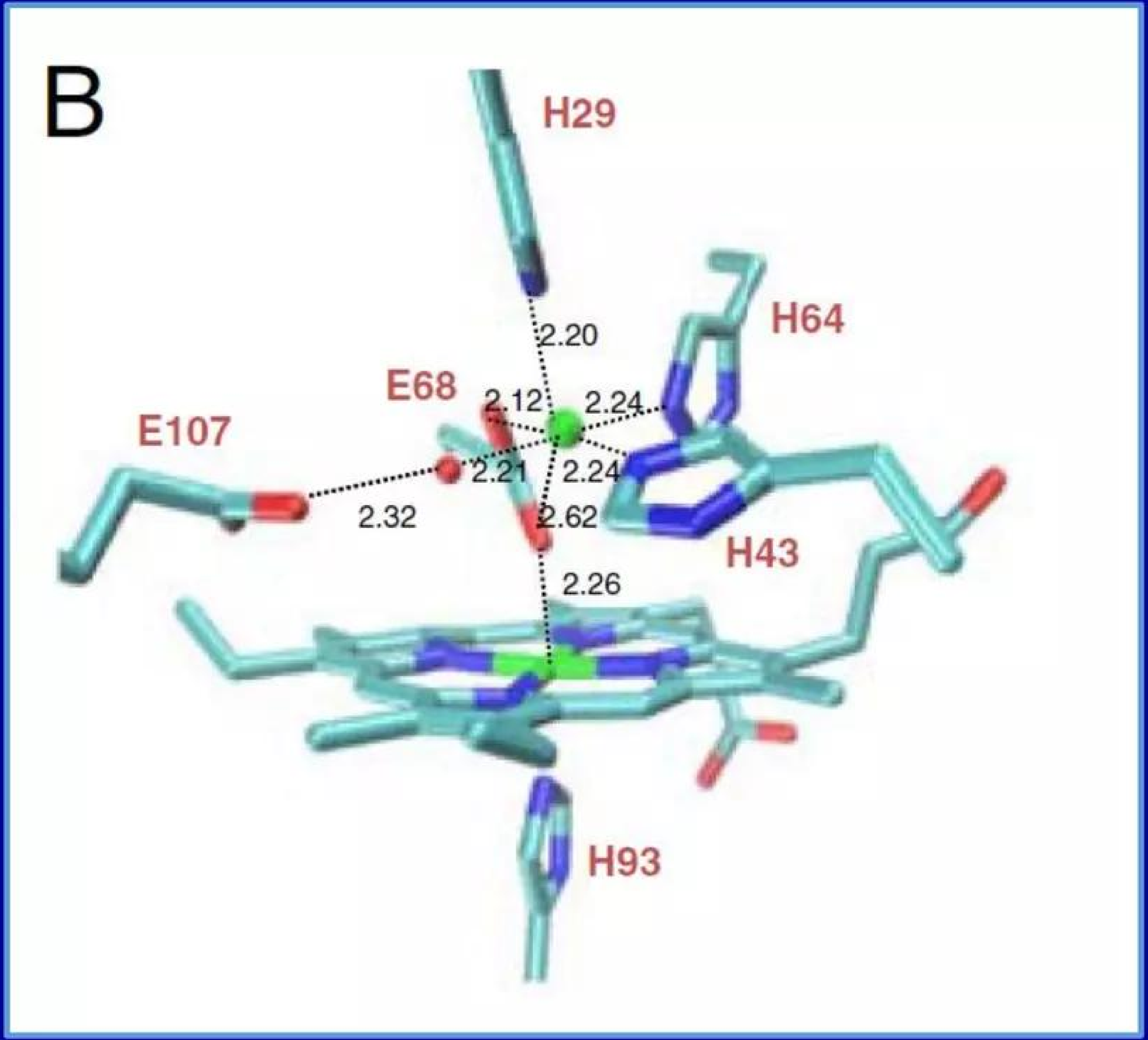
"Structural and mechanistic characterization of L-histidinol phosphate phosphatase from the polymerase and histidinol phosphatase family of proteins"
S. Ghodge *et al.*, *Biochemistry* **52** pp. 1101 - 1112 (2013)

http://www.enzymefunction.org/publications/2013/04

Details of active site in nitric oxide reductase enzyme

Note geometry and positions of Fe^{2+} ion, aromatic rings and hydrogen

Geometry, composition and electronic environment differ from previous example



"Bacterial nitric oxide reductase (NOR) is a membrane-bound enzyme that is " … critical for all life. Bacterial denitrification is a crucial part of the nitrogen cycle in nature that involves a four-step, five-electron reduction of nitrate (NO_3^-) to dinitrogen (N_2)."

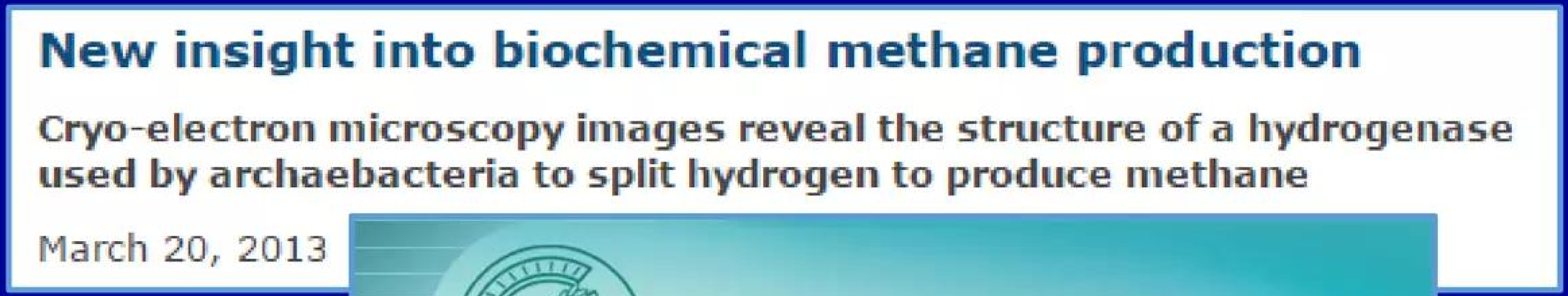
Figure 1B. Fe^{2+} ion is shown as green sphere - " … identity of the metal ion in the FeB site can tune the active site through their interactions with the His and Glu ligands, resulting in formation of different coordination geometries with different hydrogen bonds."

"Roles of glutamates and metal ions in a rationally designed nitric oxide reductase based on myoglobin"
Y-W. Lin *et al.*, *PNAS* 107 pp. 8581- 8586 (2010)

http://www.pnas.org/content/107/19/8581

Details of active sites in biological hydrogenase enzyme

12-trimers form enzyme complex that uses Fe and Ni ions in active sites

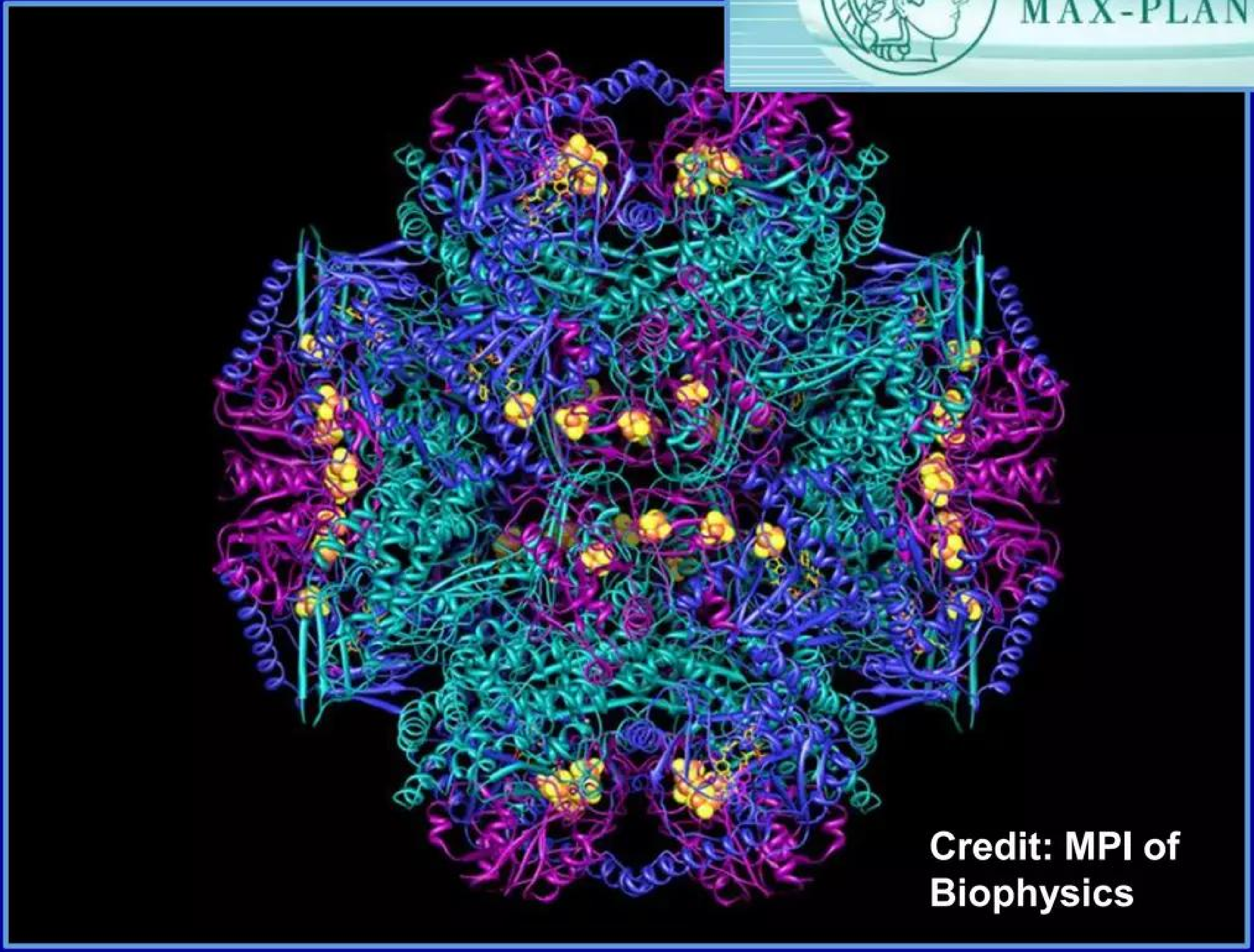


New insight into biochemical methane production

Cryo-electron microscopy images reveal the structure of a hydrogenase used by archaebacteria to split hydrogen to produce methane

March 20, 2013

MAX-PLANCK-GESELLSCHAFT



Credit: MPI of Biophysics

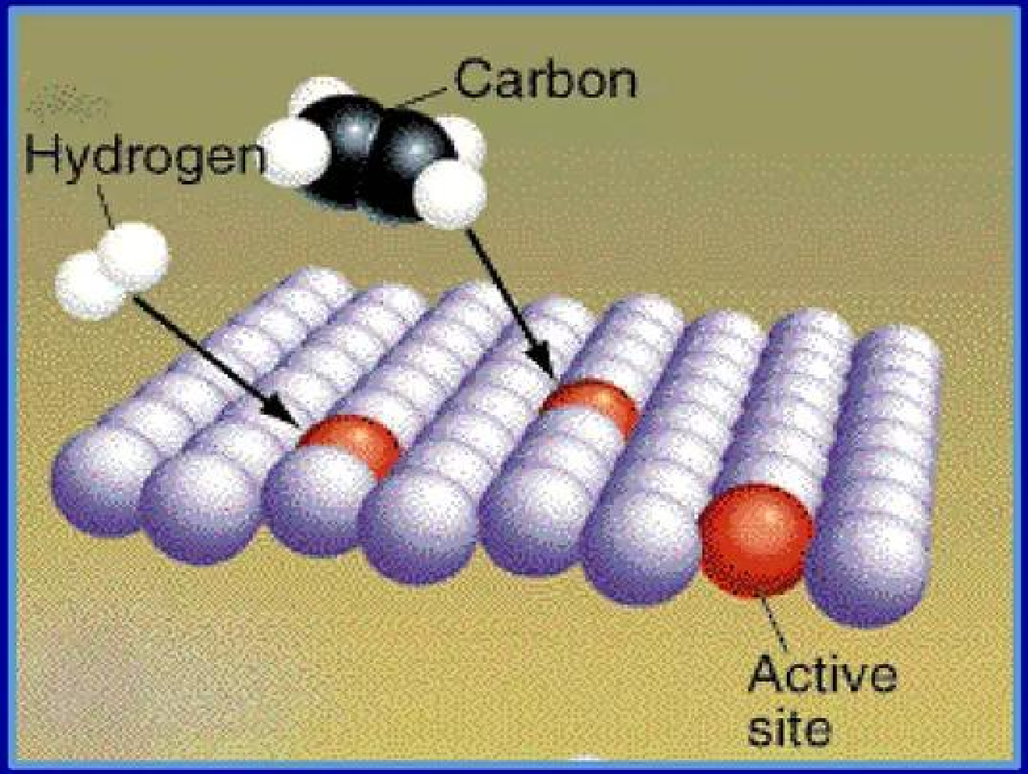
“Molecular structure of the F420-reducing [NiFe]- hydrogenase proteins: one blue, one green and one violet subunit together form a trimer. Twelve of these trimers form the entire enzyme complex. The yellow structures show the reactive metal centres. They split hydrogen molecules into protons and electrons which are then transferred to carbon dioxide in a process involving several stages.”

http://www.mpg.de/7041579/biochemical-methane-production

Overview of heterogeneous metallic industrial catalyst

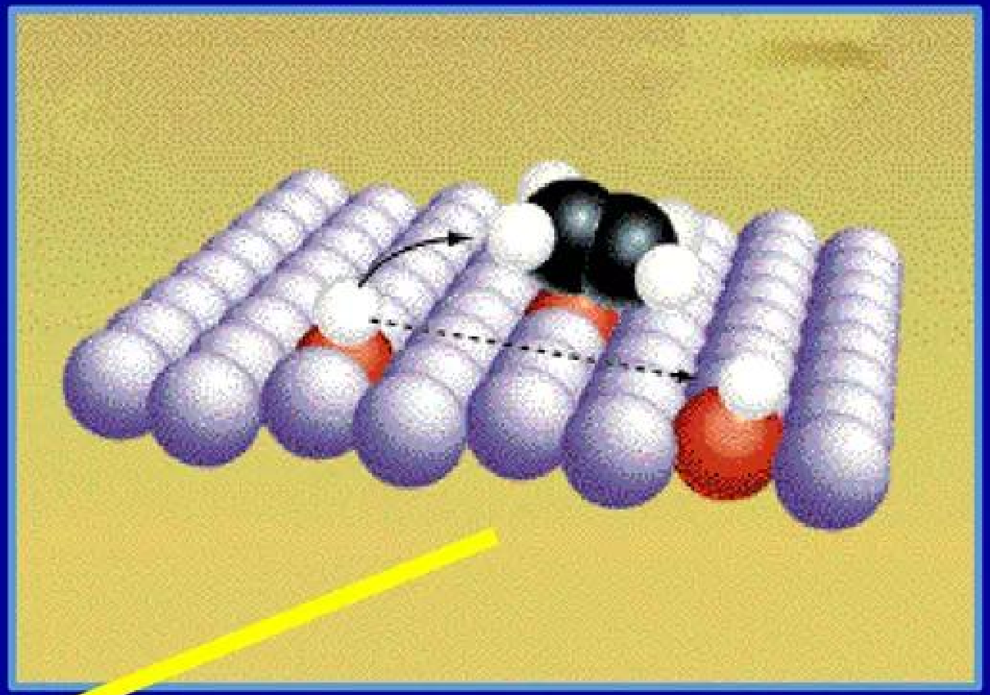
Vastly less structurally and chemically complicated vs. bioenzymes

Example: catalytic hydrogenation of ethylene CH_2CH_2 to produce ethane CH_3CH_3

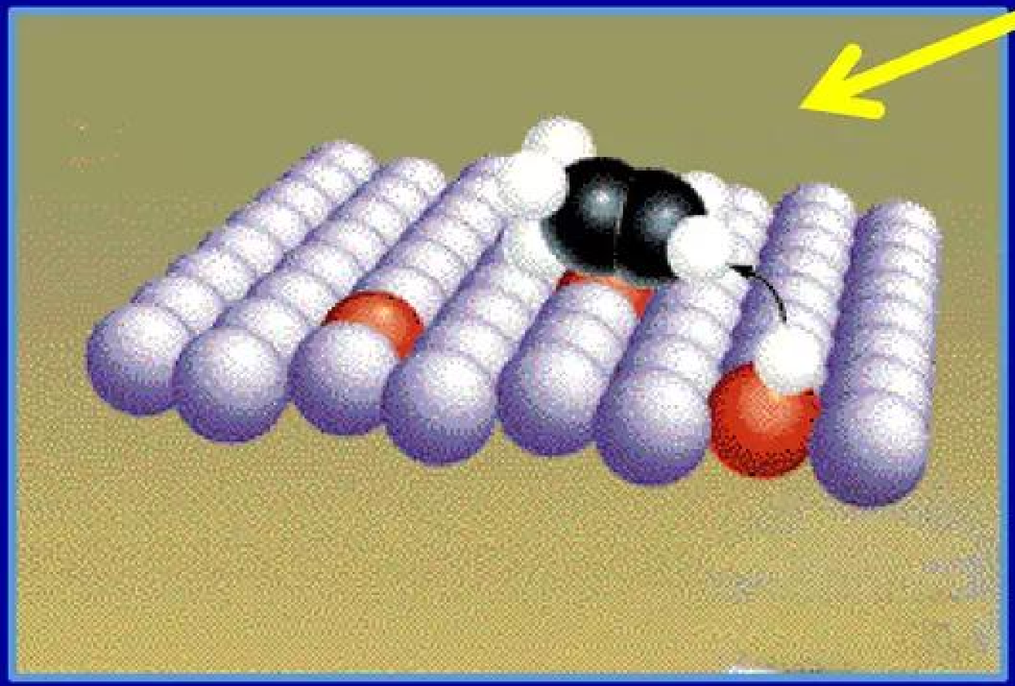


“CH_2CH_2 and H_2 molecules are attracted to the atoms of the metal catalyst”

Credit: graphics and text - Prentice-Hall

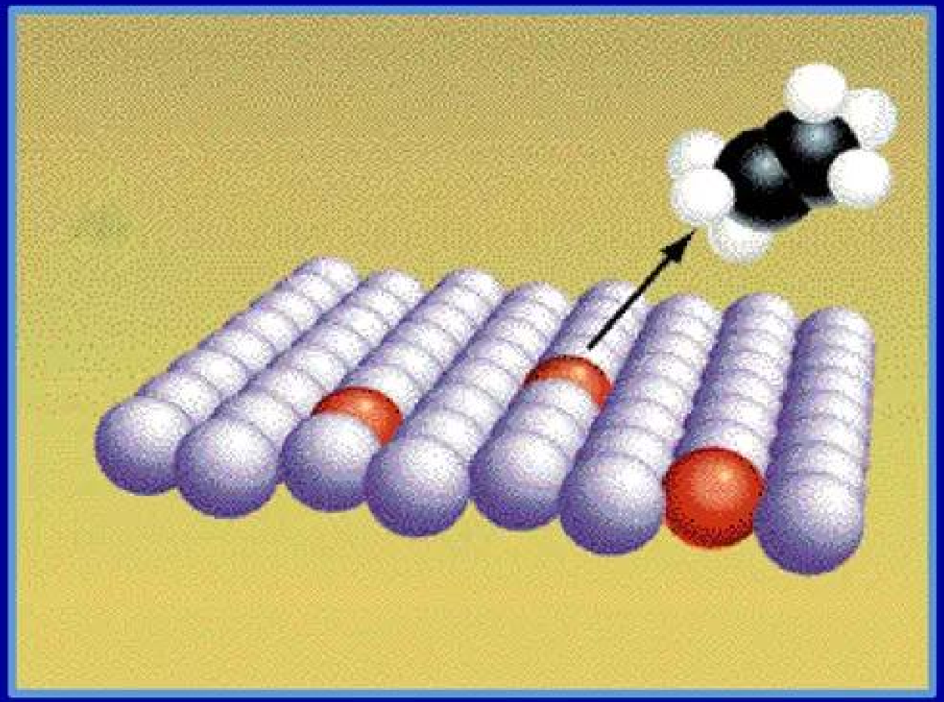


“Covalent bonds are weakened because the metal atoms attract electrons away form the ‘bonded’ atoms. The bonds between the hydrogen atoms are weaken more and break”



“Free radicals from the original hydrogen molecules move along the surface of the metal until they collide and form products”

Credit: graphics and text - Prentice-Hall

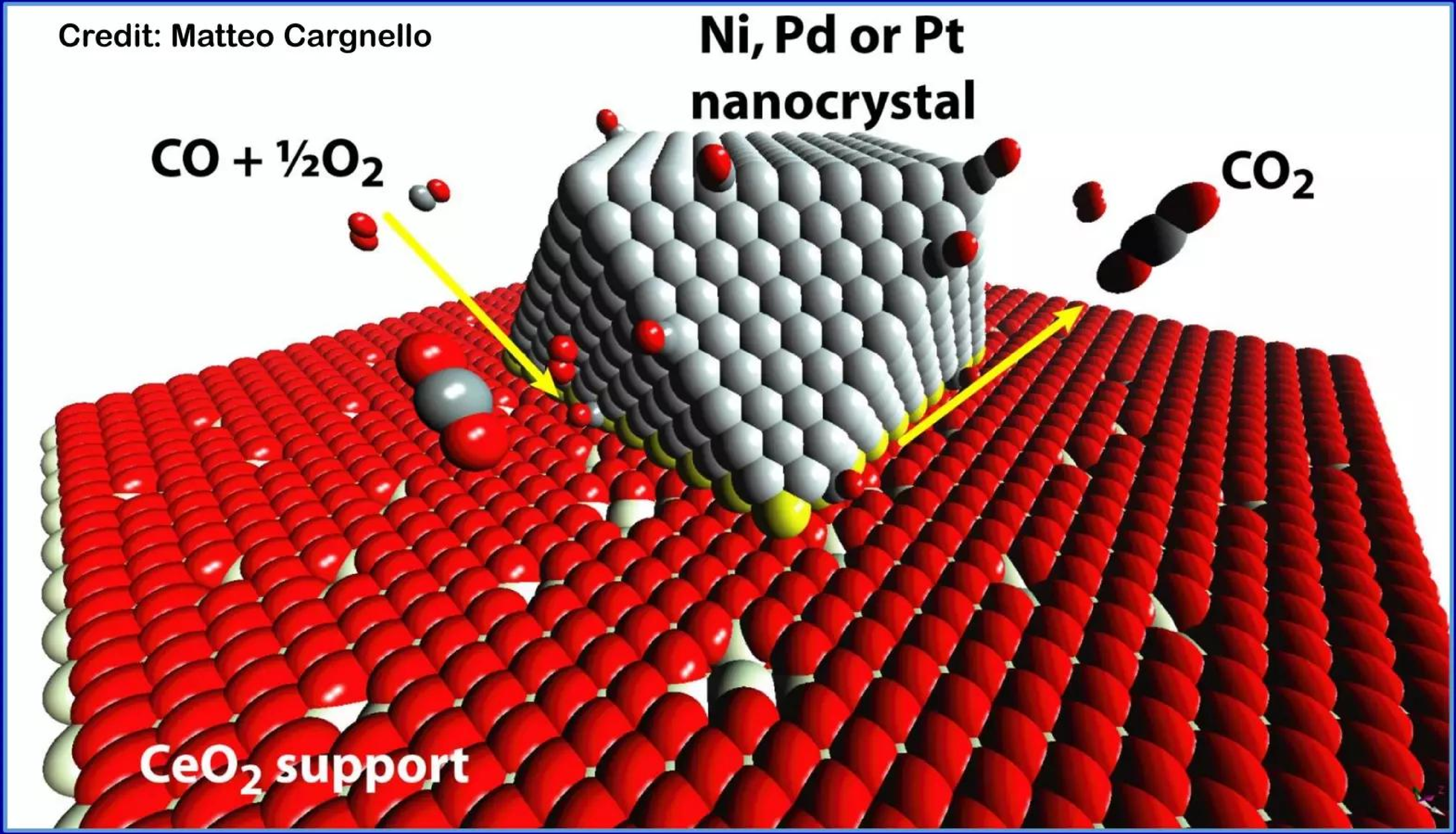


“Hydrogenated ethylene molecules (ethane), CH_3CH_3 is not as ‘electron rich’ as the ethylene, so it is not as strongly attracted to the metal. The ethane breaks away from the catalyst”

Nanotech-based heterogeneous metallic catalyst

Uses nanocrystals of Nickel (Ni), Palladium (Pd), or Platinum (Pt)

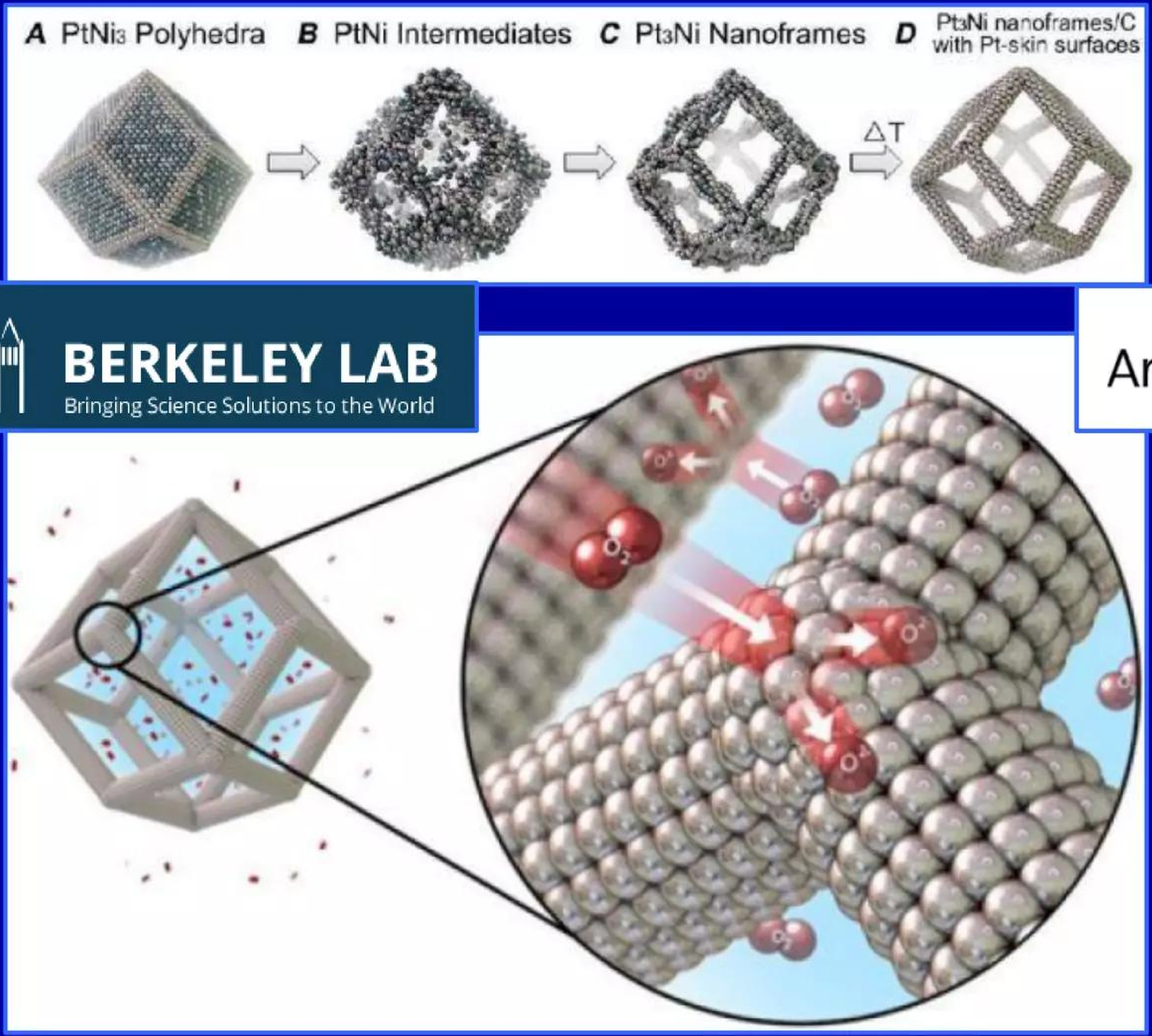
Catalyzes reaction of Carbon monoxide with Oxygen to make Carbon dioxide



http://phys.org/news/2013-07-catalytic-reactions.html

Nanotech-based heterogeneous Pt_3Ni metallic catalyst

Dodecahedral structure catalyzes Oxygen reduction on fuel cell cathode



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http://newenergytreasure.com/2014/11/03/were-seeing-a-great-deal-of-progress-in-electrocatalysis/

Hydrogen fusion reactions don't occur in condensed matter

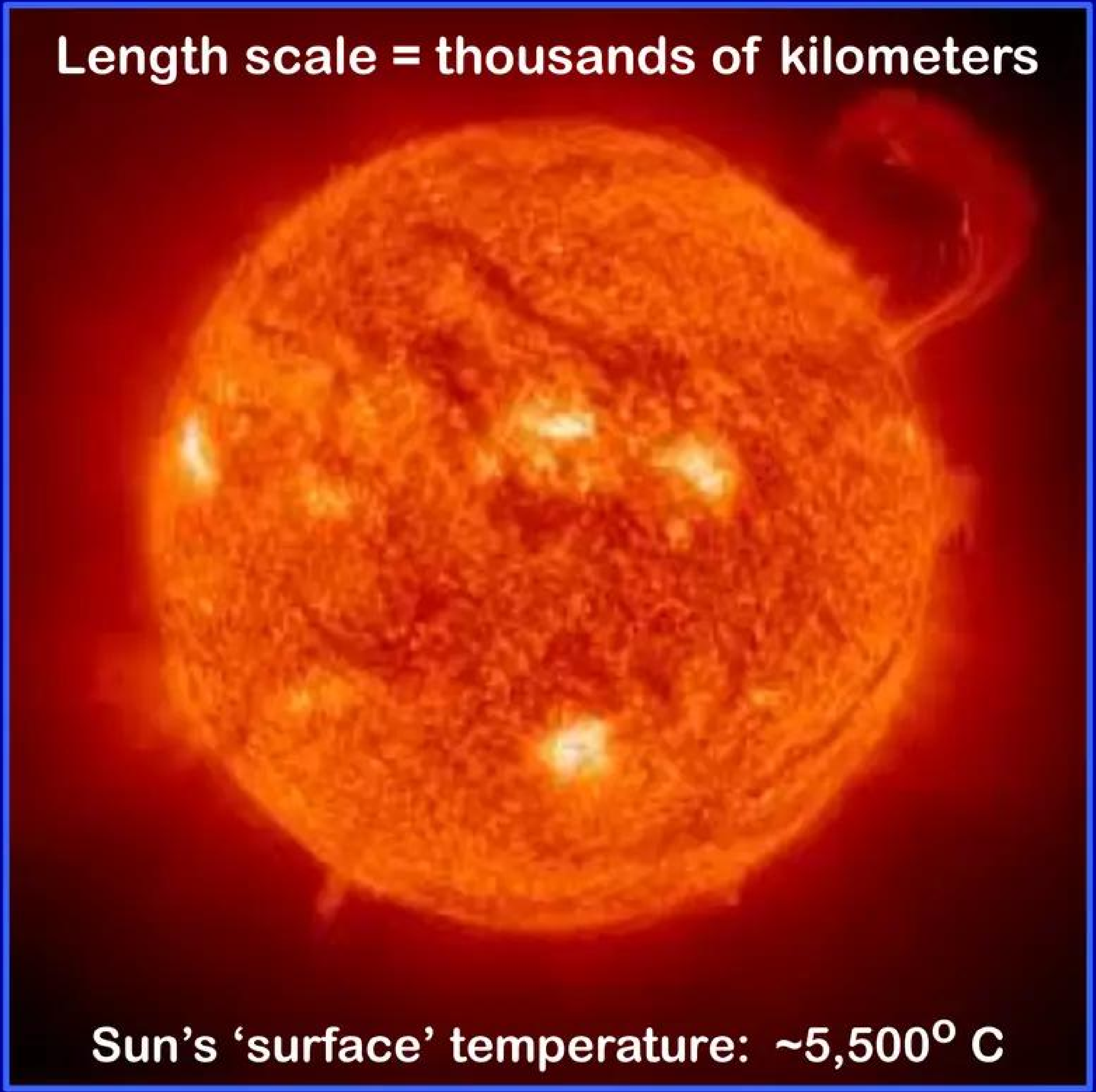
Triggering nuclear fusion processes requires huge temperatures

Stars accomplish this feat using 2-body kinetically driven reactions

Nuclear fusion processes occur primarily in Sun's 15 million degree core

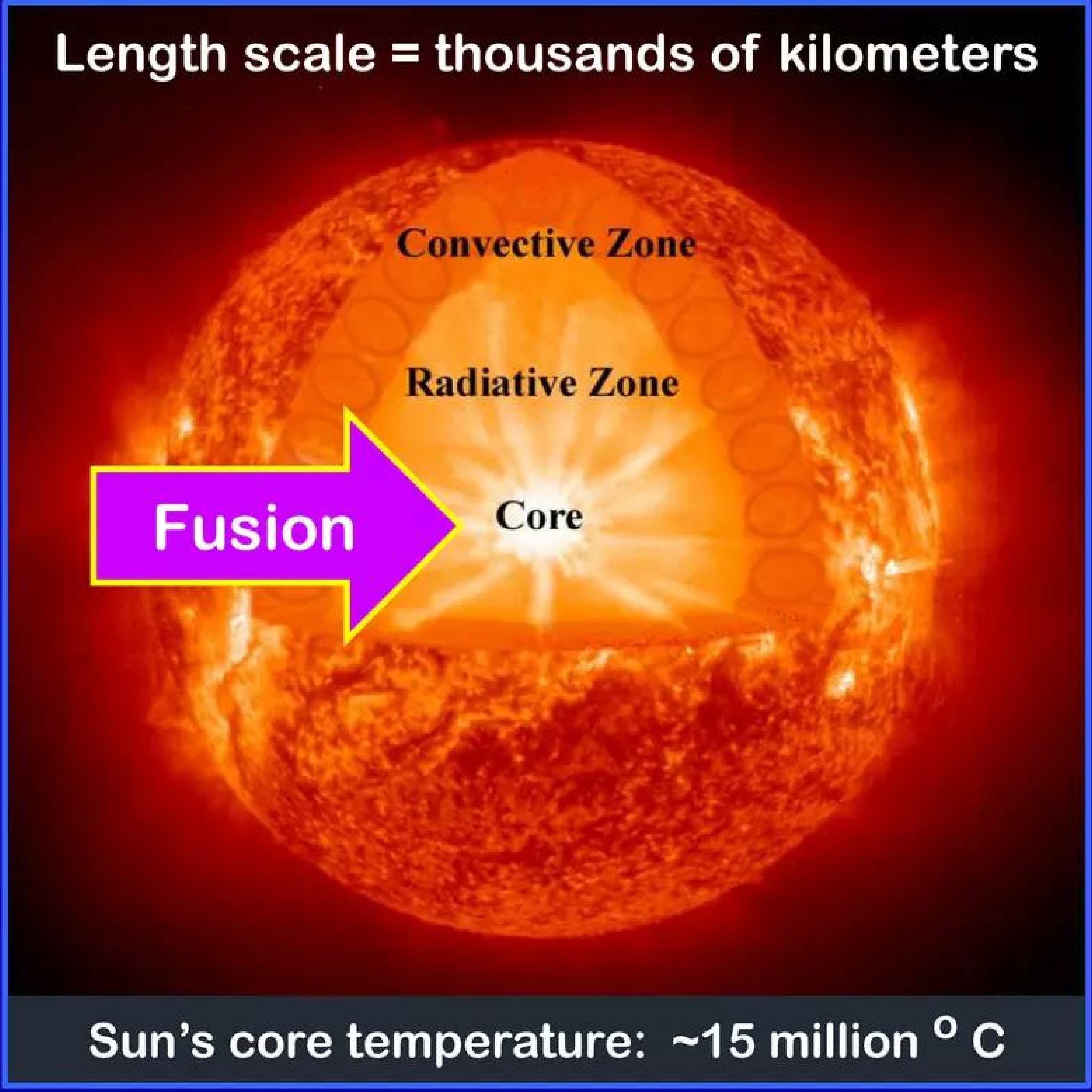
Earth's Sun is a small, long-lived G-type yellow dwarf star: fuses hydrogen in $p^+ + p^+$ reactions

Length scale = thousands of kilometers



Sun's 'surface' temperature: ~5,500° C

Length scale = thousands of kilometers



Sun's core temperature: ~15 million ° C

Two-body e + p reaction vs. many-body electroweak catalysis

In stars $e^- + p^+ \rightarrow n + \nu_e$ requires gigantic temperatures and pressures

Unlike stars, LENRs don't need multi-billion-degree temps to trigger $e^- + p^+$ reaction

In stellar supernova explosions $e + p$ neutronization begins at temperature of ~ 9×10^9 °Kelvin

Crab nebula: remnant of a supernova explosion that was observed by many Chinese astronomers in 1054 A.D.

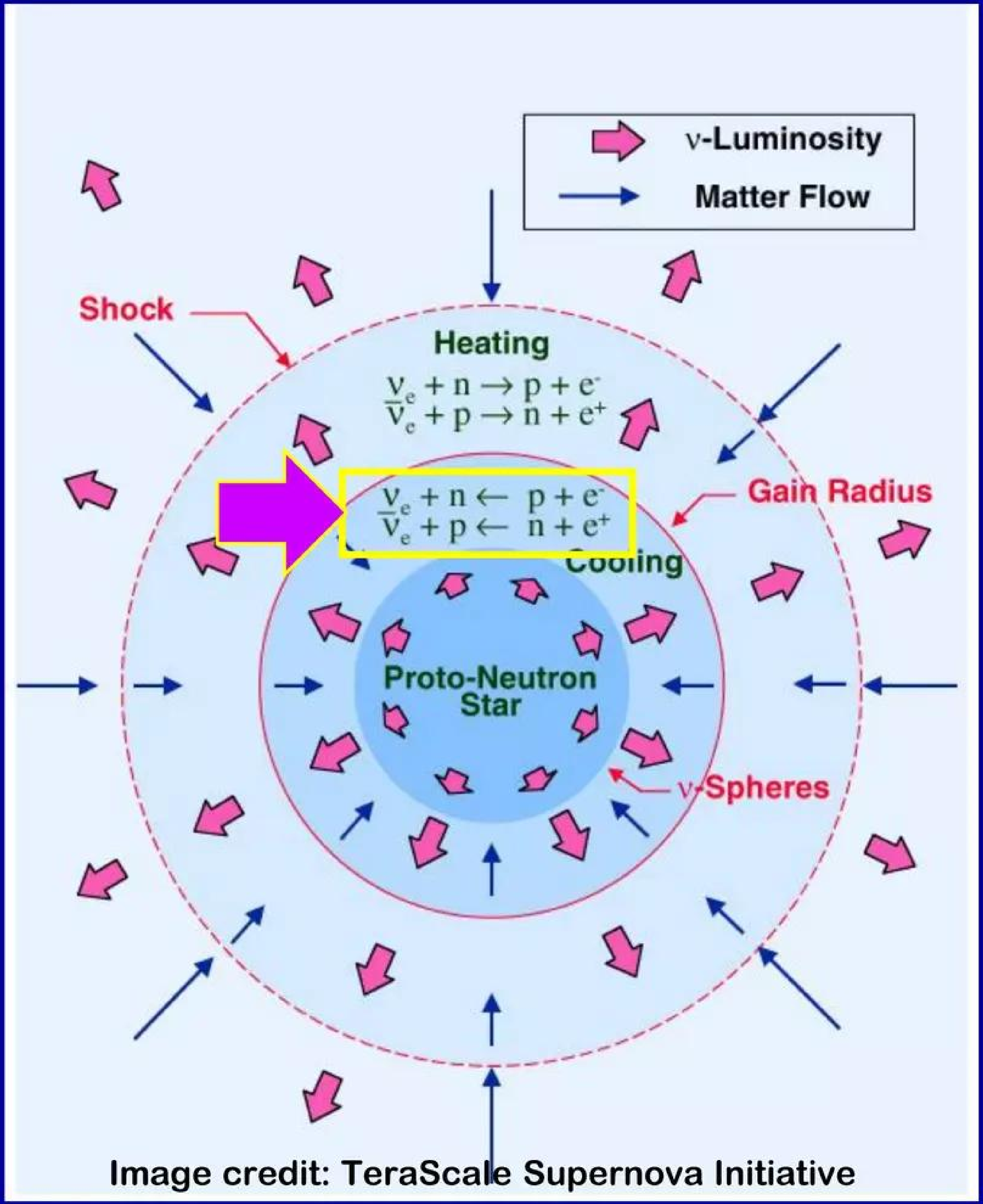
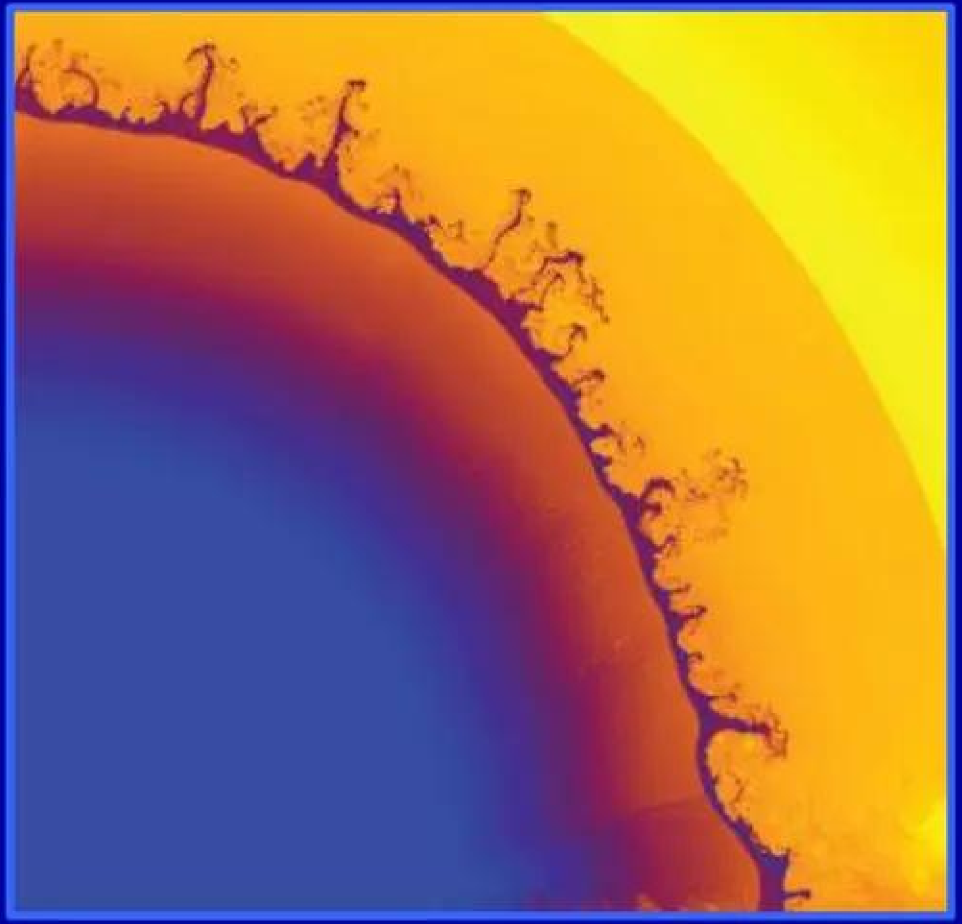


Image credit: TeraScale Supernova Initiative



"One series of NIF experiments is studying hydrodynamic instabilities in supernovae. This simulation, created by team member Tomasz Plewa from Florida State University, shows Rayleigh-Taylor instability growth during a supernova in a red supergiant star."

Neutronization reaction’s energetics and cross-section

Electroweak production of neutron and neutrino via $e^- + p^+ \rightarrow n^0 + v_e$

In a supersnova explosion protons able to react directly with electrons → neutrons

- ✓ Reaction is endothermic; requires input energy of at least 0.78 MeV or 780,000 electron Volts (eV) to have enough energy to produce neutron and neutrino photon
- ✓ Put another way: the rest mass of a neutron is larger than the combined rest masses of an electron and a proton by 0.78 MeV ($m = E/c^2$); this “mass deficit” problem must be overcome for an electroweak reaction to go forward to completion
- ✓ To drive this 2-body reaction relying on just temperature, kinetic energies of charged particles, and the high-energy ‘tail’ of the Maxwell-Boltzmann distribution, the local environment of free protons and electrons undergoing this reaction must be at a temperature of at least 9 x 10^9 ^{O}Kelvin or roughly, 10 billion degrees
- ✓ Fred Hoyle was the first theorist who conjectured this reaction as the mechanism responsible for producing neutron stars during supernova explosions (1946)
- ✓ For a free proton at rest, the cross-section for a spontaneous reaction with a nearby free electron to make a neutron and a neutrino is 1.18 x 10^{-44}/cm^2 (pp. 511 in H. Bethe, “Selected works of Hans A. Bethe: With commentary,” World Scientific Publishing 1997); i.e., $e^- + p^+ \rightarrow n + v$ is very unlikely to occur at room temperature
- ✓ Tiny 10^{-44}/cm^2 cross-section for spontaneous $e^- + p^+$ reactions in condensed matter is fortuitous; otherwise much of the Universe might be an inchoate sea of neutrons

Electroweak reaction cross-sections in supernovas

Nasu *et al.*'s calculated cross-sections still modest at billions of °K

Two neutrons are produced when electron reacts with deuteron instead of proton

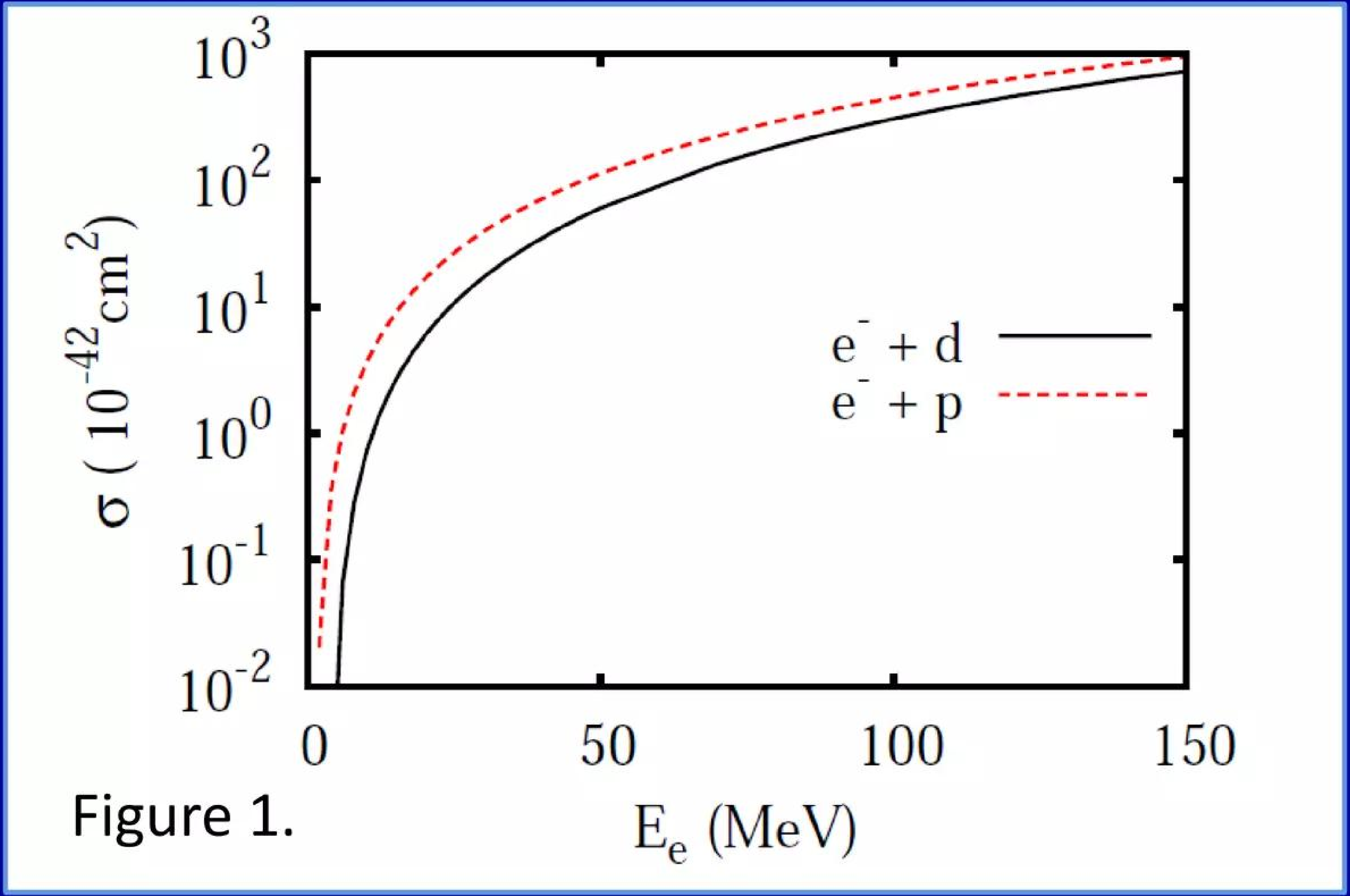


Figure 1.

"Neutrino emissivities from deuteron-breakup and formation in supernovae"
S. Nasu *et al.*, *The Astrophysical Journal* 801 78. doi:10.1088/0004-637X/801/2/78 (2015)

http://arxiv.org/pdf/1402.0959.pdf

Widom-Larsen theory of low energy neutron reactions

Three key publications that begin in March 2006 are referenced below

Many-body collective effects enable electroweak catalysis in condensed matter

"Ultra low momentum neutron catalyzed nuclear reactions on metallic hydride surfaces"
A. Widom and L. Larsen
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

"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

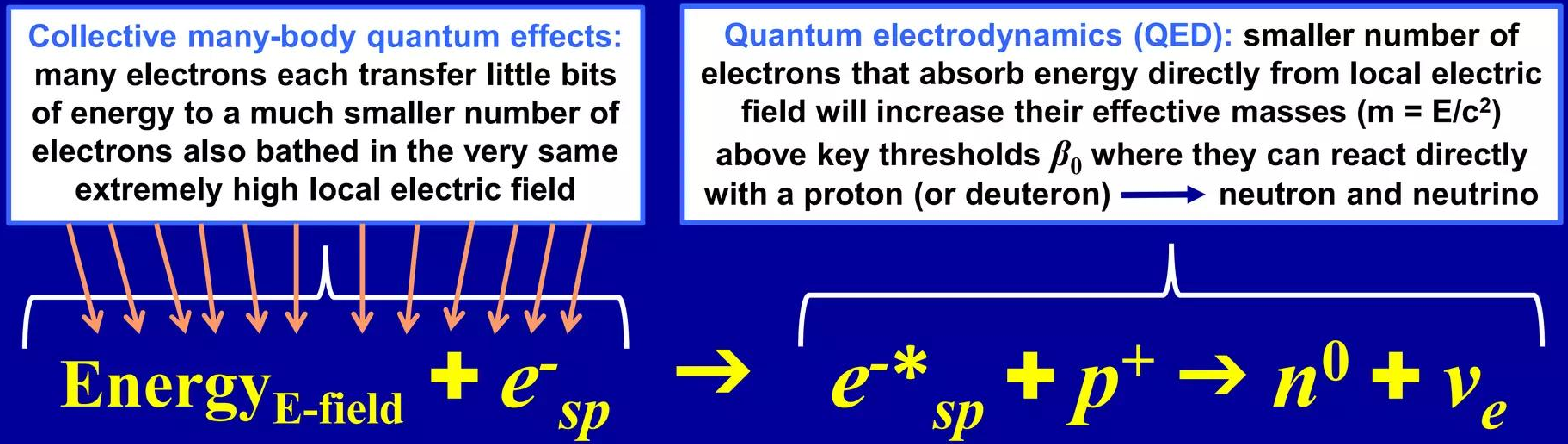
"A primer for electro-weak induced low energy nuclear reactions"
Y. Srivastava, A. Widom, and L. Larsen
Pramana - Journal of Physics 75 pp. 617 - 637 (2010)

http://www.ias.ac.in/pramana/v75/p617/fulltext.pdf

Electroweak reaction in Widom-Larsen theory is simple

Protons or deuterons react directly with electrons to make neutrons

W-L explains how $e + p$ reactions occur at substantial rates in condensed matter



Draw energy from electric fields > 10^{11} V/m

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

Collective many-body quantum effects: many electrons each transfer little bits of energy to a much smaller number of electrons also bathed in the very same extremely high local electric field

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

$$\text{Energy}_{\text{E-field}} + e^{-}_{sp} \rightarrow e^{-*}_{sp} + p^{+} \rightarrow n^{0} + \nu_{e}$$

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

$$\text{Neutrons + atomic nuclei} \xrightarrow{\text{Induce transmutation}} \text{heavier elements + decay products}$$

LENR catalysis boosts electroweak *e* + *p* reaction rate

Collective effects & Q-M entanglement make it a many-body reaction

Energy to drive reaction comes from electric fields not particle kinetic energies

Increased effective electron mass solves the mass deficit problem with *e* + *p* reaction rates

- ✓ In coherently oscillating. Q-M entangled patches of surface protons, deuterons, or tritons the Born-Oppenheimer approximation breaks down; this causes local electromagnetic coupling between surface plasmon (SP) electrons and protons, deuterons, or tritons associated/entangled with an LENR many-body active site and enables transient, nuclear-strength, collective local electric fields > 2.5 x 10^{11} V/m to be created therein. Such site is conceptually akin to a gigantic 'naked' pancake-shaped, micron$^+$ diameter atomic nucleus resting on top of a substrate surface
- ✓ LENR active site SP electrons locally bathed in nuclear-strength electric fields undergo a phenomenon called "mass renormalization" whereby their masses effectively increase. This effect, upon which the W-L theory of LENR electroweak catalysis relies, was first discovered and published by famous Russian physicists in 1970s (Landau & Lifshitz, "The Classical Theory of Fields", Sects. 17 and 47, Prob. 2, Pergamon Press, Oxford 1975 and Berestetskii, Lifshitz, & Pitaevskii, "Quantum Electrodynamics", Sect. 40, Eq. 40.15, Butterworth Heinmann, Oxford, 1997). Effect is uncontroversial and well-accepted among high-energy particle physicists
- ✓ Since such electrons are not increasing mass via kinetic energy associated with high-velocity translational motion, no bremsstrahlung radiation will be produced

W-L theory identifies ideal types of input energy

External source of input energy required to produce LENR neutrons

Charged-particle currents and electromagnetic photons are ideal energy inputs

- ✓ LENR active sites must be subjected to external non-equilibrium fluxes of charged particles or electromagnetic (E-M) photons that are able to transfer input energy directly to many-body SP or π electron surface 'films'. Examples of external energy sources include (they may be used in combination): electric currents and/or rapidly oscillating electric fields; E-M photons emitted from coherent lasers or incoherent IR-resonant E-M cavity walls, etc.; pressure gradients of p^+, d^+, and/or t^+ ions imposed across site surfaces; currents of other ions crossing SP electron 'film' in either direction (i.e., ionic fluxes); etc. Such sources can provide input energy required to surpass certain minimum H-isotope-specific enhanced electron-mass thresholds that allow production of ultralow energy neutron fluxes via many-body collective $e^* + p^+$, $e^* + d^+$, or $e^* + t^+$ electroweak LENR reactions
- ✓ N.B. please note again that surface plasmons (SP) are collective, many-body electronic phenomena closely associated with interfaces. For example, they can exist at gas/metal interfaces or metal/oxide interfaces. Thus, surface plasmon oscillations will almost certainly also be present at contact points between purely metallic surfaces and adjacent layers and/or nanoparticles composed of metallic oxides, e.g., PdO, NiO, or TiO_2, etc., or vice-versa
- ✓ Formation of new catalytically active LENR sites ceases when input energy stops

W-L theory explains creation of LENR-active sites

Needed to produce neutrons that induce transmutation of elements

Hydrogen (protons or deuterons) and heavy-mass electrons are key reactants

- ✓ Substantial quantities of Hydrogen isotopes must be brought into intimate contact with fully-H-loaded metallic hydride-forming metals (or non-metals like Se); e.g., Palladium, Platinum, Rhodium, Nickel, Titanium , Tungsten, etc. Please note that collectively oscillating, 2-D surface plasmon (SP) electrons are intrinsically present and cover the surfaces of such metals. At full lattice loading (saturation) of Hydrogenous isotopes, many-body, collectively oscillating island-like LENR active sites comprised of protons p^+, deuterons d^+, or tritons t^+ will form spontaneously at random locations on such surfaces

- ✓ Or, delocalized collectively oscillating π electrons that comprise the outer covering surfaces of fullerenes, graphene, benzene, and polycyclic aromatic hydrocarbon (PAH) molecules behave identically to SPs; when such molecules are hydrogenated, they can create many-body, collectively oscillating, entangled quantum systems that per W-L theory are functionally equivalent molecular analogues of metal hydrides. In this case, LENRs are triggered on aromatic rings; strong tendency to transmute ring Carbon atoms

- ✓ Born-Oppenheimer approximation breaks down in LENR active sites composed of nearly homogenous collections of collectively oscillating p^+, d^+, and/or t^+ ions; this enables E-M coupling between nearby SP or π electrons and hydrogen ions at active sites and creates nuclear-strength local electric fields > 2.5×10^{11} V/m. Effective masses of electrons in such E-fields increased to multiple of an electron at rest ($e \rightarrow e^*$) determined by required ~simultaneous energy input(s); this is called "mass renormalization" by particle physicists

Local breakdown of Born-Oppenheimer approximation

Key to LENR electroweak catalysis: enables huge local electric fields

In nm to *μ*-scale regions B-O breakdown → E-fields > 2.5 x 10^{11} V/m threshold

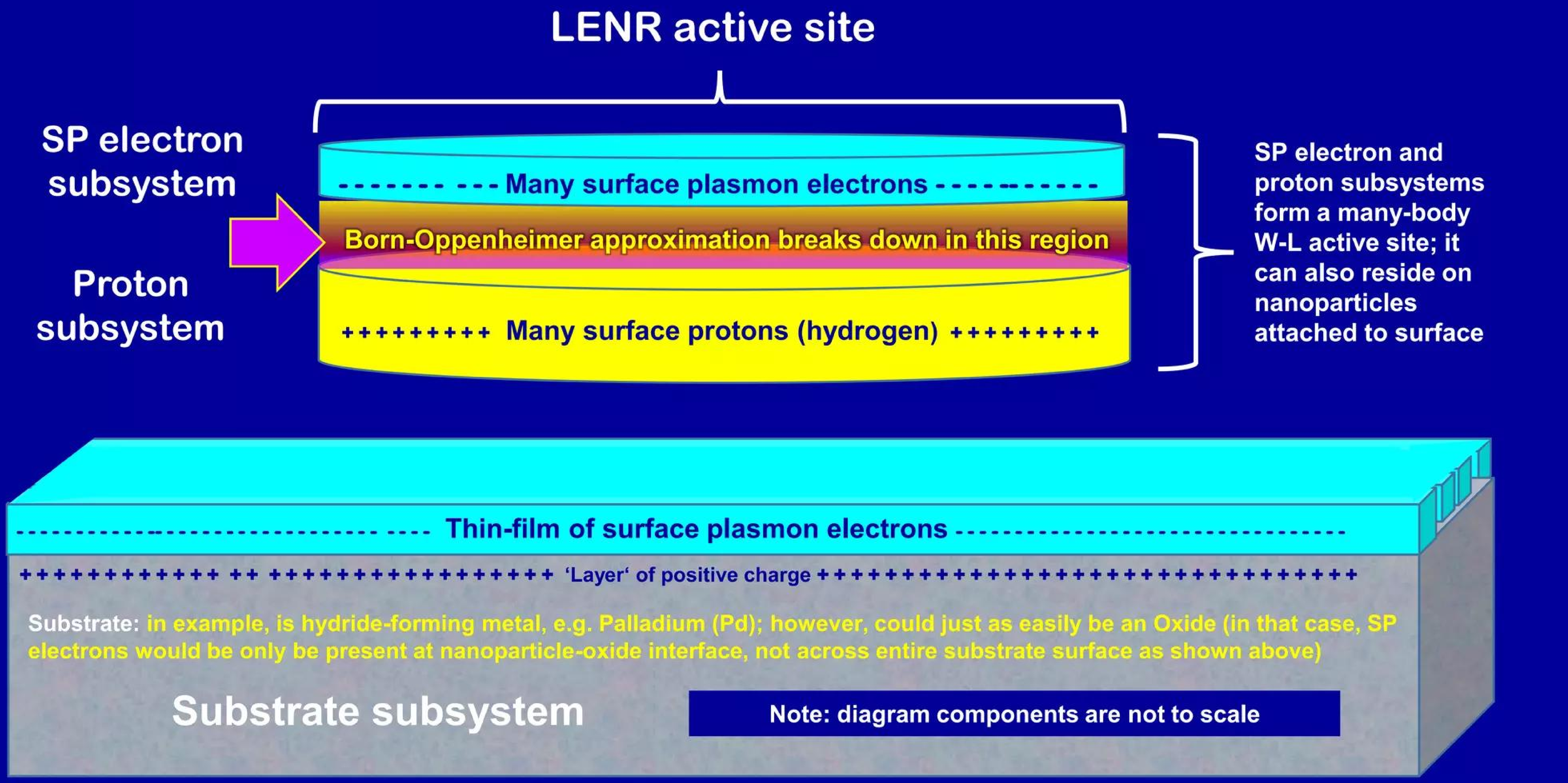
- ✓ Breakdown of Born-Oppenheimer approximation well-established as occurring under certain conditions in various types of systems; measured experimentally
- ✓ See: A. Bushmaker *et al.*, "Direct observation of Born-Oppenheimer approximation breakdown in carbon nanotubes" *Nano Letters* 9 pp. 607 (2009)
  http://core.ac.uk/download/pdf/4881613.pdf
- ✓ Well-known to break down on metallic surfaces: quoting John Tully, "Breakdown of the Born-Oppenheimer assumption is the rule rather than the exception in electron transfer reactions, photochemistry, and reactions at metal surfaces."
  http://www.chem.yale.edu/~tully/research.html
- ✓ Also known to break down on aromatic rings in conjunction with quantum entanglement of protons on those rings (see Chatzidimitriou-Dreismann & Mayers, *Journal of Chemical Physics* 116 pp. 1511 - 2002). Quoting from their paper, "… our NCS results …indicate that the physical meaning of … Born-Oppenheimer [approximation] should be critically reconsidered … at least for chemical processes in the …femtosecond time scale … [we also] demonstrate that short-lived protonic quantum entanglement and decoherence are of much broader significance than realized thus far."
  http://adsabs.harvard.edu/abs/2002JChPh.116.1511C

Concept of a microscopic LENR surface active site

Comprised of many-body patches of protons/electrons on surface

SP electrons and protons oscillate collectively and are mutually Q-M entangled

Diameters of many-body active sites randomly range from several *nm* up to ~ 100^+ microns



LENR active site

SP electron subsystem

- - - - - - - - - - Many surface plasmon electrons - - - -- - - - - -

Born-Oppenheimer approximation breaks down in this region

Proton subsystem

+ + + + + + + + + Many surface protons (hydrogen) + + + + + + + + +

SP electron and proton subsystems form a many-body W-L active site; it can also reside on nanoparticles attached to surface

- - - - - - - - - - - -- - - - - - - - - - - - - - - - - - - - - - - Thin-film of surface plasmon electrons -

+ + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + 'Layer' of positive charge +

Substrate: in example, is hydride-forming metal, e.g. Palladium (Pd); however, could just as easily be an Oxide (in that case, SP electrons would be only be present at nanoparticle-oxide interface, not across entire substrate surface as shown above)

Substrate subsystem

Note: diagram components are not to scale

W-L theory posits that LENRs are a multi-step process

Summary of key steps that occur in electroweak catalysis of neutrons

Five-step hard-radiation-free process occurs in 200 - 400 nanoseconds or less

1. Collectively oscillating, quantum mechanically entangled, many-body patches of hydrogen (protons or deuterons) form spontaneously on metallic surfaces

2. Born-Oppenheimer approximation spontaneously breaks down, allows E-M coupling between local surface plasmon electrons and patch protons; enables application of input energy to create nuclear-strength local electric fields > 2 x 10^{11} V/m - increases effective masses of surface plasmon electrons in sites

3. Heavy-mass surface plasmon electrons formed in many-body active sites can react directly with electromagnetically interacting protons; process creates neutrons and benign neutrinos via a collective electroweak $e + p$ reaction

4. Neutrons collectively created in sites have ultra-low kinetic energies; almost all absorbed by nearby atoms - few neutrons escape into environment; locally produced or ambient gammas converted directly into infrared photons by unreacted heavy electrons (US# 7,893,414 B2) - no deadly gamma emissions

5. Transmutation of atoms of locally present elements is induced at active sites

W-L explains temporal details of electroweak catalysis

Neutron production/capture occur on time-scales 10^{-22} to 10^{-12} seconds

Fast chemical reactions take nanoseconds (10^{-9} s); 1 nanosec = 10^{9} attoseconds

- ✓ Ultracold neutron production can begin in an LENR many-body active sites sometime after local electric field strength exceeds ~ 2.5 x 10^{11} V/m (i.e., e^{-*} mass renormalization ratio β now greater than the minimum threshold ratio β_0) and an adequate number of mass-renormalized e^{-*} electrons have been created (enabled by local breakdown of the Born-Oppenheimer approximation in ~temporal conjunction with nonequilibrium energy inputs to active sites)

- ✓ Electroweak $e^{-*} + p^{+}$ or $e^{-*} + d^{+}$ reactions will occur during many-body, collectively oscillating protons' brief moments of quantum coherence (evanescent Q-M entanglement within patch); duration of such proton coherence times are on the order of attoseconds (~10^{-18} sec); these times have been measured by Chatzidimitriou-Dreismann (2005) and are cited on Slide #44 in http://www.slideshare.net/lewisglarsen/lattice-energy-llctechnical-overviewpahs-and-lenrsnov-25-2009

- ✓ Once e^{-*} mass renormalization set-up process has completed and heavy e^{-*} electrons and p^{+} protons are ready to react (i.e., β now > β_0), electroweak reactions that follow will then only require ~10^{-19} to 10^{-22} sec to finish. Thus, while proton Q-M coherence times may be quite short, collective electroweak reactions that produce neutrons operate on even faster nuclear time-scales, thereby allowing collective neutron production to proceed at substantial rates

- ✓ Since collectively produced neutrons are ultra-ultra-low energy and local neutron capture processes occur on time-scales of picoseconds (10^{-12} sec), not nearly enough time for them to thermalize (that requires 0.1 - 0.2 μsec per S. Lamoreaux), so the vast majority of neutrons are captured locally on nearby atoms; systems do not emit any MeV-energy neutron radiation

LENR neutrons are produced at ultralow kinetic energies

Deeply connected to Q-M entanglement of protons in LENR active sites

In condensed matter LENRs the system of collective, highly correlated particle interactions is a an active site comprising a many-body surface patch of N_p collectively oscillating protons that are all electromagnetically coupled to many nearby collectively oscillating SP electrons N_e via local breakdown of the Born-Oppenheimer approximation. After SP electron mass renormalization and neutron production via an electroweak $e + p$ reaction occur, the final state of such localized systems contains ($N_p - 1$) protons, ($N_e - 1$) SP electrons and according to the W-L theory, one freshly produced neutron. Such a system's final state might be naively pictured as containing an isolated free neutron at roughly thermal energies with a DeBroglie wavelength λ of ~2 Angstroms (2 x 10^{-8} cm) - typical for thermalized free neutrons in condensed matter. Here that is not the case: in a many-body collective system's final state, a particular proton, say number k, has been converted into a neutron. The resulting many-body state together with all the unconverted protons may be denoted by the neutron localized $|k\rangle$. However, neutrons produced by a Q-M many-body collective process are not created in a simple state. Wave functions of such a neutron in a many-body patch of N_p identical protons is in fact a superposition of many N_p localized states best described by a delocalized band state:

$$|\psi\rangle \approx \frac{1}{\sqrt{N_p}} \sum_{k=1}^{N} |k\rangle$$

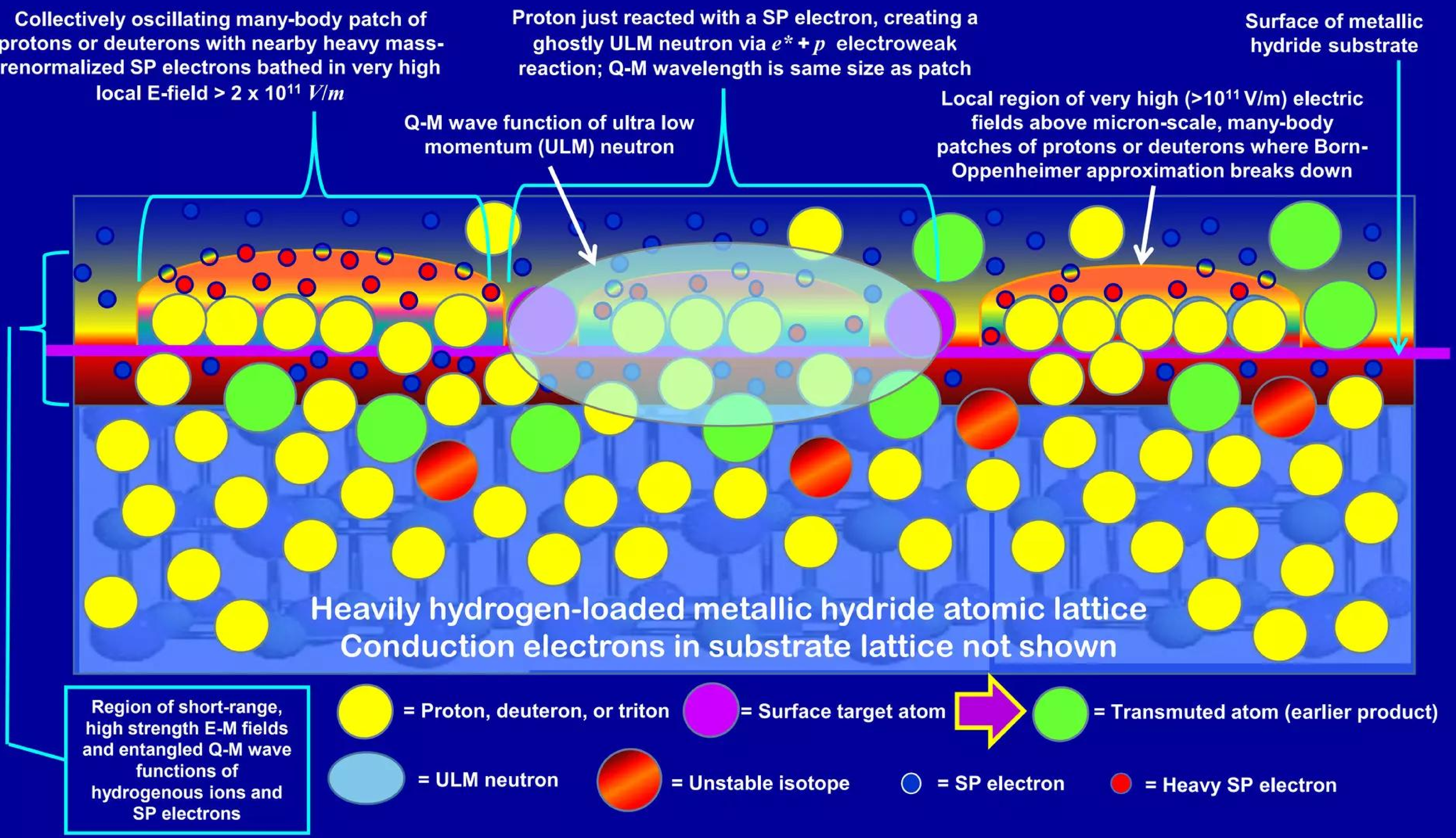
Thus the DeBroglie wavelength λ of LENR neutrons produced by a condensed matter collective system must be comparable to the spatial dimensions of the many-body active sites in which they were produced. Wavelengths of such neutrons can be on the order of $\lambda \approx 3 \times 10^{-3}$ cm or more; ultra low momentum of collectively created neutrons then follows directly from the DeBroglie relation:

$$p = \frac{h}{\lambda} = \frac{2\pi\hbar}{\lambda} = \frac{\hbar}{\lambdabar}$$

Overview of microscopic LENR active sites on surface

Conceptual overview of 5-step electroweak catalysis and transmutation

Physical size of many-body active sites can range from 2 nm up to 100^+ microns



Collectively oscillating many-body patch of protons or deuterons with nearby heavy mass-renormalized SP electrons bathed in very high local E-field > 2 x 10^{11} V/m

Proton just reacted with a SP electron, creating a ghostly ULM neutron via $e^* + p$ electroweak reaction; Q-M wavelength is same size as patch

Surface of metallic hydride substrate

Q-M wave function of ultra low momentum (ULM) neutron

Local region of very high (>10^{11} V/m) electric fields above micron-scale, many-body patches of protons or deuterons where Born-Oppenheimer approximation breaks down

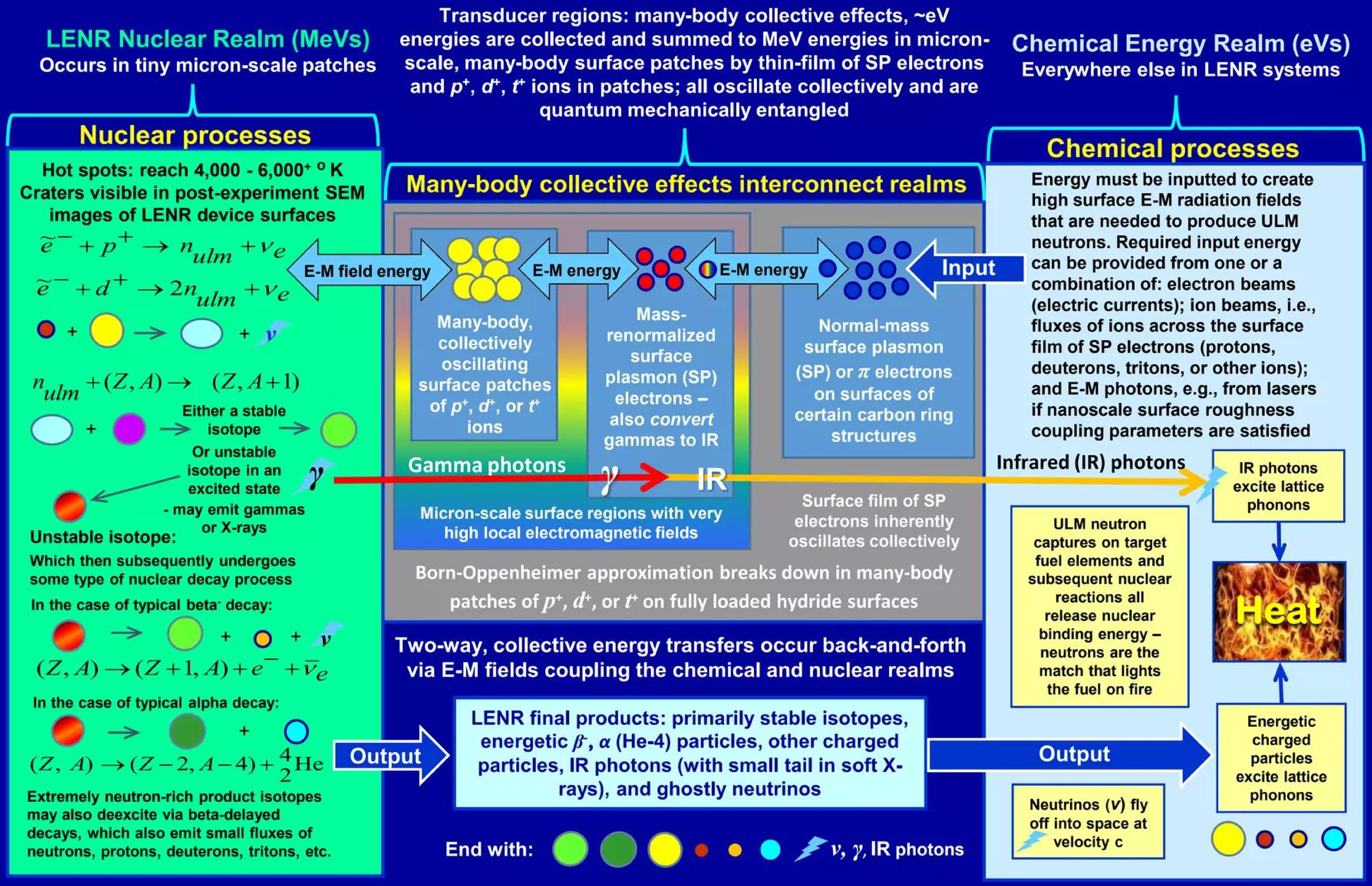
Heavily hydrogen-loaded metallic hydride atomic lattice
Conduction electrons in substrate lattice not shown

Region of short-range, high strength E-M fields and entangled Q-M wave functions of hydrogenous ions and SP electrons

🟡 = Proton, deuteron, or triton
🟣 = Surface target atom ⇨ 🟢 = Transmuted atom (earlier product)
⬭ = ULM neutron
🔴 = Unstable isotope
● = SP electron
● = Heavy SP electron

Overview of microscopic LENR active sites on surface

Sites exist for 200-400 nanoseconds before Q-M entanglement destroyed



LENR Nuclear Realm (MeVs)
Occurs in tiny micron-scale patches

Transducer regions: many-body collective effects, ~eV energies are collected and summed to MeV energies in micron-scale, many-body surface patches by thin-film of SP electrons and p^+, d^+, t^+ ions in patches; all oscillate collectively and are quantum mechanically entangled

Chemical Energy Realm (eVs)
Everywhere else in LENR systems

Nuclear processes

Hot spots: reach 4,000 - 6,000+ ° K
Craters visible in post-experiment SEM images of LENR device surfaces

$$\tilde{e}^- + p^+ \rightarrow n_{ulm} + \nu_e$$

$$\tilde{e}^- + d^+ \rightarrow 2n_{ulm} + \nu_e$$

● + ● → ● + ν

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

● + ● → Either a stable isotope → ●

Or unstable isotope in an excited state - may emit gammas or X-rays γ

Unstable isotope:
Which then subsequently undergoes some type of nuclear decay process

In the case of typical beta⁻ decay:

● → ● + ● + ν

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

In the case of typical alpha decay:

● → ● + ●

$$(Z,\ A) \rightarrow (Z-2, A-4) + {}^{4}_{2}\mathrm{He}$$

Extremely neutron-rich product isotopes may also deexcite via beta-delayed decays, which also emit small fluxes of neutrons, protons, deuterons, tritons, etc.

Many-body collective effects interconnect realms

E-M field energy

Many-body, collectively oscillating surface patches of p^+, d^+, or t^+ ions

E-M energy

Mass-renormalized surface plasmon (SP) electrons – also *convert* gammas to IR

E-M energy

Normal-mass surface plasmon (SP) or π electrons on surfaces of certain carbon ring structures

Input

Gamma photons γ → IR

Micron-scale surface regions with very high local electromagnetic fields

Surface film of SP electrons inherently oscillates collectively

Born-Oppenheimer approximation breaks down in many-body patches of p^+, d^+, or t^+ on fully loaded hydride surfaces

Two-way, collective energy transfers occur back-and-forth via E-M fields coupling the chemical and nuclear realms

Output

LENR final products: primarily stable isotopes, energetic β^-, α (He-4) particles, other charged particles, IR photons (with small tail in soft X-rays), and ghostly neutrinos

End with: ● ● ● ● ● ● ν, γ, IR photons

Chemical processes

Energy must be inputted to create high surface E-M radiation fields that are needed to produce ULM neutrons. Required input energy can be provided from one or a combination of: electron beams (electric currents); ion beams, i.e., fluxes of ions across the surface film of SP electrons (protons, deuterons, tritons, or other ions); and E-M photons, e.g., from lasers if nanoscale surface roughness coupling parameters are satisfied

Infrared (IR) photons

IR photons excite lattice phonons

ULM neutron captures on target fuel elements and subsequent nuclear reactions all release nuclear binding energy – neutrons are the match that lights the fuel on fire

Heat

Output

Energetic charged particles excite lattice phonons

Neutrinos (ν) fly off into space at velocity c

● ● ● ●

Patches of p^+ protons form spontaneously on surfaces

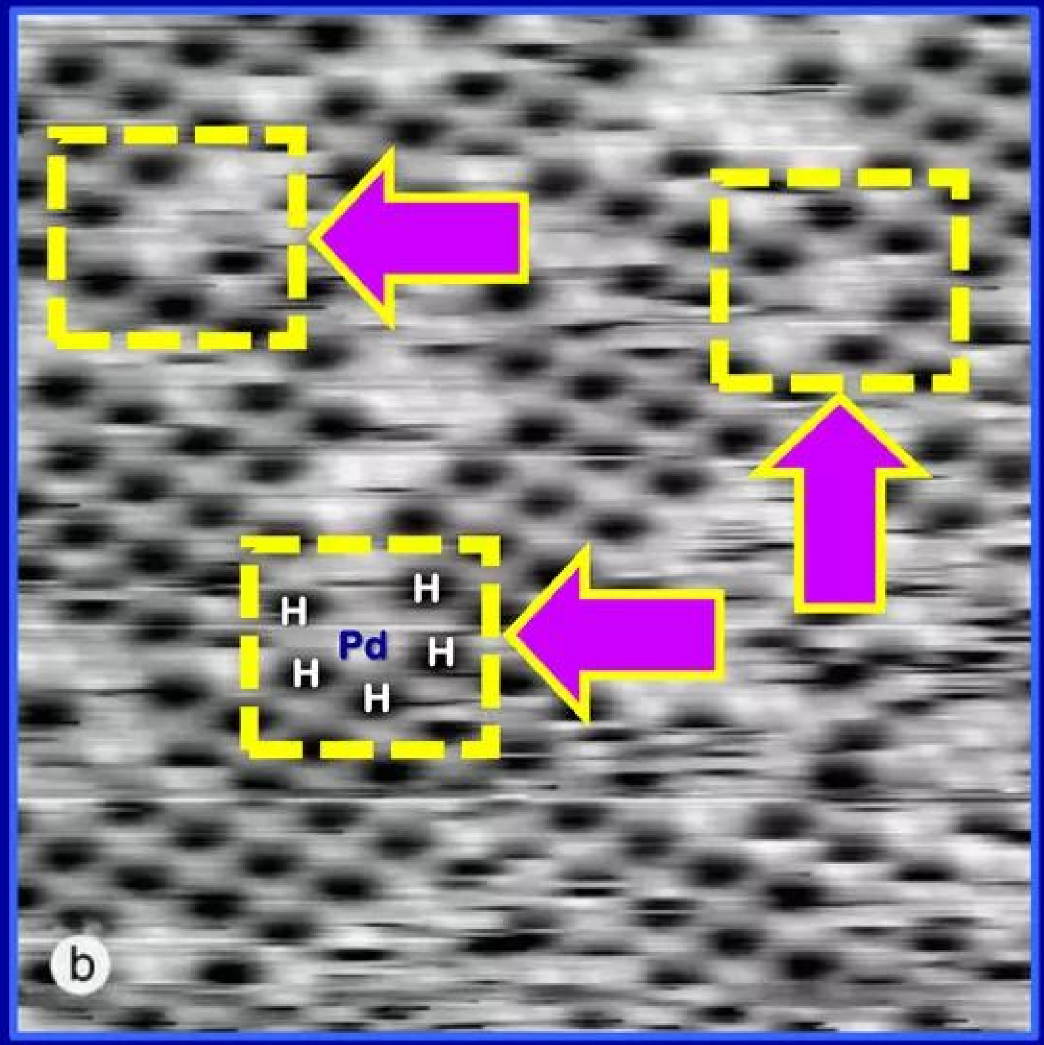
Physical size of LENR active sites ranges from 2 nm to 100^+ microns

With metal hydrides bulk lattice loading H/metal must be > 0.80 for sites to form

Example illustrates formation of hydrogenous patches on metallic hydride surface

- ✓ **Lattice comment:** image shows small many-body patches of protons on Pd surface. Visual inspection of STM image in adapted version of Fig. 1 reveals that under Mitsui *et al.'s* experimental conditions, PdHx ratios at many surface sites would appear to be comfortably above the minimal critical value of H/Pd > 0.80 known to be necessary for LENR triggering; PdHx H/Pd ratios seen at some sites can apparently range as high as x = 5.0 (see Figure 1)
- ✓ Therefore, similarly high PdHx ratios would seem to be plausible in the case of high % surface coverage of hydrogen atoms (protons) on fully loaded Pd(111) surfaces at room temperature of 273 K and beyond. **Thus, high PdHx ratios could reasonably be expected to occur within nm to micron-sized, many-body, entangled hydrogenous active sites conjectured in the Widom-Larsen theory of LENRs**

STM image of H on Pd(111) adapted from Fig. 1 in Mitsui *et al*. (2003)



"Hydrogen absorption and diffusion on Pd (111)" T. Mitsui *et al*. *Surface Science* 540 pp. 5 - 11 (2003)

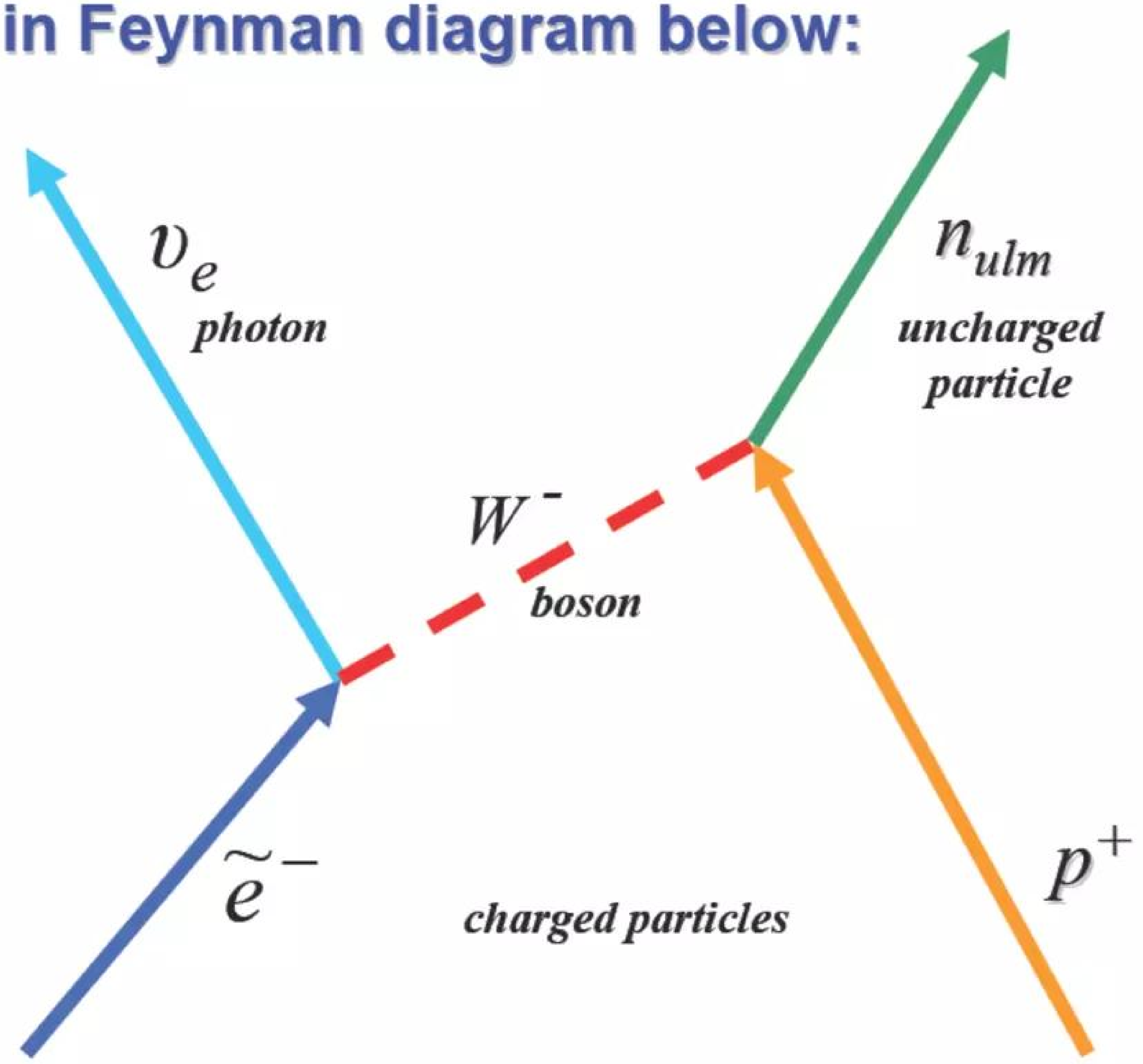
http://www.researchgate.net/publication/229342506_Hydrogen_adsorption_and_diffusion_on_Pd(111)

Many-body collective quantum effects crucial to LENRs

While written as two-body e^- + p^+ reaction LENR catalysis is many-body

Condensed matter many-body collective effects involve quantum entanglement

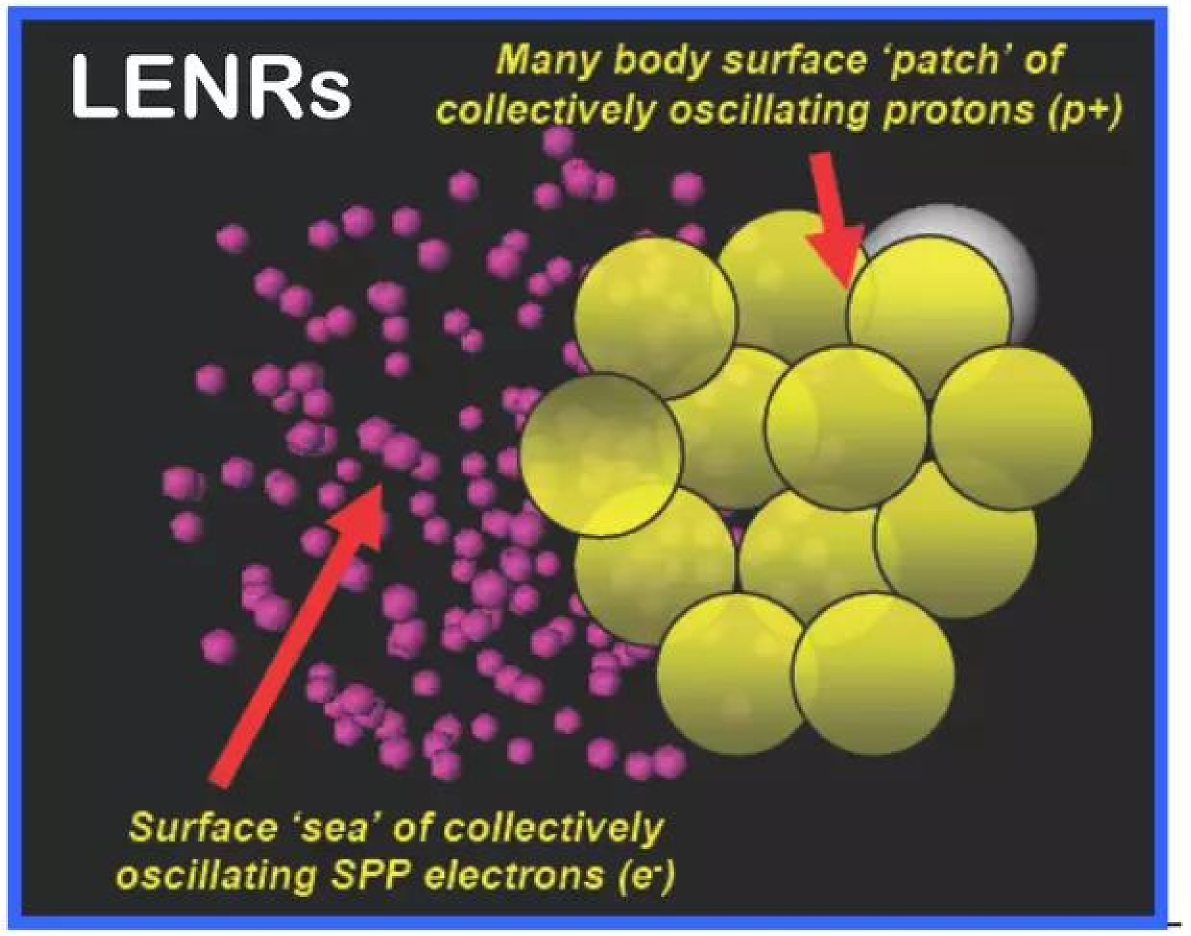
Simple two-body collision shown in Feynman diagram below:



$$\tilde{e}^- + p^+ \longrightarrow n_{ulm} + \nu_e$$

What really happens is many-body

Now add collective rearrangements from condensed matter effects. It is not just a two body collision !!!



Above is what really occurs on metallic hydride cathodes

Many-body collective quantum effects crucial to LENRs

Surface plasmon electrons e^{-}_{sp} are quantum mechanically entangled

SPs involve 10^{10} electrons and are macroscopic but nonetheless Q-M entangled

“Plasmon-assisted transmission of entangled photons” E. E.
E. Altewischer *et al.*, *Nature* 418 pp. 304 - 306 (2002)
http://home.physics.leidenuniv.nl/~exter/articles/nature.pdf

- ✓ “Here we investigate the effects of nanostructured metal optical elements on the properties of entangled photons. To this end, we place optically thick metal films perforated with a periodic array of subwavelength holes in the paths of the two entangled photons. Such arrays convert photons into surface-plasmon waves --- optically excited compressive charge density waves --- which tunnel through the holes before reradiating as photons at the far side. We address the question of whether the entanglement survives such a conversion process. Our coincidence counting measurements show that it does, so demonstrating that the surface plasmons have a true quantum nature.”
- ✓ “From a general perspective, the observed conservation of quantum entanglement for the conversion from photon → surface plasmon → photon is a demonstration of the true quantum nature of SPs.”
- ✓ “ … a simple estimate shows that SPs are very macroscopic, in the sense that they involve some 10^{10} electrons. Our experiment proves that this macroscopic nature does not impede the quantum behaviour of SPs …”

Many-body collective quantum effects crucial to LENRs

Q-M entanglement of protons & electrons is very widespread in Nature

Observed in variety of small and large molecular structures containing Hydrogen

- ✓ Protons found within a wide variety of many-body condensed matter molecular systems spontaneously oscillate coherently and collectively; their quantum mechanical (Q-M) wave functions are thus effectively entangled with each other and also with nearby collectively oscillating electrons; amazingly, this behavior occurs even in comparatively smaller, much simpler molecular systems such as $(NH_4)_2PdCl_6$, ammonium hexaclorometallate (see Krzystyniak *et al.*, 2007 and Abdul-Redah & Dreismann, 2006)

- ✓ Quoting from 2007 paper by Krzystyniak *et al.*: "… different behaviors of the observed anomaly were found for LaH_2 and LaH_3 … As recognized by Chatzidimitriou-Dreismann *et al.* … Coulombic interaction between electrons and protons may build up entanglement between electrons and protons. Such many body entangled states are subject to decoherence mechanisms due to the interaction of the relevant scattering systems with its environment … one can conclude that the vibrational dynamics of NH_4^+ protons as fairly well decoupled from the dynamics of the [attached] heavier nuclei."

- ✓ Elaborating further from Chatzidimitriou-Dreismann (2005), "Further NCS experiments confirmed the existence of this effect in quite different condensed matter systems, e.g., urea dissolved in D_2O, metallic hydrides, polymers, 'soft' condensed matter, liquid benzene, and even in liquid H_2-D_2 and HD."

Many-body collective quantum effects crucial to LENRs

Protons go in-and-out of entanglement in 100-500 x 10^{-18} s time-frames

LENRs can take advantage of this because they work on even faster time-scales

- ✓ C. Chatzidimitriou-Dreismann (Technical University of Berlin) and collaborators have published extensively on collective proton entanglement since 1995; see:

  "Attosecond quantum entanglement in neutron Compton scattering from water in the keV range" (2007) http://arxiv.org/PS_cache/cond-mat/pdf/0702/0702180v1.pdf

  Quoting from paper: "Several neutron Compton scattering (NCS) experiments on liquid and solid samples containing protons or deuterons show a striking anomaly, i.e. a shortfall in the intensity of energetic neutrons scattered by the protons; cf. [1, 2, 3, 4]. E.g., neutrons colliding with water for just 100 - 500 attoseconds (1 as = 10^{-18} s) will see a ratio of hydrogen to oxygen of roughly 1.5 to 1, instead of 2 to 1 corresponding to the chemical formula H_2O. … Recently this new effect has been independently confirmed by electron-proton Compton scattering (ECS) from a solid polymer [3, 4, 5]. The similarity of ECS and NCS results is striking because the two projectiles interact with protons via fundamentally different forces, i.e. the electromagnetic and strong forces." Proton entanglement is widespread in Nature

- ✓ Also see: "Entangled mechanical oscillators," J. Jost *et al.*, *Nature* 459 pp. 683 - 685 (2009) in which they state that the "... mechanical vibration of two ion pairs separated by a few hundred micrometres is entangled in a quantum way."

  Jost's thesis: http://www.nist.gov/pml/div688/grp10/upload/Jost2010thesis.pdf

Proton Q-M entanglement extends to mesoscopic scales

“Protons are unique to understanding quantum entanglement”

Measurements show entanglement of protons is present at 300° K

“Evidence of macroscopically entangled protons in a mixed isotope crystal of $KH_pD_{1-p}CO_3$”
F. Fillaux, A. Cousson, and M. Gutmann
Journal of Physics: Condensed Matter 22 pp. 045402 (2010)
http://iopscience.iop.org/0953-8984/22/4/045402/pdf/0953-8984_22_4_045402.pdf

Quoting directly: “The proposed theory is based upon fundamental laws of quantum mechanics applied to the crystal in question: the structure is periodic; dimers are centrosymmetric; indistinguishable protons are fermions; indistinguishable deuterons are bosons. It leads to macroscopically entangled states and, in the special case of protons, to super-rigidity and spin-symmetry with observable consequences. This theory is consistent with a large set of experimental data (neutron diffraction, QENS, INS, infrared and Raman) and, to the best of our knowledge, there is no conflict with any observation. There is, therefore, every reason to conclude that the crystal is a macroscopic quantum system for which only nonlocal observables are relevant.”

“Protons are unique to demonstrating quantum entanglement, because they are fermions and because the very large incoherent cross-section can merge into the total coherent cross-section. No other nucleus can manifest such an increase of its coherent cross-section. The enhanced features can be, therefore, unambiguously assigned to protons, in accordance with their positions in reciprocal space. They are evidences of macroscopic quantum correlations which have no counterpart in classical physics.”

“This work presents one single case of macroscopically entangled states on the scale of Avogadro's constant in a mixed isotope crystal at room temperature. The quantum theory suggests that such macroscopic quantum effects should be of significance for many hydrogen bonded crystals.”

Many-body collective quantum effects crucial to LENRs

“Our experiments prove … quantum wave nature … of up to 430 atoms”

Weight of largest molecule in study = 6.9 kDa; weight of a small enzyme = 18 kDa

“Quantum interference of large organic molecules”
S. Gerlich *et al.*, doi:10.1038/ncomms1263
Nature Communications 2, Article number: 263 (2011)
http://www.nature.com/ncomms/journal/v2/n4/pdf/ncomms1263.pdf

Abstract: “The wave nature of matter is a key ingredient of quantum physics and yet it defies our classical intuition. First proposed by Louis de Broglie a century ago, it has since been confirmed with a variety of particles from electrons up to molecules. Here we demonstrate new high-contrast quantum experiments with large and massive tailor-made organic molecules in a near-field interferometer. Our experiments prove the quantum wave nature and delocalization of compounds composed of up to 430 atoms, with a maximal size of up to 60 Å, masses up to m = 6,910 AMU and de Broglie wavelengths down to $\lambda_{dB} = h/mv \approx$ 1 pm. We show that even complex systems, with more than 1,000 internal degrees of freedom, can be prepared in quantum states that are sufficiently well isolated from their environment to avoid decoherence and to show almost perfect coherence.”

Many-body collective quantum effects crucial to LENRs

From Gerlich *et al*. “Quantum interference of large organic molecules”

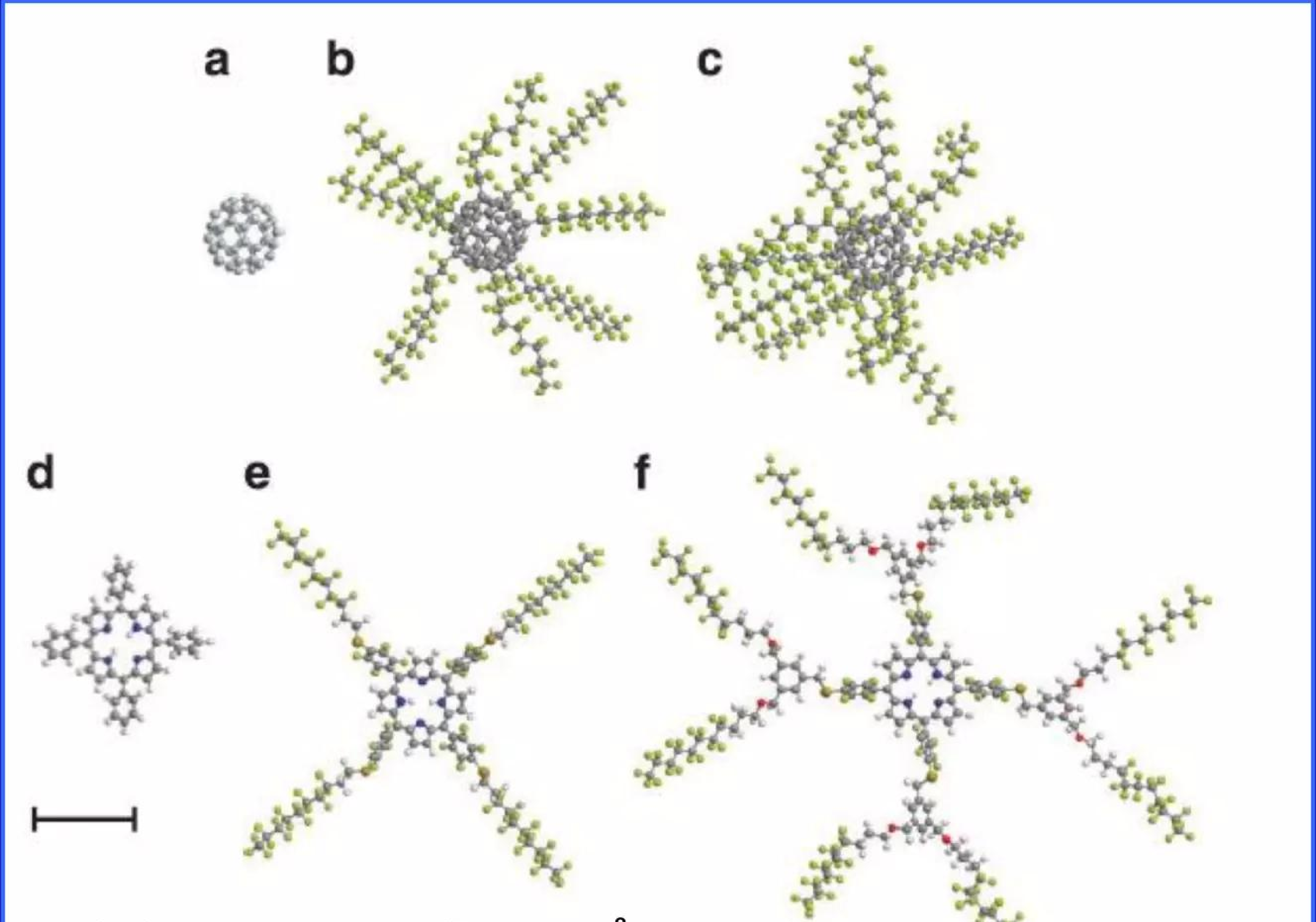
Entanglement is very persistent in large molecules and at elevated temperatures

- ✓ Experimental setup. “The particles are evaporated in a thermal source.”
- ✓ “PFNS10 and TPPF152 contain 430 atoms covalently bound in one single particle. This is ~350% more than that in all previous experiments and it compares well with the number of atoms in small Bose-Einstein condensates (BEC), which, of course, operate in a vastly different parameter regime: The molecular de Broglie wavelength λ_{dB} is about six orders of magnitude smaller than that of ultracold atoms and the internal molecular temperature exceeds typical BEC values ($T < 1\ \mu K$) by about nine orders of magnitude. Although matter wave interference of BECs relies on the de Broglie wavelength of the individual atoms, our massive molecules always appear as single entities.”
- ✓ “In our experiment, the superposition consists of having all 430 atoms simultaneously ‘in the left arm’ and ‘in the right arm’ of our interferometer, that is, two possibilities that are macroscopically distinct. The path separation is about two orders of magnitude larger than the size of the molecules.”
- ✓ “In conclusion, our experiments reveal the quantum wave nature of tailor-made organic molecules in an unprecedented mass and size domain. They open a new window for quantum experiments with nanoparticles in a complexity class comparable to that of small proteins …”

Many-body collective quantum effects crucial to LENRs

From Gerlich *et al*. "Quantum interference of large organic molecules"

Figure 1 from paper shows "Gallery of molecules used in our interference study"



Scale bar corresponds to 10 Å

Chemical and nuclear realms interoperate on surfaces

LENRs: complex interplay between E-M/chemical/nuclear processes

Resonant E-M cavities can transfer energy directly to LENR active surface sites

- ✓ It is well-known that metallic surface nanostructures and SP electrons can have configurations that can absorb electromagnetic (E-M) energy over a wide area, transport and concentrate it, and --- in conjunction with contiguous surface patches of collectively oscillating protons --- create nuclear-strength local electric fields that are required to produce neutrons in LENR active sites

- ✓ For substrate surfaces on which LENR active sites have formed, there are a myriad of different complex, nanometer-to micron-scale electromagnetic, chemical, and nuclear processes operating simultaneously. LENR active sites involve extremely complex interplays between surface plasmon electrons, E-M fields, and many different types of nanostructures with various geometries, surface locations relative to each other, different-strength local E-M fields, and varied chemical or isotopic compositions. Key: electromagnetic, chemical, and nuclear processes can coexist and interact on small length-scales at surfaces

- ✓ To varying degrees, many of these complex, time-varying surface interactions are electromagnetically coupled on many different physical length-scales. Thus, mutual E-M resonances can be very important in such systems. In addition to optical frequencies, SP and π electrons in condensed matter often also have strong absorption and emission bands in both infrared (IR) and UV portions of E-M spectrum; this can lead to formation of resonant E-M cavities

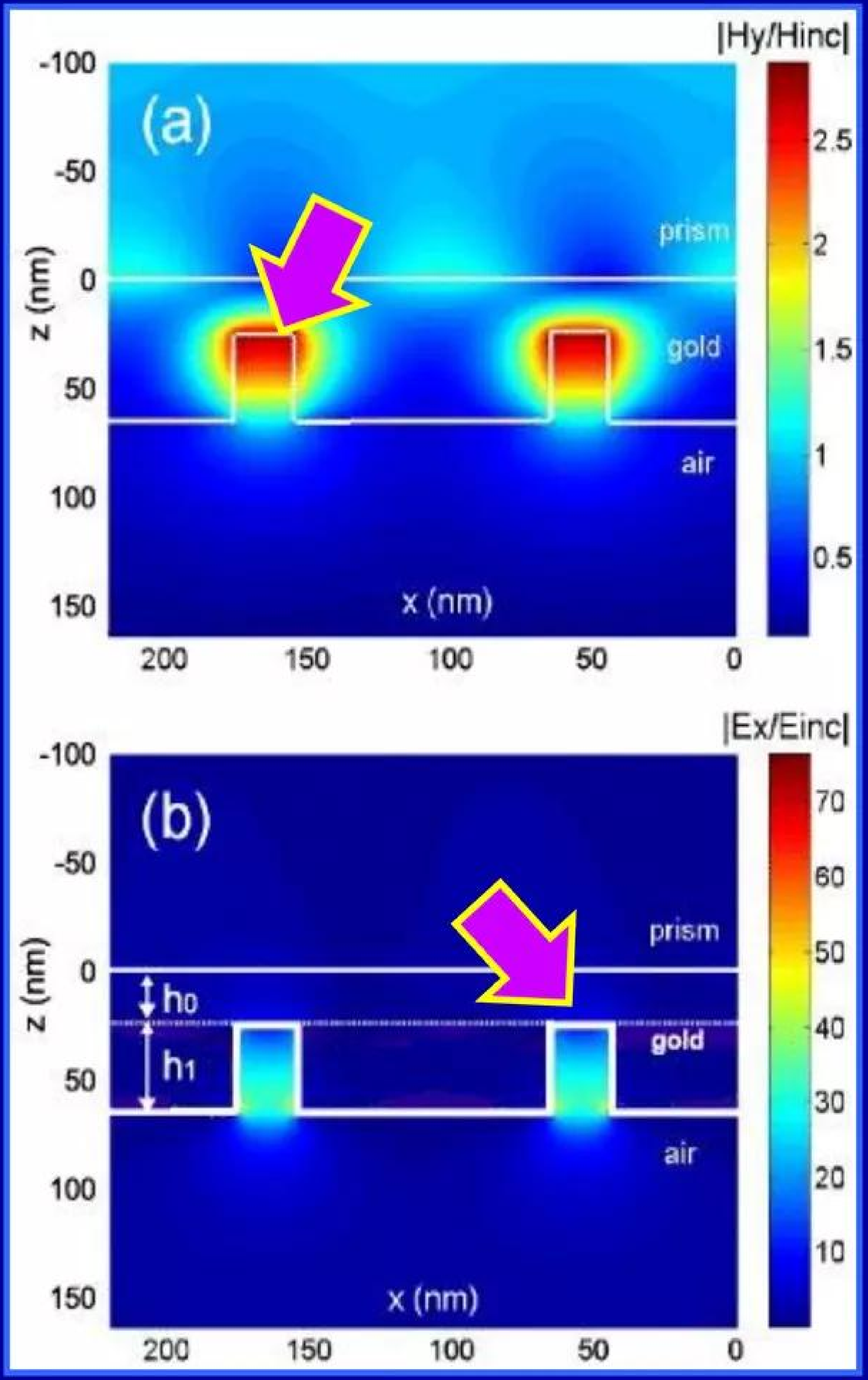
LENRs can utilize resonant electromagnetic cavities

Cavities can be radiative or non-radiative: transfer or store E-M energy

"Enhancing reactive energy through dark cavity plasmon modes" J. Le Perchec *Europhysics Letters* 92 DOI: 10.1209/0295-5075/92/67006 (2010)
http://iopscience.iop.org/0295-5075/92/6/67006

Abstract:

"We present an opto-geometrical configuration in which a metallic surface having nanometer-scale grooves can be forced to efficiently resonate without emitting radiation. The structure is excited from the backside, by an evanescent wave, which allows to inhibit light re-emission and to drastically modify the quality factor of the resonance mode. The energy balance of the system, especially the imaginary part of the complex Poynting vector flux, is theoretically analysed thanks to a modal method. It is shown how the generated hot spots (coherent cavity modes of electro-static type) can store a great amount of unused reactive energy. This behaviour might thus inspire a novel use of such highly sensitive surfaces for chemical sensing."



Credit: J. Le Perchec

LENRs can utilize resonant electromagnetic cavities

Such cavities can be designed to transfer energy to LENR active sites

"Shaping and focusing light beams with plasmonics"
B. Lee *et al.*
SPIE Newsroom 10.1117/2.1201102.003435 (2011)
http://spie.org/documents/Newsroom/Imported/003435/003435_10.pdf

"The transmitted beam from each slit acts as an independent point light source with the output phase determined by the slit width and length. The light beams focus at the distance of focal length (see Figure 4 for the intensity distribution). We used a general such rule (called a genetic algorithm) to obtain the optimal structural parameters, such as slit widths and lengths, of the multislit structure."

"In summary, we have described two methods for collimating and focusing beams of light. Converting between the SPP mode and light makes it is possible to control beam shapes using grating structures and multiple slits on a metallic layer."

Concentrating E-M energy in resonant electromagnetic cavity

Design nanostructures to position LENR active site(s) at the focal point of power (energy) flows

Arrows show direction of power flows

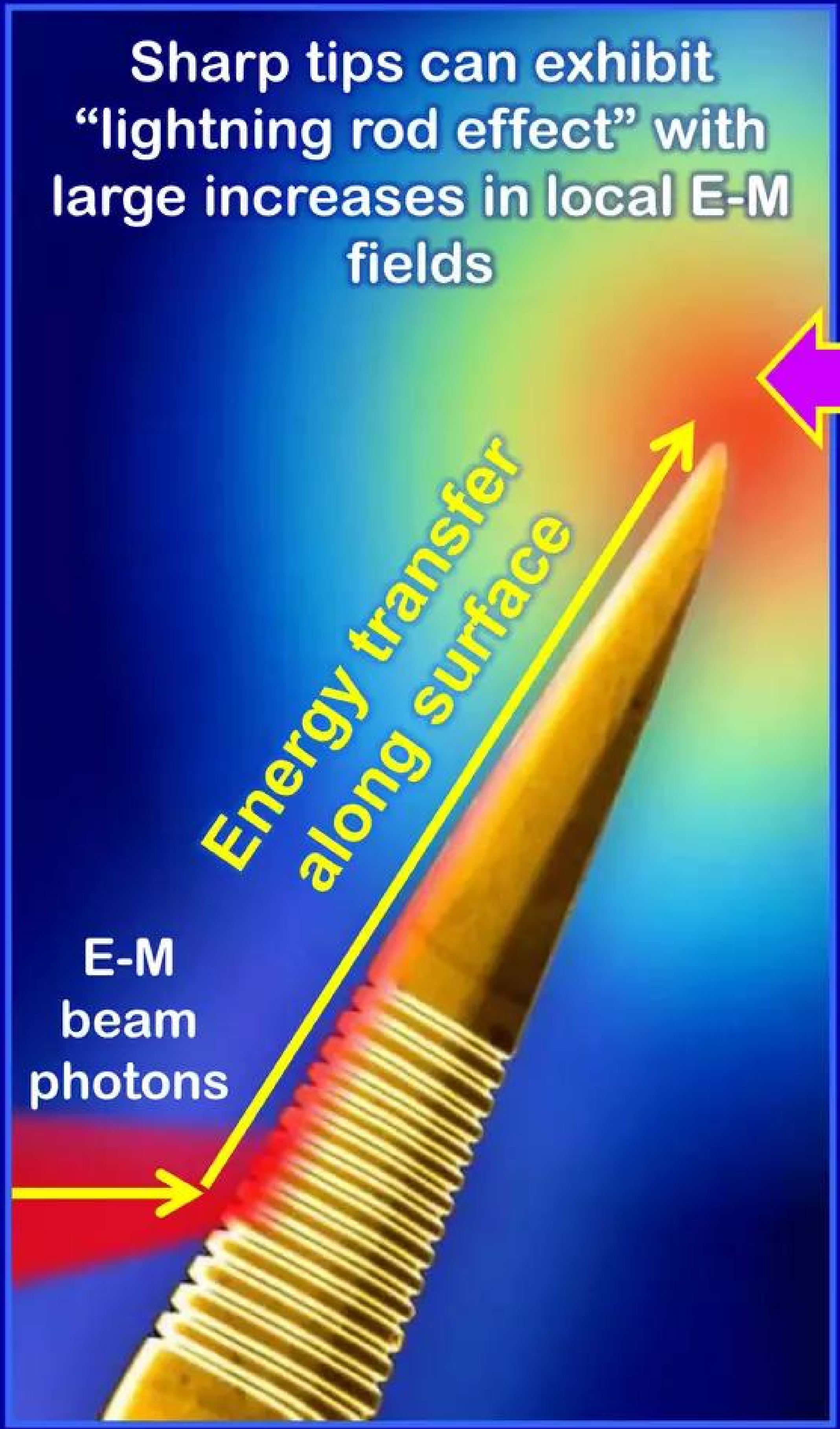
Credit: B. Lee *et al.*, Figure 4.

Nanostructures can be antennas that absorb E-M energy

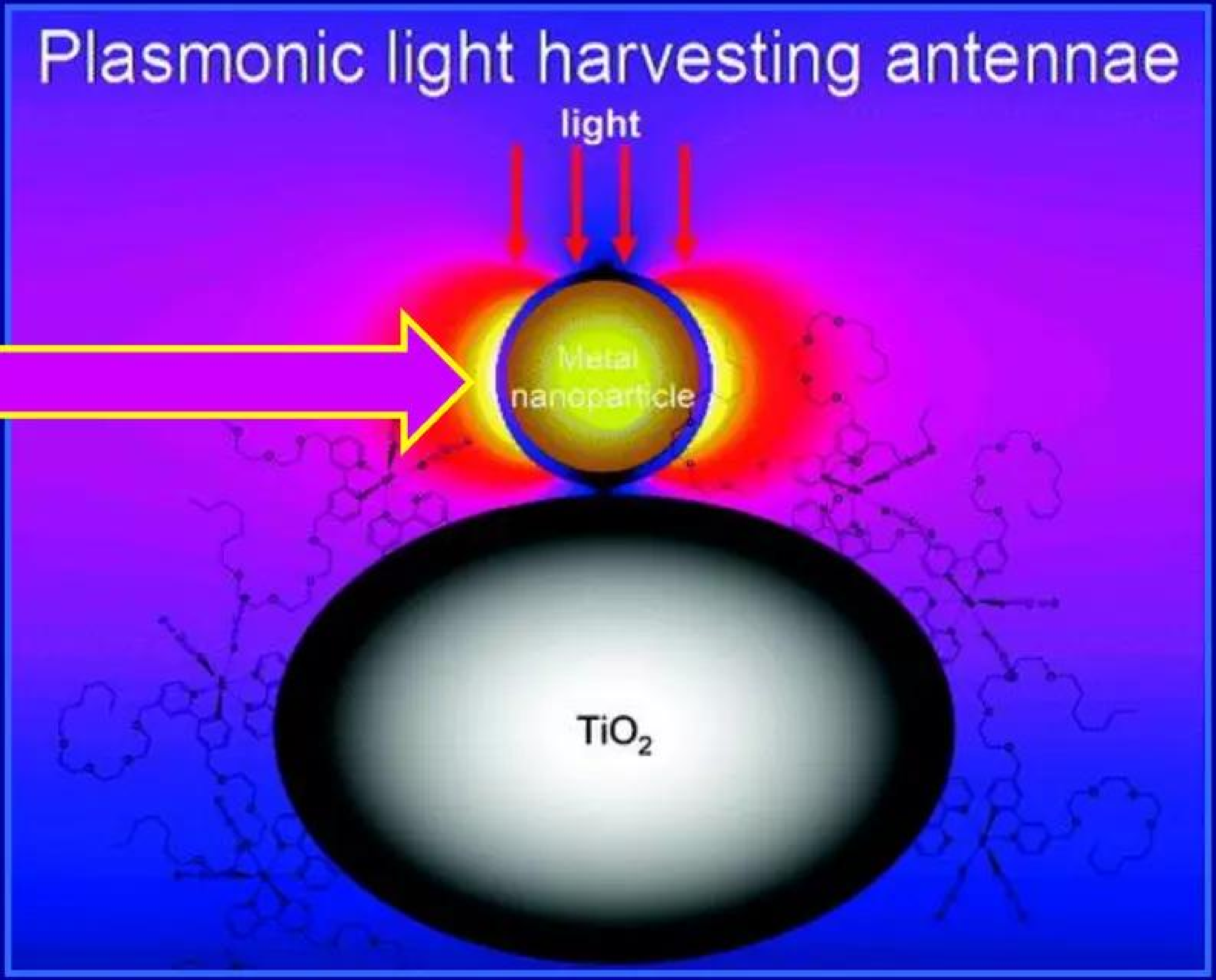
SP electrons on nanoparticles can greatly intensify local electric fields

Nanostructures can be designed that briefly create pulsed E-fields > 2 x 10^{11} V/m

Graphics show capture of E-M photons and energy transfer by SP electrons



Region of enhanced electric fields



http://people.ccmr.cornell.edu/~uli/res_optics.htm

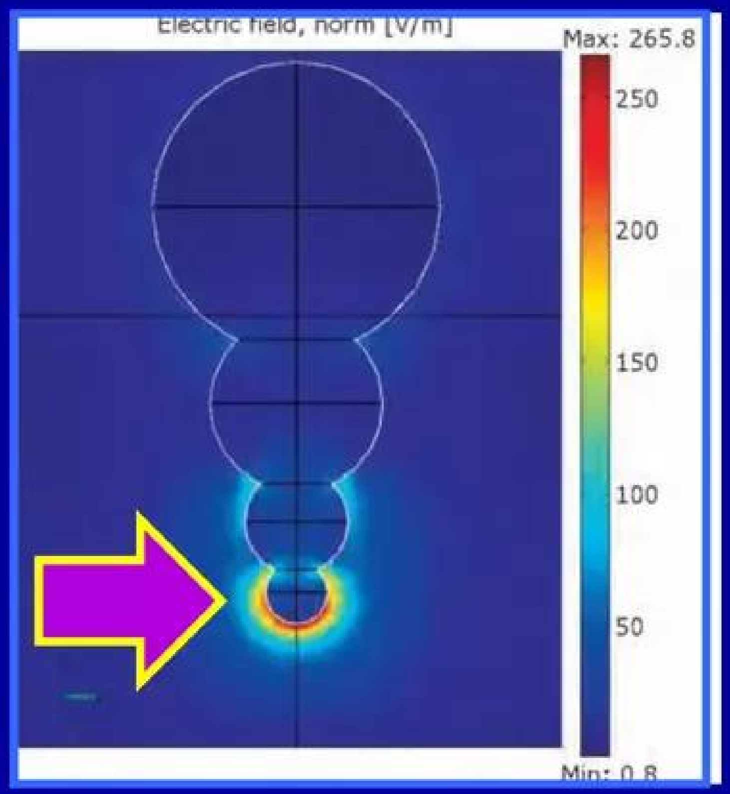
Source of above image is Wiesner Group at Cornell University:

"Plasmonic dye-sensitized solar cells using core-shell metal-insulator nanoparticles" M. Brown *et al.*, *Nano Letters* 11 pp. 438 - 445 (2011) http://pubs.acs.org/doi/abs/10.1021/nl1031106

Huge increase in local E-field strengths on nanoscale

Nanostructures of right shapes/compositions amplify electric fields

Details of nanoparticulate features on *nm* to *μ* length-scales very key to LENRs

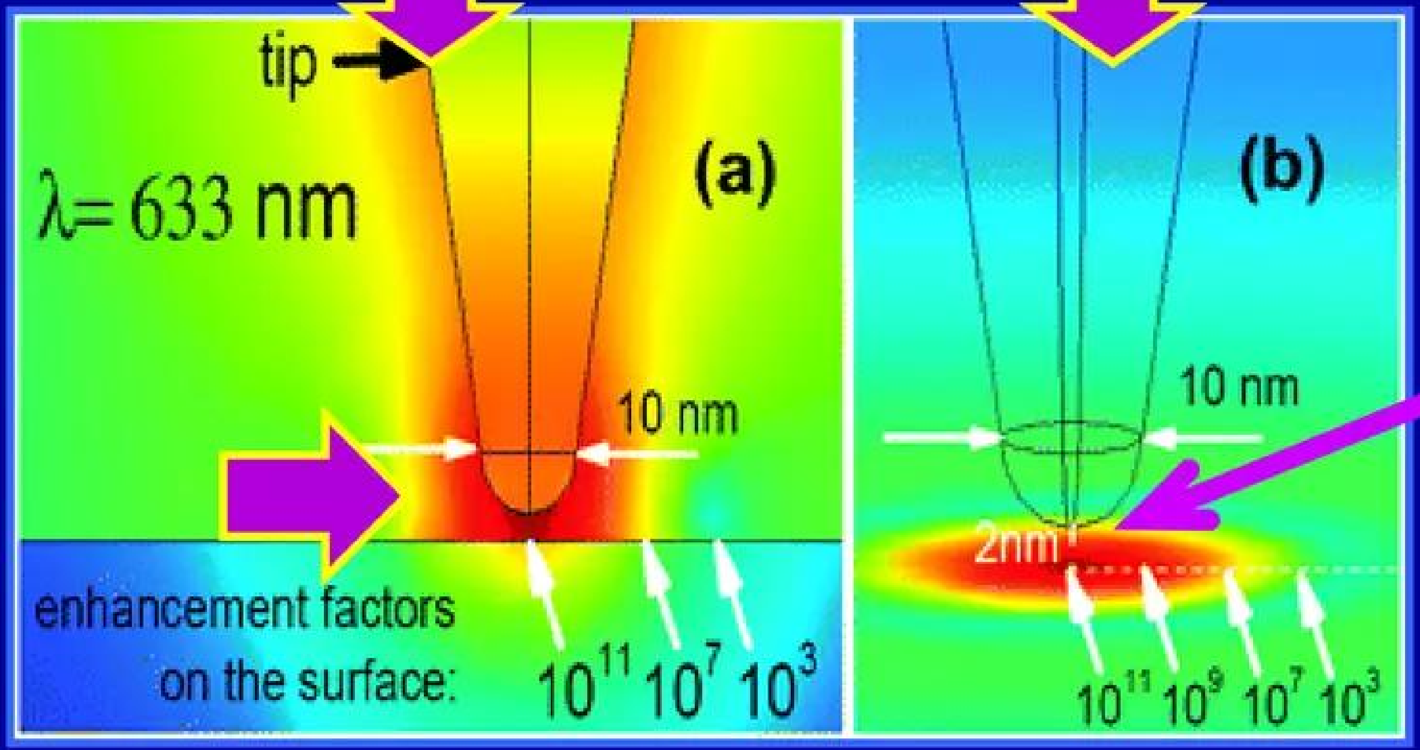


Electric field enhancement at nano-antenna tip:
R. Kappeler *et al*. (2007)


Mandelbrot fractal

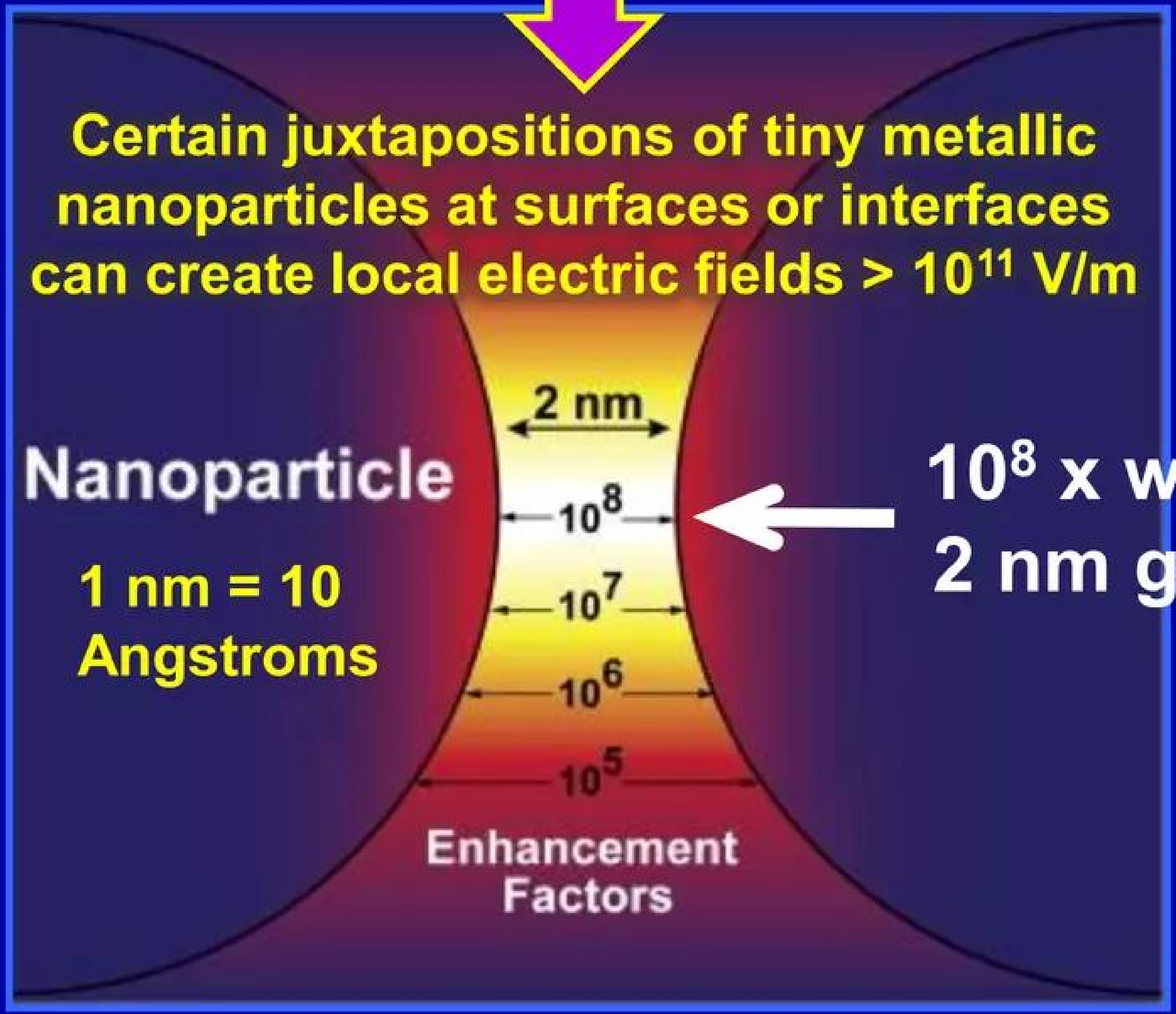
Sharp tips exhibit so-called "lightning rod effect" by creating enormous local enhancement in electric field strengths

Electric fields at tips of atomic force microscopes (AFM) often reach 10^{11} V/m



10^{11} x increase

Shows E-M field strength enhancement as a function of interparticle spacing


Certain juxtapositions of tiny metallic nanoparticles at surfaces or interfaces can create local electric fields > 10^{11} V/m

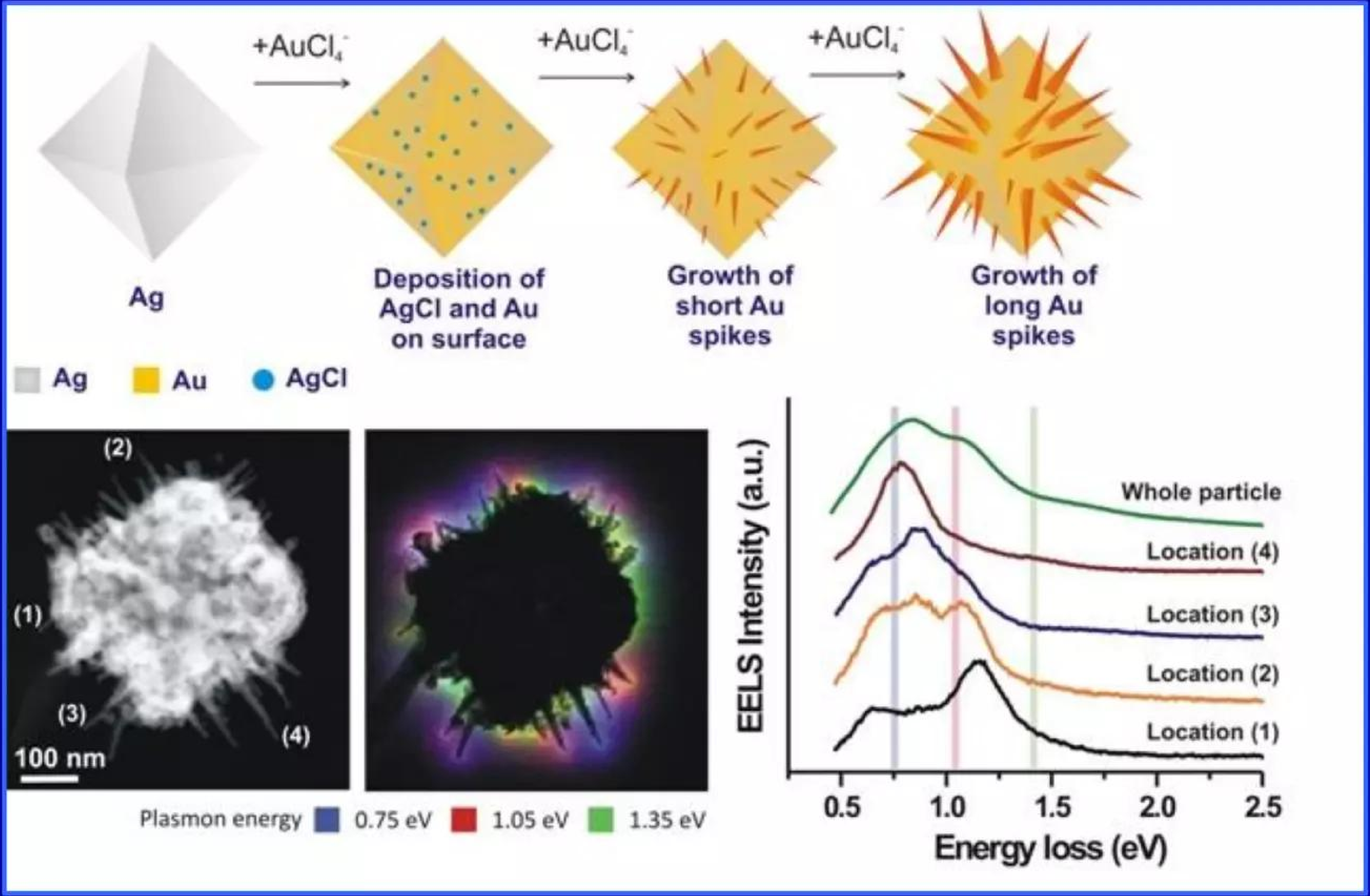
10^8 x with 2 nm gap

Nanoparticle shapes locally intensify electric fields

Grow in Nature and are readily fabricated in nanotech laboratories

Surface plasmons are present on surfaces of metallic NPs embedded in oxides

"Synthesis of spiky Ag-Au octahedral nanoparticles and their tunable optical properties" S. Pedireddy *et al.*, *J. Phys. Chem. C* 117 pp. 16640 - 16649 (2013)
http://pubs.acs.org/doi/abs/10.1021/jp4063077



Nanoparticle shapes/positioning redistribute E-fields

E-fields extremely non-uniform across the surfaces of nanoparticles

Nanostructures can be designed that briefly create pulsed E-fields > 2 x 10^{11} V/m

"Electromagnetic field redistribution in hybridized plasmonic particle-film system"
Y. Fang and Y. Huang
Applied Physics Letters 102 pp. 153108 - 153111 (2013)
http://publications.lib.chalmers.se/records/fulltext/178593/local_178593.pdf

"Combining simulation and experiment, we demonstrate that a metal nanoparticle dimer on a gold film substrate can confine more energy in the particle/film gap because of the hybridization of the dimer resonant lever and the continuous state of the film. The hybridization may even make the electric field enhancement in the dimer/film gap stronger than in the gap between particles. The resonant peak can be tuned by varying the size of the particles and the film thickness."

"By studying the electric field in the gaps A, B, and C (Figures 1(a) and 1(b)), we find that not only is the electric field in the gaps of a dimer-film system much stronger than in a single particle-film system (Figure 1(c)) but also, in a broad wavelength range, the E field in B is even stronger than in C. The maximum enhancement is more than 160 at 680 nm giving a SERS enhancement factor more than 6.5 x 10^8."

"Additional resonant modes are generated in a particle-film system by the hybridization between modes of particles and the continuous surface plasmon state of the film. These hybridized modes, which can be tuned by varying the size of particles and the thickness of the film, will lead to huge electric field enhancements in gaps between particles and film."

Nanoparticle shapes/positioning redistribute E-fields

Fang & Huang's Figs. 1 and 3 show how electric fields are redistributed

Nonuniformity can be predicted, modeled, and used to design LENR active sites

Figure 1.

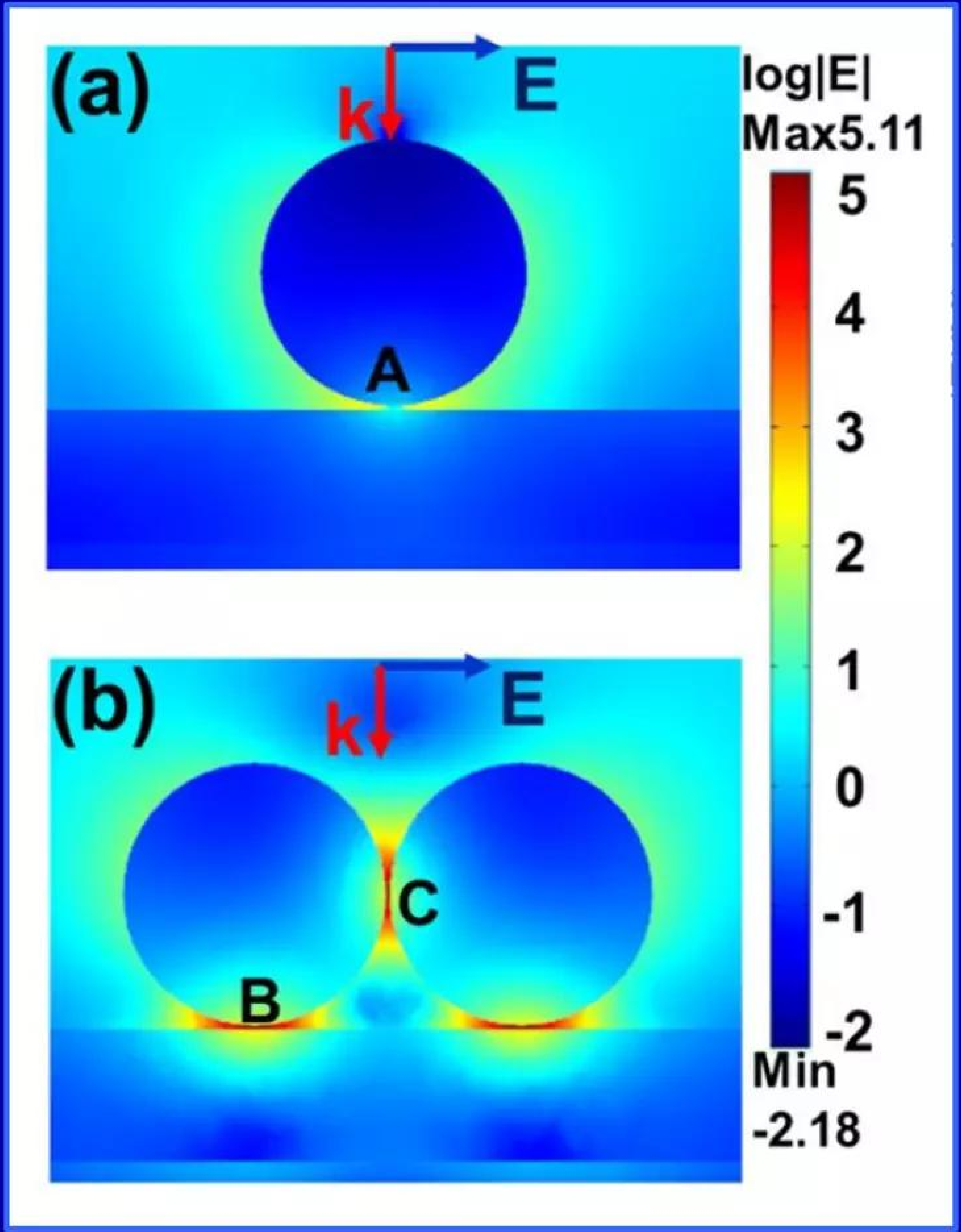
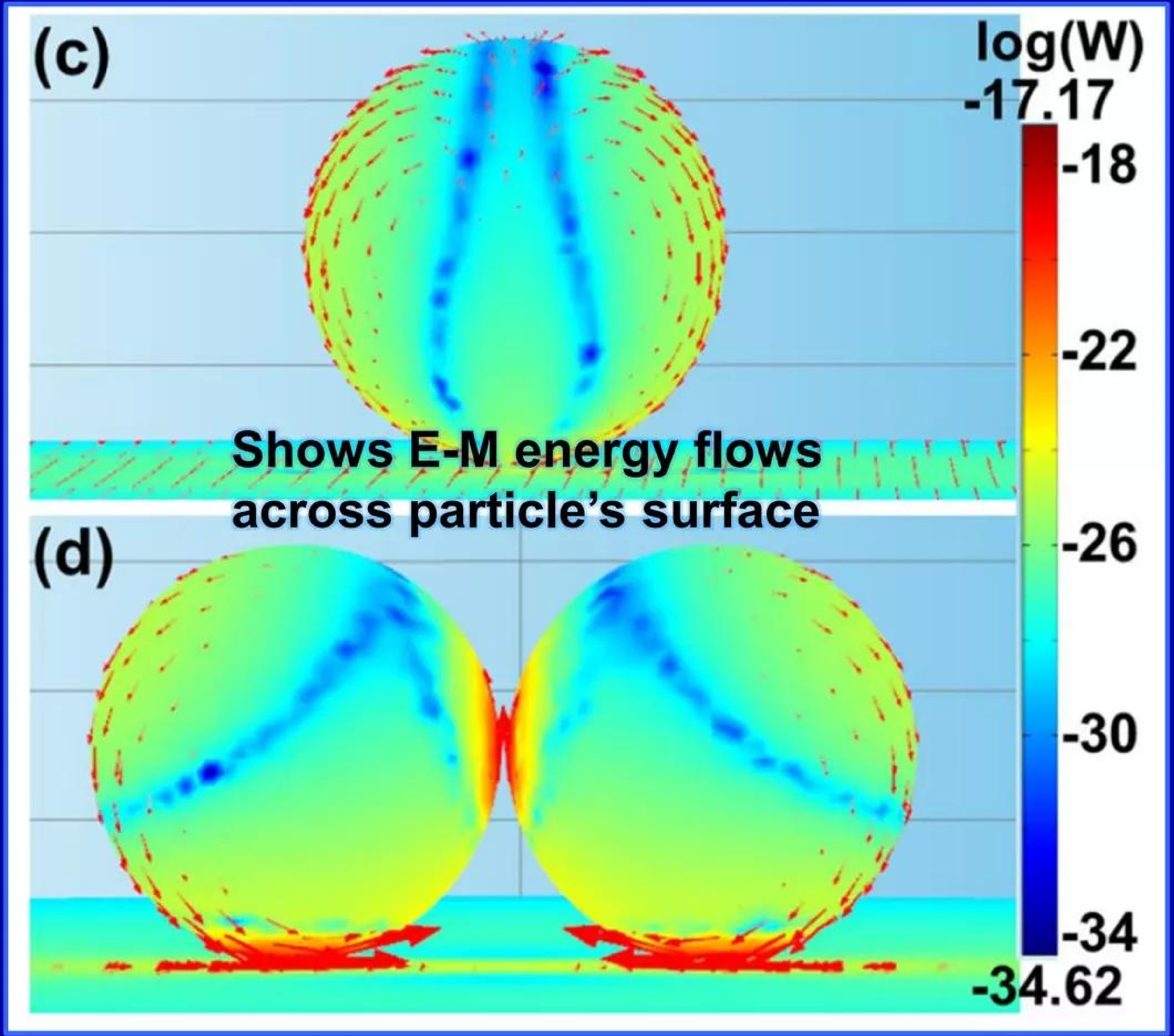


Figure 3.



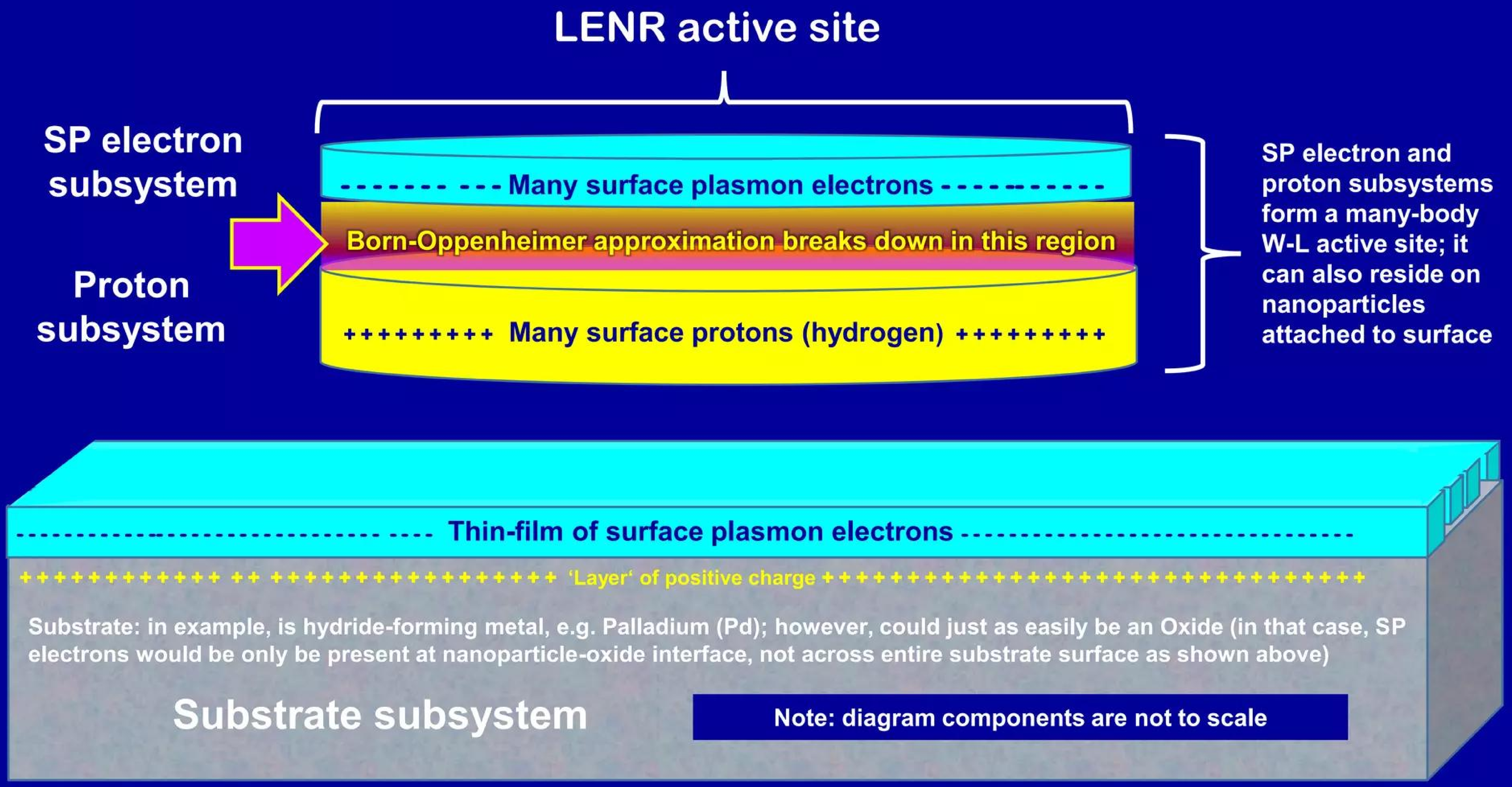
Shows E-M energy flows across particle's surface

Concept of a microscopic LENR surface active site

Comprised of many-body patches of protons/electrons on surface

SP electrons and protons oscillate collectively and are mutually Q-M entangled

Diameters of many-body active sites randomly range from several *nm* up to ~ 100^{+} microns



LENR active site

SP electron subsystem

Proton subsystem

------- --- Many surface plasmon electrons -----------

Born-Oppenheimer approximation breaks down in this region

+++++++++ Many surface protons (hydrogen) +++++++++

SP electron and proton subsystems form a many-body W-L active site; it can also reside on nanoparticles attached to surface

----------------------------- ---- Thin-film of surface plasmon electrons ------------------------------

++++++++++++ ++ ++++++++++++++++ 'Layer' of positive charge +++++++++++++++++++++++++++++++++

Substrate: in example, is hydride-forming metal, e.g. Palladium (Pd); however, could just as easily be an Oxide (in that case, SP electrons would be only be present at nanoparticle-oxide interface, not across entire substrate surface as shown above)

Substrate subsystem

Note: diagram components are not to scale

Input energy creates high electric fields in LENR active site

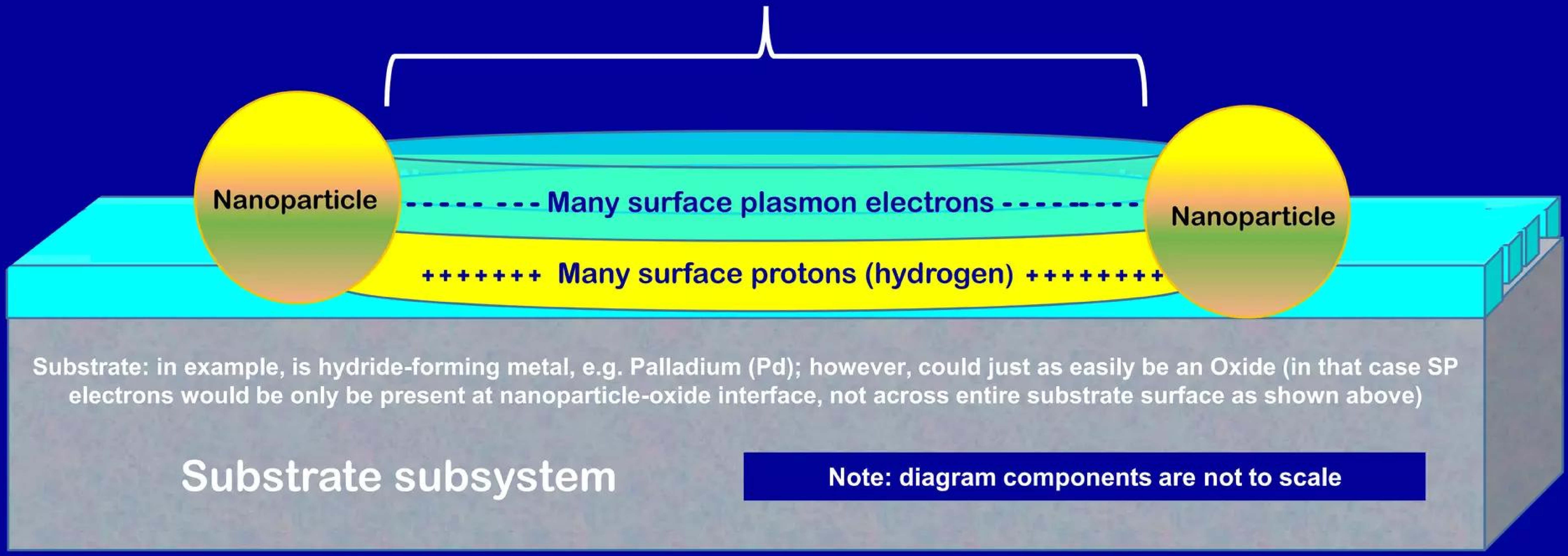
Born-Oppenheimer breakdown enables nuclear-strength local E-field

Huge electric field increase effective masses of some patch SP electrons

Appropriate input energy will create local E-field > 2 x 10^{11} V/m between adjacent nanoparticles

Input energy$_{\text{E-field}} + e^{-}_{sp} \rightarrow e^{-*}_{sp} + p^{+} \rightarrow n + \nu_e$ **[condensed matter surfaces]**

LENR active site



Nanoparticle

- - - - - - - - Many surface plasmon electrons - - - - - - - - -

Nanoparticle

+++++++ Many surface protons (hydrogen) ++++++++

Substrate: in example, is hydride-forming metal, e.g. Palladium (Pd); however, could just as easily be an Oxide (in that case SP electrons would be only be present at nanoparticle-oxide interface, not across entire substrate surface as shown above)

Substrate subsystem

Note: diagram components are not to scale

LENRs occur in microscopic active sites found on surfaces

Many-body collections of protons and electrons form spontaneously

Ultralow energy neutrons produced & captured close to LENR active sites

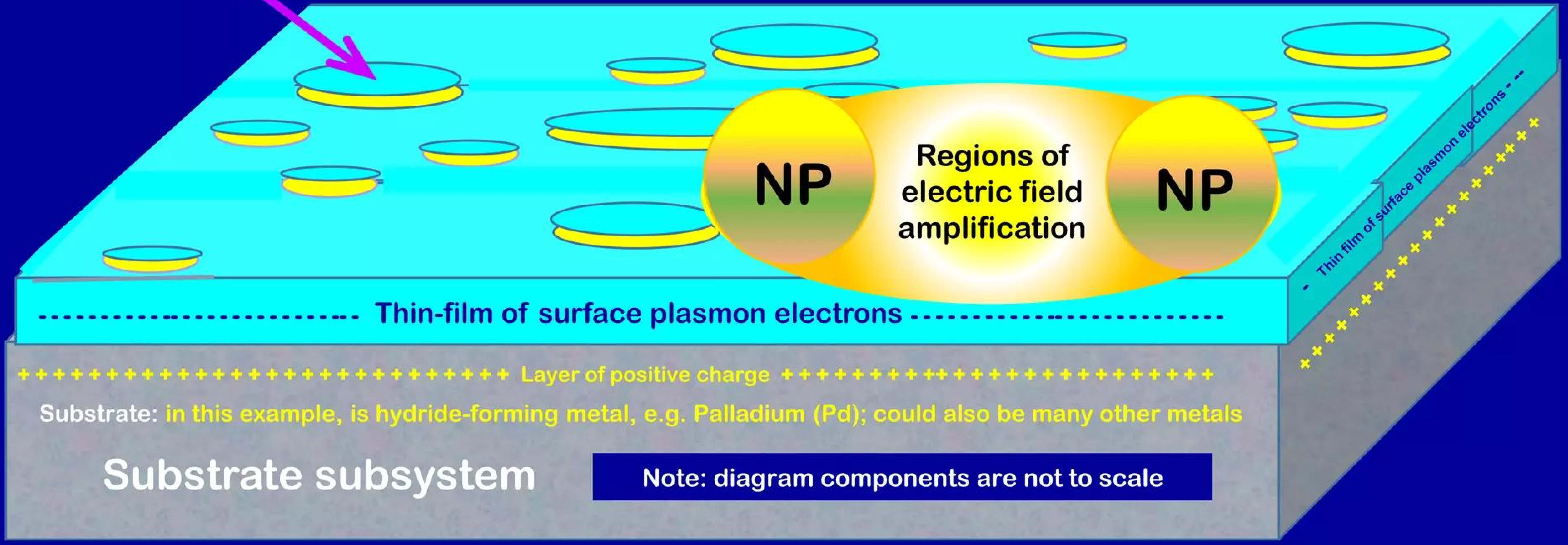
Intense heating in LENR-active sites will form μ-scale craters on certain substrate surfaces

After being produced, neutrons will capture on nearby atoms:

$n + (Z, A) \rightarrow (Z, A+1)$ [local atoms compete to capture neutrons]

$(Z, A+1) \rightarrow (Z + 1, A+1) + e_{\beta}^{-} + \nu_e$ [beta$^-$ decay]

Captures often followed by β^- decays of neutron-rich intermediate LENR products



Substrate: in this example, is hydride-forming metal, e.g. Palladium (Pd); could also be many other metals

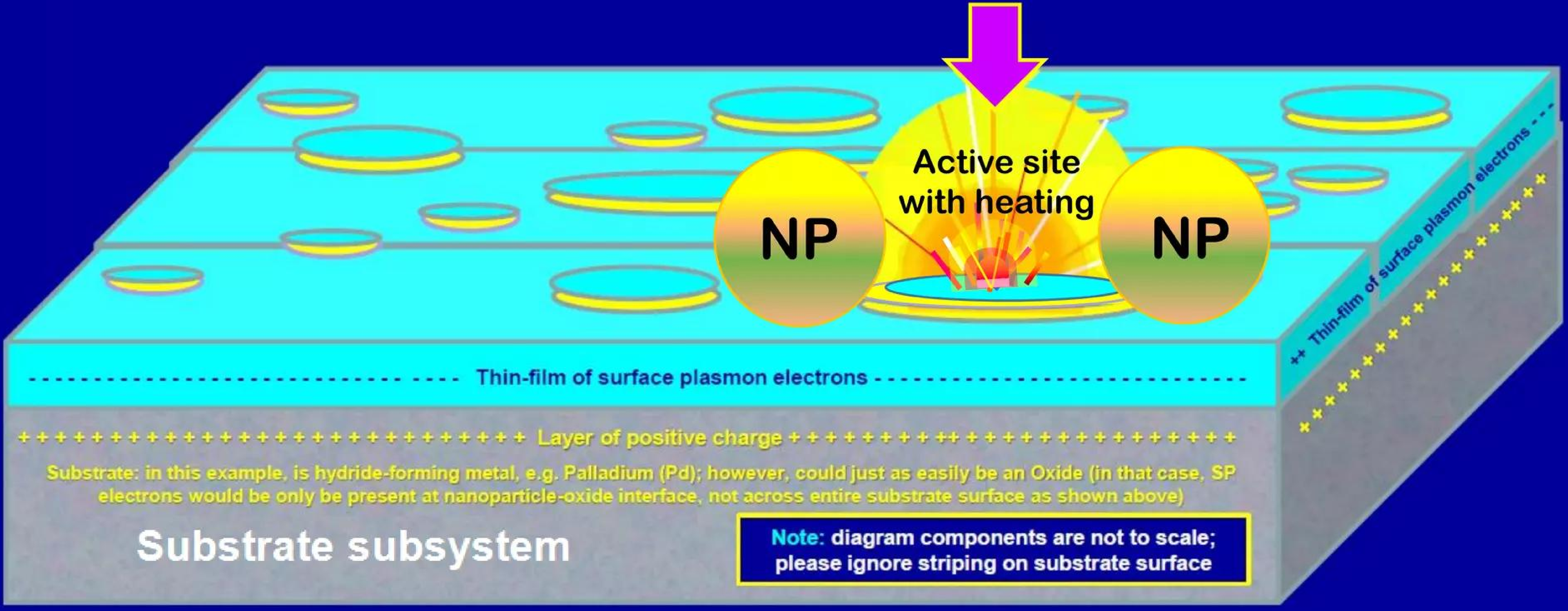
Note: diagram components are not to scale

LENR active sites will only exist for ~200 - 400 nanoseconds

Local heating will destroy needed quantum coherence and site dies

Produced neutrons captured locally; induce transmutation of elements

Neutron capture process by itself extremely fast: occurs in just picoseconds



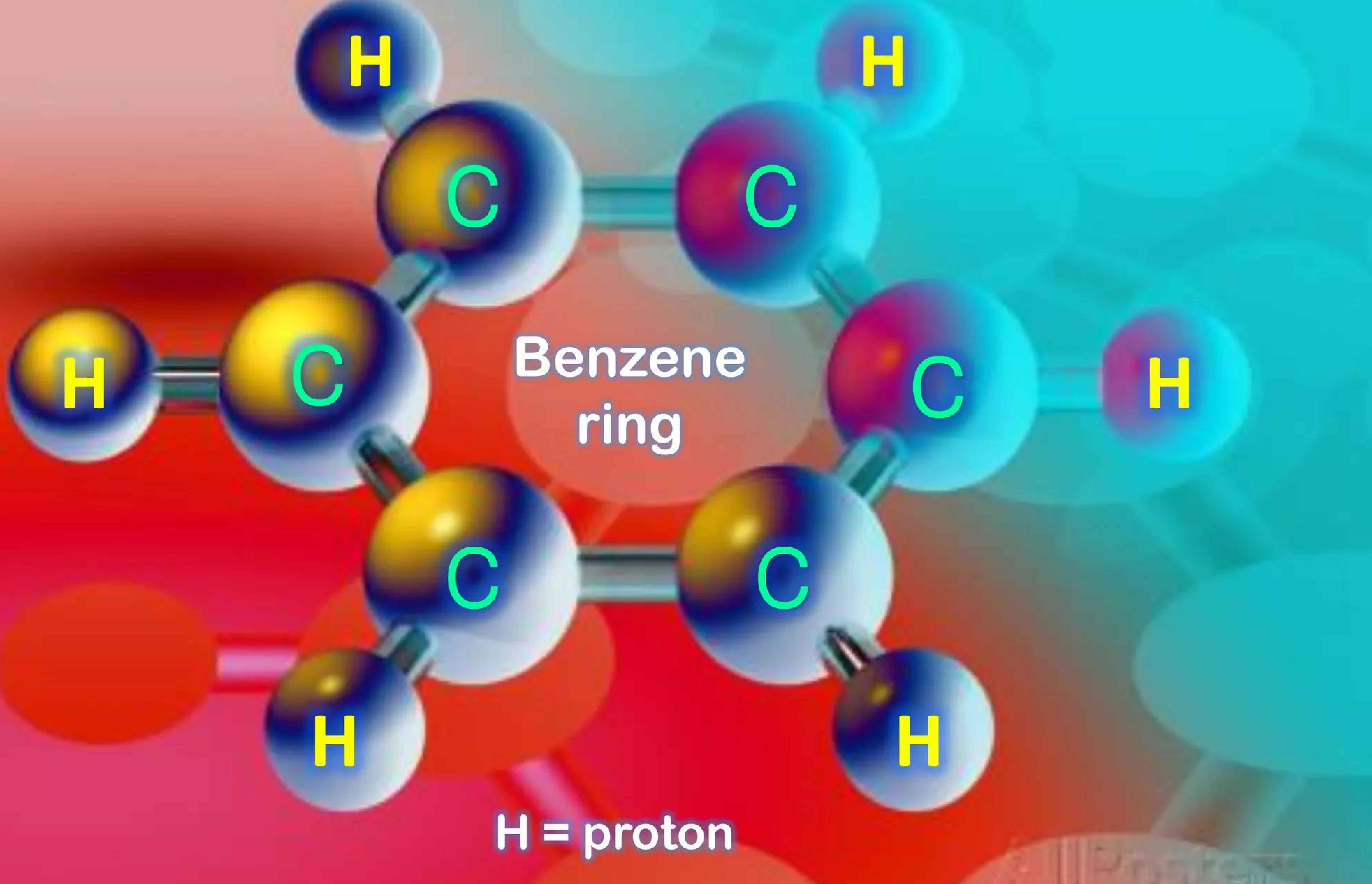
Substrate: in this example, is hydride-forming metal, e.g. Palladium (Pd); however, could just as easily be an Oxide (in that case, SP electrons would be only be present at nanoparticle-oxide interface, not across entire substrate surface as shown above)

Note: diagram components are not to scale; please ignore striping on substrate surface

On metallic substrates LENR active sites often create distinctive surface craters ~100$^+$ microns in diameter

Such craters can be observed on LENR-active metallic substrates post-experiment with scanning electron microscopes (SEM); LENR transmutation products have been observed in exactly the same areas with SIMS

Aromatic molecule: 6 Carbon atoms in ring with Hydrogen



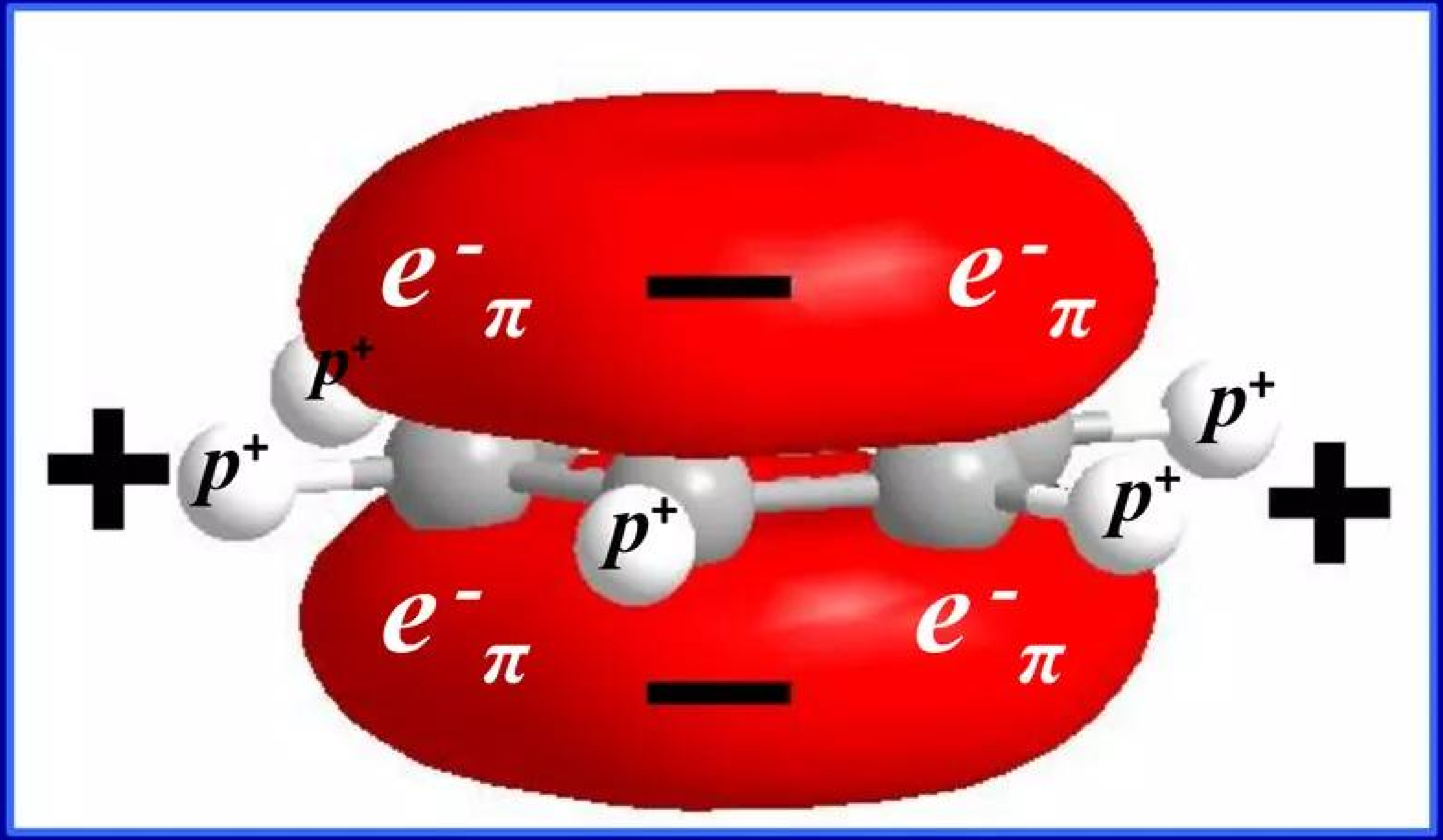
Lattice extended Widom-Larsen theory to aromatic rings

Benzene ring is 2 nm molecular analogue of LENR active site on metal

Protons (Hydrogen) on ring and related π electrons are all Q-M entangled

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

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



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

Synopsis: back in 2009, Lattice predicted that under proper conditions, electromagnetic energy can be transferred into hydrogenated aromatic rings such that ultra low momentum neutrons are created from ring hydrogens (protons) via LENR catalysis of an electroweak $e_\pi + p \rightarrow n + \nu_e$ reaction; neutrons then tend to capture on nearby ring Carbon atoms, inducing a nuclear transmutation process

"Technical Overview - PAHs and LENRs"
L. Larsen, Lattice Energy LLC
November 25, 2009 (see slides #42 - 45)

http://www.slideshare.net/lewisglarsen/lattice-energy-llctechnical-overviewpahs-and-lenrsnov-25-2009

2009: predicted surface plasmons on aromatic rings

We theoretically conjectured that experimentalists would observe this

“Tunable molecular plasmons in
polycyclic aromatic hydrocarbons”
A. Manjavacas *et al.*
ACS Nano 7 pp. 3635 - 3643 (2013)
http://pubs.acs.org/doi/abs/10.1021/nn4006297

Abstract: “We show that chemically synthesized polycyclic aromatic hydrocarbons (PAHs) exhibit molecular plasmon resonances that are remarkably sensitive to the net charge state of the molecule and the atomic structure of the edges. These molecules can be regarded as nanometer-sized forms of graphene, from which they inherit their high electrical tunability. Specifically, the addition or removal of a single electron switches on/off these molecular plasmons. Our first-principles time-dependent density-functional theory (TDDFT) calculations are in good agreement with a simpler tight-binding approach that can be easily extended to much larger systems. These fundamental insights enable the development of novel plasmonic devices based upon chemically available molecules, which, unlike colloidal or lithographic nanostructures, are free from structural imperfections. We further show a strong interaction between plasmons in neighboring molecules, quantified in significant energy shifts and field enhancement, and enabling molecular-based plasmonic designs. Our findings suggest new paradigms for electro-optical modulation and switching, single-electron detection, and sensing using individual molecules.”

Lattice extended Widom-Larsen theory to aromatic rings

Collective electroweak catalysis of neutrons on molecular LENR active site

- ✓ Delocalized clouds of π electrons situated above and below 6-Carbon aromatic ring structures are in very close physical proximity to protons (hydrogen atoms), 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 (this was first observed and reported by Chatzidimitriou-Dreismann - 2005)
- ✓ Local breakdown of Born-Oppenheimer approximation occurs on aromatic ring structures; this enables E-M 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 an aromatic structure is adsorbed onto the surface of a metallic substrate, it will spontaneously orient itself as it approaches so that the ~flat ring plane of an aromatic molecule ends-up ~parallel to the substrate surface. Born-Oppenheimer approximation also breaks down there, enabling further E-M coupling and energy transfers between Carbon-ring π electrons and thin-film 'sea' of surface plasmon electrons covering a substrate's surface (S. Jenkins, *Proc. Royal Soc.* 465 - 2009)
- ✓ Dynamics are analogous to manner in which LENR active sites operate on loaded metallic hydride surfaces. Molecular aromatic ring structure becomes functional analogue of a many-body LENR active site in which neutrons can be produced collectively via electroweak $e + p$ reaction; neutrons will tend to capture on nearby ring Carbons --- this also applies to multi-ring polycyclic aromatic hydrocarbons

Lattice extended Widom-Larsen theory to aromatic rings

Surface plasmons on metals can transfer energy into ring π electrons

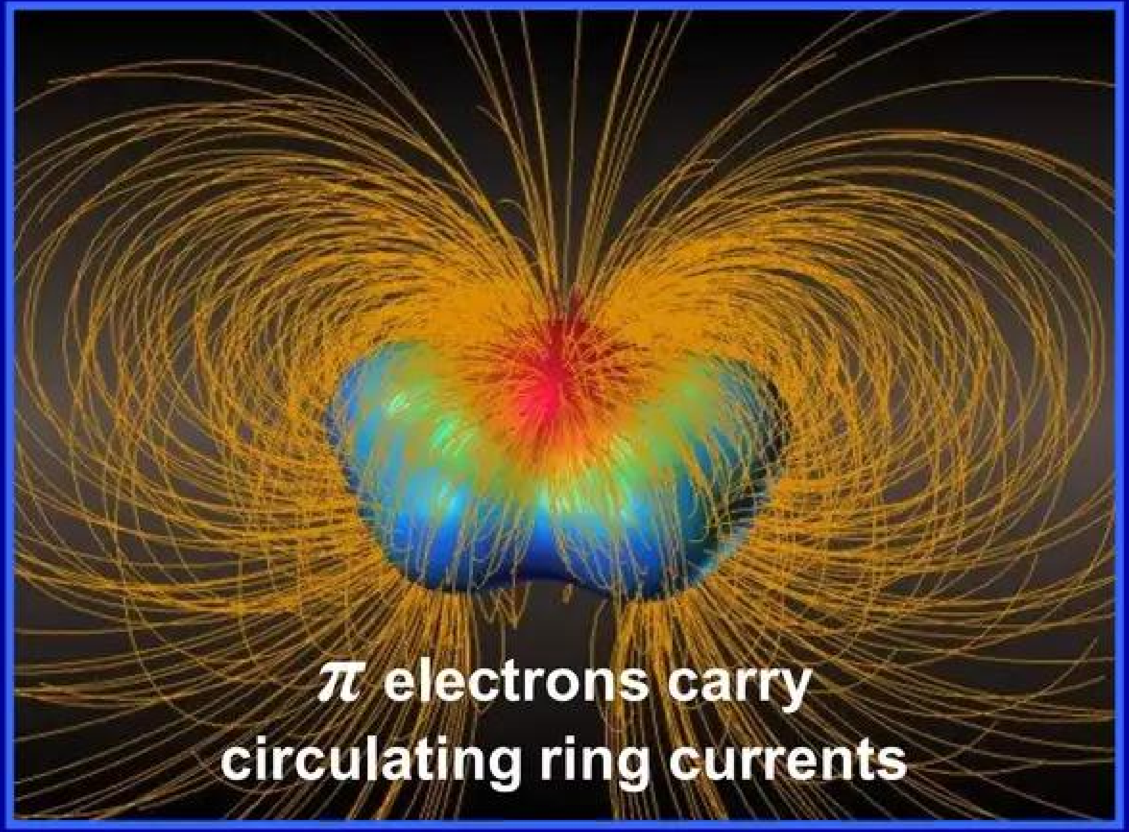
Jenkins: aromatic molecules adsorbed on metal surfaces will lay flat as possible

"Aromatic adsorption on metals via first-principles density functional theory"
S. J. Jenkins
Proceedings of the Royal Society 465
pp. 2949 - 2976 (2009)
http://rspa.royalsocietypublishing.org/content/royprsa/465/2110/2949.full.pdf

"[Benzene] adopts a flat-lying … geometry, binding to the surface through donation of electrons through one or both of its degenerate HOMOs and back-donation into one or both of its two degenerate LUMOs."

"The work of Dou *et al.* (2008) reveals a preference for a flat-lying adsorption geometry on Cu{100} in which the fused benzene rings are located above hollow sites, oriented such that two C−C bonds from each lie along one of the 011 directions … amounting to a maximum vertical separation of 0.20Å between the lowest and highest lying C atoms; the height of the molecule above the surface is in the region of 2.20Å."

E-M field lines surrounding an aromatic ring



π electrons carry circulating ring currents

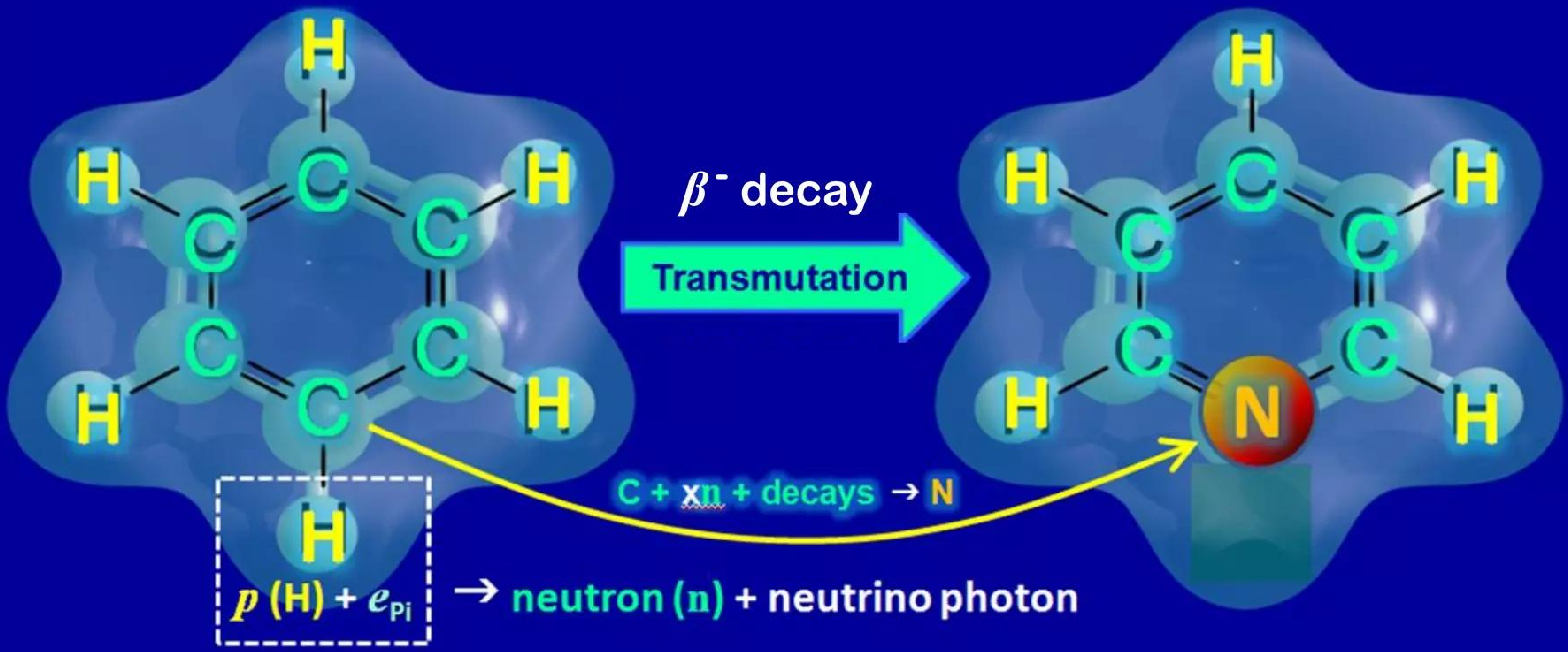
Three-ring polycyclic aromatic hydrocarbon (PAH)

Unsaturated Phenanthrene ($C_{14}H_{10}$)

Lattice extended Widom-Larsen theory to aromatic rings

Ring protons collectively react with π electrons → low energy neutrons

Neutron(s) captured by Carbon atom which is transmuted to Nitrogen via decay



Large electrostatic electric fields form at interface between aromatic ring and metal surface

So-called Schottky barrier will spontaneously form at the metal-molecule interface; this will create local interfacial electrostatic fields that can be significantly > 10^{10} V/m

https://e-reports-ext.llnl.gov/pdf/421240.pdf

Lattice extended Widom-Larsen theory to aromatic rings

Hokkaido University reported supportive experimental results in 2008

Electroweak catalysis on Phenanthrene adsorbed on metallic Platinum surface

$$\text{Input energy}_{\text{Infrared photons}} + e^-_{\pi} \rightarrow e^{-*}_{\pi} + p^+ \rightarrow n^0 + \nu_e$$

- ✓ Experiments at Hokkaido Univ. (Japan) that were first reported in 2008 demonstrated that production of neutrons via LENR electroweak catalysis followed by transmutation of Carbon can be triggered on PAH aromatic rings adsorbed on Platinum at very modest Hydrogen gas pressures and temperatures. These anomalous results of Mizuno *et al*. can be explained by Widom-Larsen theory in the context of a stainless steel reaction vessel functioning as a resonant infrared (IR) electromagnetic cavity: http://www.lenr-canr.org/acrobat/MizunoTanomaloushb.pdf

- ✓ Using mass spectroscopy to analyze residues remaining in sealed stainless steel reaction vessel post-experiment, Mizuno *et al*. observed production of anomalous Carbon-13 isotope, stable Nitrogen isotopes, and maybe also Oxygen. See Lattice discussion at: http://www.slideshare.net/lewisglarsen/lattice-energy-llctechnical-overviewpahs-and-lenrsnov-25-2009

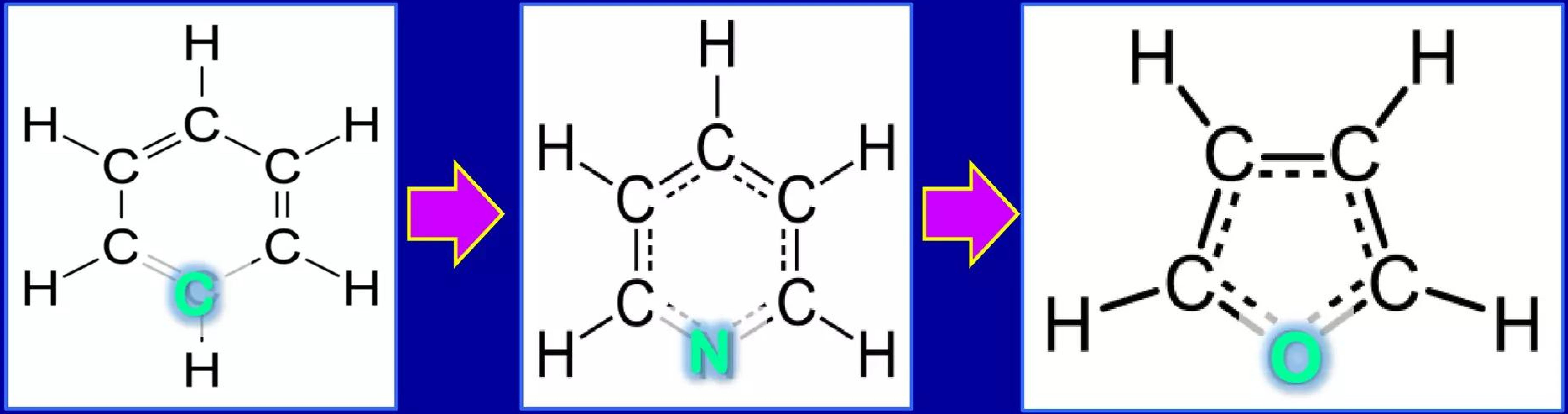
- ✓ Born-Oppenheimer approximation breaks-down on aromatic rings which enables local nuclear-strength electric fields that increase effective masses of some π electrons so that they can then react with one of a ring's protons to convert it into an ultra low energy neutron which is perforce captured by a nearby ring Carbon atom. This begins LENR Carbon transmutation process; series of successive neutron captures and beta decays can make Nitrogen, then Oxygen --- analogous to C → N → O process in stars

Lattice extended Widom-Larsen theory to aromatic rings

'Green' LENR transmutation of stable Carbon → Nitrogen → Oxygen

Similar to CNO cycle in stars but doesn't require gigantic star-like temperatures

Aromatic molecules' chemistry changes in parallel with Carbon transmutation



Benzene - aromatic

Pyridine - heterocyclic

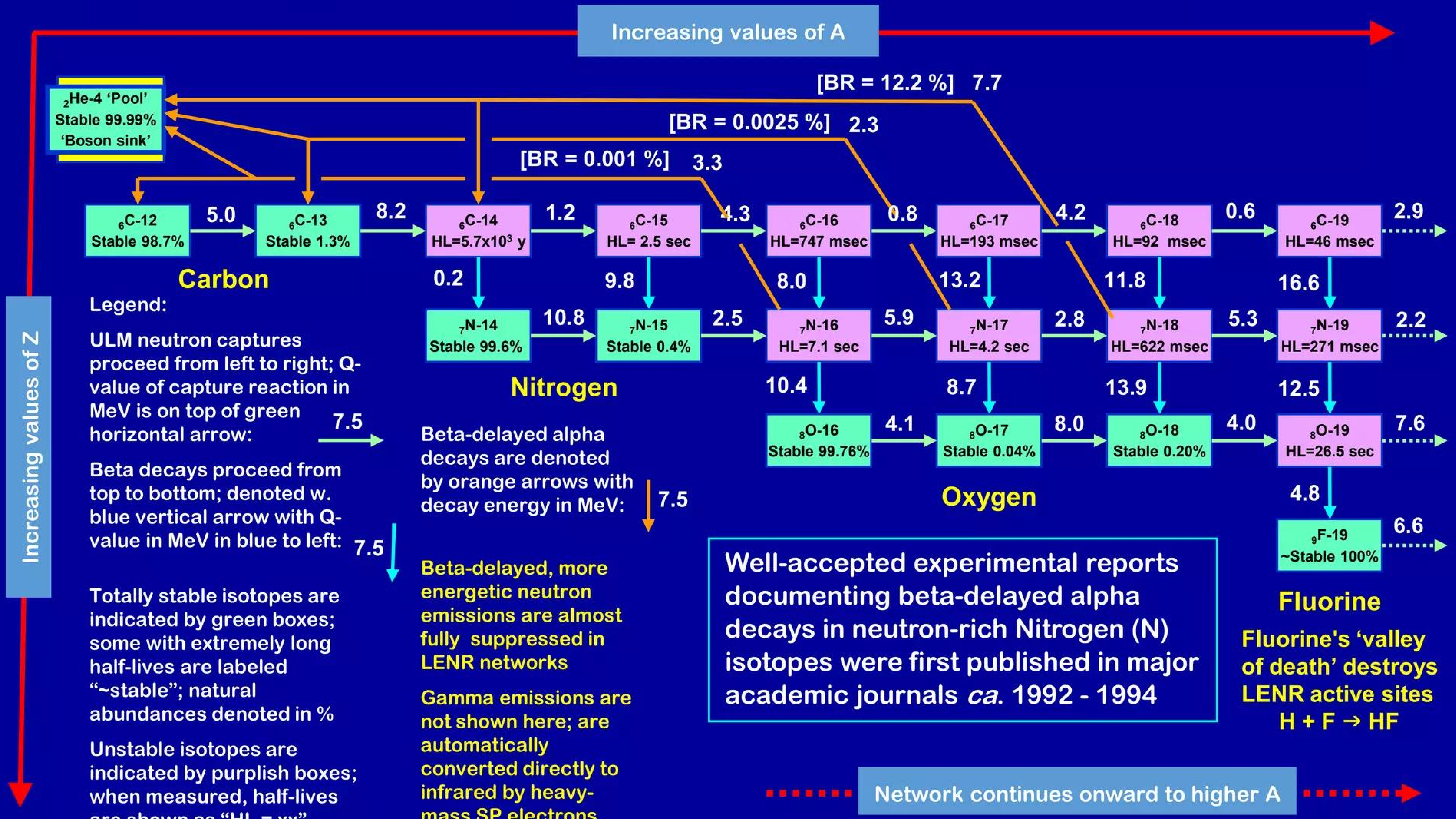
Furan - heterocyclic

LENRs interoperate with ordinary chemical reactions in condensed matter systems

Lattice extended Widom-Larsen theory to aromatic rings

Theorized LENR transmutation network starting with stable Carbon-12

Network cannot get past Oxygen-18 unless neutron fluxes are > 1 x 10^{10} cm^2/sec



$_{2}$He-4 'Pool'
Stable 99.99%
'Boson sink'

$_{6}$C-12 Stable 98.7%

$_{6}$C-13 Stable 1.3%

$_{6}$C-14 HL=5.7x10^3 y

$_{6}$C-15 HL= 2.5 sec

$_{6}$C-16 HL=747 msec

$_{6}$C-17 HL=193 msec

$_{6}$C-18 HL=92 msec

$_{6}$C-19 HL=46 msec

Carbon

$_{7}$N-14 Stable 99.6%

$_{7}$N-15 Stable 0.4%

$_{7}$N-16 HL=7.1 sec

$_{7}$N-17 HL=4.2 sec

$_{7}$N-18 HL=622 msec

$_{7}$N-19 HL=271 msec

Nitrogen

$_{8}$O-16 Stable 99.76%

$_{8}$O-17 Stable 0.04%

$_{8}$O-18 Stable 0.20%

$_{8}$O-19 HL=26.5 sec

Oxygen

$_{9}$F-19 ~Stable 100%

Fluorine

Legend:

ULM neutron captures proceed from left to right; Q-value of capture reaction in MeV is on top of green horizontal arrow: 7.5

Beta decays proceed from top to bottom; denoted w. blue vertical arrow with Q-value in MeV in blue to left: 7.5

Totally stable isotopes are indicated by green boxes; some with extremely long half-lives are labeled "~stable"; natural abundances denoted in %

Unstable isotopes are indicated by purplish boxes; when measured, half-lives are shown as "HL = xx"

Beta-delayed alpha decays are denoted by orange arrows with decay energy in MeV: 7.5

Beta-delayed, more energetic neutron emissions are almost fully suppressed in LENR networks

Gamma emissions are not shown here; are automatically converted directly to infrared by heavy-mass SP electrons

Well-accepted experimental reports documenting beta-delayed alpha decays in neutron-rich Nitrogen (N) isotopes were first published in major academic journals *ca*. 1992 - 1994

Fluorine's 'valley of death' destroys LENR active sites
H + F → HF

Network continues onward to higher A

W-L first principles *e* + *p* rate calculation agrees with data

Neutron production of ~10^{12} - 10^{14} cm^2/sec seen in electrochemical cells

Experimentalists have measured and reported implicit fluxes of neutrons

“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

- ✓ Estimates of electroweak neutron production rates in electrochemical cells are indirect (ultra low momentum neutrons are almost all captured locally before they can thermalize and be observed with outside detectors); they are calculated from published data on measured rates of production for LENR transmutation products (please note that transmutations are induced by neutron captures at roughly 1:1)
- ✓ Measurements of what are effectively electroweak neutron production rates reported by LENR experimentalists range from ~10^9 - 10^{10} cm^2/sec up to values on the order of ~10^{12} - 10^{14} cm^2/sec observed in some very well-performing systems
- ✓ Our first principles calculations assumed an aqueous electrolytic chemical cell that inputs DC electrical current to provide external energy source required to drive collective many-body electroweak *e* + *p* reactions on cell’s metallic cathode
- ✓ Calculated theoretical estimates of neutron production rates agree well with data

Key parameters controlling $e + p$ reaction rate identified

For details please see Widom & Larsen arXiv:nucl-th/0608059v2 (2007)

- ✓ Exploiting conceptual insights provided by theory, in commercial products it should be possible to increase rates of collective electroweak neutron production to levels far above what is attainable in natural systems or in experiments conducted to date
- ✓ Technologically, many-body collective electroweak neutron production rates can be manipulated by: (1) controlling total numbers and density of $e^- p^+$ pairs on a given surface (this is ~equivalent to controlling the area-density and dimensions of many-body, collectively oscillating LENR active surface sites with protons or deuterons); and (2) controlling the transfer rates and total quantity of appropriate form(s) of nonequilibrium energy input into the LENR system. Proper forms of input energy will create very high local fields that bathe SP electrons located in active sites; this determines numbers and effective masses of e^* electrons present in such sites whose increased masses surpass the minimum mass-renormalization threshold value β_0 (= 2.531 for $e^* + p$) that is required for initiating many-body $e^* + p$ or $e^* + d$ electroweak nuclear reactions. Term $(\beta - \beta_0)^2$ in our published rate equation reflects the degree to which mass-renormalized e^* electrons present in active sites exceed minimum mass enhancement ratios β_0 needed for electroweak neutron production
- ✓ All other things being equal, the higher the local density of key $e^- p^+$ reactants, and higher the transfer rate and quantity of input energy, the higher the rate of neutron production will be in an appropriately pre-configured condensed matter system

Electroweak catalysis vastly increases *e* + *p* reaction rates

Neutron fluxes on order of 10^{10} - 10^{14} cm^2/sec seen in LENR experiments

Huge rate increases compared to spontaneous reaction rate of ~10^{-44}/cm^2

- ✓ As we noted much earlier in this document, according to Hans Bethe the cross-section for a direct electroweak *e* + *p* reaction between a free resting proton and a nearby low-speed free electron at roughly room temperature and atmospheric pressure, i.e. ~ STP, is on the order of 1.18×10^{-44}/cm^2
- ✓ Even at very modest *e* + *p* neutron production rate of just 10 ultralow energy neutrons cm^2/sec - using the parlance of enzyme chemists - it would imply that the catalytic proficiency of LENR collective many-body quantum effects is an astounding ~ 10^{45} multiple of the spontaneous uncatalyzed rate; in the case of chemical cells LENR proficiency appears to be roughly 10^{54} - 10^{58}
- ✓ Please recall that the largest presently known catalytic proficiency for any biological enzyme is that of Uroporphyrinogen decarboxylase at 2.5×10^{24}
- ✓ If one looks at the concept of catalytic proficiency in terms of the reduction in temperature required to drive the *e* + *p* reaction at significant rates, then we see value of $> 3 \times 10^7$ (9×10^9 ^{o}K in supernova explosion vs. 300 ^{o}K in cell)
- ✓ Given such values, we conclude many-body collective quantum effects are quite effective at increasing reaction rates of otherwise very slow processes

Some experimental data suggests biological LENRs

Are high E-fields and collective Q-M effects crucial in enzyme catalysis?

- ✓ Bacterial LENR transmutations were first reported in Moscow 13 years ago by a Russian microbiologist working with a Ukrainian experimental physicist; at that time nobody believed the experimental claims presented in their self-published book (Mir Press). In 2012, these incredible Russian experiments were seemingly confirmed by Indian scientists working at the Indira Gandhi Centre for Atomic Research (IGCAR in Kalpakkam, India); as far as we know, Indian researchers are still trying to get their results published in a journal

  Note that we concede such claims are highly controversial and still far from bring settled; more definitive experimentation will be needed to sort it out

- ✓ Beyond that, certain bacteria appear to be altering isotopic ratios of heavy elements, e.g. Mercury and Uranium, in ways that we believe are not fully explained by some type of chemical fractionation process, mass-dependent or otherwise. LENRs may be responsible for subset of such data; however, measurement of true absolute mass-balances by isotope will be necessary to discriminate between effects of purely chemical vs. nuclear processes

- ✓ Given LENR electroweak catalysis' pivotal use of ultra-high local electric fields and many-body collective quantum effects to achieve an incredible catalytic proficiency of $\sim 10^{45+}$, let us examine enzymes and other catalysts to see whether they utilize the same tricks to increase chemical reaction rates

Common mechanisms in chemical and *e* + *p* catalysis

Do enzymes and other catalysts use big E-fields and collective effects?

Fried *et al*. (2013) reported high fields are key to catalytic activity of an isomerase

- ✓ Assuming that the Russian/Indian results suggesting bacterial transmutations would eventually be corroborated by additional researchers and claims well-validated; in 2012, we speculated that Nature would probably orchestrate such exotic processes in active sites of enzymes and/or perhaps in nanoscale structures located on cell membranes

- ✓ If LENRs really do occur in bacterial enzymes, and extrapolating from Lattice's knowledge of abiotic LENR systems, we predicted that: (1) extremely high transient E-fields would likely be observed inside enzymes' active sites and that; (2) the magnitude of electric field strengths could well be an important if not critical parameter for increasing reaction rates and thus catalytic proficiencies of chemical as well as LENR *e* + *p* catalysis processes

- ✓ Further extrapolating from knowledge of abiotic LENRs, we predicted that condensed matter many-body collective quantum effects, including tunneling, would be important - but hard to measure - for increasing the proficiency of electroweak and chemical catalysis

- ✓ Herein we explained how aromatic Carbon rings can behave as functional analogues of LENR active sites on metals and that extremely high transient E-fields would probably occur near rings' π electron clouds during dynamic processes such as hydrogenation, deprotonation, and/or transfer of E-M energy into π electron clouds from external sources

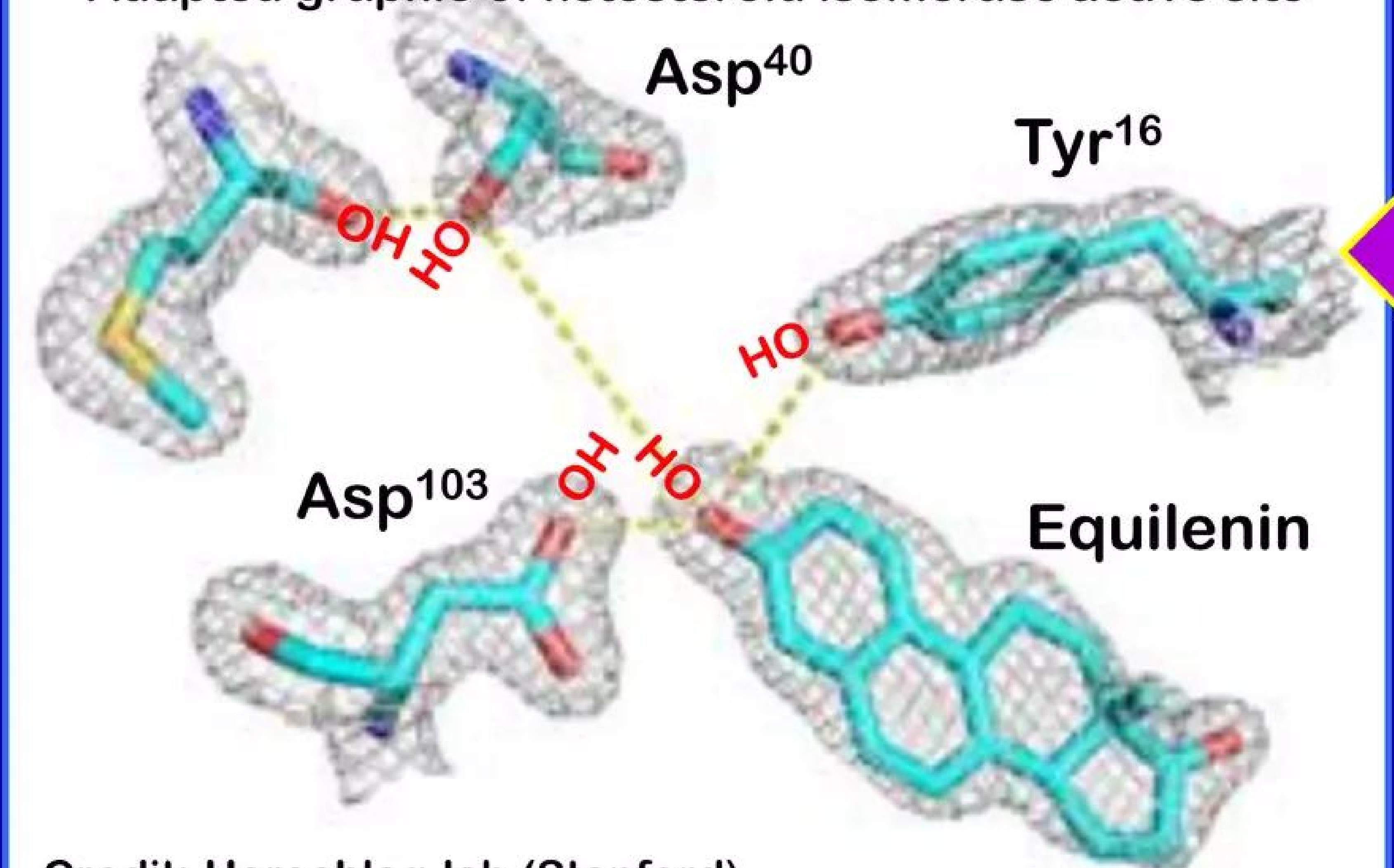
- ✓ Conformational changes are a distinctive feature of enzymes thought to be important for their functionality; another use for dynamic structural movements could be modulating local electric field strengths in active sites by shifting relative positions of charged groups

Anisotropic electric fields occur in enzyme active sites

Fafarman *et al*. measure E-field heterogeneity in isomerase active site

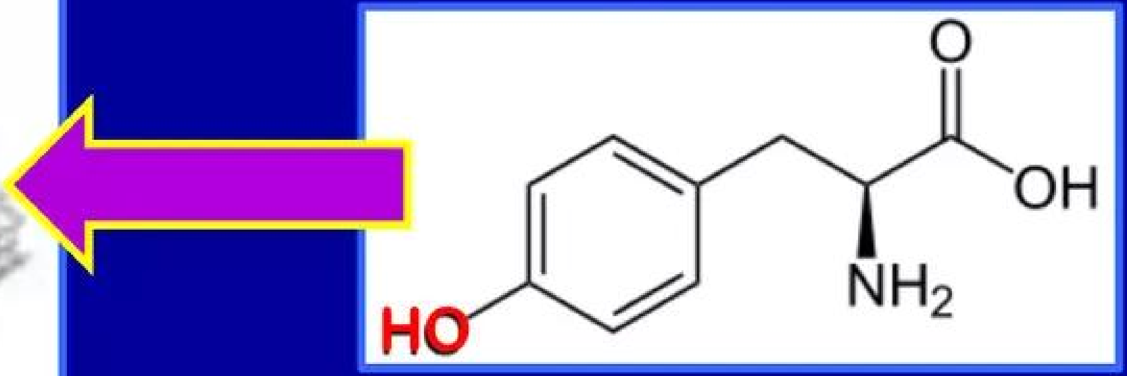
“Dispersion in local electric field … at discrete probe positions and orientations”

Adapted graphic of ketosteroid isomerase active site



Credit: Herschlag lab (Stanford)

Tyrosine



“Understanding nonequilibrium effects due to transient charge perturbations remains an important challenge.”

“Quantitative, directional measurement of electric field heterogeneity in the active site of ketosteroid isomerase”
A. Fafarman *et al.*, *PNAS* 109 pp. E299 - E308 (2012)
http://www.pnas.org/content/109/6/E299.full.pdf

Ultrahigh electric fields occur in enzyme active sites

Extreme electric fields observed in enzyme with high k_{cat} constant

"… active site's electric field … accounts for 70% of KSI's catalytic speedup"

"Extreme electric fields power catalysis in the
active site of ketosteroid isomerase"
S. Fried *et al.*, *Science* 346 pp. 1510 - 1514 (2014)
http://web.stanford.edu/group/boxer/papers/paper303.pdf

Abstract: "Enzymes use protein architecture to impose specific electrostatic fields onto their bound substrates, but the magnitude and catalytic effect of these electric fields have proven difficult to quantify with standard experimental approaches. Using vibrational Stark effect spectroscopy, we found that the active site of the enzyme ketosteroid isomerase (KSI) exerts an extremely large electric field onto the C = O chemical bond that undergoes a charge rearrangement in KSI's rate-determining step. Moreover, we found that the magnitude of the electric field exerted by the active site strongly correlates with the enzyme's catalytic rate enhancement, enabling us to quantify the fraction of the catalytic effect that is electrostatic in origin. The measurements described here may help explain the role of electrostatics in many other enzymes and biomolecular systems."

Ultrahigh electric fields occur in enzyme active sites

Continuing on Fried *et al*. re extreme E-fields in isomerase active site

Clear relationship between electric field strength and enzyme catalytic proficiency

- ✓ "Ketosteroid isomerase (KSI) is a small, proficient enzyme with one of the highest known unimolecular rate constants in biochemistry, which has prompted extensive study of its mechanism and the catalytic strategies it uses."
- ✓ "KSI may facilitate this reaction by exerting an electric field ($\vec{F}_{enz}$) on this bond that stabilizes it in the intermediate form and the preceding transition state (Fig. 1B). Using vibrational Stark effects, we have measured the electric field that KSI exerts on this C=O bond, providing quantitative experimental evidence for the connection between electrostatics and catalytic proficiency."
- ✓ "19-NT's C=O vibrational frequency shifts ~1.4/f cm–1 for every MV/cm of electric field projected onto the C=O bond axis, whether the source of that field is an external voltage (as in Stark spectroscopy) or an organized environment created by an enzyme active site ($\vec{F}_{enz}$) that we wish to characterize."
- ✓ "The C=O vibration's Stark tuning rate does not appreciably change when C=O accepts a hydrogen bond (Fig. S2), implying that the frequency still responds to fields linearly even when C=O participates in stronger interactions, although those interactions themselves are associated with larger electric fields."

Ultrahigh electric fields occur in enzyme active sites

Continuing on Fried *et al*. re extreme E-fields in isomerase active site

Measured a linear relationship between electric field strength and physical effects

Fig. 2D. "Sensitivity of the C = O stretch frequency of 19-NT to electrostatic field --- plot of 19-NT's C = O peak frequency against the calculated solvent electric field the C = O group experiences in each of those solvents"

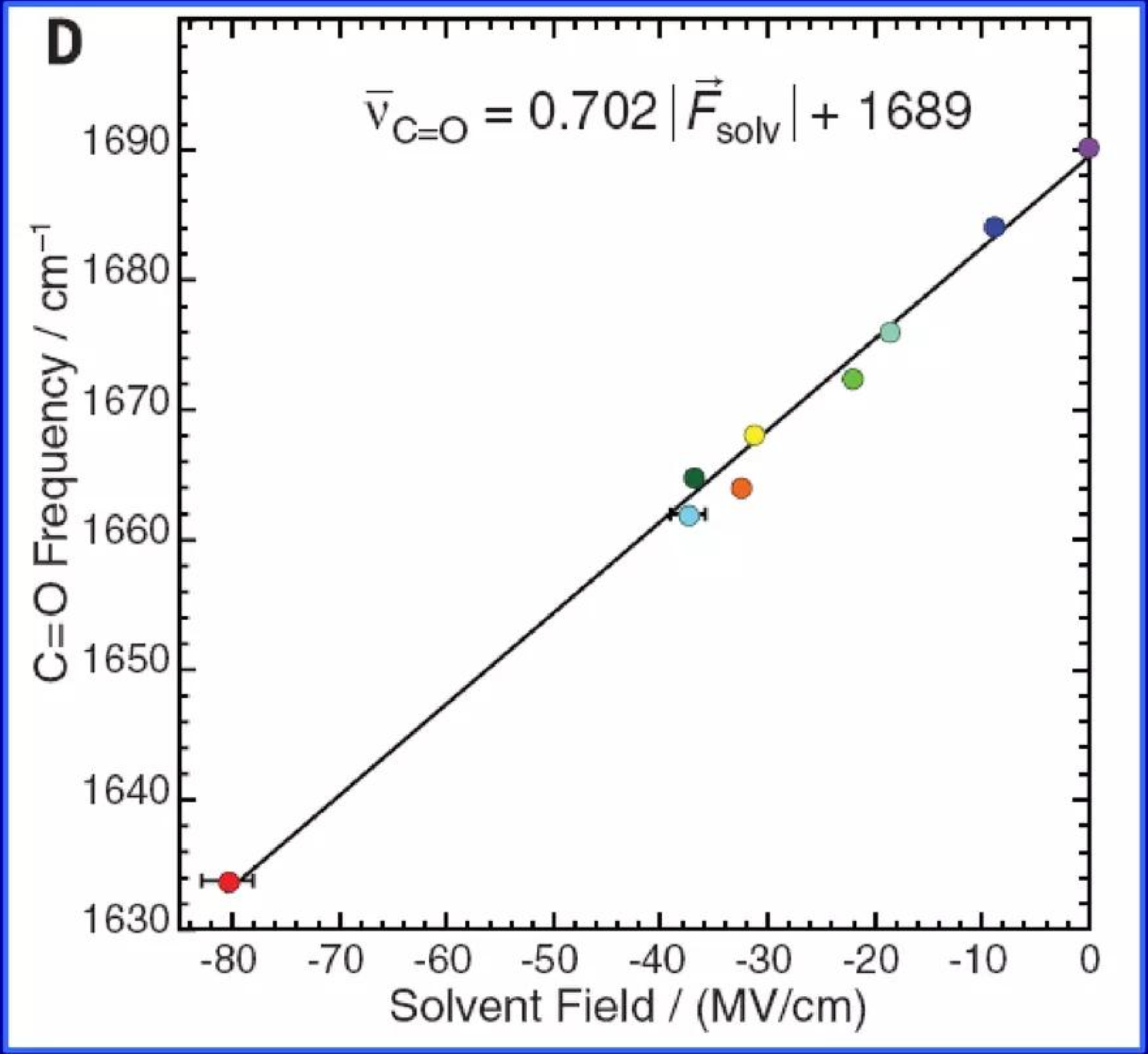
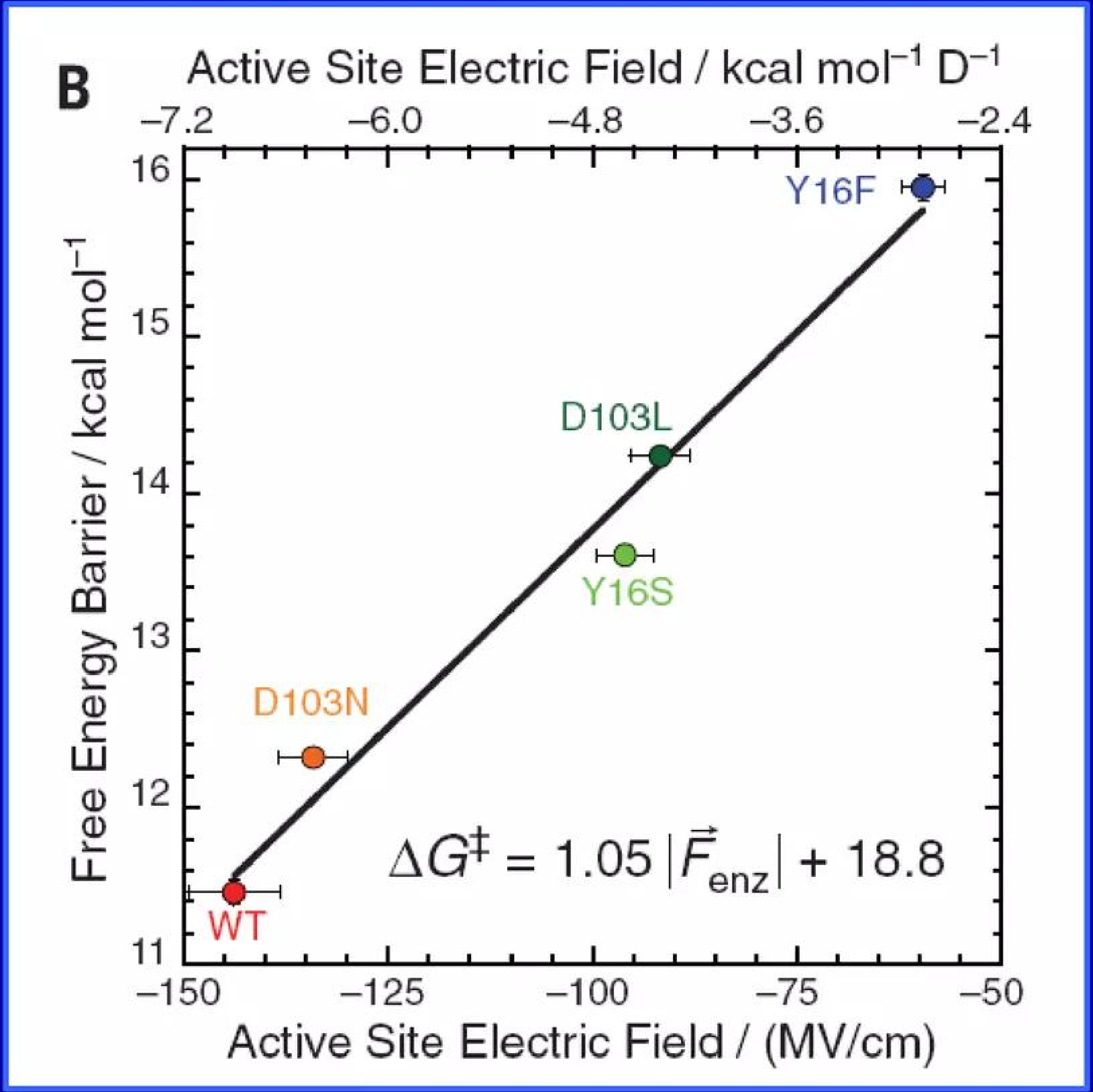


Fig. 3B. "Contribution of active-site electric fields to KSI's catalytic effect --- plot of enzymatic unimolecular free energy barrier, $\Delta G^\ddagger$, against the electric field"



Ultrahigh electric fields occur in enzyme active sites

Continuing on Fried *et al*. re extreme E-fields in isomerase active site

Measured *static* E-fields are ~10^9 V/m - fast transient fields may be much higher

- ✓ "Attributing the frequency shift to the Stark effect, the linear field frequency relationship of Fig. 2D maps this frequency value to an ensemble-average electric field of -144 ± 6 MV/cm. Although this highly redshifted frequency lies outside the known linear range from solvatochromism, additional lines of evidence suggest that the C=O vibrational frequency maintains an approximately linear relationship with the field in this regime."
- ✓ "These measurements show that the interaction between these H-bonds and the C=O group can be described … in terms of the electric field they produce."
- ✓ "Tyr^{16} [Tyrosine] H-bond alone contributes a static field of 84 ± 7 MV/cm without an accompanying increase in electric field dispersion makes it quite distinct from water, which donates close to two H-bonds to C=O on average, but taken altogether these H-bonds generate an average field of ~40 MV/cm that is also highly heterogeneous" [note: 84 ± 7 MV/cm = 8.4 x 10^9 V/m]
- ✓ "In other words, the extreme electric field experienced by 19-NT's C=O in wild-type KSI is specific to its precise position in the active site where strong local interactions and the collective effect of the overall enzyme architecture mutually reinforce each other."

Ultrahigh electric fields occur in enzyme active sites

Continuing on Fried *et al*. re extreme E-fields in isomerase active site

Reactions with larger charge displacements would be exponentially accelerated

- ✓ "A plot of each mutant's apparent activation barrier (calculated from the Michaelis-Menten k_{cat}) … against its corresponding ensemble-average active-site electric field magnitude … reveals a robust linear trend (Fig. 3B; see also fig. 7B). This relationship suggests that electric fields in KSI's active site are intimately linked to catalysis."
- ✓ "Apparently, the very large field present in the KSI active site is needed to leverage what small charge displacement is associated with the reaction's transition state. A chemical reaction with a larger charge displacement would consequently be exponentially more accelerated by these electric fields, suggesting that electric field effects may provide a natural framework for explaining the catalysis of more proficient enzymes as well."
- ✓ By comparing the intercept extrapolated to $(\overrightarrow{F_{\text{enz}}}) = 0$ from Fig. 3B (18.8 kcal mol^{-1}) to wild-type KSI's activation barrier (11.5 kcal mol^{-1}), we estimate that the active site's electric field contributes 7.3 ± 0.4 kcal mol^{-1} to KSI's barrier reduction. This corresponds to an ~10^5-fold rate enhancement and accounts for 70% of KSI's catalytic speedup relative to an uncatalyzed reference reaction in solution."

Ultrahigh electric fields occur in enzyme active sites

Continuing on Fried *et al*. re extreme E-fields in isomerase active site

Performance of the KSI active site depends upon average electric field strength

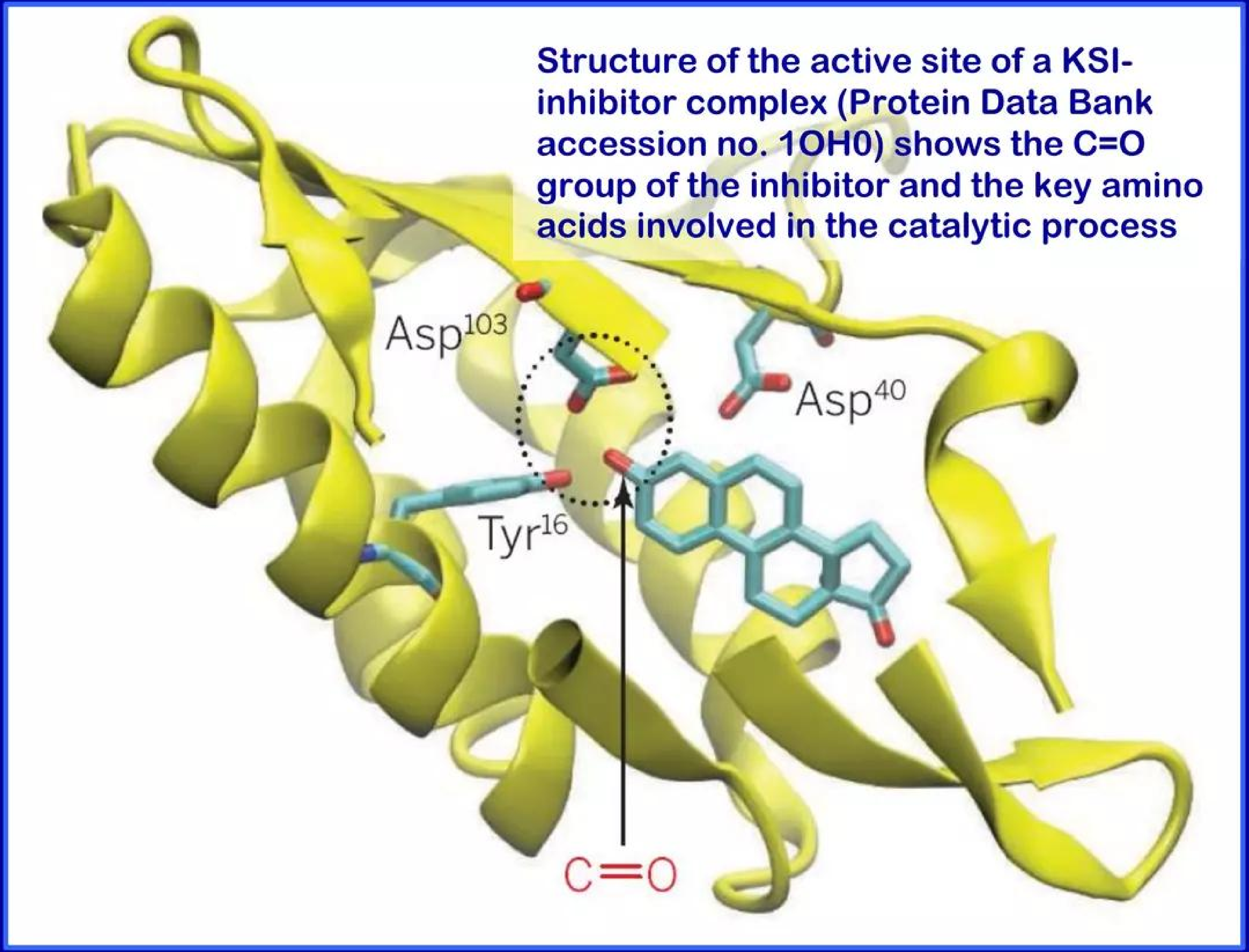
- ✓ "The remaining catalytic effect beyond electrostatics can likely be attributed to the precise positioning of the general base (Asp^{40}) with respect to the proton on the steroid to be abstracted, which is expected to be an entropic effect. From this discussion, we surmise that in enzymatic proton abstraction, electrostatic stabilization and exact positioning of reacting moieties provide the physical basis to achieve enthalpic and entropic contributions to catalysis, respectively …"
- ✓ "What is the physical basis for the extreme electric field detected in KSI's active site? Large electric fields arising from Tyr^{16} and Asp^{103} are expected when the carbonyl group of the ligand closely approaches the OH groups of these two residues and in a coplanar orientation [as indeed is seen in crystal and solution structures]. Nevertheless, these static structures cannot predict or reproduce the electric fields determined by vibrational Stark effects, likely because structures represent ensemble averages and because electric fields depend sensitively on atomic positions down to resolutions not accessible in most structural data."
- ✓ "That a substantial portion of KSI's catalytic rate enhancement can be explained in terms of its average electric field suggests that the electric field could be a useful design criterion in the ongoing efforts to engineer enzymes with unnatural or enhanced functions."

Ultrahigh electric fields occur in enzyme active sites

Comments on Fried *et al*. re extreme E-fields in isomerase active site

Statement by Peter Hildebrandt about their paper in *Science* 346 pp. 1456 (2014)

"It is very likely that the electric field-dependent acceleration of elementary reactions is a general concept in biological catalysis and perhaps also in chemical catalysis …"



Structure of the active site of a KSI-inhibitor complex (Protein Data Bank accession no. 1OH0) shows the C=O group of the inhibitor and the key amino acids involved in the catalytic process

http://web.stanford.edu/group/boxer/papers/paper303%20perspective.pdf

Ultrahigh electric fields occur in enzyme active sites

Comments on Fried *et al*. re extreme E-fields in isomerase active site

Average E-fields of 1.5 x 10^{10} V/m are close to threshold for neutron production

- ✓ Their paper is important and a must-read for those studying enzymatic catalysis
- ✓ What is most striking about Fried *et al.*'s revelatory experimental results is that two vastly different types of condensed matter systems --- one a structurally and compositionally complex Carbon-based enzyme protein --- and the other a much simpler abiotic many-body collection of collectively oscillating protons and electrons --- both use a similar combination of very high electric fields and quantum entanglement of particles located in active sites to achieve enormous increases in chemical and electroweak nuclear reaction rates, respectively
- ✓ Average electric field strength in an active site of the wild-type enzyme is ~ 150 MV/cm or 1.5 x 10^{10} V/m. However, these E-field measurements by Fried *et al.* reflect time-averaged values under quasi-equilibrium conditions; fast-transient (attosecond) pulse spikes in field strength could not be seen or measured using their methods (recent private communication with S. Boxer, coauthor on paper)
- ✓ It is reasonable to speculate that dynamic, nonequilibrium electronic processes occurring inside the enzyme's active site during catalysis could potentially create local E-field strengths that exceeded 2.5 x 10^{11} V/m for about 100 - 500 attoseconds. If that were to occur and electrons and protons in the active site happened to be properly configured, LENR electroweak catalysis could ensue

Quantum-mechanical delocalization of protons

Many-body collective Q-M proton entanglement observed in enzyme

Protons in LENR as well as enzyme active sites exhibit same type of Q-M effects

"Quantum delocalization of protons in the hydrogen-bond
network of an enzyme active site"
L. Wang *et al.*, *PNAS* 111 pp. 18454 - 18459 (2014)
http://web.stanford.edu/group/boxer/papers/paper304.pdf

- ✓ "Here, we combine experiments and state-of-the-art simulations that include the quantum nature of both the electrons and nuclei to show that the enzyme ketosteroid isomerase [KSI] contains a hydrogen-bond network in its active site that facilitates extensive quantum proton delocalization."
- ✓ "Nuclear quantum effects, such as tunneling and zero-point energy (ZPE), have been observed to lead to kinetic isotope effects of greater than 100 in biological proton and proton-coupled electron transfer processes. However, the role of nuclear quantum effects in determining the ground state thermodynamic properties of biological systems, which manifest as equilibrium isotope effects, has gained significantly less attention."
- ✓ "At these short distances, the proton's position uncertainty (de Broglie wavelength) becomes comparable with the O–O distance, indicating that nuclear quantum effects could play an important role in stabilizing the deprotonated residue. In this work, we show how nuclear quantum effects determine the properties of protons in the active-site hydrogen-bond network of KSI."

Quantum-mechanical delocalization of protons

Continuing on Wang *et al*. re entanglement of protons in KSI active site

Protons in LENR as well as enzyme active sites exhibit same type of Q-M effects

- ✓ "Inclusion of nuclear quantum effects, thus, allows the protons to delocalize between the hydroxyl oxygens to mitigate the quantum kinetic energy penalty (Fig. 3B), which is not observed classically."
- ✓ "This energy match leads to qualitatively different behavior of the protons in the active site of KSI^{D40N}: from classical hydrogen bonding to quantum delocalization. The proton delocalization between the residues allows for ionization to be shared among three tyrosine's to stabilize the deprotonation of Tyr57, leading to the large observed pKa shift relative to the value in the classical limit (Fig. S2)."
- ✓ "Although proton delocalization can occur classically at short O–O distances (<2.3 Å), nuclear quantum effects allow this to occur for a much wider range of O–O distances (up to ~2.6 Å), making delocalization feasible without incurring the steep steric costs that would be associated with bringing oxygen atoms any closer. The distances in the active-site triad motif of KSI, thus, maximize quantum proton delocalization, which acts to stabilize the deprotonated residue."
- ✓ "Our simulations, which include electronic quantum effects and exactly treat the quantum nature of the nuclei, show qualitatively and quantitatively different proton behavior compared with conventional simulations in which the nuclei are treated classically, and provide good agreement with experiment."

Q-M entangled network links distant atoms to an active site

"Debate continues about the origin of the catalytic power of enzymes"

LENR electroweak catalysis requires far-from-equilibrium conditions

"Linking protein motion to enzyme catalysis"
P. Singh, T. Abeysinghe and A. Kohen, *Molecules* 20 pp. 1192 - 1209 (2015)
http://www.mdpi.com/1420-3049/20/1/1192/pdf

- ✓ "Dynamics here address any motion of the atoms that compose the system under study: reactants, protein, and solvent. Dynamics that are associated with the catalyzed reaction and its rate … Those motions are assumed … in thermal equilibrium with their environment, and this review does not invoke any non-equilibrium, non-statistical, or otherwise non-Boltzmann distribution of states."

- ✓ Lattice comments: while this sweeping simplifying assumption may make the chemical physics of enzymes more tractable, it doesn't apply to Widom-Larsen theory collective Q-M many-body LENR electroweak catalysis where attosecond non-linear, non-equilibrium, non-Boltzmann effects are crucial to successful operation. At equilibrium, LENR electroweak processes simply won't happen

- ✓ "Along with experimental studies, theoretical investigations utilizing molecular dynamics and quantum mechanical/ molecular mechanical simulations suggest that enzyme dynamics play a role in catalysis, and support the presence of a global dynamic network of residues in *E. coli* DHFR. The term "dynamic network" in this context refers to all the residues whose motion is coupled (to each other) and is part of the reaction coordinate … refs [16, 39 - 43] suggested that several residues far from the active site are also part of that network."

- ✓ Lattice comments: we are in total agreement with this thinking. As discussed earlier herein, many-body collective effects and quantum entanglement of atoms/particles are rampant in active sites and may extend a considerable distance away to residues located elsewhere in enzyme molecules

Isotope effects important in LENR electroweak catalysis

Admixtures of hydrogen isotopes can block formation of active sites

“Mass modulation of protein dynamics associated with barrier crossing in purine nucleoside phosphorylase”
D. Antoniou *et al.*, *Physical Chemistry Letters* 3 pp. 3538 - 3544 (2012)

http://schwartzgroup1.arizona.edu/schwartzgroup/sites/default/files/steve/files/jpcl_3_3538_2012.pdf

- ✓ “Small perturbation induced by heavy isotope replacement slightly alters the dynamic features, causing less frequent coordination of the multiple dynamic events that lead to barrier crossing … combination of the experimental results demonstrating mass dependent catalytic effects and the present computational identification of altered motions linked to barrier crossing establishes the importance of these effects. Enzymes have been optimized through evolution to function with the naturally occurring isotopic elements. Enzyme structures have been optimized to hunt efficiently through configuration space for catalytically competent conformations based on the bond vibrational modes of the natural isotopic compositions. Mass perturbations in this hunt decrease the efficiency of the search and … decrease the rate of on-enzyme chemistry.”
- ✓ Lattice comments: yet another parallel between LENR electroweak catalysis and enzymes; hydrogenous ions that provide protons for e + [H^+] reaction in LENR active sites can be protons (mass ~ 1 amu), deuterons (m ~ 2), and/or tritons (m ~3). For such an active site to support coherent collective oscillations of protons, the isotopic composition of the site must be more-or-less homogeneous. If not, differing masses will interfere with collective coherence. It is well known amongst LENR experimentalists that > 2 - 3% admixtures of protium H_2 in a deuterium D_2 system (or vice-versa) will assuredly poison LENR processes

Doped VA-NCNTs to replace Platinum-based ORR catalysts

Metal-free catalysts have huge static electric fields near dopant atoms

Catalyze $4e^-$ oxygen reduction reaction with 3x higher electrocatalytic activity

"N-doped carbon nanomaterials are durable catalysts for oxygen reduction [ORR] in acidic fuel cells"
J. Shui *et al. Scientific Advances* 1 e1400129 (2015)
http://advances.sciencemag.org/content/advances/1/1/e1400129.full.pdf

- ✓ "We demonstrated that rationally designed, metal-free, nitrogen-doped carbon nanotubes and their graphene composites exhibited significantly better long-term operational stabilities and comparable gravimetric power densities with respect to the best NPMC in acidic PEM cells. This work represents a major breakthrough in removing the bottlenecks to translate low cost, metal-free, carbon-based ORR catalysts to commercial reality."
- ✓ "Traditionally, platinum has been regarded as the best catalyst for fuel cell … Can act as a metal-free electrode to catalyze a 4e− ORR process with a three times higher electrocatalytic activity and better long-term stability than commercially available platinum/C electrodes …"
- ✓ "Carbon atoms adjacent to nitrogen dopants in the NCNT structure had a substantially high positive charge density to counterbalance the strong electronic affinity of the nitrogen atom."
- ✓ "Doping carbon nanomaterials with heteroatoms as in the NCNT electrodes could efficiently create the metal-free active sites for electrochemical reduction of O_2."

Doped VA-NCNTs to replace Platinum-based ORR catalysts

Metal-free catalysts have huge static electric fields near dopant atoms

Electrostatic electric fields in TTF-TCNQ go to as much as 21.097 x 10^{11} V/m

"Single-Walled Carbon Nanohorns for Hydrogen Storage and Catalyst Supports"
D. Geohegan *et al*., Oak Ridge National Laboratory (ORNL) , Project ID ST017 (2010)
http://www.hydrogen.energy.gov/pdfs/review10/st017_geohegan_2010_p_web.pdf

"Electric fields within the crystal are in units of 10^{10}V/m --- scale shown in (b.) --- and illustrate the high-field areas where H_2 molecules are strongly bound"

Very large electrostatic electric fields occur in the vicinity of Calcium dopant atoms decorating both sides of a graphene sheet

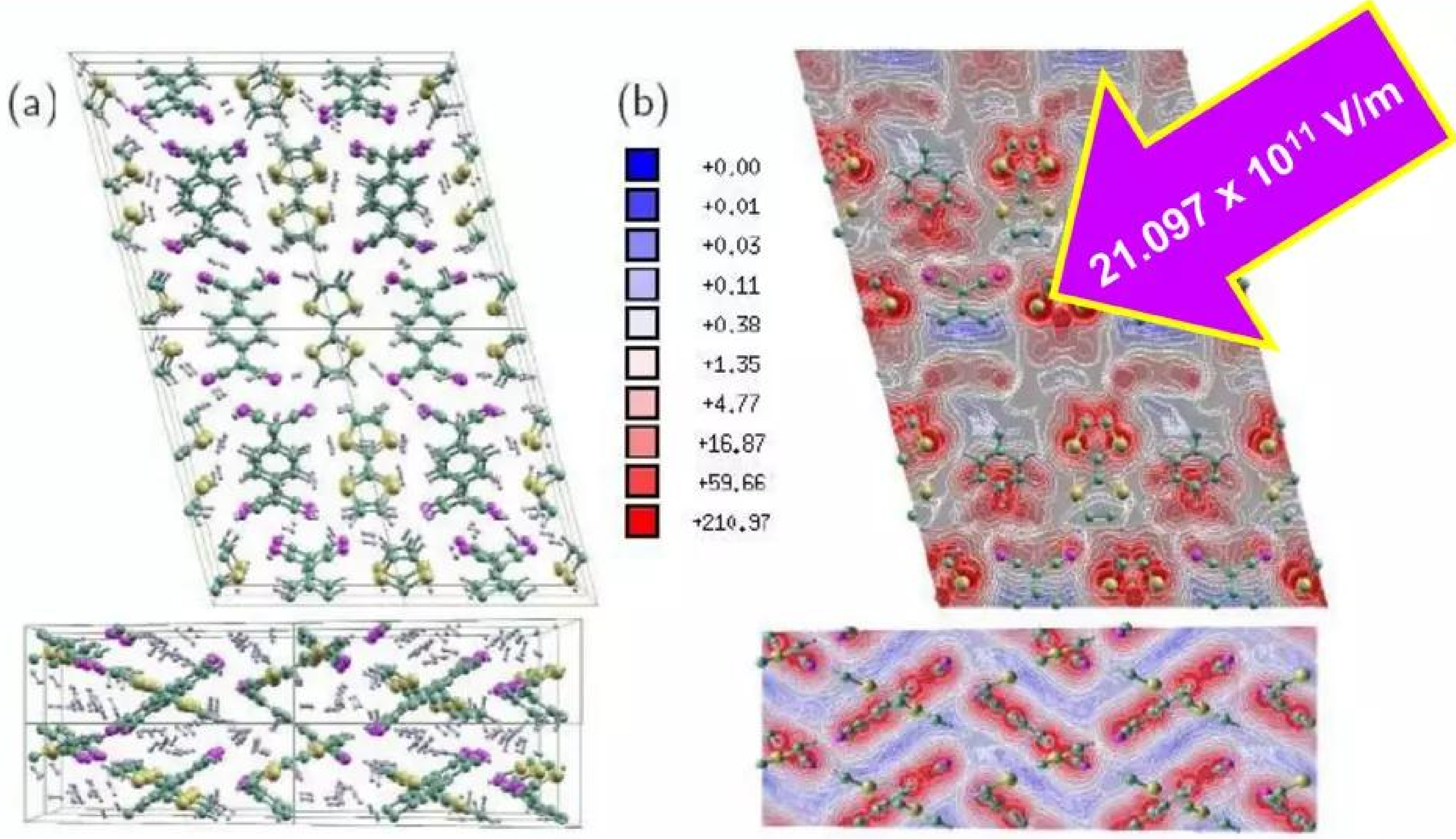
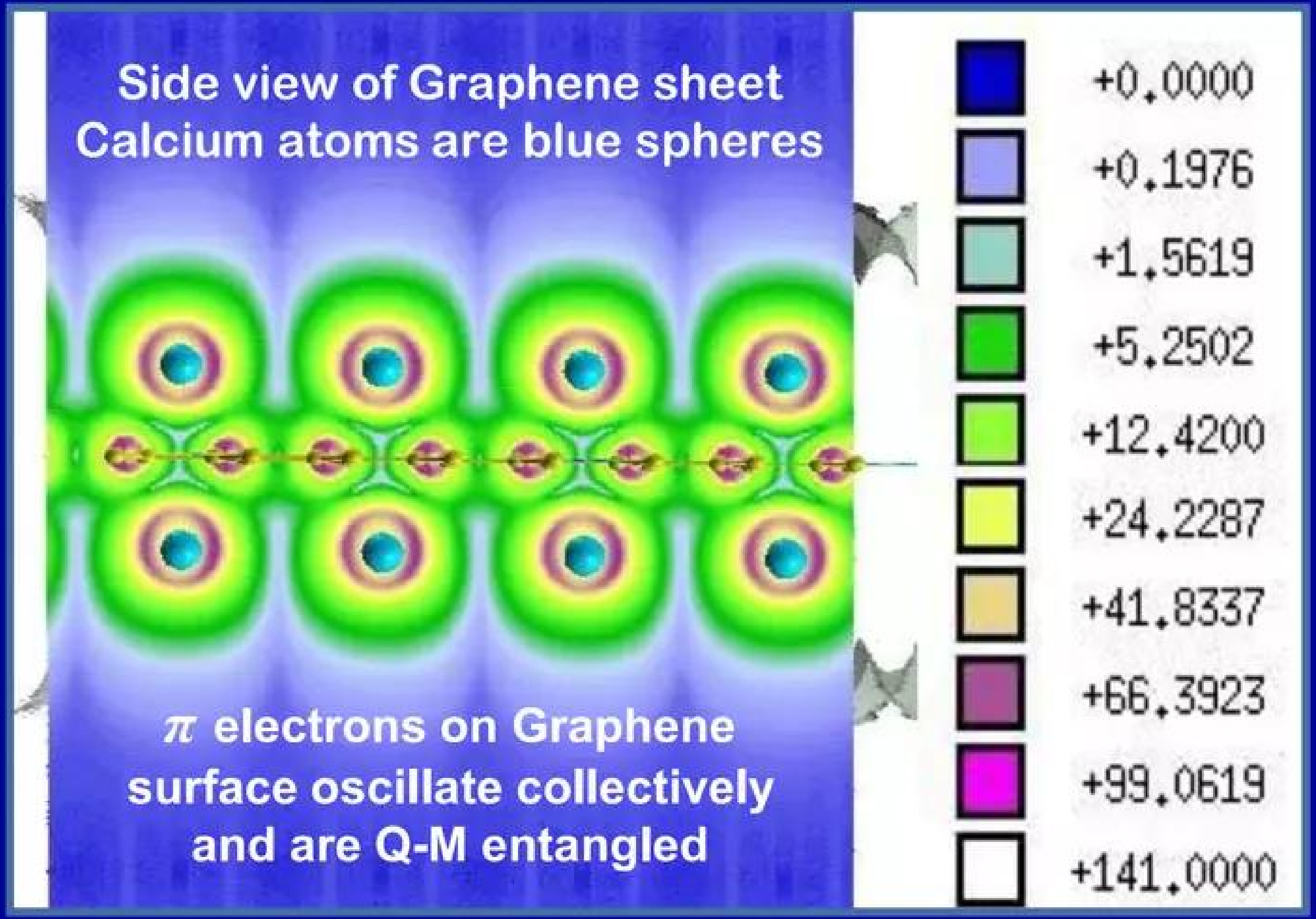


FIG. 4: (a) Crystal structure of segreggated TTF-TCNQ containing 34 H_2 in an unit cell, which corresponds to gravimetric densities 7.7 wt% and 8.2 g/l volumetric density with average H_2 binding energy 0.17 eV. Two perspective of solid structures are displayed. (b) Electric field (in the unit of 10^{10} V/m) generated in the TTF-TCNQ crystal.



Side view of Graphene sheet Calcium atoms are blue spheres

π electrons on Graphene surface oscillate collectively and are Q-M entangled

E-fields - scale at right - go up to 141 x 10^{10} V/m (= 14.1 x 10^{11} V/m)

"Ca atoms on both sides of graphene polarize and bind hydrogen molecules by electric field-induced polarization just as effectively as Ca atoms on just one side."

"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)

Laura 13

Shewanella oneidensis

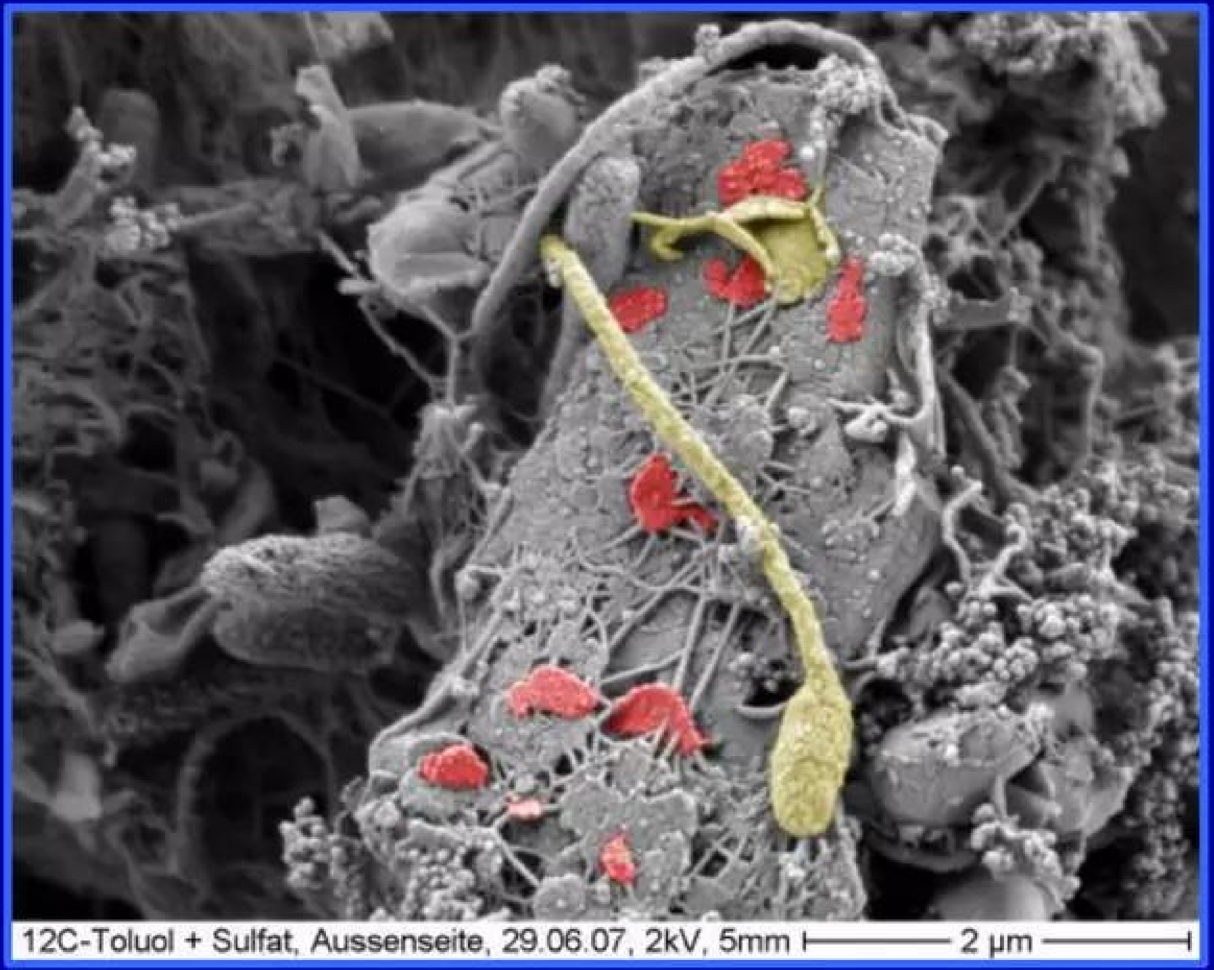
Image: R. Bencheikh and B. Arey

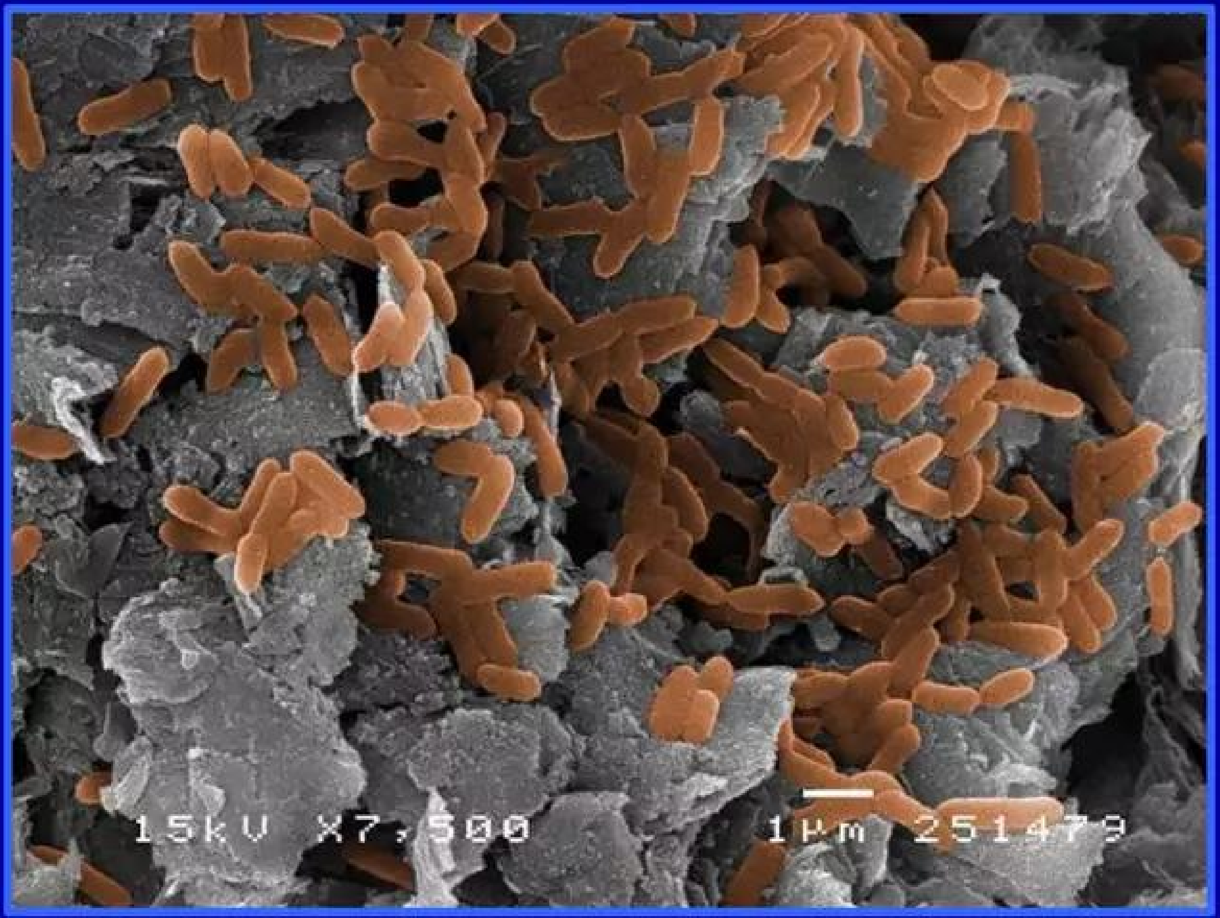
Nanowires interconnecting many bacteria

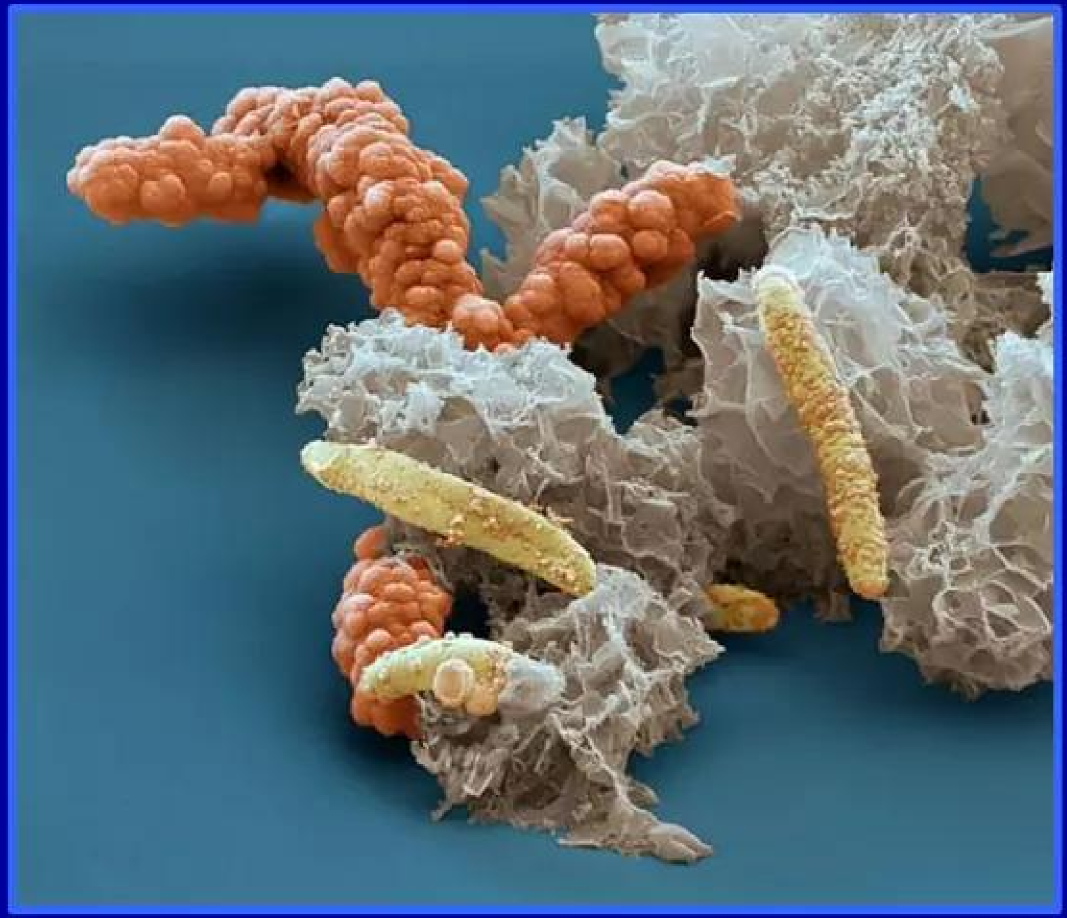
PNAS (DOI: 10.1073/pnas.0604517103)

Bacteria often grow in close proximity to mineral surfaces

Although not shown in all SEM images, bacteria connected by nanowires







Reports of major isotopic anomalies are accumulating

For years researchers assumed ^{238}U/^{235}U ratio was invariant - it is not

What causes unexpected variance: just chemical fractionation or LENRs also?

"^{238}U/^{235}U systematics in terrestrial Uranium-bearing minerals"
J. Hiess *et al*.
Science 335 no. 6076 pp. 1610-1614 (2012)
http://www.sciencemag.org/content/335/6076/1610.full

Highest variability in the ^{238}U/^{235}U ratio occurs in terrestrial materials originating in low-temperature chemical precipitates, redox ores, and/or sedimentary environments. This category accurately describes the natural environment found in the Rifle, Colorado, study site in which soil bacteria are clearly involved in shifting the ^{238}U/^{235}U ratio as well as triggering significant, time-varying shifts in Sulfur isotope abundances during roughly contemporaneous, spatially nearby redox reactions. Fig. 3 again strongly suggests that terrestrial bacteria are the culprits behind observed isotopic shifts in Uranium and Sulfur in soils and rocks

Key question: are these observed shifts produced by 'ordinary' chemical fractionation or LENR processes or both? This issue begs for further investigation by adventuresome experimentalists

Reports of major isotopic anomalies are accumulating

Bopp *et al*. show that soil bacteria are altering $^{238}U/^{235}U$ isotopic ratios

Question as to whether cause is chemical fractionation or LENRs still unresolved

"Uranium $^{238}U/^{235}U$ isotope ratios as indicators of reduction: results from an *in situ* biostimulation experiment at Rifle, Colorado, U.S.A."
C. Bopp *et al.*. *Environmental Science & Technology* 44 pp. 5927 - 5933 (2010)
http://pubs.acs.org/doi/abs/10.1021/es100643v

- ✓ Although not explicitly acknowledged by chemical isotopic fractionation theorists, an intrinsic fundamental assumption underlying all such theory and interpretation of data is that no nucleosynthetic processes are occurring anywhere in any of these systems, at any time, that are capable of altering isotope ratios and/or producing new mixtures of different elements over time; ergo, they are assuming that chemistry alone explains everything
- ✓ If Widom-Larsen theory LENRs occur out in Nature, albeit at extremely low rates, above-noted fundamental assumption is evidently wrong for a subset of such anomalous data
- ✓ If hypothesized chemical fractionation mechanisms truly worked as well on Uranium isotopes in non-gas-phase systems as proponents have claimed, one would presume that such effects would have been utilized long ago in at least one government nuclear weapons or commercial Uranium enrichment program somewhere in the world, e.g. Iran today. To our knowledge, during the past 70 years they have never been used for such a purpose anywhere. This suggests that, while they may be logical, so-called "nuclear field shift effects" are inadequate explanations for observed changes in Uranium isotope ratios

Many new exciting discoveries about bacterial energetics

Electricity is ideal source of energy input needed for LENRs in bacteria

See Cologgi (2011): why is *Geobacter* manipulating Uranium out in its nanowires?

"Extracellular reduction of Uranium via *Geobacte*r conductive pili as
a protective cellular mechanism"
D. Cologgi *et al*. *PNAS* 108 pp. 15248 - 15242 (2011)
http://www.pnas.org/content/108/37/15248.full.pdf+htm

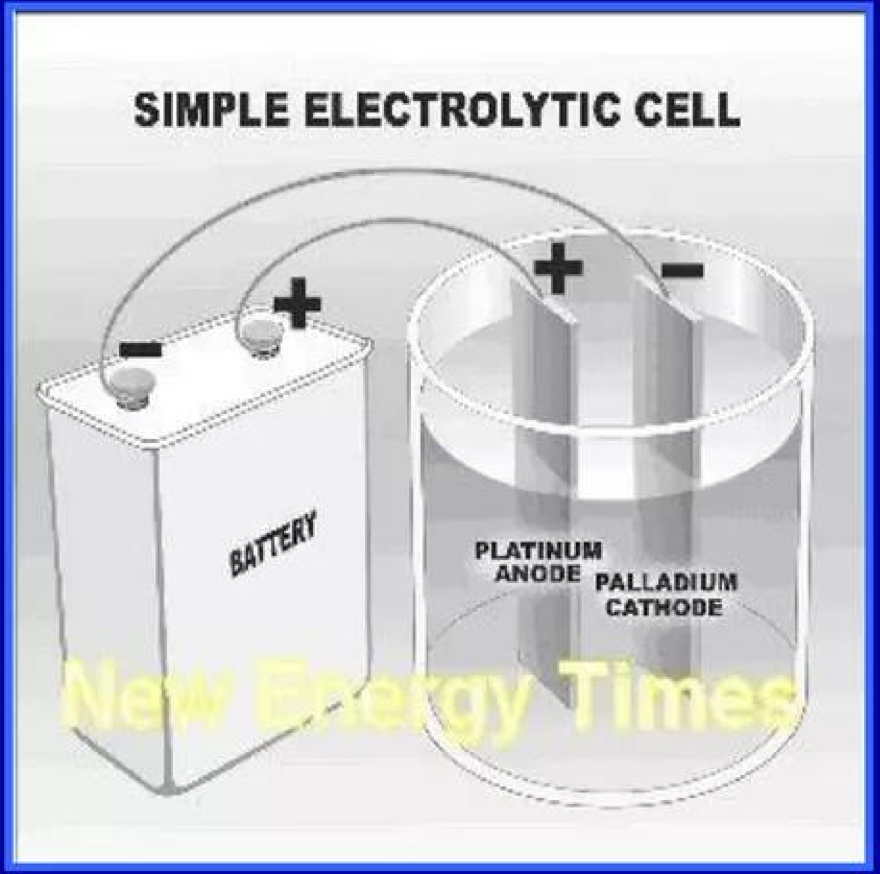
- ✓ Many papers involving the use of various types of very sensitive mass spectroscopy analysis report anomalous isotopic shifts in elements ranging from Hydrogen to Uranium that are obviously associated with activities of many bacterial species, especially the extremophiles
- ✓ Key question: how much might be caused by LENRs vs. just prosaic chemical fractionation?
- ✓ If some of it is LENRs, where does necessary external input energy to make ultralow energy neutrons come from? Is energetically expensive; requires equivalent of ~10 - 15 million ATP molecules to make one neutron. It is known that electricity is ideal LENR input power source
- ✓ Interestingly and importantly, microbiologists have recently discovered existence of highly conductive nanowires that interconnect many different species of soil and crustal bacteria. More recently, have discovered bacteria that can live on electricity as a sole energy source
- ✓ This juxtaposition of exciting new discoveries opens-up the possibility that bacteria may be living in soils and deep in the Earth's crust that could utilize electricity as a source of input energy for driving LENR-based nucleosynthetic processes that can alter isotopic ratios

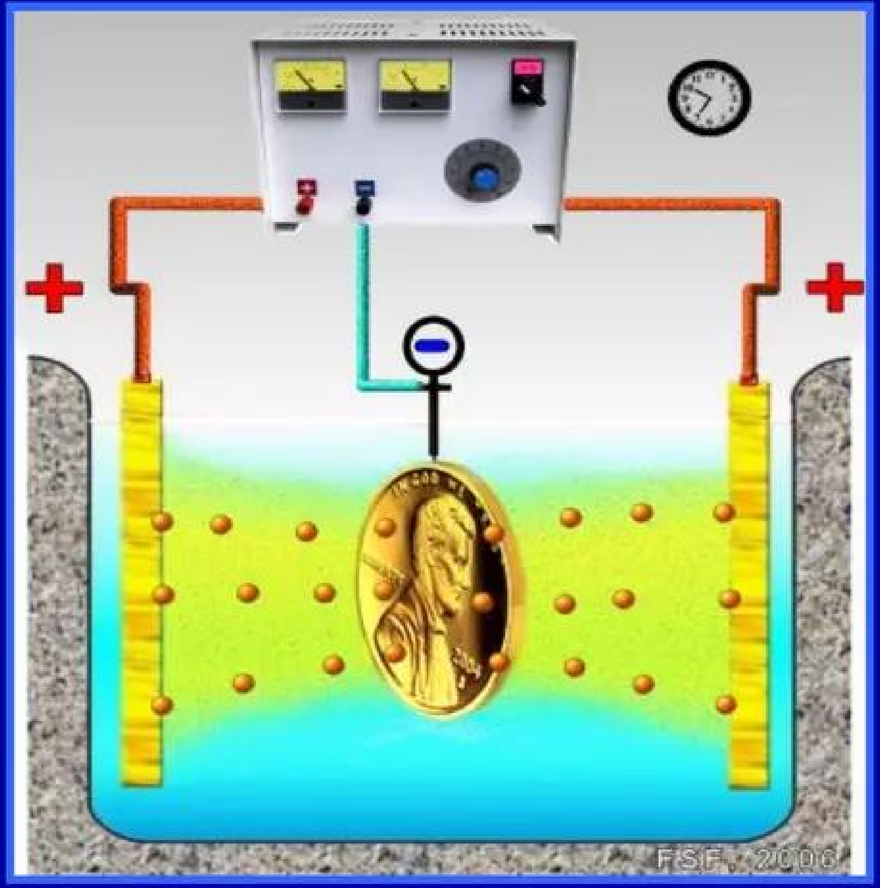
Are bacteria really transmuting elements out in Nature?

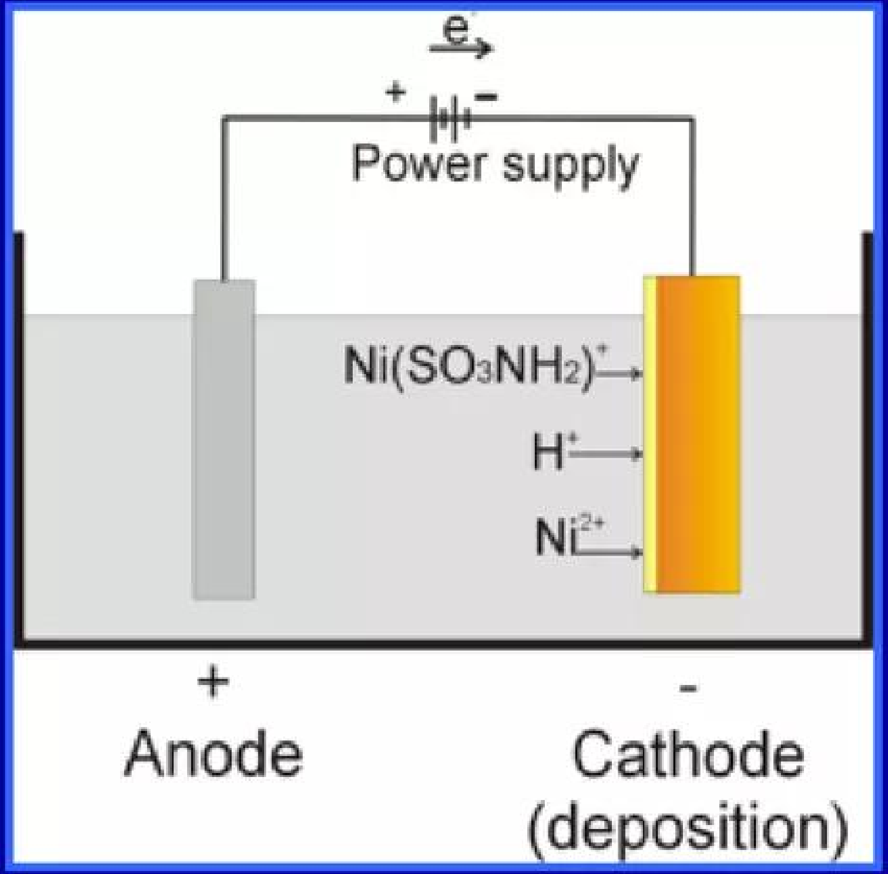
Possibly occurring in: soils, upper crust, undersea hydrothermal vents

Collective electrical interactions amongst bacteria similar to LENR chemical cells

Conceptual overviews of an LENR electrolytic chemical cell







Above are conceptual schematics for aqueous light-water electrolytic chemical cells used in many LENR experiments; typically would use DC power supply instead of a battery as a source of electrical input energy. Importantly, using modern mass spectroscopy for post-experiment analyses of cathode materials, 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, neutron fluxes were >10^{12} cm^2/sec which created a bewildering array of different types of LENR transmutation products

Hydrogen (protons) readily available within Earth's crust

Crushed andesite essentially produced ~5.0 Liters of H_2 per 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. Two types of experiments were conducted. Single crystal fracture experiments indicated that hydroxyl pairs undergo an *in situ* redox conversion to H_2 molecules plus peroxy links, $O_3Si/OO\backslash SiO_3$. While the peroxy links became part of the mineral structure, the 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) readily available within Earth's crust

Lollar *et al*. show that H_2 is surprisingly abundant in Precambrian rocks

"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

- ✓ **Note:** this paper is major new revelation because Precambrian rocks (previously thought to contain negligible amounts of H_2) comprise >70% of Earth's global continental crust
- ✓ **Quoting excerpts 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."

Are bacteria really transmuting elements out in Nature?

Scientists discovering that "electric bacteria" may well be ubiquitous

"Shows that [bacterial] life can handle the energy in its purest form - electrons"

"Meet the electric life forms that live on pure energy"

Catherine Brahic in *New Scientist: Life* July 16, 2014

Excellent, well-written popular article

http://www.newscientist.com/article/dn25894-meet-the-electric-life-forms-that-live-on-pure-energy.html

Quoting excerpts directly: "Unlike any other life on Earth, these extraordinary bacteria use energy in its purest form – they eat and breathe electrons – and they are everywhere."

"Stick an electrode in the ground, pump electrons down it, and they will come: living cells that eat electricity. We have known bacteria to survive on a variety of energy sources, but none as weird as this. Think of Frankenstein's monster, brought to life by galvanic energy, except these 'electric bacteria' are very real and are popping up all over the place."

"Unlike any other living thing on Earth, electric bacteria use energy in its purest form – naked electricity in the shape of electrons harvested from rocks and metals. We already knew about two types, *Shewanella* and *Geobacter*. Now, biologists are showing that they can entice many more out of rocks and marine mud by tempting them with a bit of electrical juice. Experiments growing bacteria on battery electrodes demonstrate that these novel, mind-boggling forms of life are essentially eating and excreting electricity."

Are bacteria really transmuting elements out in Nature?

“Such bacteria are showing up everywhere we look, says Lars Nielsen.”

“Bacterial cells that both eat and breathe electrons will soon be discovered”

“Meet the electric life forms that live on pure energy”

Catherine Brahic in *New Scientist: Life* July 16, 2014

http://www.newscientist.com/article/dn25894-meet-the-electric-life-forms-that-live-on-pure-energy.html

Quoting excerpts directly: “Electric bacteria come in all shapes and sizes. A few years ago, biologists discovered that some produce hair-like filaments that act as wires, ferrying electrons back and forth between the cells and their wider environment. They dubbed them microbial nanowires.”

“Lars Peter Nielsen and his colleagues at Aarhus University in Denmark have found that tens of thousands of electric bacteria can join together to form daisy chains that carry electrons over several centimetres – a huge distance for a bacterium only 3 or 4 micrometres long.”

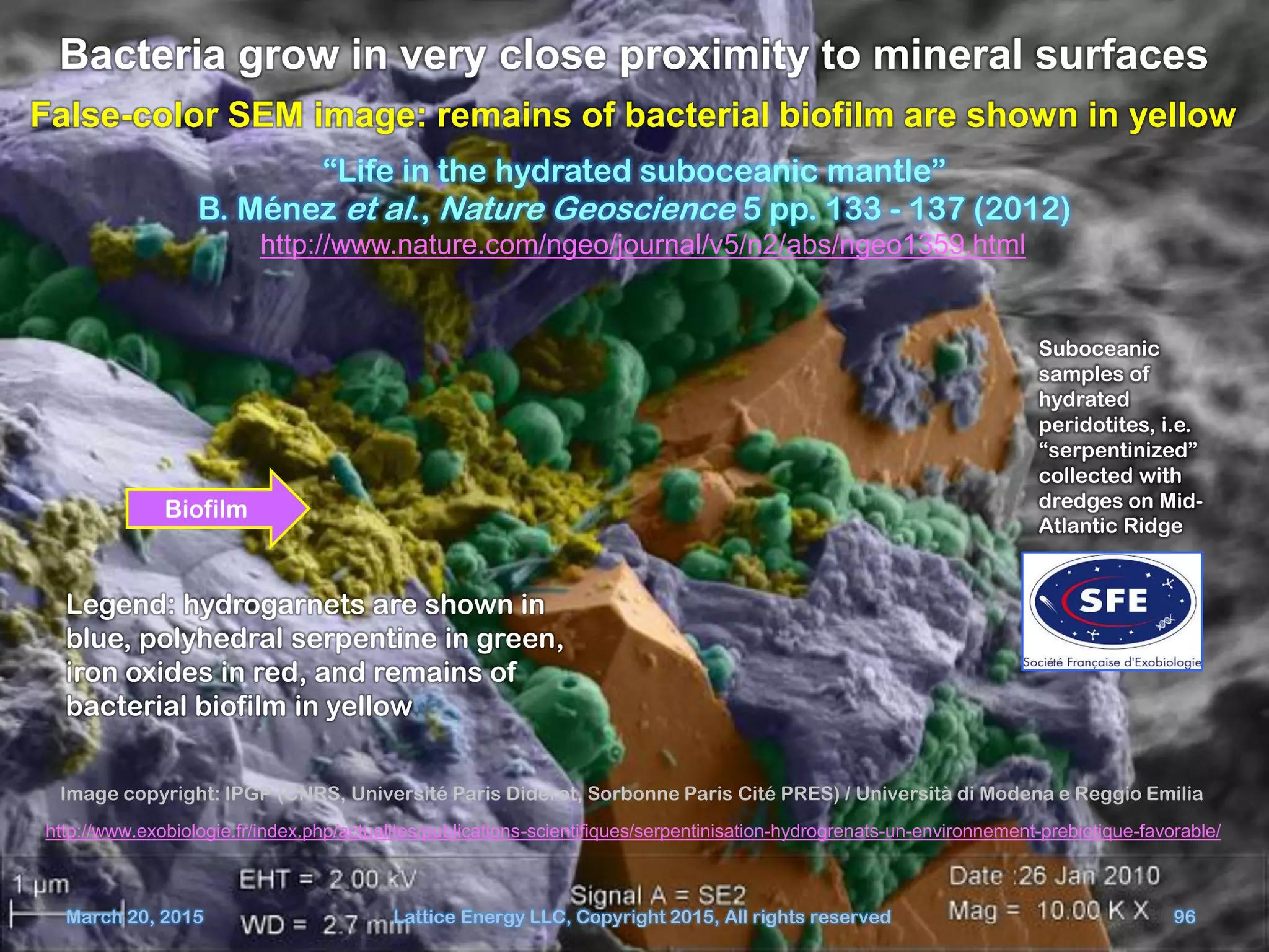
“Such bacteria are showing up everywhere we look, says Nielsen.”

“Early work shows that such cables [bacterial nanowires] conduct electricity about as well as the wires that connect your toaster to the mains.”

Bacteria grow in very close proximity to mineral surfaces

False-color SEM image: remains of bacterial biofilm are shown in yellow

"Life in the hydrated suboceanic mantle"
B. Ménez *et al.*, *Nature Geoscience* 5 pp. 133 - 137 (2012)
http://www.nature.com/ngeo/journal/v5/n2/abs/ngeo1359.html



Suboceanic samples of hydrated peridotites, i.e. "serpentinized" collected with dredges on Mid-Atlantic Ridge

SFE
Société Française d'Exobiologie

Legend: hydrogarnets are shown in blue, polyhedral serpentine in green, iron oxides in red, and remains of bacterial biofilm in yellow

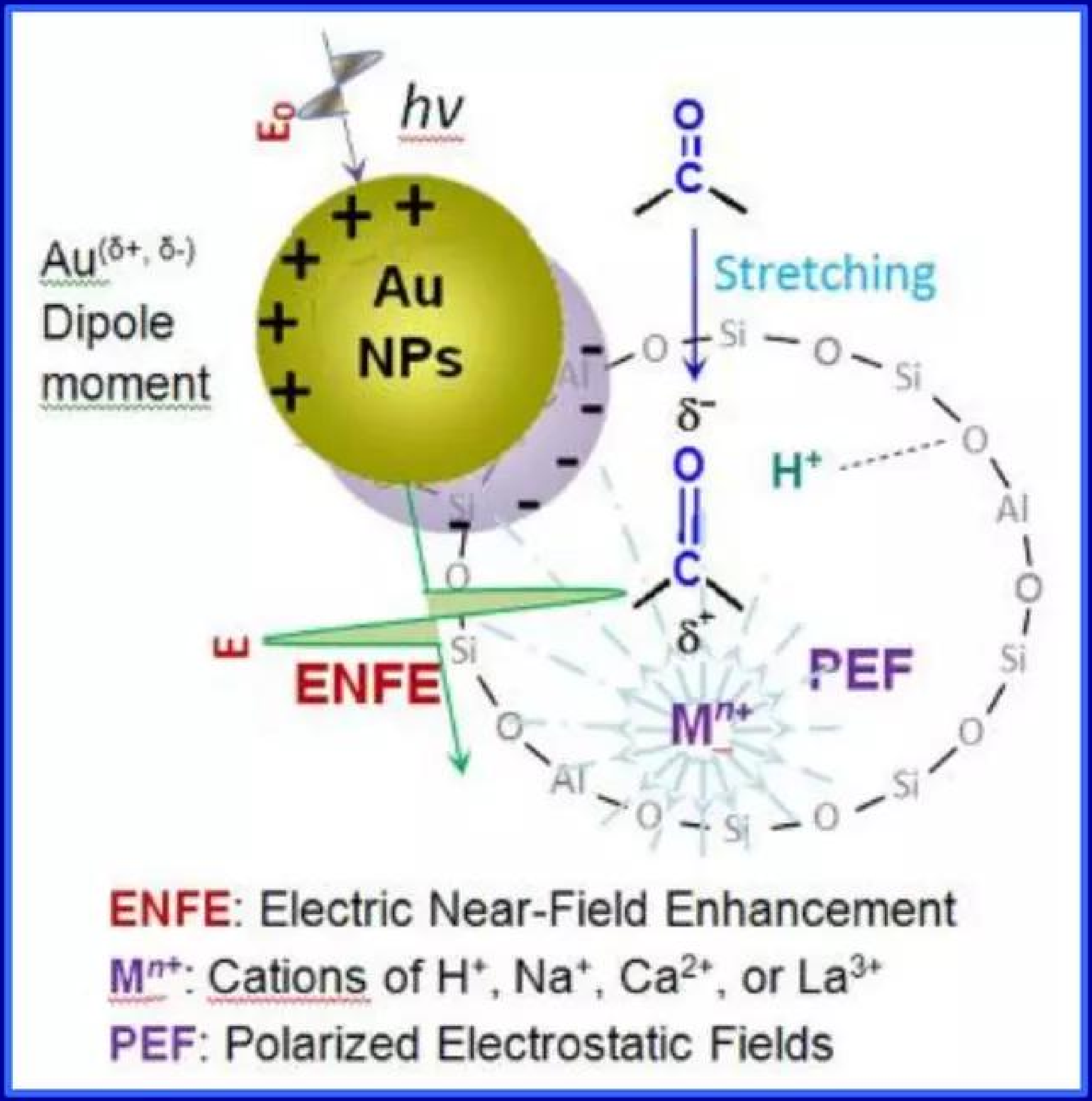
Image copyright: IPGP (CNRS, Université Paris Diderot, Sorbonne Paris Cité PRES) / Università di Modena e Reggio Emilia

http://www.exobiologie.fr/index.php/actualites/publications-scientifiques/serpentinisation-hydrogrenats-un-environnement-prebiotique-favorable/

Concluding remarks

- ✓ **Heretofore, chemical and nuclear processes were thought to be vastly distant realms; we now know that they coexist in close proximity to each other and may even interoperate on *nm* to *μ* length-scales**
- ✓ **Herein we have shown that there are some very surprising similarities between the operation of active sites in LENR electroweak, enzymatic, and abiotic industrial catalysis: all three seem to be utilizing high local electric fields and many-body collective quantum effects to achieve dramatic increases in reaction rates and catalytic proficiency**
- ✓ **With respect to LENR active sites vs. those of enzymes and other types of chemical catalysts, what separates the two major energetic realms could be presence of many-body entangled protons and electrons in close proximity, coupled with input energy that triggers attosecond-scale pulses in local electric field strength up to values > 2.5 x 10^{11} V/m**
- ✓ **It has become clear that knowledge about details of LENR electroweak catalysis can provide very useful insights into enzymatic catalysis and vice-versa. We look forward to working with others to exploit this and thus advance technical progress in both areas**

Gold nanoparticles enhance performance of zeolite catalysts



"Plasmonic nanostructures to enhance catalytic performance of zeolites under visible light"
X. Zhang *et al.*, *Scientific Reports* 4 pp. 3805 (2014)

http://www.nature.com/srep/2014/140122/srep03805/pdf/srep03805.pdf

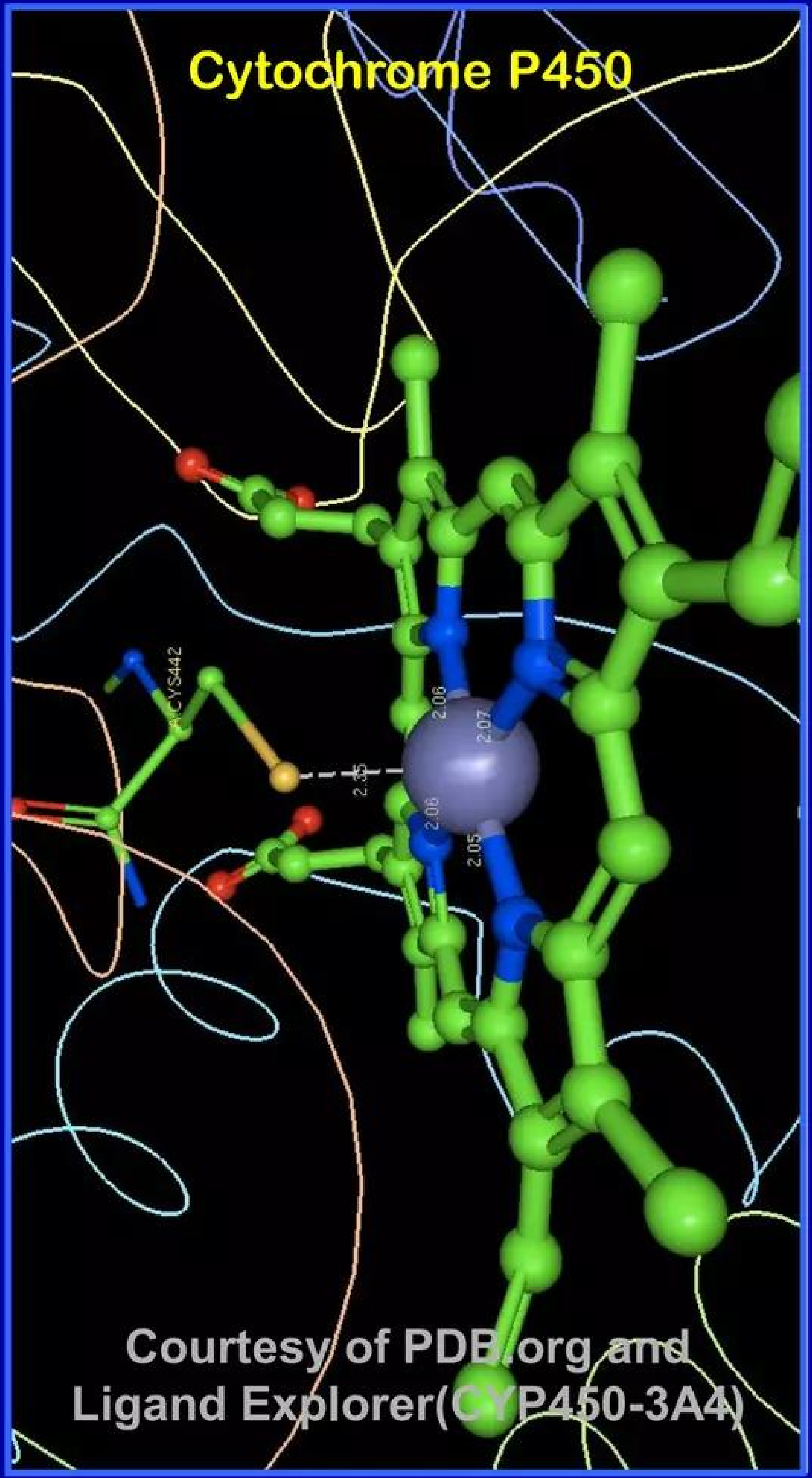
Working with Lattice

Partnering on commercialization and consulting on certain topics

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

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

- ✓ **Lattice welcomes inquiries from established large organizations that may have an interest in discussing the possibility of becoming a strategic capital and/or a key technology development partner with our US company**
- ✓ **Lewis Larsen also selectively engages in fee-based third-party consulting that does not compromise Lattice's proprietary intellectual property relating to any LENR-based power sources. Such expertise includes many areas such as optimizing industrial catalysts; LENRs as they relate to petroleum geochemistry and fracking-induced seismicity; lithium-ion battery safety; and long-term strategic implications of LENRs on high cap-ex long term investments in power generation and petroleum-related assets.**


Cytochrome P450

Courtesy of PDB.org and Ligand Explorer(CYP450-3A4)

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  A. Kohen
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Lattice Energy LLC

Commercializing a next-generation source of green nuclear energy

"A scientist is supposed to have a complete and thorough knowledge, at first hand, of some subjects and, therefore, is usually expected not to write on any topic of which he is not a master. This is regarded as a matter of *noblesse oblige*. For the present purpose I beg to renounce the *noblesse*, if any, and to be freed of the ensuing obligation. My excuse is as follows: we have inherited from our forefathers the keen longing for unified, all-embracing knowledge. The very name given to the highest institutions of learning reminds us, that from antiquity and throughout many centuries the universal aspect has been the only one to be given full credit. But the spread, both in width and depth, of the multifarious branches of knowledge during the last hundred odd years has confronted us with a queer dilemma. We feel clearly that we are only now beginning to acquire reliable material for welding together the sum-total of all that is known into a whole; but, on the other hand, it has become next to impossible for a single mind fully to command more than a small specialized portion of it. I can see no other escape from this dilemma (lest our true aim be lost forever) than that some of us should venture to embark on a synthesis of facts and theories, albeit with second-hand and incomplete knowledge of some of them --- and at the risk of making fools of ourselves."

Erwin Schrödinger "What is life?" (1944)