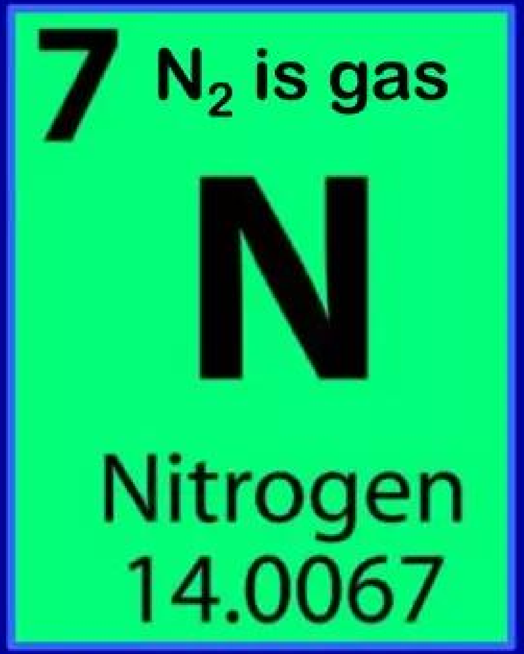
Lattice Energy LLC

Survival of 40% of world’s population heavily depends on higher food production enabled by Ammonia fertilizer produced in large plants via Haber-Bosch process as commercialized in 1909

Progress being made with new catalyst technology that could potentially reduce capital and operating costs of future Ammonia plants which would be cost-effective in much smaller sizes that enable distributed production



N_2 very inert

Lewis G. Larsen
President and CEO
Lattice Energy LLC
June 27, 2017
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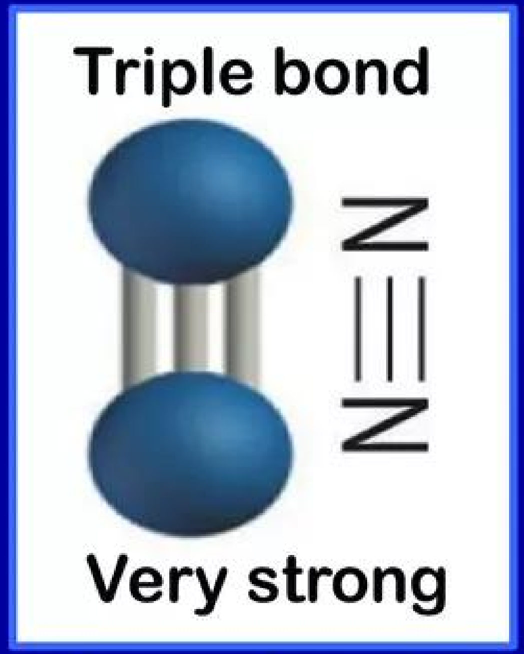


N_2 molecule

Present significance of 1909 Haber-Bosch process

> "Today, hundreds of Haber-Bosch plants are drinking in air and turning out ammonia, producing enough fertilizer not only to support a burgeoning human population but to improve average diets worldwide. All of the plants run on the same principles Haber and Bosch pioneered and are filled with the same basic catalyst that Alwin Mittasch found almost a century ago. They are however, larger and more efficient. In Carl Bosch's day, the tallest ammonia ovens were thirty feet high. Now they top one hundred feet. In 1938, it took an average of sixteen hundred workers to produce a thousand tons a day of ammonia. Today it takes 55 workers to make the same amount. In the early days it took four times as much energy to make a ton of fertilizer as it does now. Still, the demand for their products are so great that Haber-Bosch plants today consume 1 percent of all the energy on earth … This huge, almost invisible industry is feeding the world. Without these plants, somewhere between two billion and three billion people --- about 40% of the world's population … would starve to death."

Thomas Hager "The Alchemy of Air" (2008)

Major reduction in size and cost of future Ammonia plants?

Recent Japanese papers confirm Lattice's hypotheses about importance of adsorbed protons and high local electric fields for boosting reaction rates on some types of metallic catalyst surfaces

Manabe et al. achieved high yield Haber-Bosch-like synthesis of Ammonia by applying DC electric fields along with N_2, H_2, Cs/Ru catalyst and $SrZrO_3$ support at just room temperature and ~1 atmosphere pressure versus ~450° C and ~200 atm in commercial NH_3 plants

Widom-Larsen theory of LENRs predicts deep causal connection between many-body collective physics of electroweak nuclear catalysis and chemical catalysis: very high local electric fields $\geq 10^{10}$ V/m and mobile surface patches of Q-M entangled protons

In LENRs these enable: $\mathrm{Energy}_{\text{E-field}} + e^-_{sp} \rightarrow e^{-*}_{sp} + p^+ \rightarrow n^0 + \nu_e$

Widom-Larsen theory of ultralow energy neutron reactions

Many-body collective quantum effects enable $e + p$ electroweak reaction

Radiation-free nuclear catalysis can occur at very high rates in condensed matter

- ✓ Widom-Larsen theory of ultralow energy neutron reactions (LENRs) explains breakthrough physics of how many-body electroweak $e + p$ reactions between electrons and protons (or deuterons) - that normally occur at temperatures above 10 billion degrees Kelvin and pressures over 26.5 petapascals in cores of exploding stars - can proceed at substantial rates in condensed matter at roughly room temperature and atmospheric pressure. Electroweak $e + p$ reaction produces safe benign neutrinos and ultralow energy neutrons used to catalyze various nuclear transmutation reactions that release nuclear binding energy & make heat
- ✓ LENRs can achieve huge reductions in temperatures and pressures for triggering $e + p$ reaction in condensed matter by utilizing advantageous combination of many-body collective processes along with quantum entanglement between groups of charged particles (electrons & protons)
- ✓ Widom-Larsen theory's model of physics for LENR active sites as they occur in condensed matter provides useful insights that can help deepen understanding of inorganic and enzymatic chemical catalysis processes

Contents

Haber-Bosch process preeminently used to fix Nitrogen

Invented in Germany in 1909 and dominated global market ever since

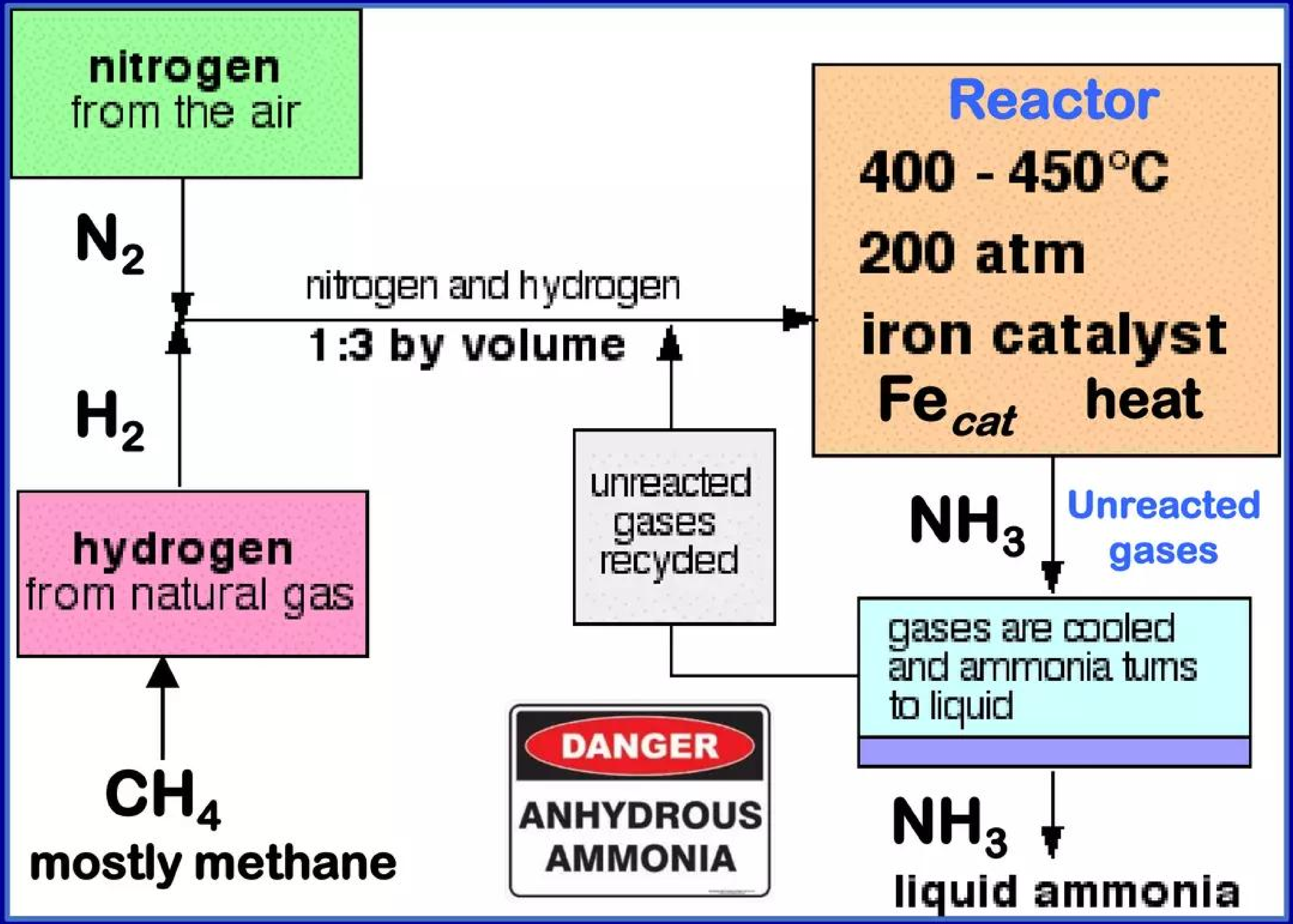
Nitrogen and Hydrogen gas react with Iron (Fe) catalyst to make usable ammonia

First make Hydrogen which is reacted with Nitrogen to produce Ammonia via:

(Natural gas) $CH_4 + 2H_2O \rightarrow 4H_2 + CO_2$ followed by: $N_2 + 3H_2 \rightarrow 2NH_3$ (Ammonia)

Overall: $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$

Fritz Haber



nitrogen
from the air

N_2

nitrogen and hydrogen
1:3 by volume

H_2

hydrogen
from natural gas

CH_4
mostly methane

Reactor
400 - 450°C
200 atm
iron catalyst
Fe_{cat} heat

unreacted gases recycled

NH_3

Unreacted gases

gases are cooled and ammonia turns to liquid

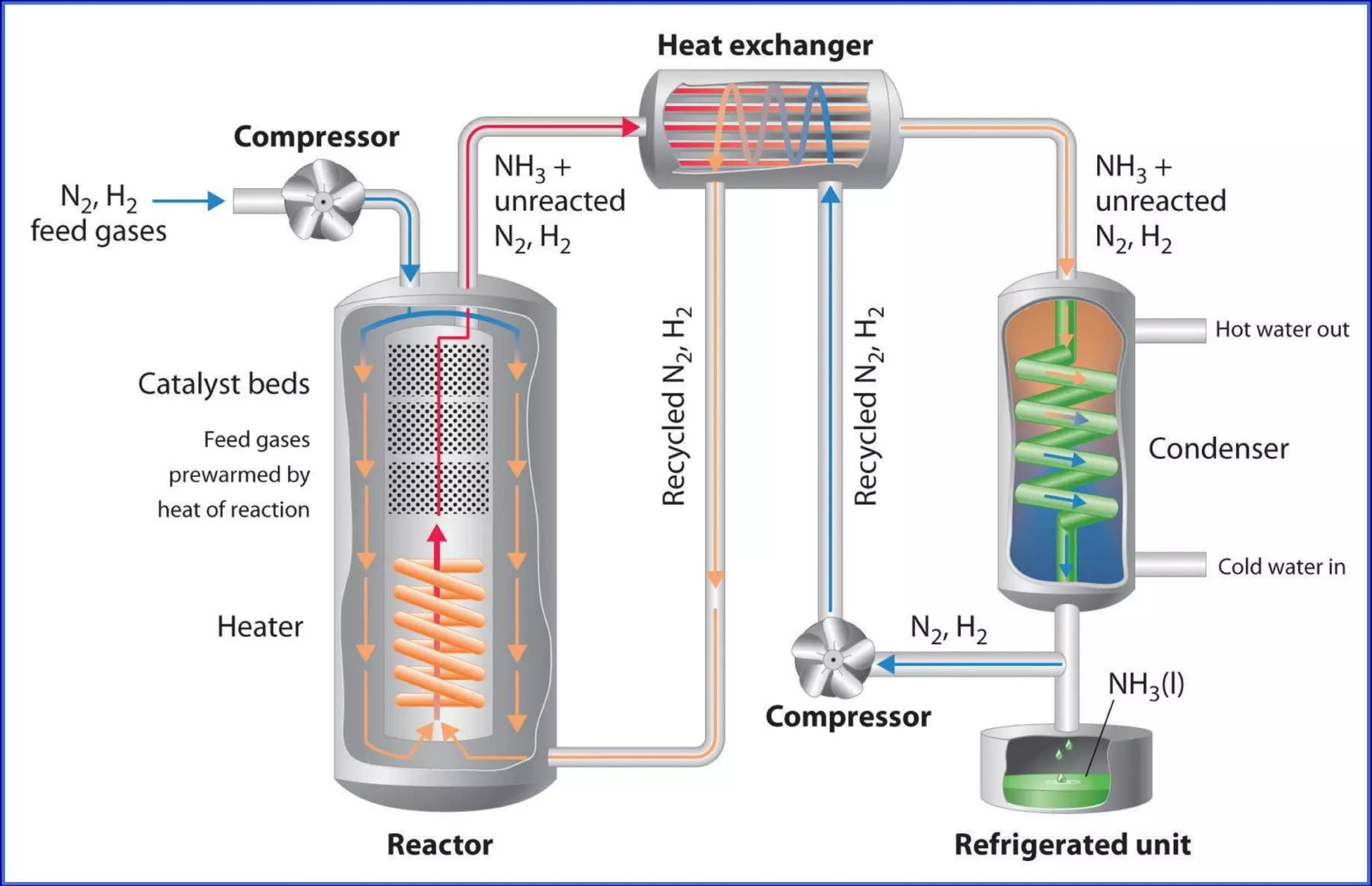
DANGER
ANHYDROUS AMMONIA

NH_3
liquid ammonia

Carl Bosch

Adapted from source: http://www.chemguide.co.uk/physical/equilibria/haber.html

Schematic diagram of Haber-Bosch ammonia plant



Credit: "Controlling the Products of Reactions", section 15.6 from the book *Principles of General Chemistry*

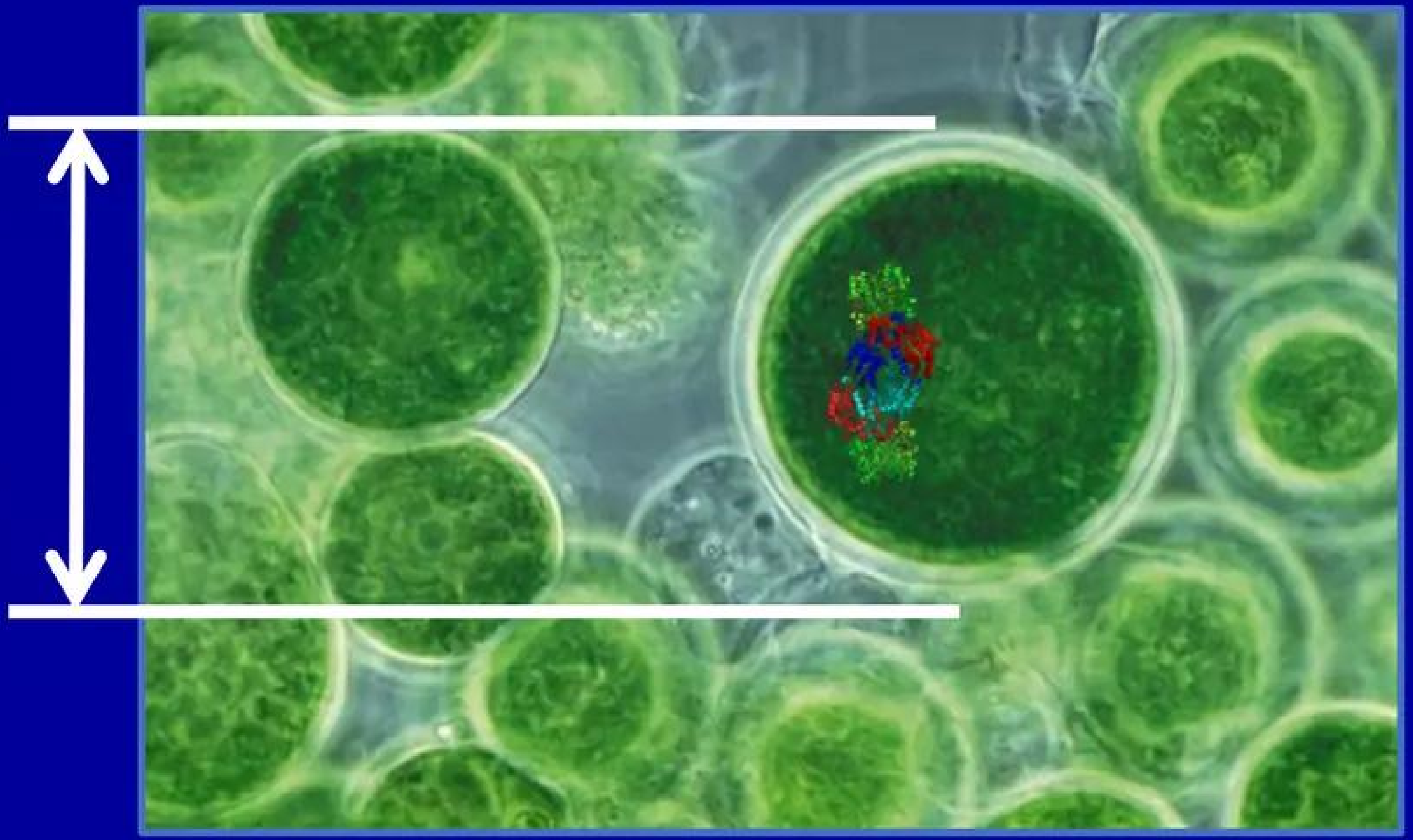
Bacteria able to fix Nitrogen: produce NH_3 like Haber-Bosch

Nitrogenase enzyme enables huge reduction in temps, pressure, and size

Burrup ammonia plant (Australia)

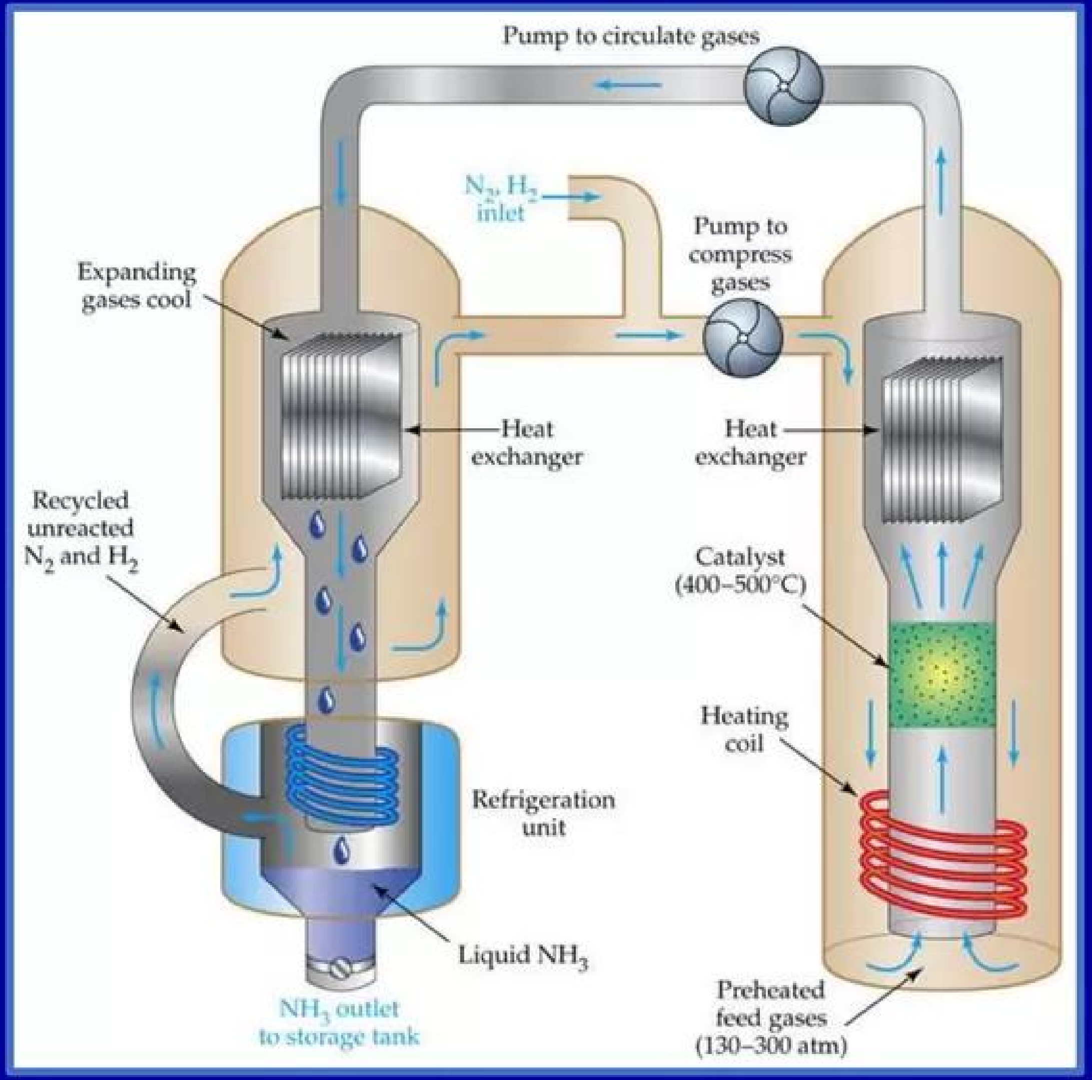
~ 100 feet

Single isolated Cyanobacterium



~ 5 microns = 1.6×10^{-6} feet

Haber-Bosch uses Iron (Fe) catalyst to fix N_2

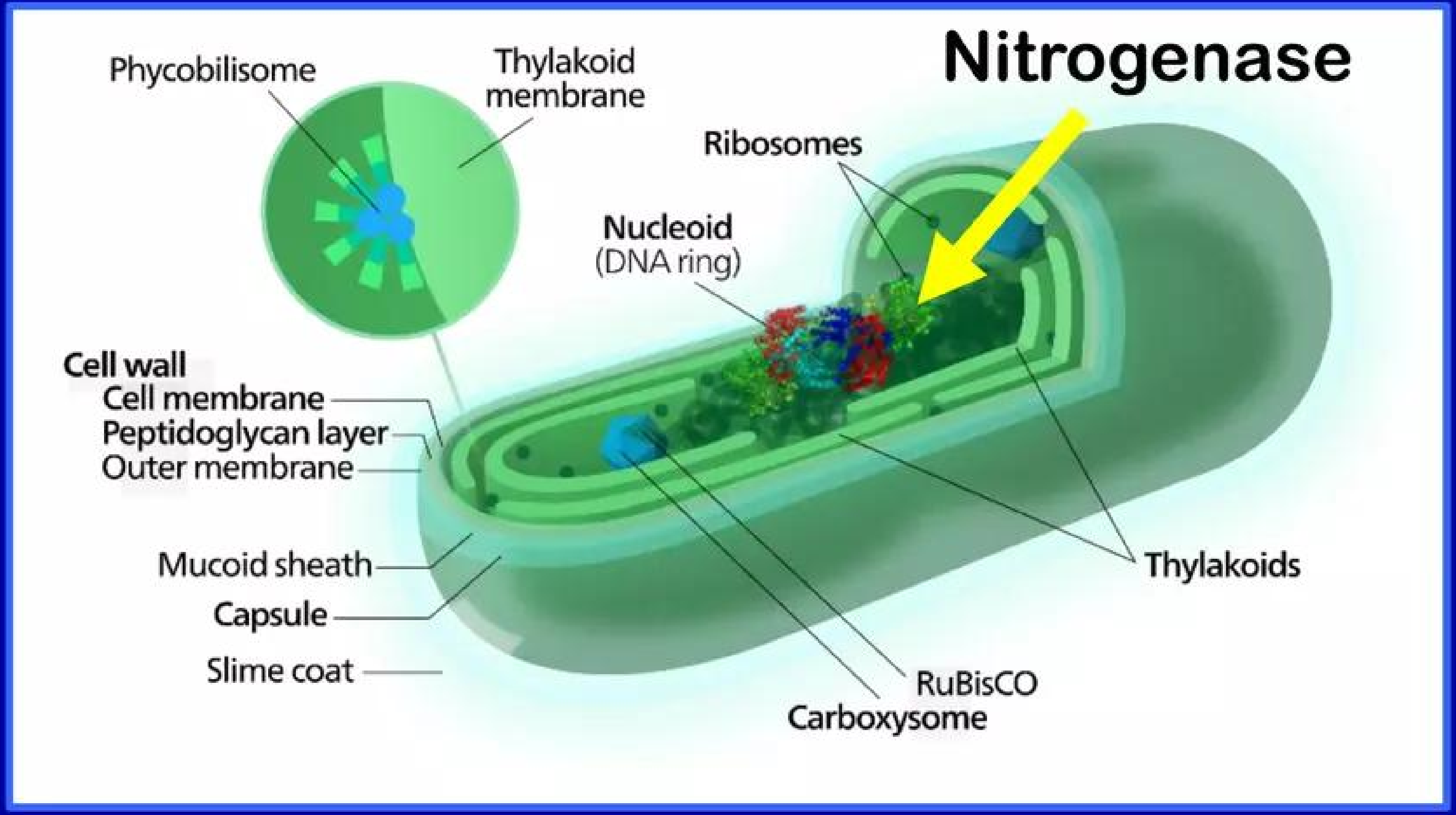


Graphic source: quarkology.com

450° C and 200 atm

23° C and 1 atm

Cyanobacteria use Nitrogenase enzyme to fix N_2



Adapted from graphic source: Wikipedia

Nitrogenase is the only enzyme in Nature that can fix N_2

Converts triple-bonded Nitrogen molecule into chemically usable NH_3

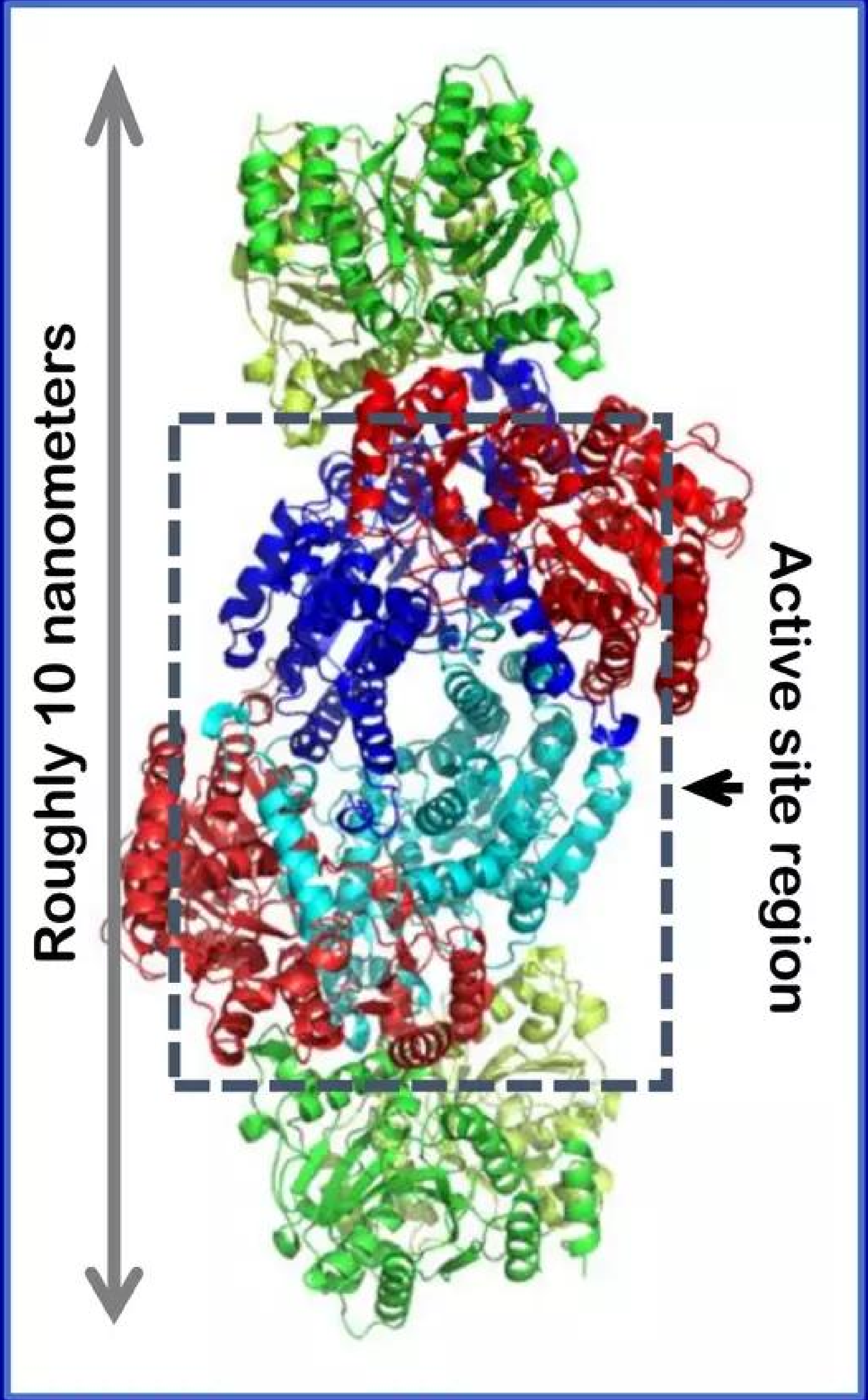
Unlike the Haber-Bosch process, enzyme fixes Nitrogen at low temps/pressures

$$\mathrm{N_2 + 8\,H^+ + 8\,e^- + 16\,ATP \longrightarrow 2\,NH_3 + H_2 + 16\,ADP + 16\,P_i}$$

Energy needed to drive reactions comes from ATP; no CO_2 produced

- ✓ Only family of enzymes in Nature able to break (fix) strong N_2 triple bond to make usable ammonia (NH_3)
- ✓ Higher organisms can't do this; Nitrogenase found only in green sulfur bacteria, azotobacteria, and symbiotic diazotrophs that --- among other things --- live in association with roots and nodules in plants (soybeans for example); diverse diazotroph group includes Rhizobia, Frankias, and cyanobacteria
- ✓ Molybdenum (Mo) cation in active site is critical to catalysis; less proficient variants of this enzyme substitute Vanadium (V) or Iron (Fe) for Mo in site
- ✓ General consensus amongst researchers that key details of catalytic process in enzyme's active site not completely understood; FeMo cofactor is crucial

Nitrogenase structure



Haber-Bosch process used to make NH_3 is hugely important

Needs temps 400 - 600 °K and pressures 200 - 400 atm for good yields

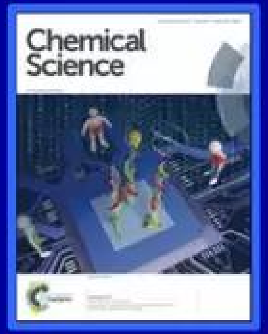
CO_2-free Ammonia synthesis at low temps and pressures is “Holy Grail”

- ✓ Without producing any CO_2 , Nitrogenase enzyme can fix Nitrogen (N_2) from air at vastly lower temperatures and pressures vs. those used in industrial versions of Haber-Bosch process. Unfortunately after many years of R&D, crucial details of exactly how this enzyme functions to produce remarkably high Ammonia yields still not totally understood
- ✓ Recent efforts by researchers to develop improved types of CO_2-free abiotic chemical processes to fix gaseous Nitrogen have produced promising advances. Best results to date were recently reported by Manabe et al. in *Chemical Science* (May 2017 - open access journal). They achieved high yield Haber-Bosch-like synthesis of Ammonia using DC electric fields with N_2, H_2, and Cs-Ru/ZrO_3 catalyst at room temperature and pressures ranging from atmospheric up to 0.9 MPa
- ✓ Development of economically viable process for creating Ammonia at low temps/pressures would allow small-scale, CO_2-free, lower capital cost distributed Ammonia production facilities to make NH_3 fertilizer in locations not presently served by today’s large Haber-Bosch plants

Dramatic temp/pressure reduction for Haber-Bosch process

Quote: "Hopping protons activate N_2 even at low temperatures"

"Electrocatalytic synthesis of ammonia by surface proton hopping"



R. Manabe et al., *Chemical Science* (June 2017)

DOI: 10.1039/c7sc00840f

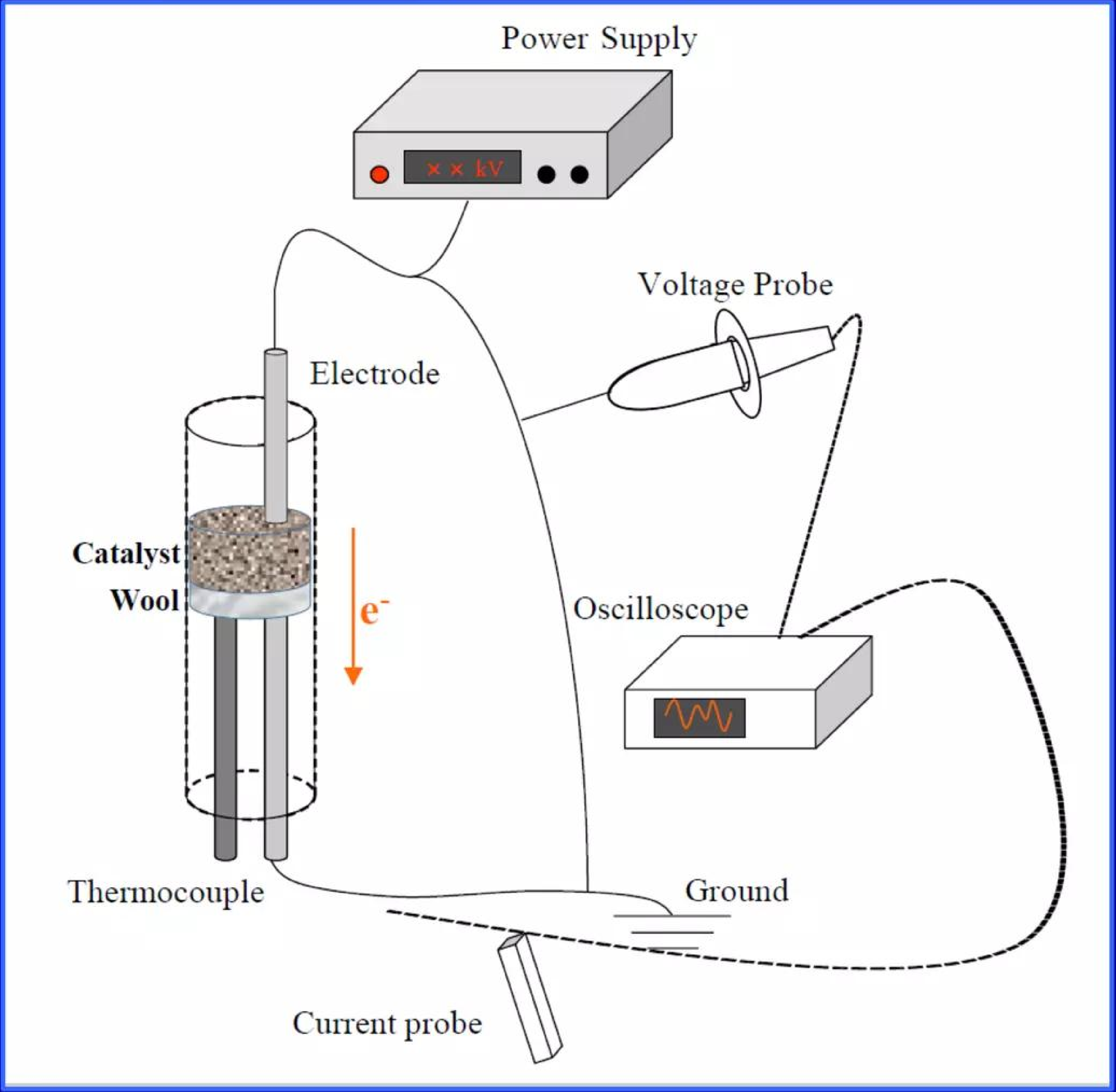
http://pubs.rsc.org/en/Content/ArticleLanding/2017/SC/C7SC00840F#!divAbstract

Abstract: "Highly efficient ammonia synthesis at a low temperature is desirable for future energy and material sources. We accomplished efficient electrocatalytic low-temperature ammonia synthesis with the highest yield ever reported. The maximum ammonia synthesis rate was 30 099 μmol g_{cat}^{-1} h^{-1} over a 9.9 wt% Cs/5.0 wt% Ru/SrZrO3 catalyst, which is a very high rate. Proton hopping on the surface of the heterogeneous catalyst played an important role in the reaction, revealed by *in situ* IR measurements. Hopping protons activate N_2 even at low temperatures, and they moderate the harsh reaction condition requirements. Application of an electric field to the catalyst resulted in a drastic decrease in the apparent activation energy from 121 kJ mol^{-1} to 37 kJ mol^{-1}. N_2 dissociative adsorption is markedly promoted by the application of the electric field, as evidenced by DFT calculations. The process described herein opens the door for small-scale, on-demand ammonia synthesis."

Overview of their experimental apparatus and key materials

9.9 wt% Cs (Cesium) / 5.0 wt% Ru (Ruthenium) on $SrZrO_3$ catalyst support

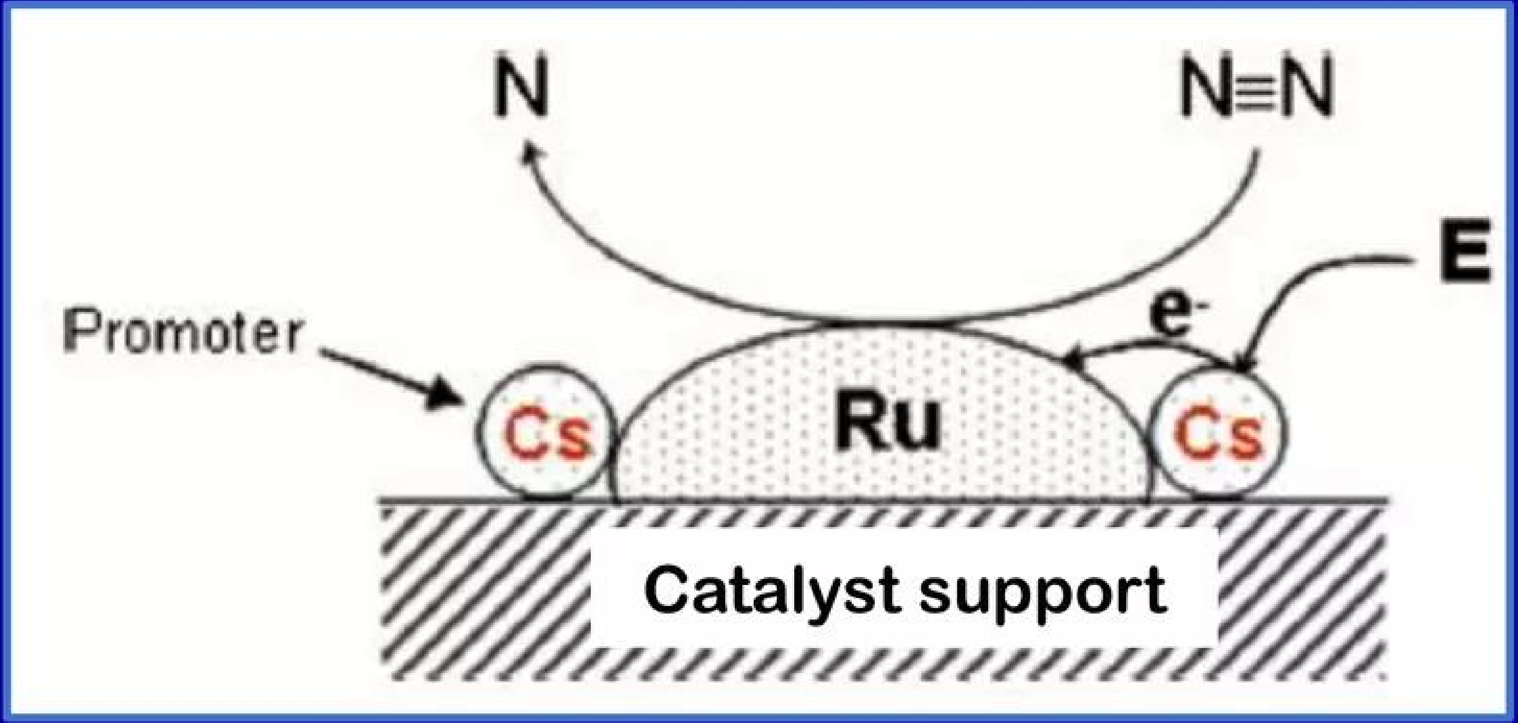
Fig. S8 in Supplementary Information



Credit: R. Manabe et al.
DOI: 10.1039/c7sc00840f (June 2017)

Note: although Cs not explicitly shown in Manabe et al. graphics, Cs located in close proximity to Ru particle is thought to function as donor of sufficiently energetic electrons that are transferred to Ru, and then to the adsorbed N_2 which helps weaken and break the molecule's strong triple bond

Cs promoter w. Ru catalyst nanoparticle

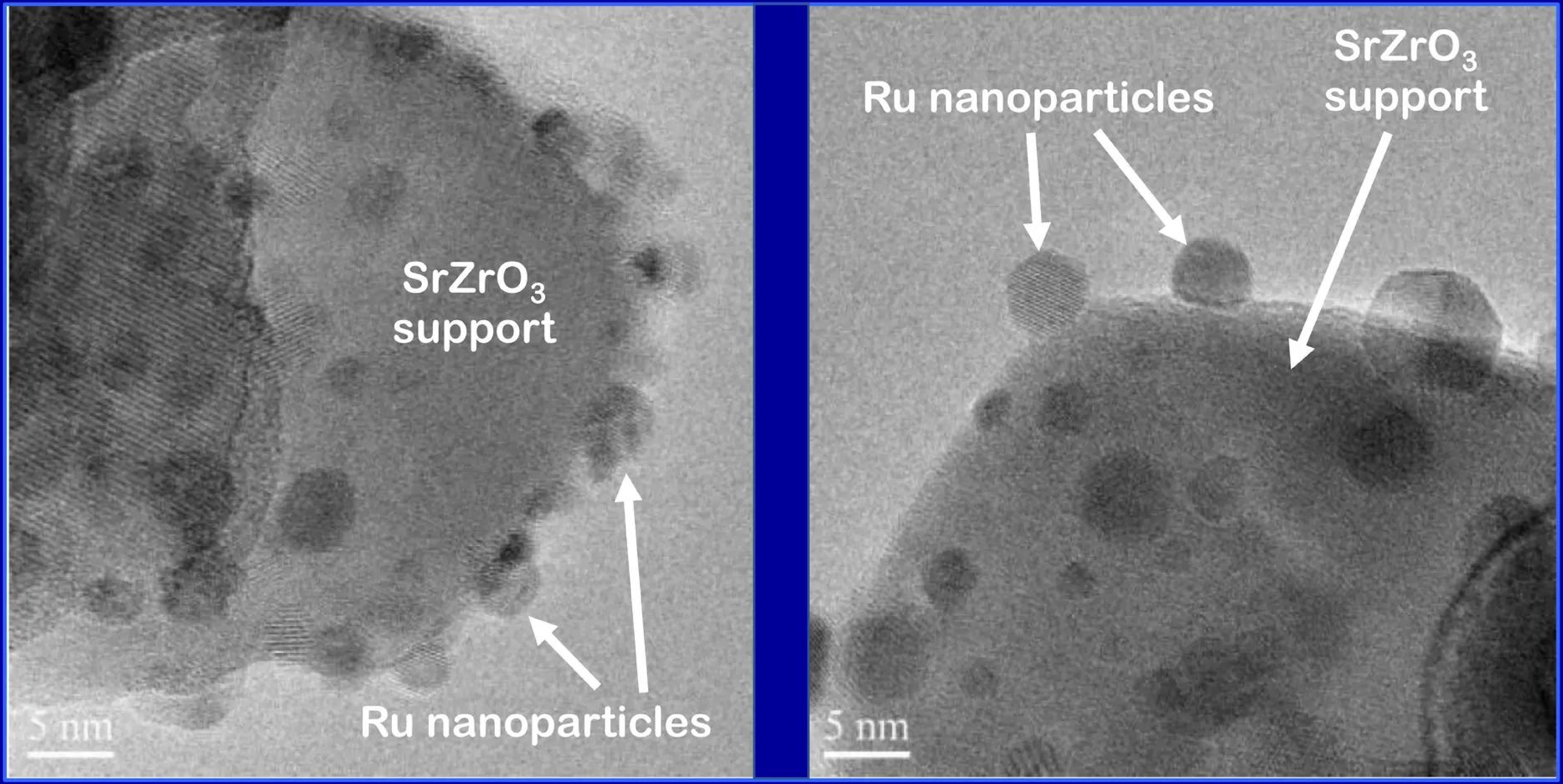


Credit: adapted from P. Peng et al.
DOI: 10.1007/s11090-016-9713-6 (June 2016)

Sizes of Ru nanoparticles can vary from ~ 2 nm up to ~ 8 nm

Nanoparticles emplaced on surface of $SrZrO_3$ substrate support material

TEM images of Ru nanoparticles supported on $SrZrO_3$ substrate material
Fig. S14 in Supplementary Information



Credit: Adapted from R. Manabe et al. - DOI: 10.1039/c7sc00840f (June 2017)

"N_2 activation steps were promoted by the electric field"

Spark discharge occurs without H_2; suggests protons are charge carriers

N_2 dissociative adsorption is very fast and enhanced irreversibly in electric field

- ✓ "Apparent activation energy decreased from 121 kJ mol^{-1} to 37 kJ mol^{-1} upon applying the electric field at 0.9 MPa. These results suggest … ammonia synthesis reaction mechanism is affected by … electric field and … rate-determining step of … reaction changes."
- ✓ "… upon application of the electric field … N_2 and H_2 pressure dependencies of the ammonia synthesis rate changed drastically … N_2 pressure dependence of the reaction rate decreased upon applying … electric field, indicating that … N_2 activation steps were promoted by the electric field … poisoning of Ru by hydrogen disappeared to some extent upon application of the electric field." "
- ✓ " … without a hydrogen supply, application of the electric field resulted in a spark discharge. This phenomenon demonstrates … hydrogen, or a chemical compound containing hydrogen, plays the role of an ion carrier, enabling the stable application of the electric field."
- ✓ " … results indicate that N_2 dissociative adsorption is very rapid and is enhanced irreversibly in the electric field."

NH_4^+ detected on catalyst surface after applying electric field

Presumably produced on surface by reaction of mobile protons with NH_3

Concluded that injection of positive charge enhanced electric field on Ru surface

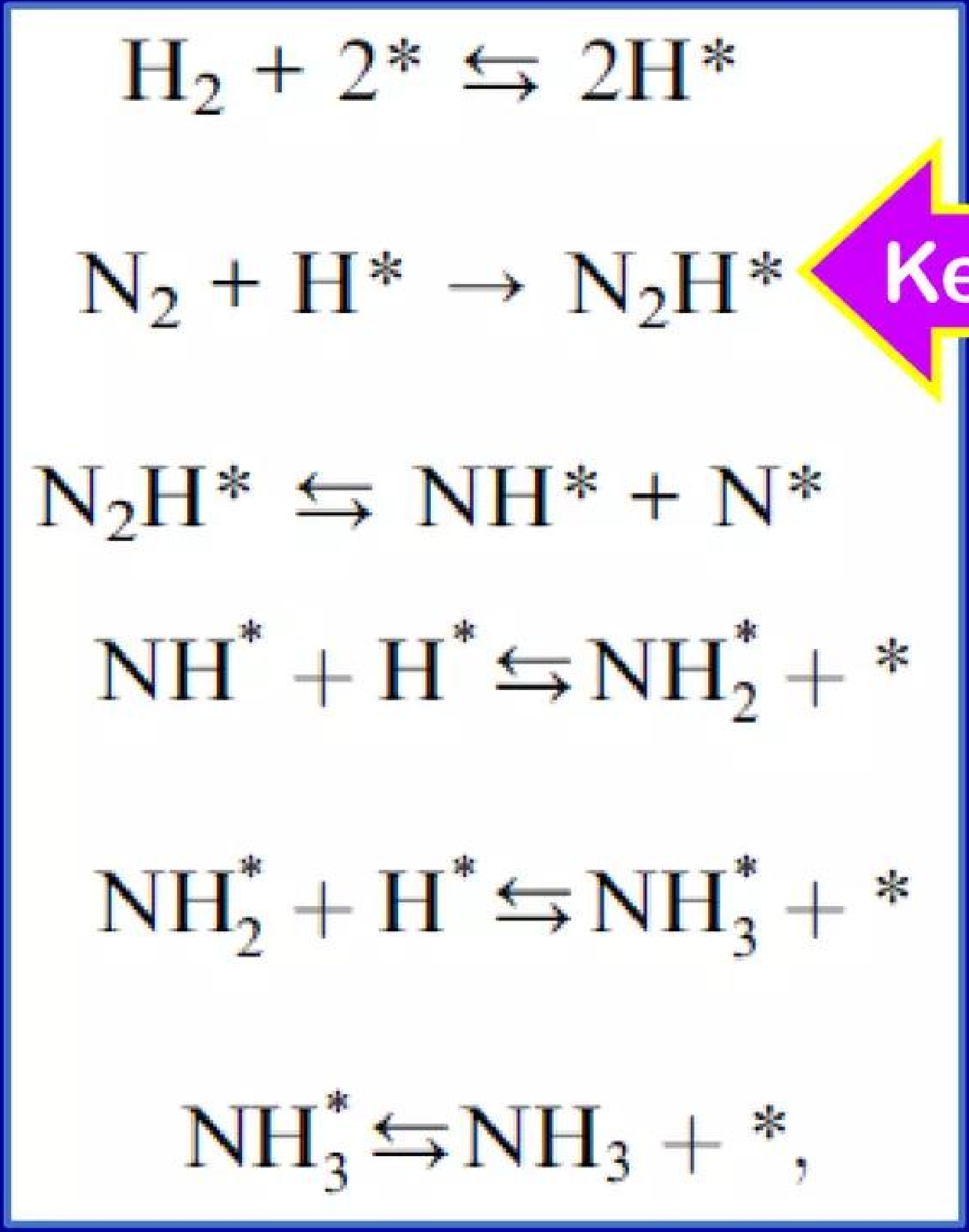
- ✓ " … these four peaks were observed only when … electric field was applied to … catalyst bed. They were assigned to … stretching, combination tone, overtone and bending modes of N–H vibrations derived from NH_4^+ … these species remained on … catalyst surface after cessation of the electric field. Presumably, NH_4^+ was produced from synthesized NH_3 and protons … protons are generated from H_2 and hop on … catalyst surface when the electric field is applied. The ammonium cation only exists in a stable form on the catalyst."
- ✓ "Based on the above observations, the protons are considered to hop via NH_4^+ ions and the catalyst support when the electric field is applied to the catalyst bed. The electric field could not be applied without supplying H_2."
  " … results show … surface protonics occur only when … forward reaction for ammonia synthesis proceeds in … presence of … electric field."
- ✓ "… blue shift of … CO vibrational mode was observed to occur when positive charge was introduced into … system, irrespective of … facet and adsorption site … these results suggest that … effect of an electric field on Ru is well expressed by introducing positive charge into the system."

Applied electric field greatly decreases activation energy E_a

Associative mechanism operates during NH_3 synthesis with electric field

" … results show … application of an electric field, which is stimulated by … positive charge in the system, induces an increase in ΔE for N_2 dissociation but a decrease in ΔE for N_2H formation. As a result, without an electric field, the formation of N_2H is an endothermic process but it becomes an exothermic process under an applied electric field … calculated activation energies (E_a) of these processes … also indicate that N_2H is more easily formed when an electric field is applied; E_a significantly decreased from 0.93 eV (N_2 dissociation) to 0.61 eV (N_2H formation) when 15 positive charges were introduced into the computational model. Here, the E_a values on Ru(1011) were used because this surface has a larger area in the assumed Ru particle (Fig. 4). This explains … significant decrease of … activation energy with … application of an electric field."

Manabe et al.'s theorized associative mechanism



$$H_2 + 2^* \leftrightarrows 2H^*$$

$$N_2 + H^* \rightarrow N_2H^*$$

Key

$$N_2H^* \leftrightarrows NH^* + N^*$$

$$NH^* + H^* \leftrightarrows NH_2^* + *$$

$$NH_2^* + H^* \leftrightarrows NH_3^* + *$$

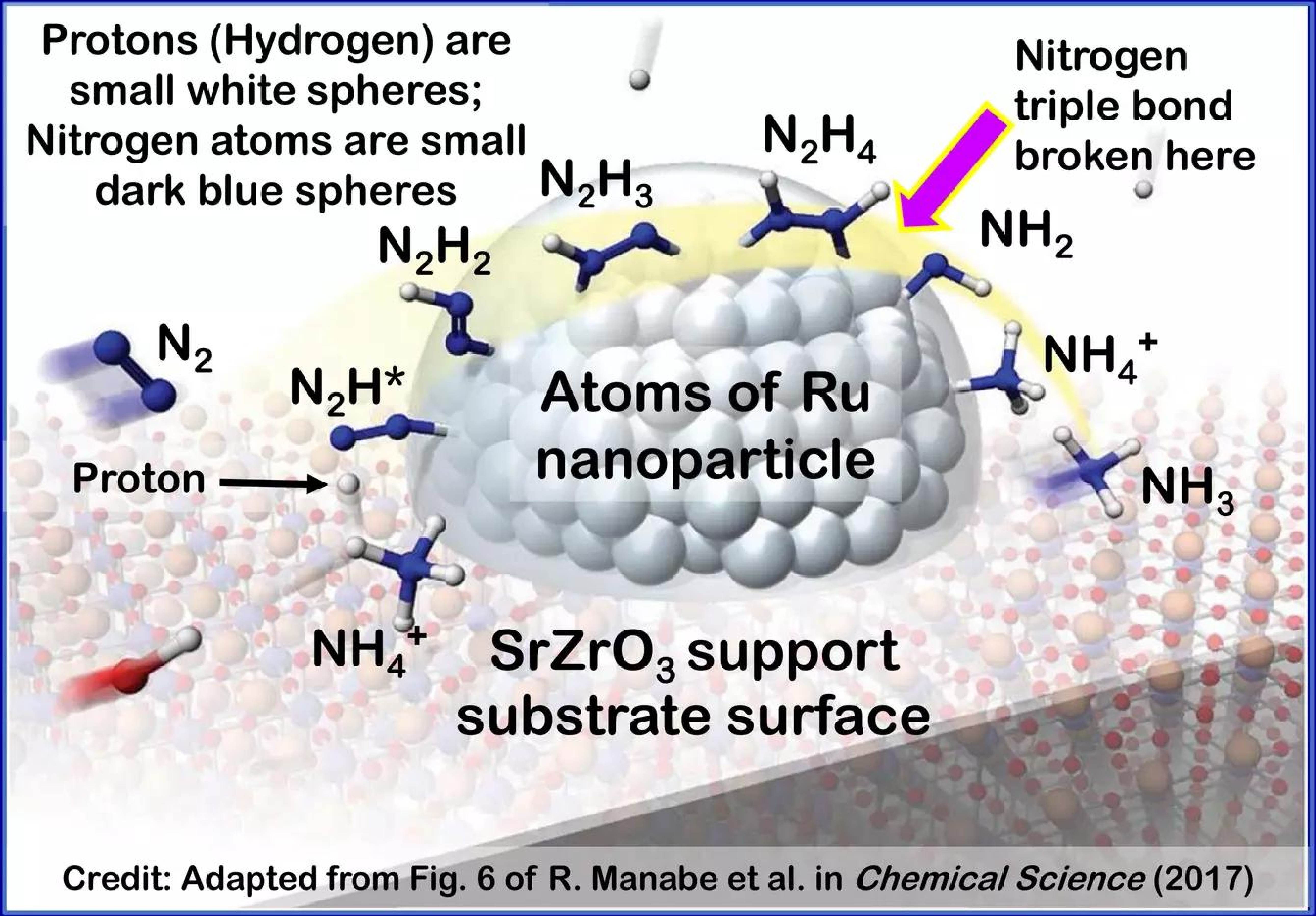
$$NH_3^* \leftrightarrows NH_3 + *,$$

Eq. (16) - (21) in paper
"Asterisk (*) denotes vacant surface site and species with an asterisk is an adsorbed species"

Conclusions of Manabe et al. in *Chemical Science* (2017)

Proton hopping mechanism hypothesized by R. Manabe et al. in Fig. 6

"E_a significantly decreased from 0.93 eV (N_2 dissociation) to 0.61 eV (N_2H formation) when 15 positive charges were introduced into the computational model." **Question: indicative of many-body reaction between N_2 and nearby clusters of ~15 quantum mechanically entangled protons like $e + p$ reaction ?**



Credit: Adapted from Fig. 6 of R. Manabe et al. in *Chemical Science* (2017)

Conclusions of Manabe et al. in *Chemical Science* (2017)

"In summary, surface protonics induced by application of an electric field have an important role to play in enhancement of catalytic ammonia synthesis under mild conditions."

- ✓ "Our experimental and theoretical investigations demonstrated … proton hopping in … electric field on … catalyst surface plays … important role in N_2 activation at low temperatures … proposed mechanism for ammonia synthesis in … electric field … presented in Fig. 6. Peculiar surface conduction caused by … electric field, proton hopping, is considered to enable ammonia synthesis at low temperatures and atmospheric pressure."
- ✓ "Ammonia synthesis activity of … catalyst increased drastically upon application of electric field under both atmospheric and 0.9 MPa pressure, even at low reaction temperatures … maximum ammonia yield per gram of catalyst … 30 099 μmol g^{-1} h^{-1} … highest value reported to date."
- ✓ "Isotope exchange tests demonstrated that N_2 dissociative adsorption was markedly promoted by application of the electric field … *in situ* DRIFTS results revealed that proton conduction via NH_4^+ and the catalyst support occurred when the electric field was applied. These unique surface protonics are strongly associated with N_2 activation, which moderates the severe conditions required for ammonia synthesis."

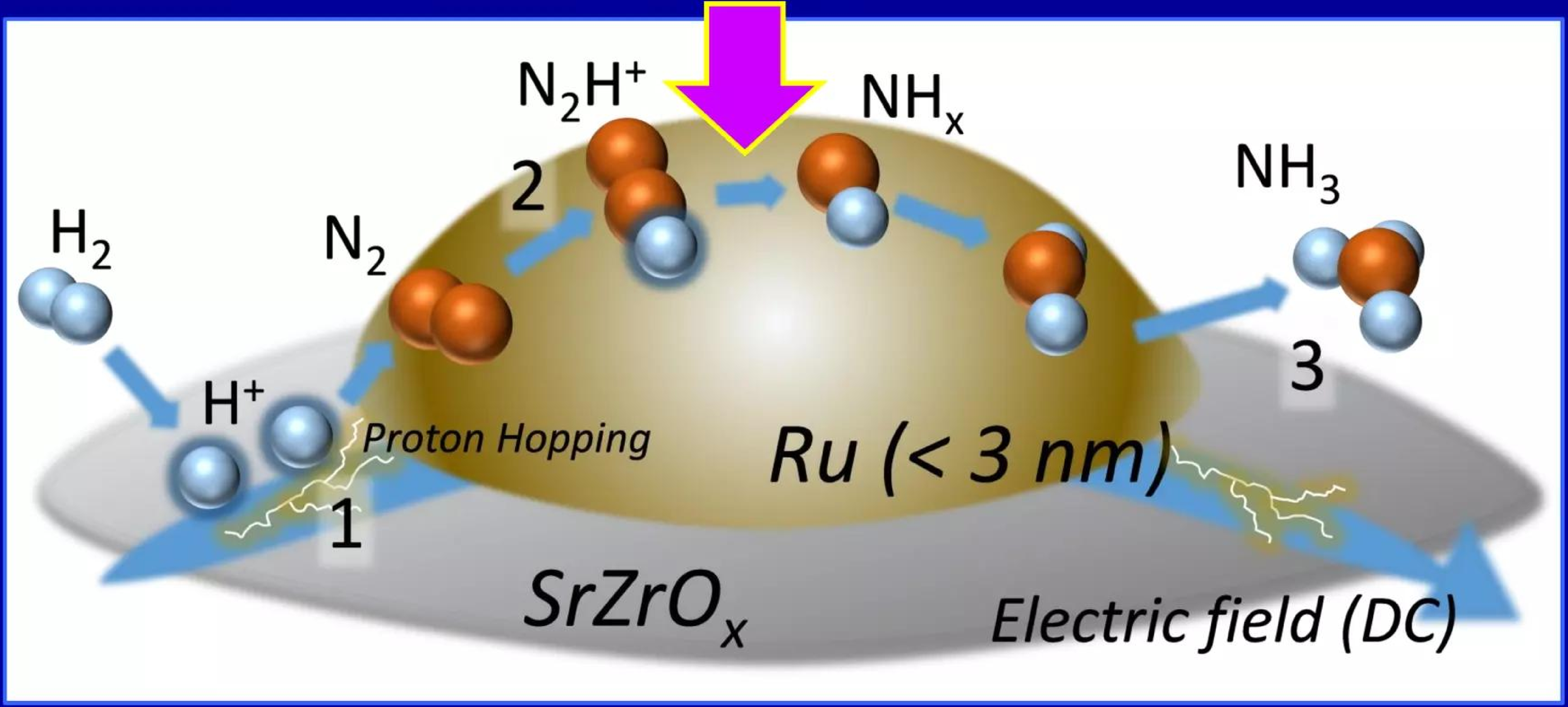
Manabe et al.'s reaction sequence on < 3 nm Ru nanoparticle

Electric field facilitates N_2 dissociation ; protons then help N react with H

E - field-powered hopping protons facilitate N_2 dissociation and then react with N

"E_a significantly decreased from 0.93 eV (N_2 dissociation) to 0.61 eV (N_2H formation) when 15 positive charges were introduced into the computational model."

Lattice remark: is many-body $N_{1\text{-}2}H_{2\text{ - }15}{}^+$ complex lurking somewhere in this step?



Credit: prepared by Manabe et al. for press release by Waseda University (Japan)

https://www.waseda.jp/top/en-news/51814

Earlier paper reports enhancement of catalysis by protons

Eq. (1) in paper: $CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$ where $\Delta H^0_{198} = 164.9$ kJ mol^{-1}

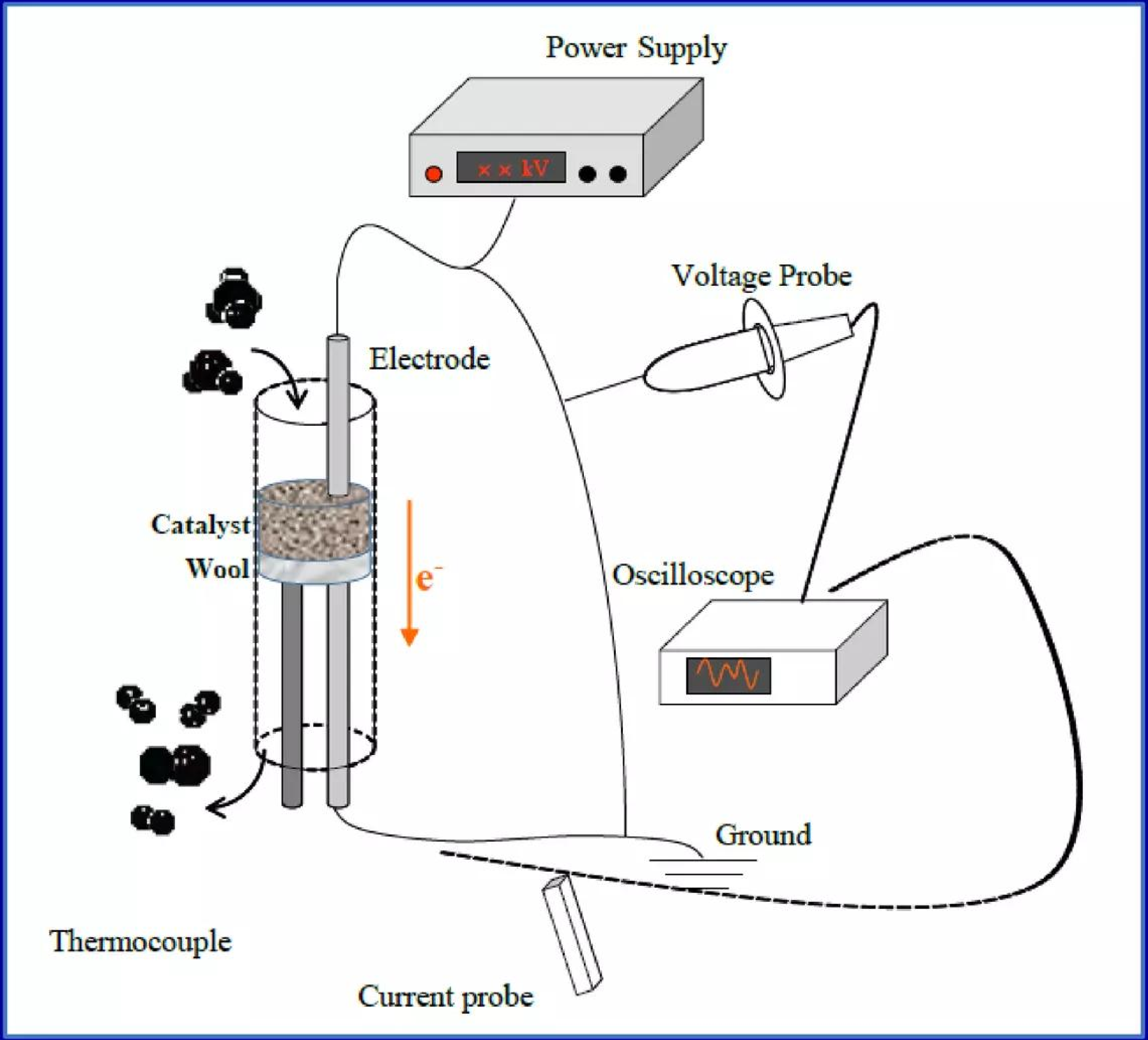
"Surface protonics promotes catalysis"
R. Manabe et al., *Scientific Reports* 6:3807 (December 2016)
https://www.nature.com/articles/srep38007.pdf

SCIENTIFIC REPORTS

Abstract: "Catalytic steam reforming of methane for hydrogen production proceeds even at 473^{o} K over 1wt% Pd/CeO_2 catalyst in an electric field, thanks to the surface protonics. Kinetic analyses demonstrated the synergetic effect between catalytic reaction and electric field, revealing strengthened water pressure dependence of the reaction rate when applying an electric field, with one-third the apparent activation energy at the lower reaction temperature range. *Operando*–IR measurements revealed that proton conduction via adsorbed water on the catalyst surface occurred during electric field application. Methane was activated by proton collision at the Pd–CeO_2 interface, based on the inverse kinetic isotope effect. Proton conduction on the catalyst surface plays an important role in methane activation at low temperature. This report is the first describing promotion of the catalytic reaction by surface protonics."

Manabe et al. schematic overview of experimental apparatus

Fig. S1 in Supplementary Information



Credit: R. Manabe et al. in *Scientific Reports* 6:3807 (December 2016)

Catalytic activity greatly increased by applying electric field

Pt or Pd catalyst nanoparticles supported on CeO_2 effective for reforming

Electric field-driven surface protonics enabled catalytic steam reforming at 423° K

- ✓ "Our previous studies revealed that a steam reforming process in an electric field, *Electreforming* (ER), shows high activity even at a low temperature of 423 K. For ER, Pt or Pd catalysts supported on CeO_2-based oxide are effective catalysts. Activities were increased drastically by the application of an electric field with lower electric power consumption of less than a few watts. We conducted kinetic measurements and *operando*-IR measurements for methane steam reforming in an electric field. Results show that the application of the electric field promoted surface protonics. Moreover, it enabled catalytic steam reforming even at the low temperature of 423 K."
- ✓ " … methane conversion increased drastically because of the application of an electric field to the catalyst bed, even at low temperatures. The activities for ER at low temperatures were over the limitation of thermodynamic equilibrium curve, indicating that the reaction in an electric field includes some irreversible elementary steps."
- ✓ " … rate-determining step of methane steam reforming is the methane dissociative adsorption step."

Conclusion: Joule heating is not important for ER process

Hypothesis: methane activation involves proton hopping on surfaces

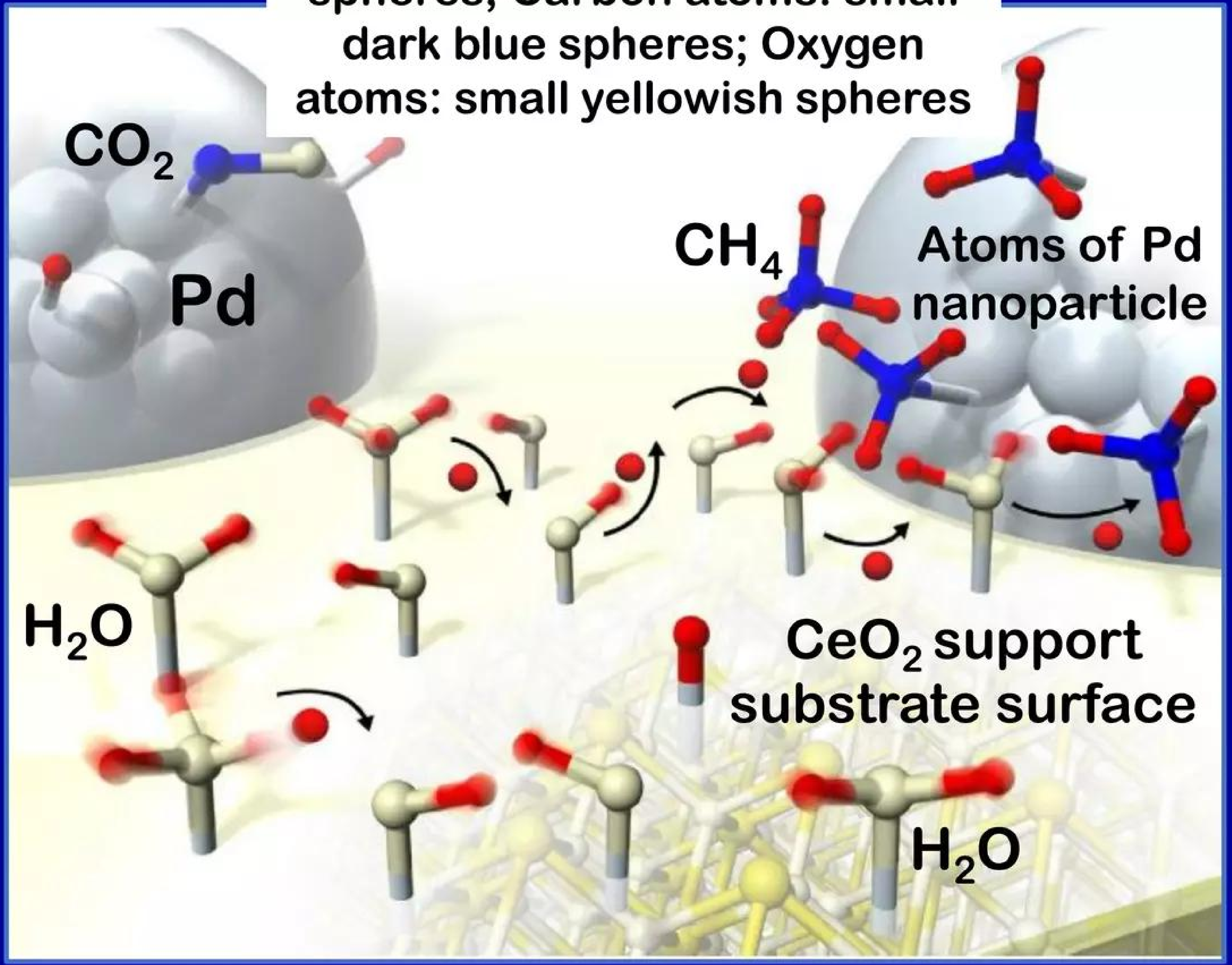
Experimental data indicates ER reaction occurs mainly at Pd-CeO_2 interface

- ✓ "Pd supported on CeO_2 is regarded as an active site for ER."
- ✓ "… result gives evidence that reaction mechanisms with and without an electric field differ markedly … result also demonstrates that Joule heat is unimportant for ER, as suggested by kinetic analysis results."
- ✓ " … peak is regarded as having a strong relation with the Grotthuss mechanism, a widely known mechanism of proton conduction. By this mechanism, protons hop via water molecules with a distorted O–H bond … results reveal that proton hopping occurred via adsorbed water on the catalyst surface during ER."
- ✓ " … results support the inference that the methane activation process includes proton hopping on the catalyst surface … methane activation with proton is likely to occur at the Pd–CeO_2 interface."
- ✓ "ER activity showed strong dependence on the Pd perimeter, rather than on the Pd specific surface area, which indicates that the ER reaction proceeds mainly at the Pd–CeO_2 interface."

Conclusions of Manabe et al. in *Scientific Reports* (2016) Eq.

Methane reforming equation is these reactions: $CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$

Schematic image of mechanism for *Electreforming* (ER) of Methane (CH_4)



Protons (Hydrogen): small red spheres; Carbon atoms: small dark blue spheres; Oxygen atoms: small yellowish spheres

Credit: Adapted from R. Manabe et al. Fig. 5 in *Scientific Reports* 6:3807 (Dec. 2016)

Conclusions of Manabe et al. in *Scientific Reports* (2016)

- ✓ “Our *operando* analyses revealed that proton hopping promotes methane activation at the Pd–CeO_2 interface. Furthermore, our *in-situ* XAFS measurements … demonstrated that the electronic state (work function) and the structure of Pd/CeO_2 catalyst were not changed by application of the electric field. Therefore, surface protonics is a dominant factor for the activity increase. A schematic image of the mechanism for *Electreforming is* presented in Fig. 5. Methane is activated at the interface by hopping proton derived from Grotthuss mechanism, resulting in adsorption onto Pd. By application of the electric field to methane steam reforming, methane can be activated at a low temperature, which never occurs without the electric field. Applying an electric field enables surface protonics via adsorbed water on the catalyst. It promotes a surface catalytic reaction.”

- ✓ “Application of an electric field increased the activity drastically … mechanisms with and without electric field differ considerably … methane was activated by proton collision derived from the Grotthuss mechanism. Furthermore, ER proceeds mainly at the interface between Pd and CeO_2. Therefore, the surface protonics by the application of electric field serve an important role in the enhancement of catalytic methane steam reforming at a low reaction temperature.”

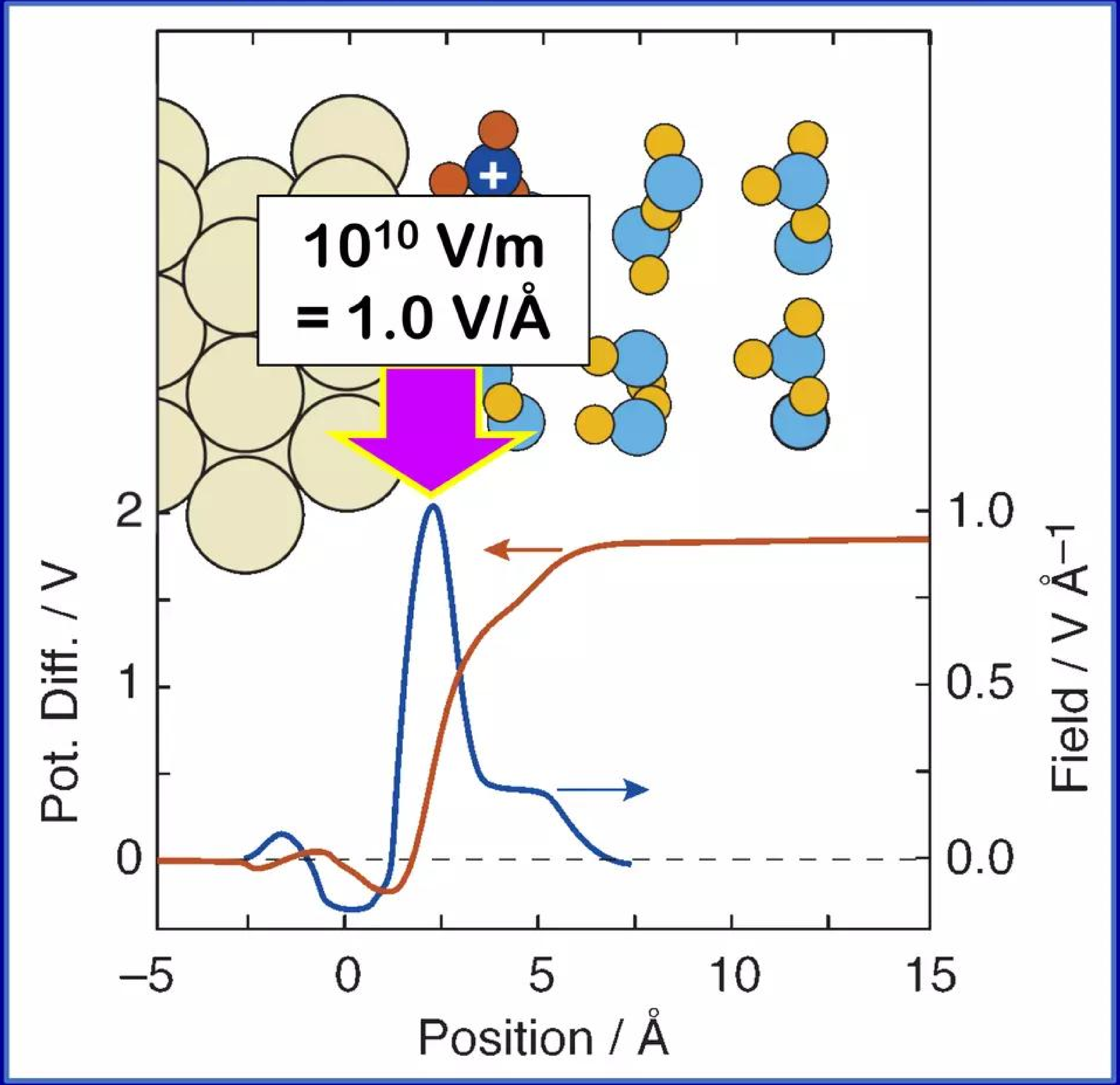
Local electric fields can exceed 1 V/Å (10^{10} V/m) near surface

See E. Stuve's article titled "Interfacial chemistry in high electric fields"

Red curve = potential profile; blue curve = field profile (differentiated potential)

"Magnitude of electric fields necessary to influence surface chemistry can be estimated by two simple observations: first, most chemical bonds are on the order of a few (1 - 5) eV; second, most chemical bonds are on the order of a few (1 - 3) Å. The ratio of these two estimates is of the order of 1 eV/Å, or simply 1 V/Å, as an electron has one unit of charge. This corresponds to a field of 100 MV/cm, a very large quantity! … Field amplification [occurs] at sharp metal tips … field emitter tip with tip radius of 300 Å can produce fields of 1 V/Å or greater with tip potentials of about 5,000 V."

Fig. 2. DFT/molecular dynamics simulation of charged Pt(111) slab with 3 water layers

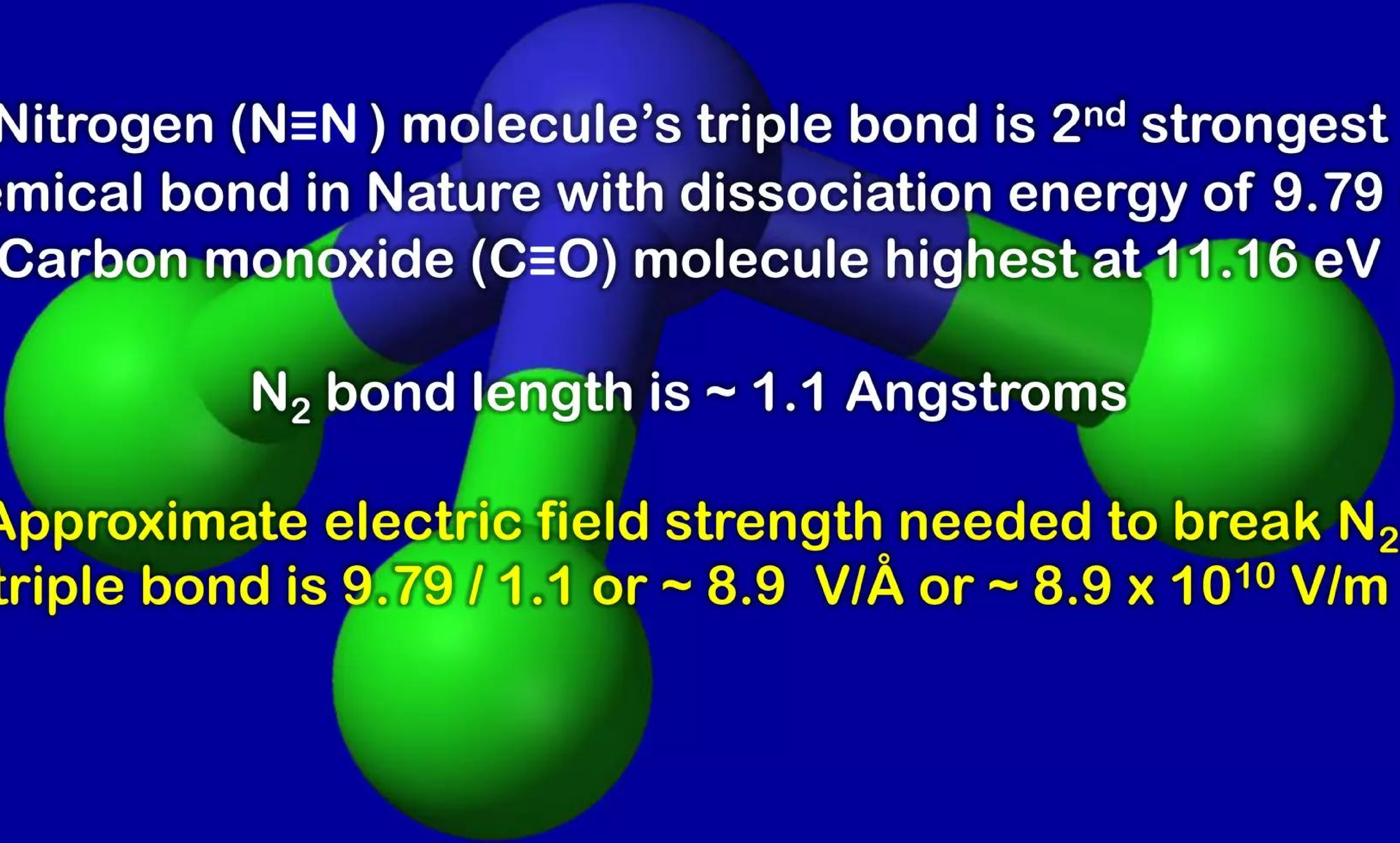


http://faculty.washington.edu/stuve/fi_water.htm

Nitrogen molecule's triple bond is 2nd strongest in Nature

Electric field strength needed to break N_2 triple bond is ~ 8.9 x 10^{10} V/m

Very high local electric fields on surfaces needed to catalyze dissociation of N_2



Nitrogen (N≡N) molecule's triple bond is 2nd strongest chemical bond in Nature with dissociation energy of 9.79 eV
Carbon monoxide (C≡O) molecule highest at 11.16 eV

N_2 bond length is ~ 1.1 Angstroms

Approximate electric field strength needed to break N_2 triple bond is 9.79 / 1.1 or ~ 8.9 V/Å or ~ 8.9 x 10^{10} V/m

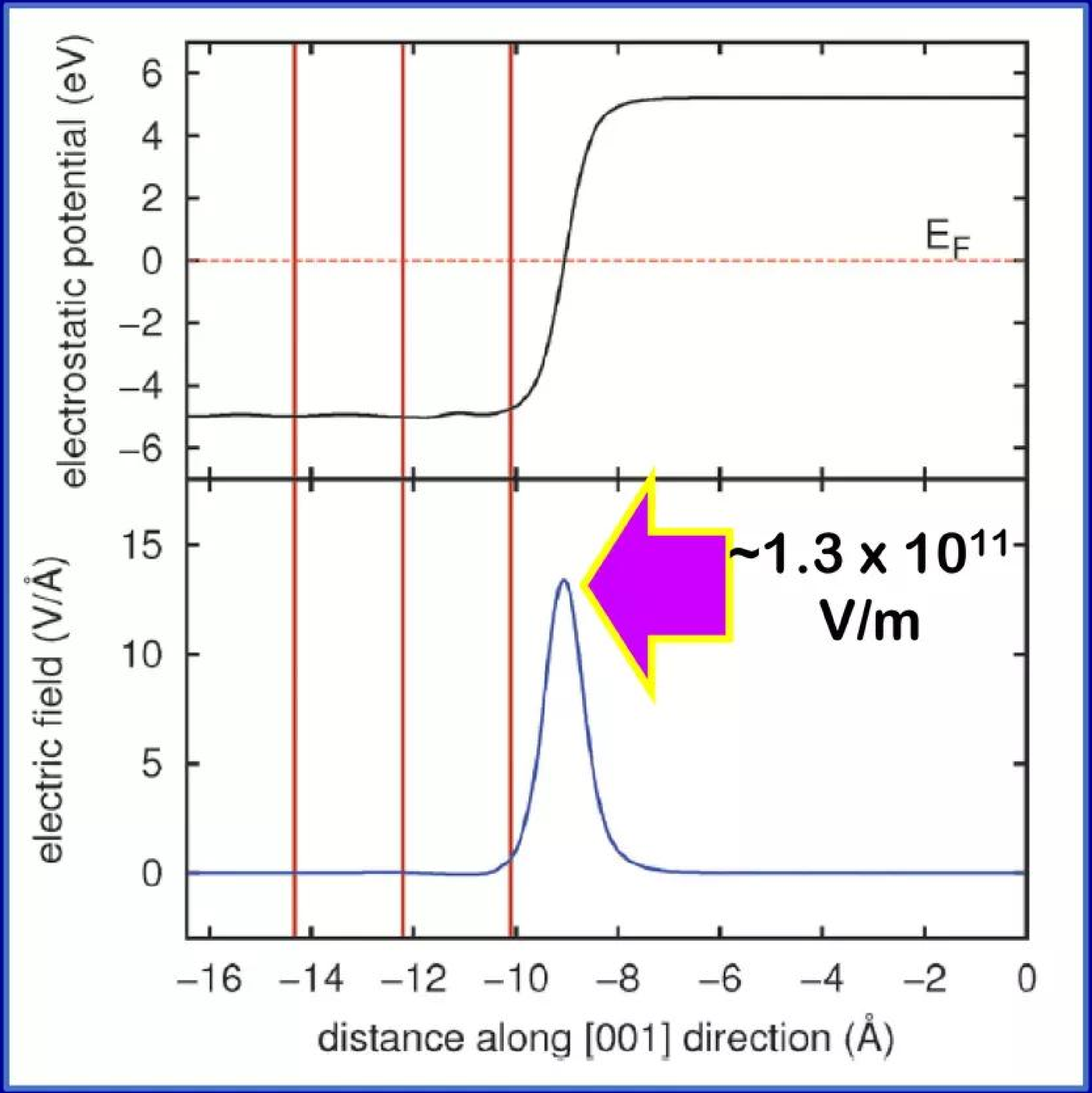
Laporte et al. (2015): high electric fields on MgO(001) surface

Peak E-field strength at MgO/vacuum interface reaches ~ 1.3 x 10^{11} V/m

"Strong electric fields at a prototypical oxide/water interface probed by *ab initio* molecular dynamics: MgO(001)"
S. Laporte et al., *Physical Chemistry Chemical Physics* 17 pp. 20382 (2015)
http://pubs.rsc.org/en/content/articlelanding/2015/cp/c5cp02097b#!divAbstract

"Fig. 1 shows … electrostatic potential and electric field profiles at the MgO(001)/vacuum interface. For clarity … potential is shown as felt by the electrons … in Fig. 1, electric field at … MgO(001)/vacuum interface is intense and permeates beyond … surface layer, although it is highly localized. There is window extending to about 3 Å from surface atoms in which field is high enough to influence potential adsorbates, their structure and reactivity."

Fig. 1 Surface/vacuum interface

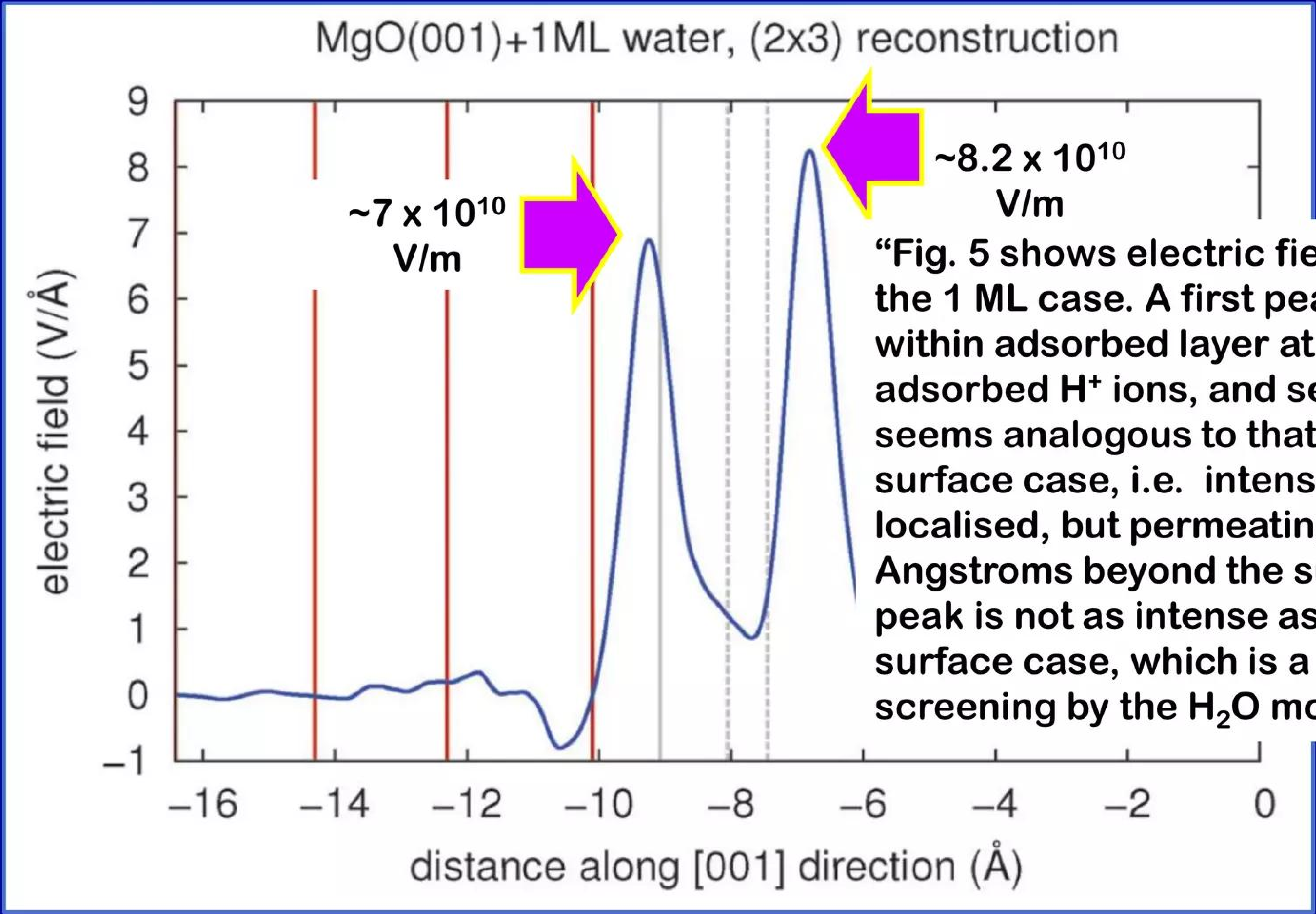


~1.3 x 10^{11} V/m

Laporte et al. (2015): high electric fields on MgO(001) surface

E-field strength in H^+ ion monolayer on surface can reach ~ 8.2 x 10^{10} V/m

Fig. 5 Electric field profile of Mg(001) with monolayer of H_2O adsorbed



~7 x 10^{10} V/m

~8.2 x 10^{10} V/m

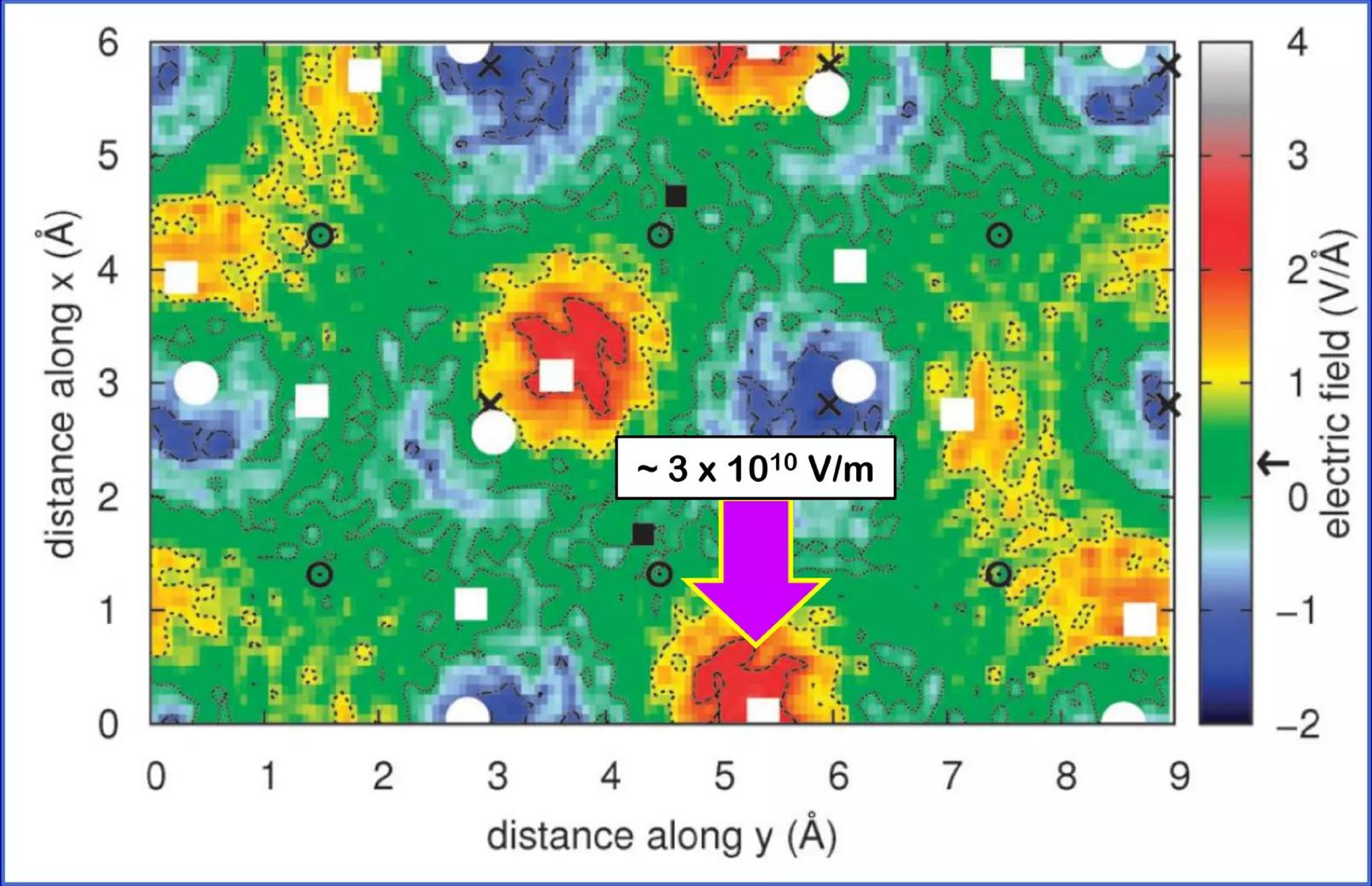
"Fig. 5 shows electric field profile in the 1 ML case. A first peak occurs within adsorbed layer at height of adsorbed H^+ ions, and second peak seems analogous to that in bare surface case, i.e. intense, highly localised, but permeating a few Angstroms beyond the surface. This peak is not as intense as in bare surface case, which is a sign of screening by the H_2O molecules."

Laporte et al. (2015): high electric fields on MgO(001) surface

Average E-field strength at 4.0 Å from surface ranges up to ~ 3 x 10^{10} V/m

Graphic shows landscape of calculated electric field strengths across surface

Figure 6. z-component of electric field in xy plane at 4.0 Å above surface of Mg(001)



Merte et al. (2012): protons can be very mobile on surfaces

Hydrogens (protons) will form many-body clusters on different surfaces

"Water-mediated proton hopping on an Iron oxide surface"
L. Merte et al., *Science* 336 pp. 889 - 893 (2012)
http://science.sciencemag.org/content/336/6083/889.full

- ✓ "Fundamental atomistic mechanisms underlying hydrogen diffusion on solid surfaces and … factors influencing them still remain unsettled because of … great complexity of oxide materials and … difficulty in characterizing them at … atomic level … experimental studies of hydrogen diffusion on well-defined model oxide surfaces are scarce and have been limited almost exclusively to rutile $TiO_2(110)$ … Here, we investigated proton hopping on oxygen-terminated FeO(111) monolayer film on Pt(111)."
- ✓ "Using an atomic hydrogen source, H adatoms bound to FeO lattice oxygen can be produced in a well-controlled manner … H atoms preferred certain sites in the film's moiré superstructure, which caused them to organize in distinct groups ["clusters" or "patches" of protons]."
- ✓ "Temporal sequence of STM images of … hydrogenated film, obtained at 105 K, shows … movements of H atoms induced by a water molecule that moved quickly across surface … While water molecule was trapped at … cluster, H atoms within the group rearranged rapidly and repeatedly on time scale of STM measurement (~18 ms per scan line)"

Merte et al. (2012): protons can be very mobile on surfaces

Mobile protons function as charge carriers when moving across surfaces

"Our use of both STM and DFT methods revealed that mobility of hydrogen on FeO(111) thin film grown on Pt(111) is completely dominated by water-mediated hopping mechanism. This mechanism, revealed for H atoms on fcc domains, consists of transfer of a surface proton to a water molecule, leading to short-lived hydronium ion species [H_3O^+] at the transition state. No bonding occurs between water molecule[s] and metal cations of FeO thin film."

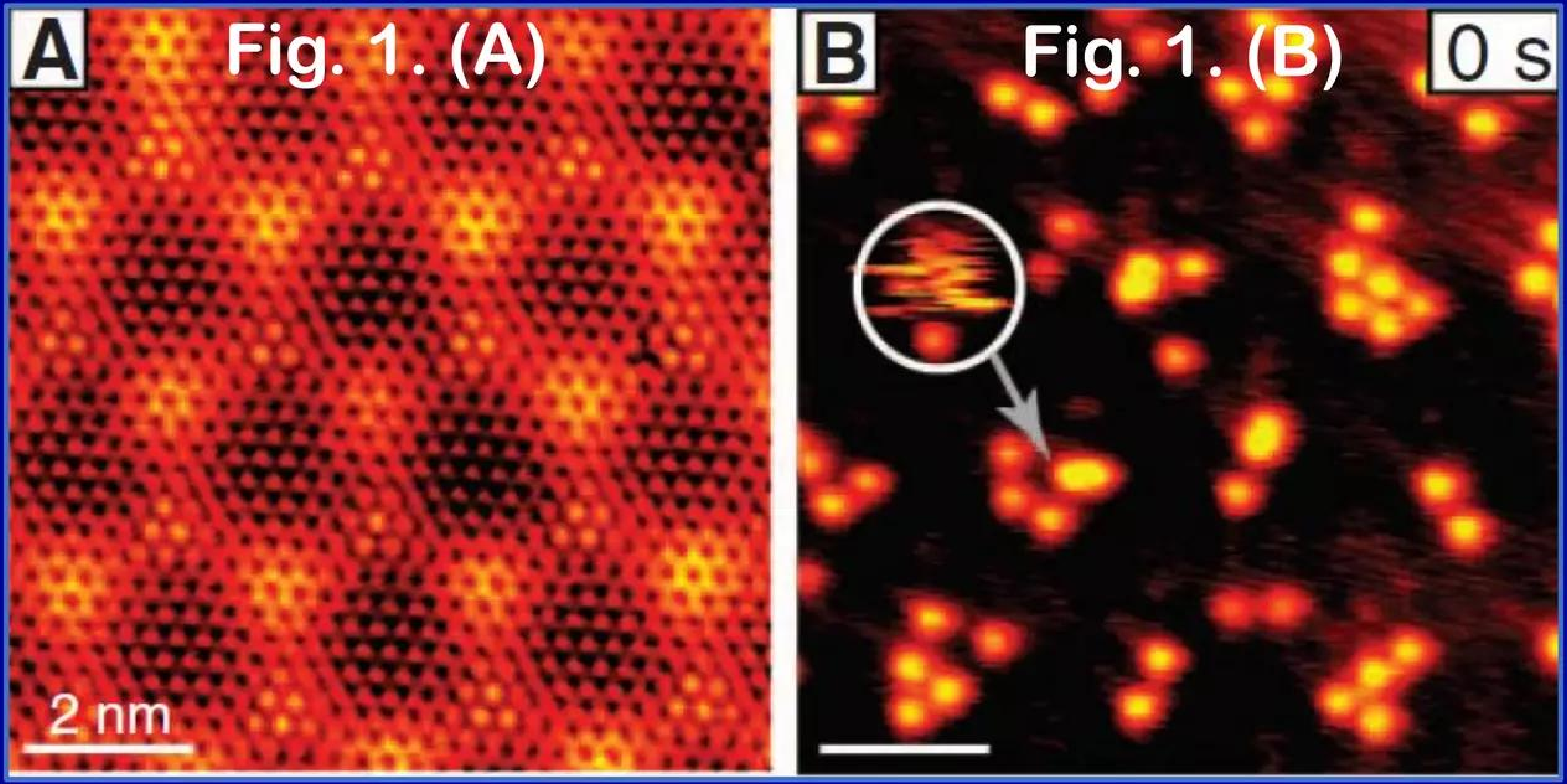


Fig. 1. (A) "Atomically resolved STM image of bare FeO film, showing moiré structure and protrusions due to individual Fe and O atoms."

Fig. 1. (B) "STM image of hydrogenated FeO film on Pt(111) at 105 K … hydrogen atoms (bright spots) diffuse rapidly [due to] water molecule."

Merte et al. (2012): protons can be very mobile on surfaces

Image shows organized many-body clusters of protons on FeO surface

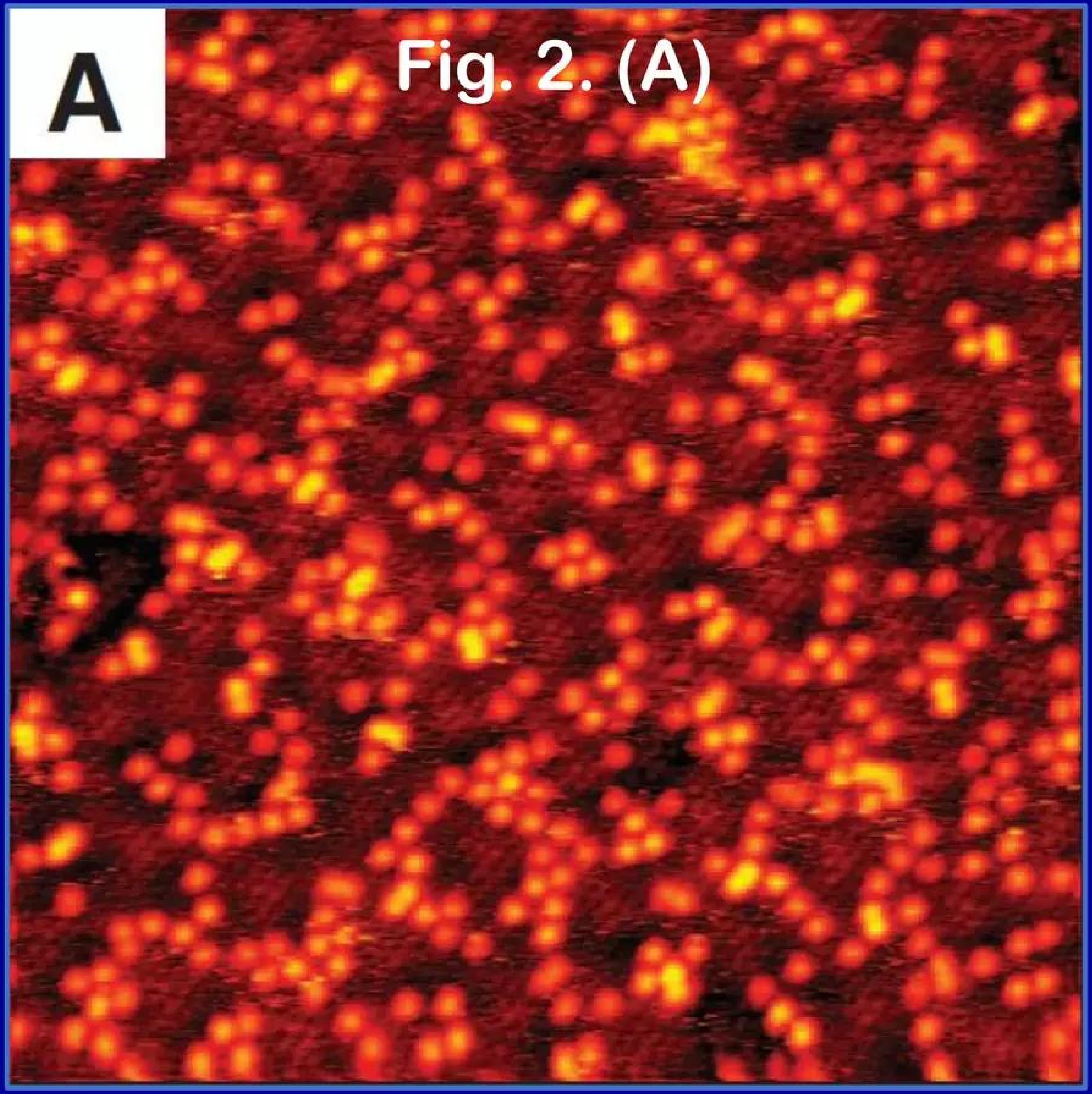


Fig. 2. (A) “Time-resolved STM measurements of hydrogen atoms on FeO(111)/Pt(111) at room temperature … frame [A - above] shows a single 180 Å × 180 Å STM image of FeO film; H atoms visible as bright protrusions.”

Key data and conclusions of Merte et al. in *Science* (2012)

Proton hopping process can be very fast; speed varies between materials

Observed large, correlated collective proton diffusion events spanning 10s of nm

- ✓ "Hopping events are correlated in time, and larger-scale STM measurements further reveal correlations in space on the scale of tens of nanometers."
- ✓ "Observed rapid proton hopping on FeO(111) in form of large 'collective' diffusion events is related not only to ease with which protons are exchanged but also to combination of high stability and high mobility of water molecules adsorbed through hydrogen bonding."
- ✓ "These correlations are easily explained by a diffusion mechanism where mediating species diffuse across the surface and induce diffusion of nearby H atoms."
- ✓ "Our results demonstrate that even in the absence of Lewis acid sites, water-mediated proton hopping still occurs … process is more rapid than that observed on TiO2(110) … On FeO(111), H diffusion process is too fast to be directly resolvable on a similar time scale, even at 105 K."

Electric fields and protons are often important in catalysis

Local electric field strength > 2.5 x 10^{11} V/m can trigger nuclear reactions

- ✓ Manabe et al. (2017, 2016) showed how applied electric fields and hopping proton charge carriers on Cs/Ru catalyst and $SrZrO_3$ support substrates can vastly improve performance of Haber-Bosch NH_3 catalysis reactions in terms of reducing required operating temperatures and pressures as well as substantially increasing the yields of ammonia at low temperatures

- ✓ Stuve (2013), Laporte et al.(2015), and Merte et al. (2012) showed that local electric field strengths that occur in close proximity to inorganic catalysts and supporting substrate surfaces routinely reach time-averaged values on the order of 10^{10} to 10^{11} V/m. Such strong E-fields can facilitate extreme proton mobility (hopping) as well as total dissociation of many different types of molecules, including water (H_2O) and Nitrogen (N_2)

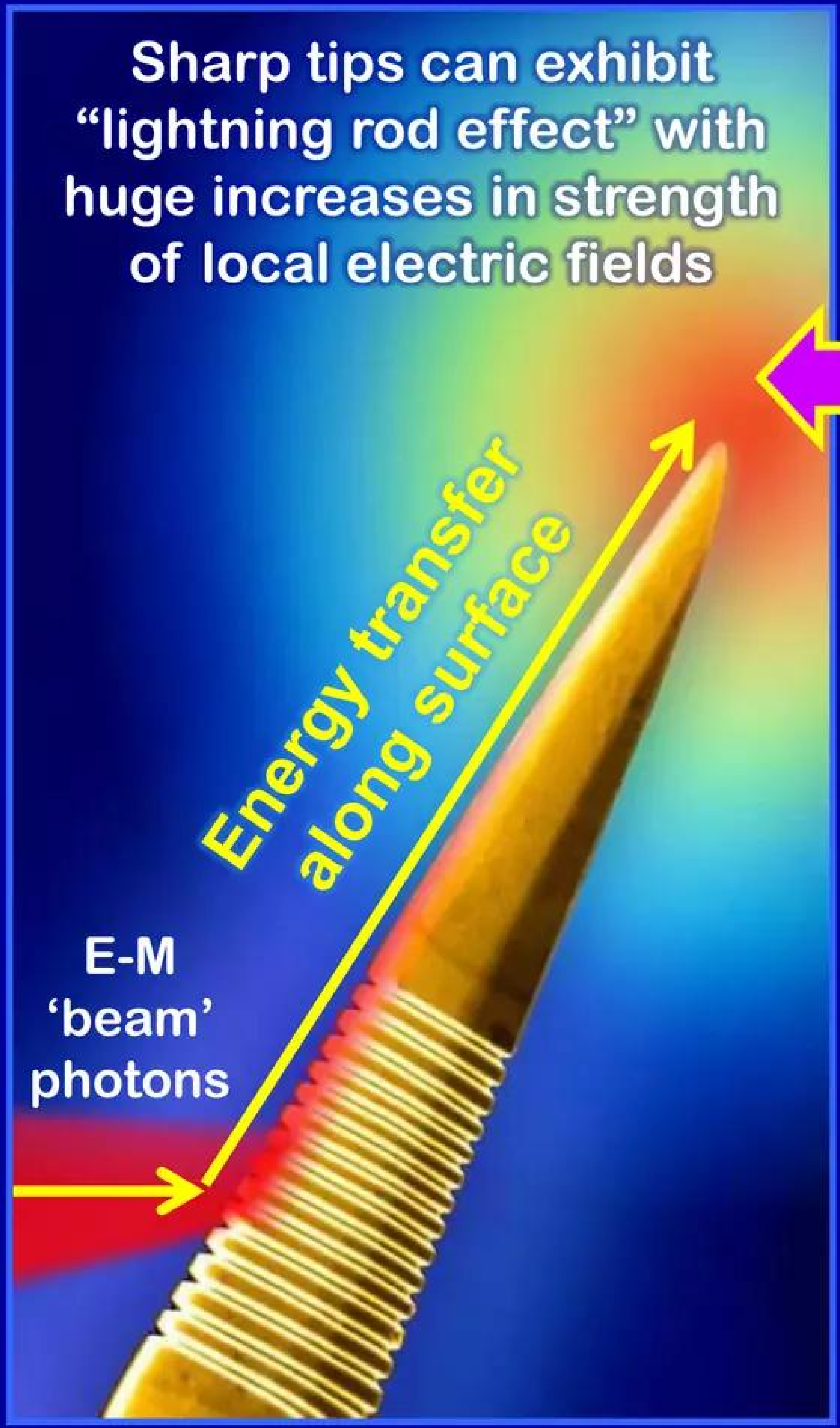
- ✓ Electric fields and mobile protons are likely to be important for many types chemical catalysis. The Widom-Larsen theory of ultralow energy neutron reactions (LENRs) shows how --- under specified conditions --- attosecond surges of local electric field strengths above 2.5 x 10^{11} V/m, on many of the same types of metallic catalysts and substrate support surfaces, can enable production of neutrons and neutrinos via a many-body collective electroweak $e + p$ reaction between electrons and protons. Neutrons are absorbed by local atoms, triggering radiation-free nuclear transmutation

Nanostructures can act as antennas that absorb E-M energy

Surface plasmons (SP) intensify local electric fields on nanoparticles

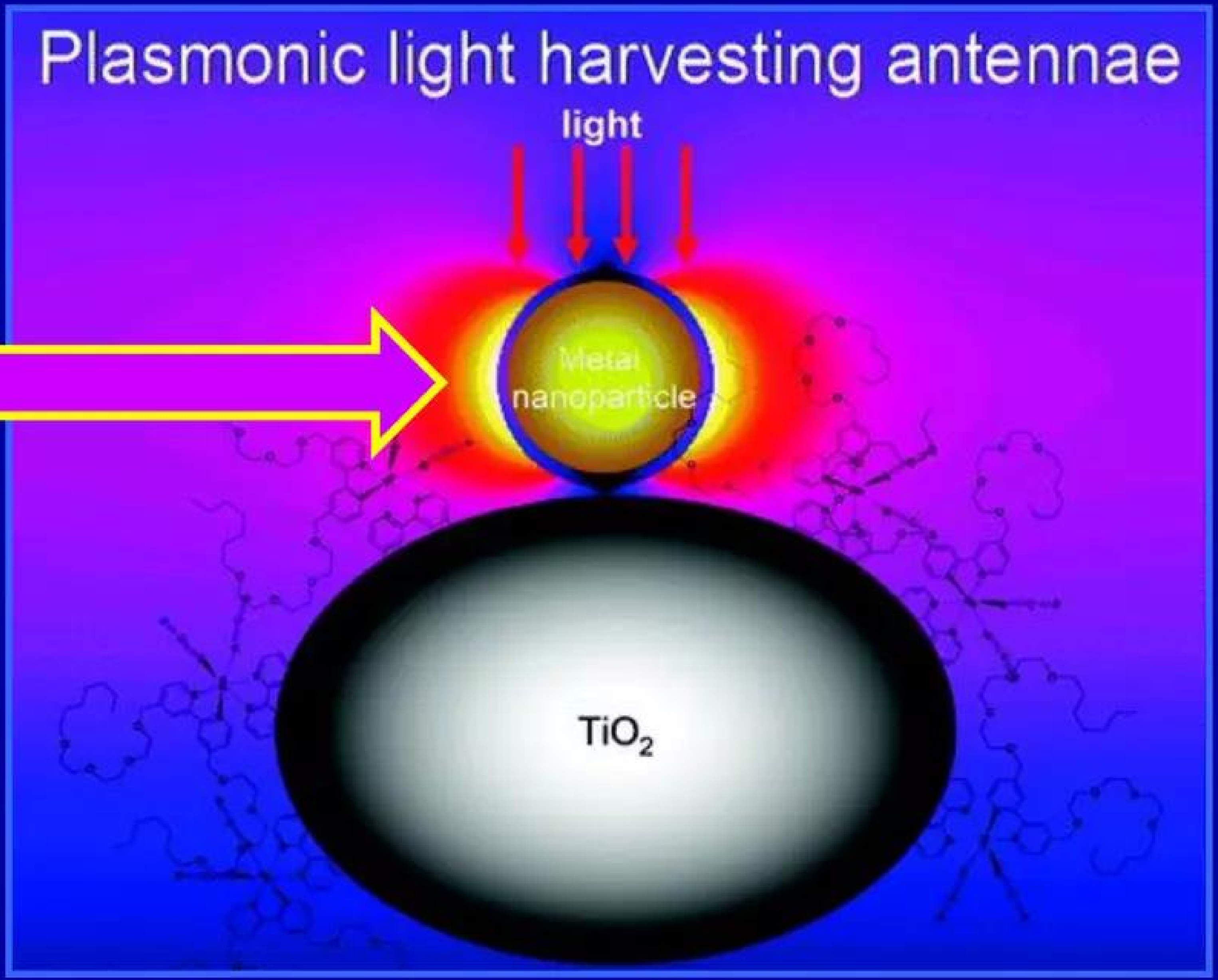
Nanostructures can be designed to create pulsed E-fields > 2.5 x 10^{11} V/m

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



Sharp tips can exhibit "lightning rod effect" with huge increases in strength of local electric fields

Regions of increased electric fields



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

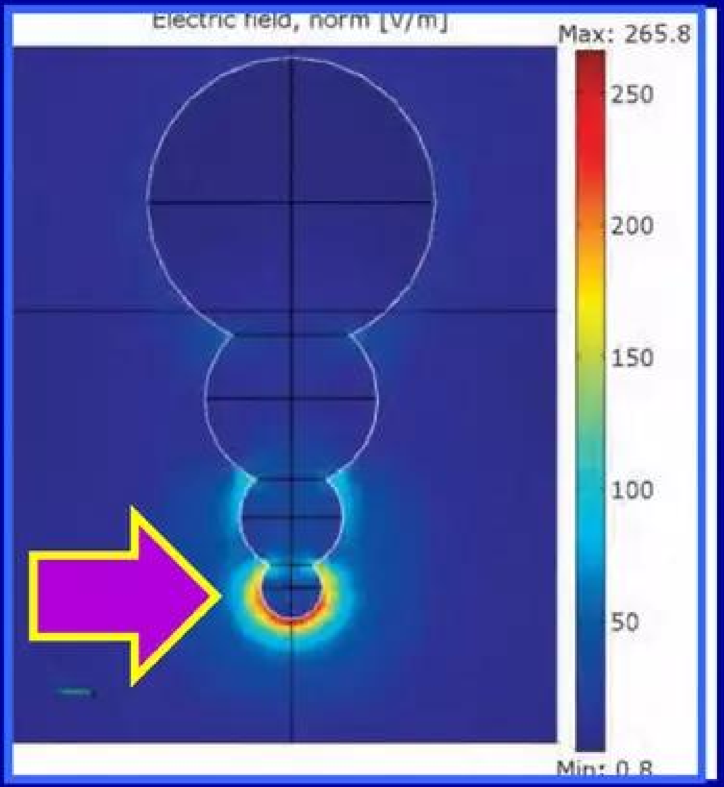
Source of above image is Wiesner Group at Cornell University:

"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 nanoscales

Nanostructures of right shapes/compositions amplify electric fields

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

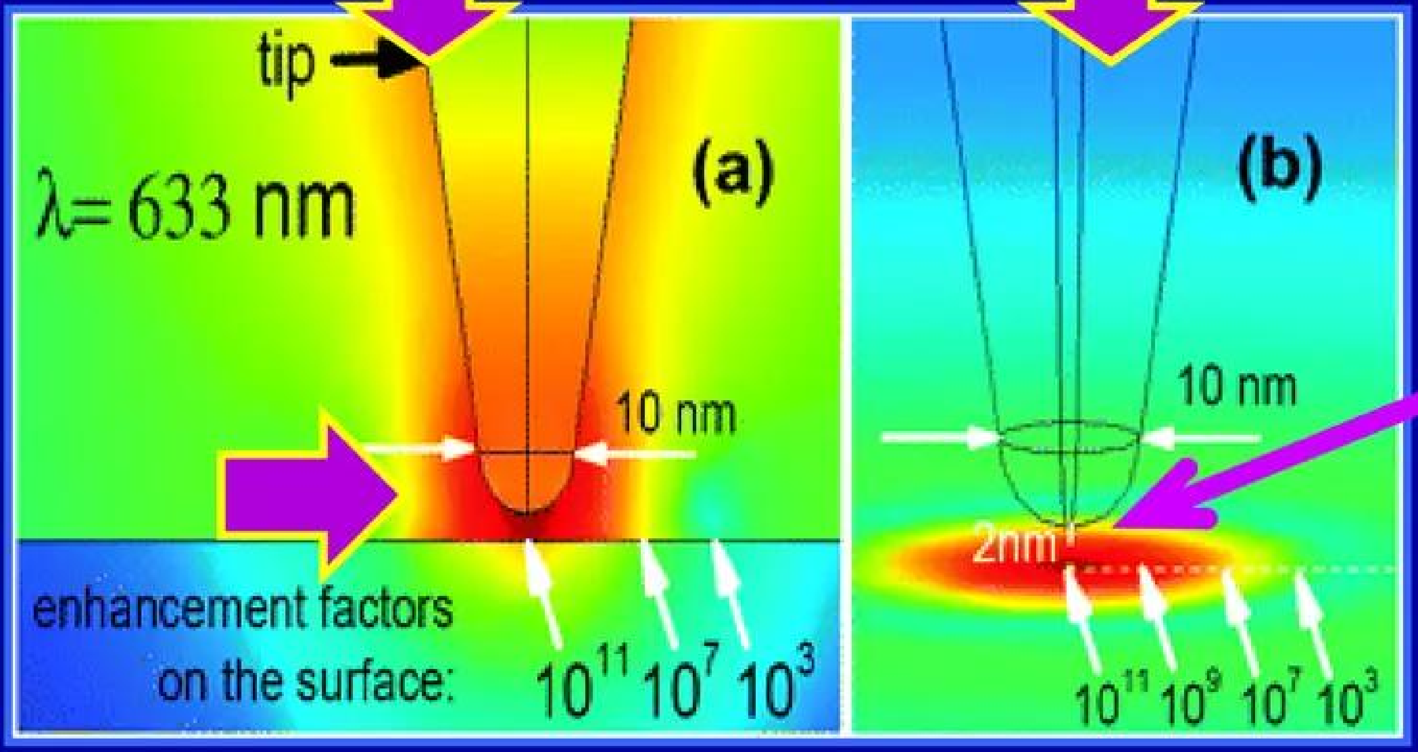


Sharp tips exhibit so-called "lightning rod effect" by creating enormous local enhancement of electric field strengths

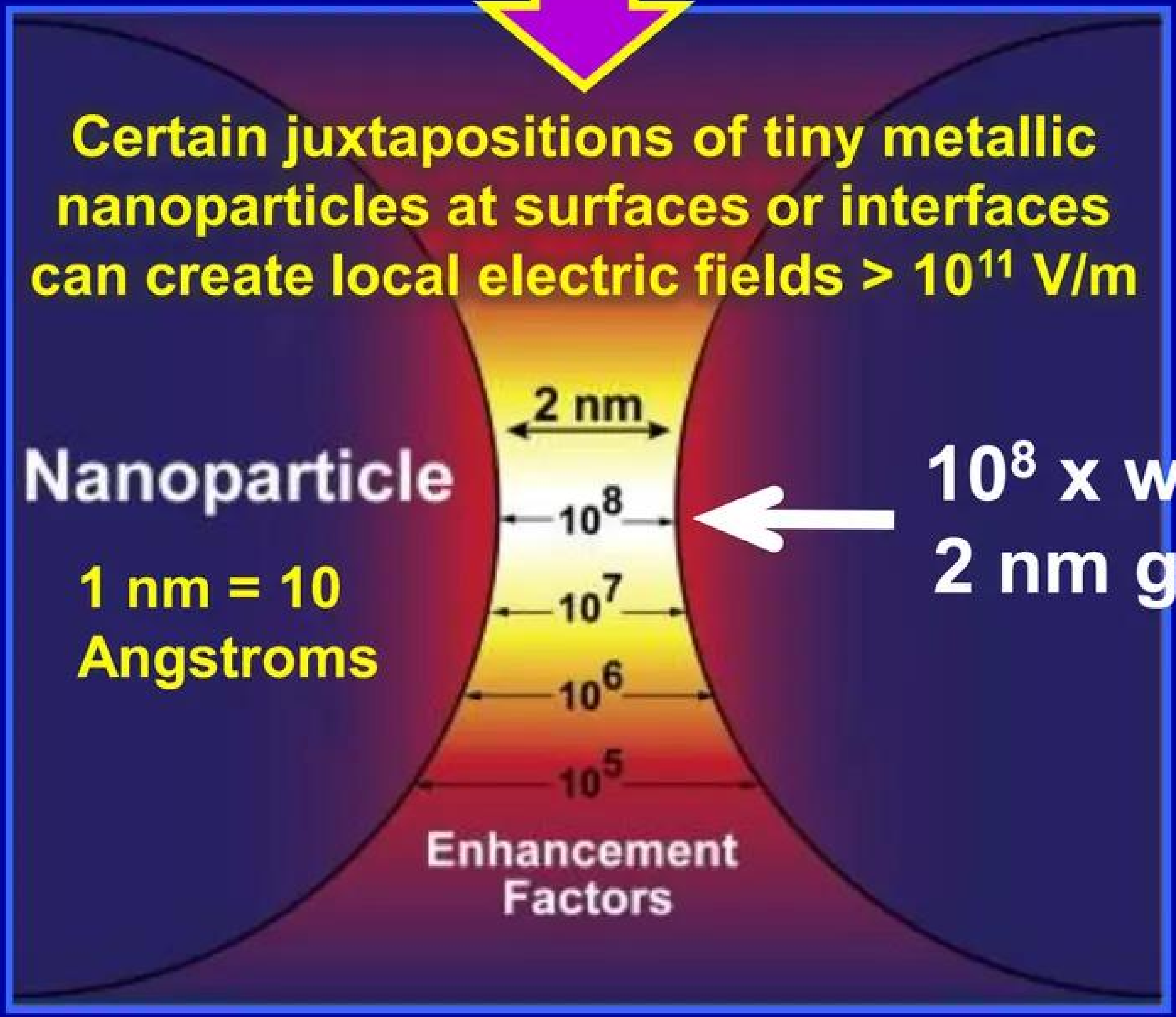
Shows E-M field strength enhancement as a function of interparticle spacing

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

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



10^{11} x increase



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

1 nm = 10 Angstroms

10^8 x with 2 nm gap

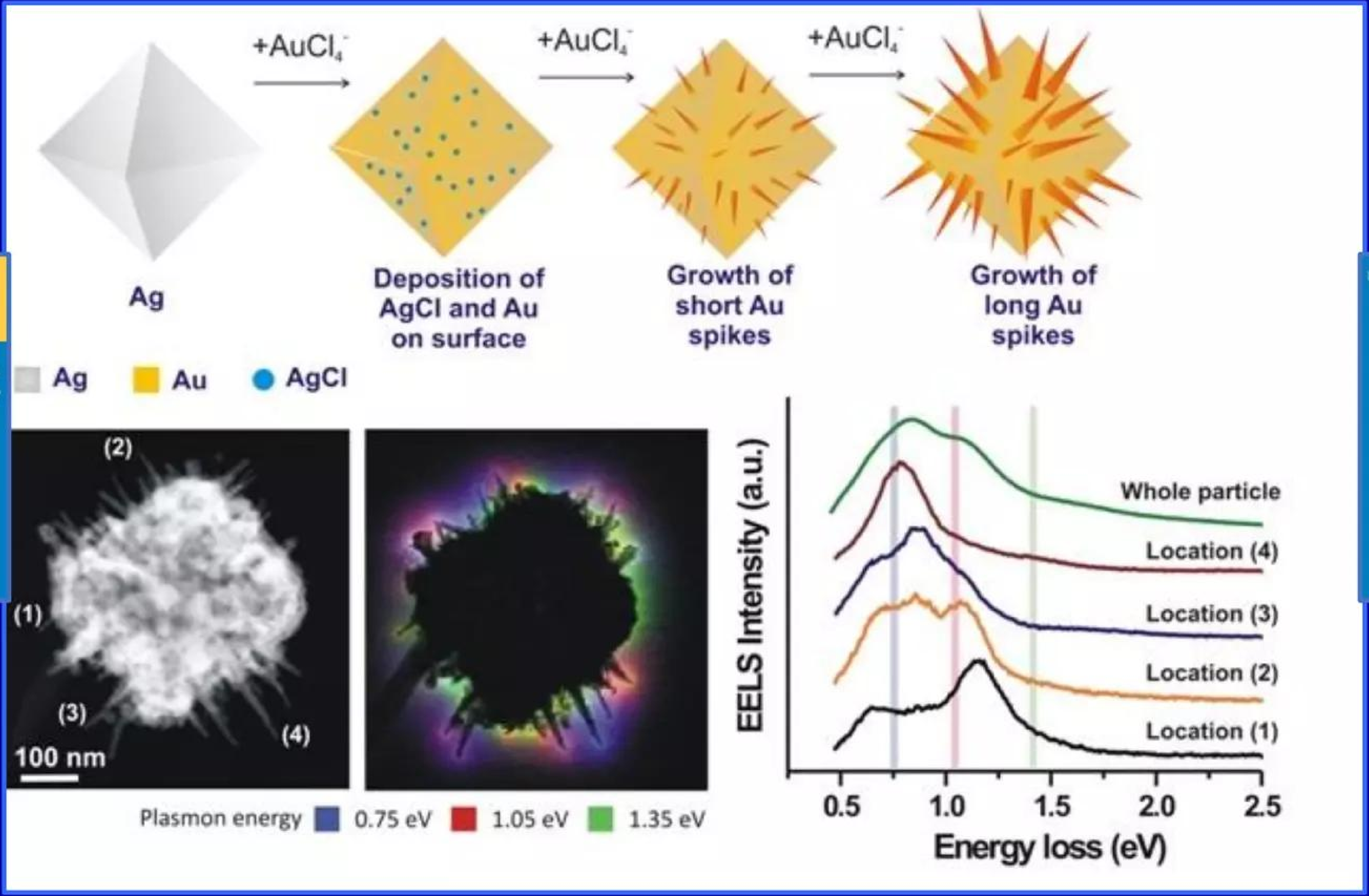
Nanoparticle shapes can locally intensify electric fields

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 may be present 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

Conductive nanostructures can channel currents and amplify local electric fields

Figure 1.

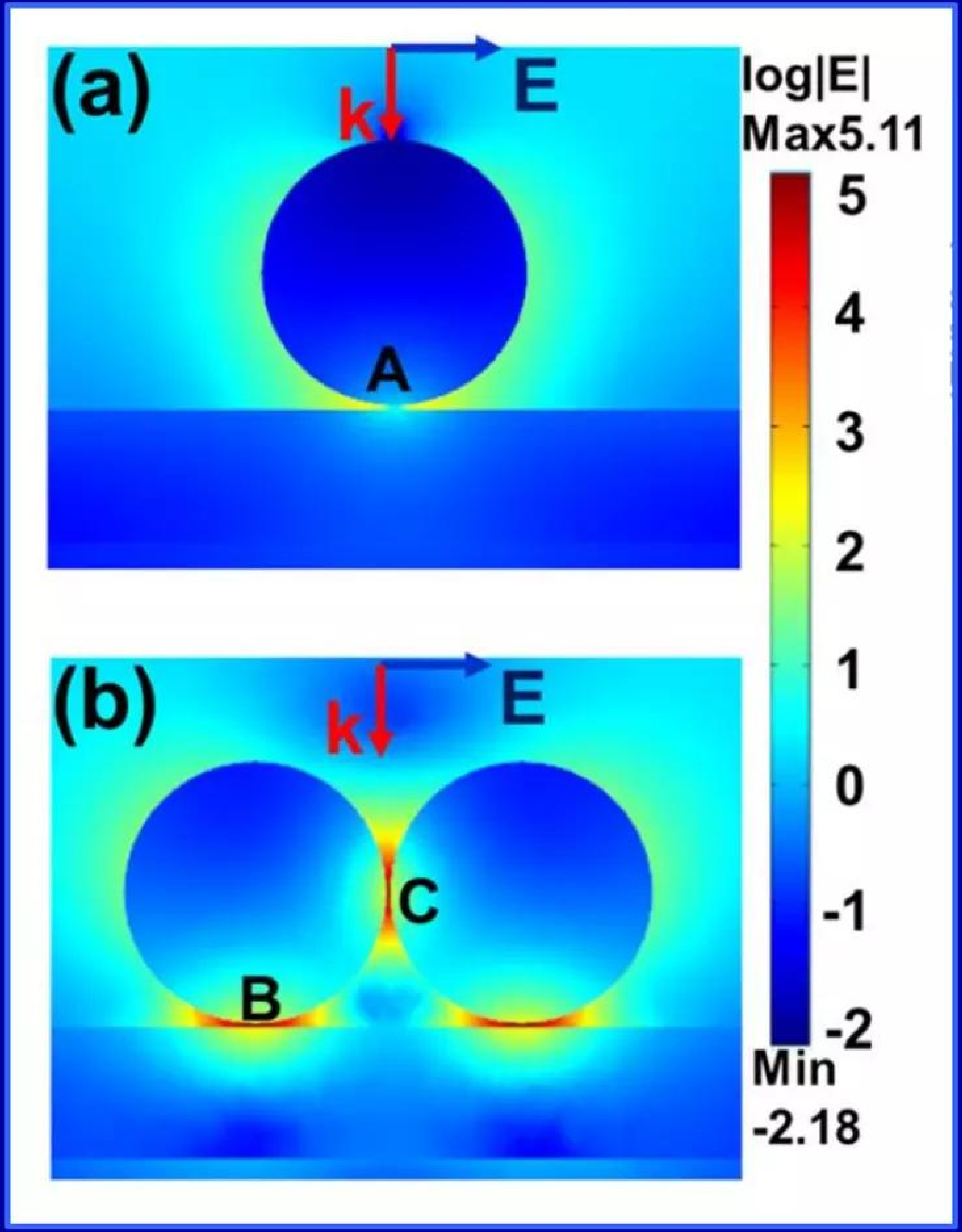
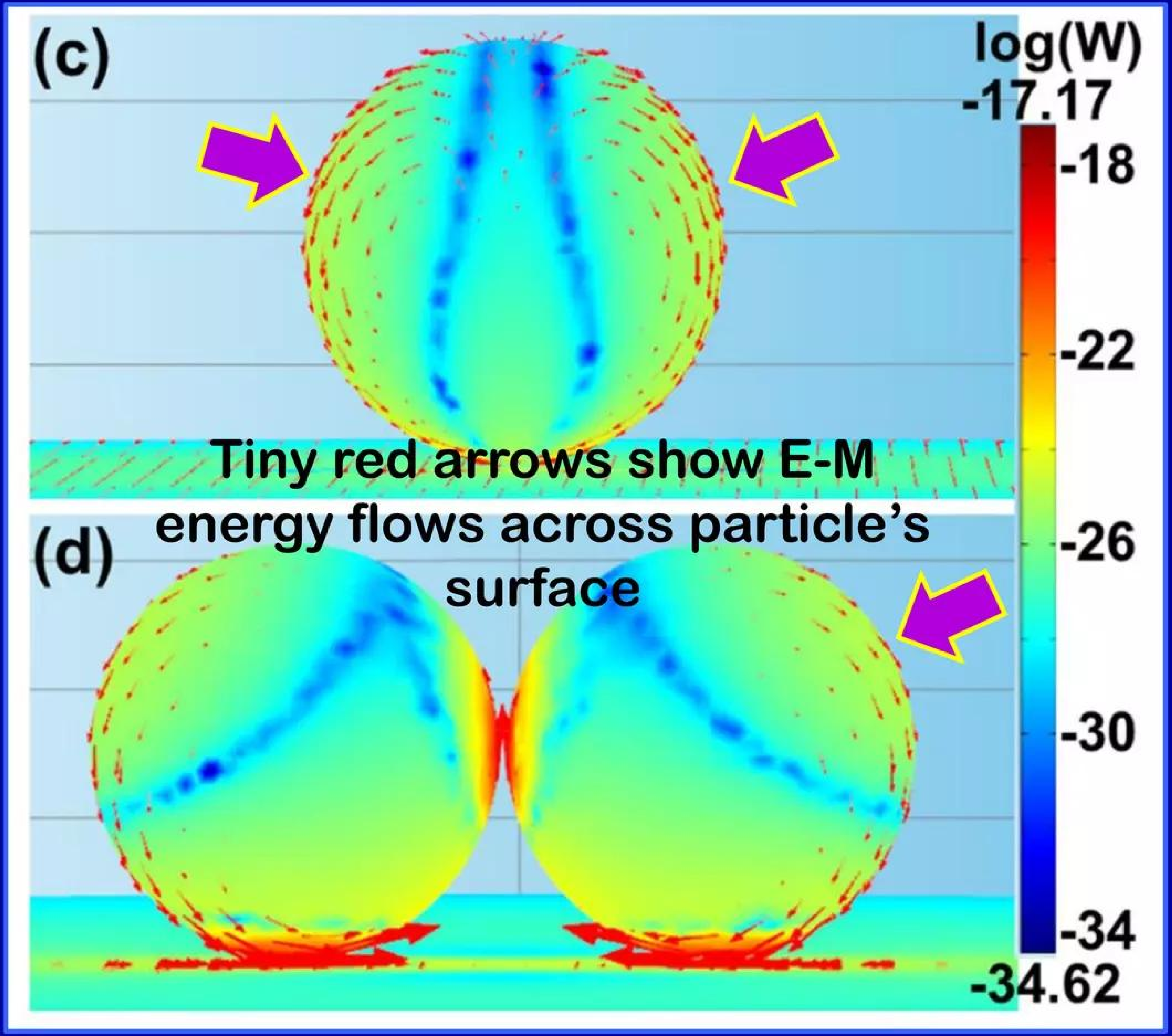


Figure 3.

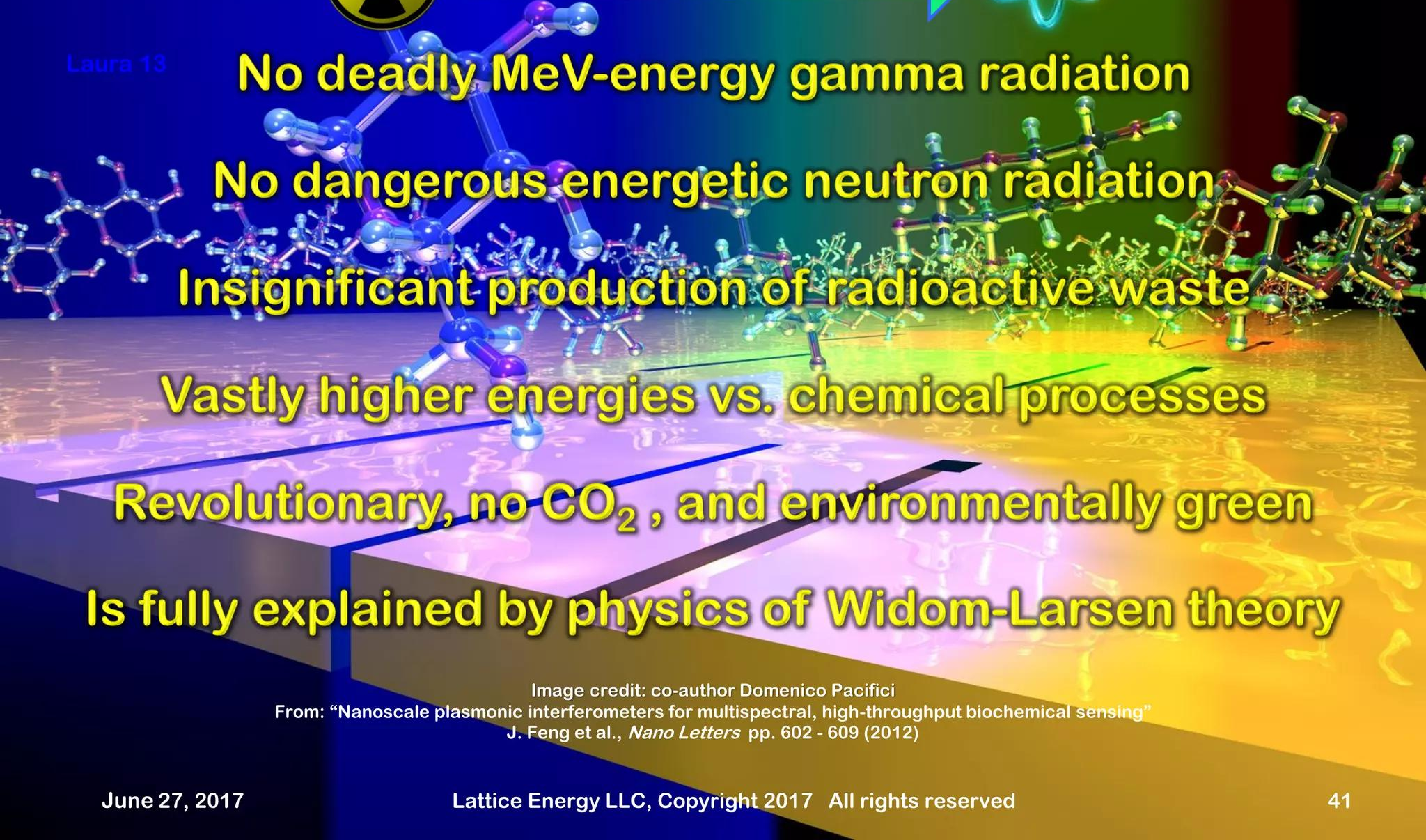


Tiny red arrows show E-M energy flows across particle's surface

Revolutionary ultralow energy neutron reactions (LENRs)

Radiation-free LENRs transmute stable elements to other stable elements

Fission and fusion → Evolution of nuclear technology → Safe green LENRs



Laura 13

No deadly MeV-energy gamma radiation

No dangerous energetic neutron radiation

Insignificant production of radioactive waste

Vastly higher energies vs. chemical processes

Revolutionary, no CO_2 , and environmentally green

Is fully explained by physics of Widom-Larsen theory

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

Comparison of LENRs to fission and fusion

Fission, fusion, and LENRs all involve controlled release of nuclear binding energy (heat) for power generation: no CO_2 emissions; scale of energy release is MeVs (nuclear regime) > 1,000,000x energy density of chemical energy power sources

Heavy element fission: involves shattering heavy nuclei to release stored nuclear binding energy; requires massive shielding and containment structures to handle radiation; major radioactive waste clean-up issues and costs; limited sources of fuel: today, almost entirely Uranium; Thorium-based fuel cycles now under development; heavy element U-235 (fissile isotope fuel) + neutrons → complex array of lower-mass fission products (some are very long-lived radioisotopes) + energetic gamma radiation + energetic neutron radiation + heat

Fusion of light nuclei: involves smashing light nuclei together to release stored nuclear binding energy; present multi-billion $ development efforts (e.g., ITER, NIF, other Tokamaks) focusing mainly on D+T fusion reaction; requires massive shielding/containment structures to handle 14 MeV neutron radiation; minor radioactive waste clean-up $ costs vs. fission

Two key sources of fuel: Deuterium and Tritium (both are heavy isotopes of Hydrogen)

Most likely to be developed commercial fusion reaction involves the following:

D + T → He-4 (helium) + neutron + heat (total energy yield 17.6 MeV; ~14.1 MeV in neutron)

Ultralow energy neutron reactions (LENRs): distinguishing feature is neutron production via electroweak reaction; neutron capture on fuel + gamma conversion to IR + decays [β^-, α] releases nuclear binding energy; early-stage technology; no emission of energetic neutron or gamma radiation and no long-lived radioactive waste products; LENR systems would not require massive, expensive radiation shielding or containment structures → much lower $$$ cost; many possible fuels --- any element/isotope that can capture LENR neutrons; involves neutron-catalyzed transmutation of fuels into heavier stable elements; process creates heat

Before 2006 *e* + *p* thought to occur only in huge supernovas

Simple two-body reaction requires enormous temperatures inside stars

Graphic shows *e* + *p* neutronization reaction during supernova explosion of star

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

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

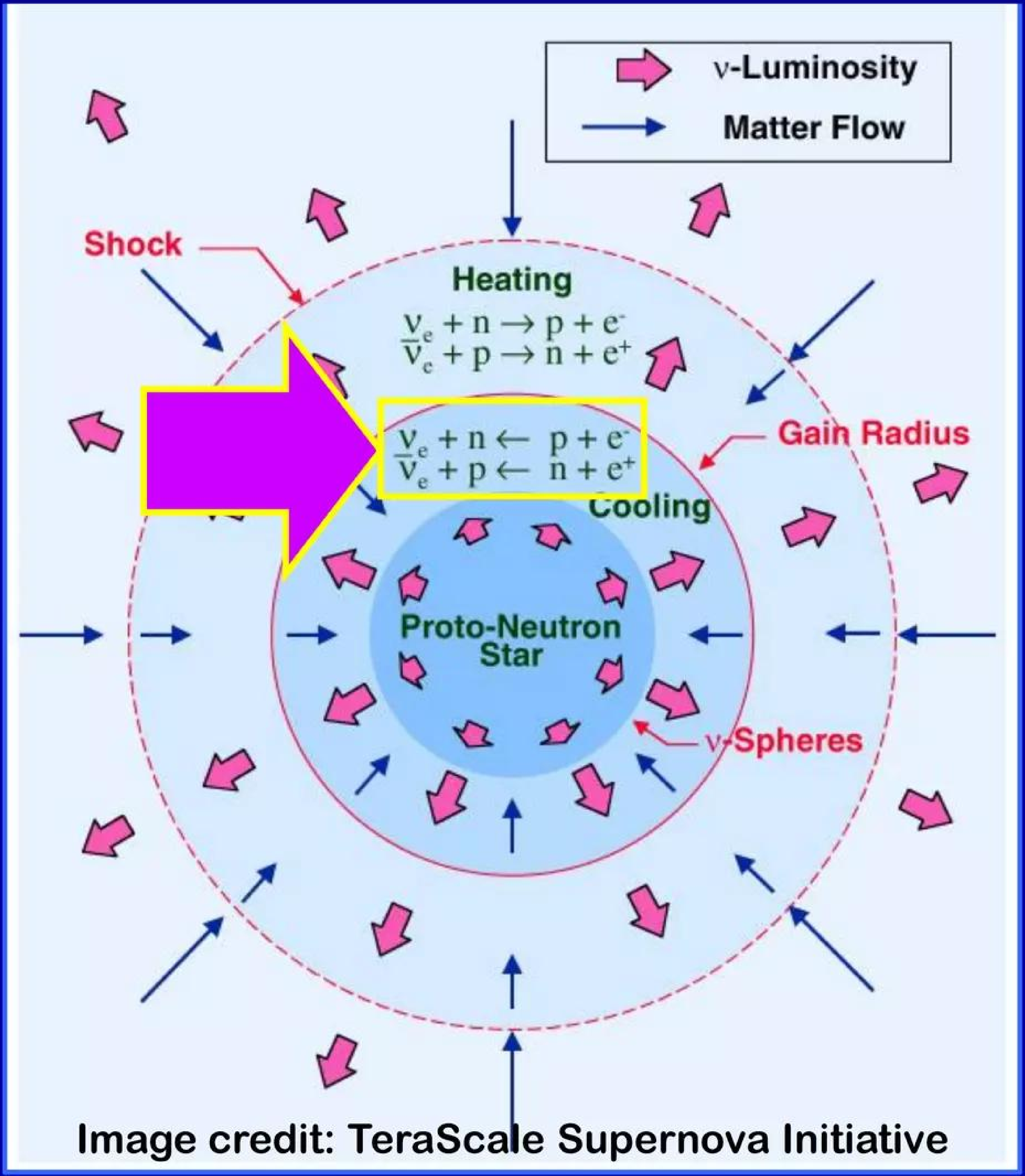


Image credit: TeraScale Supernova Initiative

Neutronization reaction's energetics and cross-section

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

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

- ✓ Fred Hoyle was first theorist who conjectured this reaction as mechanism responsible for producing neutron stars during supernova explosions (1946)
- ✓ Reaction is endothermic: requires input energy of ≥ 0.78 MeV or 780,000 electron Volts (eV) for enough energy to produce neutron and a neutrino
- ✓ Put another way: rest mass of neutron is larger than 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 $e + p$ reaction to go forward to completion
- ✓ To drive simple 2-body reaction relying only on combination of temperature, kinetic energies of charged particles, and high-energy 'tail' of the Maxwell-Boltzmann distribution, local environment of free protons and electrons undergoing $e + p$ reaction must be at ≥ 9×10^9 ° Kelvin or ~ 10 billion degrees
- ✓ For free proton at rest, cross-section for 2-body spontaneous reaction with nearby free electron to make a neutron and neutrino is $1.18 \times 10^{-44}/\text{cm}^2$; i.e., 2-body $e + p$ extremely unlikely to occur spontaneously at room temperature
- ✓ **Many-body collective quantum effects enable $e_n + p_n \rightarrow n_{ulm} + v_e$ at substantial rates at modest temperatures and pressures in condensed matter systems**

Many-body collective quantum effects are crucial to LENRs

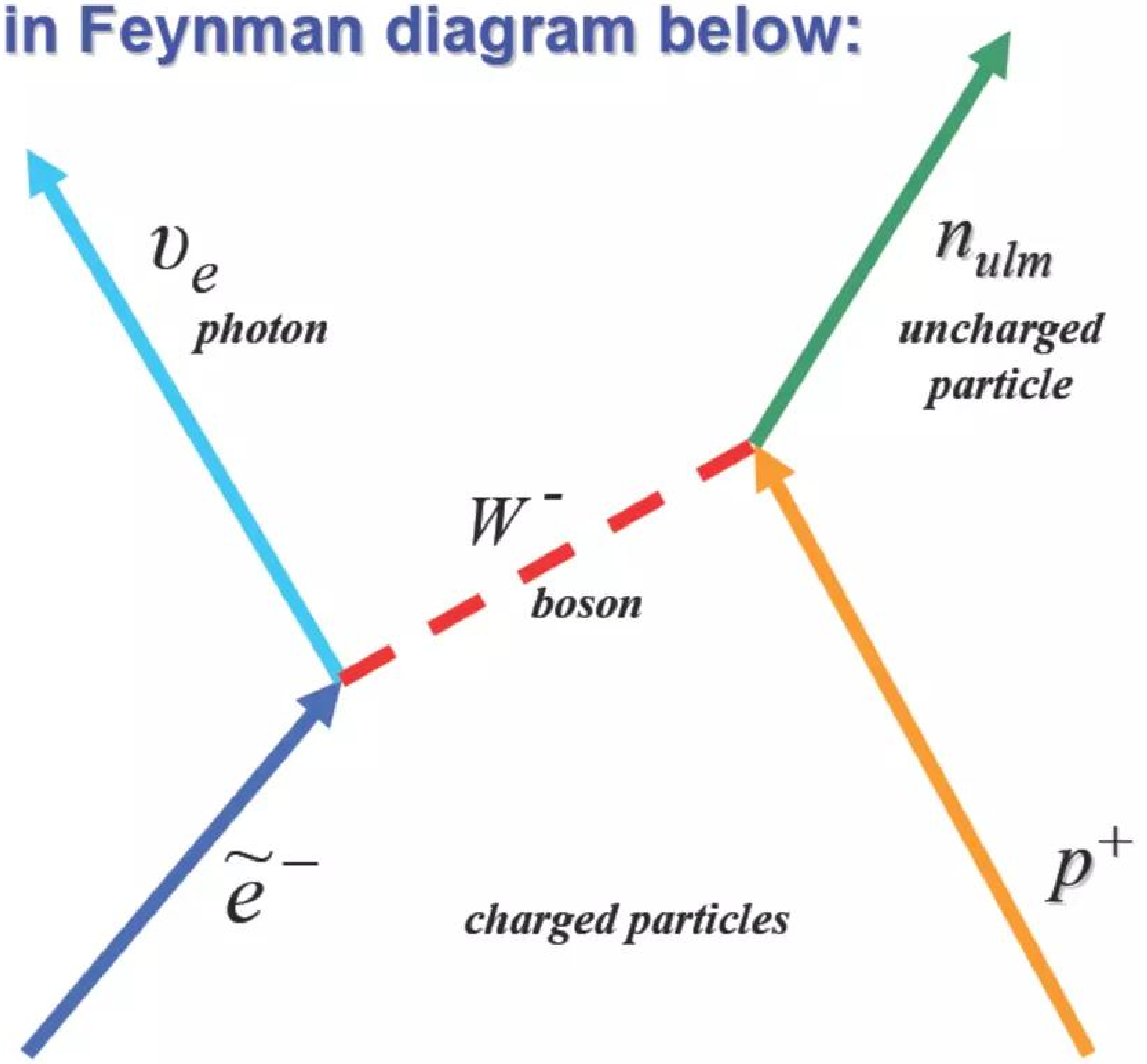
Written as two-body e^- + p^+ reaction but what happens is many-body

Many-body collective effects involve mutual quantum entanglement

What really happens is many-body reaction between entangled particles

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

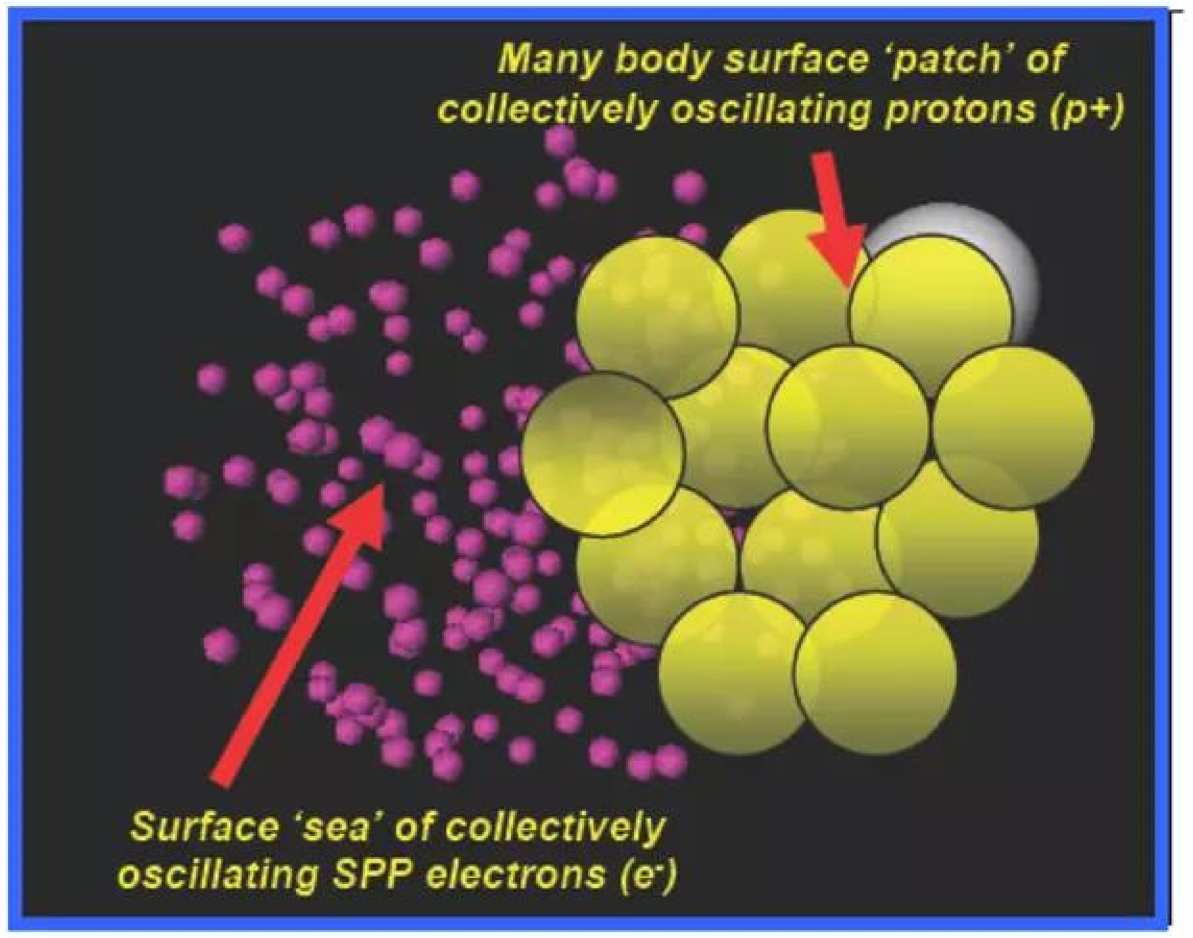
Simple two-body collision shown in Feynman diagram below:



What really happens is many-body process

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

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

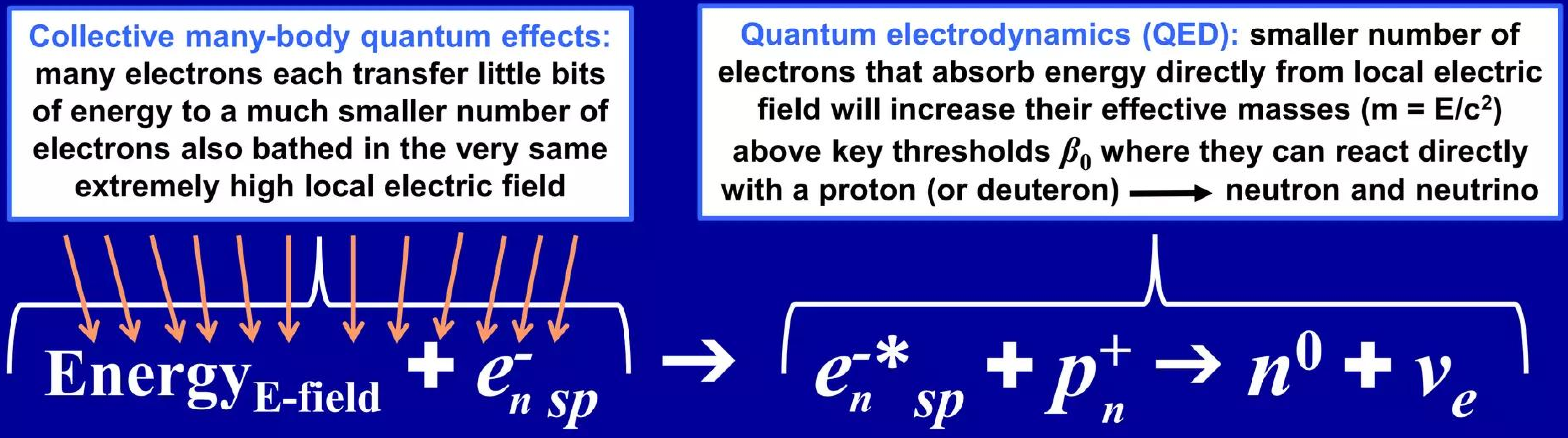


Electroweak reaction in Widom-Larsen theory is simple

Protons or deuterons react directly with electrons to make neutrons

W-L explains how many-body $e + p$ reactions can occur 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

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

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

Induces safe hard-radiation-free nuclear transmutation

Neutrons + atomic nuclei ⟶ heavier elements + decay products

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

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

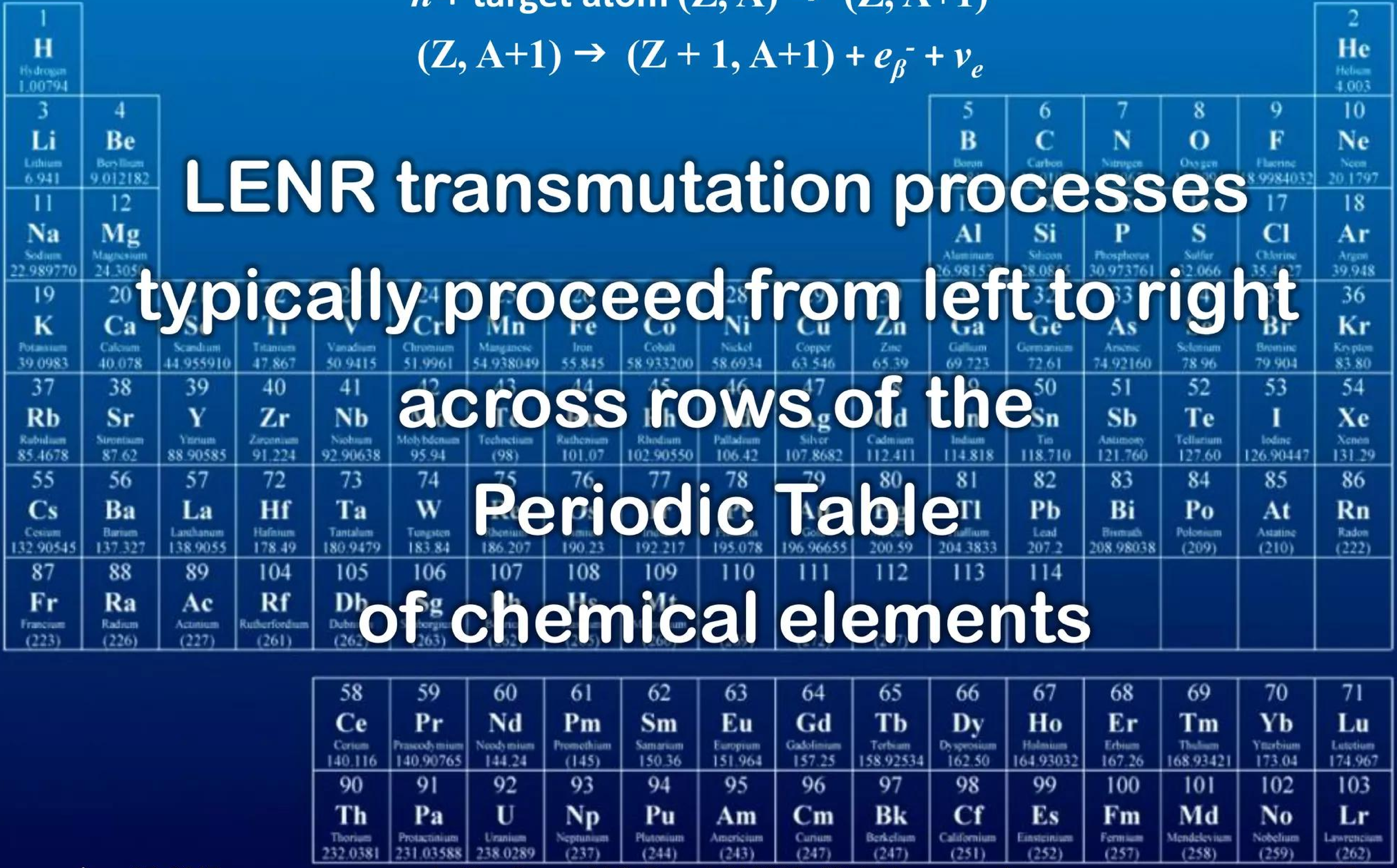
Neutron capture-driven transmutation of isotopes and elements

Neutrons are charge-neutral; atoms readily absorb them

Capture of neutrons by atoms will transmute them into other isotopes

$$n + \text{target atom } (Z, A) \rightarrow (Z, A+1)$$

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



LENR transmutation processes typically proceed from left to right across rows of the Periodic Table of chemical elements

Summary of steps in Widom-Larsen theory of LENRs

5-step process in active sites occurs in 300 - 400 nanoseconds or less

Collective many-body surface patches of protons can become LENR active sites

1. Collectively oscillating, quantum mechanically entangled, many-body patches of Hydrogen (either +-charged protons or deuterons) will form spontaneously on metallic hydride surfaces or at certain types of interfaces, e.g. metal/oxide

2. Born-Oppenheimer approximation spontaneously breaks down, allows E-M coupling between local surface plasmon electrons and patch protons; application of input energy creates nuclear-strength local electric fields >2.5 x 10^{11} V/m - increases effective masses of surface plasmon electrons in patches

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

4. Neutrons collectively created in patch have ultralow kinetic energies and are all absorbed locally by nearby atoms - no dangerous energetic neutron fluxes escape apparatus; any locally produced or incident gammas are converted directly into safe infrared photons (heat) by unreacted heavy electrons (Lattice patent US# 7,893,414 B2) - no hard MeV-energy gamma emissions

5. Transmutation of elements and formation of craters at active sites begins

Application of input energy is required to produce neutrons

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

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

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

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

Patches of p^+ protons form spontaneously on surfaces

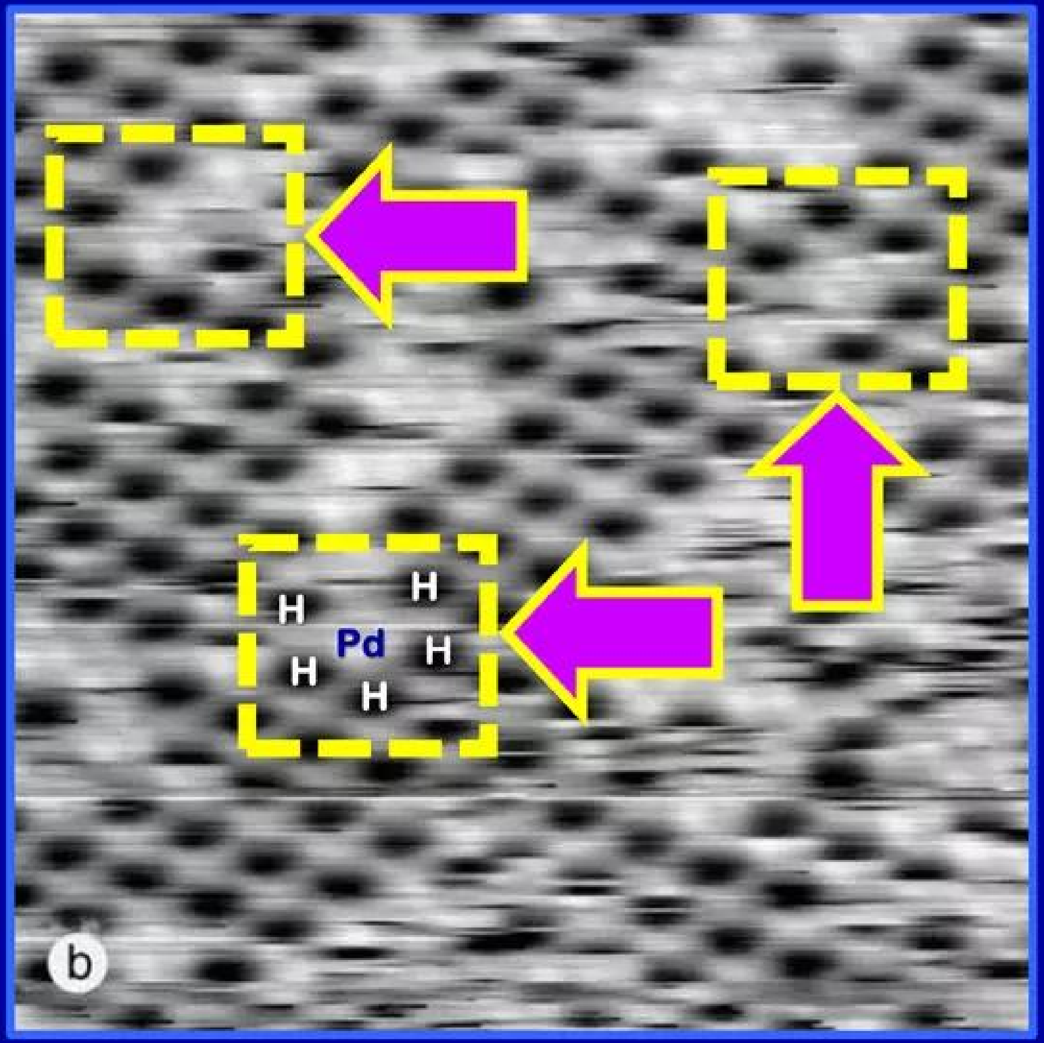
Physical size of LENR active sites ranges from 2 nm to 100^+ microns

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)

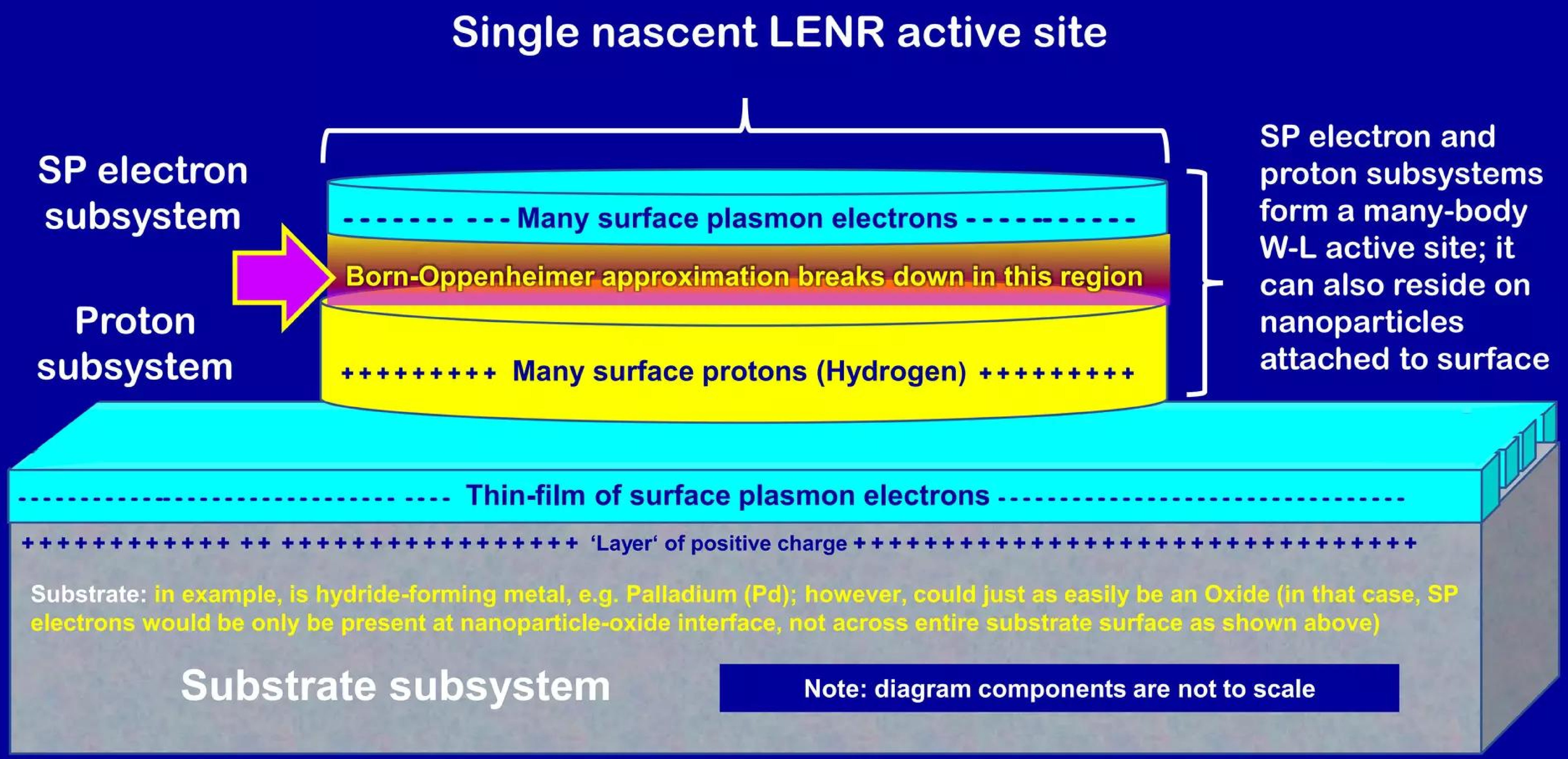
http://www.researchgate.net/publication/229342506_Hydrogen_adsorption_and_diffusion_on_Pd(111)

W-L concept of a microscopic LENR active surface site

Comprised of many-body patches of protons and 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



Single nascent 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

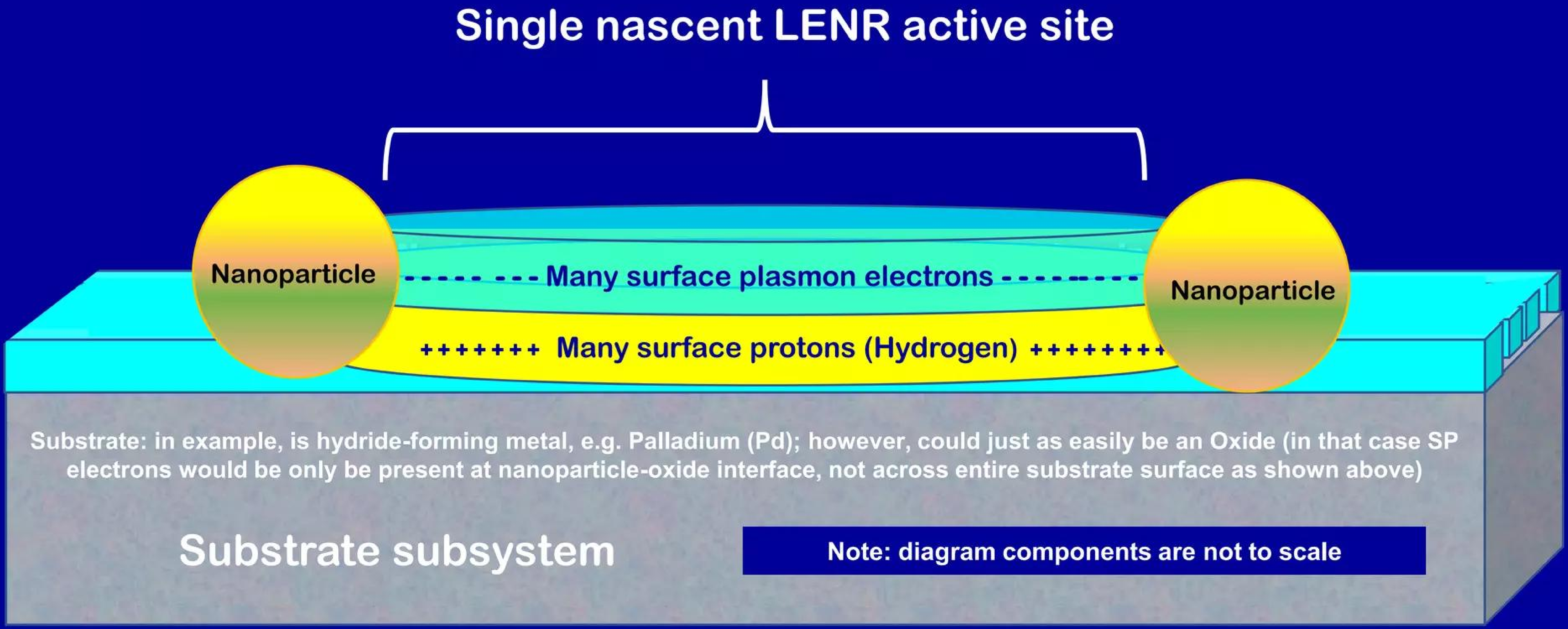
Input energy creates high electric fields in LENR active sites

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

Huge electric field increases effective masses of some patch SP electrons

Correct input energies create huge local E-fields > 2.5 x 10^{11} V/m between adjacent nanoparticles

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



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

After being produced neutrons capture on targets in and around active sites

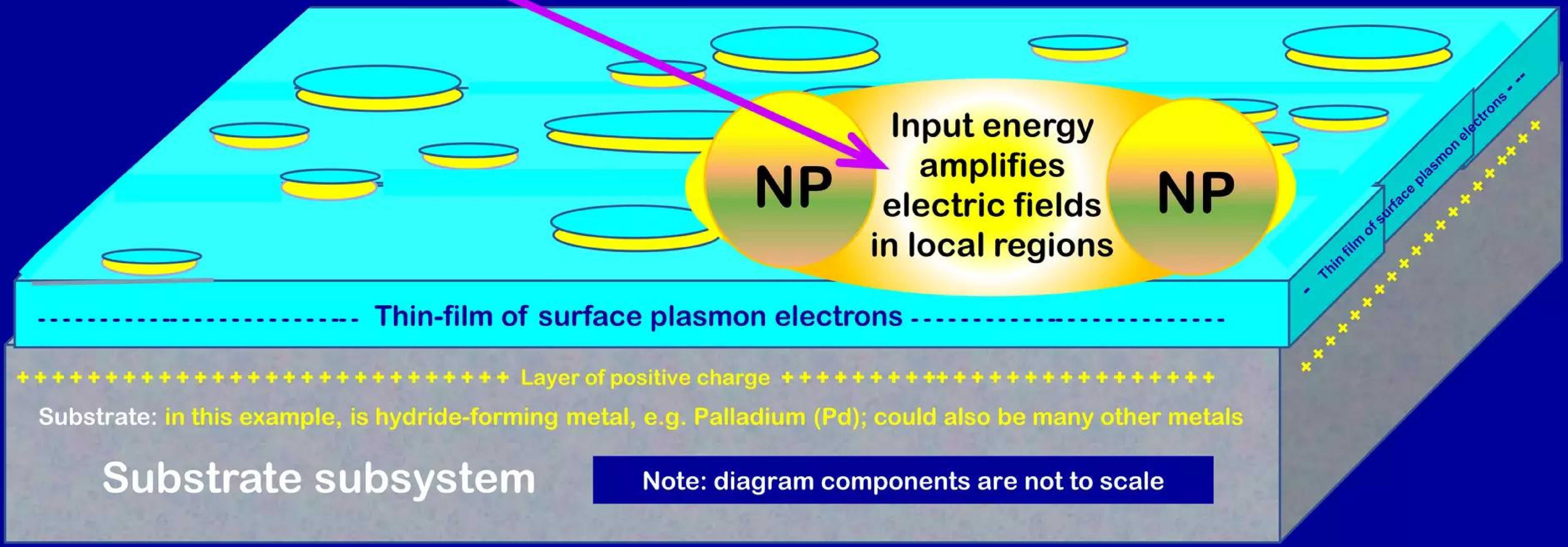
Intense heating in LENR active sites will form μ-scale event craters on substrate surfaces

$n + (Z, A) \rightarrow (Z, A{+}1)$ [neutrons capture on nearby target atoms]

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

Often followed by β^- decays of neutron-rich intermediate isotopic products

● = Metallic nanoparticle (NP)



NP

Input energy amplifies electric fields in local regions

NP

- Thin-film of surface plasmon electrons -

+ Layer of positive charge +

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

Substrate subsystem

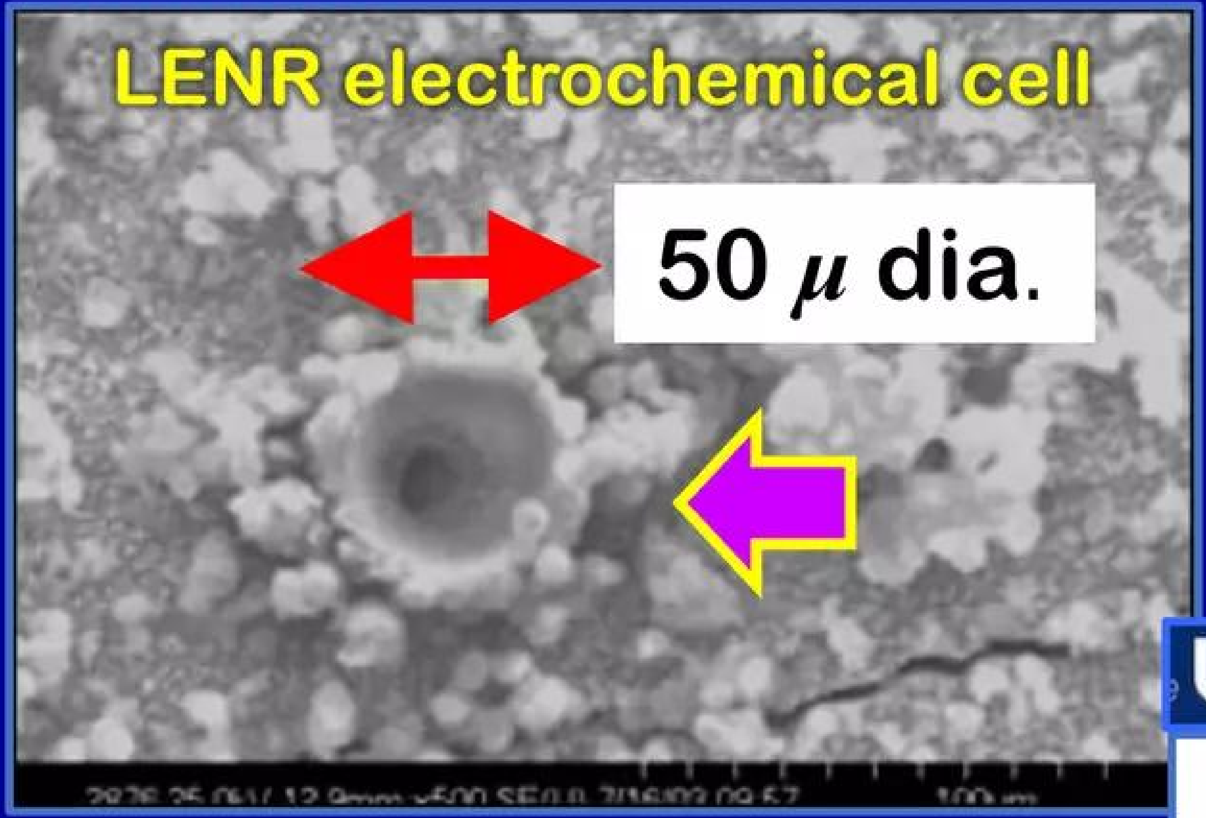
Note: diagram components are not to scale

LENR active sites create very distinctive surface features

Size of LENR active sites ranges from 2 nanometers up to ~100$^+$ microns

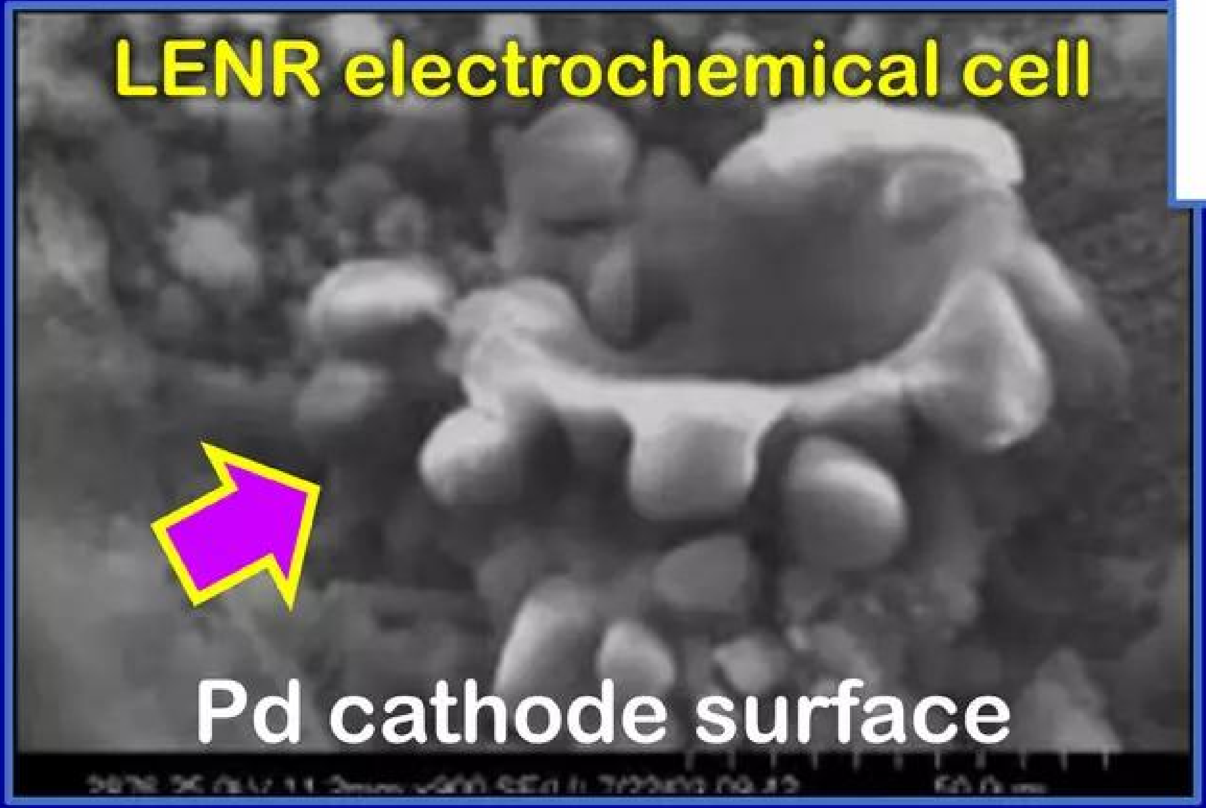
Post-experiment SEM images of Pd surface; infrared video of working Pd cathode

50 μ LENR active site crater in Pd cathode



Credit: P. Boss, U.S. Navy SPAWAR

LENR active site crater



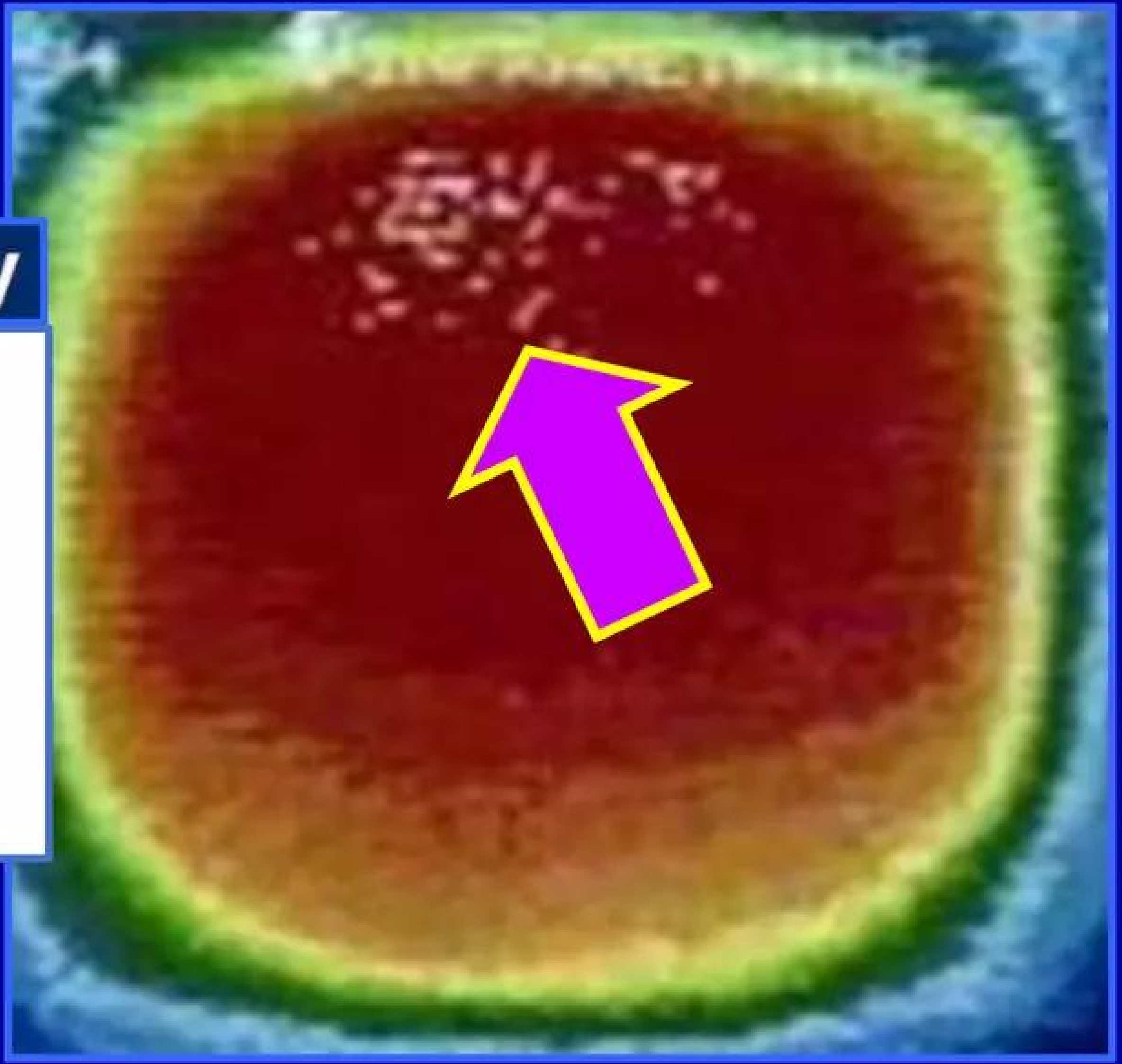
Credit: P. Boss, U.S. Navy SPAWAR

United States Navy

SPAWAR

Systems Center
PACIFIC

Infrared video of tiny LENR hotspots that form spontaneously on Pd cathode surfaces in aqueous electrochemical cells



http://www.youtube.com/watch?v=OUVmOQXBS68

Credit: P. Boss, U.S. Navy SPAWAR (1994)

LENR active sites create flash-melted craters on surfaces

SIMS and NanoSIMS detect isotopic shifts and transmutation products

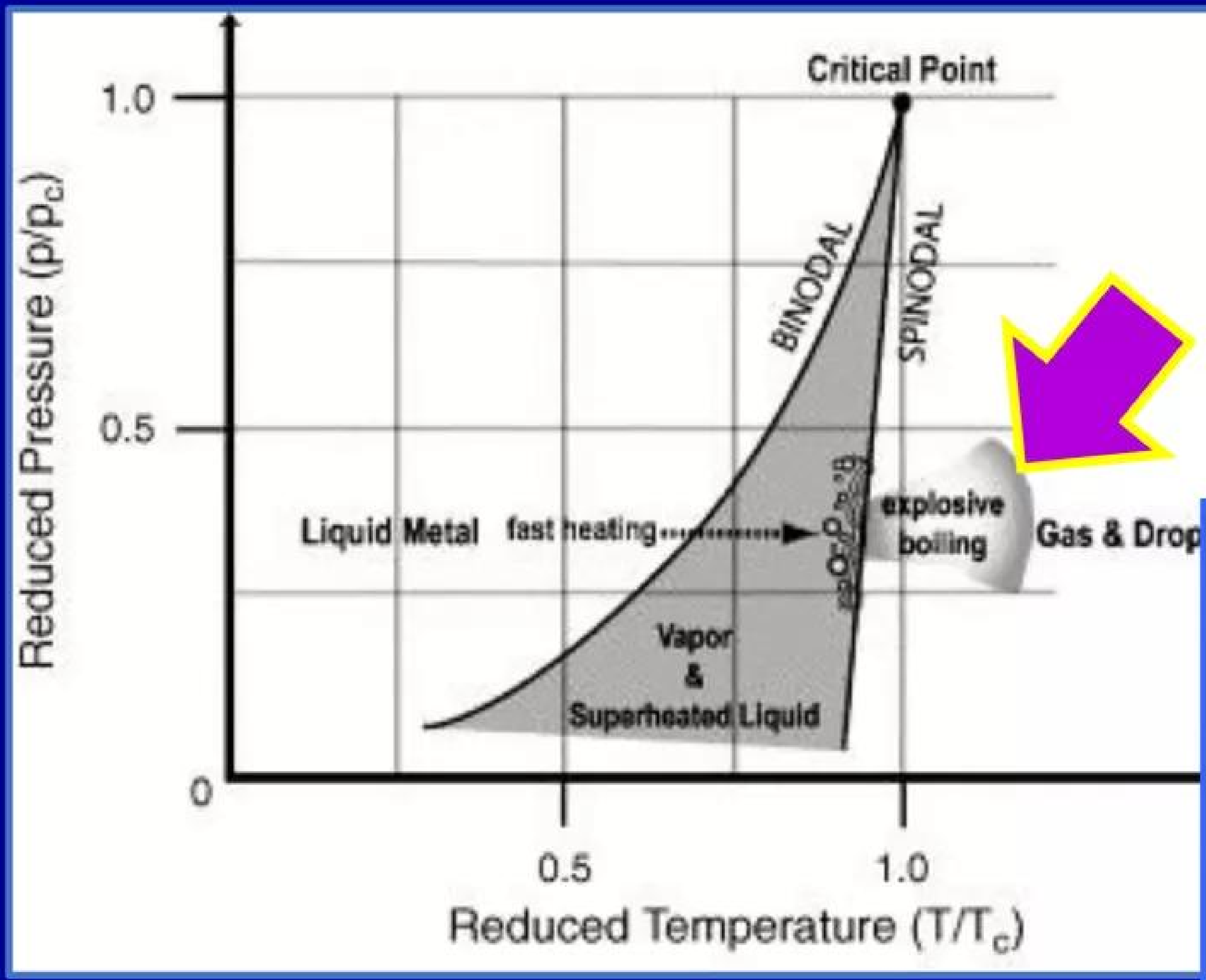
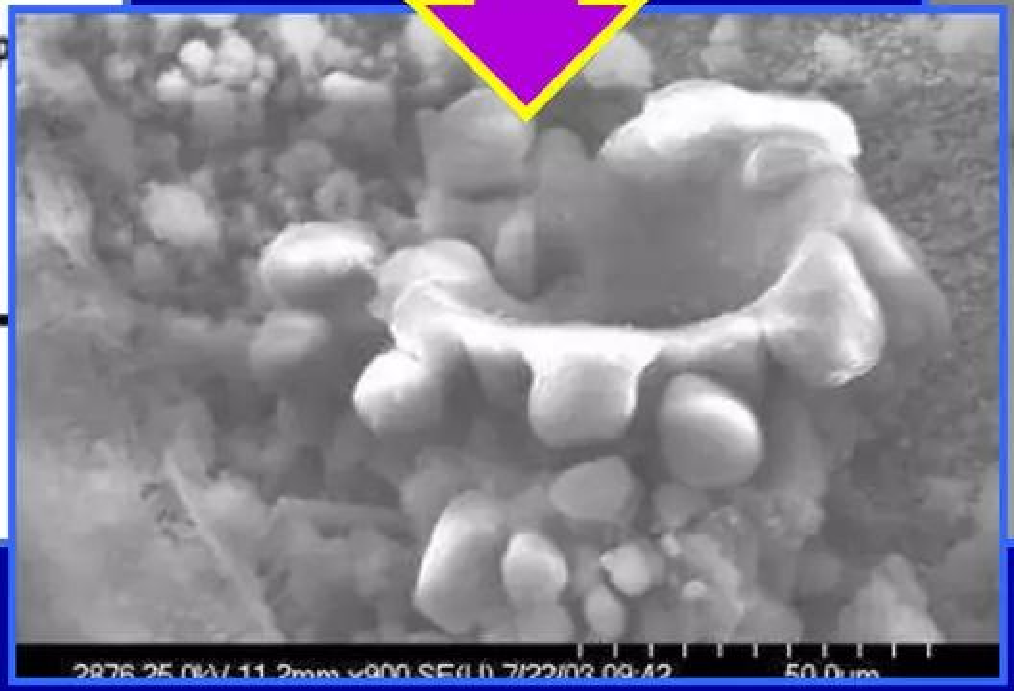


Fig. 1. Phase stability diagram of a liquid metal near the critical point. For fast heating, as obtained during *ns* laser ablation, the melt can be pushed close to critical conditions (superheating), which favors the realization of explosive boiling

LENR crater on Palladium cathode surface after electrolysis



Pd surface post-experiment SEM
P. Boss *et al.*
U.S. Navy - SPAWAR

Hydrodynamic analogue of boiling

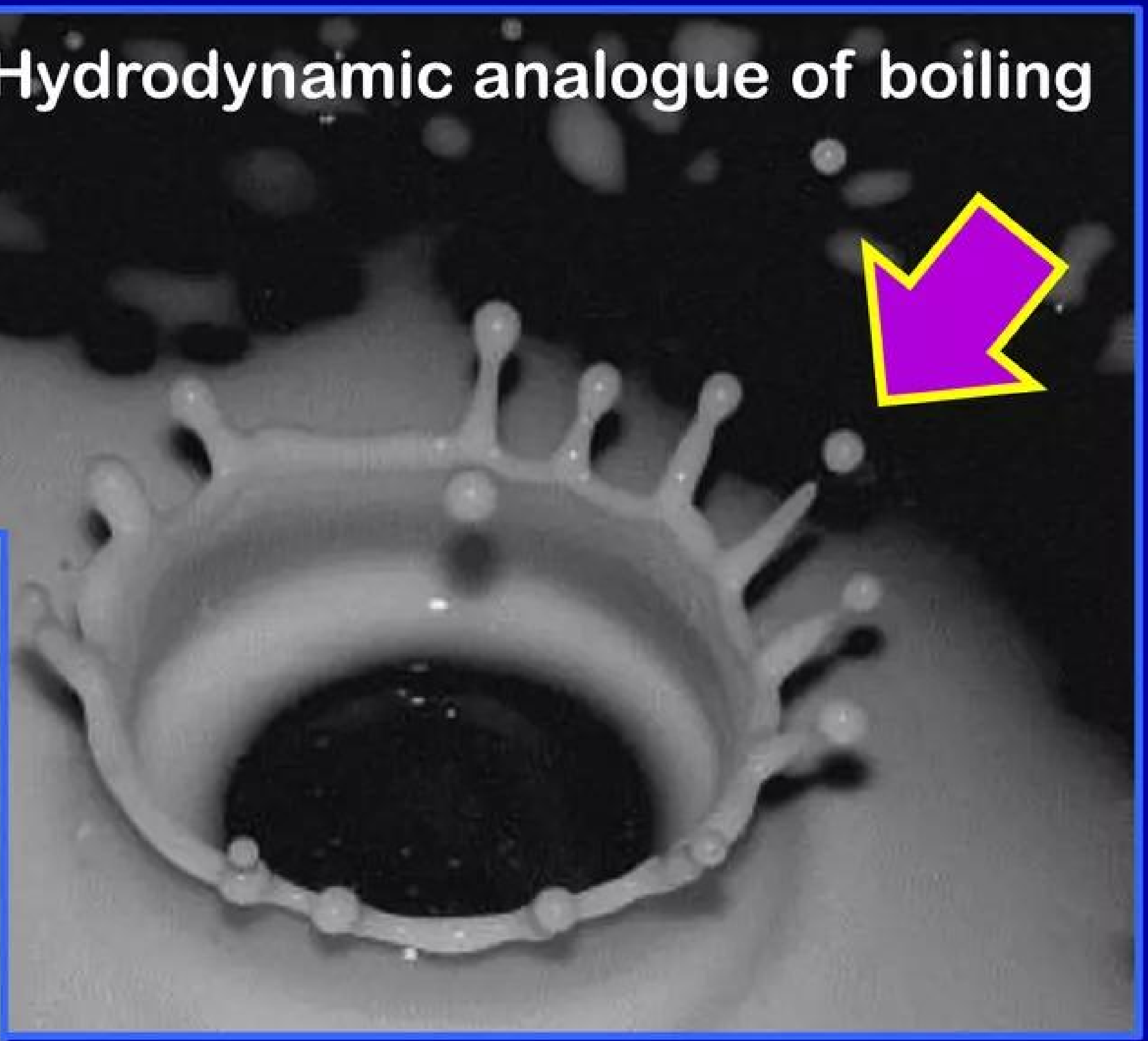


Fig. 2. Schematic visualization of the hydrodynamic evolution of a fluid system under and impulse stress (here milk). Note the non-deterministic formation of jets at the sides and their break-up into droplets. From Ref. [58].

Excerpted and quoted from: "Multiplicity and contiguity of ablation mechanisms in laser-assisted analytical micro-sampling" D. Bleiner and A. Bogaerts *Spectrochimica Acta Part B: Atomic Spectroscopy* 61 pp. 421 - 432 (2006)

http://www.sciencedirect.com/science/article/pii/S0584854706000437

Chemical and LENR processes actively coexist on surfaces

LENRs: complex interplay among E-M, chemical, and nuclear processes

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

- ✓ Well-known that metallic surface nanostructures and surface plasmon electrons can have configurations that can absorb electromagnetic (E-M) energy over a wide area, transport and greatly localize that energy, and --- in conjunction with contiguous surface patches of collectively oscillating protons --- create nuclear-strength local electric fields > 2.5 x 10^{11} V/m that are required to produce ultralow energy neutrons in LENR active sites
- ✓ For substrate surfaces on which LENR active sites have formed, there are a myriad of different, nanometer-to micron-scale electromagnetic (E-M), 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 take-away: electromagnetic, chemical, and nuclear processes can coexist and interact on small length-scales on different types of surfaces

Characteristics of LENR and chemical catalytic active sites

Chemical and nuclear processes can coexist and interoperate on surfaces

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	Inorganic chemical
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)	Yes, Aragones *et al.* *Nature* (2016)
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)	Yes, probably
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	

Widom-Larsen theory of LENRs relates to chemical catalysis

Local electric fields >10^{10} V/m with Q-M entangled protons and electrons

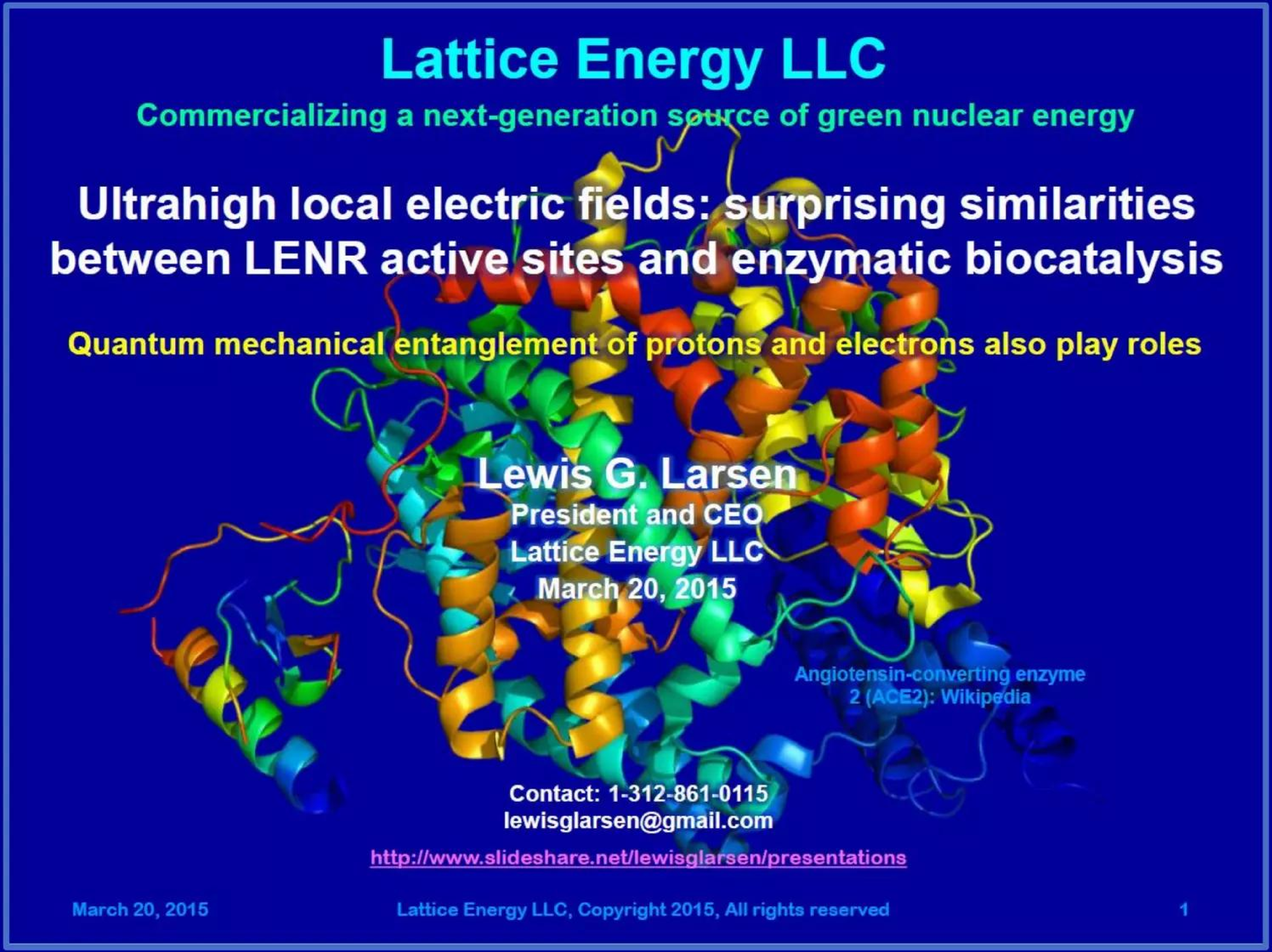
Experimental data in publications by other researchers supports our hypothesis

- ✓ Based on experimental data published by scientists in Russia back in 2003, in 2010 Lattice hypothesized that very high electric fields > 10^{10} V/m and many-body collective quantum effects would prove to be important for normal operation of active sites in many enzymes; this was eventually confirmed experimentally by Fried et al. in *Science* (2014)
- ✓ Extending this thinking, and joining with many other theoretical chemists, in early 2015 Lattice also hypothesized that high local electric fields --- this is referred to as "electrostatic catalysis" among chemists --- would prove to be important in variety of catalytic chemical processes; data published by Aragonès et al. in *Nature* (2016) confirmed this hypothesis
- ✓ In April 2015, Lattice further conjectured that very high electric local electric fields 10^{10} V/m and many-body collective quantum effects would prove to be important for reducing temperatures and pressures required for the Haber-Bosch process for producing ammonia; data published by Manabe et al. in *Chemical Science* (2017) confirmed Lattice's hypothesis

March 2015: Lattice relates W-L theory to enzymatic catalysis

Hypothesis: local electric fields > 10^{10} V/m occur in enzyme active sites

http://www.slideshare.net/lewisglarsen/lattice-energy-llc-surprising-similarities-between-lenr-active-sites-and-enzymatic-catalysis-march-20-2015



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

Lewis G. Larsen
President and CEO
Lattice Energy LLC
March 20, 2015

Angiotensin-converting enzyme 2 (ACE2): Wikipedia

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

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

March 20, 2015 Lattice Energy LLC, Copyright 2015, All rights reserved 1

Enzyme active sites create very high local electric fields

Quasi-static E-fields ~ 1.5 x 10^{10} V/m were measured in WT isomerase

Unable to measure very fast transients that represent even higher field strengths

"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

- ✓ Using Stark Effect, measured quasi-static, near-equilibrium, time averaged electric fields of ~ 1.5 x 10^{10} V/m in Wild Type (WT) ketosteroid isomerase's active site. Researchers admitted that fast-transient, way-higher spikes in active sites' local electric field-strength could potentially occur under dynamic non-equilibrium conditions but they can't presently be measured (S. Boxer, co-author of paper and group leader; private communication)
- ✓ Observed linear relationship between E-field strength and effect on C=O double bond and importantly concluded that electric field strength in enzyme's active site was responsible for " … 70% of KSI's catalytic speedup relative to an uncatalyzed reference reaction"
- ✓ To make neutrons via $e + p$ reaction need E-field strengths > 2.5 x 10^{11} V/m for tens of attoseconds; do fast transients in active sites get high enough?

Large E-fields >10^{10} V/m link enzymes, catalysts, and LENRs

Electric fields and Q-M effects enable chemical & electroweak catalysis

Statement by P. Hildebrandt re Fried *et al.*'s paper published in *Science* (2014):

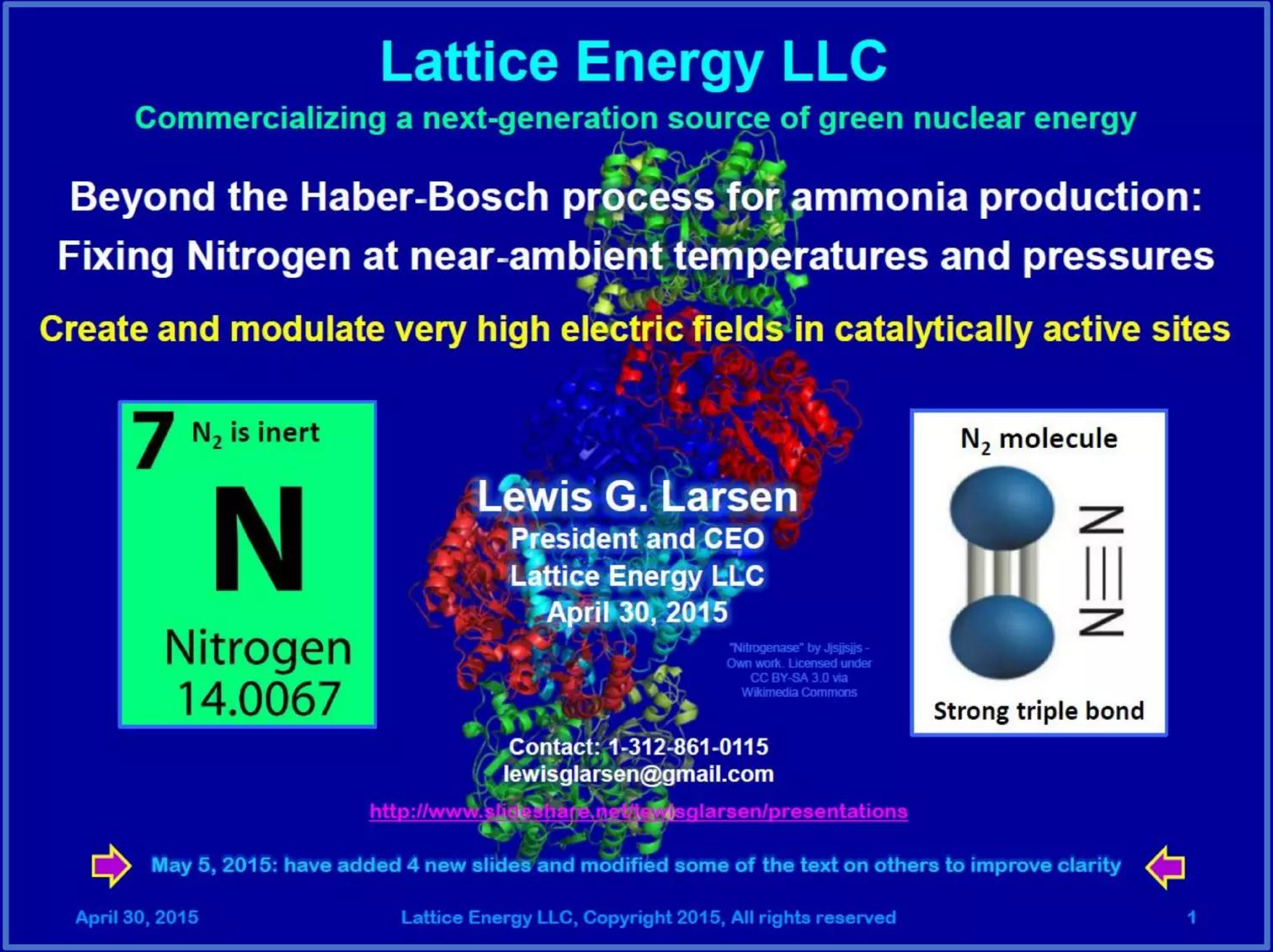
> "It is very likely that the electric field-dependent acceleration of elementary reactions is a general concept in biological catalysis and perhaps also in chemical catalysis …" P.H.

- ✓ Thanks to work of Fried *et al.* (*Science*, 2014), we now know that time-averaged Å-scale local electric fields > 10^{10} V/m exist inside the active site of at least one isomerase enzyme and are responsible for most (est. 70%) of its high catalytic proficiency; they also found that E-field effects on C=O bond stretching increase linearly with local electric field strength - like Hildebrandt, Lattice thinks this applies to abiotic chemical catalysis
- ✓ Lattice theorizes that the physics of both biological enzymatic and abiotic chemical catalysis are quite similar to electroweak $e + p$ catalysis in that extremely high local electric fields on length-scales from 2 - 3 Å up to ~100 μ are critical to high levels of catalytic activity and that these high local fields are enabled by many-body collective E-M and Q-M effects between electrons and protons in and near active sites; likely that LENRs and chemical processes coexist and interoperate on small length-scales

April 2015: Lattice relates W-L theory to Haber-Bosch

Hypothesis: high electric fields may reduce temps/pressures for process

http://www.slideshare.net/lewisglarsen/lattice-energy-llc-beyond-the-haberbosch-process-for-ammonia-production-april-30-2015



Lattice Energy LLC

Commercializing a next-generation source of green nuclear energy

Beyond the Haber-Bosch process for ammonia production: Fixing Nitrogen at near-ambient temperatures and pressures

Create and modulate very high electric fields in catalytically active sites

Lewis G. Larsen
President and CEO
Lattice Energy LLC
April 30, 2015

"Nitrogenase" by Jjsjjsjjs - Own work. Licensed under CC BY-SA 3.0 via Wikimedia Commons

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

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

May 5, 2015: have added 4 new slides and modified some of the text on others to improve clarity

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Lattice's R&D strategy for going beyond Haber-Bosch

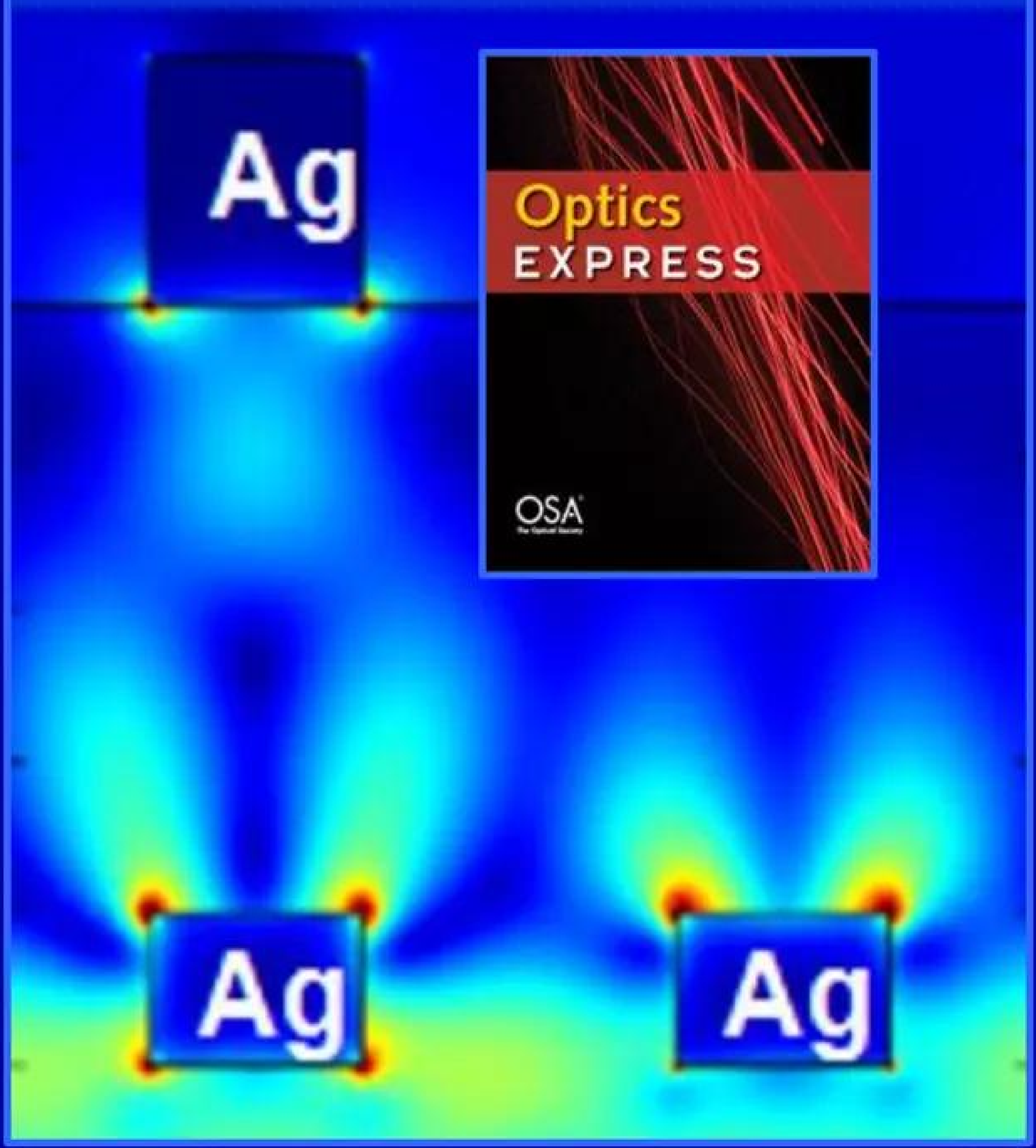
Apply knowledge of LENR active sites and plasmonics to N_2 fixation

Boost catalytic proficiency and keep working temps & pressures near ambient

- ✓ It has become apparent that deep technical knowledge about details of abiotic LENR electroweak catalysis can provide valuable insights into the operation of both enzymatic and abiotic chemical catalysis. There is thus an opportunity to use new and unique conceptual insights to help greatly increase performance and reduce production costs for industrial abiotic, non-Haber-Bosch catalysis of Nitrogen fixation
- ✓ Chalcogens are good place to start thanks to the new discovery by Bannerjee et al. (*JACS* 2015); importantly, surface plasmons are well-known on chalcogenides in other nanotech applications
- ✓ Nanotechnology, plasmonics, and many-body collective quantum effects can be applied to selected FeMoS materials to purpose-design catalytically active nanoscale sites in which local electric field strengths are high enough to cleave the Nitrogen triple bond to react with Hydrogen

A. Lin et al. *Optics Express* (2013)

"Electric field profile of optimized energy transfer structure"

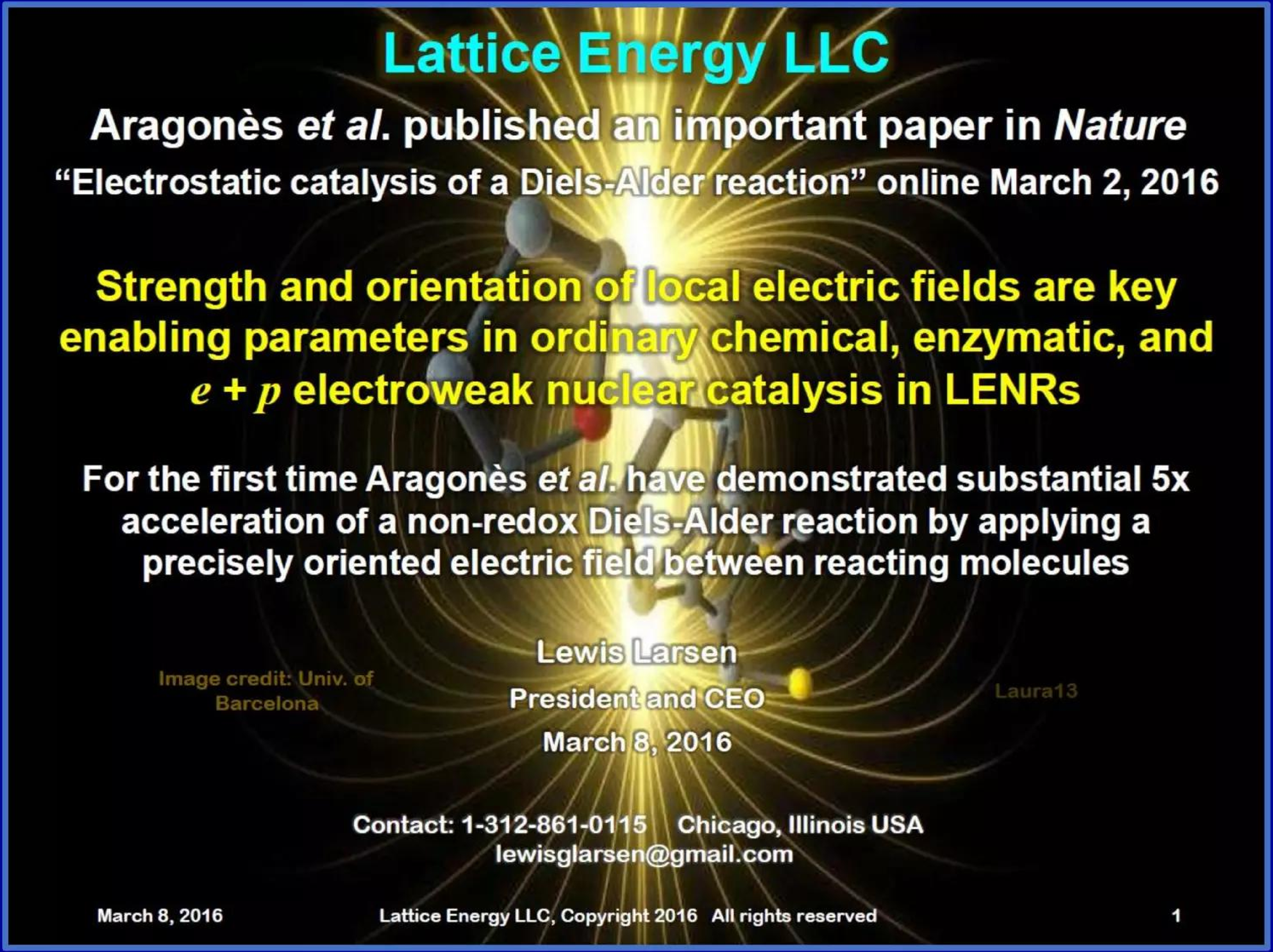


http://tinyurl.com/qypprkz

March 2016: Lattice reviews important data of Aragonès et al.

Hypothesis: high electric fields can accelerate many chemical reactions

http://www.slideshare.net/lewisglarsen/lattice-energy-llc-electroweak-nuclear-catalysis-and-chemical-catalysis-are-deeply-interrelated-via-extremely-high-local-electric-fields-march-8-2016



Lattice Energy LLC

Aragonès *et al*. published an important paper in *Nature*

"Electrostatic catalysis of a Diels-Alder reaction" online March 2, 2016

Strength and orientation of local electric fields are key enabling parameters in ordinary chemical, enzymatic, and $e + p$ electroweak nuclear catalysis in LENRs

For the first time Aragonès *et al.* have demonstrated substantial 5x acceleration of a non-redox Diels-Alder reaction by applying a precisely oriented electric field between reacting molecules

Image credit: Univ. of Barcelona

Laura13

Lewis Larsen
President and CEO
March 8, 2016

Contact: 1-312-861-0115 Chicago, Illinois USA
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Abstract of important *Nature* paper by Aragonès et al. (2016)

"Electrostatic catalysis of a Diels-Alder reaction"
A. Aragonès *et al. Nature* 531 pp. 88 - 91 (March 3, 2016)

http://www.nature.com/nature/journal/v531/n7592/full/nature16989.html

"It is often thought that the ability to control reaction rates with an applied electrical potential gradient is unique to redox systems. However, recent theoretical studies suggest that oriented electric fields could affect the outcomes of a range of chemical reactions, regardless of whether a redox system is involved. This possibility arises because many formally covalent species can be stabilized via minor charge-separated resonance contributors. When an applied electric field is aligned in such a way as to electrostatically stabilize one of these minor forms, the degree of resonance increases, resulting in the overall stabilization of the molecule or transition state. This means that it should be possible to manipulate the kinetics and thermodynamics of non-redox processes using an external electric field, as long as the orientation of the approaching reactants with respect to the field stimulus can be controlled. Here, we provide experimental evidence that the formation of carbon–carbon bonds is accelerated by an electric field. We have designed a surface model system to probe the Diels–Alder reaction, and coupled it with a scanning tunnelling microscopy break-junction approach. This technique, performed at the single-molecule level, is perfectly suited to deliver an electric-field stimulus across approaching reactants. We find a fivefold increase in the frequency of formation of single-molecule junctions, resulting from the reaction that occurs when the electric field is present and aligned so as to favour electron flow from the dienophile to the diene. Our results are qualitatively consistent with those predicted by quantum-chemical calculations in a theoretical model of this system, and herald a new approach to chemical catalysis."

Editor’s summary of *Nature* paper by Aragonès et al. (2016)

nature International weekly journal of science

http://www.nature.com/nature/journal/v531/n7592/full/nature16989.html

Directly quoting the Editor's summary:

“Theory suggests that many chemical reactions — not simply, as is often thought, redox reactions — might be catalysed by an applied electrical field. Experimental evidence for this is now provided from single-molecule studies of the formation of carbon–carbon bonds in a Diels-Alder reaction. In a series of scanning tunneling microscopy break-junction experiments, the authors observe a fivefold increase in the frequency of single-molecule junction formation when the electrical field is present and aligned in the direction to favour electron flow from the dienophile to the diene. The demonstration that it is possible to manipulate chemical reactions with electric fields offers proof-of-principle for a novel approach to heterogeneous catalysis.”

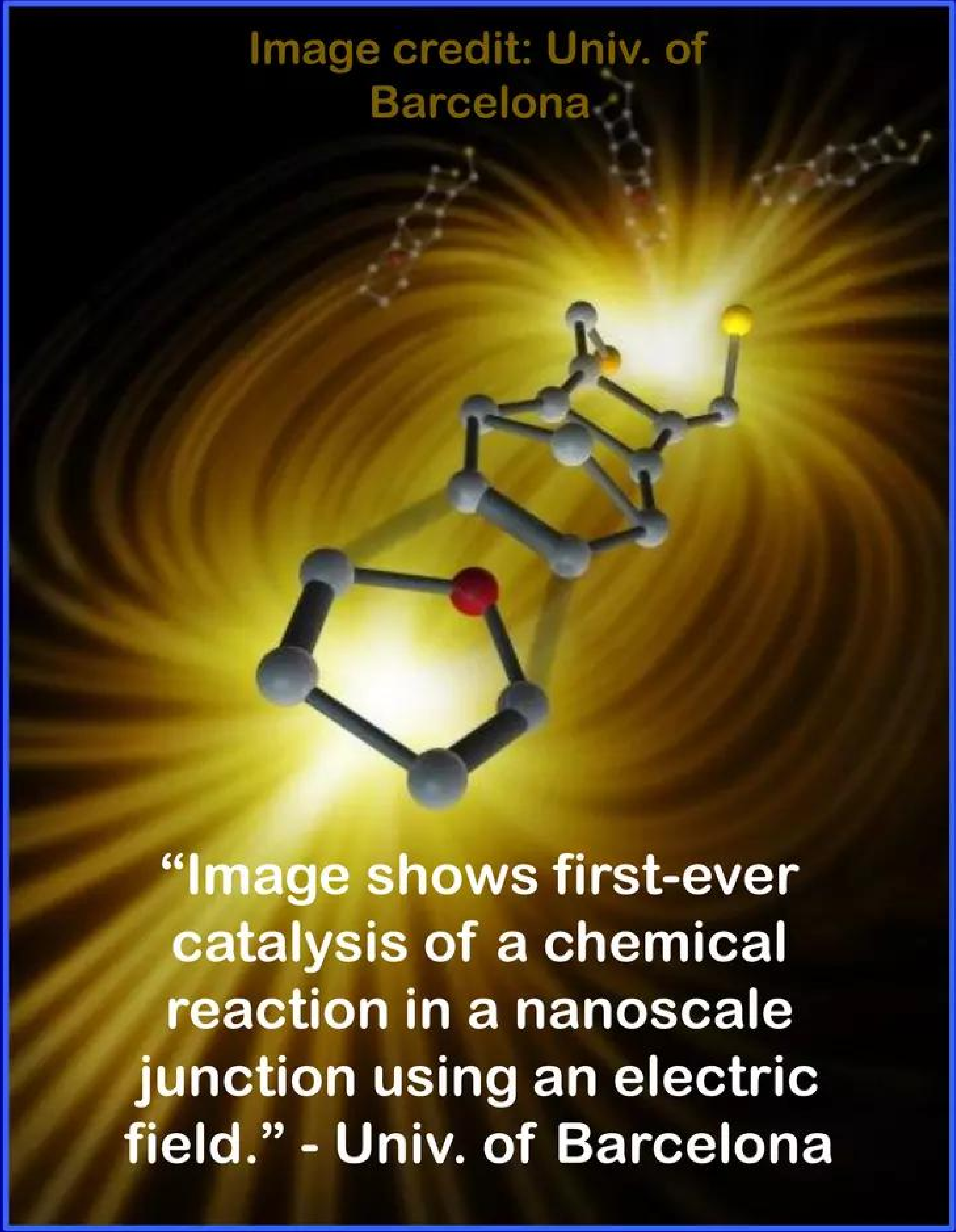


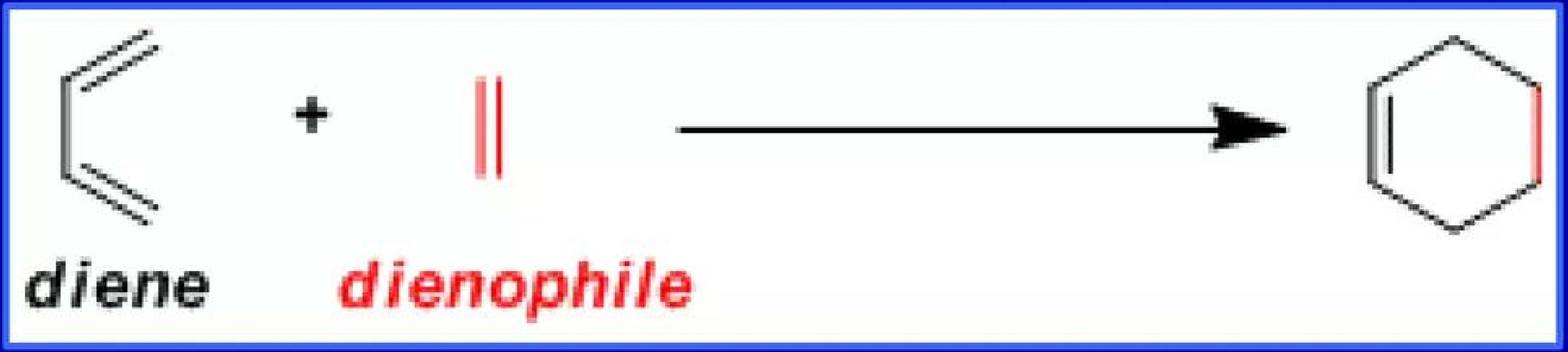
Image credit: Univ. of Barcelona

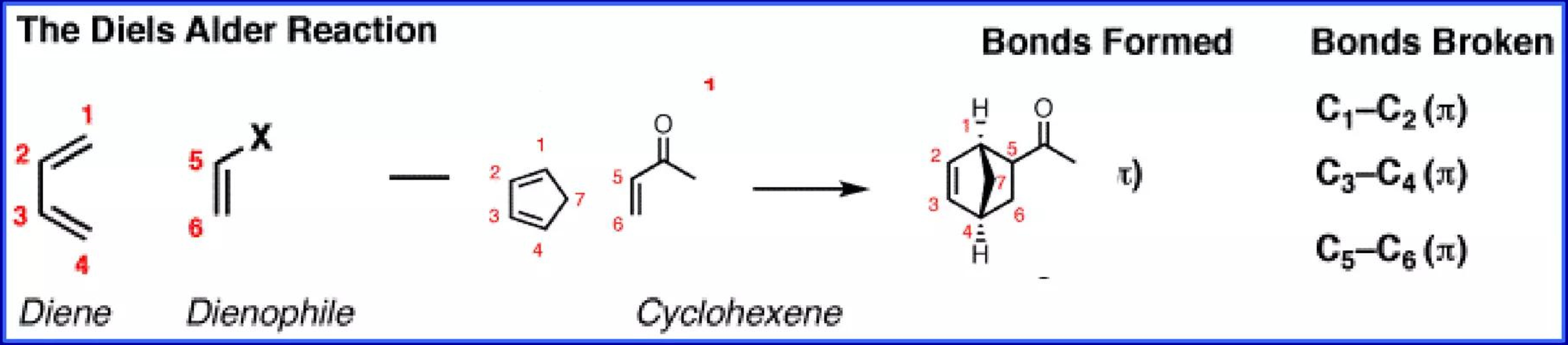
“Image shows first-ever catalysis of a chemical reaction in a nanoscale junction using an electric field.” - Univ. of Barcelona

Diels-Alder reaction creates aromatic ring molecules

"Diels Alder reaction converts a diene and an alkene (usually electron-poor, called a "dienophile") into a six-membered ring containing an alkene (cyclohexene)."

Master Organic Chemistry




The Diels Alder Reaction

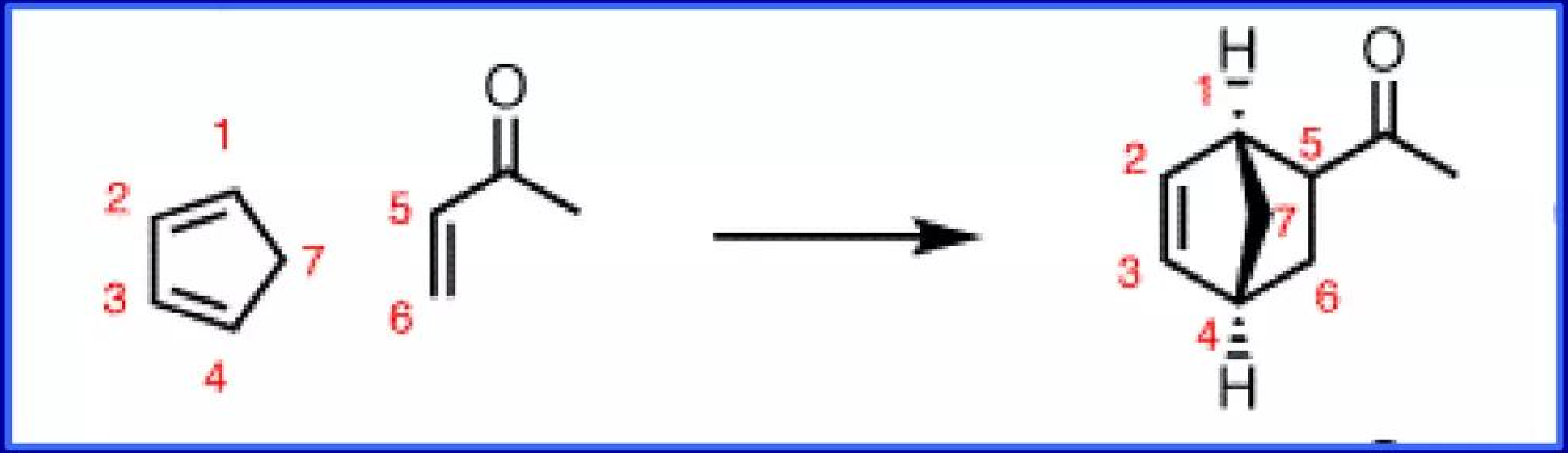
Bonds Formed

Bonds Broken

C_1–C_2 (π)

C_3–C_4 (π)

C_5–C_6 (π)



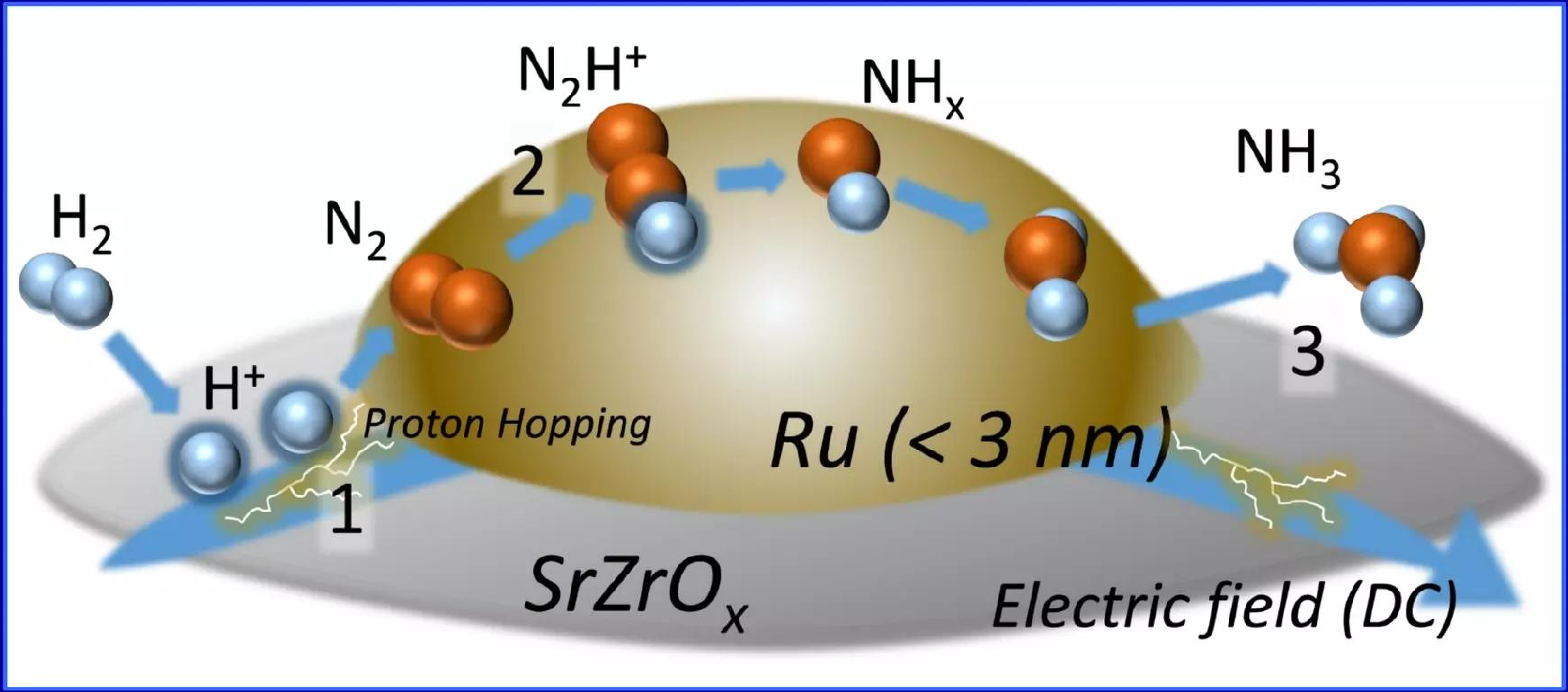
http://www.masterorganicchemistry.com/reaction-guide/diels-alder-reaction-of-dienes-and-dienophiles/

June 2017: Lattice relates W-L theory to data of Manabe et al.

Prediction: E-fields >10^{10} V/m occur on Ru nanoparticles & nearby $SrZrO_X$

Reactions between Nitrogen and Hydrogen could be many-body like *e* + *p* in LENR

Lattice predictions: local electric fields > ~ 9 x 10^{10} V/m should occur on the surfaces of Ru nanoparticles and nearby on $SrZrO_x$ support substrate; many-body patches of mobile, entangled protons located in same areas should: (1) help to intensify local E-fields and (2) participate as a reactant with Nitrogen



Credit: prepared by Manabe et al. for press release by Waseda University (Japan)

Publications about the Widom-Larsen theory of LENRs

Index provides comprehensive guide to available online information

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

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

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

"Index to key concepts and documents" all hyperlinks in document are live
v. #21 updated and revised through Sept. 7, 2015
L. Larsen, Lattice Energy LLC, May 28, 2013 [133 slides] download is enabled
http://www.slideshare.net/lewisglarsen/lattice-energy-llc-hyperlinked-index-to-documents-re-widomlarsen-theory-and-lenrs-september-7-2015

Key conclusion of theoretical paper published in Pramana

Journal is peer-reviewed publication of Indian Academy of Sciences

"A primer for electro-weak induced low energy nuclear reactions"

"The analysis presented in this paper leads us to conclude that realistic possibilities exist for designing LENR devices capable of producing 'green energy', that is, production of excess heat at low cost without lethal nuclear waste, dangerous γ-rays or unwanted neutrons. The necessary tools and the essential theoretical know-how to manufacture such devices appear to be well within the reach of the technology available now. Vigorous efforts must now be made to develop such devices whose functionality requires all three interactions of the Standard Model acting in concert."

Recent books about LENRs and the Widom-Larsen theory

Three volumes in series titled “Explorations in Nuclear Research”

Provides overview of entire field at level of *Scientific American* article

“Hacking the Atom” (Volume 1)
Steven B. Krivit
Pacific Oaks Press, San Rafael, CA, September 11, 2016 (484 pages)
Paperback US$16.00; hardcover US$48.00; Kindle US$3.99

https://www.amazon.com/dp/0996886451

“Fusion Fiasco” (Volume 2)
Steven B. Krivit
Pacific Oaks Press, San Rafael, CA, November 11, 2016 (531 pages)
Paperback US$16.00; hardcover US$48.00; Kindle US$3.99

https://www.amazon.com/dp/0976054523

PowerPoint synopsis of book with additional commentary:

http://tinyurl.com/z6fsbn2

“Lost History” (Volume 3)
Steven B. Krivit
Pacific Oaks Press, San Rafael, CA, November 11, 2016 (380 pages)
Paperback US$16.00; hardcover US$48.00; Kindle US$3.99
https://www.amazon.com/dp/0996886419

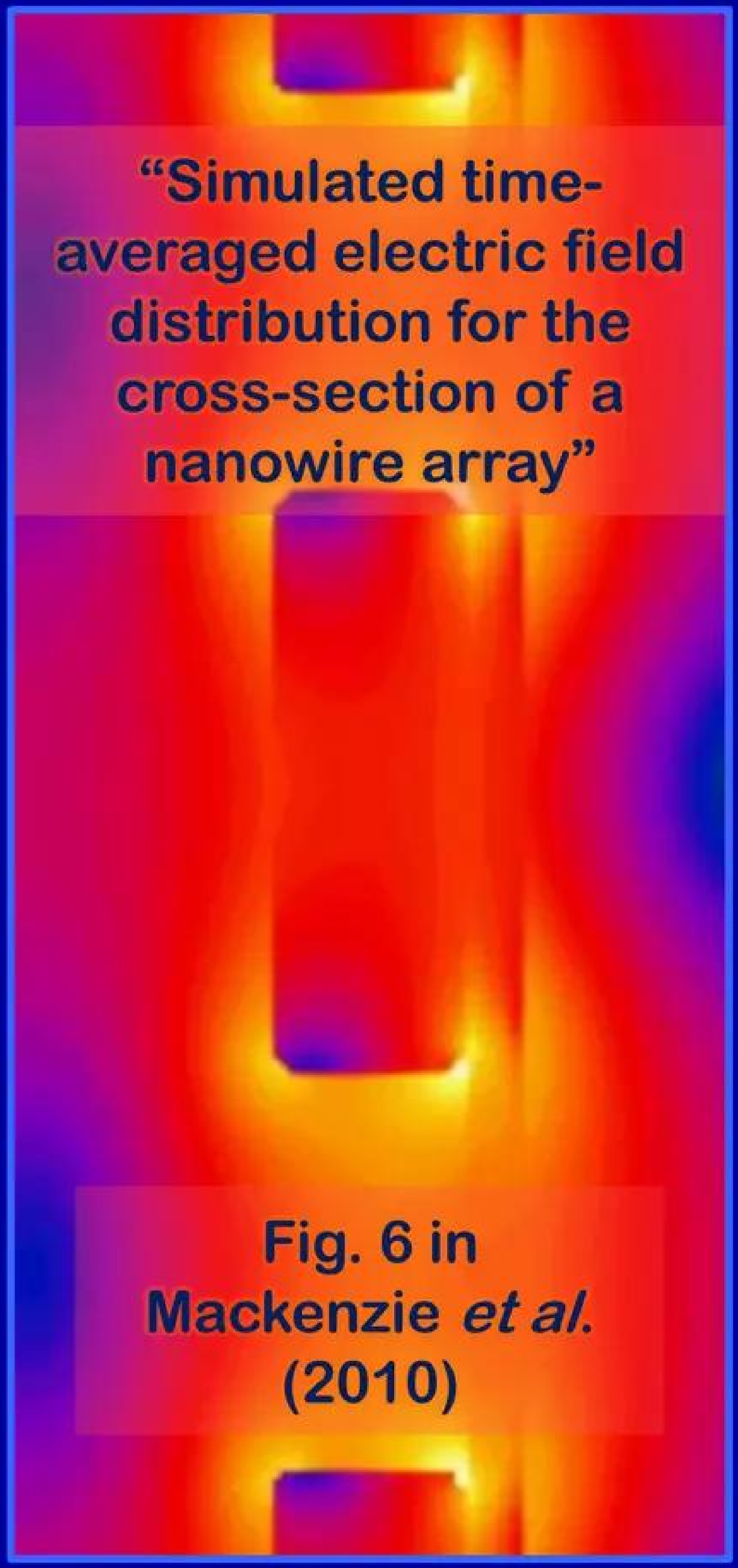
Working with Lattice

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 key technology development partner with our private Chicago-based company to commercialize LENRs
- ✓ Lewis Larsen can explain arcane physics and technical issues in conversational English. Besides running Lattice, he also consults on evaluation of potential future impact of LENRs (from a long-term investment risk perspective) on pending large-CAPEX oil & gas, petrochemicals, transportation, and utility projects that have multi-decadal operating lifetimes; renewables and their impact on electric grid stability; as well as improving industrial catalyst performance and Lithium battery safety issues



"Simulated time-averaged electric field distribution for the cross-section of a nanowire array"

Fig. 6 in Mackenzie *et al.* (2010)

http://tinyurl.com/lzvvyv9