Lattice Energy LLC

Commercializing a next-generation source of green nuclear energy

Revolutionary radiation-free nuclear propulsion for advanced types of hypersonic aircraft

Triggering LENRs on target fuel nanoparticles injected into dusty plasmas

AVIATION WEEK
& SPACE TECHNOLOGY

Image credit: Lockheed Martin

Lewis Larsen

President and CEO

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

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

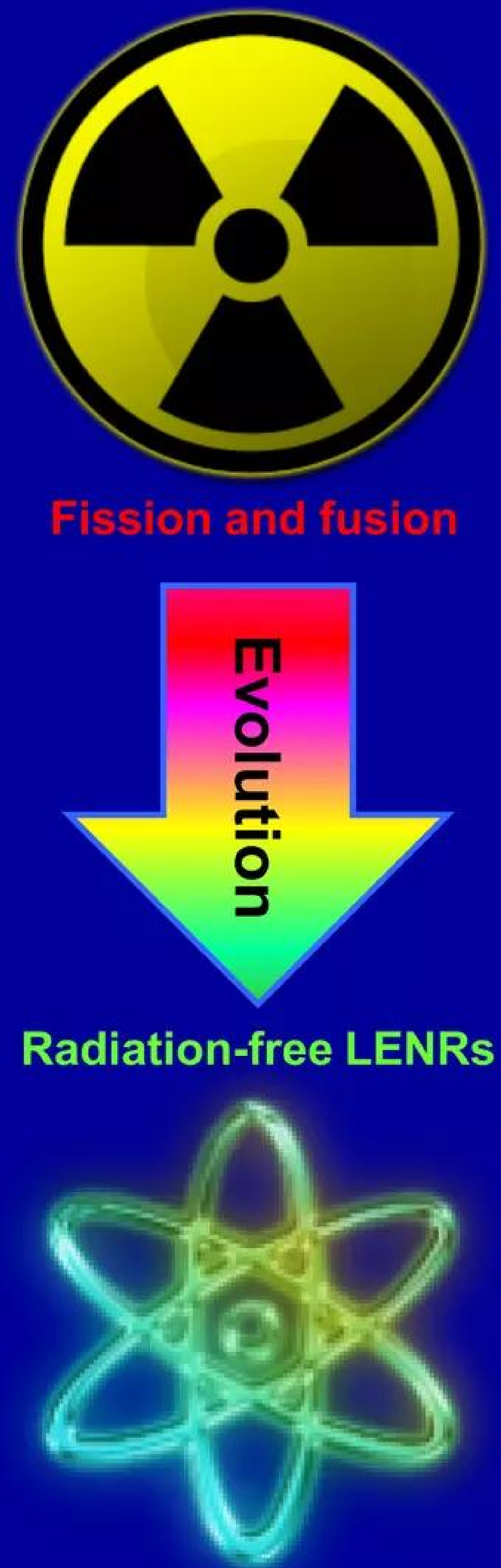
Key

take-aways

Lattice Energy LLC

Key take-aways

- ✓ Document outlines our speculative concepts about propulsion of hypersonic aircraft by the controlled triggering LENRs on nanoparticles in dusty plasmas
- ✓ Lattice published document to stimulate interest in further developing this new approach to propulsion
- ✓ Please note that this technical discussion presumes that further progress will be made on commercially fabricating and triggering μ-scale LENR-active sites on planar substrate surfaces and on non-planar surfaces of purpose-engineered nanoparticles comprised of multiple elements and varied isotopes
- ✓ Unique properties of so called “dusty plasmas” are key to operation of this exciting application in LENR technology; these plasmas were appreciated only relatively recently, so the bulk of relevant literature about such plasmas is mostly less than 25 years old



Lattice Energy LLC

Key take-aways

- ✓ Unlike hypersonic Lockheed Martin SR-72 UAV, Lattice would integrate an LENR dusty plasma scramjet engine with an LENR-powered 50^{+}% efficient Brayton combined cycle turbine that generates DC electricity for power
- ✓ Enormous flexibility in designing and engineering LENR nanoparticle target fuels; can choose among huge selection of different elements and materials
- ✓ Could utilize optimized combinations of LENR nuclear and very energetic chemical reactions simultaneously inside the very same reaction chamber
- ✓ Engine thrust control achieved by tightly regulating *a*mounts of DC input current into dusty plasma and LENR target fuel injection rates
- ✓ Incredibly high energy densities and low weight of LENR nanoparticulate target fuels might allow an LENR dusty plasma scramjet the luxury of carrying multiple fuel types that are optimized for different flight envelopes
- ✓ Unlike fission or fusion technologies there would not be any radiation or radioactivity problems, even with a bad crash event in populated area
- ✓ **Please note that many key proprietary engineering-related details have been deliberately omitted from this presentation for obvious commercial reasons**

Lattice Energy LLC

Contents

CalPoly investigates potential impact of LENRs on aircraft design - January 2014 ...…………………..….... 6

NASA: NARI Seedling Technical Seminar - LENR Aircraft - February 2014 ..……………..…………………..… 7 - 10

NASA/Boeing: NASA/CR-2012-217556 - Subsonic ultra green aircraft - May 2012 ………………….………. 11 - 19

LENRs could power Rankine and Brayton cycle engines ………………………………………………………. 20 - 24

Widom-Larsen theory and LENRs ………………………..……………,………………………...……..….. 25 - 49

LENRs create enormous local peak power densities and temperatures on target fuel surfaces ……….. 50 - 58

Similarities of craters produced by LENRs vs. by laser ablation imply fast energy transfers …………... 59 - 69

LENR-produced metallic phase/Coulomb explosions create huge volume expansion ratios …………… 70 - 73

Very energetic chemical reactions occur in parallel with LENRs in hot dusty plasmas ………………….. 74 - 77

Comparison of volume expansion ratios of metallic phase explosions with different explosives …….. 78

Electric arcs can heat dusty plasmas up to temperatures as high as 20,000^{o} C ……………..,……….... 79 - 80

Widom-Larsen theory of LENRs applies to dusty plasma scramjet plasma …….……………………….... 81

List of reference documents that are relevant to balance of discussion ……………………………….... 82

Discussion of Lattice's concept for LENR-powered dusty plasma scramjet engine …..……..………… 83 - 94

Final thoughts …………………………………………………………………………………..…………… 95

Further reading ……………………………..………………………..…………………………………… 96

Working with Lattice ……………………………………………………..…………..…………….……… 97

Quote: Wolfgang Pauli ……….…………………………..…..………………..…………………………..……. 98

Lattice Energy LLC

McDonald *et al*. explore impact of LENRs on aircraft design

Prepared for 52nd Aerospace Sciences Meeting - January 2014

Aircraft Design with Electric Propulsion

Impact of Advanced Energy Technologies on Aircraft Design

Robert A. McDonald, California Polytechnic State University

Chapter DOI: 10.2514/6.2014-0538

Publication Date: 13-17 January 2014

Rob A. McDonald
Associate Professor
CalPoly, Dept. of Aerospace Engineering
https://aero.calpoly.edu/faculty/robert-mcdonald/

CAL POLY
SAN LUIS OBISPO

Impact of Advanced Energy Technologies on Aircraft Design

Robert A. McDonald*, Adam T. Chase†, Clayton Green‡ and Michael J. Waddington§

California Polytechnic State University, San Luis Obispo, California, 93407

CAL POLY
SAN LUIS OBISPO

HALE UAV " … with multi-year endurance is conceptualized …"

The impact of low energy nuclear reaction (LENR) technology on the design of aircraft is examined. Energy conversion possibilities considered and a Brayton cycle engine with an LENR heat exchanger is selected. Potential aerospace applications of LENR devices are discussed and a high altitude long endurance (HALE) unmanned aerial vehicle with multi-year endurance is conceptualized with primary focus on energy management.

I. Introduction

Low energy nuclear reactions are a potentially revolutionary area of study in physics. Popularized in recent years by Allan Widom and Lewis Larsen, LENR are a radiation-free source of nuclear energy based on ultra-low momentum neutron catalyzed neutron reactions.[1] On metallic hydride surfaces, Widom and Larsen contend that a chain reaction can occur in which these ultra-low momentum neutrons lead to reactions that produce considerable amounts of heat.

See: http://arc.aiaa.org/doi/abs/10.2514/6.2014-0538

Lattice Energy LLC

NASA believes that LENRs are an “ideal energy solution”

Recent document reveals: studying possible use of LENRs to power future advanced green subsonic aircraft

http://nari.arc.nasa.gov/sites/default/files/attachments/17WELLS_ABSTRACT.pdf

Two screenshots of 1-page pdf Abstract (continues on next slide)

Low Energy Nuclear Reaction Aircraft

Investigator(s): Doug Wells, NASA Langley Research Center

Purpose

The purpose of this research is to investigate the potential vehicle performance impact of applying the emergent Low Energy Nuclear Reaction (LENR) technology to aircraft propulsion systems. LENR potentially has over 4,000 times the density of chemical energy with zero greenhouse gas or hydrocarbon emissions. This technology could enable the use of an abundance of inexpensive energy to remove active design constraints, leading to new aircraft designs with very low fuel consumption, low noise, and no emissions. The objectives of this project are to: (1) gather as many perspectives as possible on how and where to use LENR for aircraft including the benefits arising from its application, (2) explore the performance, safety, and operational impacts to individual aircraft and the fleet, (3) evaluate potential propulsion system concepts, and (4) foster multi- disciplinary interaction within NASA.

Lattice Energy LLC

NASA believes that LENRs are an "ideal energy solution"

Studying possible use of LENRs to power future green aircraft

Background

LENR is a type of nuclear energy and is expected to be clean, safe, portable, scalable, and abundant. The expected benefits make it an ideal energy solution. When it is applied to aircraft, LENR removes the environmental impacts of fuel burn and emission from combustion. Excess energy can be used to reduce noise so that all three of NASA's technology goals for future subsonic vehicles are either eliminated or addressed. Furthermore, aviation impacts almost every part of our daily lives, civilian and military. A revolutionary technology like LENR has the potential to completely change how businesses, military, and the country operate as a whole, giving a tremendous financial, tactical, and resource advantage to the country that utilizes it in the most effective way.

LENR creates some unique capabilities as well as challenges for integration into aircraft. The LENR concept that has reported most of the success generates heat in a catalyst process that combines nickel metal (Ni) with hydrogen gas (H). The initial testing and theory show that radiation and radioisotopes are extremely short lived and can be easily shielded. Although nuclear fission has been looked at for use in aircraft, LENR is different. LENR has a higher energy density and no radioactive by products.

Success of this research will provide a firm foundation for future research and investment for LENR technology integration into aircraft. Key research and development areas will be identified with any gaps in the current technology research. This research will guide NASA on the most effective way to invest in LENR to be the world leader in LENR aircraft research.

Source: http://nari.arc.nasa.gov/sites/default/files/attachments/17WELLS_ABSTRACT.pdf

Lattice Energy LLC

NASA believes LENRs can potentially power large aircraft

Feb. 25, 2014: LENR Aircraft - NARI Seedling Seminar (Doug Wells)

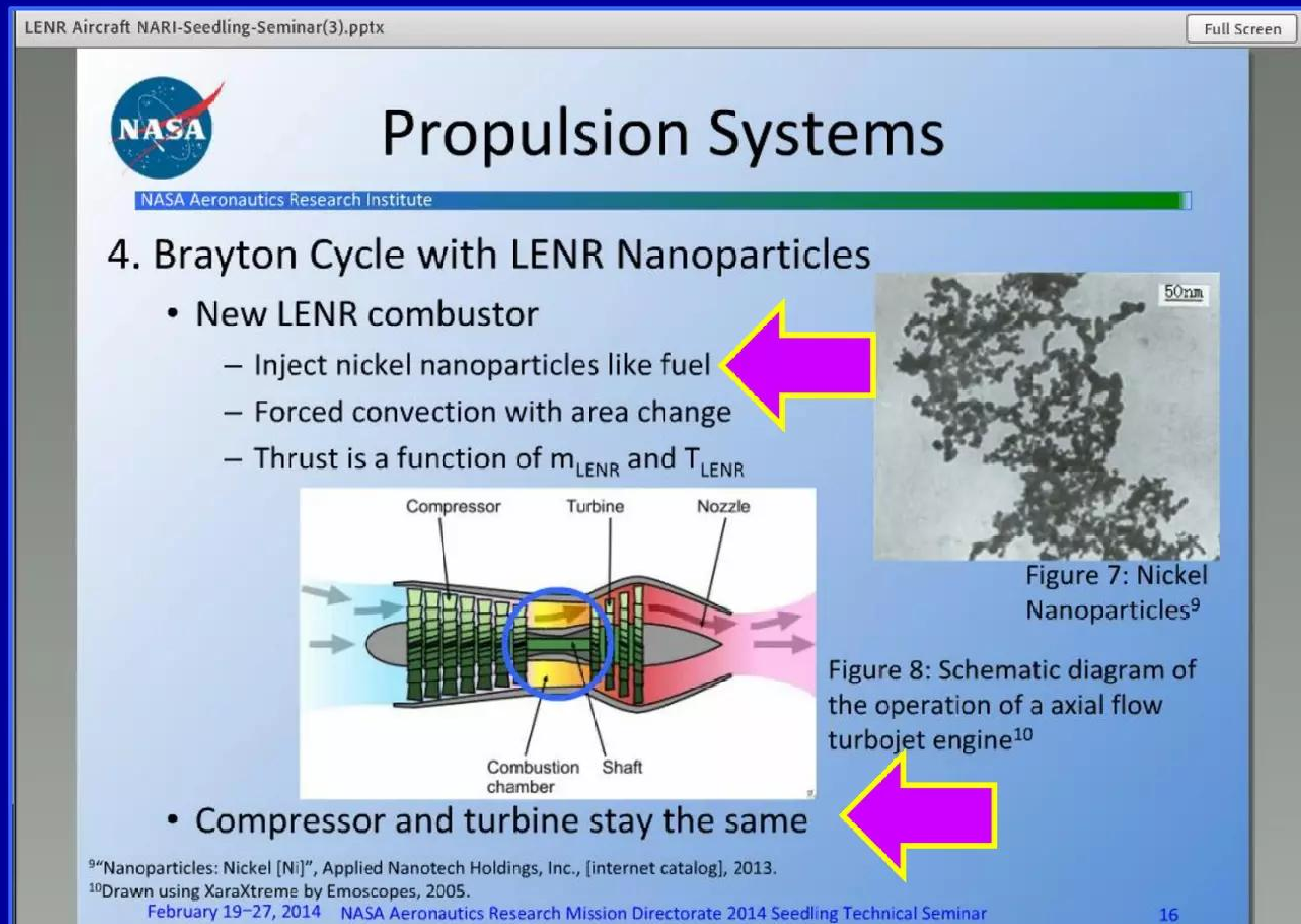
Conceptualization of very large *Sky Train* subsonic aircraft taking-off

Source: http://nari.arc.nasa.gov/sites/default/files/attachments/SeedlingSeminar2014.pdf

Lattice Energy LLC

NASA believes LENRs can potentially power large aircraft

Feb. 25, 2014: LENR Aircraft - NARI Seedling Seminar (Doug Wells)



New Energy Times **(Steven Krivit) reported in 2012 about NASA's questionable shenanigans with Lattice:**

https://news.newenergytimes.net/2012/05/24/nasa-and-widom-larsen-theory-inside-story/

NASA/CR-2012-217556 report dated May 2012

Specifics of previously cited recent NASA document are uncertain

Might be related to an earlier contract first revealed in May 2012

NASA/CR-2012-217556

Subsonic Ultra Green Aircraft Research
Phase II: N+4 Advanced Concept Development

Marty K. Bradley and Christopher K. Droney
Boeing Research and Technology, Huntington Beach, California

Source of document for screen-capture images: http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120009038_2012008934.pdf

Lattice Energy LLC

Contract NASA/CR-2012-217556

Found on final page A-11 of report document

Documents that NASA and Boeing are performing together on this particular contract

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, Virginia 23681-2199
The Boeing Company
Boeing Research and Technology
5301 Bolsa Avenue
Huntington Beach, CA 92647

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SP... NITORING AGENCY NAME(S) AND AD... RESS(ES)
National ... utics and Space Administration
Washingt... 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S)
NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
NASA/CR-2012-217556

12. DISTRIBUTION/AVAILABILITY STATEMENT

Boeing's contract team works for the Advanced Network & Space Systems Group which operates out of a large 50 year-old R&D facility located in Huntington Beach, CA

REPORT DOCUMENTATION PAGE — Form Approved OMB No. 0704-0188

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY): 01- 05 - 2012
2. REPORT TYPE: Contractor Report
3. DATES COVERED (From - To):
4. TITLE AND SUBTITLE: Subsonic Ultra Green Aircraft Research Phase II: N+4 Advanced Concept Development
5a. CONTRACT NUMBER: NNL08AA16B
5b. GRANT NUMBER:
5c. PROGRAM ELEMENT NUMBER:
5d. PROJECT NUMBER:
5e. TASK NUMBER: NNL11AA00T
5f. WORK UNIT NUMBER: 561581.02.08.07.42.03
6. AUTHOR(S): Bradley, Marty K.; Droney, Christopher K.
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES): NASA Langley Research Center, Hampton, Virginia 23681-2199; The Boeing Company, Boeing Research and Technology, 5301 Bolsa Avenue, Huntington Beach, CA 92647
8. PERFORMING ORGANIZATION REPORT NUMBER:
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES): National Aeronautics and Space Administration, Washington, DC 20546-0001
10. SPONSOR/MONITOR'S ACRONYM(S): NASA
11. SPONSOR/MONITOR'S REPORT NUMBER(S): NASA/CR-2012-217556
12. DISTRIBUTION/AVAILABILITY STATEMENT: Unclassified - Unlimited; Subject Category 05; Availability: NASA CASI (443) 757-5802
13. SUPPLEMENTARY NOTES: Langley Technical Monitor: Erik D. Olson
14. ABSTRACT: This final report documents the work of the Boeing Subsonic Ultra Green Aircraft Research (SUGAR) team on Task 1 of the Phase II effort. The team consisted of Boeing Research and Technology, Boeing Commercial Airplanes, General Electric, and Georgia Tech. Using a quantitative workshop process, the following technologies, appropriate to aircraft operational in the N+4 2040 timeframe, were identified: Liquefied Natural Gas (LNG), Hydrogen, fuel cell hybrids, battery electric hybrids, Low Energy Nuclear (LENR), boundary layer ingestion propulsion (BLI), unducted fans and advanced propellers, and combinations. Technology development plans were developed.
15. SUBJECT TERMS: Aircraft; Design; Electric; Emissions; Hybrid; Hydrogen; Noise; Nuclear; Propulsion

16a. REPORT	16b. ABSTRACT	16c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON	19b. TELEPHONE NUMBER (Include area code)
U	U	U	UU	148	STI Help Desk (email: help@sti.nasa.gov)	(443) 757-5802

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

Lattice Energy LLC

Contract NASA/CR-2012-217556

Found on page i of report document

"Following technologies were identified: … Low Energy Nuclear (LENR), …"

NASA Contract NNL08AA16B – NNL11AA00T – Subsonic Ultra Green Aircraft Research – Phase II
N+4 Advanced Concept Development

Abstract

This final report documents the work of the Boeing Subsonic Ultra Green Aircraft Research (SUGAR) team on Task 1 of the Phase II effort. The team consisted of Boeing Research and Technology, Boeing Commercial Airplanes, General Electric, and Georgia Tech.

Using a quantitative workshop process, the following technologies, appropriate to aircraft operational in the N+4 2040 timeframe, were identified: Liquefied Natural Gas (LNG), Hydrogen, fuel cell hybrids, battery electric hybrids, Low Energy Nuclear (LENR), boundary layer ingestion propulsion (BLI), unducted fans and advanced propellers, and combinations. Technology development plans were developed.

The team generated a series of configurations with different combinations of some of these technologies. The higher heating value of LNG reduces the weight of fuel burned, but because of heavier aircraft systems, more energy is used for a given flight. LNG fueled aircraft have the potential for significant emissions advantages and LNG enhances the integration of fuel cells into the aircraft propulsion and power system.

An unducted fan increases propulsive efficiency and reduces fuel burn. Adding a fuel cell and electric motor into the propulsion system also leads to improvements in emissions and fuel burn. An aft fuselage boundary layer propulsor also resulted in a fuel burn benefit.

Lattice Energy LLC

Contract NASA/CR-2012-217556

Found on page 82 of report document

Quoting: **"Initial LENR testing and theory have suggested that any radiation or radio-isotopes produced in the LENR reactions are very short lived and can be easily shielded. In addition, some prototypes that may be harnessing the LENR process can be controlled safely within designed operating parameters and the reaction can be shut down in acceptable time frames. This heat generating process should reduce radiological, shielding and hazardous materials barriers to entry of aviation LENR systems."**

A copy of this contract report document annotated by Lattice to highlight key sections relevant to LENRs is available:

http://www.slideshare.net/lewisglarsen/lattice-energy-llc-report-reveals-boeing-and-nasa-investigating-lenrpowered-aircraftaug-3-2012

6.2.3 Low Energy Nuclear Reactor Technologies

Goals and Objectives:

Develop technologies for Low Energy Nuclear Reaction (LENR) propulsion systems.

Performance Area and Impact:

Traditional fuel burn and emissions will be reduced or eliminated by using LENR energy.

Noise may be reduced by using LENR heat instead of combustion in the engines.

Technical Description:

LENR energy has the potential to eliminate traditional fuel burn and associated emissions. In the current concept, a LENR reactor generates heat that is distributed to heat engines that use the LENR heat instead of combustion. This concept is dependent on successful development of LENR technology, which has reportedly had some success in generating heat in a catalytic process that combines nickel (Ni) with hydrogen (H) gas[8]. This process is reported to produce safe byproducts, such as copper, with no radioactive materials used and no long-lasting radioactive byproducts generated. Upon further investigation, it is thought that low level radiation may be generated during active energy cycles, but that it could be easily shielded and would stop quickly after reactor shutdown. Further development of LENR would be required to produce heat at a high enough temperature to support heat engines in a flight-weight installation. LENR physics analysis and evidence of high temperature pitting in LENR metal substrates indicate that temperatures appropriate for heat engines may have been achieved. It is thought that LENR would use very small amounts of fuel.

Initial LENR testing and theory have suggested that any radiation or radio-isotopes produced in the LENR reactions are very short lived and can be easily shielded. In addition, some prototypes[9] that may be harnessing the LENR process can be controlled safely within designed operating parameters and the reaction can be shut down in acceptable time frames. This heat generating process should reduce radiological, shielding and hazardous materials barriers to entry of aviation LENR systems.

Should LENR development prove successful, a few technology components will need to be developed for LENR-based aircraft propulsion. Heat engines, which run a thermodynamic cycle by adding heat via heat transfer instead of combustion, need to be developed. A system for distributing heat from the LENR core to the heat engines also needs to be developed. Additional systems may need to be developed for supporting the LENR core, including systems to deliver reactants and remove byproducts. The Ni-H LENR system would use pure hydrogen and a proprietary nickel and catalyst substrate. Hydrogen usage would be small compared to systems that combust hydrogen. Initially, hydrogen storage might involve cryogenics. The cold liquid hydrogen (LH_2) fluid might be used in a regenerative system whereby cooling is supplied to super-conducting generators, electric feeders, and motors while the gas would be used as a fuel

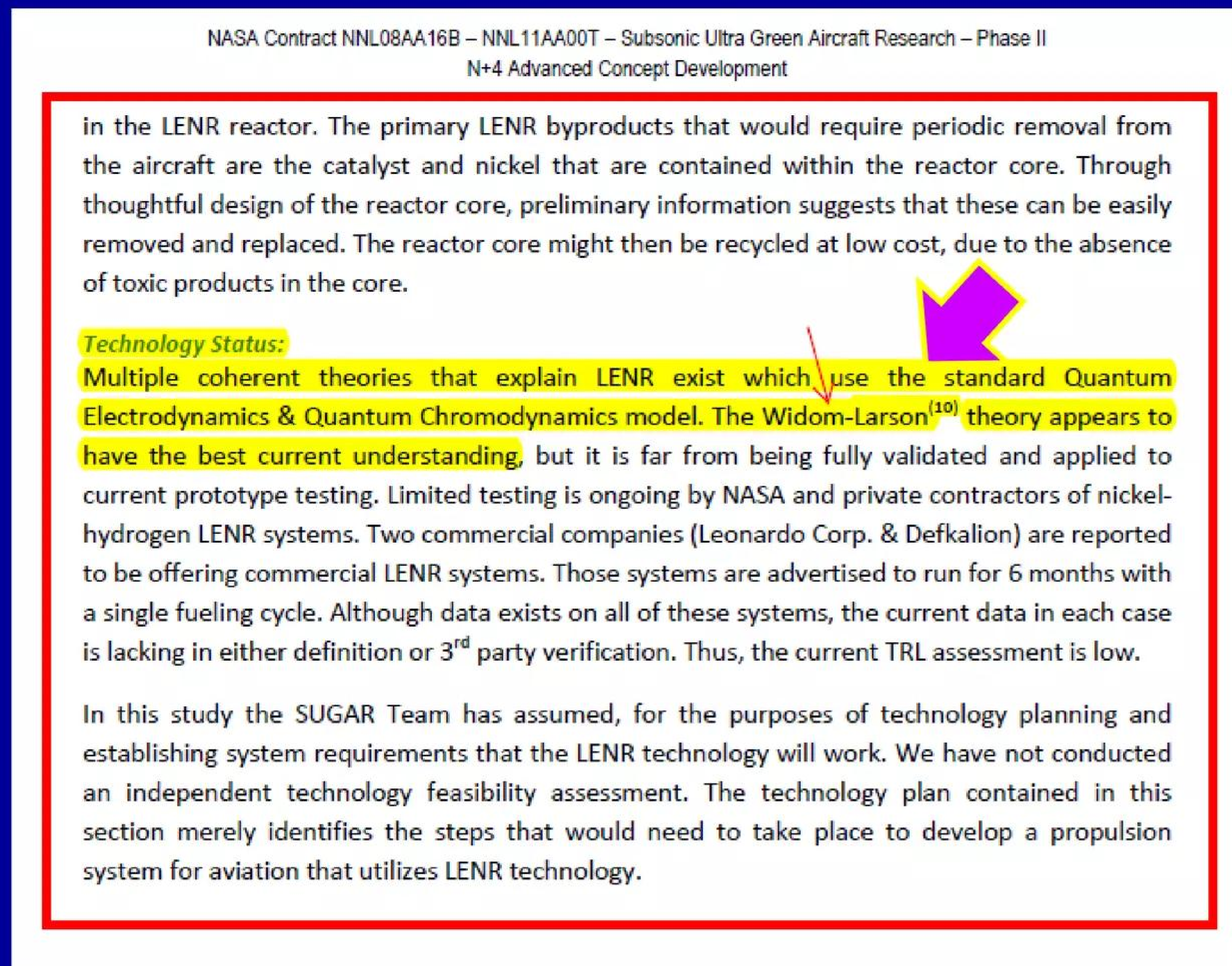
82

Lattice Energy LLC

Contract NASA/CR-2012-217556

Found on page 83 of report document

"Widom-Larson theory appears to have the best current understanding."



NASA Contract NNL08AA16B – NNL11AA00T – Subsonic Ultra Green Aircraft Research – Phase II
N+4 Advanced Concept Development

in the LENR reactor. The primary LENR byproducts that would require periodic removal from the aircraft are the catalyst and nickel that are contained within the reactor core. Through thoughtful design of the reactor core, preliminary information suggests that these can be easily removed and replaced. The reactor core might then be recycled at low cost, due to the absence of toxic products in the core.

Technology Status:
Multiple coherent theories that explain LENR exist which use the standard Quantum Electrodynamics & Quantum Chromodynamics model. The Widom-Larson[10] theory appears to have the best current understanding, but it is far from being fully validated and applied to current prototype testing. Limited testing is ongoing by NASA and private contractors of nickel-hydrogen LENR systems. Two commercial companies (Leonardo Corp. & Defkalion) are reported to be offering commercial LENR systems. Those systems are advertised to run for 6 months with a single fueling cycle. Although data exists on all of these systems, the current data in each case is lacking in either definition or 3rd party verification. Thus, the current TRL assessment is low.

In this study the SUGAR Team has assumed, for the purposes of technology planning and establishing system requirements that the LENR technology will work. We have not conducted an independent technology feasibility assessment. The technology plan contained in this section merely identifies the steps that would need to take place to develop a propulsion system for aviation that utilizes LENR technology.

Lattice Energy LLC

Contract NASA/CR-2012-217556

Table 7.1 found on page 120 of report document

NASA Contract NNL08AA16B – NNL11AA00T – Subsonic Ultra Green Aircraft Research – Phase II
N+4 Advanced Concept Development

A summary of the technologies investigated in this study is shown in Table 7.1.

Table 7.1 – Task 1 Technology Summary

Technology	Impact	Goals	Relationships	Major Concerns
LNG	Very Significant	Fuel Burn, Emissions, (Fuel Cost), (Fuel Supply)	Enabling to Fuel Cells and Low Emission Combustors	Methane Emissions, Safety, Infrastructure
Unducted Fan	Very Significant	Fuel Burn	Enhancing	Noise, Safety
Engine Fuel Cell	Significant	Fuel Burn, Emissions	Enhancing, Dependent on LNG or Hydrogen	
BLI Aft Propulsor	Significant	Fuel Burn, Emissions, Noise	Enhancing, Dependent on power source (fuel cell or batteries) for electric motor	
LENR	Game Changing	Fuel Burn, Energy Use, Emissions, Noise	Dependent on Hybrid Technology (gas turbine or electric hybrid)	Feasibility, Safety, Weight, Customer Acceptance
Hydrogen	Very Significant	Fuel Burn, Emissions	Enabling to Fuel Cells and Low Emission Combustors, Dependent on Production Technology	Low Cost Green Production, Safety, Customer Acceptance, Infrastructure

Lattice Energy LLC

Contract NASA/CR-2012-217556

Found on page 120 of report document

"LENR technology is potentially game-changing"

LNG technologies should continue to be investigated as there are significant potential emissions advantages, as well as advantages in cost and energy availability. However adding LNG to the aviation propellant infrastructure would be a significant challenge. Also, active research into methane leakage during natural gas extraction, processing, storage, and use should be monitored, as this could have an additional negative environmental impact.

Unducted fans, fuel cells, and BLI are potential enhancing technologies that offer significant improvements.

LENR technology is potentially game-changing to not just aviation, but the worldwide energy mix as well. This technology should be followed to determine feasibility and potential performance.

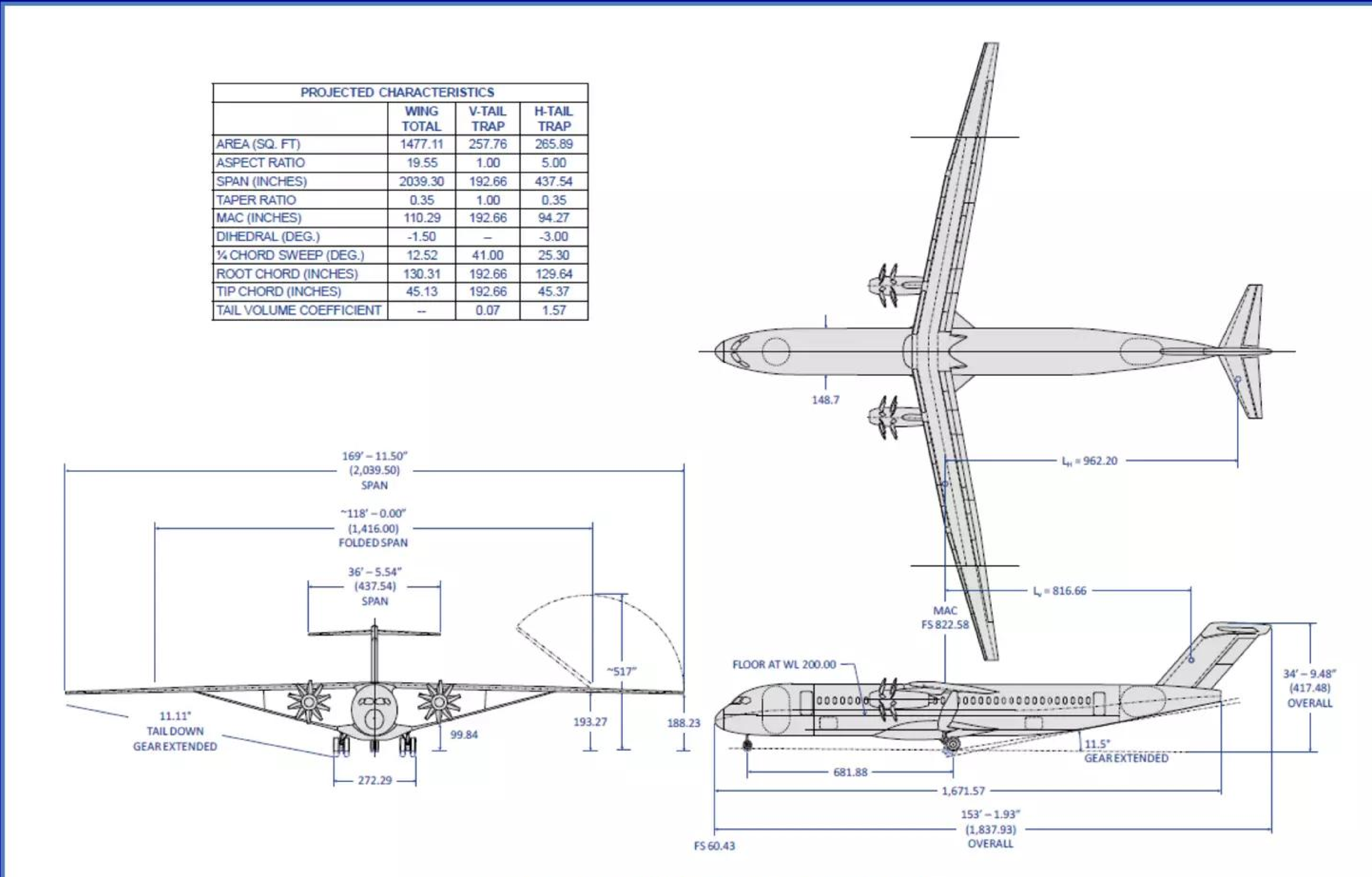
Hydrogen technology also has potential benefits, but widespread aviation use of hydrogen requires large infrastructure changes as well as significant improvements to produce hydrogen in a low cost environmentally friendly process.

Lattice Energy LLC

Contract NASA/CR-2012-217556

Figure 5.19 found on page 39 of report document

Subsonic Ultra Green Aircraft Research (SUGAR) Volt future aircraft design



PROJECTED CHARACTERISTICS	WING TOTAL	V-TAIL TRAP	H-TAIL TRAP
AREA (SQ. FT)	1477.11	257.76	265.89
ASPECT RATIO	19.55	1.00	5.00
SPAN (INCHES)	2039.30	192.66	437.54
TAPER RATIO	0.35	1.00	0.35
MAC (INCHES)	110.29	192.66	94.27
DIHEDRAL (DEG.)	-1.50	--	-3.00
¼ CHORD SWEEP (DEG.)	12.52	41.00	25.30
ROOT CHORD (INCHES)	130.31	192.66	129.64
TIP CHORD (INCHES)	45.13	192.66	45.37
TAIL VOLUME COEFFICIENT	--	0.07	1.57

Figure 5.19 – 765-095-TS3 - Truss Braced Wing With LNG UDF

Lattice Energy LLC

Future aircraft could potentially be powered by LENRs

Megawatts are required to provide propulsion for large civilian aircraft

Herein will outline Lattice's concepts re use of LENRs for hypersonic propulsion

- ✓ Total power required to propel a large future subsonic aircraft as depicted in the NASA/Boeing image to right measured in tens of megawatts (MW)
- ✓ For example, a modern General Electric GE90 fanjet system that powers large Boeing 777s (there are two such engines per plane) puts out roughly 160,000 horsepower or ~117MW (smallish coal-fired power plant has peak electrical output of ~500 - 600 MW)
- ✓ NASA and Boeing clearly believe that LENRs can potentially scale-up total system power outputs into the 50 - 100 MW range which can power big planes
- ✓ Herein we will outline Lattice's present ideas on how dusty plasma embodiments might be used to scale-up total LENR system power outputs to performance levels usable for very advanced hypersonic aircraft

Contract NASA/CR-2012-217556

Image credit: NASA/The Boeing Company

Lattice Energy LLC

LENRs could power Rankine and Brayton cycle engines

Utilize new thermal-to-electric systems developed for CSP applications

Engineer efficient thermal interface between LENR heat source and CSP receiver

- ✓ Elsewhere we have discussed how commercial versions of LENR thermal sources could likely produce neutron fluxes of 1 x 10^{14} cm^2/sec that can create thermal power fluxes of ~ 428 W/cm^2 using a Lithium target fuel
- ✓ Thermal fluxes created at focus receivers of concentrated solar power (CSP) systems can reach values on the order of roughly 200 - 400 W/cm^2 ; ~ matches LENR fluxes above
- ✓ Google, Abengoa Solar, Brayton Energy, and others have investigated and/or developed Brayton cycle thermal-to-electric conversion systems for use in CSP applications
- ✓ Minimizing technology development risks, similarity in sizes of thermal fluxes creates potential opportunities to adapt and integrate such Brayton cycle CSP systems for use in modular LENR-based power generation systems

Lattice Energy LLC

LENRs could power Rankine and Brayton cycle engines

Utilize new thermal-to-electric systems developed for CSP applications

Brayton cycle LENR-based CHP power generation systems might be 30% efficient

High LENR temps may enable development of 50 - 60% efficient combined cycle systems

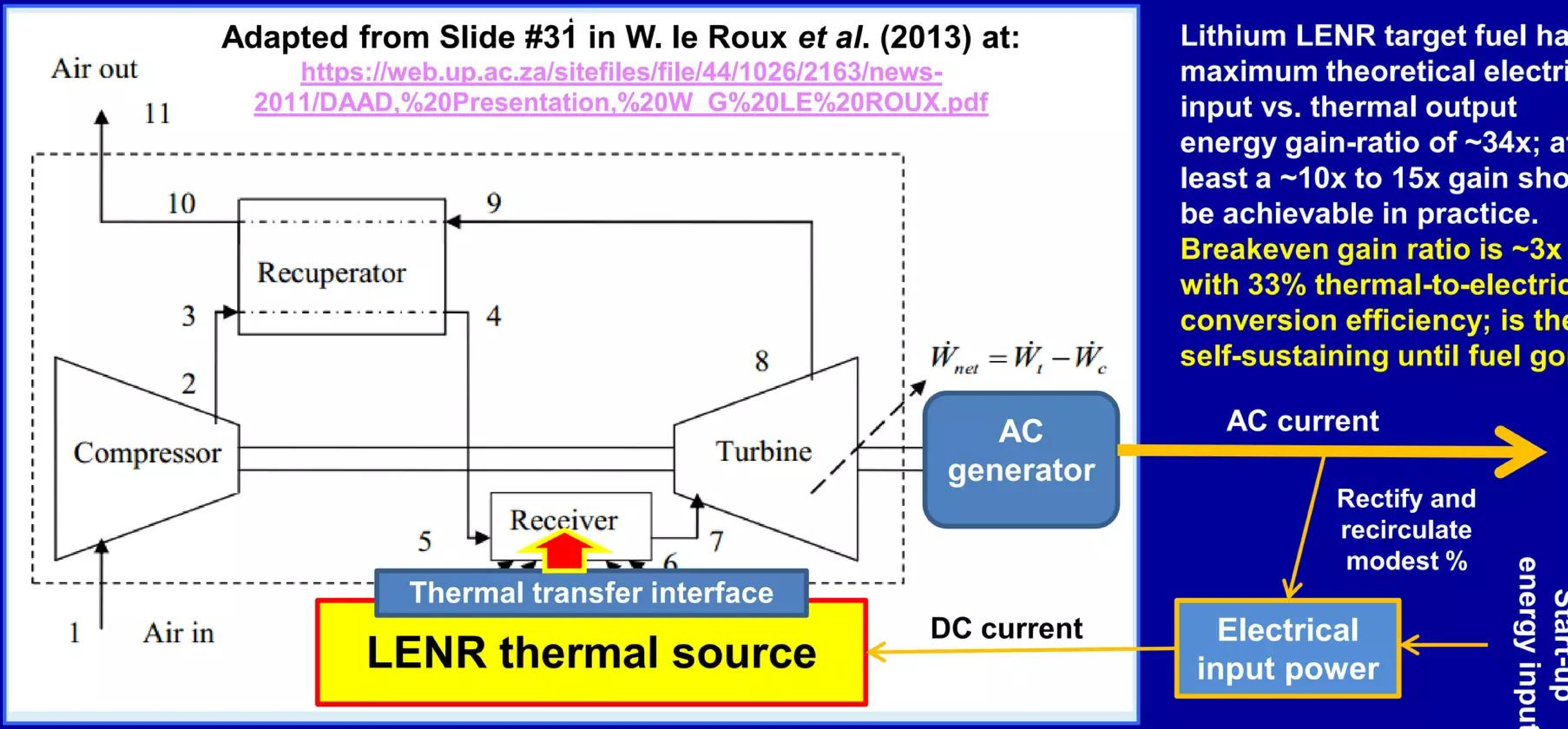
- ✓ Google investigated development of Brayton cycle for CSP system because Brayton does not require any water to produce power or for cooling (air in, air out) and design could scale up to 1 Megawatt; they estimated Brayton engine efficiency by itself at 37% and integrated system efficiency at ~30%; abandoned project for many reasons
- ✓ As shown herein, LENR sites get extremely hot; limitations on macroscopic working temperatures in LENR systems would mostly be determined by thermal tolerances of materials used in system. If its components can reliably withstand extremely high temperatures over long periods of time, LENRs could provide whatever temperatures are necessary, well-tailored to specific application requirements. This opens-up a possibility to maybe develop combined cycle LENR-based power systems that scale from a few kilowatts up to megawatts; then might achieve 50 - 60% overall efficiencies
- ✓ Since no combustion, external venting of exhaust gases is unnecessary; thus LENR-based Brayton-cycle-only power systems could safely be used indoors for combined heat and power (CHP); effective application efficiencies could then approach 80 - 90%

Lattice Energy LLC

LENRs could power Rankine and Brayton cycle engines

Utilize new thermal-to-electric systems developed for CSP applications

Schematic system block diagram: LENR-based Brayton cycle AC power generator



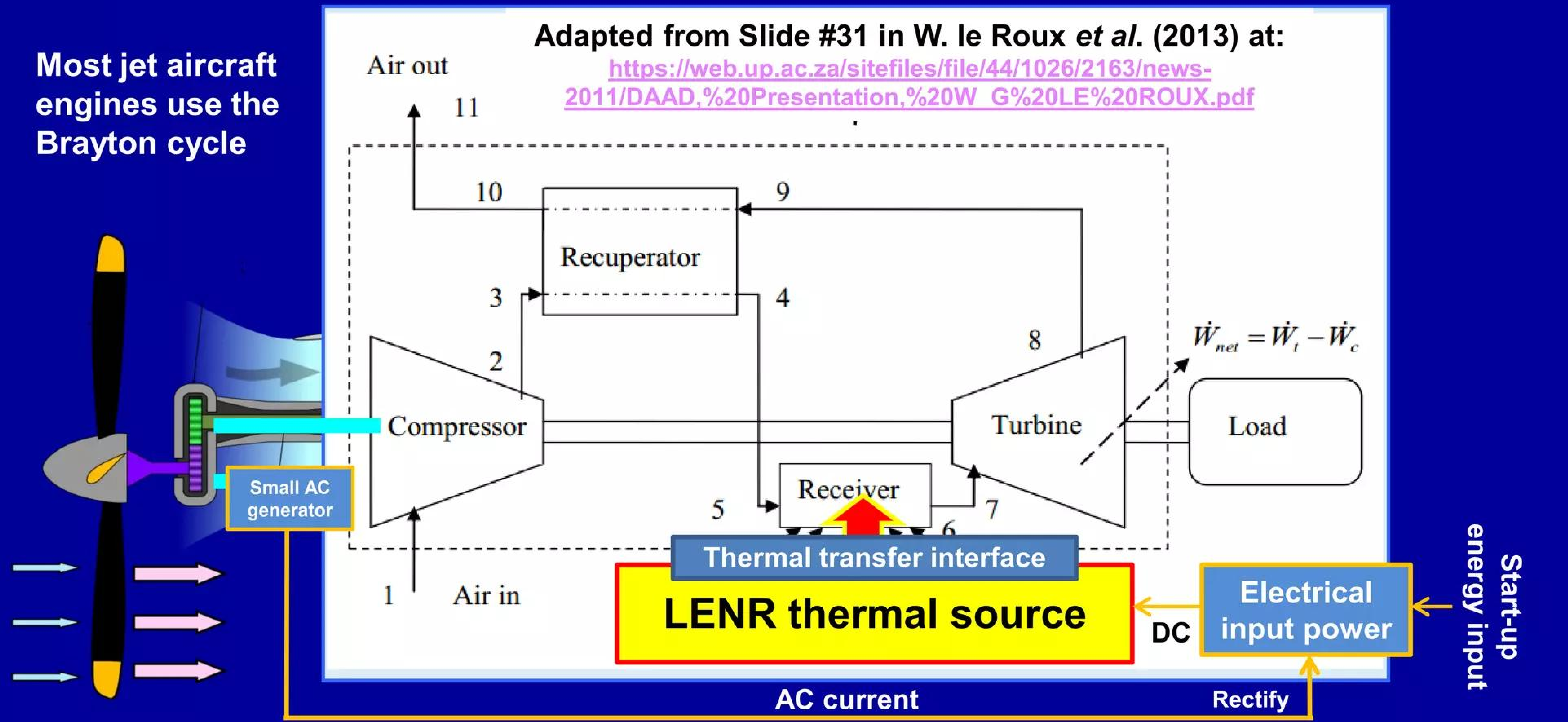
Lithium LENR target fuel has a maximum theoretical electrical input vs. thermal output energy gain-ratio of ~34x; at least a ~10x to 15x gain should be achievable in practice. Breakeven gain ratio is ~3x with 33% thermal-to-electric conversion efficiency; is then self-sustaining until fuel gone

LENRs could power Rankine and Brayton cycle engines

LENR-based Brayton cycle system can be used for direct propulsion

Turboprop: gearbox is used to drive a rotating propeller for aircraft propulsion

Most jet aircraft engines use the Brayton cycle



Lattice Energy LLC

LENRs could power Rankine and Brayton cycle engines

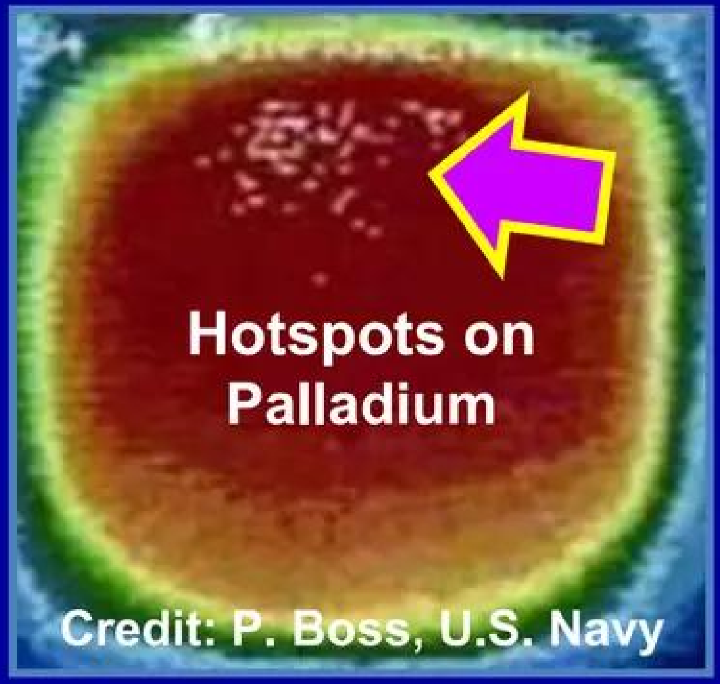
Utilize new thermal-to-electric systems developed for CSP applications

LENRs generate extremely high temperatures ideally suited for the Brayton cycle

- ✓ LENRs intrinsically occur in localized micron-scale LENR-active sites on ~planar surfaces or curved surfaces of nanoparticles
- ✓ Tiny LENR-active sites live for less than ~300 - 400 nanoseconds before being destroyed by intense heat; local peak temps range from 4,000 - 6,000° C; LENR-active sites will spontaneously reform under right conditions in properly engineered devices
- ✓ Microscopic 100-micron LENR hotspot release up to 5^+ Watts of heat in less than 400 nanoseconds; create crater-like features on surfaces that are visible in SEM images and showing clear evidence for flash-boiling of precious and refractory metals
- ✓ Peak local LENR power density can hit > 1.0 x 10^{21} Joules/sec·m^3
- ✓ Control macroscopic-scale temperatures in LENR systems by tightly regulating total input energy and/or total area/volumetric densities of LENR-active sites present in a reaction chamber

100 μ crater in Palladium

IR video of LENR hotspots



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

Lattice Energy LLC

Basic Widom-Larsen reactions in LENRs are very simple

Protons or deuterons react directly with electrons to make neutrons

Neutrons are then captured by other atoms → catalyze nuclear transmutations

Input energy is absorbed by electrons

Collective many-body quantum effects: many electrons each donate little bits of energy to a much smaller number of electrons that are also embedded in same high electric field

Heavy-mass electrons + protons create neutrons

Quantum electrodynamics (QED): smaller number of electrons that absorb energy from electric field can increase their effective masses ($m = E/c^2$) to point where e^{-*} can react directly with protons (or deuterons) to make neutrons and neutrinos

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

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

Neutron-capture-catalyzed transmutations release energy stored in atoms:

Neutrons + target fuels ⟶ heavier elements + decay products

Releases vast amounts of stored nuclear binding energy as energetic particles/photons that create heat

Lattice Energy LLC

Summary of steps in Widom-Larsen theory of LENRs

Entire 5-step green process occurs in 300 - 400 nanoseconds or less

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

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

3. Heavy-mass surface plasmon electrons formed in many-body patches 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 patch have ultra-low kinetic energies and are all absorbed locally by targets - no neutrons escape into environment; locally produced gammas converted directly into safe infrared photons by unreacted heavy electrons (Lattice patent US# 7,893,414 B2) - no hard gamma emissions

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

Lattice Energy LLC

LENRs enable new ultra high performance thermal sources

Heat produced by gamma conversion to IR and energetic particle decays

- ✓ Please note that LENRs do not involve any "free energy" --- there is a front-end cost in the form of input energy that is required to create ultra low energy neutrons which are subsequently absorbed by target fuel nuclei that in turn triggers release of large amounts of stored nuclear binding energy
- ✓ Absorbed ULM neutrons can be conceptualized as nuclear 'matches' that 'light the logs' of target fuel nuclei, which releases nuclear binding energy stored in such 'logs' since they were created in stars billions of years ago
- ✓ Excess heat produced by well-performing LENR systems comes from:
  - Energetic charged particles (e.g., alphas, betas, protons, deuterons, tritons) banging into the nearby environment, heating it by transferring kinetic energy
  - Direct conversion of dangerous gamma photons created by neutron capture and nuclear decay processes directly into useful infrared photons (IR - heat) which are then absorbed by nearby matter; see Lattice's fundamental patent involving this amazing process: US# 7,893,414 B2 issued on February 22, 2011
  - Note: neutrino photons do not contribute to excess heat; they bleed-off excess nuclear energy into space by emission of totally benign radiation

Lattice Energy LLC

Neutron-catalyzed LENRs can have good energy-gain ratios

Target fuels for LENR systems are extremely varied and inexpensive

- ✓ LENRs occur in micron-scale active sites located on surfaces onto which external energy is inputted to create neutron fluxes via e + p reactions; target fuel nanoparticles are pre-positioned in close proximity to LENR-active sites
- ✓ Collectively produced, ultra-low energy neutrons can be absorbed (captured) by nuclei/isotopes of almost any 'target' fuel element (Ti, Ni, Li, C, etc.); this triggers release of nuclear binding energy stored in such nuclei when they were originally created in super-hot cores of stars many billions of years ago
- ✓ If ordinary Hydrogen (protons) used the create such neutrons, it 'costs' 0.78 MeV per produced neutron in terms of the required amount of input energy
- ✓ Unlike more finicky fission and fusion processes, almost any stable element can be used as an LENR target fuel; however, some work much better than others in that they are able create LENR network pathways that release much more nuclear binding energy (in the form of energetic photons and charged particles that end-up creating thermal heat) for every neutron that is captured
- ✓ Stable Lithium is very good LENR target fuel; in a short sequence of nuclear reactions it enables the release of ~34x more thermal energy than it costs to make the neutrons that drive it; Carbon and transition metals also excellent

Lattice Energy LLC

Peer-reviewed Widom-Larsen theory explains LENRs

Specifies certain critical requirements necessary to trigger reactions

- ✓ 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 loading of H, many-body, collectively oscillating island-like patches of protons (p^+), deuterons (d^+), or tritons (t^+) will form spontaneously at random locations scattered across 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 very similarly 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 analogues of loaded metallic hydrides (trigger LENRs on aromatic rings)
- ✓ Born-Oppenheimer approximation breaks down in tiny surface patches of contiguous collections of collectively oscillating p^+, d^+, and/or t^+ ions; enables E-M coupling between nearby SP or π electrons and hydrogen ions at these locations; creates nuclear-strength local electric fields > 2 x 10^{11} V/m; effective masses of electrons in that field are then increased to a multiple of an electron at rest ($e \rightarrow e^*$) - determined by required ~simultaneous energy input(s)

Lattice Energy LLC

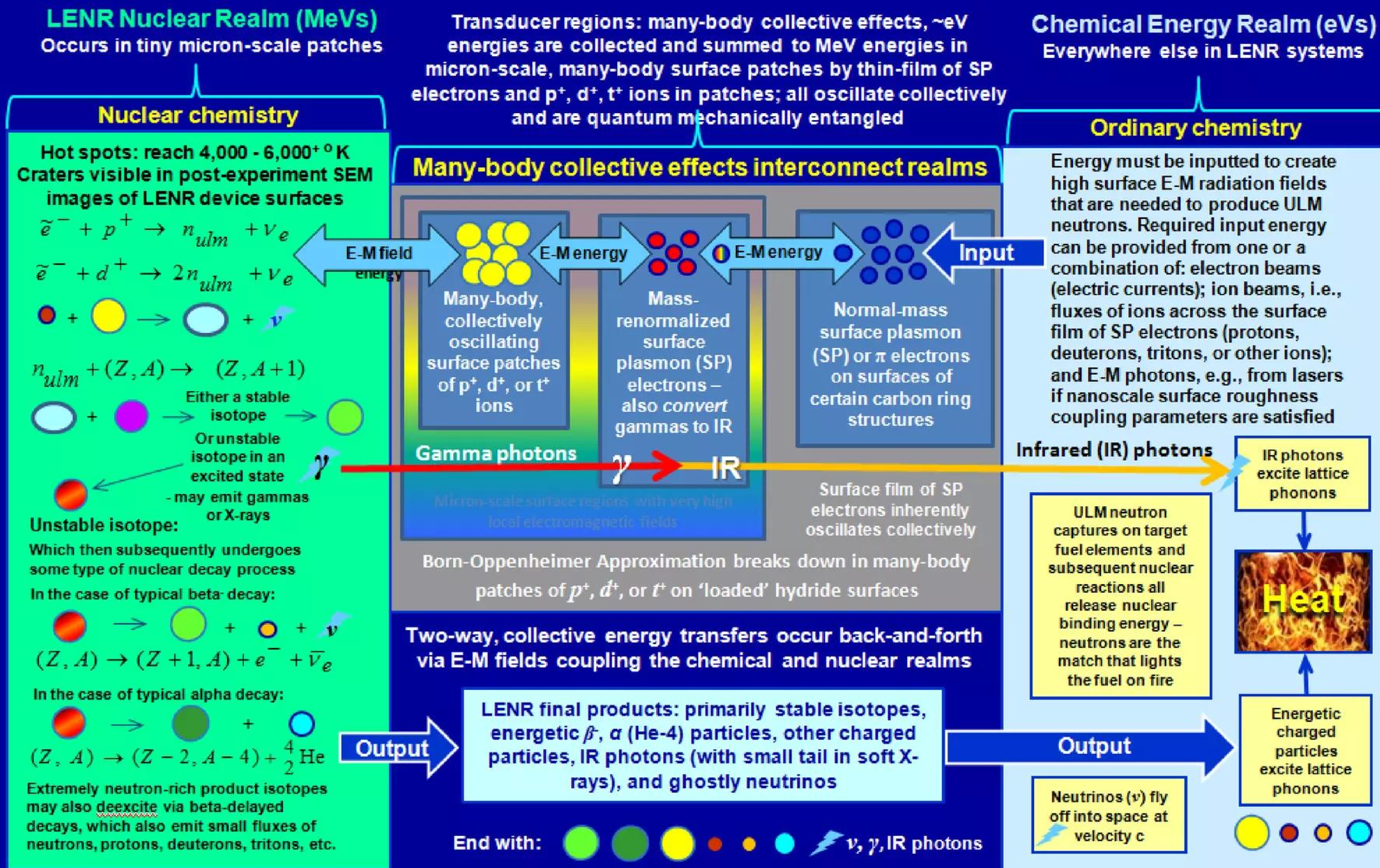
Peer-reviewed Widom-Larsen theory explains LENRs

Specifies certain critical requirements necessary to trigger reactions

- ✓ System must be subjected to external non-equilibrium fluxes of charged particles or E-M photons that are able to transfer input energy directly to many-body SP or π electron surface films. Examples of such external energy sources include (they may be used in combination): electric currents (i.e., electron beams); E-M photons (e.g., emitted from lasers, IR-resonant E-M cavity walls, etc.); pressure gradients of p^+, d^+, and/or t^+ ions imposed across surfaces; currents of other ions crossing the SP electron surface in either direction (ion beams); etc. Such sources can provide additional input energy required to surpass certain minimum H-isotope-specific electron-mass thresholds that allow production of ULM neutron fluxes via $e^* + p^+$, $e^* + d^+$, or $e^* + t^+$ weak interactions
- ✓ N.B.: please note again that surface plasmons 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 adsorbed target nanoparticles composed of metallic oxides, e.g., PdO, NiO, or TiO_2, etc., or vice-versa

Lattice Energy LLC

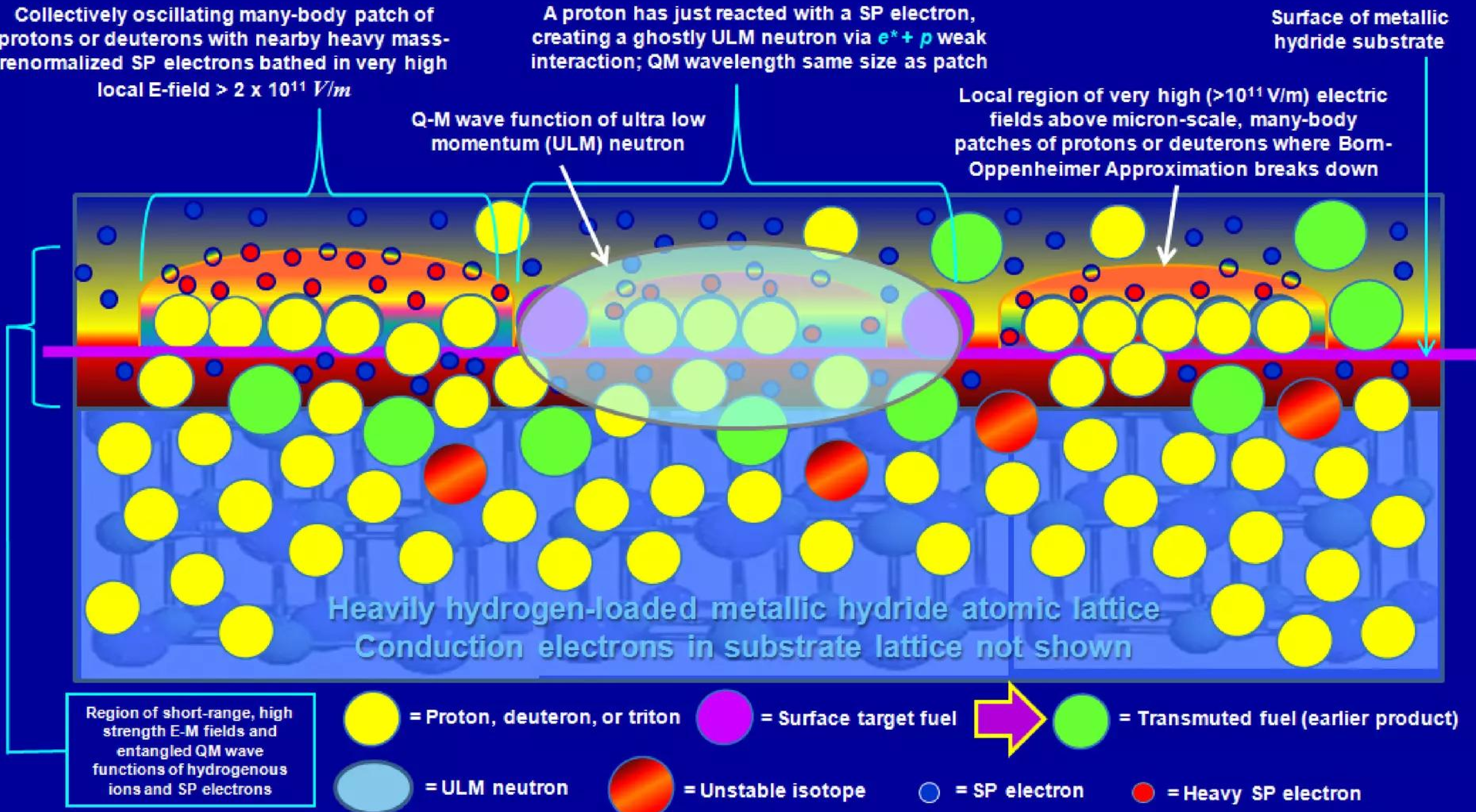
Nuclear and chemical energy realms connect on surfaces



Lattice Energy LLC

Conceptual overview of three LENR-active surface sites

Side view - just prior to explosive crater formation



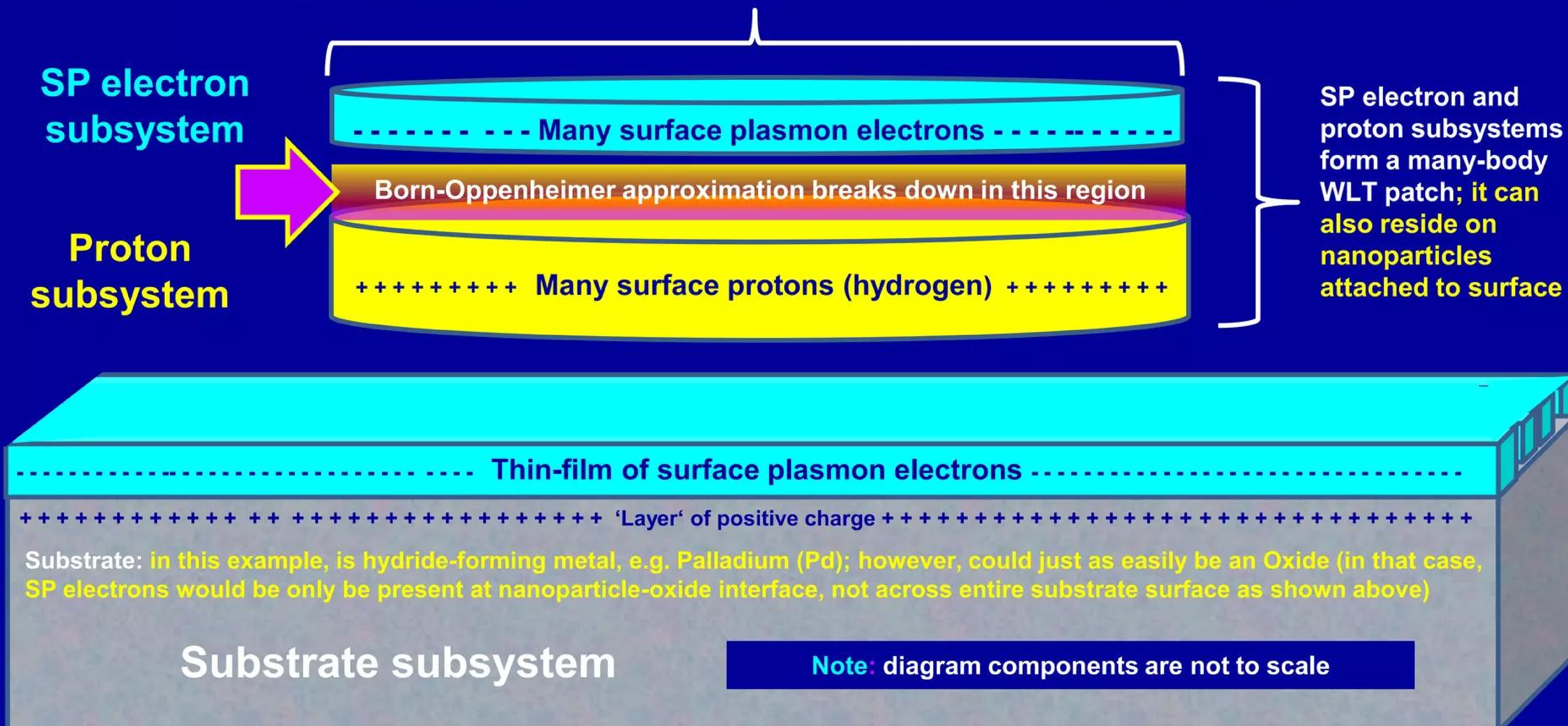
Lattice Energy LLC

Anatomy of a micron-scale LENR-active surface site

Conceptual overview of many-body patches that form on surfaces

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

Diameters of many-body patches randomly range from several *nm* up to perhaps ~100⁺ microns



Lattice Energy LLC

Input energy creates high E-fields in surface sites

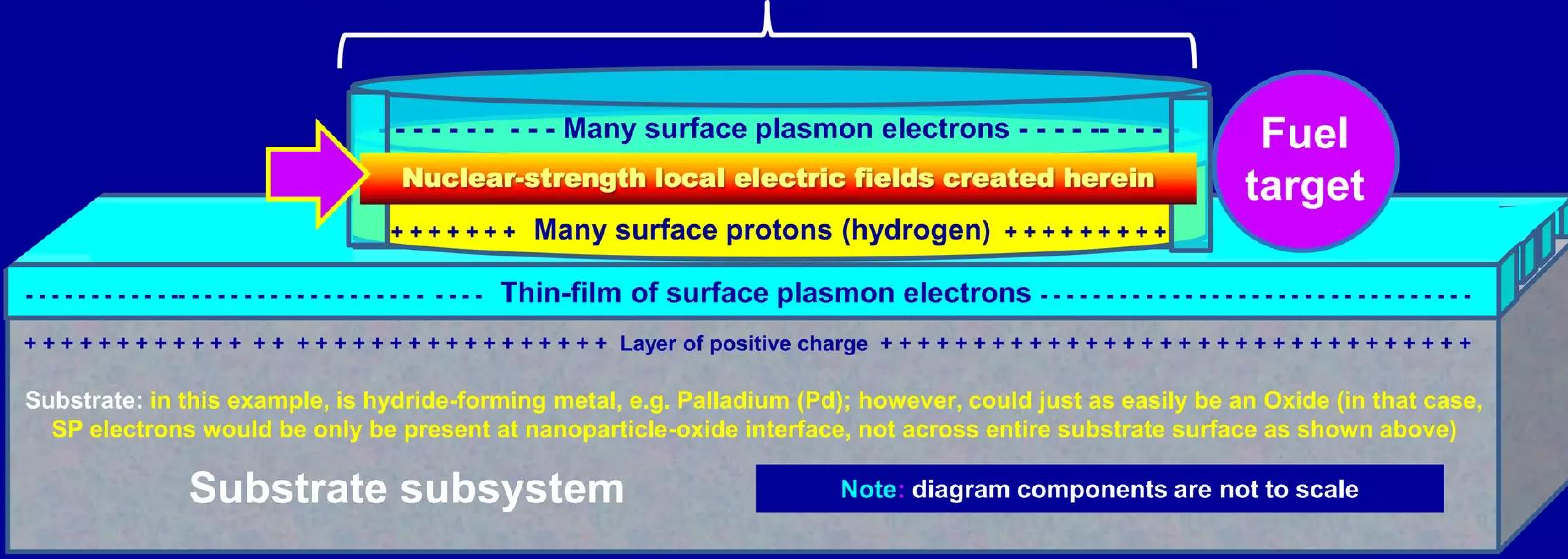
Born-Oppenheimer breakdown enables nuclear-strength e-fields

High local electric fields increase effective masses of some patch SP electrons

Sufficient input energy will create local E-fields > 10^{11} V/m within a patch which permits:

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

Diameters of many-body patches randomly range from several *nm* up to perhaps ~100⁺ microns



Lattice Energy LLC

LENRs occur in discrete regions located on surfaces

Many-body collections of protons and electrons form spontaneously

Are created in very wide range of diameters scattered randomly across surfaces

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

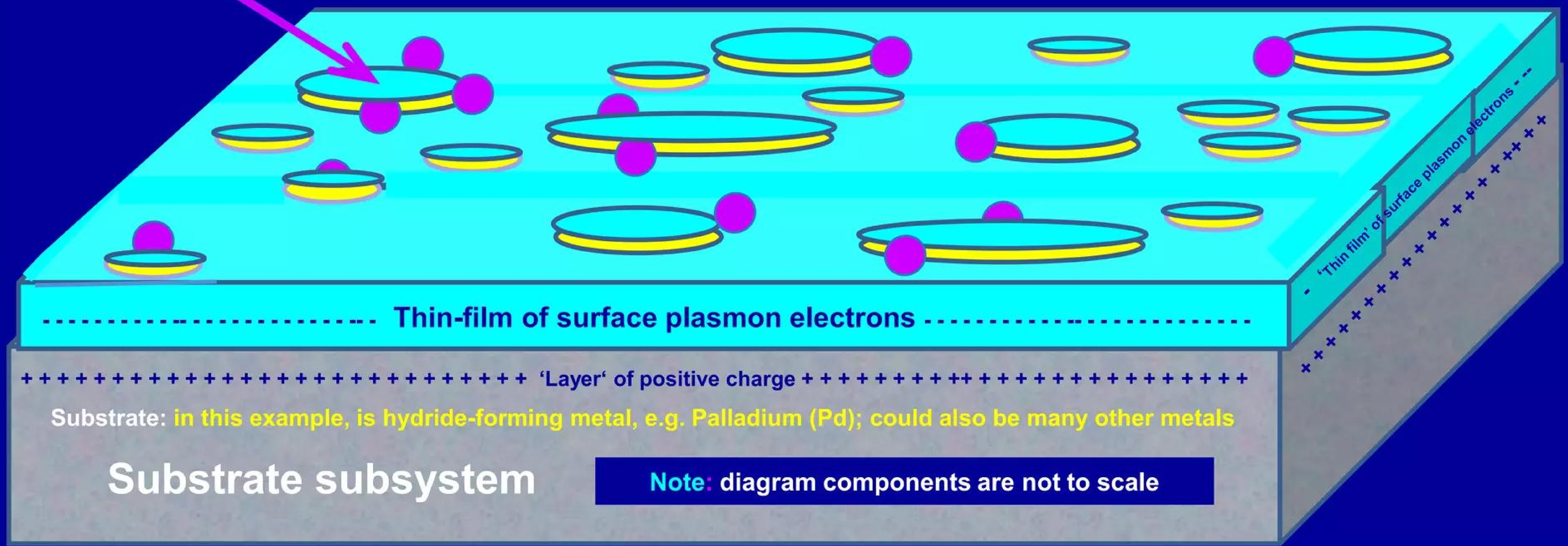
After being produced, neutrons will capture on targets in/around patches:

n + (Z, A) → (Z, A+1) [neutron capture on targets]

(Z, A+1) → (Z + 1, A+1) + e_{β}^{-} + ν_e [beta^{-} decay]

= Target nanoparticle

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



Lattice Energy LLC

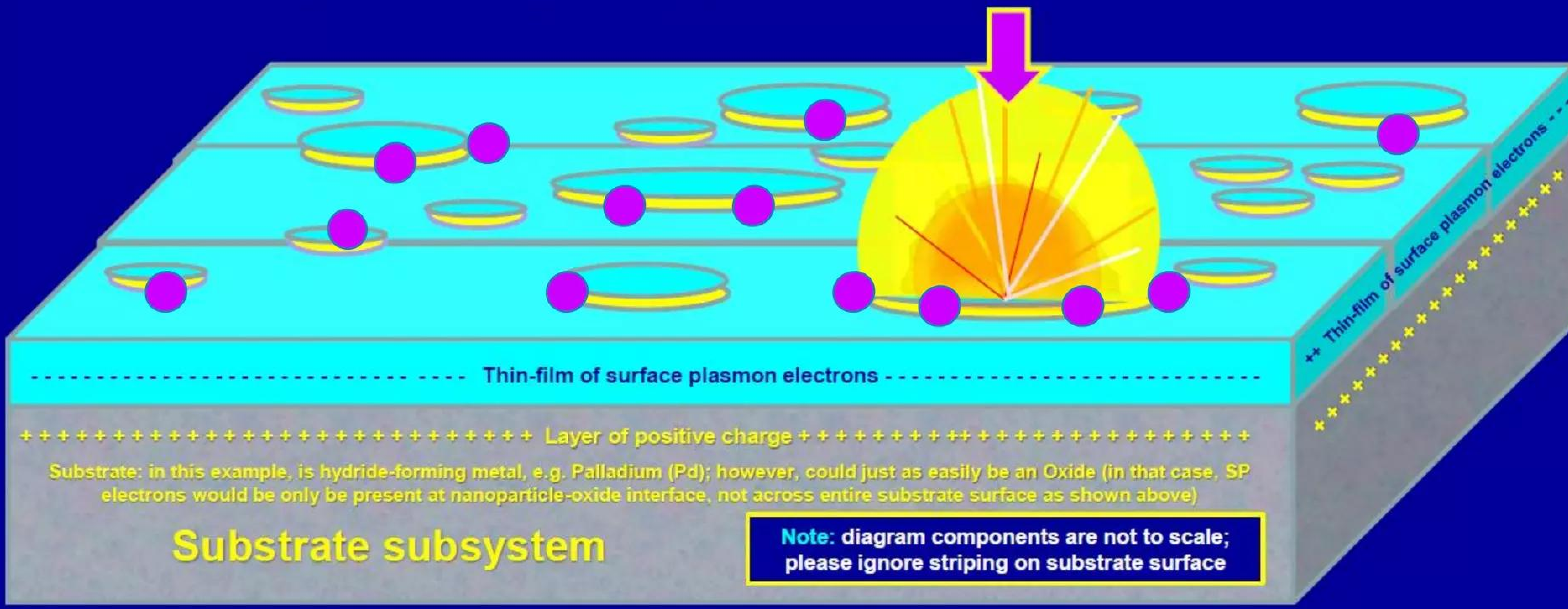
IR heat released explosively when patch goes nuclear

Fuels are positioned near active sites to absorb low energy neutrons

Releases nuclear binding energy stored in LENR fuels and transmutes elements

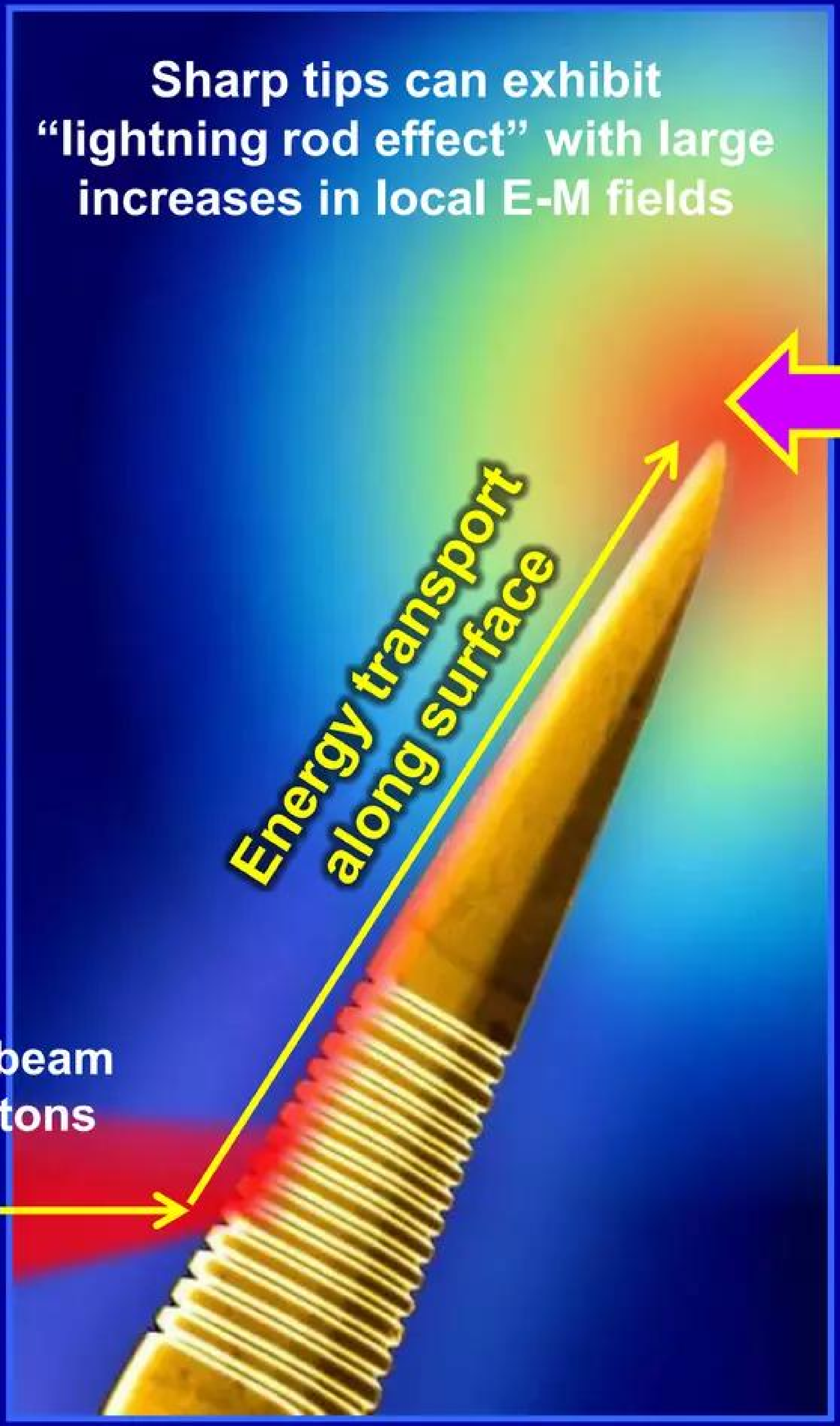
Explosive LENR 'hotspots' create distinctive surface craters ~2 - 100 microns in diameter

Observed on LENR-active substrates post-experiment with scanning electron microscopes (SEM); LENR transmutation products are found in same areas with SIMS

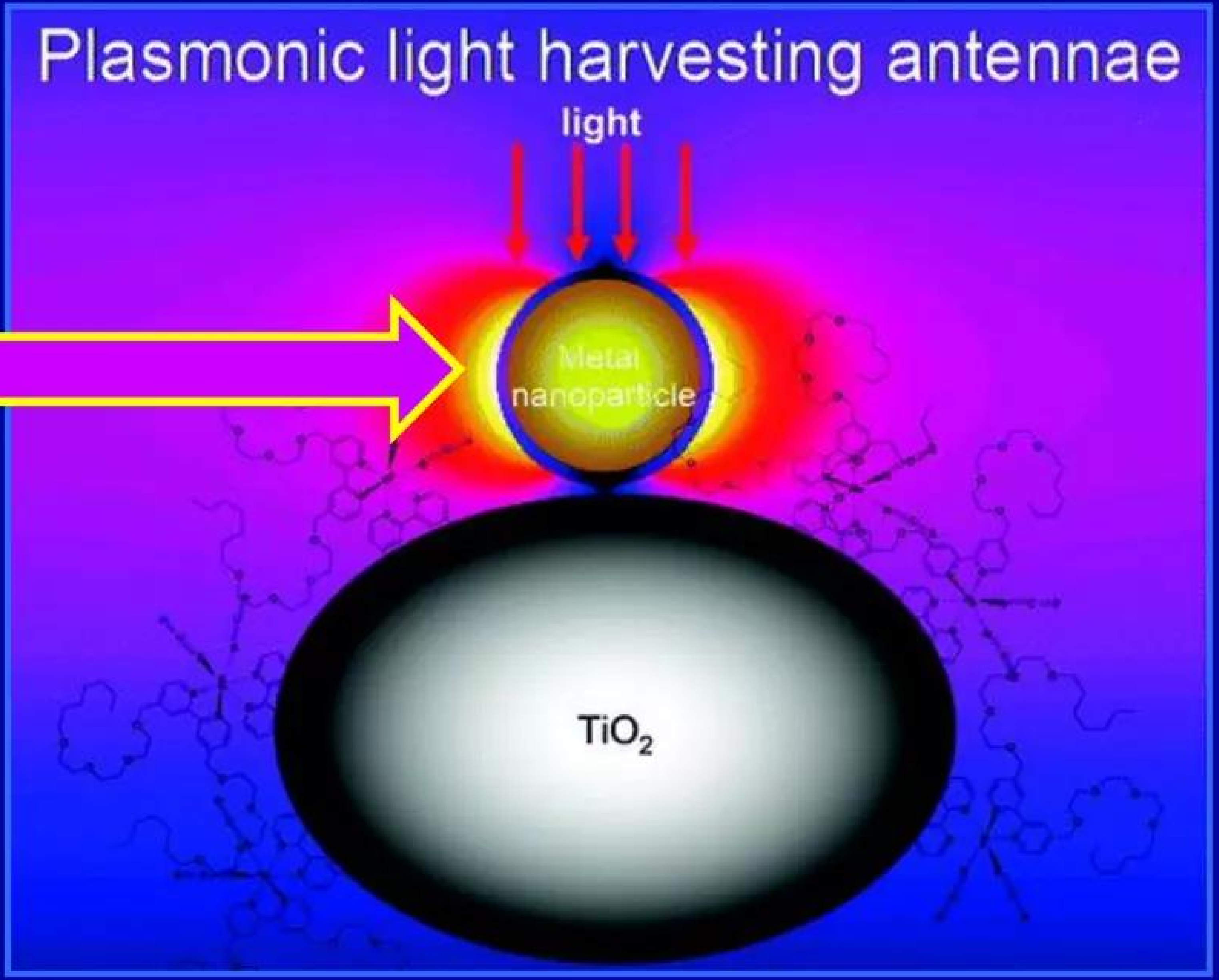


Surface plasmon electrons: key players in Widom-Larsen

e^{-}_{sp} can absorb, transport, concentrate, and store required input energy



Region of enhanced E-M fields



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

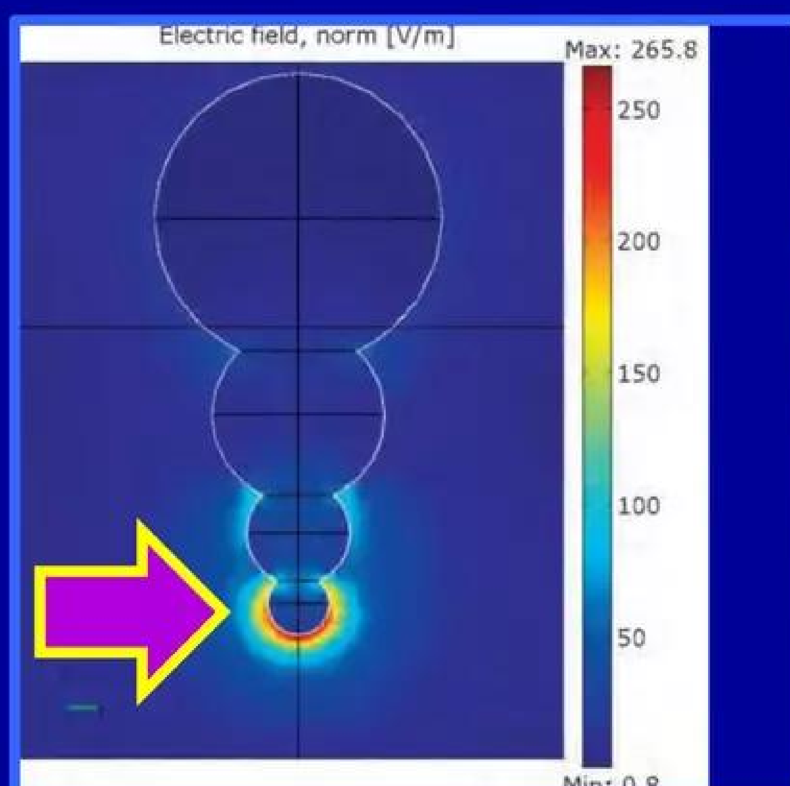
Source of above image is the Wiesner Group at Cornell University:

See: "Plasmonic dye-sensitized solar cells using core-shell metal-insulator nanoparticles," M. Brown *et al.*, *Nano Letters* 11 (2) pp. 438 - 445 (2011) http://pubs.acs.org/doi/abs/10.1021/nl1031106

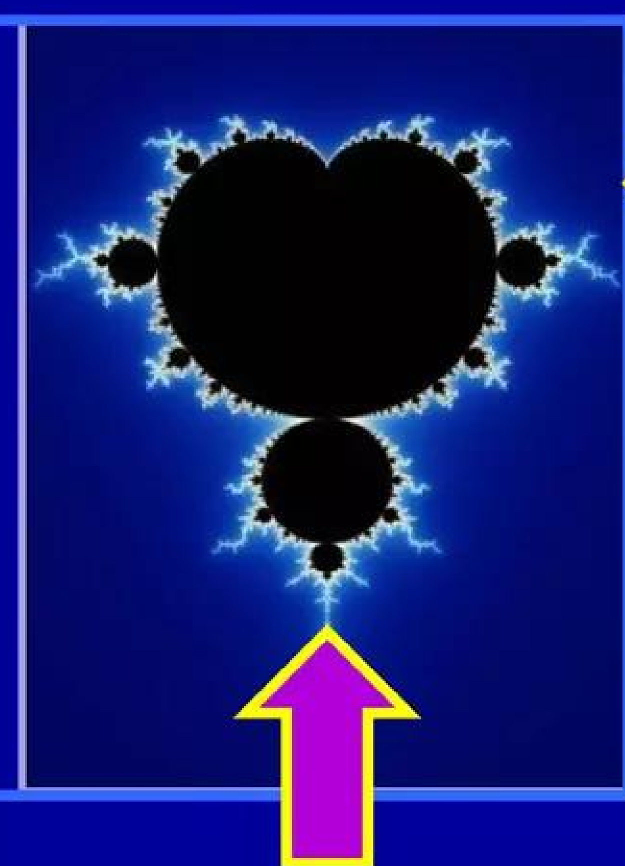
Lattice Energy LLC

Cathodic arcs and LENRS involve high local electric fields

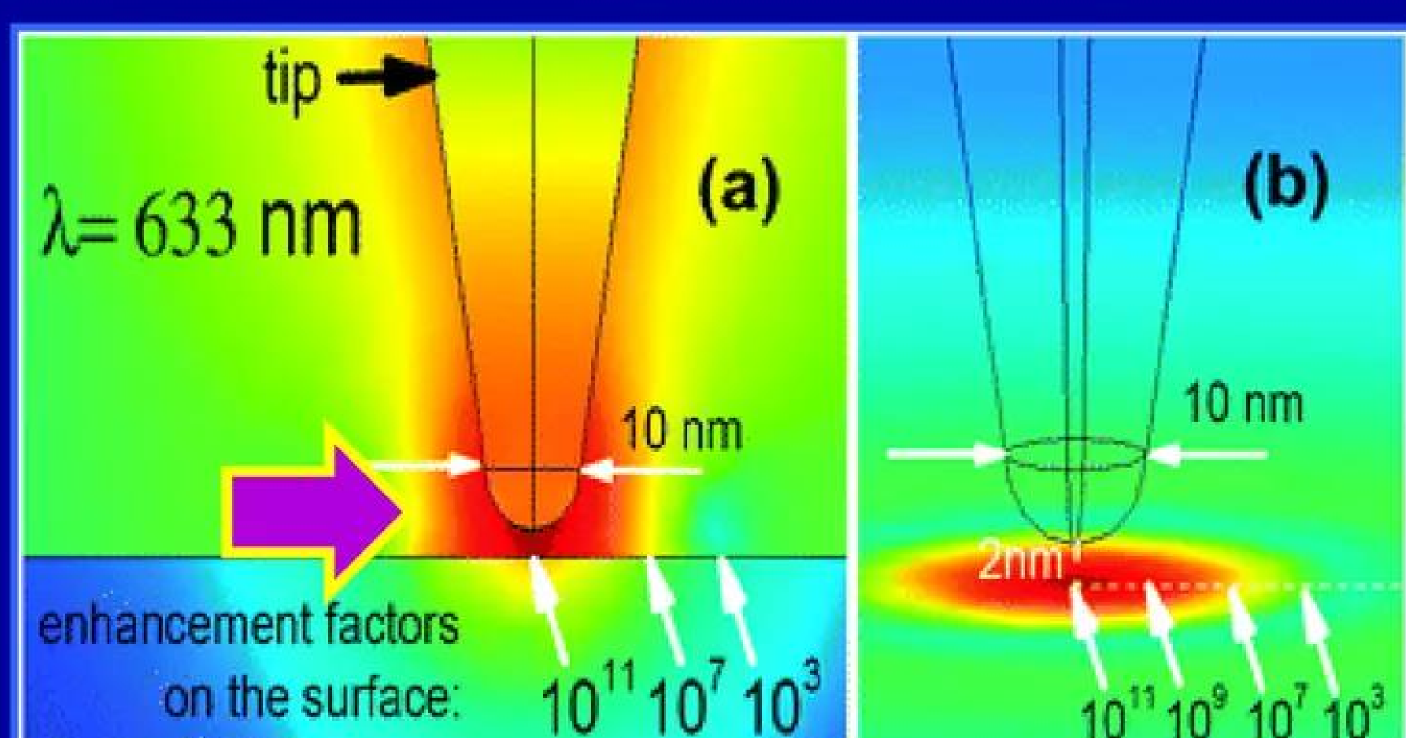
E-fields increase greatly between nanoparticles and at sharp pointed tips



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

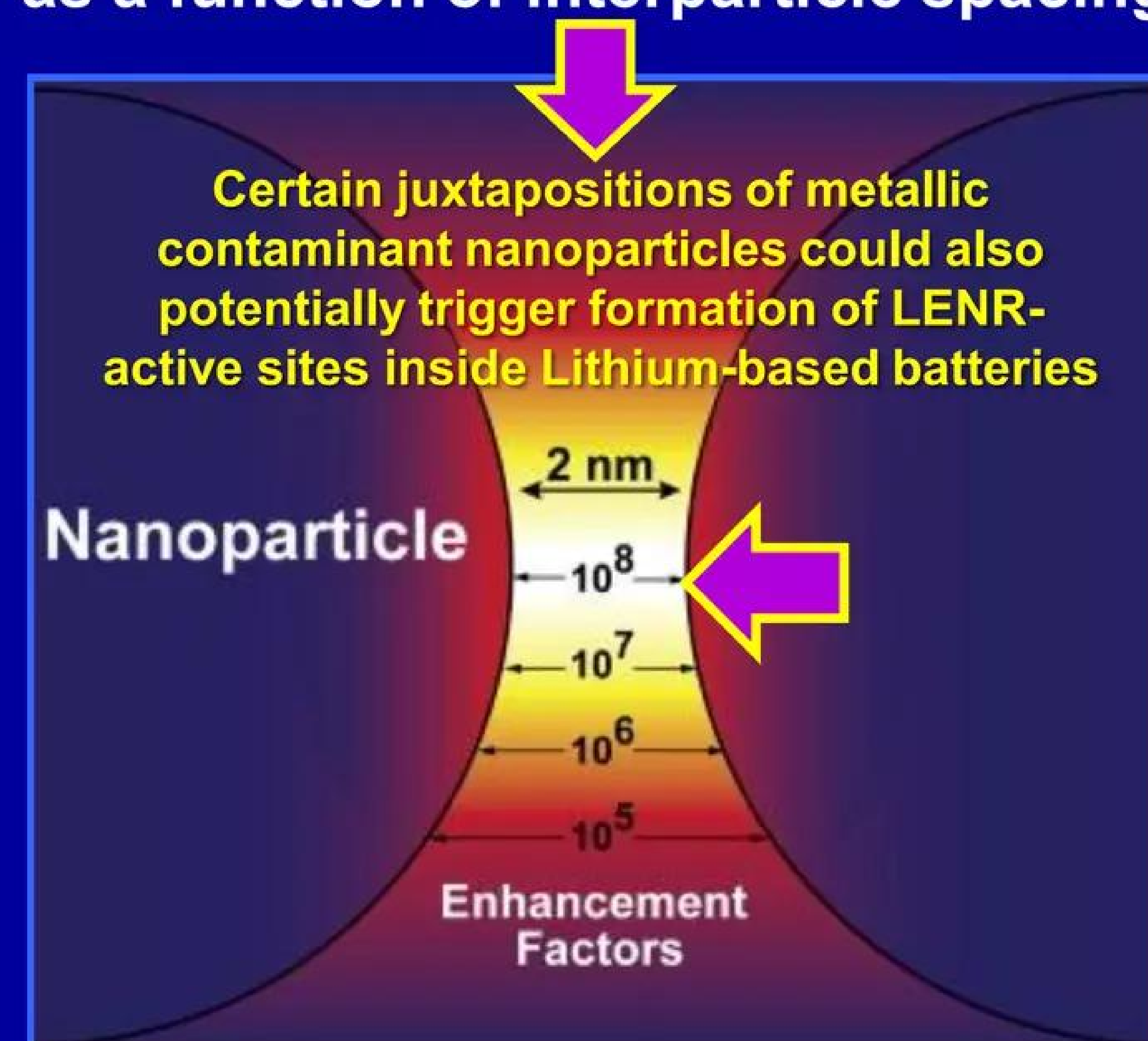


Above: classic Mandelbrot fractal form



Sharp tips can exhibit the so-called "lightning rod effect" in terms of local enhancement of electric field strengths; dendrites are but one type of such a structure – there are others

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



Lattice Energy LLC

Overview of Widom-Larsen theory of LENRs

E-M, chemical, and nuclear processes can interplay on surfaces

Key role of surface plasmon electrons makes E-M resonances very important

- ✓ **On LENR-active substrate surfaces, there are a myriad of different complex, nanometer-to micron-scale electromagnetic, chemical, and nuclear processes operating simultaneously. LENRs involve very complex interactions between surface plasmon electrons, E-M fields, and many different types of nanostructures with varied geometries, surface locations relative to each other, different-strength local E-M fields, and varied chemical or isotopic compositions; chemical and nuclear energy realms coexist at small length-scales on 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 some absorption and emission bands in infrared (IR) and UV portions of E-M spectrum**

Lattice Energy LLC

Application of the Widom-Larsen theory of LENRs

Metallic reaction vessels can be resonant electromagnetic cavities

Beginning in early 1990s several Italian researchers used this to trigger LENRs

- ✓ **Walls of gas-phase metallic or glass LENR reaction vessels can emit various wavelengths of electromagnetic (E-M) photon energy into the interior space; glass tubes with inside surfaces coated with complex phosphors can also effectively function as resonant E-M cavities**
- ✓ **Target nanostructures, nanoparticles, and/or molecules located anywhere inside such vessel cavities can absorb IR, UV, or visible photons radiated from vessel walls if their absorption bands happen (or are engineered) to fall in same resonant spectral range as E-M cavity wall radiation emissions**
- ✓ **Complex two-way E-M interactions occur between interior targets and walls (imagine interior of reaction vessel as arrays of E-M nanoantennas with walls and targets effectively having two-way send/receive channels)**
- ✓ **Starting in early 1990s, series of LENR experiments done in Italy utilized stainless steel reactor vessels that functioned as resonant E-M cavities**

Lattice Energy LLC

Italians triggered LENRS in resonant E-M cavities

Used Nickel reaction vessels, H_2 gas, modest temps and pressures

Some experiments produced large amounts of heat but no 'hard' γ radiation

- ✓ **First conceived in mid-1989 by Francesco Piantelli (Univ. of Siena), about 1990 small group of Italian scientists broke with earlier practice and began new types of LENR experiments using stainless steel reactor vessels, Nickel (Ni) metal rods or planar bars and ordinary H_2 gas; modest gas pressures/temps and initial resistance heating successfully triggered LENRs**
- ✓ **Although reproducibility was very spotty, very large amounts of measured heat (up to as much as ~900 megajoules) were produced during certain experiments over relatively long periods of time (months)**

"Anomalous Heat Production in Ni-H Systems"
S. Focardi, R. Habel, and F. Piantelli
Nuovo Cimento 107A pp. 163-167 (1994)
Peer reviewed: Italian Physical Society

"Evidence of electromagnetic radiation from Ni-H systems"
S. Focardi et al.
Proceedings of ICCF-11, pp. 70 - 80, France, 31 October - 5 November 2004
J-P. Biberian, *ed.*
World Scientific Publishing (2006)
DOI No: 10.1142/9789812774354_0034

Conference presentation may differ from World Scientific version:

http://www.lenr-canr.org/acrobat/FocardiSevidenceof.pdf

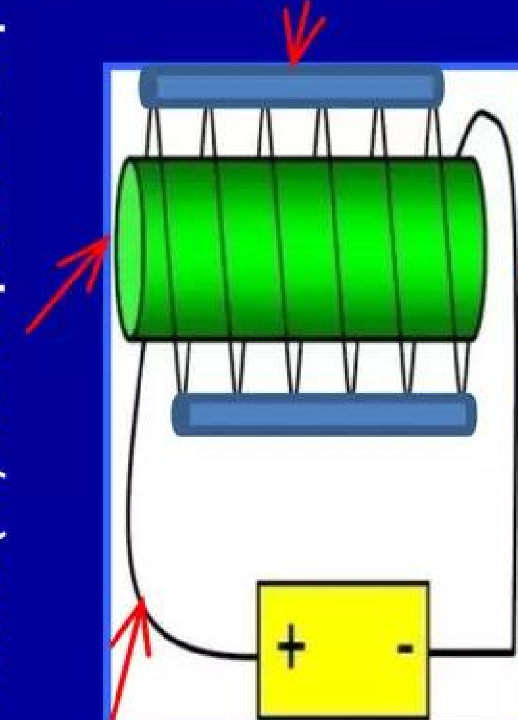
Overview of Italian LENR H_2 gas/Ni experimental apparatus

Ca. 1992 Piantelli-Focardi Ni-H Cell (photo credit: S. B. Krivit)

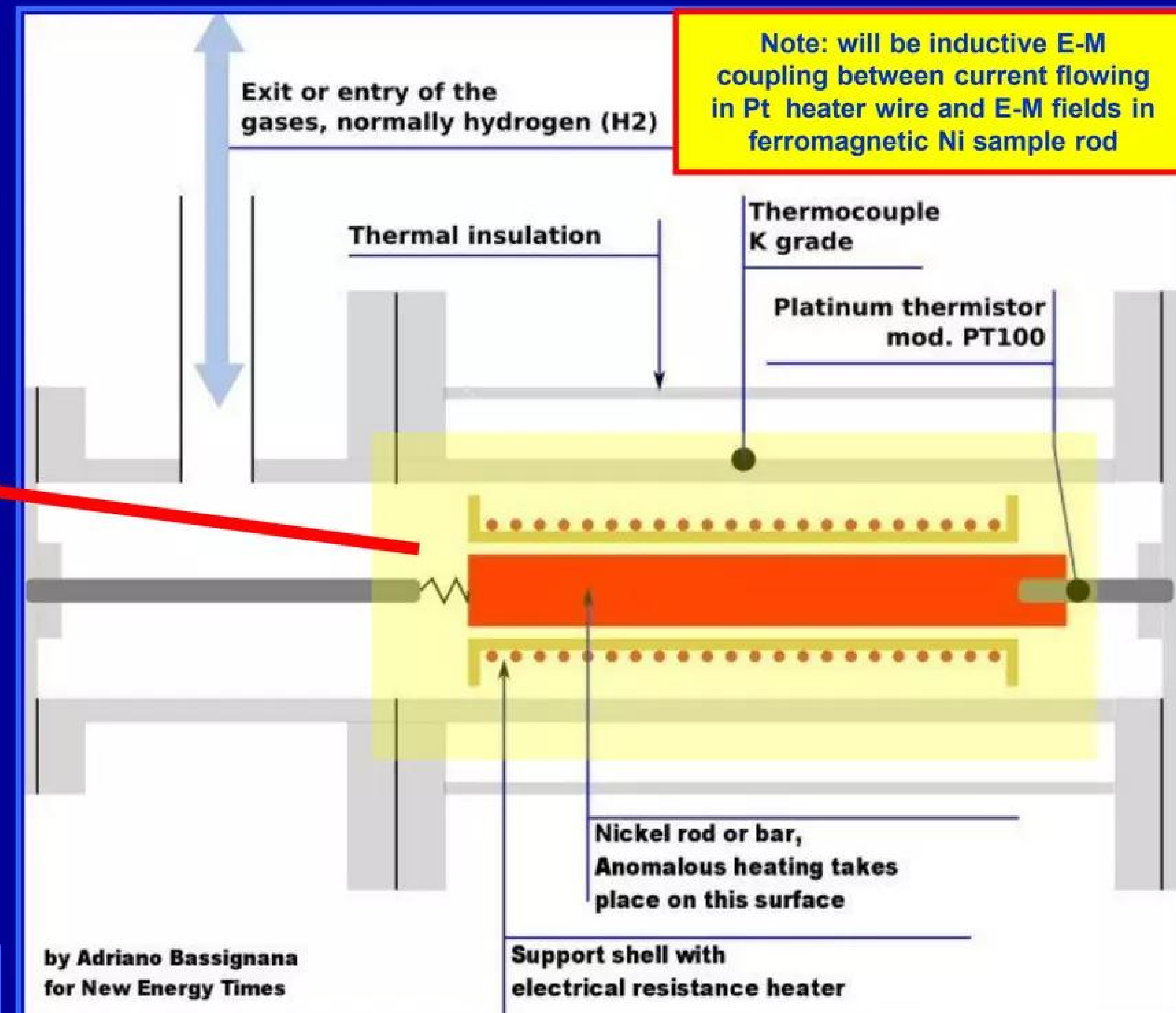
Schematic of electrical resistance heater:

Ceramic support rods (total of 3 - only two shown):

Nickel (Ni) rod or planar sample

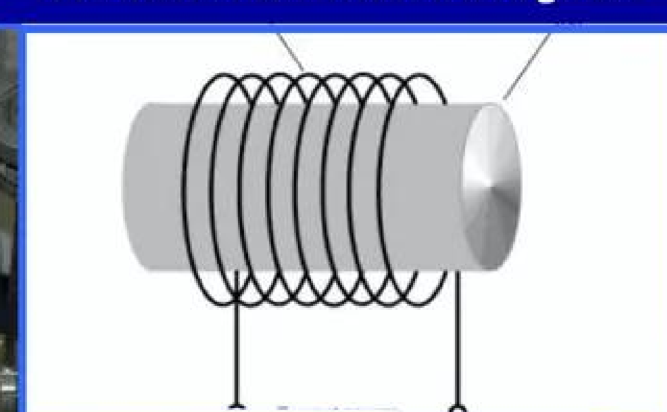


Platinum (Pt) heater wire

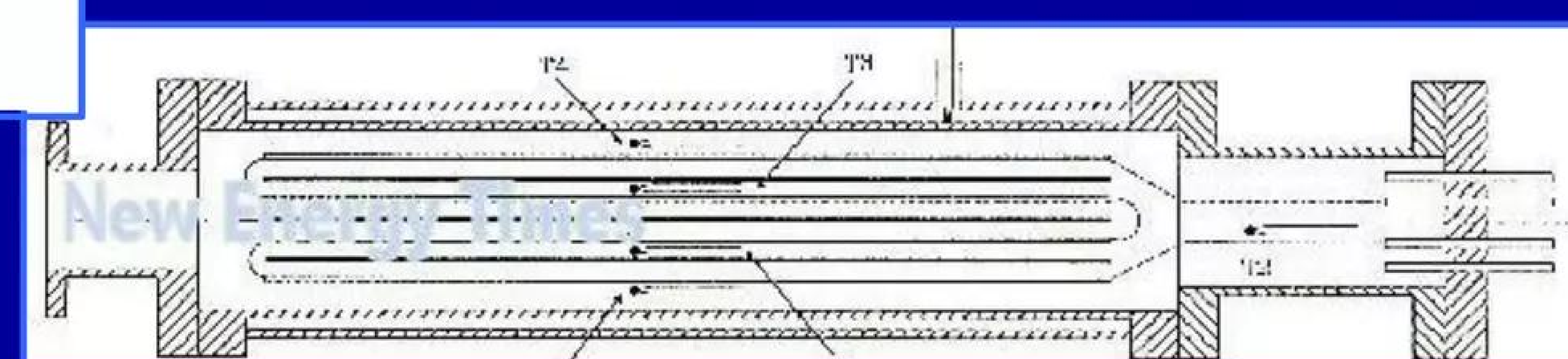


Conceptual diagram of Piantelli-Focardi-type Ni-H Cell

Schematic of electromagnet



Ca. 1992 Piantelli-Focardi Ni-H Cell (photo credit: S. B. Krivit)



Engineering drawing of Piantelli-Focardi-type Ni-H Cell

Lattice Energy LLC

Italians triggered LENRS in resonant E-M cavities

Experiments producing large heat did not emit 'hard' γ radiation

Widom-Larsen theory of LENRs predicts this surprising experimental result

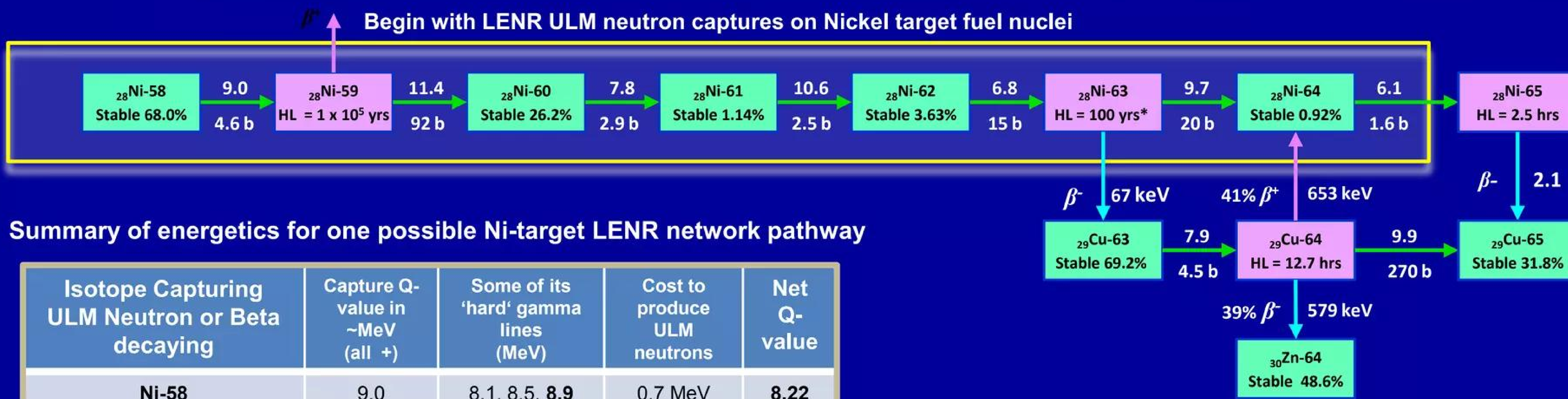
- ✓ System-startup energy inputs were modest H_2 pressures (mbar up to ~1 bar) with initial heat provided by an electrical resistance heater (Pt heating wire coiled around long axis of ferromagnetic Ni cylinder, or planar Ni bars, attached to three equidistant ceramic support rods)
- ✓ Experiments exhibiting very large heat production did not produce any large, readily detectible fluxes of 'hard' (photon energies of ~1 MeV and higher) gamma radiation; no large fluxes of energetic MeV neutrons were detected nor significant production of any long-lived radioactive isotopes; all of this is predicted by the Widom-Larsen theory of LENRs
- ✓ Results showed evidence of positive thermal feedback from 420-720^o K. If correct, it suggests walls of SS reaction vessels may be behaving as resonant E-M radiation cavities; thus, LENRs may turn 'on-and- off" as Nickel surface nanostructures move in and out of resonance with spectral peaks of temperature-dependent emitted cavity radiation

Lattice Energy LLC

Italians triggered LENRS in resonant E-M cavities

Per Widom-Larsen: neutron-captures on Nickel isotopes makes heat

Prompt capture gammas are converted directly to IR by heavy-mass electrons



Summary of energetics for one possible Ni-target LENR network pathway

Isotope Capturing ULM Neutron or Beta decaying	Capture Q-value in ~MeV (all +)	Some of its 'hard' gamma lines (MeV)	Cost to produce ULM neutrons	Net Q-value
Ni-58	9.0	8.1, 8.5, **8.9**	0.7 MeV	**8.22**
Ni-59	11.4	Not in IAEA	0.78 MeV	**10.62**
Ni-60	7.8	7.5, **7.8**	0.78 MeV	**7.02**
Ni-61	10.6	Not in IAEA	0.78 MeV	**9.82**
Ni-62	6.8	6.3, **6.8**	0.78 MeV	**6.02**
Ni-63	9.7	Not in IAEA	0.78 MeV	**8.92**
Ni-64	6.1	6.0	0.78 MeV	**5.32**
Ni-65 β^- decay	2.1	1.5	~1 (*neutrino)	**~1.1***
Totals (MeV)	**63.5**	**NA**	**6.46**	**57.04**
Gain = (net total Q-value for entire pathway) divided by (total cost) = 8.83				

ULM neutron captures go from left to right; Q-value of *n* capture reaction (MeV) shown above green horizontal arrow; capture cross-sections (illustrative selected data in barns b @ thermal energies) below green arrow. Beta$^-$ decays go down (blue); Beta$^+$ decays go upward (purple)

IAEA (Vienna, Austria) database of prompt neutron capture (n,γ) gammas (2006):

http://www-nds.iaea.org/pgaa/tecdoc.pdf

Lattice Energy LLC

Italians triggered LENRS in resonant E-M cavities

Per Widom-Larsen: neutron-captures on Nickel isotopes makes heat

Positive gain on LENR pathway is evidence that gammas being converted to IR

- ✓ Please examine Nickel-target LENR transmutation network pathway and Table shown on previous slide. Note that prompt gamma ray emission can comprise a substantial percentage of positive Q-values for ULM neutron capture process; that being the case, energy associated with gamma emission can comprise vast majority of pathway's total net Q-value of 57.04 MeV and also a strongly positive total gain of 8.83 across entire pathway
- ✓ Now consider a stainless steel reaction vessel with a resonant infrared (IR) E-M cavity inside it as a system. If neutron captures occurred inside the cavity per network pathway shown and gamma conversion to IR by heavy electrons did NOT take place, the vast majority of released nuclear binding energy associated with 'hard' gammas would likely escape through the SS cavity walls (at the wall thicknesses used in laboratory systems) and would thus be 'lost' to the system proper. Without gamma conversion to IR per Widom-Larsen theory, from the system's standpoint as a resonant IR cavity, net energy gain would likely be negative, not a strongly positive 8.83

Lattice Energy LLC

Italians triggered LENRS in resonant E-M cavities

Consequences of W-L direct conversion of gammas to IR explained

Exploit positive feedback loop of resonant E-M cavity to make more neutrons

- ✓ Unlike extremely penetrating 'hard' gammas, SS cavity walls are relatively opaque to IR radiation; moreover, with thermal conductivity of only 12 - 45 W/(m·K) SS retains the heat inside much better than Copper at 401 W/(m·K)
- ✓ When gamma conversion to IR occurs, released nuclear binding energy in the form of IR tends to stay inside the cavity and is thus available to heat it up
- ✓ Heat retention within a resonant cavity allows photon radiation (energy) to be reabsorbed by surface plasmons (found on cavity walls and objects located inside the cavity) that can further concentrate such incident energy and transport it to many-body surface 'patches' of collectively oscillating protons or deuterons which in turn can produce more ULM neutrons via $e + p$ reaction
- ✓ This 'virtuous circle' enables the possibility of a positive thermal feedback loop between releases of nuclear binding energy, conversion of γ radiation to benign IR, local energy retention, absorption of cavity IR by SP electrons on nanostructures, followed by additional neutron production --- in a potentially self-sustaining cycle until a given system effectively exhausts all its reactants

Lattice Energy LLC

LENRs can create thrust directly usable for propulsion

Exploit LENR-active sites' very rapid release of nuclear binding energy

LENRs create tiny microscopic explosions on nanometer to micron length-scales

- ✓ In 1883, Marcellin Berthelot defined a chemical explosion as a, "Sudden expansion of gases in a volume much greater than the initial one, accompanied by noise and violent mechanical effects."
- ✓ Lately, Neil Bourne said, "A physical explosion involves … rapid application of heat to a substance … lead[ing] to instantaneous vaporization … [with] rapid expansion of the surrounding air, and vaporization of material … [A] chemical explosion … undergoes particular chemical reactions that produce both gas and heat and occur over a short time … [The] material must produce the hot, high-pressure gas required for doing significant work on its surroundings." *Materials in Mechanical Extremes: Fundamentals and Applications*, Cambridge University Press (2013) page 24
- ✓ LENR-active sites involve explosions on nm to μ length-scales; herein we will see how this may be directly exploited for vehicular propulsion via many-body collective electromagnetic (E-M) effects

100 μ crater in Palladium

IR video of LENR hotspots

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

Lattice Energy LLC

LENRs can create thrust directly usable for propulsion

Piezoelectric detection of nano-explosions on LENR electrode surface

Quoting directly: "The flashes observed in the IR experiments suggest 'mini-explosions' so we designed an experimental set-up to see if we could record these events using a piezoelectric sensor. Again, the co-deposition approach made this possible. A piezoelectric transducer was coated with epoxy as an insulation layer except for approximately 1 sq. cm on the front on which an electrically conducting material (Ag) was deposited. This became the cathode onto which Pd was co-deposited from the PdCl in a deuterated water solution. The experimental setup and instrumentation is shown."

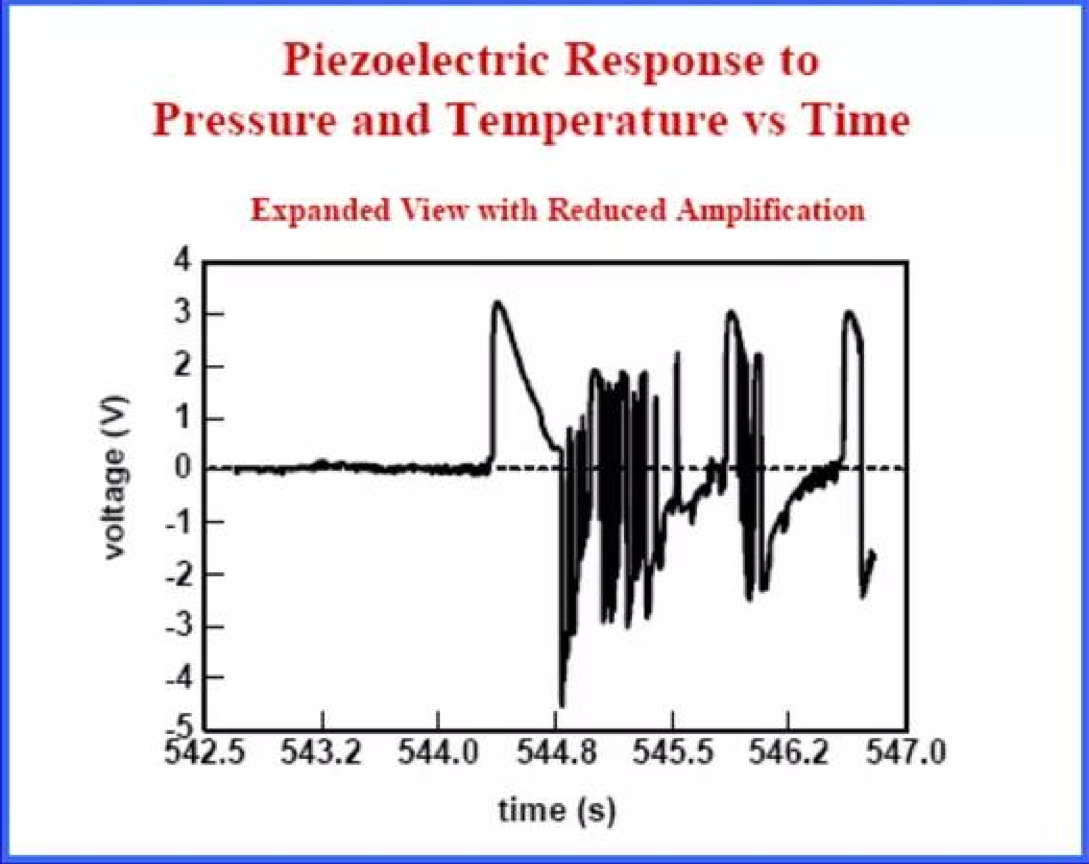
Polarized $D^+/Pd–D_2O$ system: Hot spots and mini–explosions

S. Szpak, P.A. Mosier–Boss, J. Dea and F. Gordon
Spawar Systems Center San Diego, San Diego, CA 92152–5001

Abstract

Two types of activities occurring within the polarized $D^+/Pd–D_2O$ system, viz. the presence of localized heat sources (hot spots) and associated with them mini–explosions, are described. The "birth and death" of hot spots is monitored by IR imaging while the mini–explosions are displayed by the voltage spikes exhibited by a piezoelectric substrate onto which a Pd/D film was co–deposited. Processes leading to the formation of unstable domains as a precursor to the observed behavior is examined.

Lattice comment: U.S. Navy SPAWAR researchers observed acoustic events in parallel with thermal imaging of transient LENR hot spots on electrodes

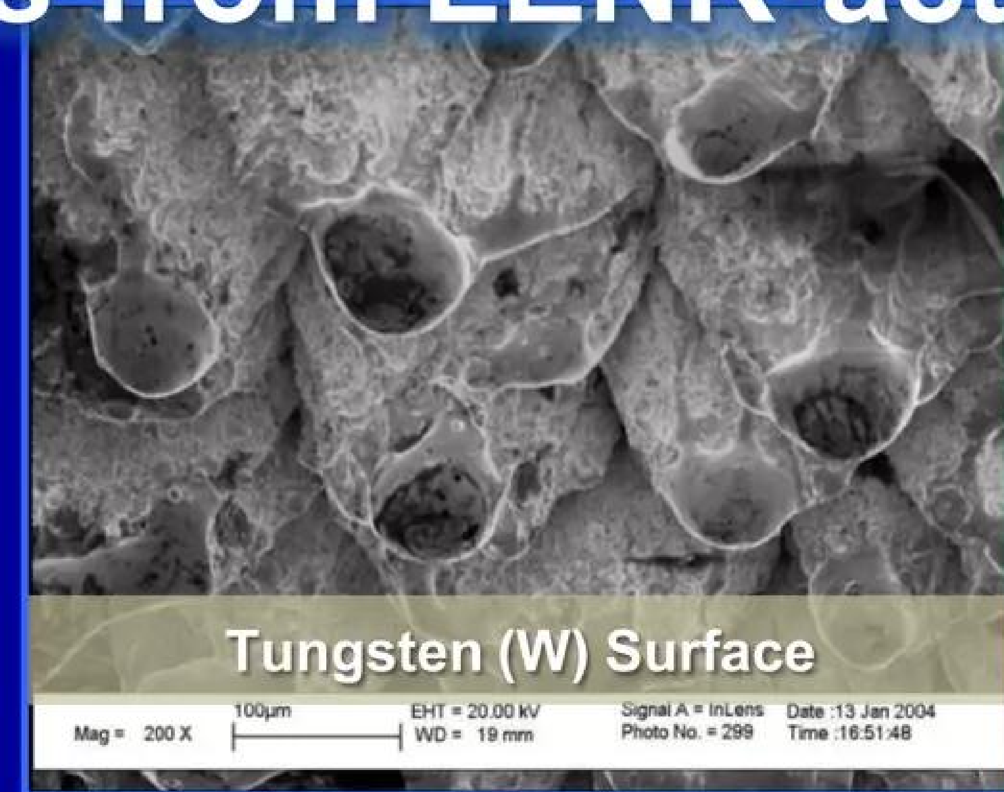


Copy of PowerPoint slides presented at ICCF-10 LENR conference held in Cambridge, MA (2003); this document may differ from the accompanying paper that was published by World Scientific, Inc. in official conference *Proceedings* (2003)

http://lenr-canr.org/acrobat/SzpakSpolarizedda.pdf

Examples of craters from LENR-active sites on surfaces

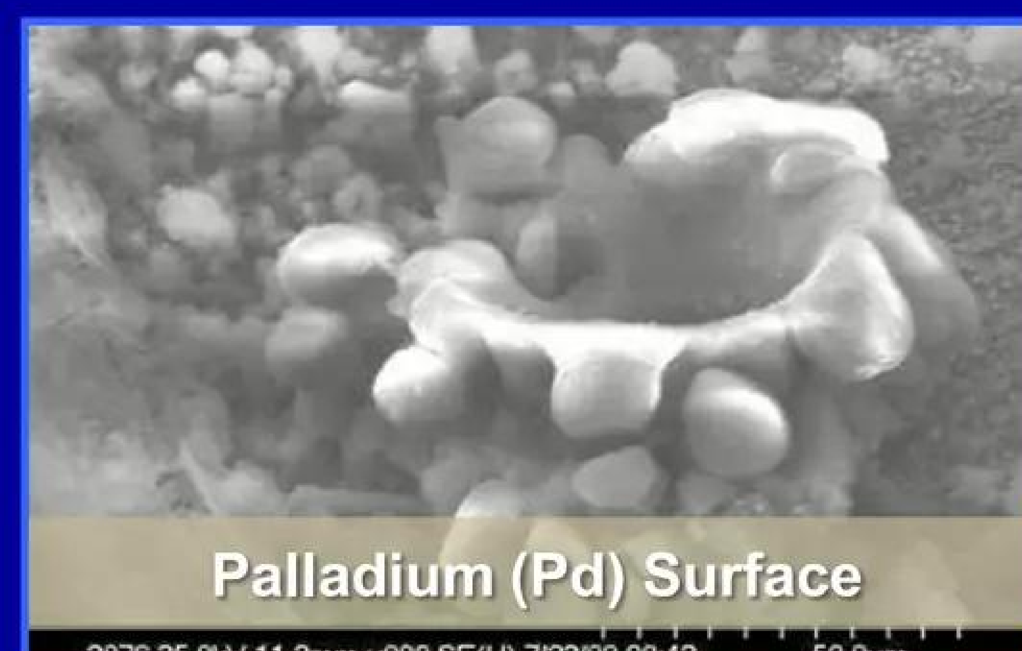
Credit: Y. Toriabe *et al.*



Credit: Cirillo & Iorio

Credit: P. Boss *et al.*

Credit: Y. Toriabe *et al.*



Credit: P. Boss *et al.*

Credit: Energetics Technologies Ltd.

Credit: Y. Toriabe *et al.*

Credit: P. Boss *et al.*

Note: besides the examples shown here, nanostructures created by LENRs display an extremely varied array of different morphologies and can range in size from just several nanometers all the way up to ~100 microns or more

Lattice Energy LLC

Enormous power densities created in LENR-active sites

LENRs occur at modest macroscopic temperatures in tiny devices

Collective many-body physics enables nuclear-strength local surface E-fields

Prof. David Seidman's candid remarks about electron field emission and breakdown found in a grant proposal written in 2005

Seidman is the Walter P. Murphy Professor of Materials Science and Engineering at Northwestern University in Evanston, IL, and leads the Seidman Research Group at NWU's Center for Atom-Probe Tomography (NUCAPT) - http://arc.nucapt.northwestern.edu/Seidman_Group

Seidman has a unique knowledge of high surface electric fields, field emission, and arc discharges as a result of his many years of work with atom-probe tomography (APT) which uses nanoscale local electric fields of 10^{10} V/m and higher to image the structure and analyze the chemical composition of surfaces on near atomic-scales (see image to right courtesy of Imago, Inc., a manufacturer of APTs)

Quoting (*ca.* 2005), "NUCAPT is among the world leaders in the field of three-dimensional atom-probe microscopy, particularly as result of the recent installation of a LEAP microscope, manufactured by Imago Scientific Instruments. Currently only three other LEAP microscopes, with a comparable performance, exist throughout the world."

According to Widom-Larsen theory, local field emission and arc-like phenomena may accompany nuclear processes in LENR-active sites

Seidman's quoted remarks were made in the context of a publicly posted DOE grant proposal: *"Experimental study of high field limits of RF cavities"* D. Seidman and J. Norem (2005)

Please see source URL:

http://www.hep.uiuc.edu/LCRD/LCRD_UCLC_proposal_FY05/2_49_Seidman_Norem.pdf

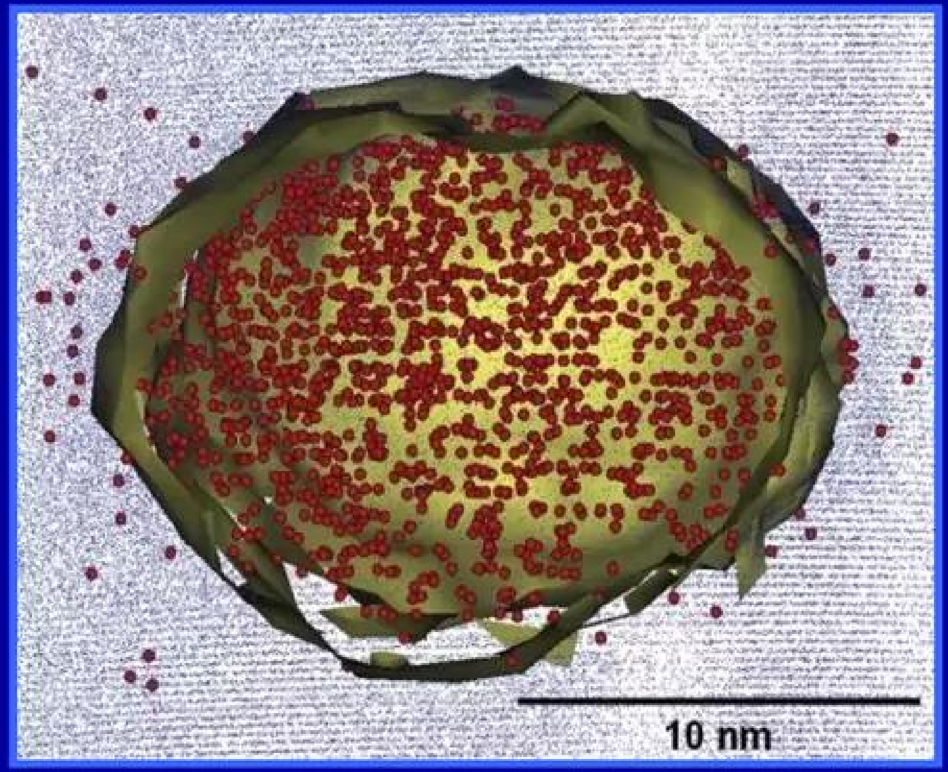


Image: Larson & Kelly, Imago, Inc., local-electrode atom probe image of ordered $L1_2$ Al_3Sc precipitate in aluminum matrix (Al – blue, Sc – red). The <200> planar spacing of the crystalline Al lattice (spacing ~0.2nm) is evident and contrasts with the <100> planar spacing (~0.4 nm) of the Al_3Sc precipitate. Alloy provided by van Dalen, Dun, and Seidman

Lattice Energy LLC

Enormous power densities created in LENR-active sites

LENR only needs modest macroscopic temperatures and tiny devices

Electric breakdown briefly creates local power densities of ~ 10^{21} W/m^3

Quoting further from Seidman & Norem (2005):

"[Electric arc] breakdown at surfaces was discovered by Earhart and Michelson, at [the University of] Chicago, in 1900 … While checking the new 'electron' theory of gas breakdown at small distances, they discovered that there were two mechanisms present, at large distances gas breakdown dominated, and at small distances [i.e., on small length-scales] breakdown of the surface was correctly identified as the mechanism. The break point where the two mechanisms met, at atmospheric pressure, occurs at about 300 V … This was confirmed 5 years later by Hobbs and Millikan, and is consistent with modern data on vacuum breakdown."

"Although high electric fields have been used in DC and RF applications for many years, up to now there has been no fundamental agreement on the cause of breakdown in these systems … Until our work, no theoretical understanding of this process developed over the last 100 years, although many papers have been written."

"Another interesting feature of this [electrical breakdown] mechanism is that the power densities involved are enormous. The numbers can be obtained from the values we measured for field emitted currents, electric field, the emitter dimensions, and volume for transferring electromagnetic field energy into electron kinetic energy. Combining these gives, (10 GV/m)(10^{-7} m)(1 mA)/(10^{-7}m)^3 = 10^{21} W/sec·m^3, a value that seems to be greater than all other natural effects, except perhaps Gamma Ray Bursters (GRB's). The power density is comparable to nuclear weapons. Michelson and Millikan noticed the 'hot sparks' in 1905, bought a vacuum pump, (which they didn't have), and invented vacuum ultraviolet spectroscopy. Both moved on, and did not look in detail at the mechanisms involved."

"Experimental study of high field limits of RF cavities" Seidman & Norem (2005)

Again, please refer to source URL:

http://www.hep.uiuc.edu/LCRD/LCRD_UCLC_proposal_FY05/2_49_Seidman_Norem.pdf

In the following slide, we modify a chart shown in Seidman & Norem's above-noted proposal to illustrate the very approximate regions of physical parameter space in which LENRs may occur if all the necessary preconditions that we have previously outlined are obtained. Please note carefully that just the presence of very high local E-M fields by itself does not guarantee that LENRs will take place at a given location in time and space

Also please note that once the nuclear processes begin, power densities in LENR-active patches can go even higher for brief periods of time until nearby nanostructures are destroyed by violent flash heating and LENRs temporarily cease in a given surface patch site (all of this occurs in a duration of <1 to as much as 300 - 400 nanoseconds)

Lattice Energy LLC

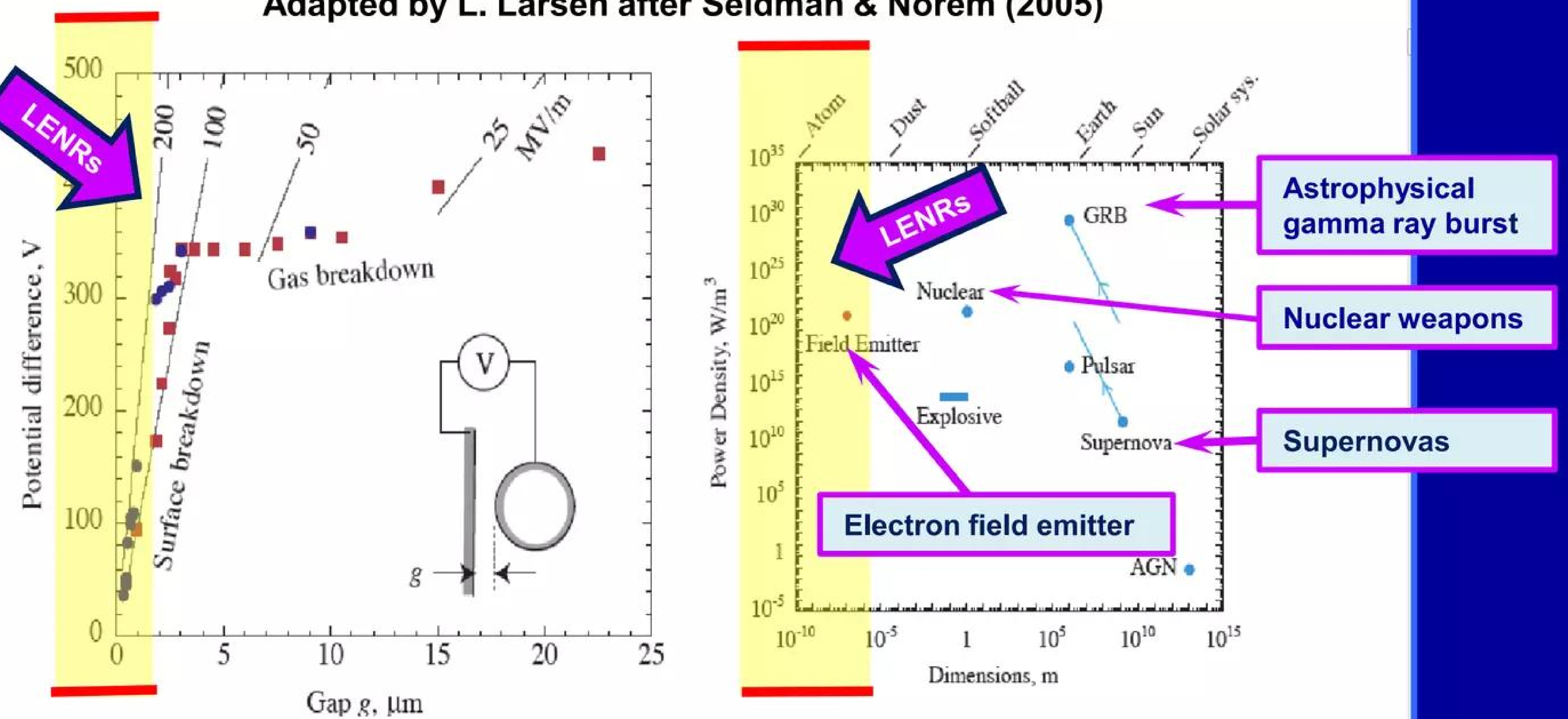
Enormous power densities created in LENR-active sites

LENR only needs modest macroscopic temperatures and tiny devices

Collective many-body device physics enables nuclear-strength *μ*-scale E-fields

LENRs exceed power densities reached during electrical breakdown per Seidman & Norem

Adapted by L. Larsen after Seidman & Norem (2005)



Lattice modification of original chart: yellow-shaded regions capped by red-colored bars are approx. regions of parameter space where LENRs may occur in condensed matter systems IFF all of the necessary conditions met (please refer back to earlier Slides)

Source: Fig. 2, pp. #3, Seidman & Norem 2005 DOE proposal, "Experimental study of high field limits of RF cavities"

Lattice Energy LLC

Enormous power densities created in LENR-active sites

LENR only needs modest macroscopic temperatures and tiny devices

"… mechanism produces highest power density commonly found in Nature"

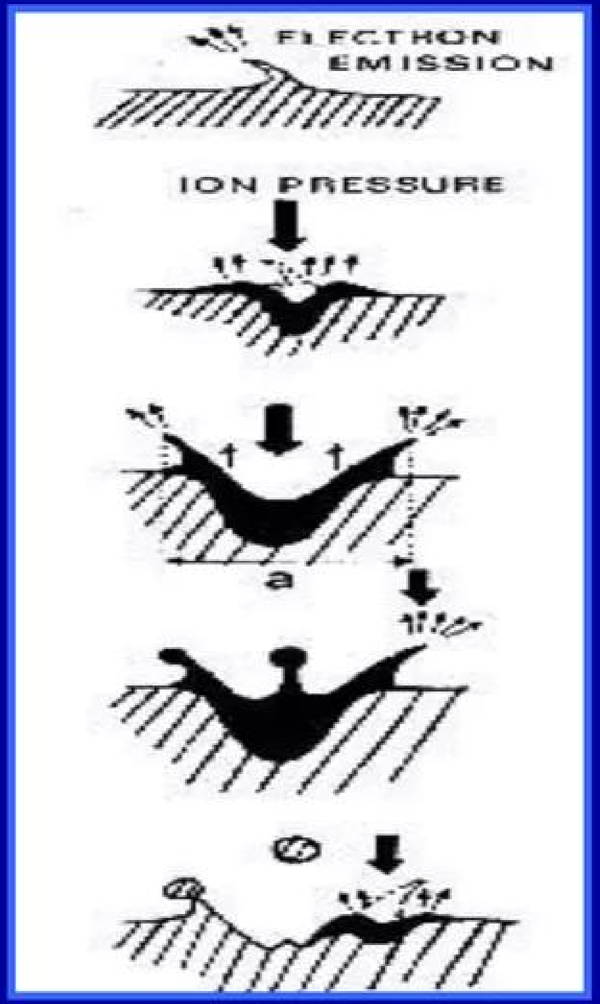
Quoting from Seidman & Norem (2005):

"We think we have developed a model of breakdown that explains the phenomenon in almost all environments ….The model strongly argues that breakdown events are the result of fragments or clusters breaking off of the surface and rapidly being ionized in the electron beams from the field emitter. Within the active volume, the power involved in these beams is comparable to nuclear weapons. This model is also generally in agreement with the experience with APFIM samples at the high fields used. Tiny APFIM samples operate at fields about 5 times higher than the local E field limit we postulate, but they also frequently fail, however there has been no systematic study of these failure modes." [LENRs ??????]

"Combining these two ideas, however, one can conclude that: 1) this mechanism produces perhaps the highest power density commonly found in nature, and, 2) it is accessible to anyone with a wall switch or an electric light, and is used many times a day by everyone."

"While there has been extensive study of the time development of breakdown events from the first small local ionization to complete breakdown of a cavity, the trigger for breakdown, and how it was related to the metallurgy of surfaces has received very little attention until now. Our model predicts that the production of clusters and fragments is an essential component of breakdown. This is consistent with experience in Atom Probe Tomography, however there is almost no systematic data on sample failures under the high field environment used in data taking. Our previous work has been published in three refereed papers and many conference papers."

Pulsed Laser Atom Probe Microscope at NWU
Source: Fig. 7, pp. #9, Seidman & Norem proposal (2005)



Breakdown of surface
Figure courtesy of B. Jüttner, Berlin

Lattice Energy LLC

Enormous power densities created in LENR-active sites

LENRs only need modest macroscopic temperatures and tiny devices

Peak in power densities at LENR sites could briefly be ~3.6 x 10^{19}x solar core's

Simply calculated comparison of LENR patch power densities vs. those thought to occur in the Sun's core --- LENRs are amazingly high:

- ✓ Stromgrew (1965) calculated that peak fusion power density in Sun's core is $E_{(J)}$ = 276.5 Joules/sec·m^3 (2.765 x 10^2) - in earlier slide
- ✓ Seidman & Norem (2005) stated they believed that power densities in small sites on surfaces where collective electron field emission and electrical breakdown are occurring are = 1.0 x 10^{21} Watts/sec·m^3
- ✓ While we might safely presume that peak power density in an LENR-active patch could likely be higher than that Seidman & Norem's number, let's conservatively assume it's just the very same value for total LENR energy releases that occur during a given surface site's brief effective working lifetime before it dies and then cools-off
- ✓ Thus, according to formula shown above to the upper right, these assumptions would suggest that peak local power density from an LENR-active patch might be as high as $E_{(J)}$ = 1.0 x 10^{21} Joules/sec·m^3
- ✓ Dividing 1.0 x 10^{21} (LENRs) by 2.765 x 10^2 (Sun's core) we calculate LENRs' relative power density = ~3.6 x 10^{19} times the solar core's

Energy E in joules (J) is equal to the power P in Watts (W), times the time period t in seconds (s):

$$E_{(J)} = P_{(W)} \times t_{(s)}$$

Comments re technological issues:

- ✓ One could quibble with details in these simplistic estimates; however, conclusion of this calculation is that LENR-active sites briefly have energy power densities that can be substantially higher than the Sun's inner core
- ✓ This comparison suggests that LENRs could well have excellent potential as a new green energy source, provided that methods are found to fabricate high area-densities of LENR-active sites and that they can be reliably triggered and their rates fully-controlled

Lattice Energy LLC

Craters created explosively by LENRs in surface sites

Microscopic physical model can explain initiation of LENR-active sites

Dr. Andre Anders of Lawrence Berkeley National Lab has model:

Steps 1 – 4 below describe his "arc spot ignition" model as follows:

High local electric field and subsequent field emission enhanced by:

- **Protrusion (e.g. roughness, previous arcing) [dendrites on surfaces] or**
- **Charged dielectrics (e.g. dust particles, flakes) [nanoparticle surfaces]**

Positive thermal feedback loop

1. **Higher field leads to locally greater e-emission**
2. **Joule heating enhances temperature of emission site** +
3. **Higher temperature amplifies e-emission non-linearly**
4. **Runaway electric arc discharge may then begin followed by:**

To which Lattice would add, based on Widom-Larsen theory

5. **LENRs --- if other necessary preconditions are also fulfilled, as we have outlined elsewhere in this document**

LENR hotspot crater being created

Timeline

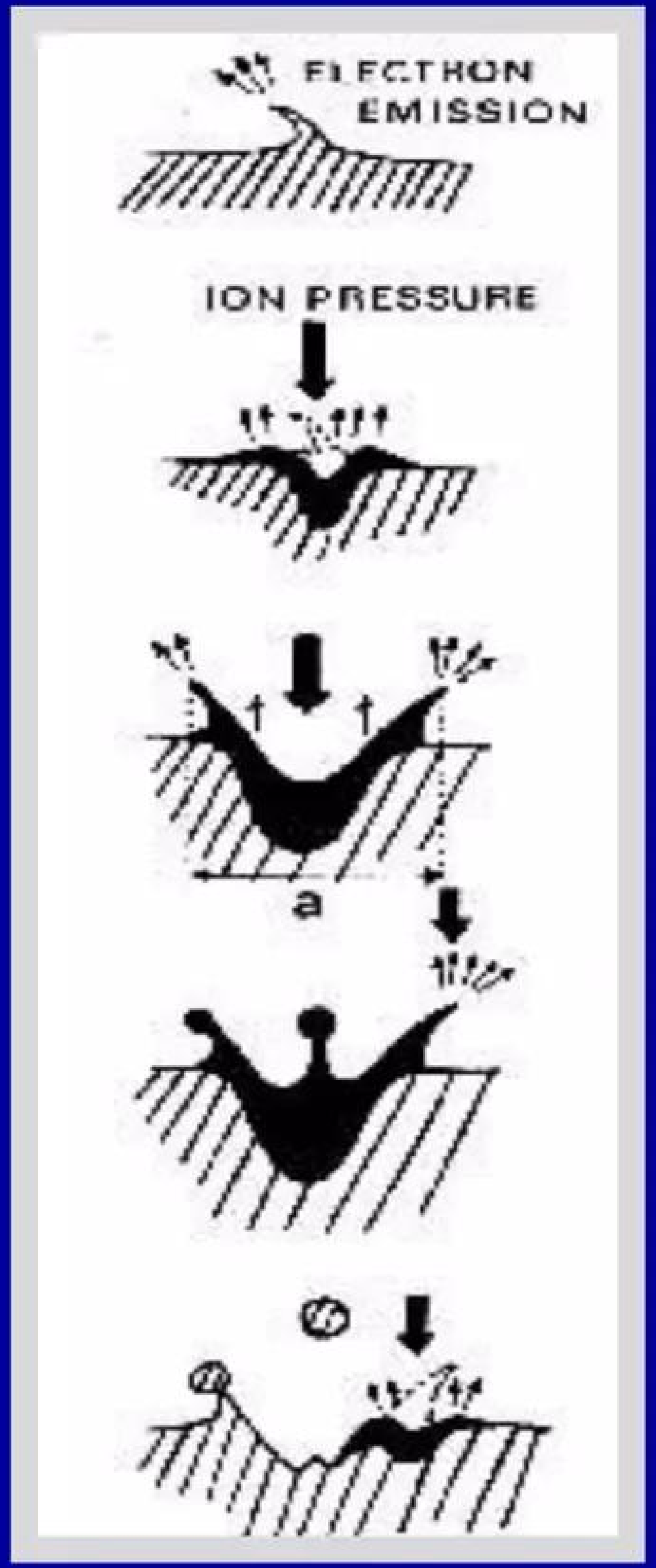


Figure credit: B. Jüttner, Berlin

Lattice Energy LLC

Cathode spots *a la* Anders produce surface craters

Such spots known to briefly hit peak temperatures high as 15,000° C

Pulse of heat creates high velocity (10 km/s) jets of vaporized cathode material

Beilis Model - Hydrodynamic Plasma Expansion

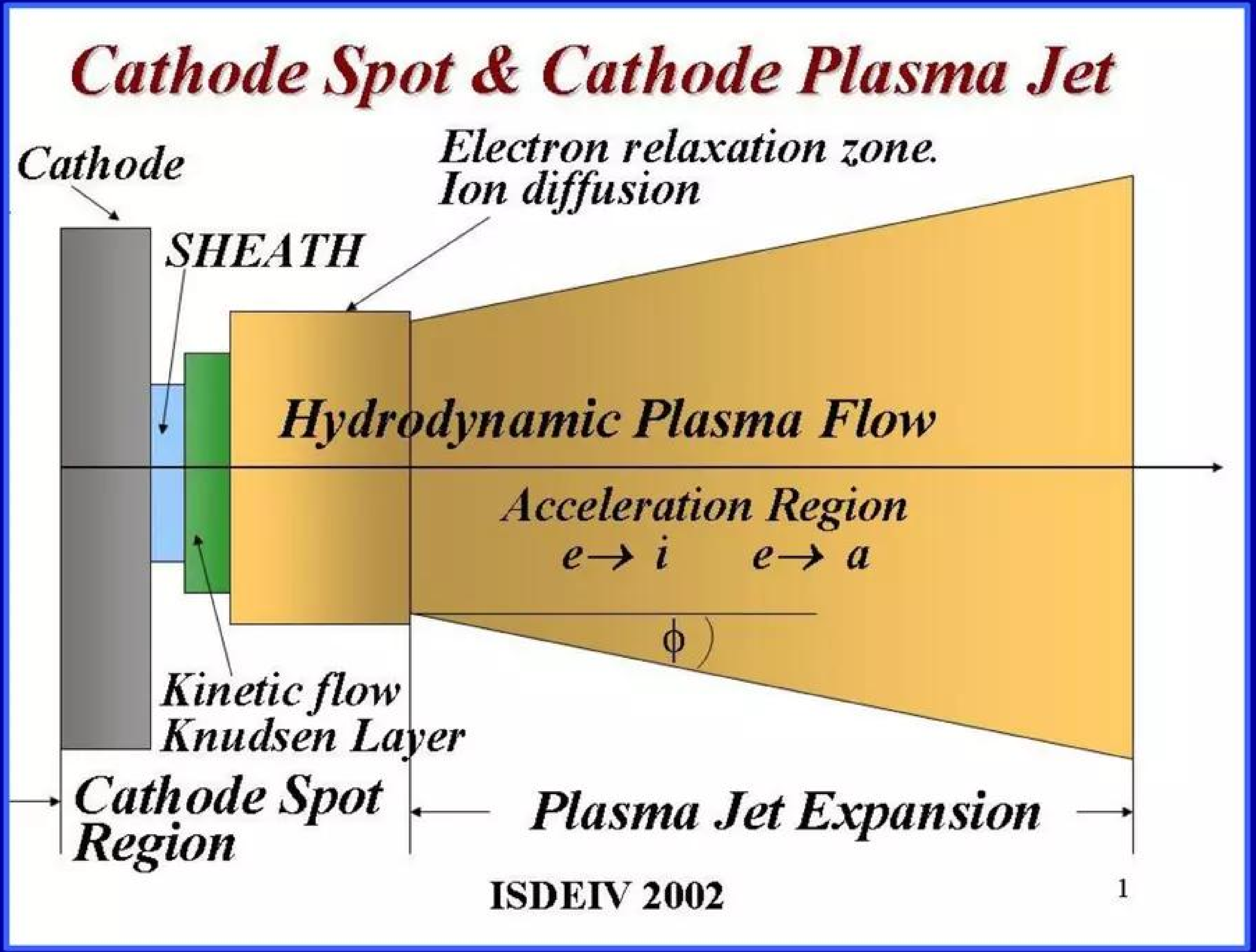
Like in jet engine – conversion of thermal→ directed kinetic energy

But plasma heated all along length

Continuous heating, conversion into kinetic energy, so

T_i ~3 eV

E_i ~20 - 150 eV



Credit: Raymond L. Boxman
Electrical Discharge and Plasma Laboratory
School of Electrical Engineering, Tel-Aviv University

Source: Slide #12 in http://www.lnl.infn.it/~master/slideshow/wednesday/Boxman_Padua%20Lect.ppt

Irradiated dusty plasmas reach very high temperatures

Mixtures of neutral diatomic/monatomic gases, ionized gases, electrons

"Fundamentals of hypersonic flight - properties of high temperature gases", P. Barbante and T. Magin, NATO report RTO-EN-AVT-116 (2004)

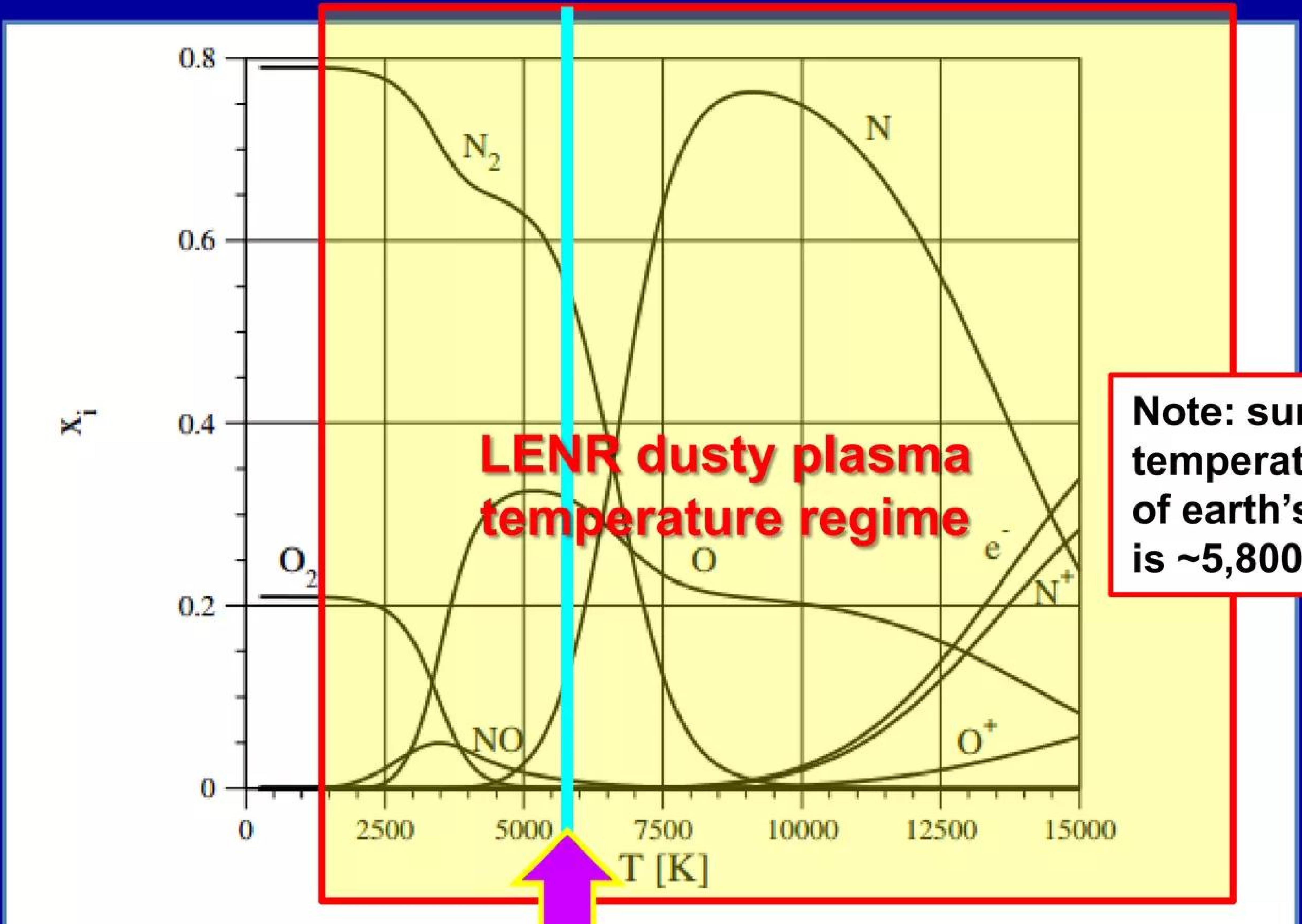


Figure 7: Major components of air at 1 atm.

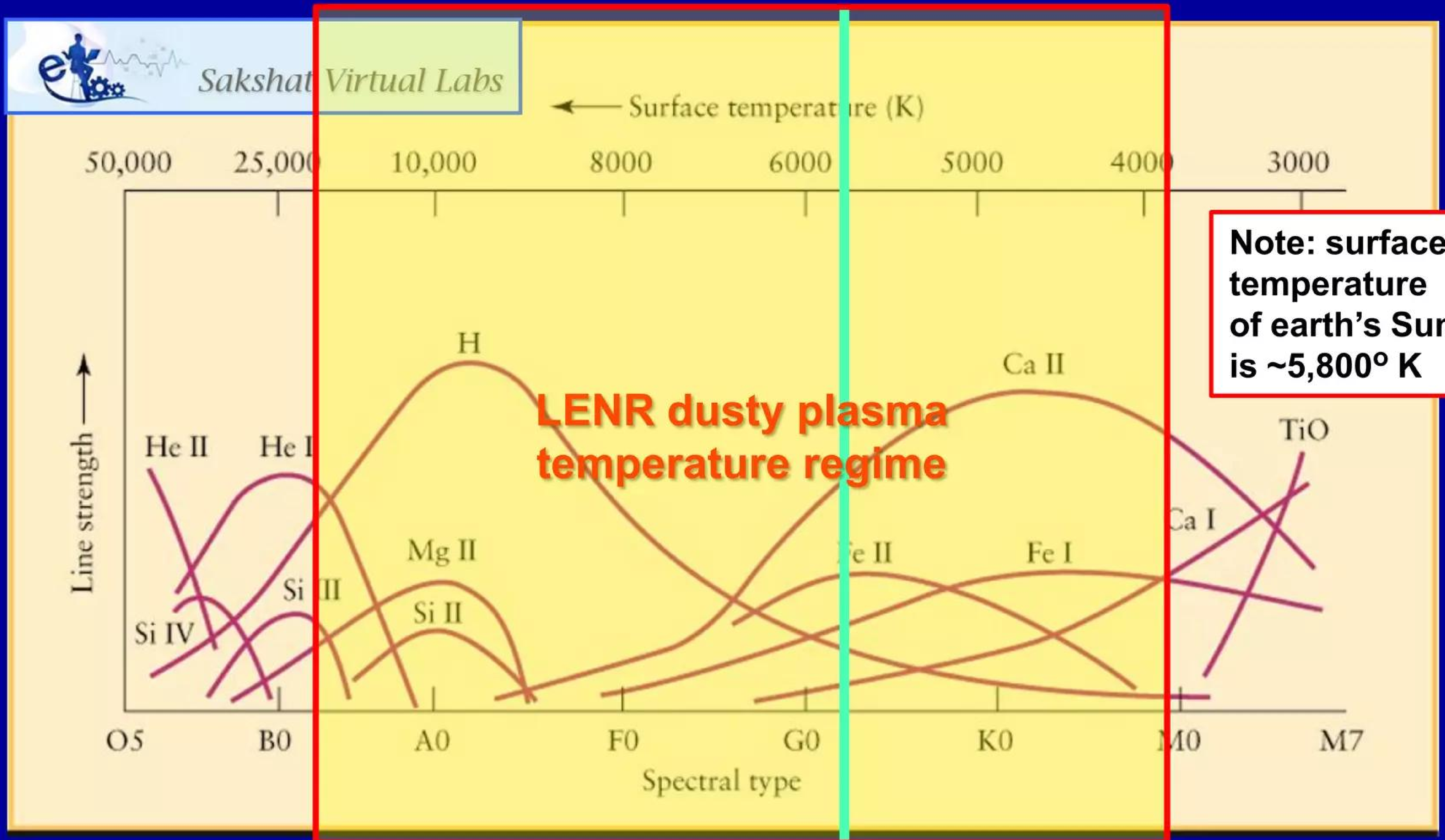
Note: surface temperature of earth's Sun is ~5,800° K

Source: http://ftp.rta.nato.int/public/PubFullText/RTO/EN/RTO-EN-AVT-116/EN-AVT-116-05.pdf

Lattice Energy LLC

Irradiated dusty plasma temperatures like stars' surfaces

Star surface temperatures by spectral type vs. line strength of elements



Source - Sakshat Virtual labs: http://iitk.vlab.co.in/?sub=27&brch=83&sim=797&cnt=1

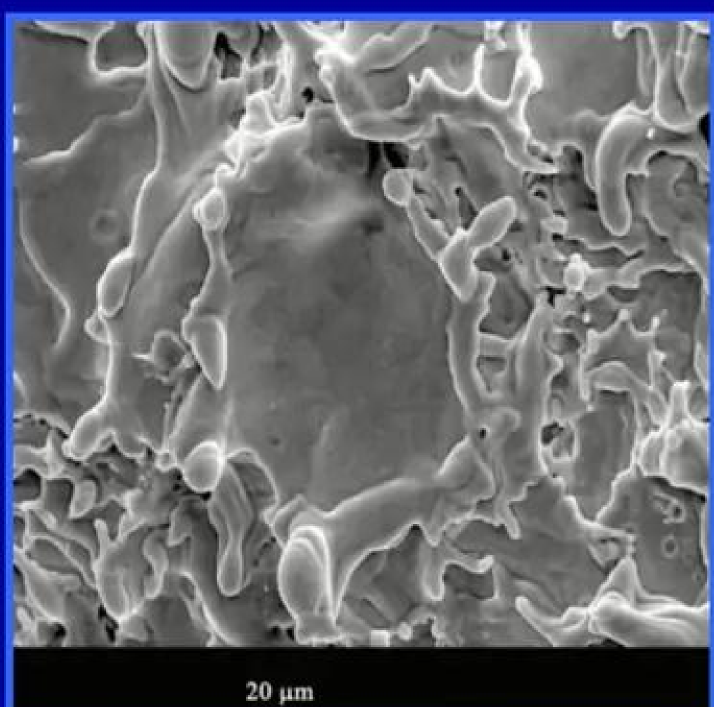
Lattice Energy LLC

Enormous local power densities create surface craters

Quenched spherical droplets ‘frozen’ in mid-formation on crater rims

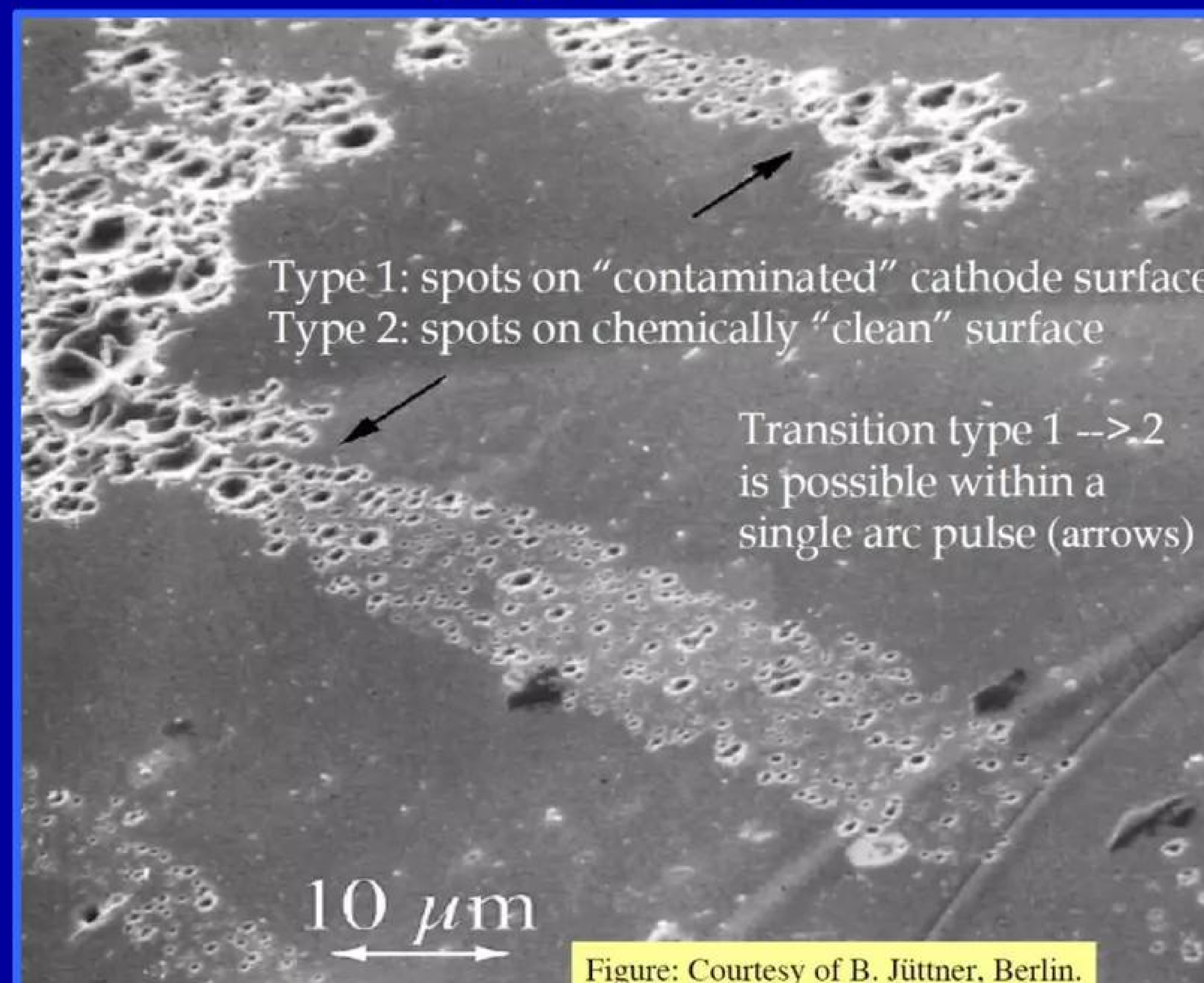
Anders’ cathodic arc craters vs. LENR-produced surface craters on Palladium

Cathodic arcs | **Cathodic arcs** | **LENRs**

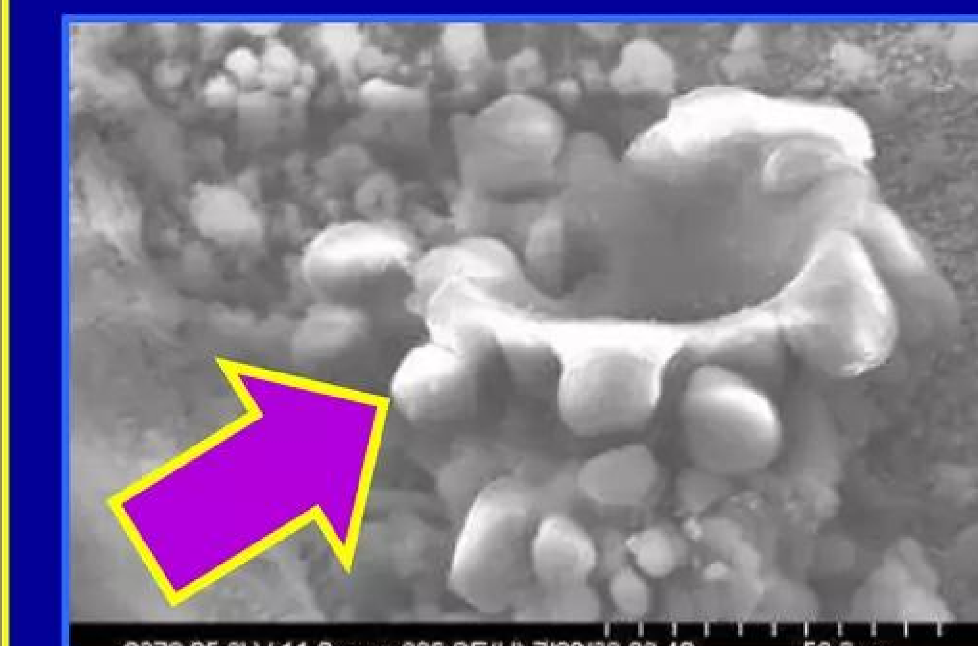


A. Anders “Cathodic Arcs, and related phenomena” (2010)

Anders: Slide #27



A. Anders “Cathodic Arcs, and related phenomena” (2010)



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

Lattice Energy LLC

Enormous local power densities create surface craters

U.S. Navy SEM images of LENR-active Pd surfaces show μ-scale craters

Crater produced by laser ablation

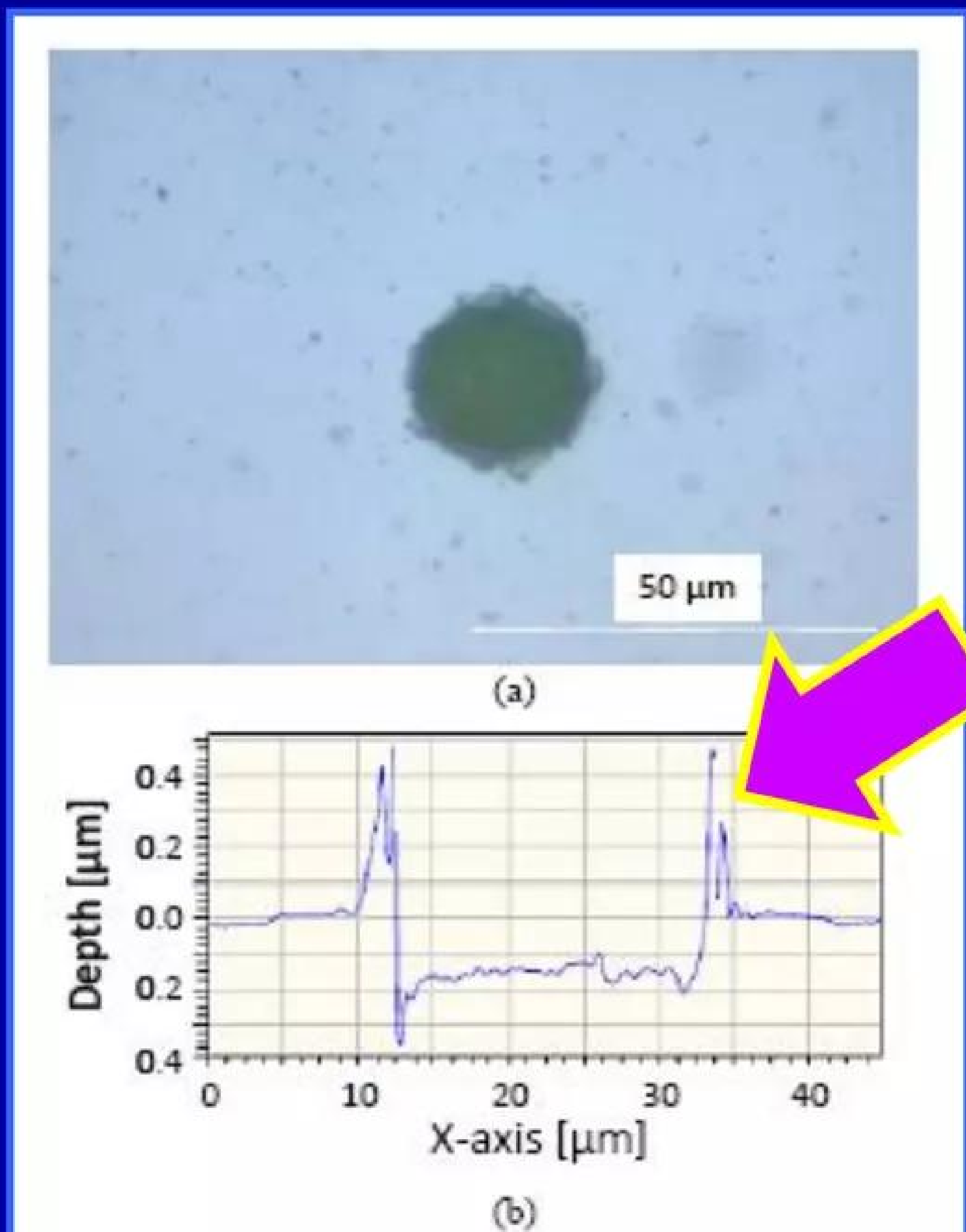


Fig. 6 (a) Optical microscope image of ps laser ablated cathode crater on LEP. Single pulse ablation, 532nm, 10ps, 2.5µJ; Bar 50µm, (b) Depth profile of the ablated crater, depth~140nm. Scale (X):2.5µm/div, (Y):25nm/div.

Quoting from Karnakis *et al.*:

"Laser irradiation at fluences between 137-360 *m*J/cm^2 removed the cathode layer only, resulting in a uniform flat floor and an intact LEP surface, allowing a relatively wide process window for cathode removal.

A typical example of such laser patterned Ba/Al cathode layer on the OLED stack is shown in Figure 6.

The average fluence was 230 mJ/cm^2 irradiated with an estimated spot diameter at 1/*e*^{2} of 35 *µm*.

This resulted in a crater diameter of 21.5 *µm*."

Fig. 6 Excerpted and quoted directly from:

"Ultrafast laser patterning of OLEDs on flexible substrate for solid-state lighting"
D. Karnakis, A. Kearsley, and M. Knowles
***Journal of Laser Micro/Nanoengineering* 4 pp. 218 - 223 (2009)**
http://www.jlps.gr.jp/jlmn/upload/25e2c628adb23db70b26356271d20180.pdf

Shows evidence for explosive boiling of metals

Morphology of LENR craters is similar to ablative effects of energetic laser irradiation

Note microspheres formed at lips of craters

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

LENR craters have sharp relief and high aspect-ratios like laser ablation

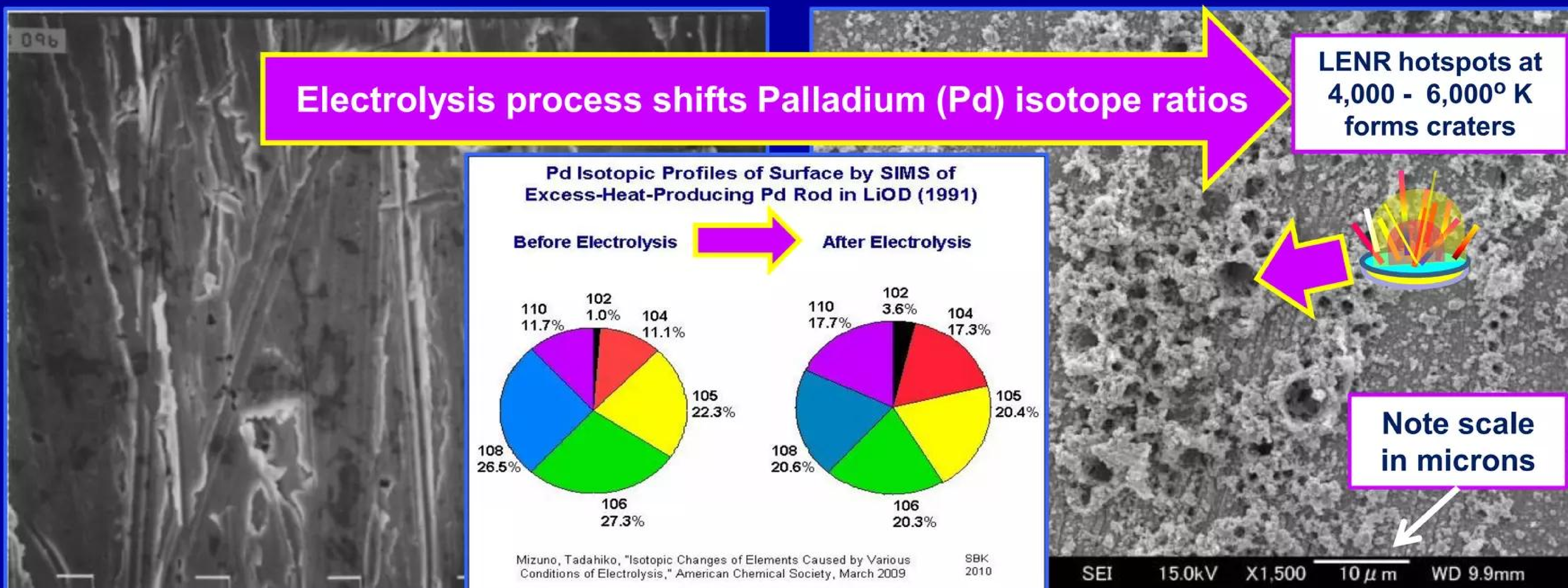
Lattice Energy LLC

LENR transmutation products seen near surface craters

SEM-EDX/SEM-SIMS show some nuclear reaction products near craters

Mizuno *et al.* reported shifts in isotopic profiles of Palladium on device surfaces

Before: relatively smooth surface **After: rugged terrain with *μ*-scale craters**



Quoting Slide #5 caption in ICCF-17 presentation: "These photo are the Pd electrode before and after the electrolysis. Electrolysis was conducted for a long time, several day or several week. Typical current density was 20mA/cm^2. Here, you see the metal particle (100 nm or less) on the surface after electrolysis. Some of them are less than 10 nano-meter of size."

Source: 41-slide ICCF-17 conference (Aug. 12-17, 2012, Daejeon, Korea) presentation titled, "Theoretical Analysis of Chemically Assisted Nuclear Reactions (CANR) in Nanoparticles," T. Mizuno, M. Okuyama, Y. Ishikawa, and T. Oheki

Copy of slides at: http://newenergytimes.com/v2/conferences/2012/ICCF17/papers/Mizuno-Theoretical-Analysis-Slides-ICCF-17.pdf

Lattice Energy LLC

LENR transmutation products seen near surface craters

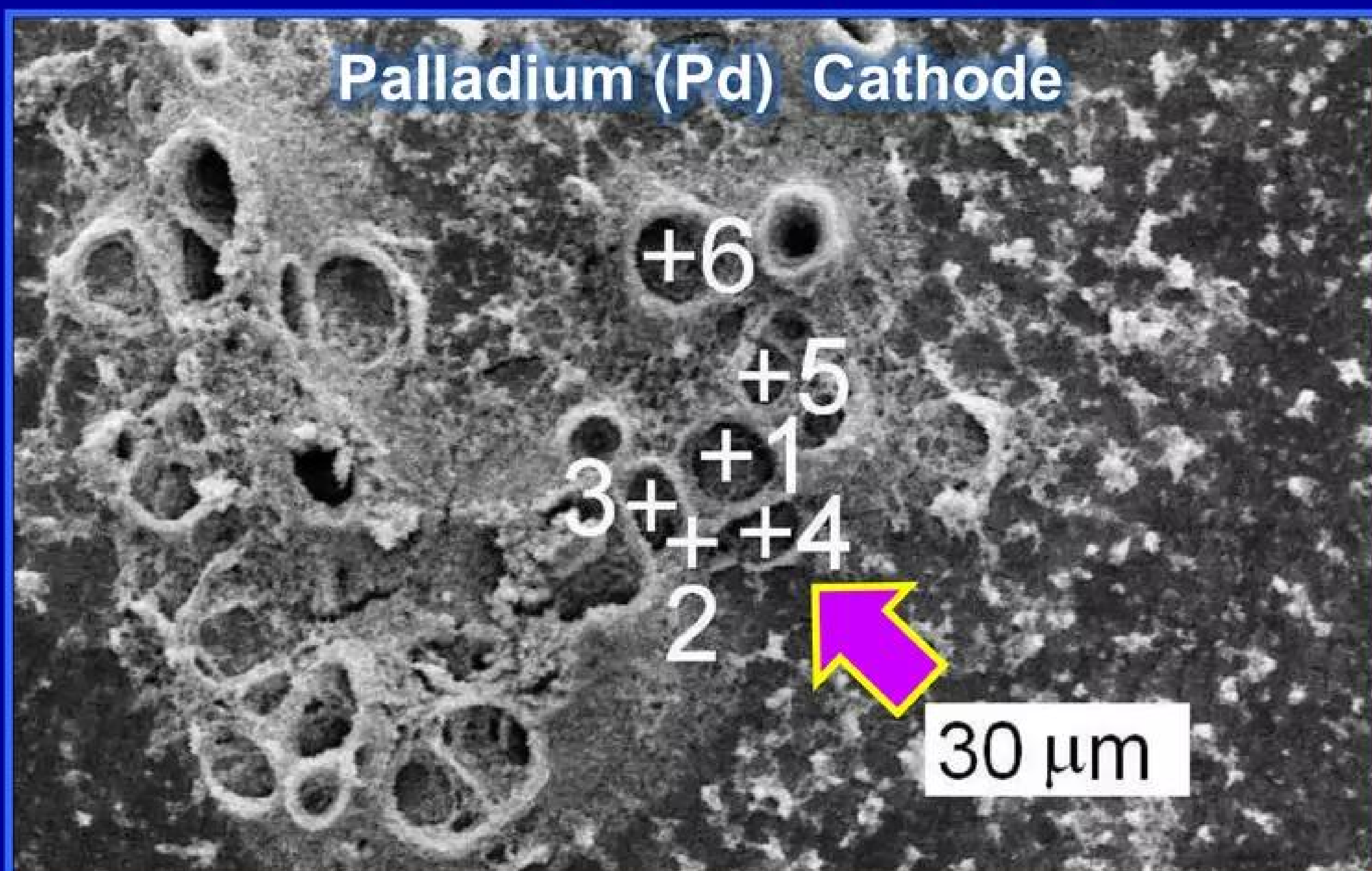
Palladium transmuted to Silver with ULM neutron capture and β-decay

Following nuclear reactions explain how Silver was produced in the experiments

neutron capture process — β^- nuclear decay process

[Multiple stable Palladium isotopes] Pd + n → [unstable neutron-rich Pd isotopes] → Ag [two stable Silver isotopes]

LENRs: Zhang & Dash (2007) - Fig. 8



Note: Pd boiling point = 2,970 ^oC

LENRs: Zhang & Dash (2007) - Fig. 9

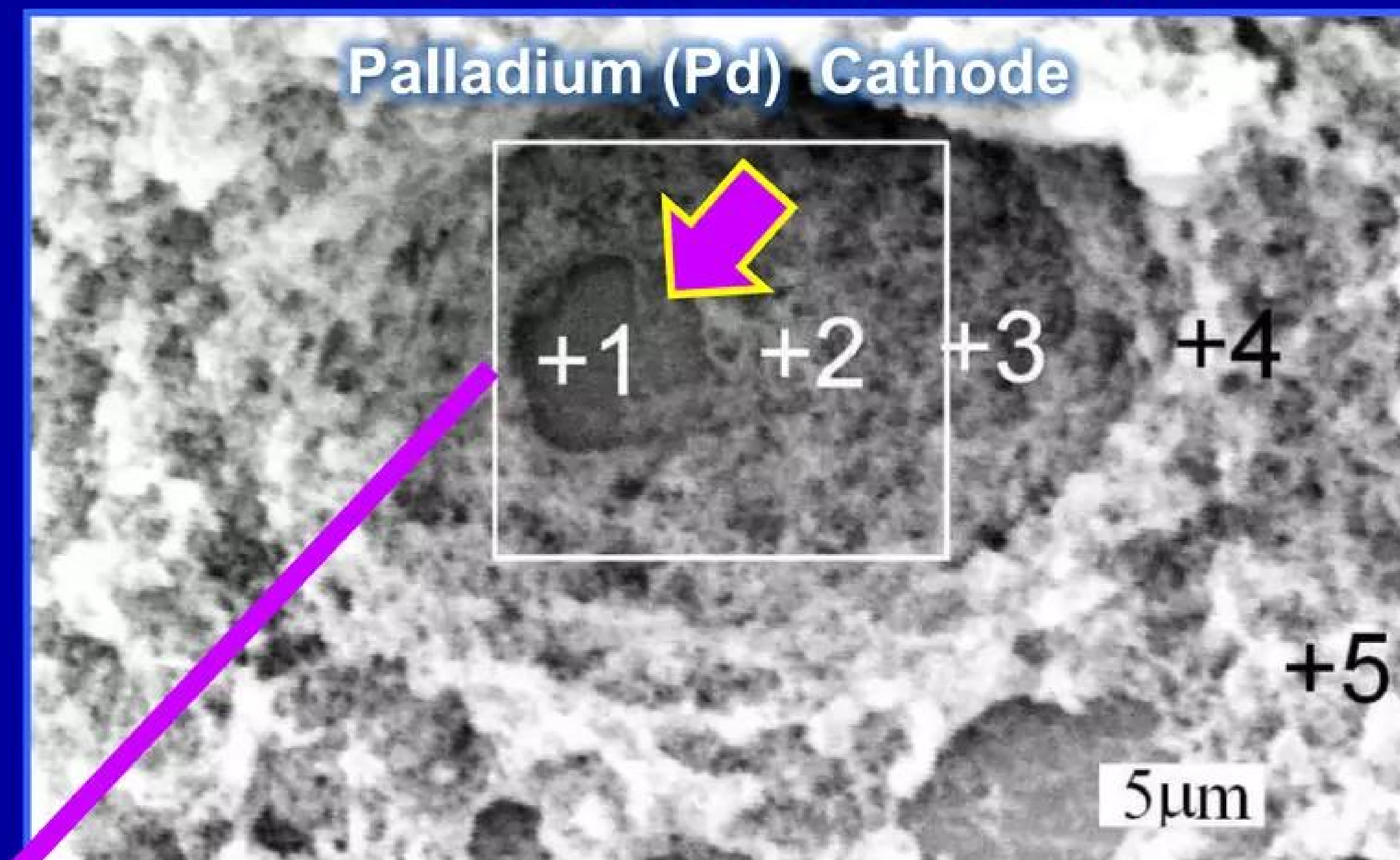


Fig. 9. SEM picture of crater at another time. SEM No.WS060607Pd-H-CC-i2-2kX

Quoting: "The most common finding is that Silver occurs in craters, such as those shown in Fig. 8. These craters with rims almost certainly formed during electrolysis. Pt deposition was concentrated on these protruding rims."

Zhang & Dash: Table IX. Relative atomic percent concentrations of Silver (Ag) in area and spots shown in Fig. 9

Spot #	wa*	area**	+1	+2	+3	+4	+5
Ag/(Pd+Ag)	1.2 +/- 0.5	5.6 +/- 0.4	6.8 +/- 0.4	5.6 +/- 0.3	6.3 +/- 0.4	3.6 +/- 0.6	1.2 +/- 0.5

*wa = whole entire area comprising image in Fig. 9

** area = delimited by the white square outlined in Fig. 9

Lattice Energy LLC

LENR transmutation products seen near surface craters

Anomalous Nickel (Ni) found on Palladium surface post-experiment

Silver (Ag) and Nickel (Ni) not present on surface when LENR experiments began

Reference:

"*Excess heat reproducibility and evidence of anomalous elements after electrolysis in Pd/D_2O + H_2SO_4 electrolytic cells*"

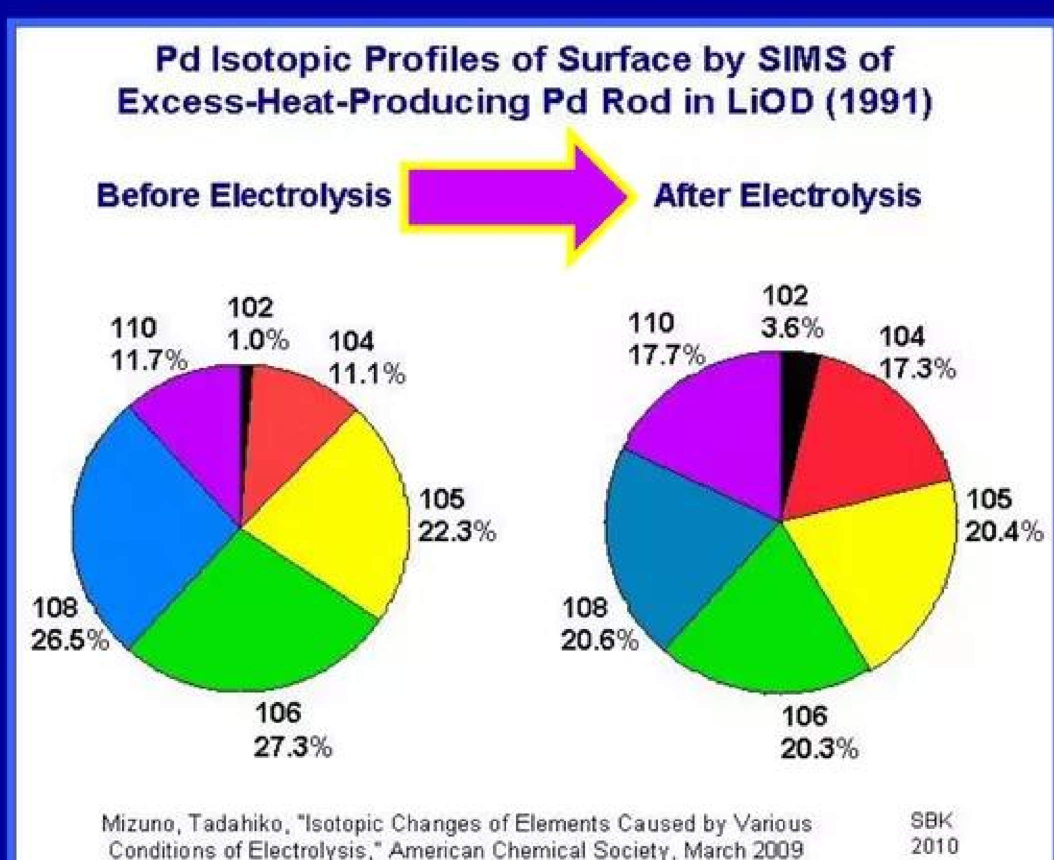
W. Zhang and J. Dash

Presented at the 13th International Conference on Condensed Matter Nuclear Science, Sochi, Russia (2007)

Free copy of above paper available at:

http://www.lenr-canr.org/acrobat/ZhangWSexcessheat.pdf

T. Mizuno & H. Kozima - ACS (March 2009):



Quoting from discussion of Fig. 10: "Ni was listed as '*not detected*' in the chemical analysis provided by the vendor of the Pd foil. It is very unlikely to have resulted from the cold rolling process or from electrodeposition because it is highly localized near one corner of the cathode. If it is the result of either contamination from the rolling mill or from electroplating it should not be highly localized on only one corner of the cathode. It could not have resulted from SEM systems because the stainless steel components of the SEM chamber also contain Fe and Cr. Fe and/or Cr are not present in any of the spectra. The SEM does not have components made of pure Ni. Therefore, the origin of the Ni is not known."

Zhang & Dash (2007) --- Fig. 10. SEM picture of region #2 in Fig. 4(b). SEM No.WS060424Pd-H-CC-i2-150X

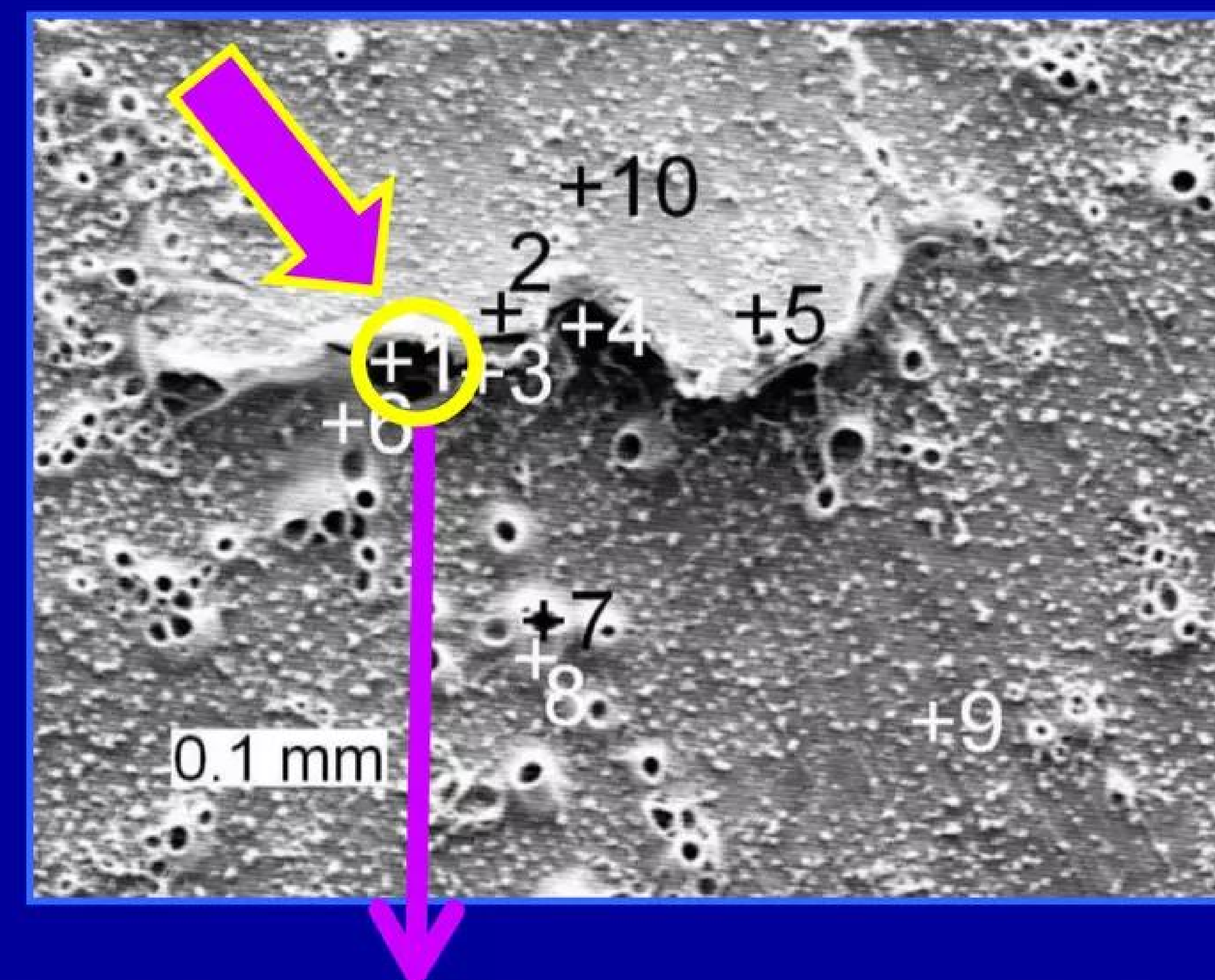
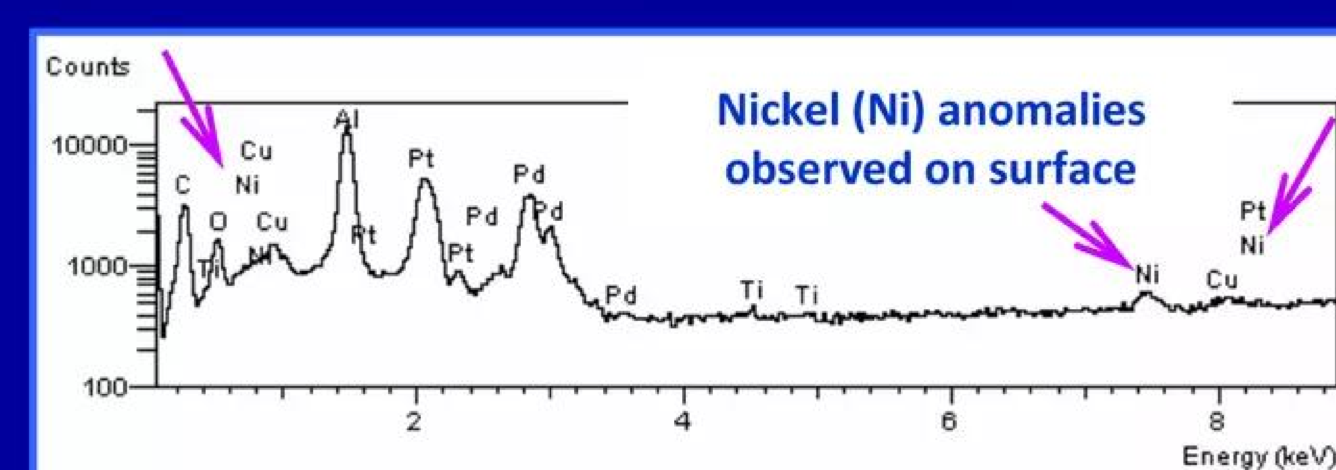


Fig. 11. Characteristic X-ray spectrum of Spot #1 in Fig. 10



Lattice Energy LLC

LENR-produced and laser ablation craters very similar

Spherically-shaped droplets are created in explosive boiling processes

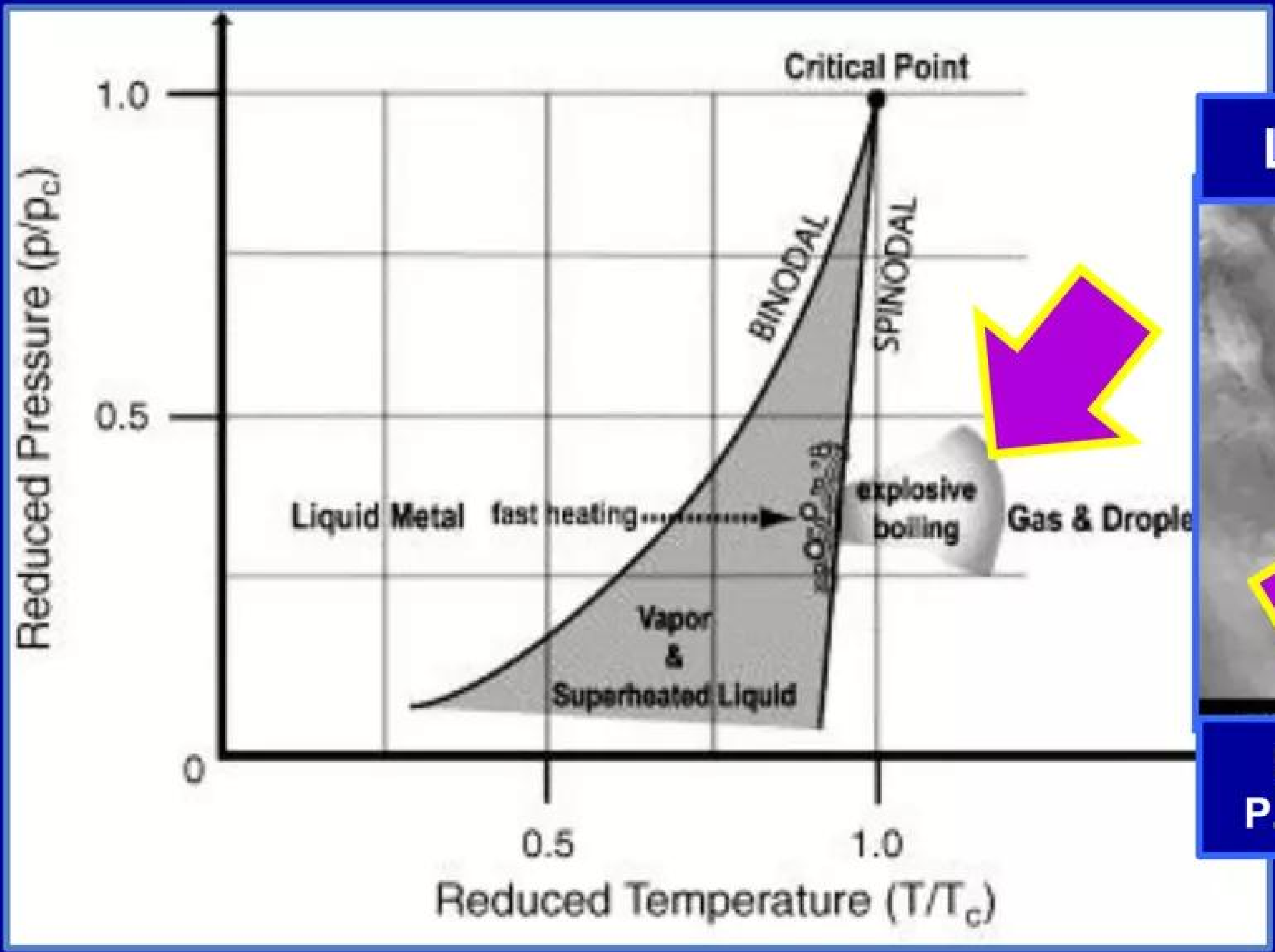
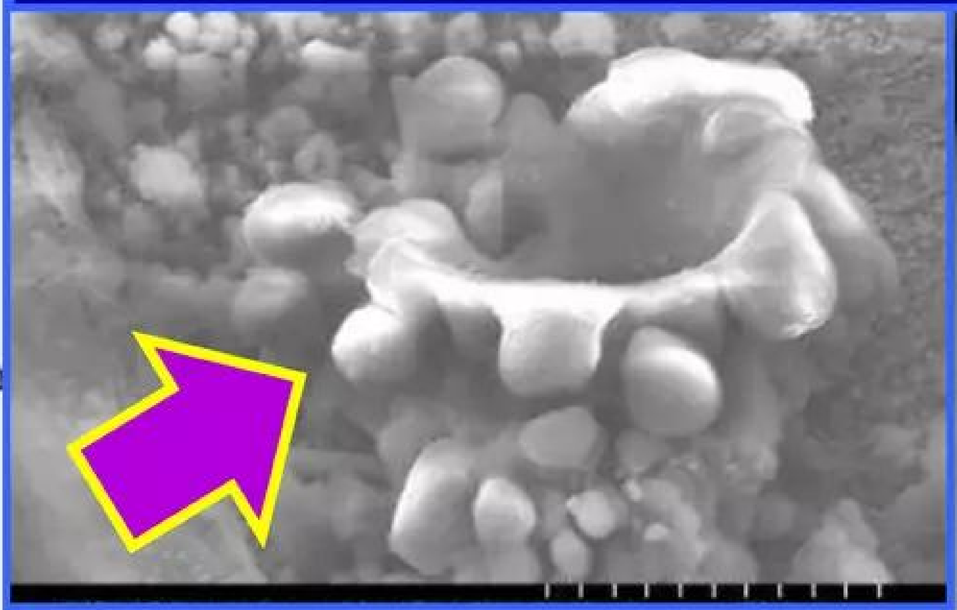


Fig. 1. Phase stability diagram of a liquid metal near the critical point. For fast heating, as obtained during *ns* laser ablation, the melt can be pushed close to critical conditions (superheating), which favors the realization of explosive boiling

LENR

LENR crater on Palladium



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

Hydrodynamic analogue of boiling

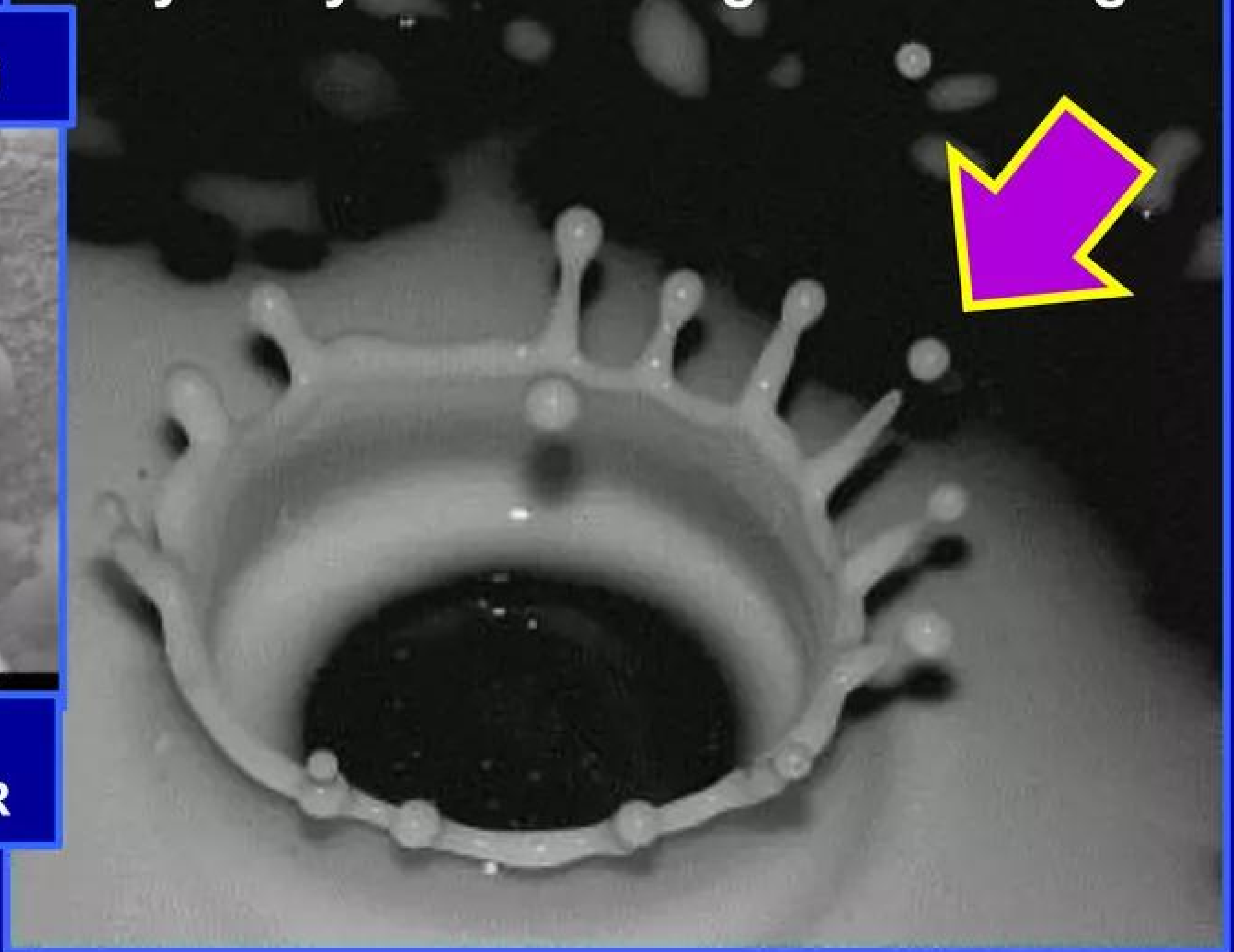


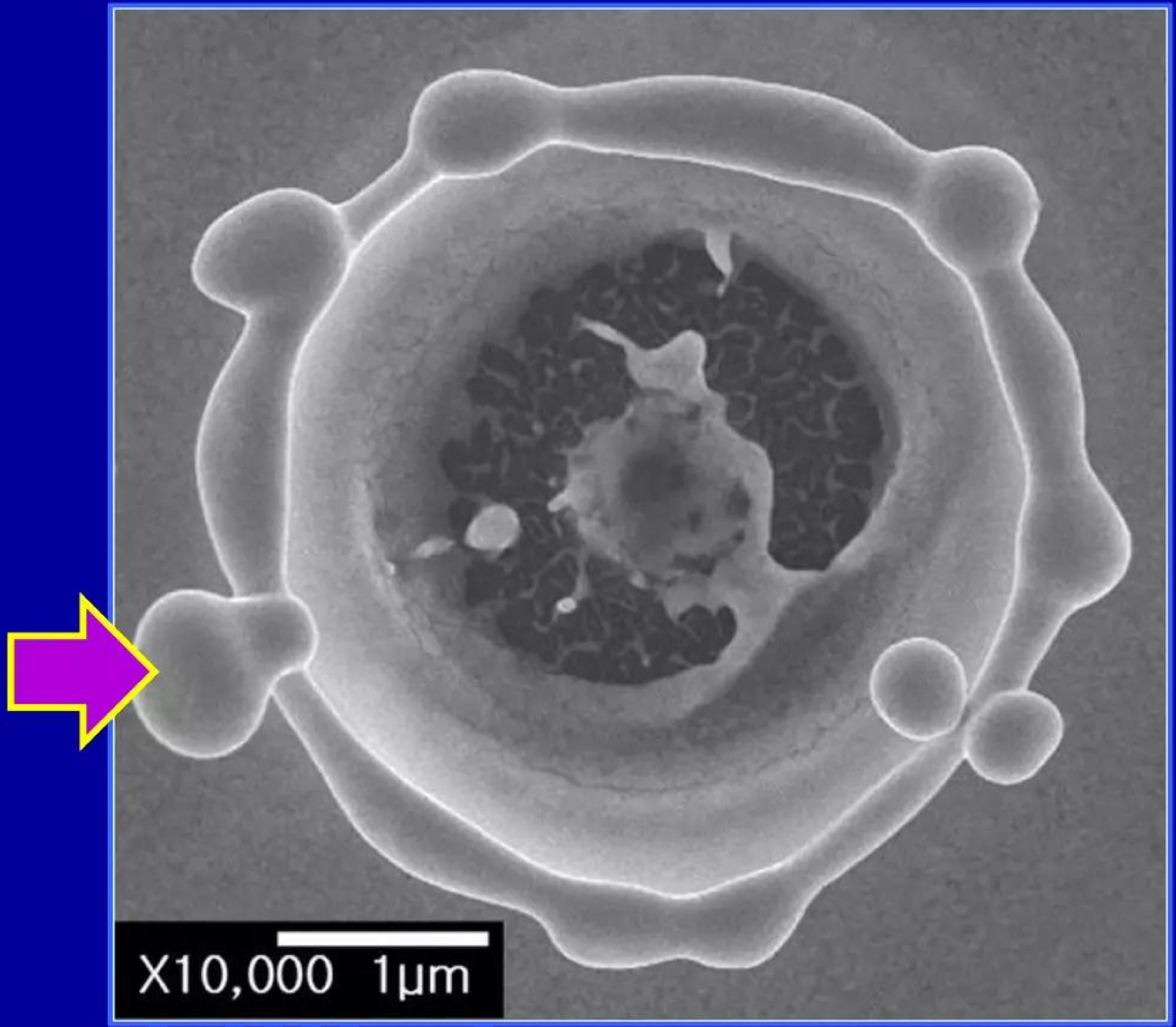
Fig. 2. Schematic visualization of the hydrodynamic evolution of a fluid system under and impulse stress (here milk). Note the non-deterministic formation of jets at the sides and their break-up into droplets. From Ref. [58].

Excerpted and quoted directly 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

Lattice Energy LLC

LENR-produced and laser ablation craters very similar

Droplets on crater rim identical to U.S. Navy SEM images of Pd craters



"Nanosecond laser ablation of silver nanoparticle film", J. Chung *et al. Optical Engineeering* 52 pp. 024302 (2013)

Source: http://opticalengineering.spiedigitallibrary.org/article.aspx?articleid=1569388

Lattice Energy LLC

Laser ablation process complex on many time-scales

Still not fully understood in many aspects and active area of research

LENR-driven ablation is more complicated because nuclear processes operate

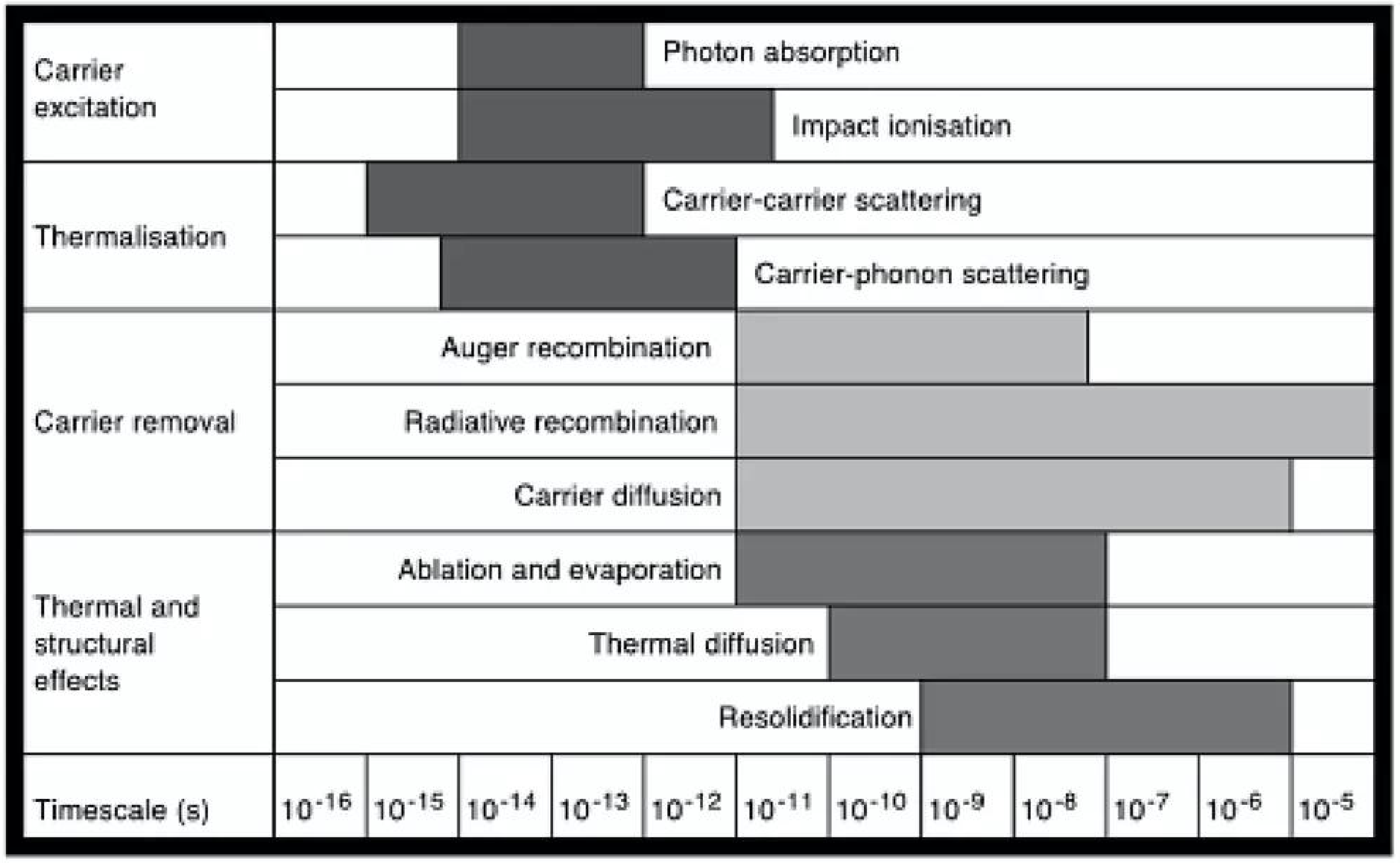


Figure 2.1. Processes (and associated timescales) taking place in the target following the absorption of the laser pulse. Ablation typically takes place on a timescale of ps (onset) to a fraction of a ns (complete). (Adapted from Ref. [22]).

"Laser ablation in liquids: principles and applications in preparation of nanomaterials"
G. Yang *ed.*, Fig. 2.1 on pp. 115, Pan Stanford Publishing Pte. Ltd., (2012) 1,125 pages ISBN 978-981-4310-95-6

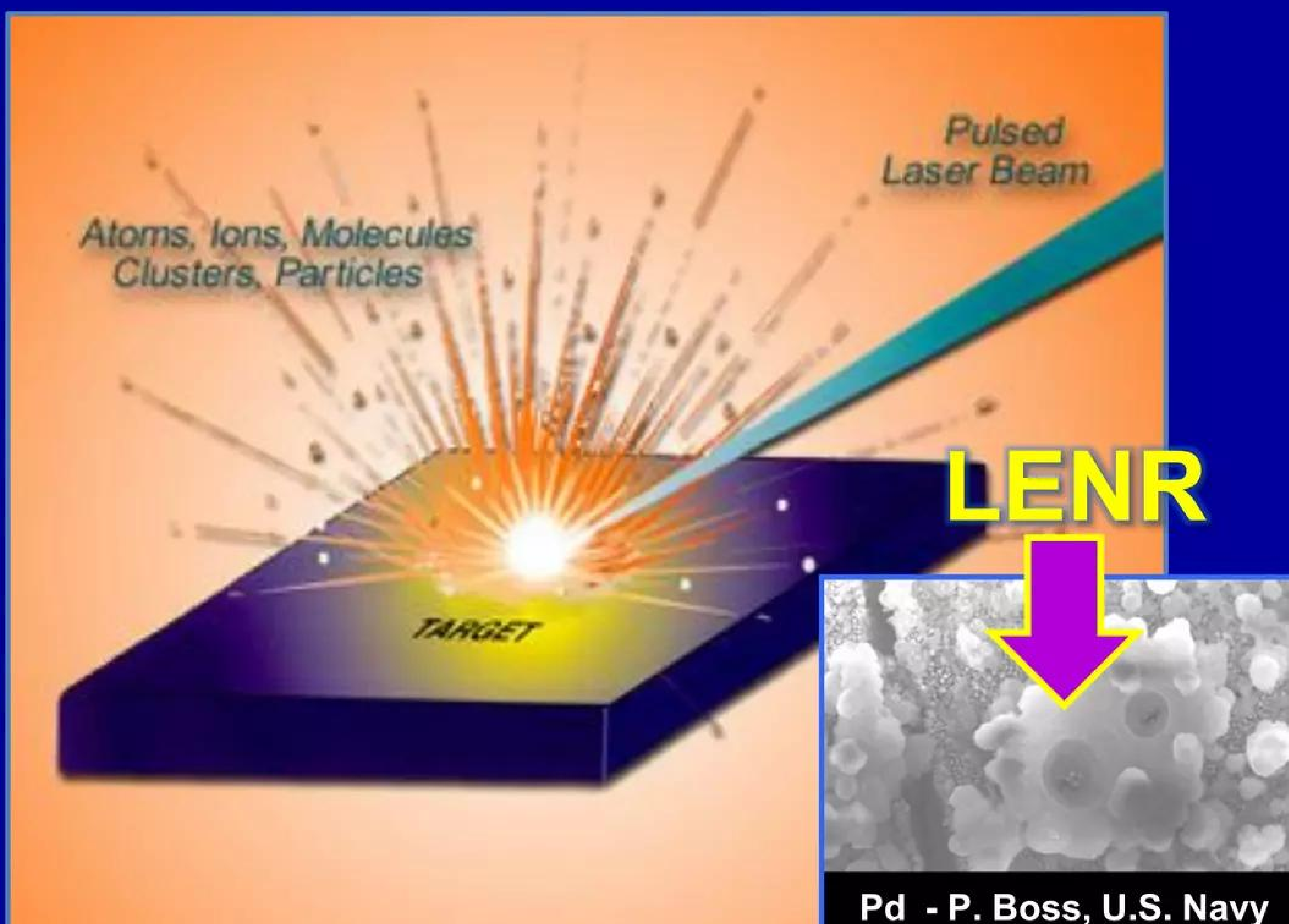
Lattice Energy LLC

LENR-produced and laser ablation craters very similar

Produce micron-scale craters having similar sizes and morphologies

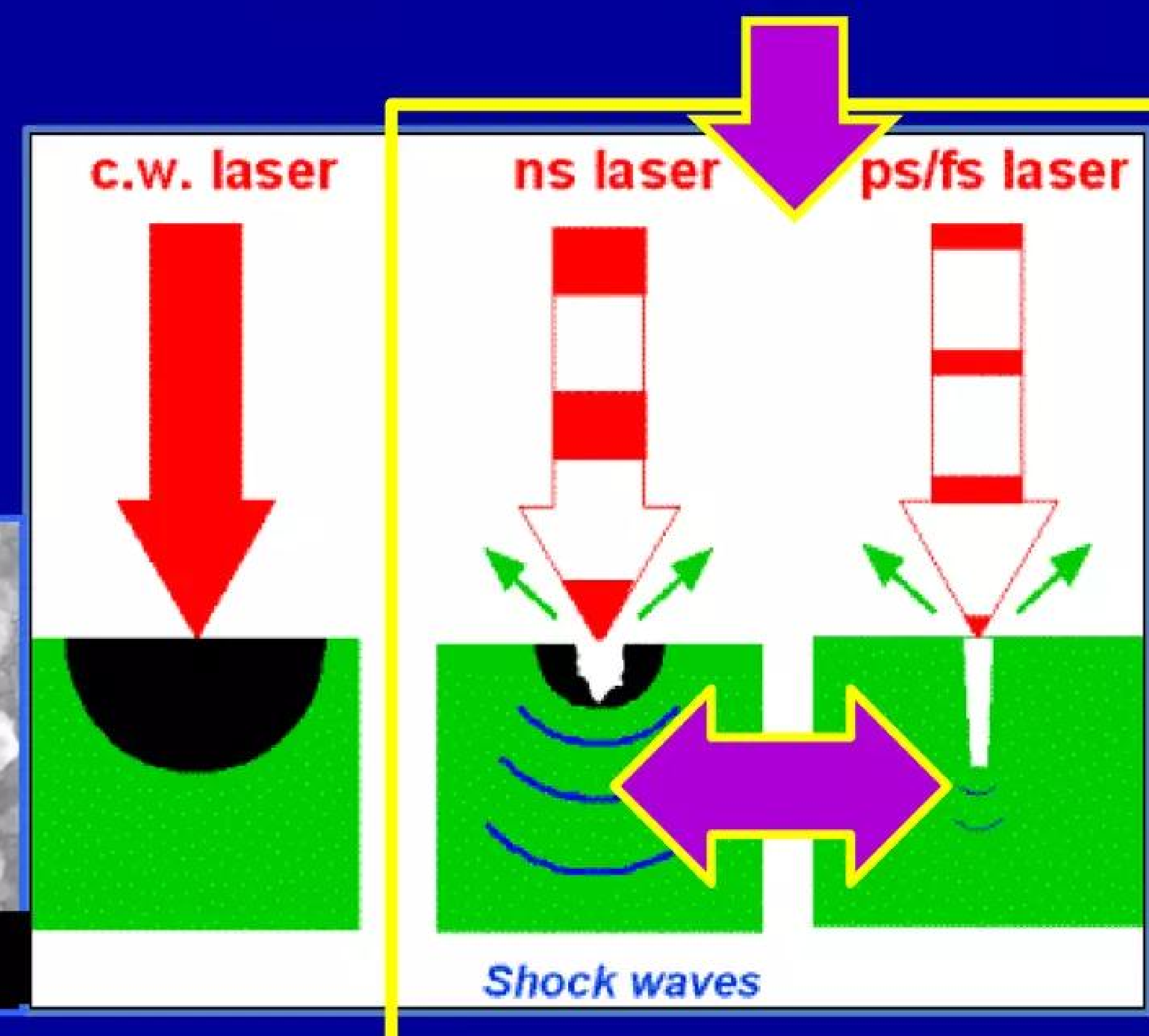
Some LENR craters exhibit steep walls that suggest very rapid energy releases

Direct gamma conversion in LENR-active sites creates intense infrared radiation sources



Pd - P. Boss, U.S. Navy

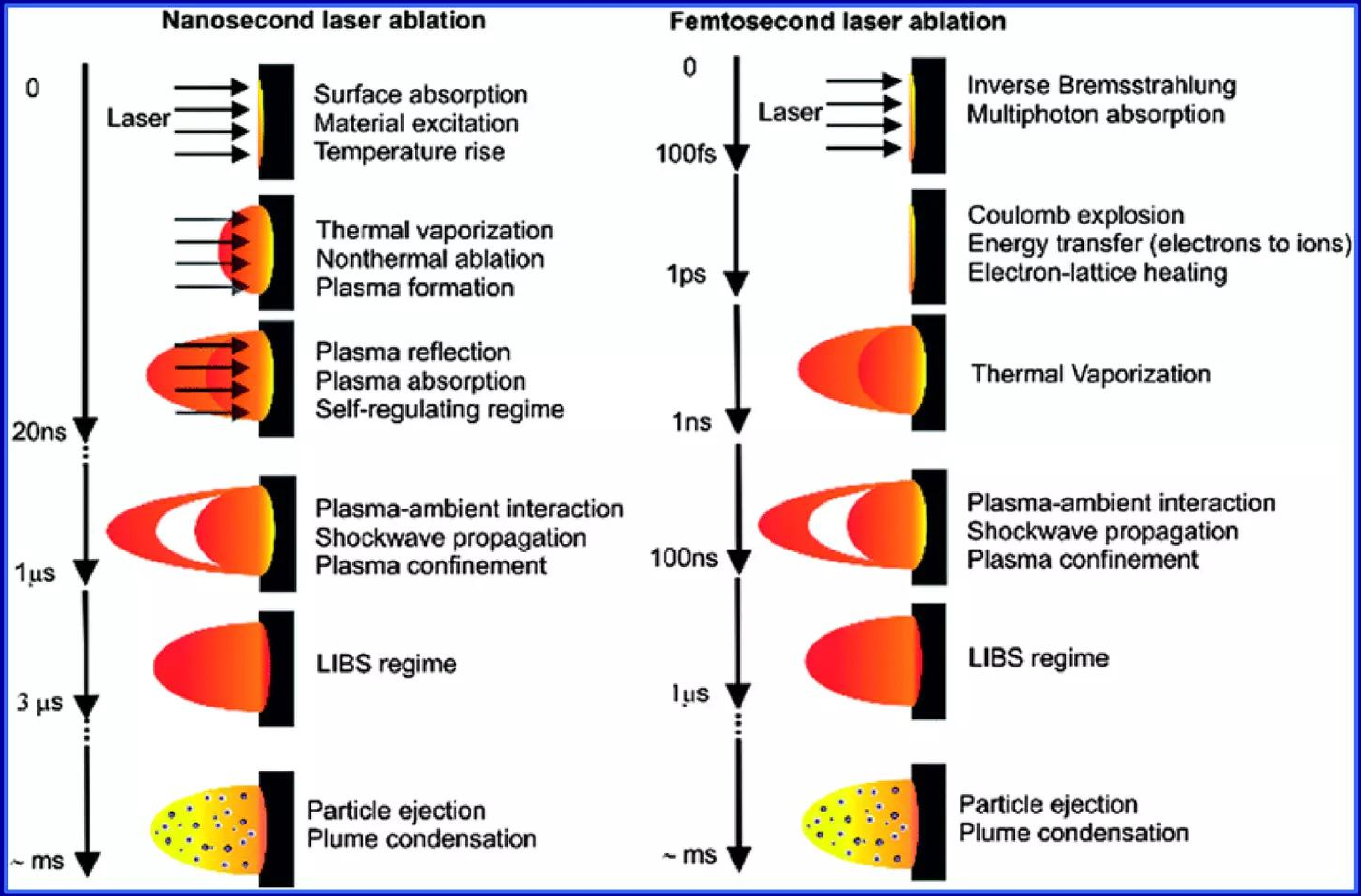
Shorter-duration laser pulses produce craters with steeper, sharply defined vertical walls



Lattice Energy LLC

LENR-produced and laser ablation craters very similar

Energy pulse duration changes temporal evolution of ablation process

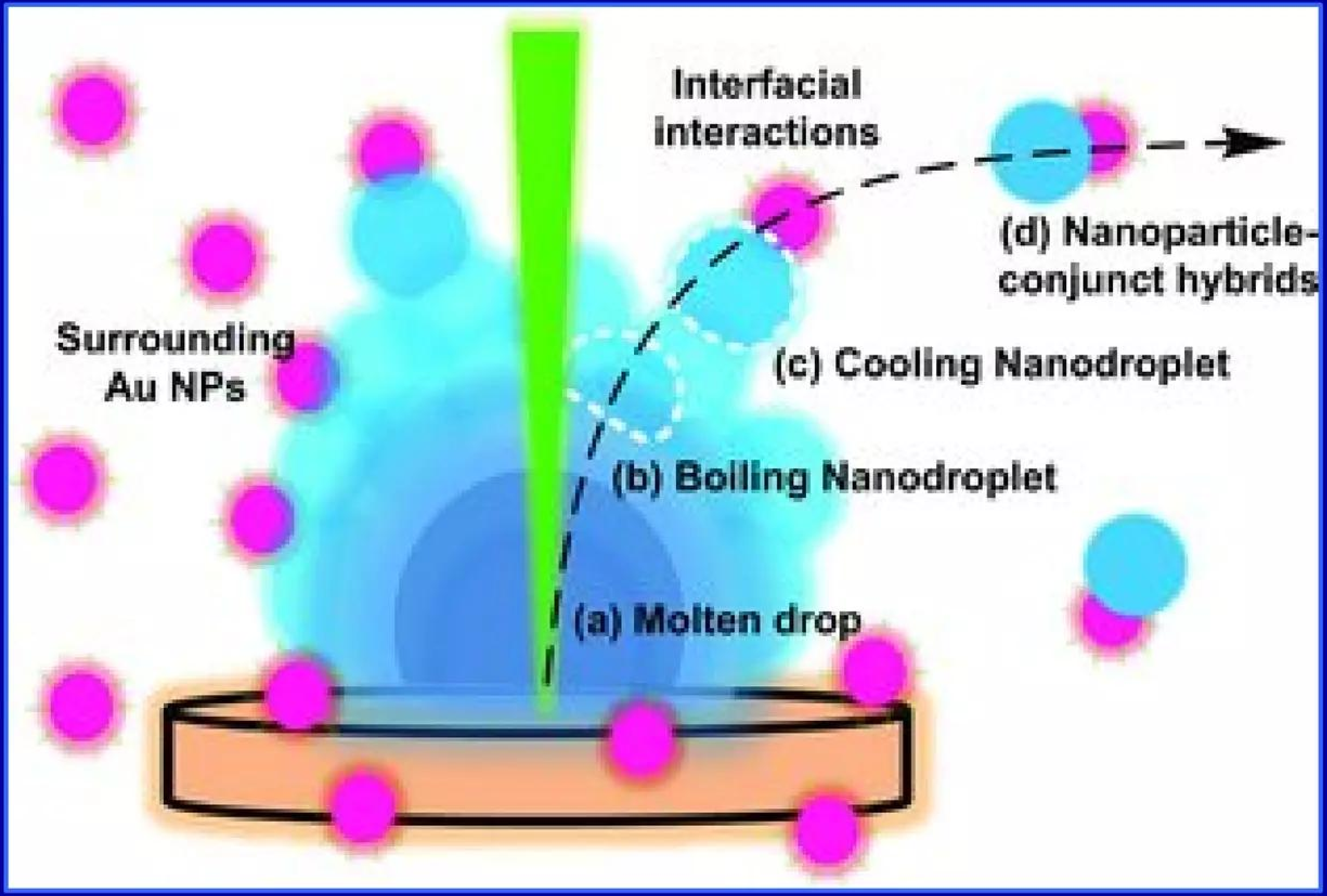


Lattice Energy LLC

LENR-produced and laser ablation craters very similar

Ablation produces energetic electrons, ions, molecules, and droplets

Particles all embedded in a rapidly expanding ball of hot, dense, ionized plasma



Source: "Complex oxide-noble metal conjugated nanoparticles"
J-L. Guo *et al., Advanced Materials* 25 pp. 2040 - 2044 (2013)

Metal phase explosions involve huge volume expansions

Microscopic detonations are caused by thermal vaporization of metals

Solid-to-vapor phase expansion ratios with metals can range up to ~150,000x

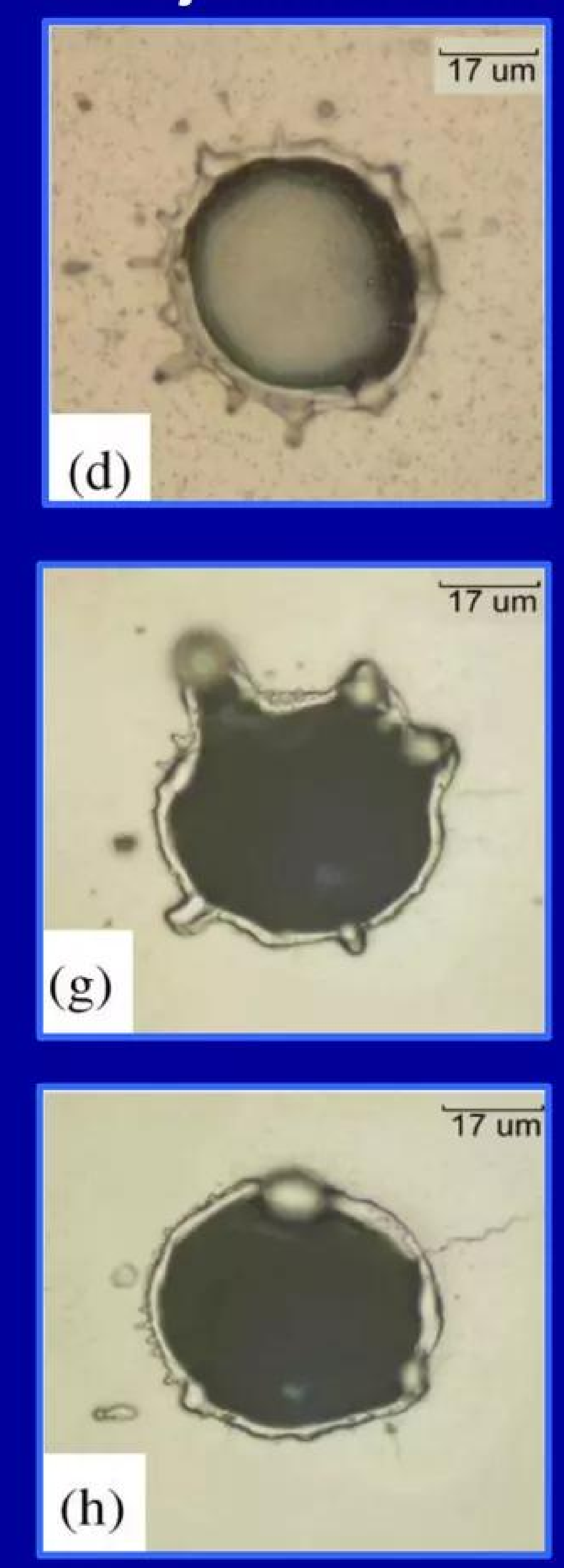
Intense heating by nuclear processes during short lifetimes of micron-scale LENR-active sites on metallic substrates can result in local flash-boiling of metals in what is also known as a phase explosion. In such events, a local region of metal is vaporized; depending on metal and peak temperature reached, heated material can expand as a vapor by 40,000 to 150,000 times its previous volume as a solid. Vapor cloud cools and condenses into tiny droplets, creating perfect microspheres; these can be observed in NTSB SEM images of the ruins of $LiCoO_2$ GS-Yuasa battery involved in 2013 Logan Boeing 787 Dreamliner runaway

"Phase explosion and Marangoni flow effects during laser micromachining of thin metal films"
http://lyle.smu.edu/~mhendija/index_files/Hendijanifard%20SPIE2008.pdf

Their most recently published work alone this line of inquiry is:

"Nanosecond time-resolved measurements of transient hole opening during laser micromachining of an Aluminum film"
M. Hendijanifard and D. Willis
***Journal of Heat Transfer* 35 article #091201 (2013)**

Hendijanifard & Willis



Lattice Energy LLC

Craters from LENRs and laser ablation are very similar

Same morphologies imply both are fast thermal transfers to surfaces

Energy transfer causes phase and Coulomb explosions of metals and plasmas

- ✓ **Metallic phase explosions can propel relatively large amounts of material into immediate surroundings; consequence: nearby plasmas or neutral gases will undergo strong heating with further ionization of components**
- ✓ **LENR-produced thermal ablation at 4,000 - 6,000° K on surface sites will create populations of energetic electrons, fast ions, charged molecules, charged metallic clusters, gas, and high-velocity neutral nanoparticulates**
- ✓ **LENRs may also trigger Coulomb explosions ("cold ablation") in which intense pulses of IR and UV photon radiation from LENR-active sites either cause "avalanche" photoionization or utilize direct interband absorption to generate Coulomb explosion threshold charge densities; expands 'cloud' of charged particles driven by electrostatic repulsion - see: http://upload.wikimedia.org/wikipedia/commons/thumb/5/52/Bucky1.gif/220px-Bucky1.gif**
- ✓ **Various very fast, energetic chemical reactions also occur in such hot, dusty plasmas; chemistry therein is very much akin to surfaces of stars**

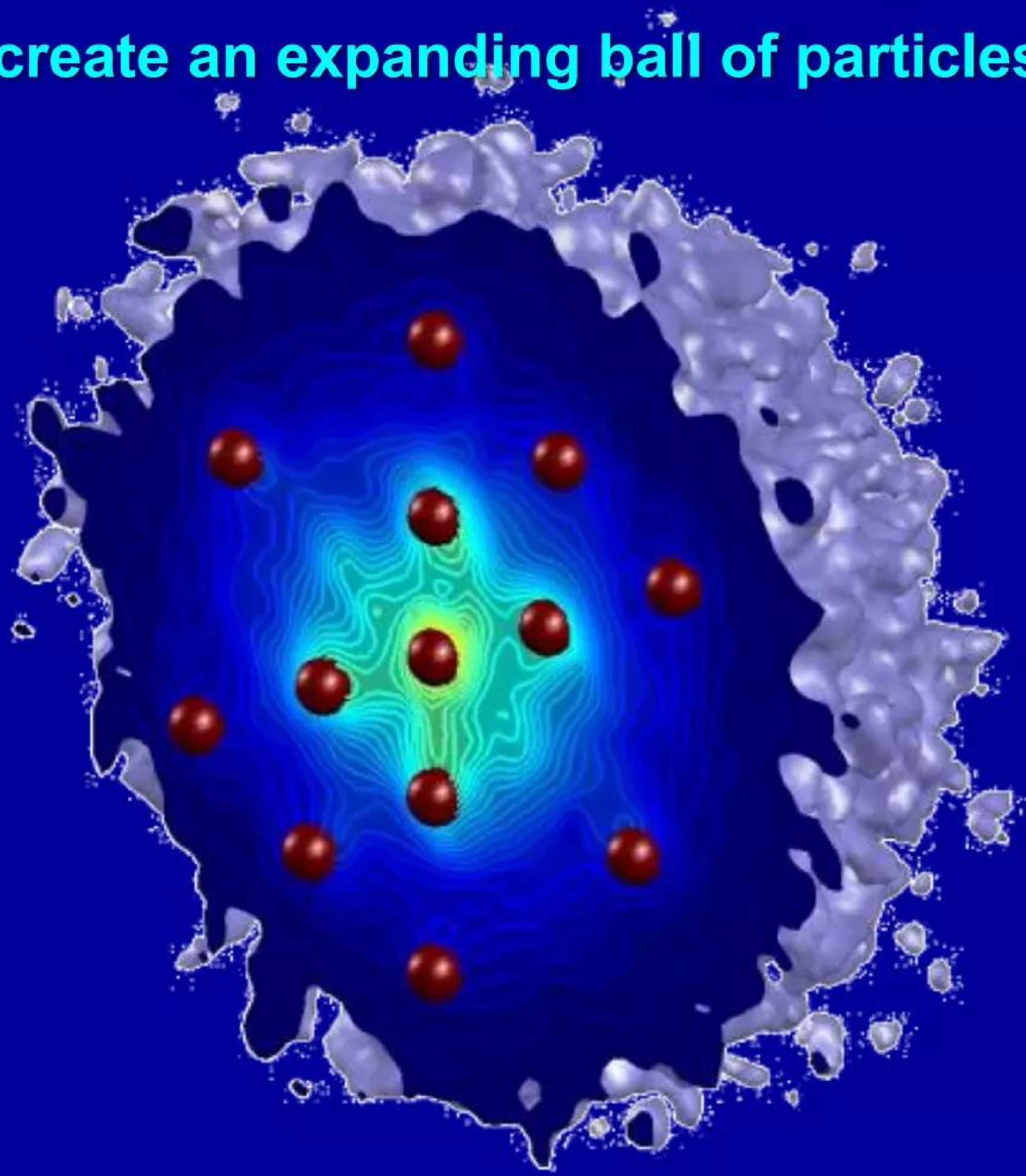
Lattice Energy LLC

‘Cold’ Coulomb explosions driven by electrostatic forces

Simulation depicts Coulomb explosion of an irradiated Sodium cluster

Coulomb explosions create an expanding ball of particles during “cold ablation”

Quoting: “The image shows the electron density of a Na_{55} cluster after resonant excitation with a 50 fs laser pulse (E_{photon}=2.7eV). The snapshot of the electron density is taken 50 fs after the pulse maximum showing the expanding ions surrounded by a hot electron cloud. The density is highly non-uniform as displayed for the y=0 plane. (n_e=1.8×10^{22} cm^{-3} in the cluster center, the blue isosurface corresponds to n_e=10^{20} cm^{-3}).”



Quoting: “Metal clusters are ideal subjects to investigate the impact of many-particle effects on the dynamics of intense laser-matter processes. As a results of electron delocalization, nanoparticles from simple metals exhibit a pronounced surface plasmon in their optical spectrum. For intense femtosecond laser excitations sufficiently close to a collective mode, the surface plasmon, high energy deposition leads to the rapid creation of a hot and dense plasma - followed by a Coulomb explosion of the highly excited system.”

Image source Prof. Ronald Redmer (Univ. of Rostock): http://web.physik.uni-rostock.de/statphys/pages/radiation.html

Lattice Energy LLC

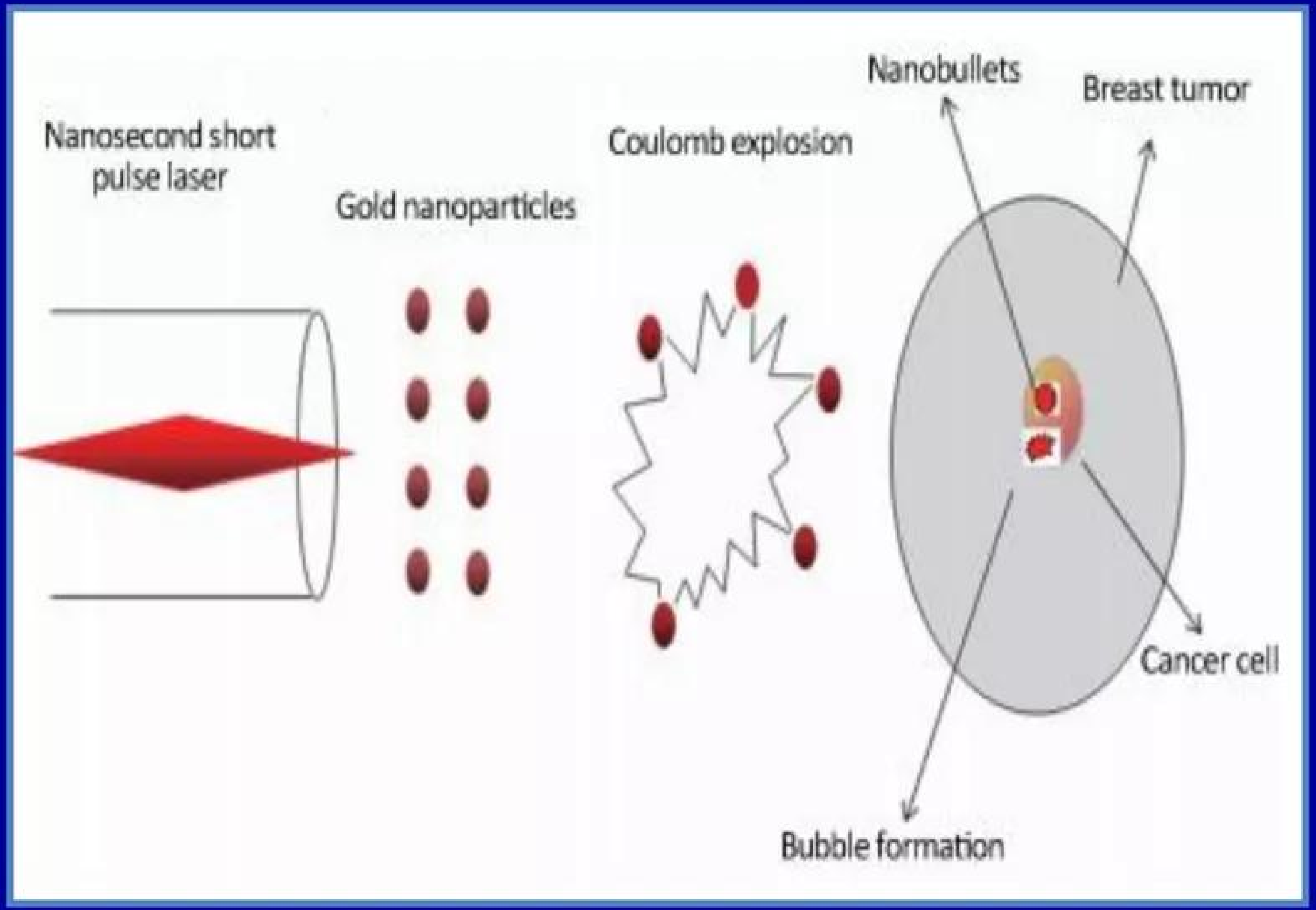
'Cold' Coulomb explosions driven by electrostatic forces

Laser used to trigger Coulomb explosion of a 10 nm Gold nanocluster

Coulomb explosion volume expansion ratio of nanoparticle cluster = ~6.4 x 10^7x

- ✓ "When a gold nanoparticles cluster of 10 nm radius is irradiated by laser pulse duration of 10 ns, a bubble with a radius of 4 µm (4,000 nm) is produced inside aqueous breast cancer [tissue]."
- ✓ Spherical Gold nanoparticle cluster with r = 10 nm has a volume = 4,189 nm^3 = 4.189 x 10^3 nm^3
- ✓ After irradiated with short laser pulse, Coulomb explosion of Gold target nanoparticle creates spherical bubble with radius (4 microns) 4,000 nm has volume = 2.68 x 10^{11} nm^3 ; contains tiny pieces of nanoparticle, steam, tumor materials
- ✓ Expansion ratio of bubble volume vs. that of prior Au nanoparticle cluster is = ~6.4 x 10^7x

Fig. 2 Schematic diagram of short pulse laser interaction with gold nanoparticles



"Breast cancer therapy by laser-induced Coulomb explosion of gold nanoparticles," M. Ashiq *et al.*, *Chinese Journal of Cancer Research* 25 pp. 756 - 761 (2013)

Source: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3872559/pdf/cjcr-25-06-756.pdf

Lattice Energy LLC

Energetic chemical reactions can occur in dusty plasmas

Operate parallel with energetic LENR-based phase/Coulomb explosions

"Burn 'em all --- let God sort 'em out." [1.]

"You can run, but you can't hide." [2.]

LENRs are themselves energetic materials and quickly create other energetic materials

- ✓ LENRs and arc discharges create local temperatures comparable to those found on stellar surfaces; LENR-based dusty plasma propulsion systems can be engineered to reliably handle such temperatures safely
- ✓ Formidable local "witches' brew" cauldrons of rapidly inter-reacting compounds and ions are created in reaction chambers of hypersonic vehicles; hyper-accelerated reaction rates occur in superheated zones
- ✓ Witches' brews can internally generate their own supplies of molecular Oxygen to support fast detonation processes that propagate spatially through reaction vessels via supersonic, autocatalytic flame-fronts coupled with intense emission of thermal infrared and UV radiation
- ✓ LENR- and electric arc-heated regions' behavior is almost more akin to chemistry of stellar atmospheres than ordinary combustion processes

Adapted from a U.S. military motto

Popularized by U.S. special operations forces during the 1960s Vietnam war

1.. Underlying motto unofficially adopted by various military groups; originally, was modernized from Latin, "Caedite eos. Novit enim Dominus qui sunt eius" which literally translated means "Kill them all. God will recognize His own." Quote attributed to Arnaud, Abbot of Citeaux, in reply to question asking how one might tell Cathar heretics from orthodox Catholics during siege of Beziers in Albigensian Crusade (July, 1209)

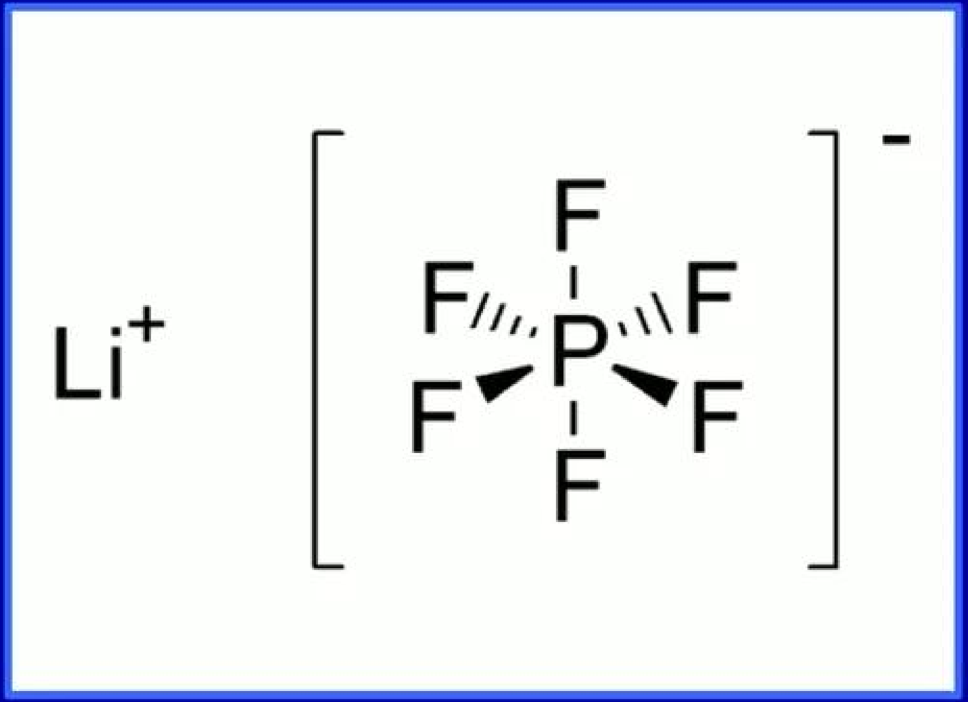
2. Threat made to Mad Max by murderous character named "Wez" in Mel Gibson's cult-classic film, "The Road Warrior" (1981)

Lattice Energy LLC

Energetic chemical reactions can occur in dusty plasmas

Formation of Lithium Fluoride releases enormous amounts of heat

- ✓ $LiPF_6$ = Lithium hexafluorophosphate; at right - ionic molecular structure
- ✓ Noted in NTSB technical report as being detected during Logan Airport Boeing 787 thermal runaway incident GS-Yuasa battery materials analysis
- ✓ Chosen for ferrying Li^+ ions between battery anode and cathode because highly soluble in non-aqueous, nonpolar electrolyte solvents such as diethyl carbonate and dimethoxyethane
- ✓ Melts at ~194° C; thermal decomposition begins at 262 - 284° C; it then decomposes into LiF and PF_5
- ✓ Formation of LiF releases one of the highest known energy per mass of reactants, only second to that of BeO --- see next slide for details about energetics



Lattice Energy LLC

Energetic chemical reactions can occur in dusty plasmas

Gaseous Lithium and Fluorine ions near LENR-active sites can form LiF

Once a dusty plasma plume is locally heated to thousands of degrees and materials begin to intermix, the variety and complexity of chemical as well as LENR reactions that become possible increase substantially and somewhat unpredictably; this confluence of energetic processes creates what Prof. Michel Armand (Univ. Picardie, Paris) calls a **"witches' brew"**

Formation of solid lithium fluoride from the gaseous Li^+ and F^- ions:

$$Li^+(g) + F^-(g) \longrightarrow LiF(s)$$

Formation of solid lithium fluoride from the gaseous Li^+ and F^- ions:

$$Li^+(g) + F^-(g) \longrightarrow LiF(s)$$

This corresponds to the lattice energy for LiF, which is −1047 kJ/mol.

Since the sum of these five processes yields the desired overall reaction the sum of the individual energy changes gives the overall energy change:

Process	Energy Change (kJ)
$Li(s) \rightarrow Li(g)$	161
$Li(g) \rightarrow Li^+(g) + e^-$	520
$\frac{1}{2}F_2(g) \rightarrow F(g)$	77
$F(g) + e^- \rightarrow F^-(g)$	−328
$Li^+(g) + F^-(g) \rightarrow LiF(s)$	−1047
Overall: $Li(s) + \frac{1}{2}F_2(g) \rightarrow LiF(s)$	−617 kJ (per mole of LiF)

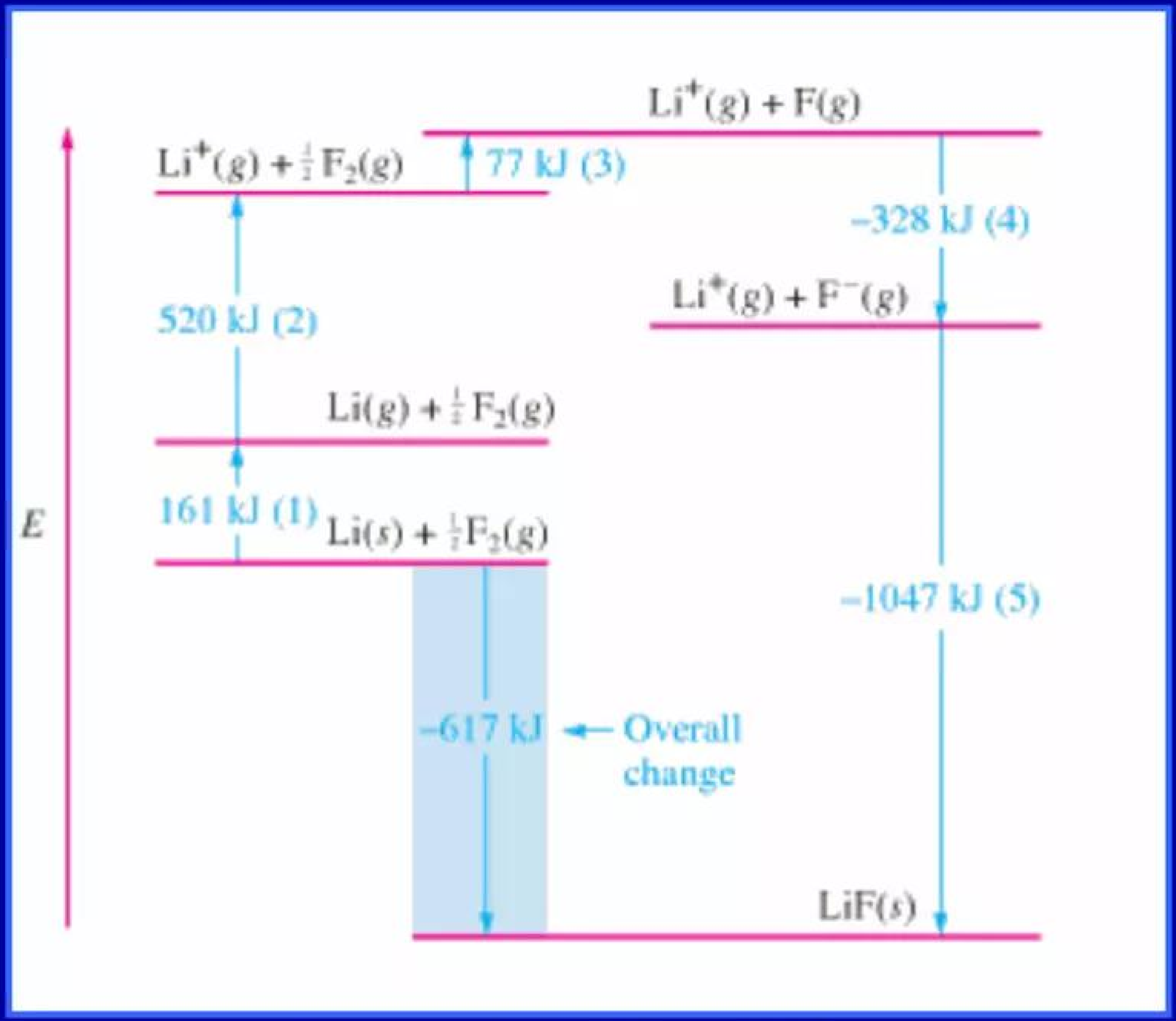


Figure 13.9 in Zumdahl

Source: "Chemical Principles" S. Zumdahl, pp. 608 in 6th edition, Houghton Mifflin (2009)

Lattice Energy LLC

Energetic chemical reactions can occur in dusty plasmas

Al + HF reaction below releases ~ 6x as much thermal energy vs. TNT

Engineered target fuel particles can support both LENRs and chemical reactions

Examples of two classic very exothermic thermite reactions:

$Fe_2O_3 + 2\,Al \rightarrow 2\,Fe + Al_2O_3$

Al_2O_3 △f H° (solid) = - 780 kJ/mol.

$3\,CuO + 2\,Al \rightarrow 3\,Cu + Al_2O_3$

Al + HF is 2x CuO + Al and ~6x TNT

- ✓ Please recall that LiF can be formed in LENR dusty plasmas; when it is heated enough beyond its B.P. (1,681° C) in witches' cauldrons it can decompose to form HF, which can then enable the following reaction:

AlF_3 △f H° (solid) = - 1510.4 kJ/mol.

$$2\,Al(s) + 6\,HF(g) \xrightarrow{400\text{ - }600^{o}C} 2\,AlF_3(s) + 3\,H_2(g)$$

- ✓ Highest-temperature regions in and around localized witches' cauldrons (almost star-like in many ways) can be hot enough to liberate metal ions which can then react with Oxygen to create burning metals, which is a high-temperature process
- ✓ Cobalt metal burns in air @ ~2,760° C; Aluminum @ ~3,827° C; Iron @ ~870° C; burning metals release huge amounts of heat

Note: Al, Fe, Cu, O, etc. can be included in engineered LENR target fuel nanoparticles; potential to form various types of energetic materials in witches' brew cauldron areas

material	energy density	
	by mass: MJ/KG	by volume: MJ/L
aluminothermic incendiaries		
Thermite ($Al + Fe_2O_3$)	4.13	18.40
Copper Thermite (Al + CuO)	4.00	20.90
nitro-aromatic explosives		
TNT (Trinitrotoluene)	4.61	6.92

Can dynamically synthesize explosive nano-pyrotechnic compounds in localized regions in or near fuel nanoparticles

Lattice Energy LLC

Phase explosions can have very large expansion ratios

How do metal phase explosions compare to other types of explosives?

> "A physical explosion involves … rapid application of heat lead[ing] to instantaneous vaporization … [with] rapid expansion … and vaporization of [heated] material … [to] produce both gas and heat and occur over a short time … [The explosion] must produce … hot, high-pressure gas required for doing significant work on its surroundings."
>
> Neil Bourne on page 24 in *Materials in Mechanical Extremes: Fundamentals and Applications*, Cambridge University Press (2013)

- ✓ **Iron (Fe) metallic phase-change explosion:** if heated up to 10,000° K will expand in volume by ~150,000x vs. its solid phase; other metals will expand by 40,000x - 70,000x from original volumes in going from solid to a vapor
- ✓ **Steam explosion (purely phase change):** liter of liquid water (H_2O) heated to pressure of 101.3 kPa and temperature of 1,500° K will expand by 8,047x
- ✓ **Hydrogen peroxide (H_2O_2 - HP - explosive decomposition into steam):** expansion ratio for 70% HP is ~2,500x and for 85% HP the value is ~4,500x
- ✓ **Chemical explosives (detonation):** measured expansion ratios for ANFO, emulsion explosives (EM), nitromethane (NM), and BA (highly aluminized slurry explosive) range from 10x up to ~10,000x; nitroglycerin is ~5,888x

Lattice Energy LLC

Electric arcs strongly heat conductive dusty plasmas

DC electric currents can raise plasma temperatures up to 20,000º C

Injections of high-current electrical energy trigger LENRs in such plasmas

- ✓ Injection of DC electric arc currents can be used as input energy required to trigger LENRs on surfaces of target fuel nanoparticles embedded in very conductive dusty plasmas; these plasmas can be safely contained inside magnetic flux tubes having ~cylindrical geometries
- ✓ Triggering energy is in the form of electromagnetic pulses rather than via thermochemical mechanisms like chemical deflagration or detonation, so LENR input energy can propagate vastly faster though a reaction chamber compared to much slower O_2 combustion processes
- ✓ From published experimental data on electrical input energy pulse widths we know that LENR-active sites can set-up and initiate neutron production as little as a few tens of nanoseconds (ns); this is small percentage of their estimated total lifetime of ~300 - 400 ns
- ✓ Neutron captures occur within picoseconds (capture gammas converted directly to IR by heavy-mass SP electrons), so neutron production and capture rates much higher than local beta-decay rates; this leads to creation of local metastable population of extremely neutron-rich intermediate isotopic products with very short half-lives that accumulate temporarily
- ✓ When LENR-active sites 'die' these neutron-rich products decay vary rapidly into stable elements; thus, essentially zero production of hazardous long-lived radioactive isotopes

Lattice Energy LLC

Electric arcs strongly heat conductive dusty plasmas

DC electric currents can raise plasma temperatures up to 20,000° C

High-current electric discharges can readily trigger LENRs in such plasmas

Electromagnetic energy input triggers LENR nuclear	Location	Temperature range in ° C	Physical dimensions	What happens therein?	Comments
Energy Input: Electric discharges: that is, DC arcs or sparks Used to further heat dusty plasmas and trigger LENRs	Outer edges of tubular arc plasma sheath Innermost core of arc plasma's tubular sheath-like structure	~2,727 up to ~4,727 ~9,726 up to ~20,000	Arc lengths can range in length from 2 nm between metallic nanoparticles all the way up to as long as number of meters (m) between larger structures	Chemical and LENR reactions can occur within; depends on amounts of current	IR heat radiation is mainly created via Joule heating by electrons and ions found in arc discharge plasma; irradiates everything inside of reaction chamber
Energy Release: LENR-active hotspots: can occur on metallic surfaces or at oxide-metal interfaces anywhere on nanoparticles	On surfaces or at interfaces on LENRs target fuel nanoparticles	~4,000 up to ~6,000	2 nanometers (nm) up to as large as ~100$^+$ microns (μ) in diameter; roughly circular in shape	MeV-energy nuclear reactions occur within	Directly emit infrared heat photon energy; ionizes nearby molecules, materials, destroys μ-scale nanostructures

Lattice Energy LLC

Widom-Larsen theory applies to dusty plasma scramjet

Injections of electrical input energy can trigger LENRs in such plasmas

- ✓ In 2007, Widom-Larsen LENR theory was extended from metallic hydride cells to exploding wires; we call this other regime in which our theory applies the "magnetic analog" in which direct many-body collective magnetic field effects substitute for collective many-body quantum effects that create nuclear-strength local electric fields and ULM neutrons via *e* + *p* weak reaction in metallic hydride cells
- ✓ Upshot of this is that gamma conversion mechanism is not guaranteed for charged particles directly accelerated by collective magnetic fields in plasmas where the W-L magnetic analog physics is operating; gamma radiation can be emitted; that said, this issue can be controlled
- ✓ Note that for some interval during exploding wire event it is best described as dense, dusty nanoparticulate plasma
- ✓ Dusty plasmas are complex: electric field dominated W-L is operating on nanoparticle surfaces while the magnetic analog is occurring simultaneously in the plasma proper

Simple Carbon electric arc

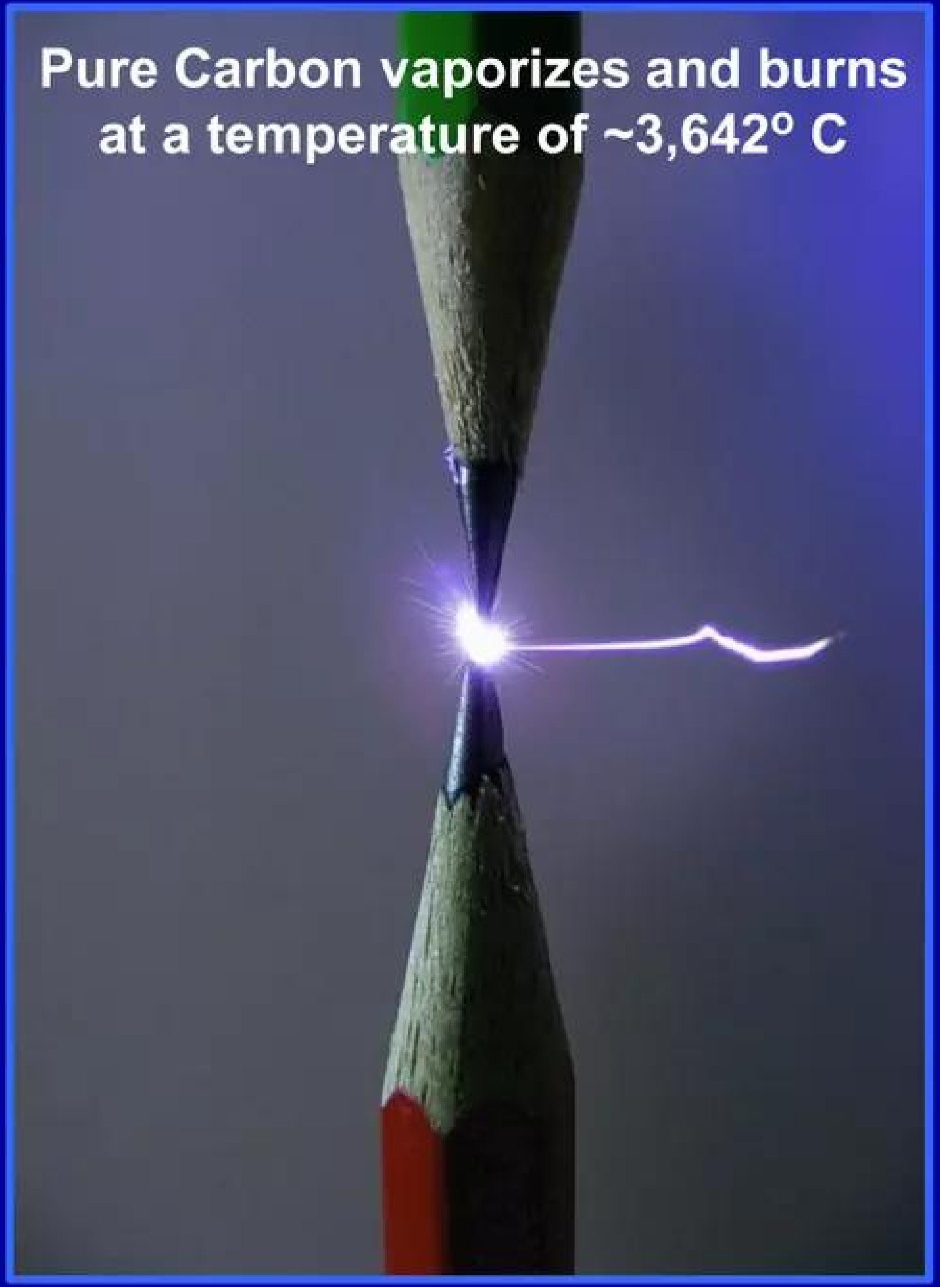


Photo credit: Conorod (UK - 2009) using a FujiFilm FinePix S5700 S700 digital camera; Exposure details: exposure time : 1/2 sec; F number : f 3.5; ISO speed rating : 100

Lattice Energy LLC

Following documents are relevant to balance of discussion

- ✓ **Energetic electrons and nuclear transmutations in exploding wires,"** A. Widom, Y. Srivastava and L. Larsen (2007)
  http://arxiv.org/PS_cache/arxiv/pdf/0709/0709.1222v1.pdf

  Synopsis: Widom-Larsen theory is applied to case of high-current exploding wires; results of analysis used to explain data reported in Wendt-Irion experiments (Univ. of Chicago) conducted and published in *Science* back in 1922

- ✓ **"High energy particles in the solar corona,"** A. Widom, Y. Srivastava and L. Larsen (2008)
  http://arxiv.org/PS_cache/arxiv/pdf/0804/0804.2647v1.pdf

  Synopsis: applies many-body collective, magnetically dominated regime of the Widom-Larsen theory of LENRs to explain anomalous heating of the solar corona

- ✓ **"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
  See especially pages: pp. 618 (Eq. 3 and 4) - 619; pp. 620 (Eq. 8,9) - 622; and pp. 628 - 635

- ✓ **"Electroweak neutron production and capture in lightning discharges,"** [15 slides] L. Larsen
  American Nuclear Society Winter Meeting, San Diego, CA (2012)
  http://www.slideshare.net/lewisglarsen/larsen-electroweak-neutron-production-and-capture-in-lightning-dischargesans-meeting-san-diego-nov-2012

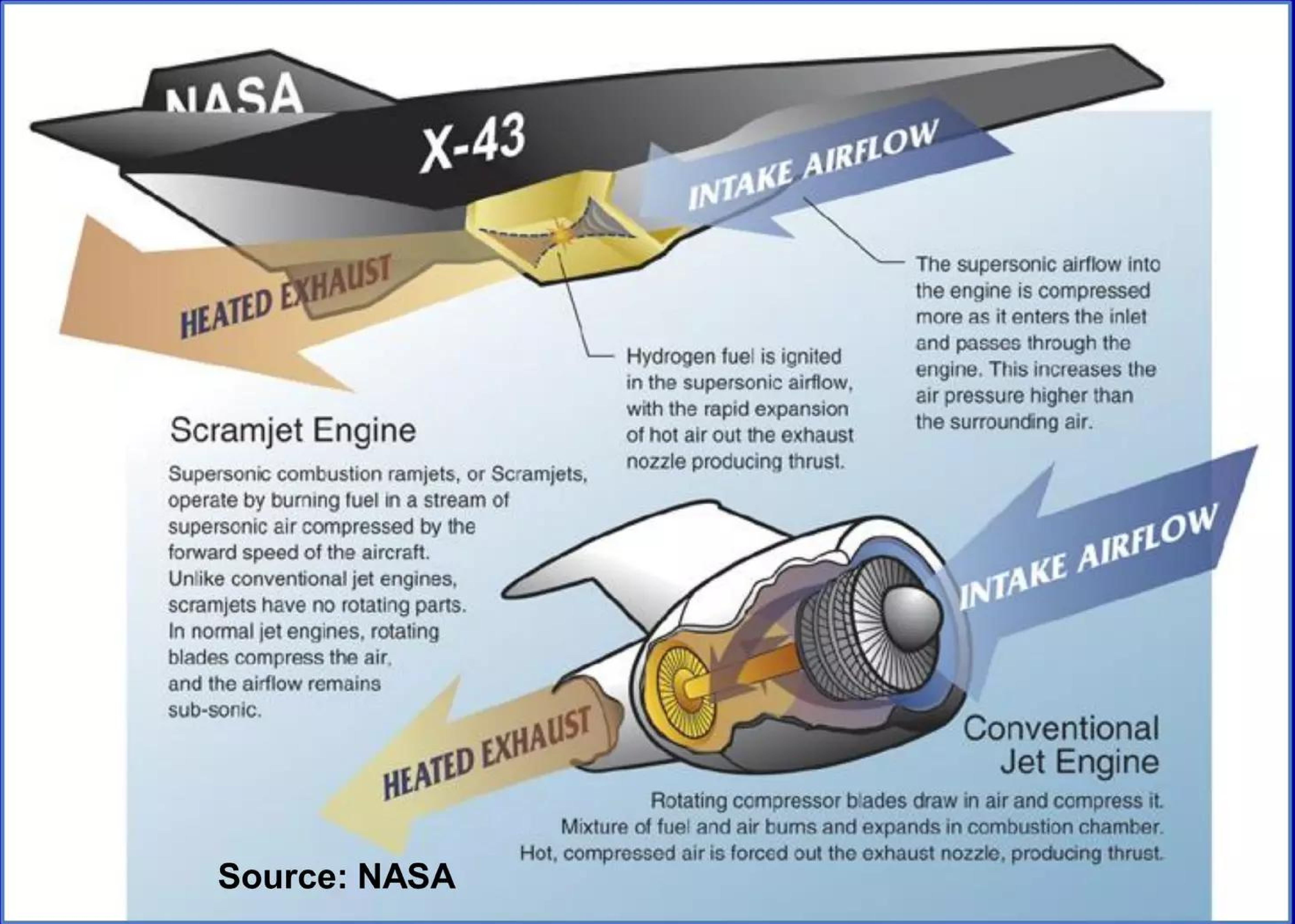
- ✓ **"Dusty plasma based fission fragment nuclear reactor,"** R. Clark and R. Sheldon
  American Institute of Aeronautics and Astronautics Paper #4460
  41st AIAA/ASME/SAE/ASEE Joint propulsion Conference & Exhibit, Tucson, AZ (2005)
  http://www.rbsp.info/rbs/RbS/PDF/aiaa05.pdf

- ✓ **"Final report: concept assessment of a fission fragment rocket engine (FFRE) propelled spacecraft"**
  W. Werka, P.I., NASA MSFC EV-72, R. Clark, R. Sheldon, and T. Percy
  FY11 NIAC Phase 1 Study, Aug. 15, 2011 to Sept. 30, 2012
  http://www.nasa.gov/pdf/718391main_Werka_2011_PhI_FFRE.pdf

Lattice Energy LLC

Airflow through scramjet engine is at supersonic speeds

Are reaction rates of LENRs and E-M triggering ideal for such engines?



Source: NASA

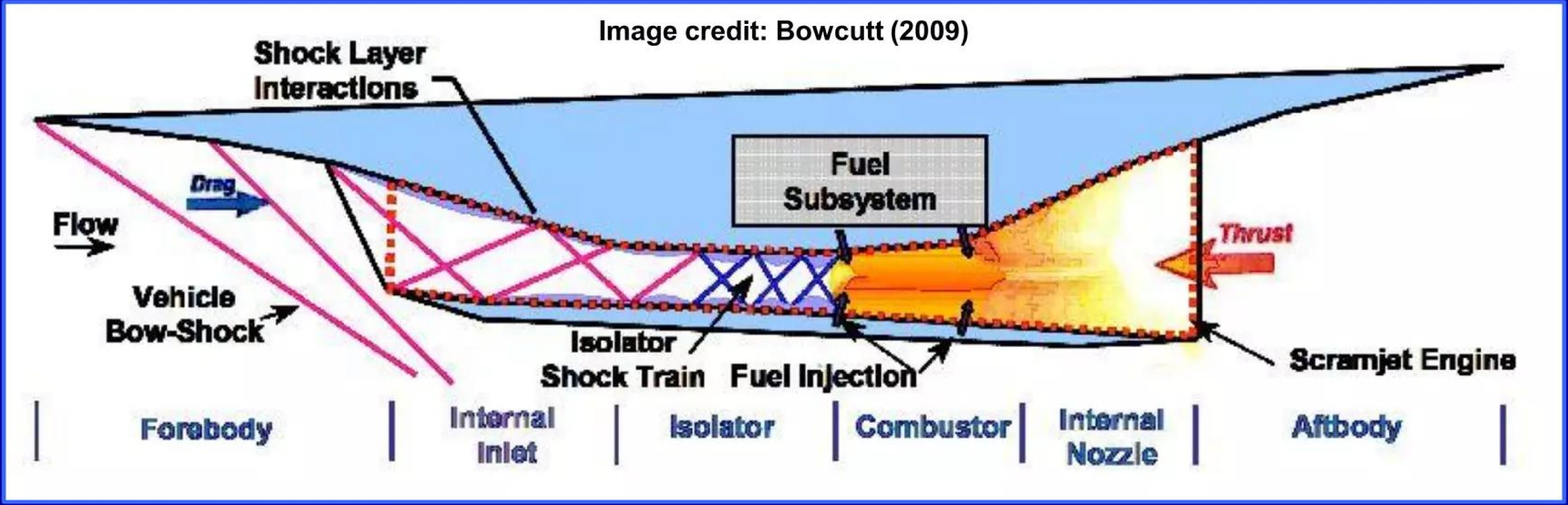
Lattice Energy LLC

Airflow through scramjet engine is at supersonic speeds

Concept of engine operation is explained in graphic by Bowcutt (2009)

Key goal: release as much energy as is possible prior to exhaust exiting engine

FIG. 3 - Air-breathing supersonic combustion ramjet (scramjet)



"Plasma-Assisted Ignition and Combustion
A. Starikovskiy and N. Aleksandrov
Chapter 12 in "Aeronautics and Astronautics," M. Mulder, *ed*., ISBN 978-953-307-473-3 (2011)
under CC BY-NC-SA 3.0 license

Source: http://www.intechopen.com/books/aeronautics-and-astronautics/plasma-assisted-ignition-and-combustion

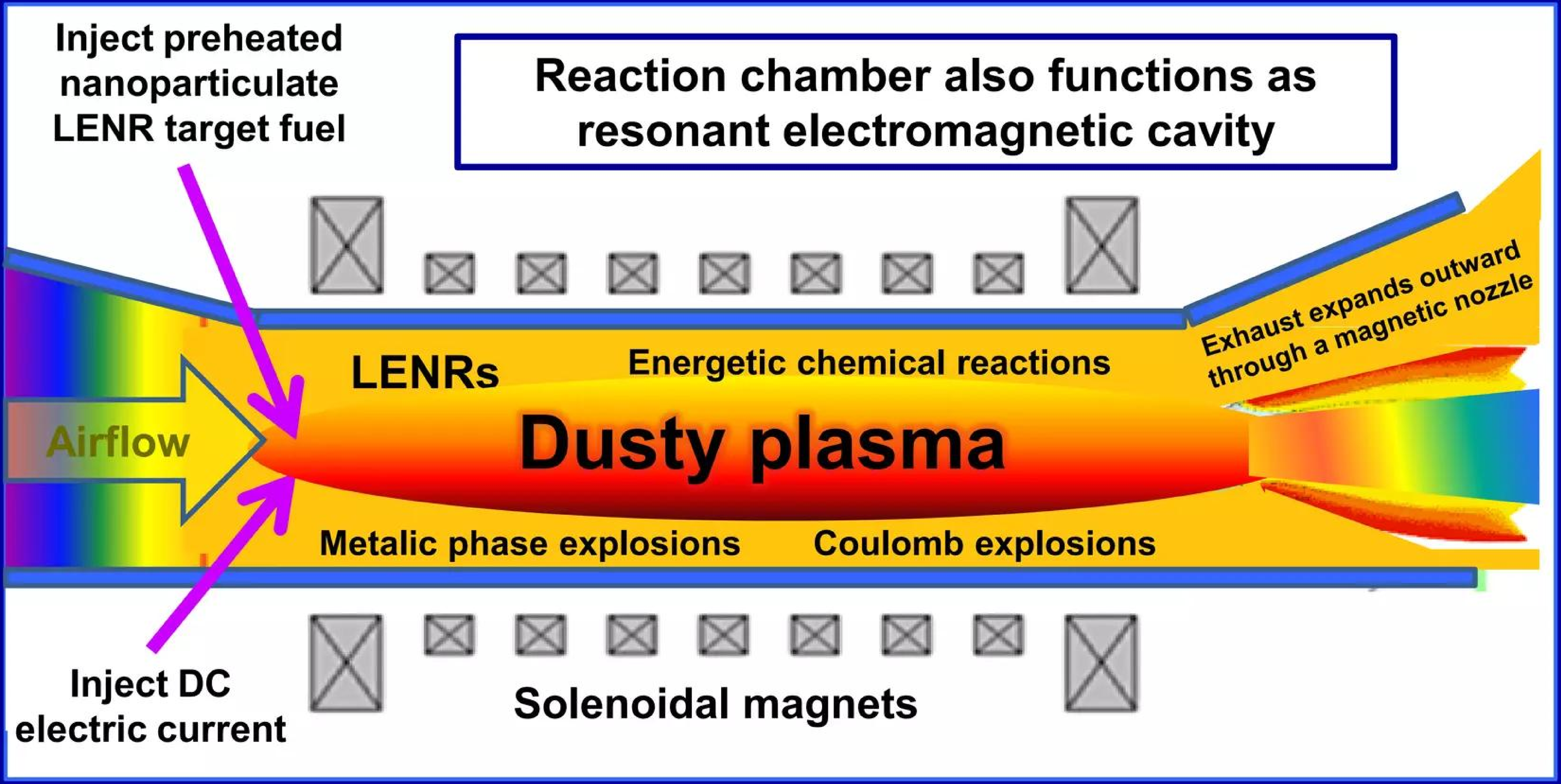
Lattice Energy LLC

Conceptual overview of a dusty plasma scramjet engine

Plasma kept away from walls and confined with an axial magnetic field

Energy from LENRs, metallic phase/Coulomb explosions, and chemical reactions

LENRs are triggered electromagnetically so very tiny propagation delays



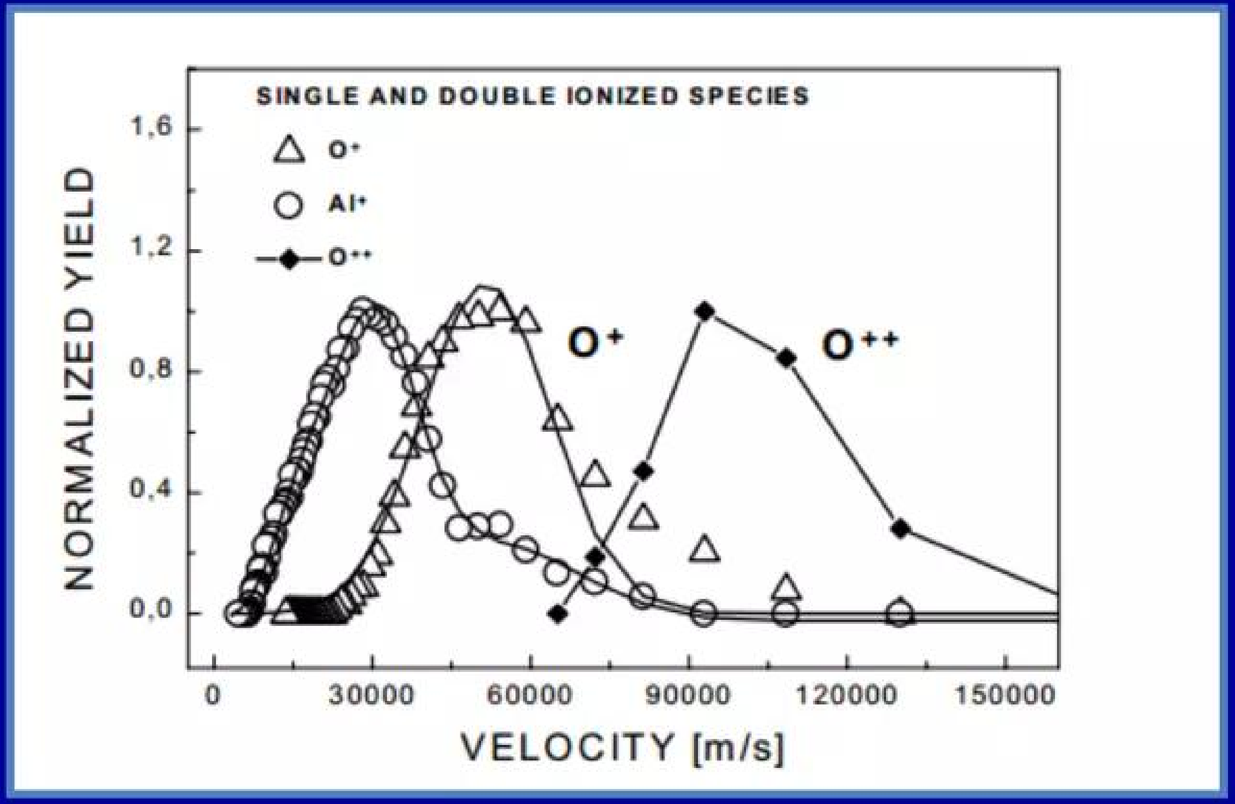
Lattice Energy LLC

LENR scramjet's average exhaust velocity presently unclear

Exhaust contains many materials traveling at very different velocities

e.g. O^+ O^{++} ions likely moving at speeds of 30,000 to 150,000 meters/second

- ✓ **Enormous flexibility in designing and engineering LENR nanoparticle target fuels - huge selection of many different elements and materials (remember, ULM neutrons are quite omnivorous re capture)**
- ✓ **Design LENR fuel nanoparticles so LENR-sites triggered thereon will have just enough energy release to totally vaporize the entire nanoparticle**
- ✓ **Some charged particles in exhaust stream would be moving at extremely high average velocities**
- ✓ **Combination of metallic phase explosions and Coulomb explosions will cause extreme volume expansions and heating; suggests good thrust**
- ✓ **Need experimentation to determine likely average exhaust velocity and thrust of an LENR-powered scramjet engine for specific types of target fuels**



Lattice Energy LLC

Lockheed Martin SR-72 would be unmanned aircraft

Earlier manned SR-71 Blackbird cruised at an airspeed of ~ Mach 3.0

SR-72's present concept integrates a low-speed turbine engine with a scramjet

"Envisioned as an unmanned aircraft, the SR-72 would fly at speeds up to Mach 6, or six times the speed of sound."

"SR-72's design incorporates lessons learned from the HTV-2, which flew to a top speed of Mach 20, or 13,000 mph, with a surface temperature of 3500°F."

Source: Lockheed Martin website http://www.lockheedmartin.com/us/news/features/2013/sr-72.html

Source: Lockheed Martin

Lattice Energy LLC

Lockheed Martin SR-72 would be unmanned aircraft

Present "combined cycle" concept integrates turbine and a scramjet

Source: Lockheed Martin

Lattice Energy LLC

Energy density of LENR fuels is revolutionary for aircraft

Roughly 5,000 times more energy-dense than any gasoline or jet fuels

LENRs are safe, CO_2-free, and dramatically reduce size of logistics tail for fuels

Typical gasoline or diesel tanker truck carries ~5,000 - 12,000 US Gallons of Jet-A aviation fuel

LENR fuels producing same # of BTUs could fit into just two (2) FedEx boxes

Astounding possibility illustrates the benefits of exploiting huge nuclear energy densities

Lattice Energy LLC

Energy density of LENR fuels is revolutionary for aircraft

Roughly 5,000 times more energy-dense than any gasoline or jet fuels

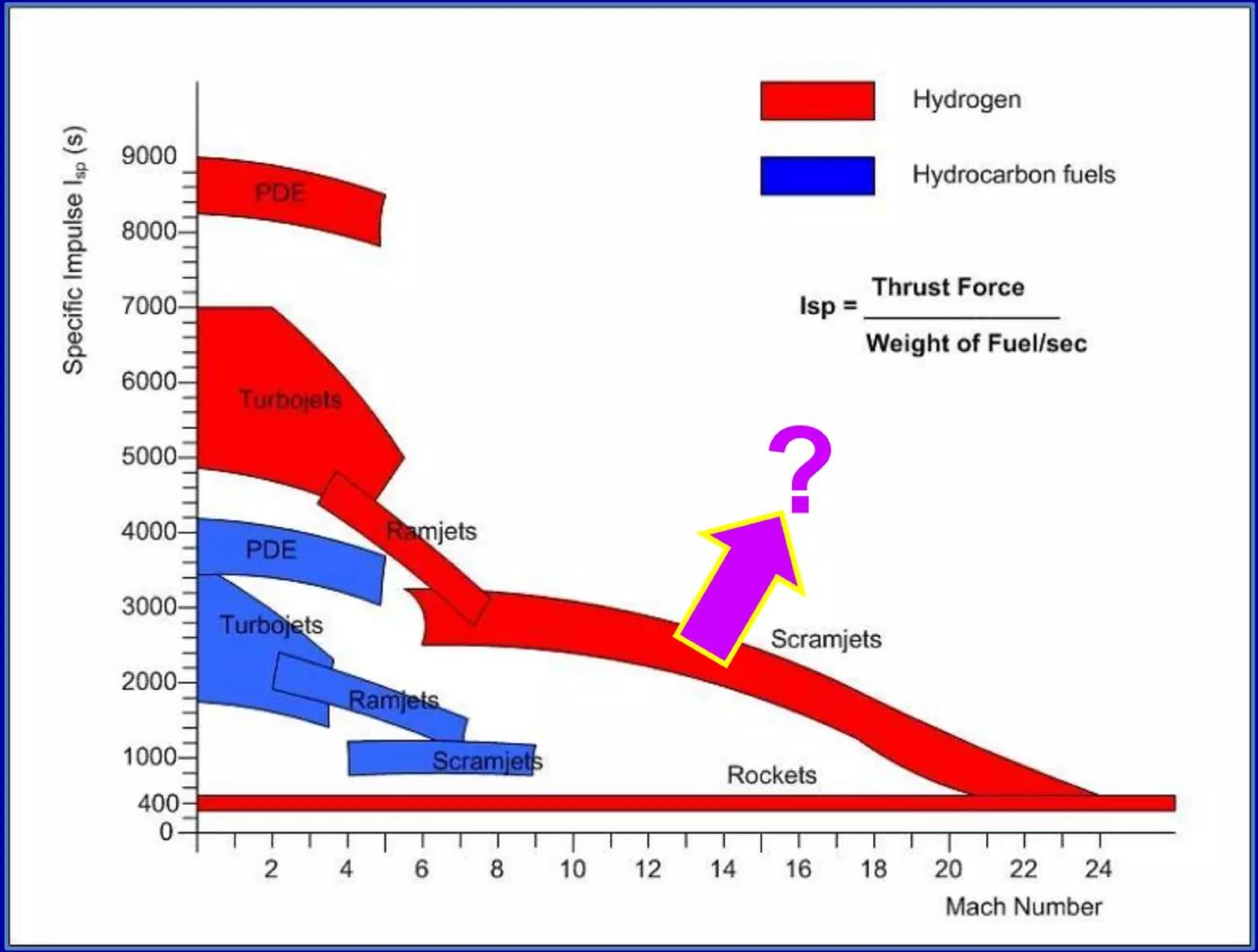
Fuel for Lockheed Martin SR-71 mission could likely fit in two FedEx boxes

SR-71 Blackbird carried ~12,000 gallons of JP-7 aviation fuel with full tanks; permitted unrefueled range of about 3,250 miles traveling at Mach 3.0

Lattice Energy LLC

Energy density of LENR fuels is revolutionary for aircraft

Tiny weight of LENR fuels vs. thrust may enable higher I_{sp} for scramjets

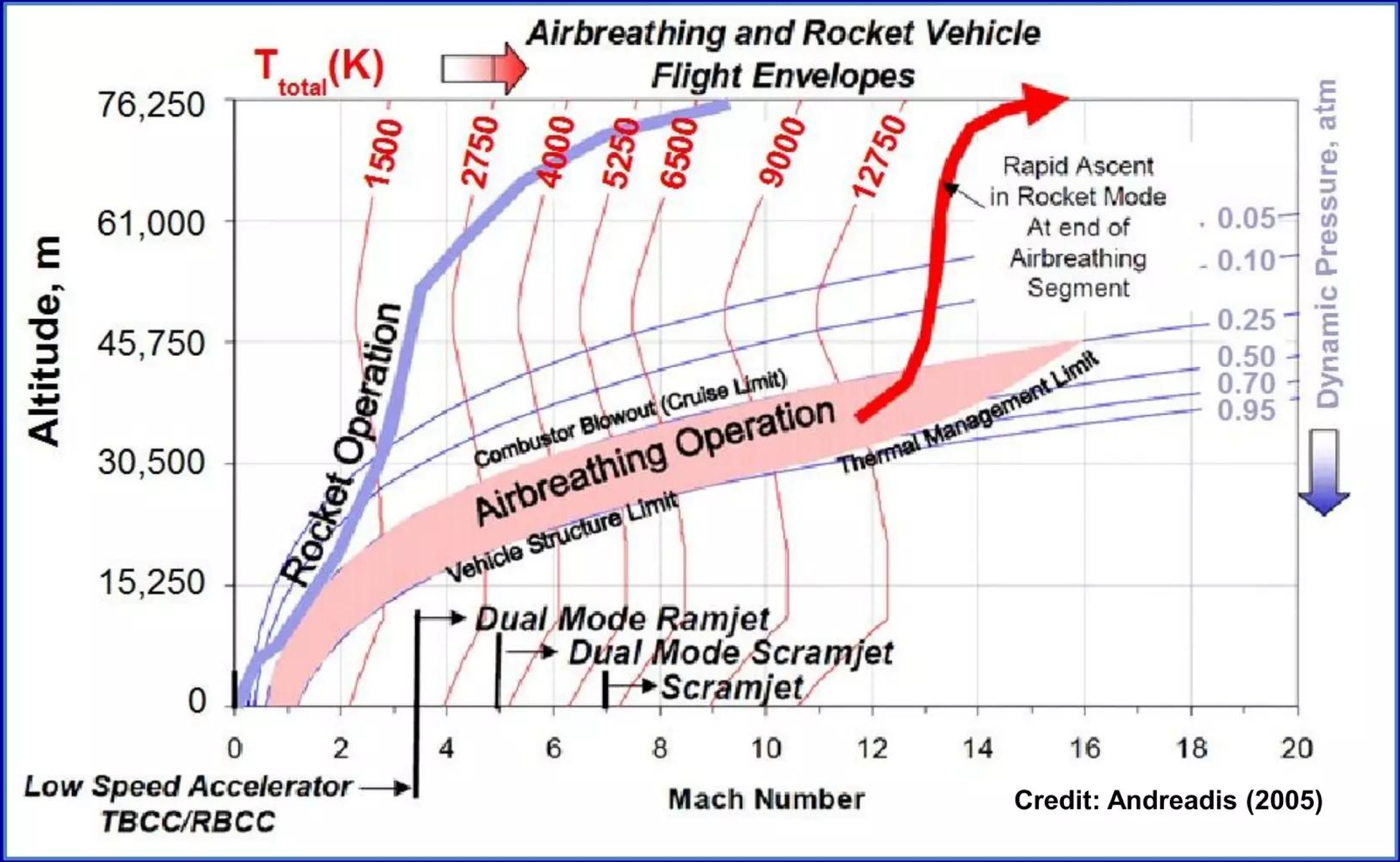


Source: http://arc.uta.edu/research/pde.htm

Lattice Energy LLC

Perhaps different LENR fuels for different flight envelopes?

FIGURE 1. Air-breathing hypersonic vehicle flight trajectory and operational limits



Source: http://www.intechopen.com/books/aeronautics-and-astronautics/plasma-assisted-ignition-and-combustion

Lattice Energy LLC

LENR dusty plasma scramjet could be revolutionary

Enables simultaneous utilization of nuclear and chemical reactions

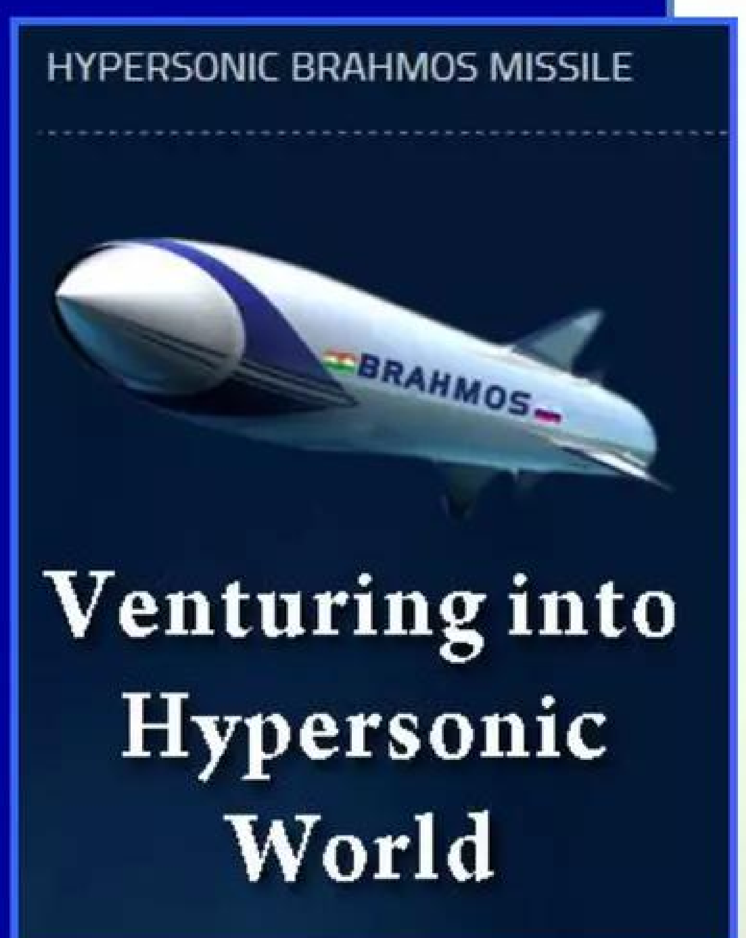
- ✓ Unlike SR-72, Lattice would integrate an LENR dusty plasma scramjet engine with an LENR-powered 50⁺% efficient Brayton combined cycle turbine that generates DC electricity; waste heat from turbine dumped into scramjet or air bypass flow if feasible
- ✓ DC power from turbine generator injected into dusty plasma to trigger LENRs on fuel
- ✓ LENR scramjet reaction chamber walls will get extremely hot and probably need some cooling even with containment of plasma by axial magnetic field. If hypersonic aerodynamics permit, should investigate possibility of creating an air bypass flow surrounding the scramjet walls to cool them. If this were proven feasible, might have an opportunity to create the scramjet analogue of a high-bypass turbofan engine
- ✓ Incredibly high energy densities and low weight of LENR nanoparticulate target fuels might allow an LENR dusty plasma scramjet the luxury of carrying multiple fuel types that are optimized for different flight envelopes. A target fuel containing much Oxygen could be used to operate like a rocket for take-off and then switched to a hypersonic fuel type when proper airspeed is reached --- could utilize optimized combinations of nuclear and very energetic chemical reactions simultaneously inside the very same reaction chamber
- ✓ While radioactivity and radiation are not issues, given complexity of 'witches brew' inside LENR scramjet reaction chamber, must evaluate environmental impact of exhaust streams
- ✓ Thrust control achieved by regulating *a*mounts of DC current and target fuel injection rates

Lattice Energy LLC

Indian-Russian BrahMos is now fastest cruise missile

LENR dusty plasma propulsion might be good for hypersonic UAVs

BrahMos' present range is 290 km - could be >10x more with LENR propulsion



Company website: http://www.brahmos.com/content.php?id=10&sid=10

Chinese hypersonic cruse missle: http://www.youtube.com/watch?v=T0h6pGr-IPs

Lattice Energy LLC

Final thoughts

LENR dusty plasma scramjet propulsion could be promising

More experimentation and engineering is needed to validate this possibility

- ✓ **Potential aircraft performance enhancements using LENR-based dusty plasma scramjet propulsion are quite alluring**
- ✓ **Unlike fission or fusion technologies there would not be any radiation or radioactivity problems, even in a bad crash event**
- ✓ **For manned aircraft one thing that must be factored into system engineering is to maximize LENRs taking place on the *surfaces* of LENR nanoparticulate target fuels as opposed to via direct particle reactions in the plasma proper; hard gamma suppression is much less effective in W-L magnetic analog**
- ✓ **This document was published to foster technical discussion**

Lattice Energy LLC

Additional reading for the technically inclined

Excellent introductory book concerning the science and expanding literature of dusty plasmas:

"Introduction to Dusty Plasma Physics"
P. K. Shukla and A. A. Mamun, Series in Plasma Physics, Taylor & Francis Ltd, IOP Publishing (2002)

http://www.amazon.com/Introduction-Dusty-Plasma-Physics-Series/dp/075030653X

Index to large collection of documents about LENR theory, experimental data, and the technology:

"Index to key concepts and documents" v. #17
L. Larsen, Lattice Energy LLC, May 28, 2013 [113 slides] Updated and revised through January 12, 2014

http://www.slideshare.net/lewisglarsen/lattice-energy-llc-index-to-documents-re-widomlarsen-theory-of-lenrsmay-28-2013

Review paper that covers all theoretical aspects of basic Widom-Larsen theory published to date:

"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)

Abstract: "Under special circumstances, electromagnetic and weak interactions can induce low-energy nuclear reactions to occur with observable rates for a variety of processes. A common element in all these applications is that the electromagnetic energy stored in many relatively slow-moving electrons can (under appropriate circumstances) be collectively transferred into fewer, much faster electrons with energies sufficient for the latter to combine with protons (or deuterons, if present) to produce neutrons via weak interactions. The produced neutrons can then initiate low-energy nuclear reactions through further nuclear transmutations. The aim of this paper is to extend and enlarge upon various examples analyzed previously, present order of magnitude estimates for each and to illuminate a common unifying theme amongst all of them."

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

Lattice Energy LLC

Working with Lattice

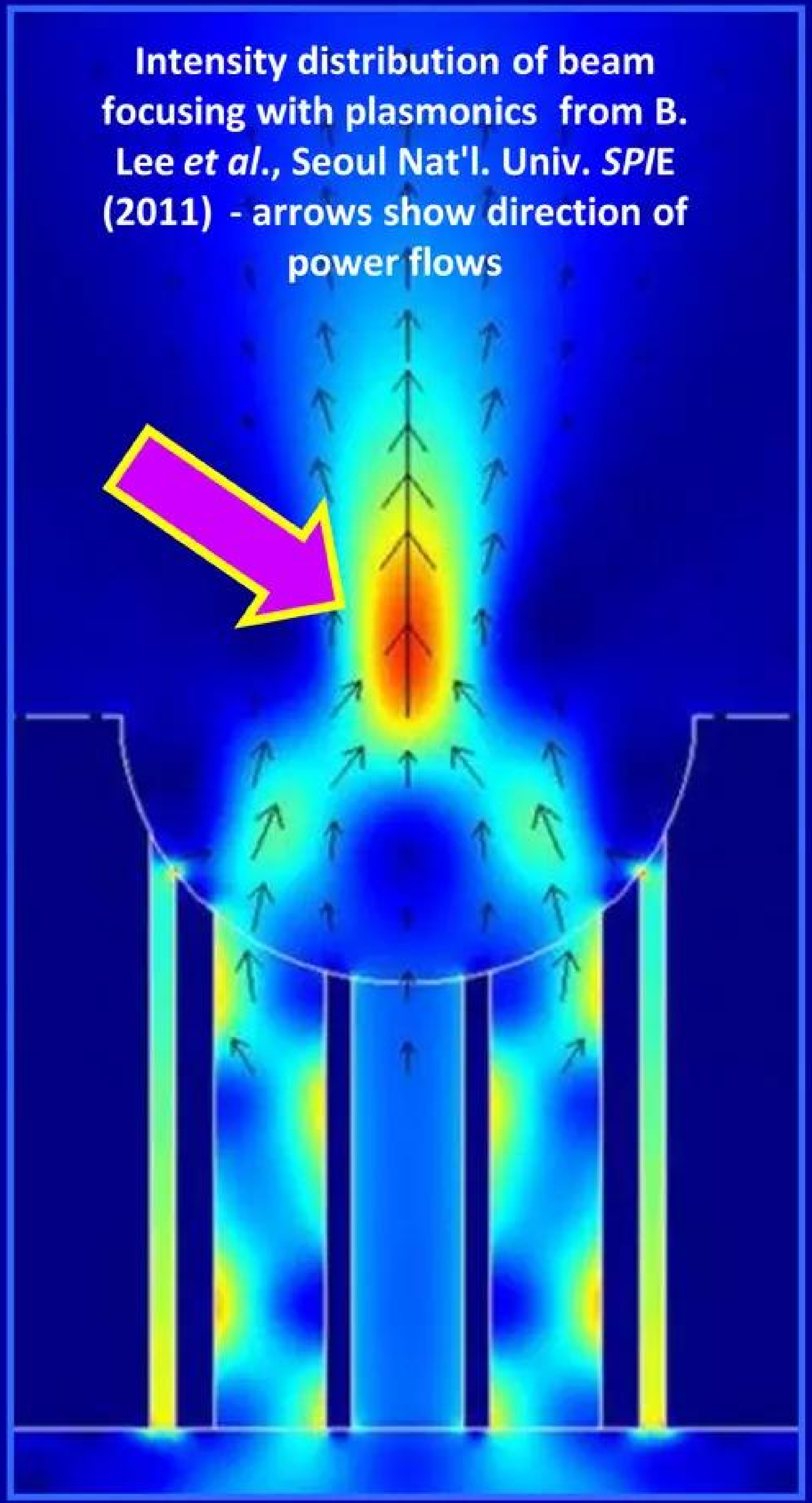
Commercializing LENRs and consult to advance LENR technology

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

- **Lattice welcomes inquiries from established companies and other types of private or government organizations**
- **Lattice also selectively engages in some fee-based third-party consulting. We will consult on any subject matter in which we have unique knowledge and expertise as long as it does not involve disclosing any proprietary engineering details that would be applicable to Lattice's planned family of LENR-based power generation systems**
- **Consulting is subservient to company's main goal: commercializing LENRs for applications in ultra-high energy density portable, mobile, and stationary power generation systems; are looking for corporate partners**
- **Larsen c.v.:**

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

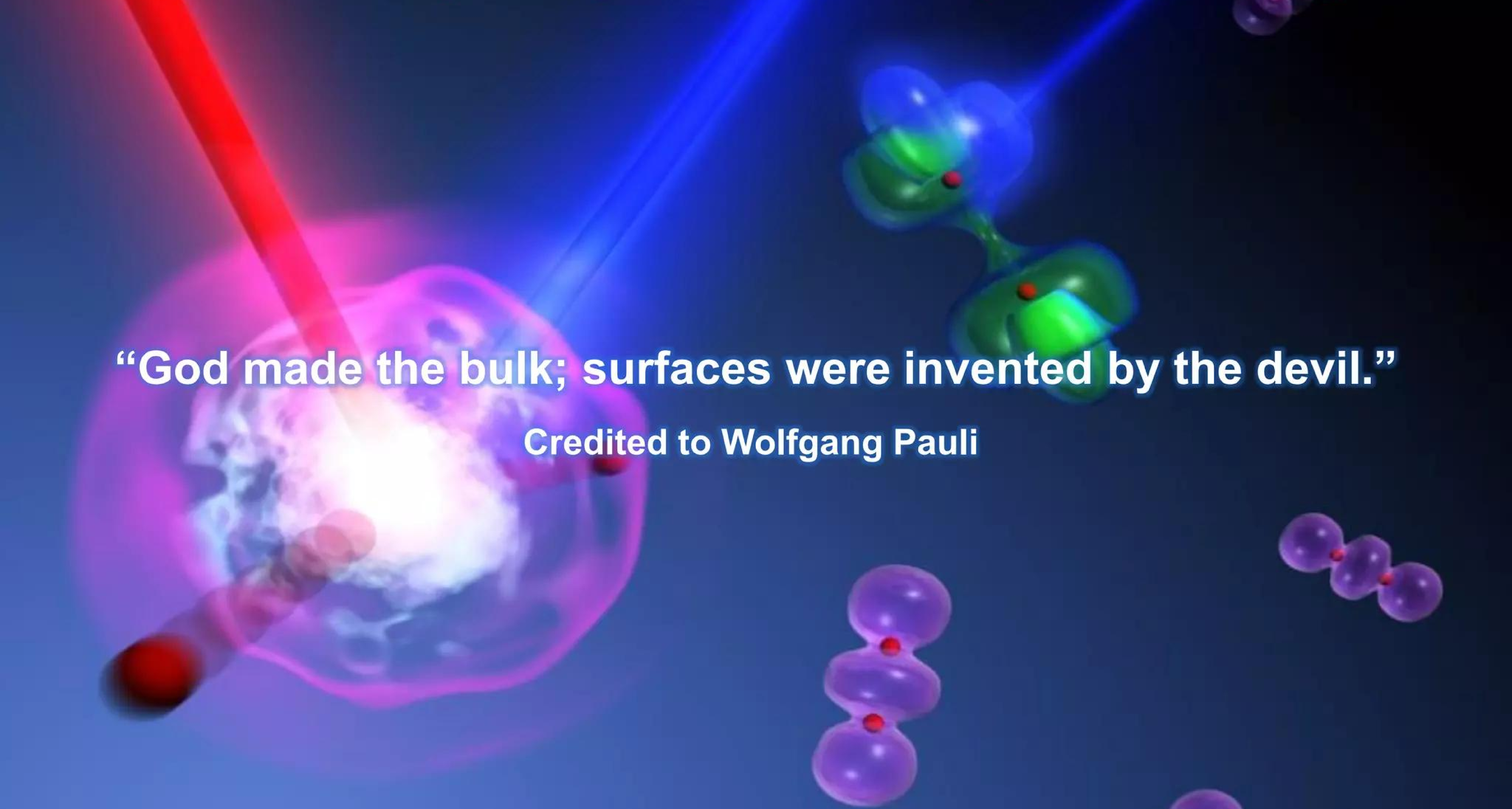
Concentrating E-M energy in resonant electromagnetic cavity



http://spie.org/documents/Newsroom/Imported/003435/003435_10.pdf

Lattice Energy LLC

Commercializing a next-generation source of green nuclear energy



"God made the bulk; surfaces were invented by the devil."

Credited to Wolfgang Pauli

Credit: Greg Kuebler, JILA

Violent explosion of N_2 molecule with laser - Image source http://www.redorbit.com/images/pic/84898/pf3213_euv_h/