

November 25, 2011

Dear Mr. Krivit:

This letter is in response to your Freedom of Information Act (FOIA) request dated September 22, 2011, to NASA Headquarters and forwarded to NASA Langley's FOIA office on October 13, 2011, from NASA Glenn's Research Center (GRC). Your request was for a copy the slides presented at the LENR Workshop held at GRC on September 22, 2011.

Enclosed are copies of the two presentations presented by NASA Langley Research Center employees. This information is furnished under the provisions of the FOIA. The fees associated with the processing of your request are less than \$15 and are not being charged in accordance with 14 CFR Â§1206.700(i)(2). If you have questions, I can be reached at 757-864-4274 or carissa.s.wheeler@nasa.gov

Sincerely,
Carissa S. Wheeler
NASA LaRC's FOIA Officer

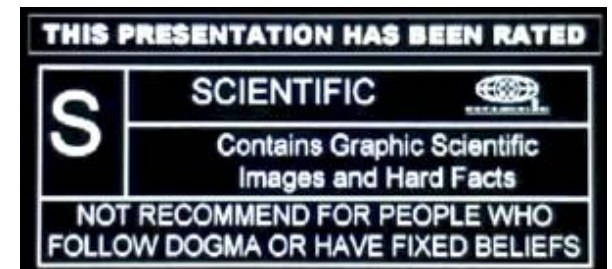
Low Energy Nuclear Reactions

**Is there better way to do nuclear
power?**

Dr. Joseph M. Zawodny
NASA Langley Research Center

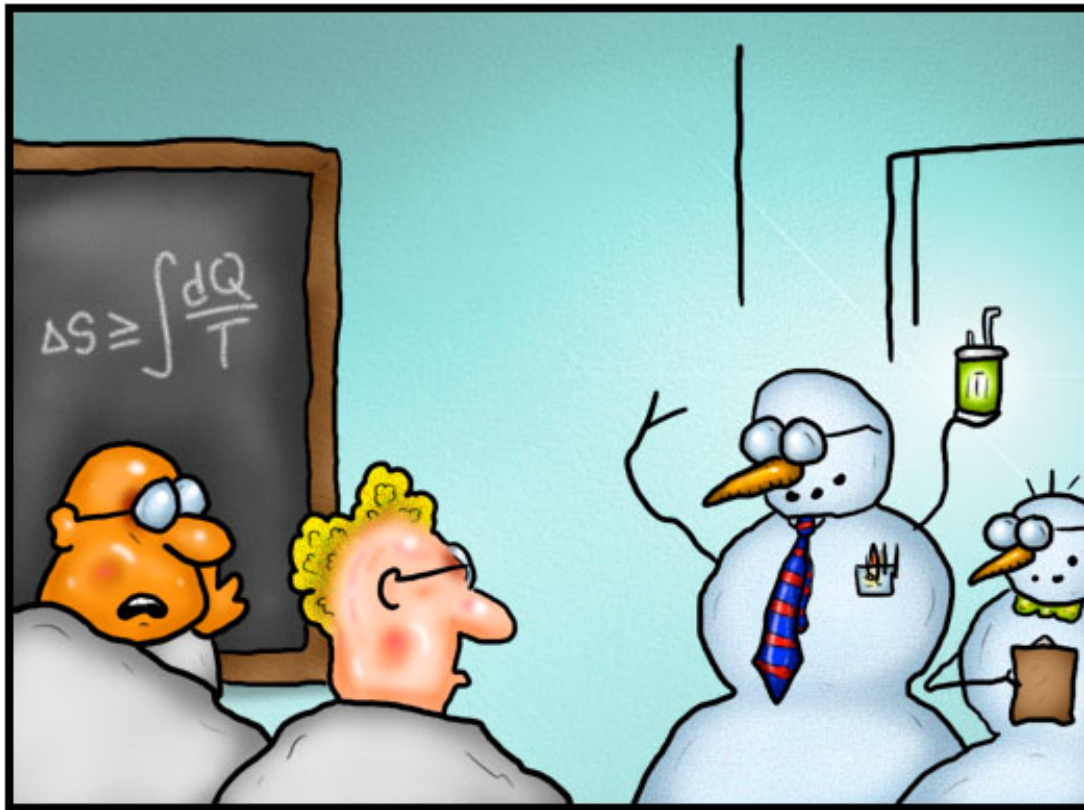
Outline for this talk

- Historical Overview
- Do we have a theory?
- Implications for Aerospace and beyond



HISTORY

DOCTOR FUN



"It's those cold fusion guys again."

The Early Days



- J.J. Thompson: “Dr. Electron”
- Was certain electric currents could cause elemental transmutation



- Ernest Rutherford: “Dr. Nucleon” and student of Thompson
- Was certain transmutations were due to nucleons
- Wendt & Irion extend Thompson’s work with high currents

The Cold Fusion Debacle

- Pons & Fleischmann
- Electrochemists
- Pd-D Experiments
- Calorimetry
- Excess heat
- Actually did good work, but the work was very hard to replicate
- Claimed ${}^2\text{H} + {}^2\text{H} \Rightarrow {}^4\text{He}$ (aka Cold Fusion)
- Should have stuck to what their paper said “Unexplained nuclear reactions”



Elemental Transmutations

- Tadahiko Mizuno: Japan
- Worked with many systems
- Elemental Transmutations (90's)
- Hydration of PAHs (2008)
- Phenanthrene hydration with Pt catalyst
- Produced excess ^{13}C & created ^{14}N from ^{12}C
- Was convinced early on that neutrons were responsible for transmutations.



Real Power

- Piantelli & Focardi: Italy
- Emerged in early 1990's
- Investigated Ni-H systems
- Sporadic successes
- When it worked, it worked very well
- 10's to 100's of Watts net output
- Self-sustaining, sometimes for 100's of days
- Magnitude of energy produced well beyond any possible chemical source
- Both Ni and H are abundant and cheap



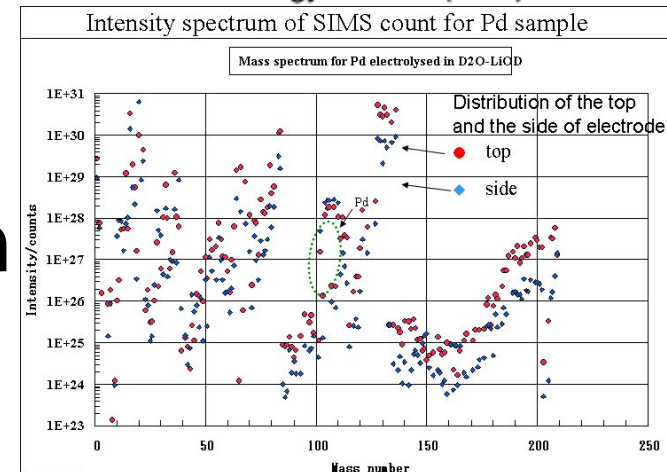
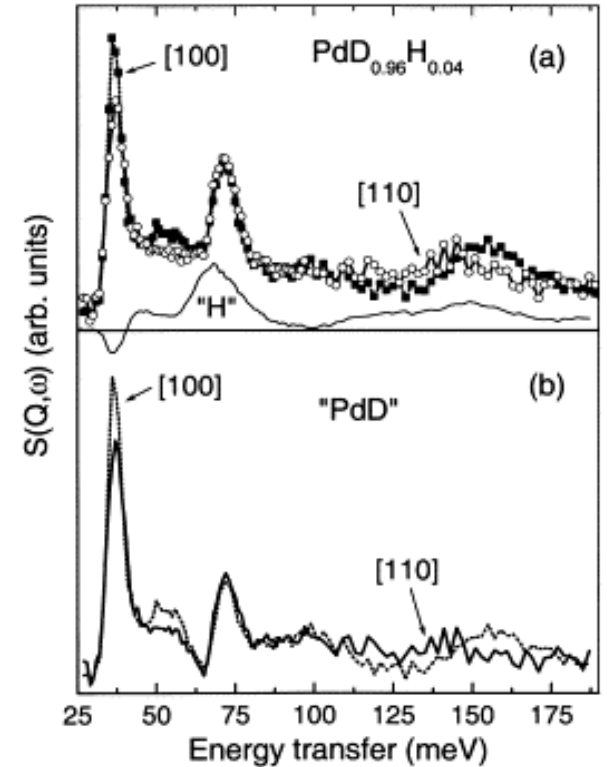
Mechanistic Insights

- Letts & Cravens: US
- Experimentalists
- Willing to try anything
- Explore the variables
- Determine what works
- Built upon the evidence suggesting that transient forcing was important
- Employed two tunable lasers and tuned the beat frequency across the IR spectrum
- Result: Hydride dynamics are important



Summary of Evidence

- Metal hydrides of both H & D
- High H loading required
- Not just ^4He being produced
- Full range of elemental transmutations
- Energy input needed
- Forcing at resonant hydride frequencies is effective
- Sporadic detection of neutron or gamma radiation



D+D "Cold Fusion" Output Inconsistencies

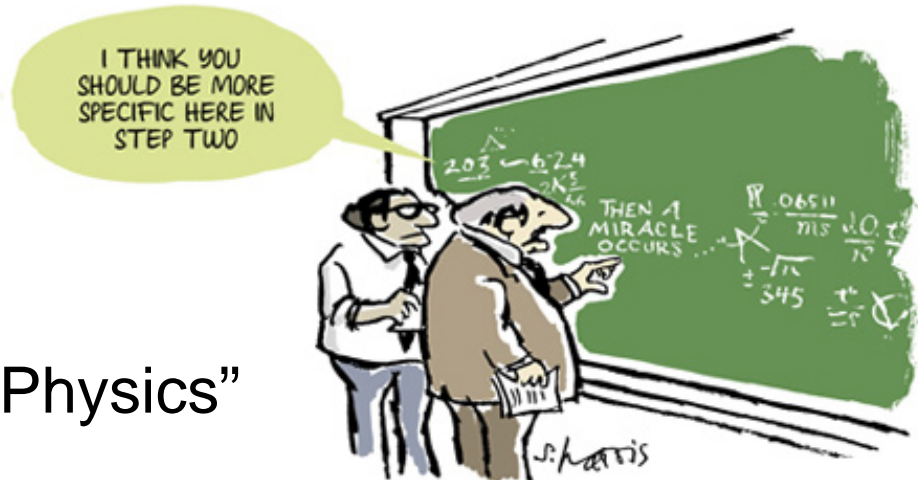
Tritium	Isotopic Shifts	Low-Flux Neutrons
D+D --> 3Helium (0.82 MeV) + neutron (2.45 MeV) [50%]		
D+D --> Tritium (1.01 MeV) + proton (3.02 MeV) [50%]		
D+D --> <u>4Helium (0.08 MeV)</u> + gamma (23.77 MeV) [10⁻⁶]		
Heavy Z Transmutations	Energetic Alphas	
	(11-16 MeV)	

Image Courtesy of New Energy Times

You can't ignore data

THEORY

You have to justify "New Physics"



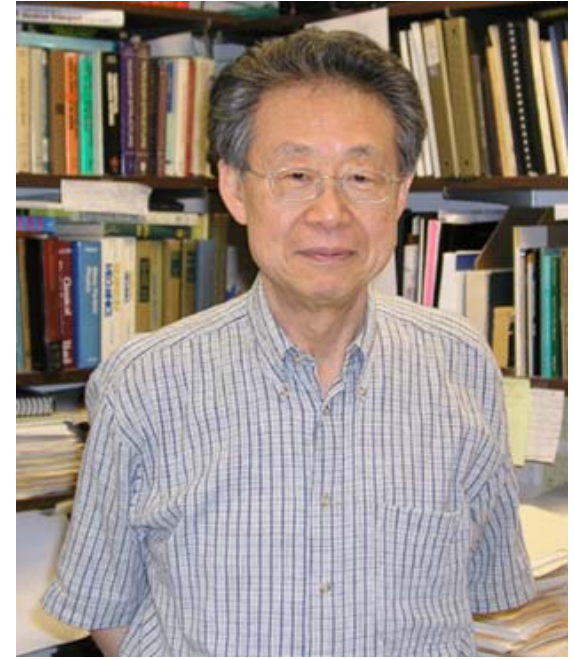
Mills' Hydrino Theory

- Randell Mills: Blacklight Power
- Non-nuclear explanation
- Hydrino Theory
- Requires fractional quanta
- $1/137$ of $h/2\pi$
- Accessed only by special resonant processes
- *Mills' ideas of "CQM" and "hydrinos" have been criticised by mainstream physicists^{[5][6][7][8]} as "pseudoscience" and rejected as "just silliness".^[2] from Wikipedia.*



Kim's Bose-Einstein Condensates

- Yeong Kim: Purdue
- Nuclear Physicist
- Theory: variant of cold fusion
- Room temperature BEC
- Appears to violate physics
- Coupling energies require low thermal noise
- Arguments on interpretation/application of statistical thermodynamics are flawed
- Explains a subset of the evidence



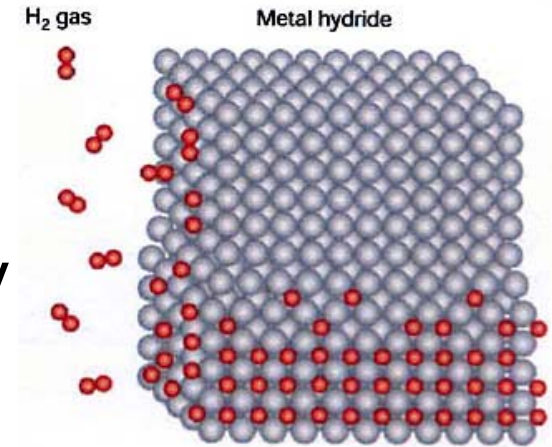
Widom-Larsen Theory

- Widom & Larsen
- Eur. Phys. J. C. (2006)
- $p + e^* \Rightarrow n + \bar{\nu}_e$
- Inhibited by 0.78MeV
- e^* is a “heavy electron” allowed by QED - requires electric fields ($\sim 10^{11}$ V/m or 10V/Å)
- Field results from a breakdown of the Born-Oppenheimer Approximation via a coupling of Surface Plasmon Polaritons to a collective proton resonance in the metal hydride.



WLT Overview continued

- Via collective effects, the result of the electron capture is an Ultra Low Momentum Neutron which is rapidly absorbed by nearby nuclei
- Absorption cross sections are huge and assure virtually all neutrons remain within the lattice
- Subsequent absorptions and decays release significant energy - primarily α , β , or γ particles
- γ rays get thermalized by heavy electrons
- Select impurities/catalysts determine the overall energetics



WLT Energetics

- An example of the Li-Be-He cycle energetics
 - $p + e^* \Rightarrow n + \bar{\nu}_e$ Inhibited: $0.78\text{MeV} \times 6 = \sim 5\text{MeV}$
 - ${}^6\text{Li} + n \Rightarrow {}^7\text{Li}$
 - ${}^7\text{Li} + n \Rightarrow {}^8\text{Li}$
 - ${}^8\text{Li} \Rightarrow {}^8\text{Be} + \beta + \nu_e$
 - ${}^8\text{Be} \Rightarrow {}^4\text{He} + {}^4\text{He}$ $\sim 27\text{MeV}$ released to this point
 - ${}^4\text{He} + n \Rightarrow {}^5\text{He}$ This cycle runs twice
 - ${}^5\text{He} + n \Rightarrow {}^6\text{He}$
 - ${}^6\text{He} \Rightarrow {}^6\text{Li} + \beta + \nu_e$ $\sim 3\text{MeV} \times 2$ released here
- In this cycle 6 protons and 3 electrons are converted to a ${}^6\text{Li}$ and 9 (anti)neutrinos with a net release of $\sim 28\text{MeV}$ (other cycles exist)

Why WLT may be Correct?

Hydration: Collective and coherent proton/deuteron motions require near-stoichiometric hydrogen loading

Resonance: Works for any 'pure' hydrogen isotope - no need to discard evidence (e.g., NiH, PdH)

THz Plasmons: Plasmon mixing with multi-wavelength laser excitation - Highly likely SPPs are important

Transmutation: Highly reactive neutrons produce a wide range of transmutations and anomalous isotopic ratios

Simplicity: Only need one theory to explain all the LENR data as well as a few other long standing anomalies

Experimental Implications

- LENR experiments employing electrochemical cells are basically uncontrolled experiments
- IF the right pattern of dendrites/textures occurs, it is a random occurrence - almost pure luck
- This is why replication is so sporadic, why some experiments take so long before they become active, and why some never do
- Need to design, fabricate, and maintain the surface texture and/or grains - not rely on chance
- MeV/He not a unique, let alone important, metric

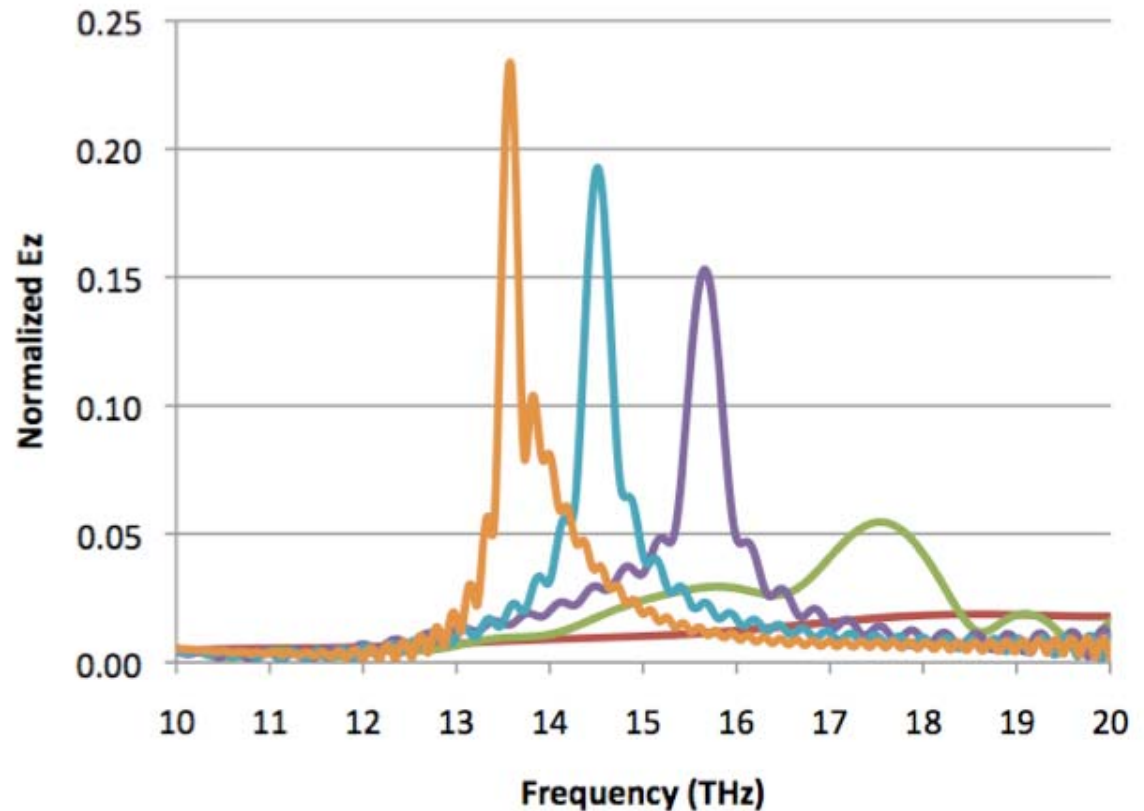
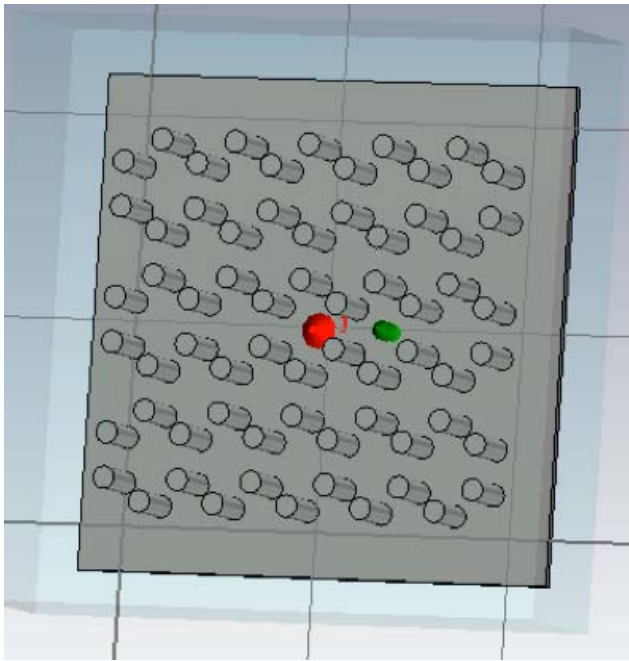


WLT Predictions

- Reaction rate is related to the SPP amplitudes at the proton resonant frequency (e.g., increasing T)
- Reactions are sporadic on smooth or randomly patterned devices driven by broadband SPPs (e.g., virtually all electrochemical cell experiments)
- Reaction rate should increase when driven at the proper frequency (e.g., multi-wavelength lasers)
- Reaction rate should increase for patterned / resonant devices (no one has tried this - yet!)

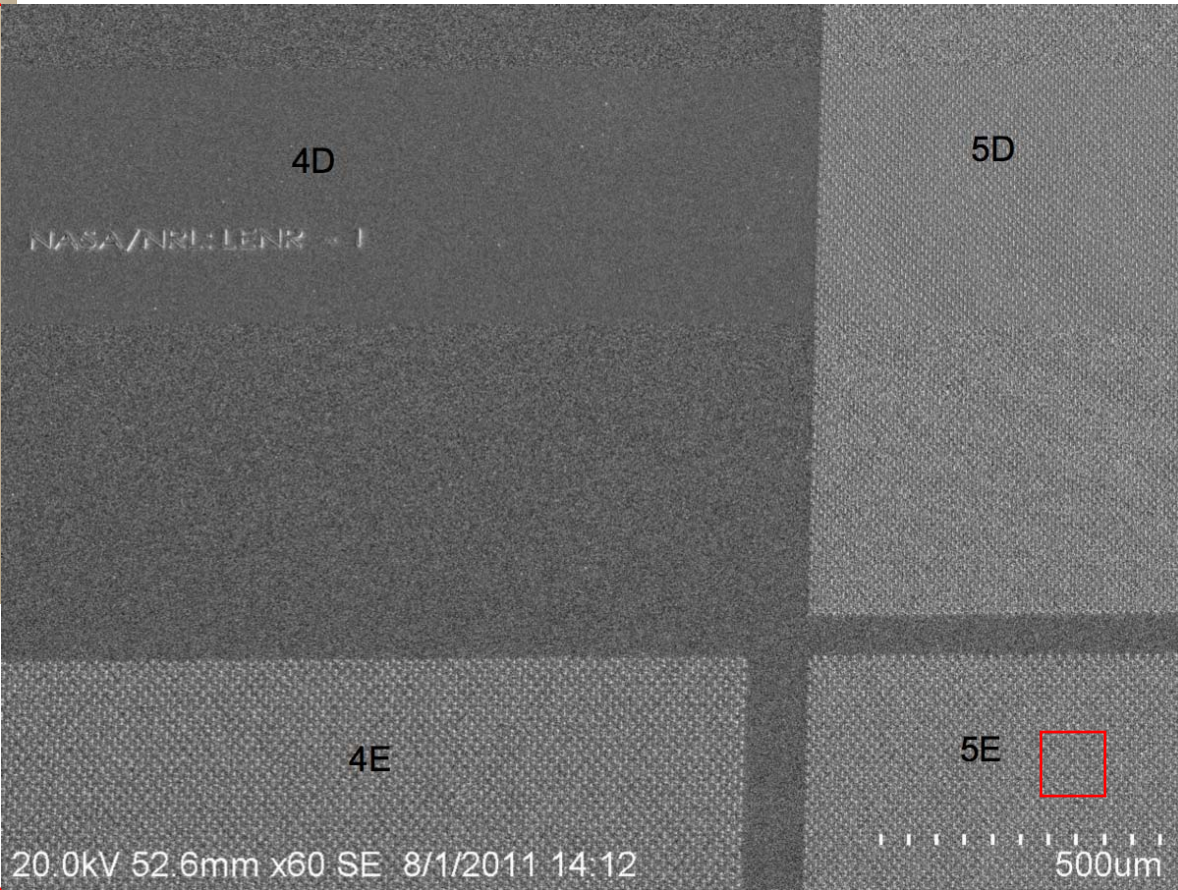
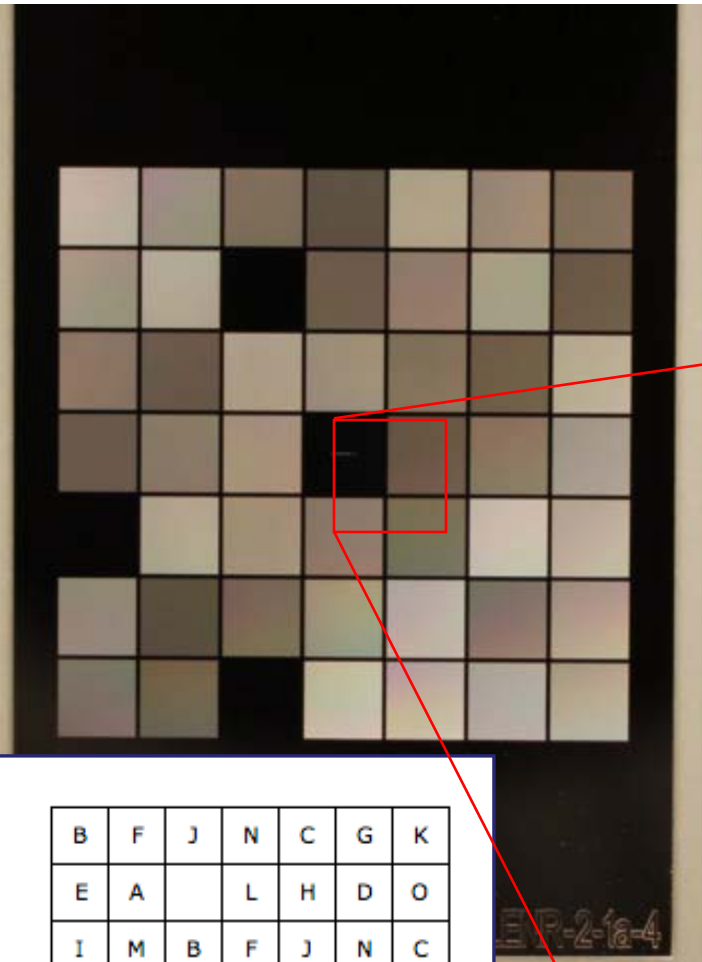
Simulations

- Design a SPP resonating structure in Mid-IR
- Frequency and Q determined by geometry
- Behaves as a filter to limit SPP spectrum



Optical Images: LENR-2-1a-4

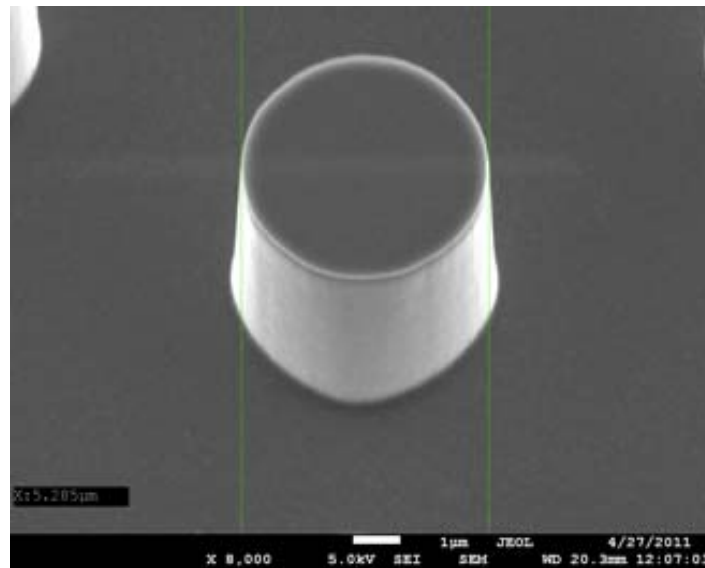
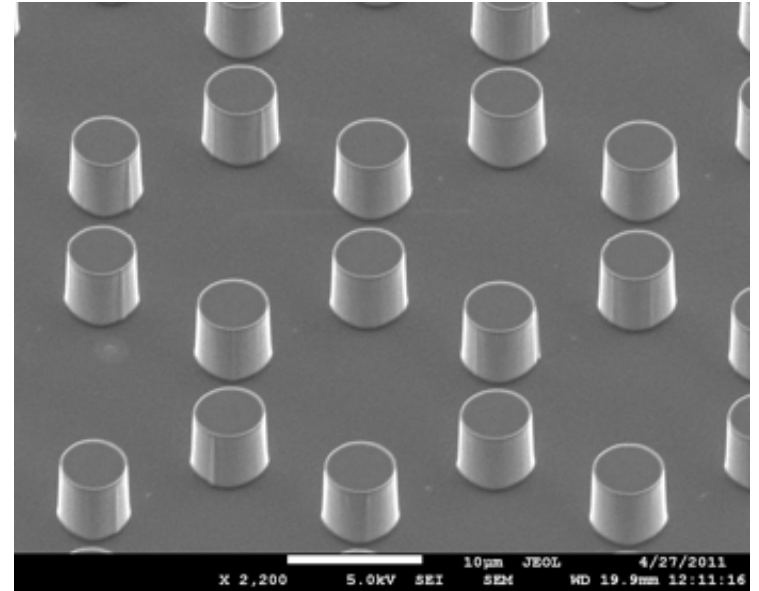
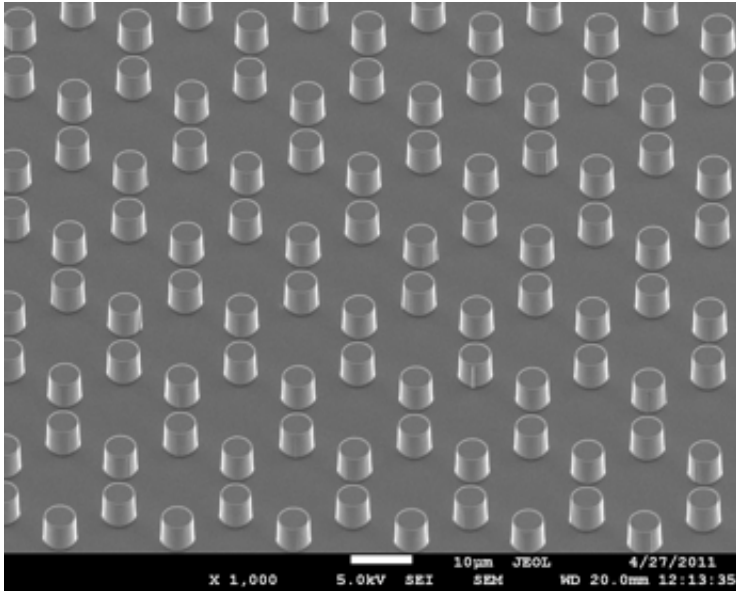
- Device spans an octave
- 3 sets of 15 samples
- Differential thermal signal



B	F	J	N	C	G	K
E	A		L	H	D	O
I	M	B	F	J	N	C
L	H	D	2	O	K	G
	A	E	I	M	B	F
D	O	K	G	C	N	J
H	L		A	E	I	M

Characterization

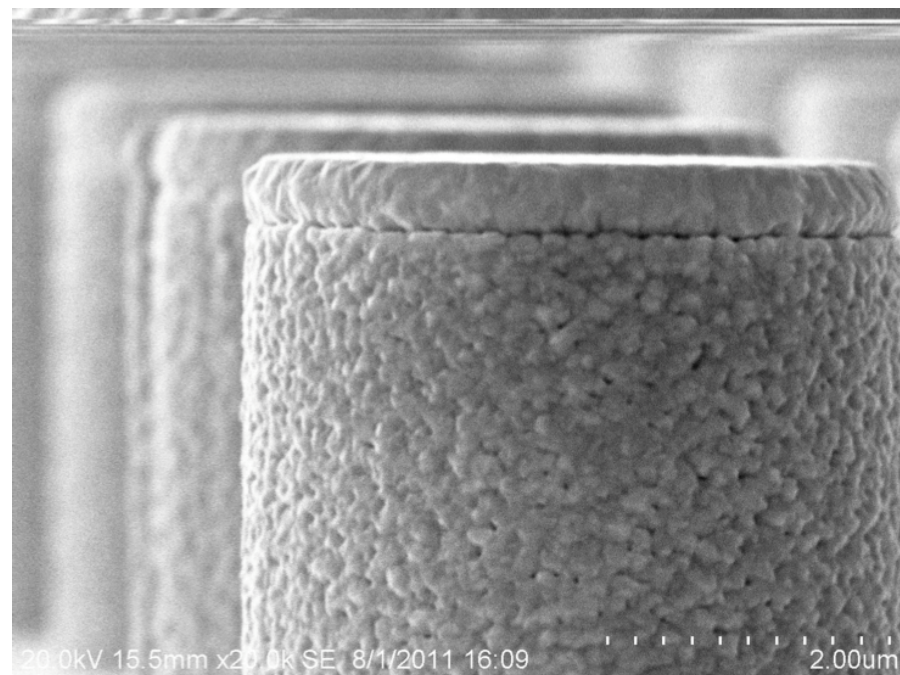
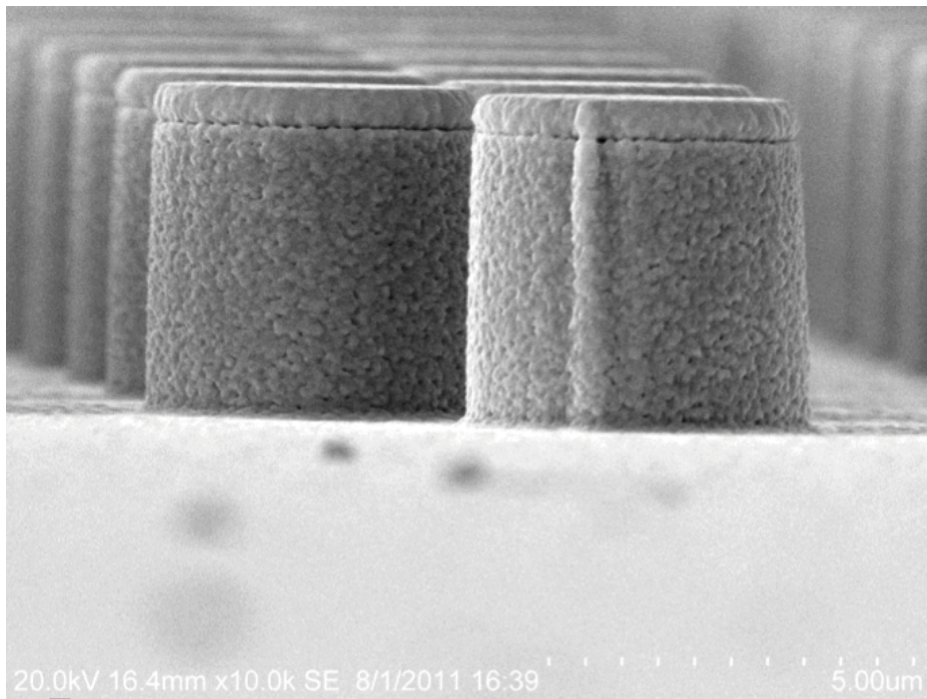
Scanning Electron Microscopy (SEM)



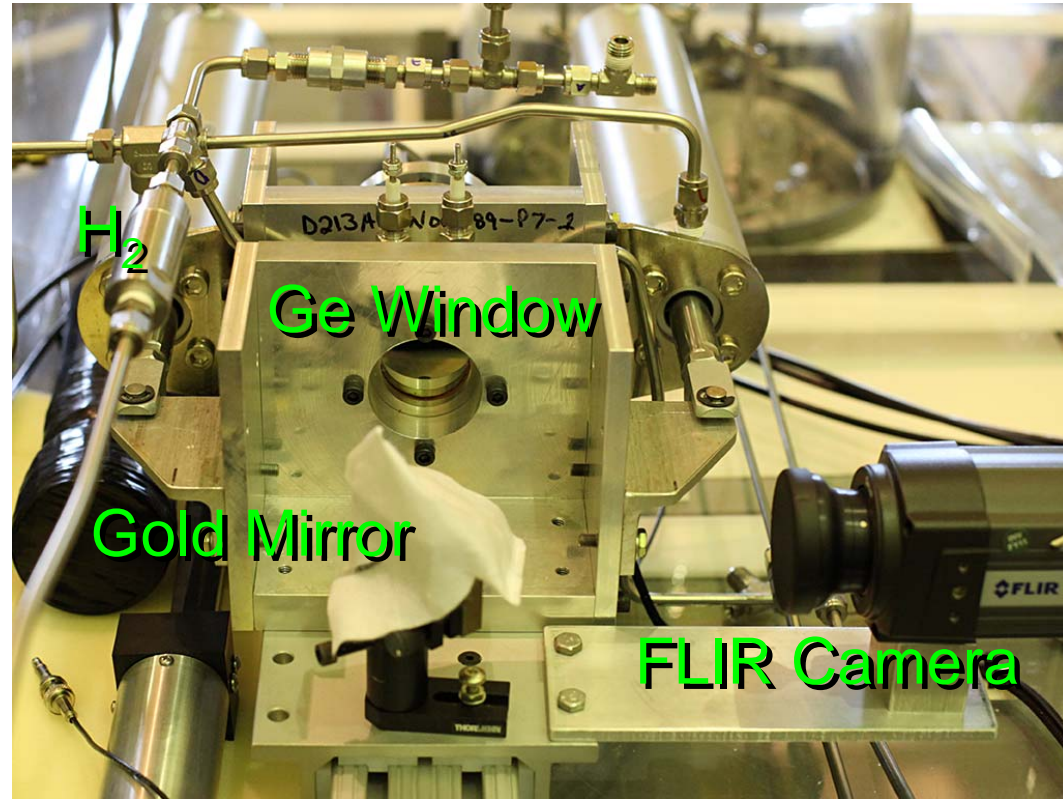
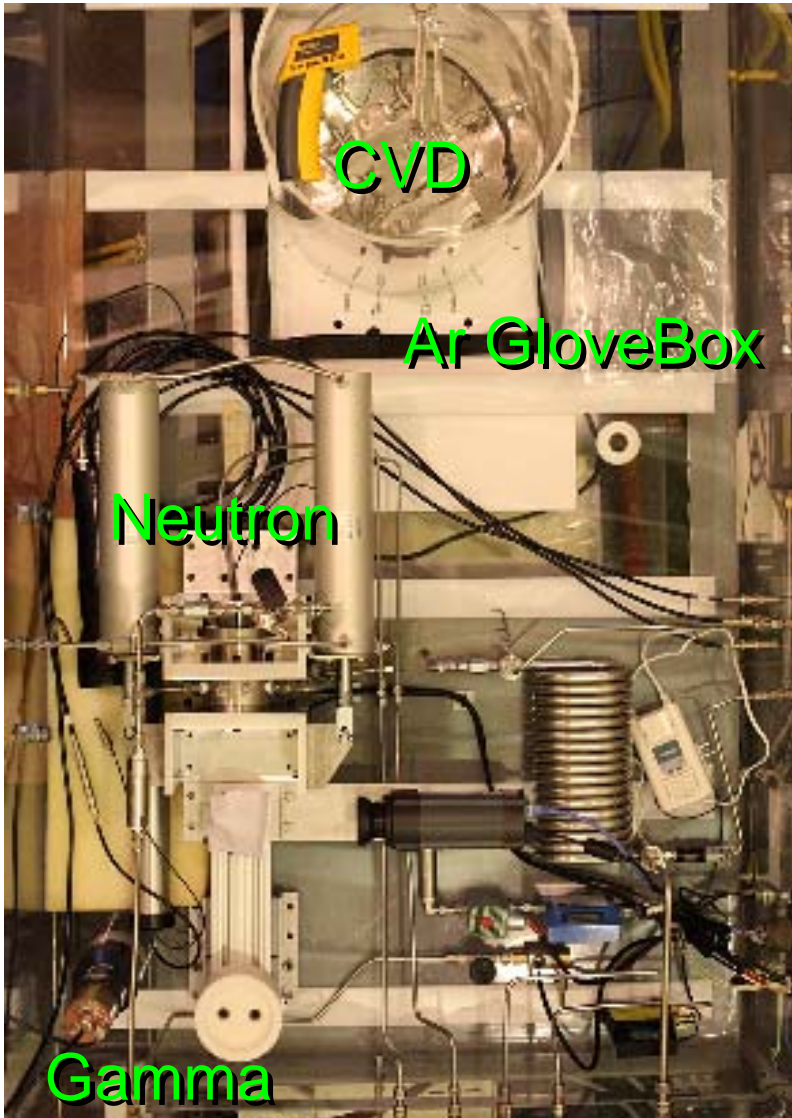
Tile "M"

Metallization

Scanning Electron Microscopy (SEM)



Experimental Setup



Pressure modulation
Differential thermal imaging
Neutron & Gamma Spectrometers

So What is LENR?

- LENR is a form of nuclear power
- However, LENR is NOT cold fusion
- Transmutation products most consistent with neutron absorption process
- Decay products readily thermalized
- Gamma rays are screened out
- Very likely linked to the resonance of the hydrogen in/on the metal lattice
- Despite claims to the contrary, devices that can be turned ON/OFF not yet demonstrated



ONCE I GOT THE COLD FUSION PROBLEM OUT OF THE WAY,
THE REST WAS EASY!



IMPLICATIONS

Fission / Fusion / LENR Comparison

- **Fission** - Strong nuclear force - 3% Efficient
 - $^{235}\text{U} + n \Rightarrow ^{92}\text{Kr} + ^{141}\text{Ba} + 3n + \sim 200\text{MeV}$
 - 88 GJ/g or **1,900,000 times chemical**
- **Fusion** - Strong nuclear force - ~5% Efficient
 - $^2\text{H} + ^3\text{H} \Rightarrow ^4\text{He} + n + \sim 18\text{MeV}$
 - $^2\text{H} + ^2\text{H} \Rightarrow ^3\text{H} + p + \sim 4\text{MeV}$
 - or $\Rightarrow ^3\text{He} + n + \sim 3\text{MeV}$
 - 337 GJ/g or **7,300,000 times chemical**
- **LENR** - Weak nuclear force - TBD% Efficient
 - $6p + 3e \Rightarrow ^6\text{Li} + 6 \bar{\nu}_e + 3 \nu_e + 28\text{MeV}$
 - ~370 GJ/g or **8,000,000 times chemical!**
 - W-L conservative estimate - 4,000 times chemical

Ramifications

- **Scalable:** Nuclear energy densities from μW to GW
- **Portable:** Little or no need for radiation shielding
 - Adaptable to the full range of transportation systems
 - Does not have the weight, safety, and costs of fission
- **Revolutionizes Aviation and Access to Space**
 - Decouples energetics from reaction mass
 - Fuel mass essentially goes away for air-breathing applications, reduces total mass
 - No GHG (CO_2 , H_2O , aerosols, ...) concerns
 - Fuel is very cheap (Nickel abundant, electrolysis of H_2O)
- **Total replacement of fossil fuels** for everything but synthetic organic chemistry

Design Metrics

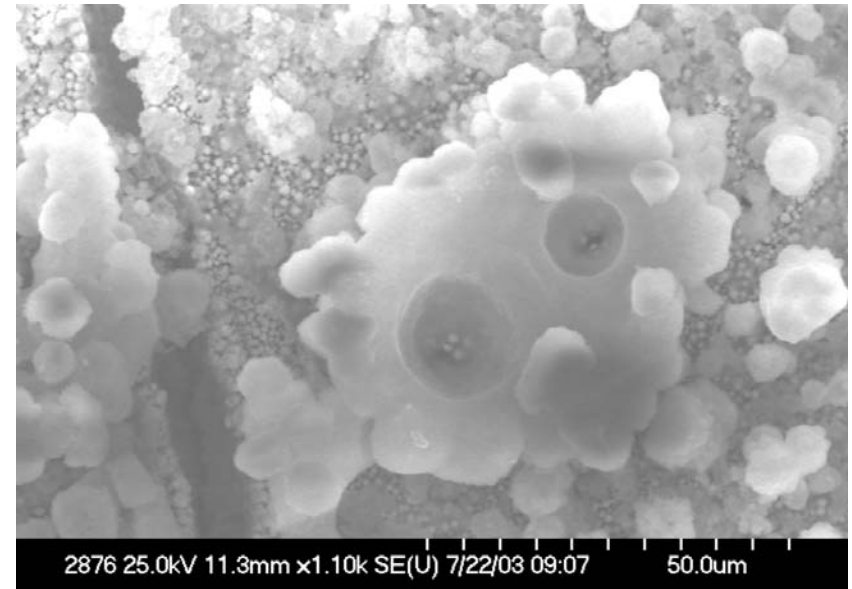
- **Fuel mass and volume are negligible:**
 - Mass is essentially constant from take-off to landing
 - Increase in payload as percentage of TOW
 - Optimizations for increased landing weight
- **Increase in performance**
 - Energetics favorable for supersonic cruise
 - Greatly extended range/capacity for rotorcraft
- Overall reduction in mass opens up the micro and nano vehicle design space

New Missions

- Increase in capability results in new applications
 - Mini - Micro - Nano air vehicles
 - Sensor swarms/meshes
 - Package delivery
 - Huge implications for ATC
 - Personal Air Vehicles
 - Performance equates to increased safety
 - Performance fully enables true point-to-point
 - Greatly extended range (Local -> Global!)
 - Huge implications for ATC
 - Military
 - Unlimited loiter
 - Enhanced mobility with a reduction of supply logistics
 - Horizontal take-off access to orbit

Materials and Thermal Management

- Quality of heat is high
LOCALLY
- Current devices tend to self destruct
- Need to engineer the materials for both composition and structure
- At high power, thermal management is unlike anything you have dealt with before



Where's My Flying Car?



Commercial Aircraft

- 14% Payload
- 43% Fuel
- 43% Structure
- What if fuel is 0%?
- Can't land at GTOW
- Much of the structure is there to lift other structure
- What is the payload fraction of an LENR long-haul aircraft?



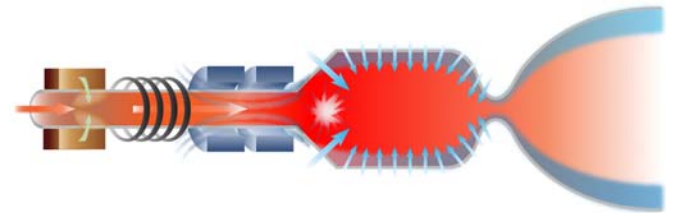
Military and Intel Applications

- Long-range hypersonic or suborbital vehicle
- Unlimited loiter
- Shift in payload fraction improves all measures of performance
- Self deploying sensors
- Networks and Swarms
- Single-use nano-weapons
- Pilots need not apply!



Access to Space

- Fully reusable Single Stage to Orbit (SSTO) vehicle
- 20,000lb to LEO
- Engine similar to SSME
- Non-cryogenic “propellant”
- Size, Mass similar to DC-9
- Vehicle had significant (50%) mass margin
- Potential for increasing reliability, maintainability, ...



New Applications and Challenges

- Practical point-to-point package delivery
- Agricultural applications
- Environmental sensing and control

- New models for airspace management
- Highly autonomous vehicles
- Quiet vehicles



Summary

- A cheap, abundant, clean, scalable, portable source of energy will impact EVERYONE.
- Singular solution to peak oil, climate change, fresh water, and associated geopolitical instabilities.
- Drop-in replacement for traditional utility heat sources. Minimal impact to existing infrastructure
- Enables widely distributed generation. Homes and businesses generate what they need - on site.
- Enables whole new approaches to all of NASA's missions - we can affordably get off this rock!