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Lattice Confinement Fusion (LCF) Overview

Nuclear Processes by which Nuclei are Fused to Produce Energy

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Novel Nuclear Fusion Reactions as an Energy Source

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- Harnessing fusion would provide humanity nearly limitless energy
- For 30 years multiple labs have observed fusion reactions suggesting Lattice Confinement Fusion (LCF)
- LCF may be the key to harnessing fusion within a compact contained system
  - **Eliminates need for weapons-grade uranium (HEU)**
  - **Reduces safety, security, and supply concerns**
  - **Compact, controllable power**
  - **Zero radioactive waste**

Potential Long-Term Applications

** Note: LCF offers near-term means for terrestrial exploration of warm dense matter, Heliophysics, and Astrophysics*

How LCF Works

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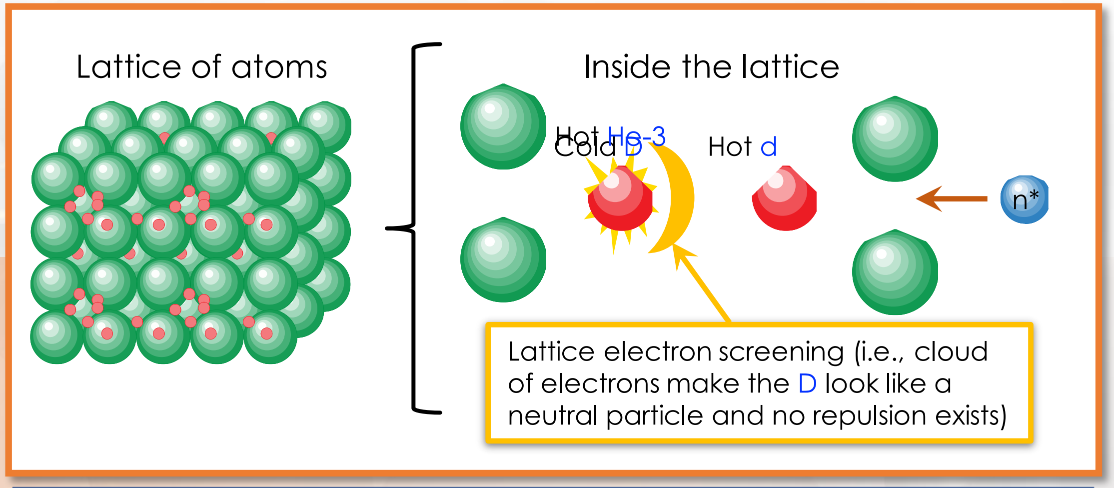
- Traditional fusion: Heats plasma 10x hotter than center of sun – *hard to control*
- LCF addresses the pressure, temperature, and containment challenges with fusion
  - Heats **very few** atoms at a time
  - Approaches solar fuel density
  - Lattice provides containment

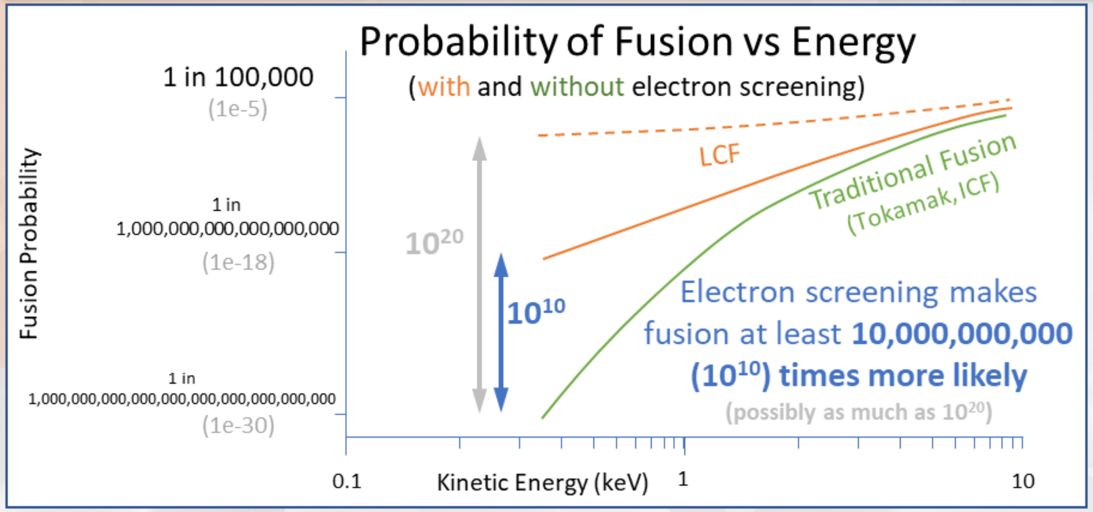


Technical Details Simplified

Part A: **Electron Screening** (increases fusion probability)

Part B: **High Fuel Density** (billion times more dense than traditional fusion)

A + B (+ trigger) = Viable Fusion



LCF Variables (Triggering and Loading Mechanisms)

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Triggering

- Bremsstrahlung photo-neutrons
  - *Collisional heating (PRC)* 64,000 eV
  - NASA: *Physical Review C*
- Accelerated Deuteron Plasma
  - *Electron Screened fusion* 1,200 eV
  - DoE LBNL: *Nature and J. of Applied Physics*
- Electrolytically enhanced Screening
  - *Electron Screened nuclear reactions* 10 eV
  - NASA: *Int. J. of Hydrogen Energy*
- Deuterium flux
  - *Induced nuclear reactions* 1 eV
  - NASA: *J. of Electroanalytical Chemistry*

All these reactions produce millions of eV energy/reaction.

Figure of Merit: Output Energy/Input Energy

Loading

- Heat and pressure
  - TiD_2, $ErD_{2.8}$
- Plasma discharge
  - TiD_2, PdD
- Gas Cycle
  - $Pd_{.75}Ag_{.25}$
- Electrolytically
  - Ti, $Pd_{.75}Ag_{.25}$, Pd, Th, U, YBCO

LCF Variables (Materials)

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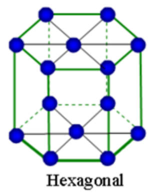
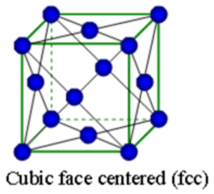
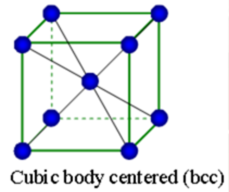
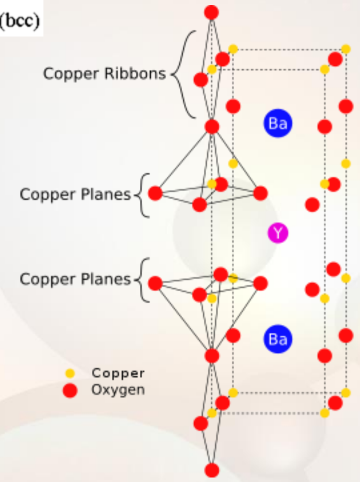
- TiD_2 Titanium, (Hexagonal)
  - TiD_2
- Palladium, (Face Centered Cubic)
  - PdD
- Erbium, (Hexagonal Close Packed)
  - $ErD_{2.8}$
- Thorium (Body Centered Cubic)
  - ThD_4
- Uranium, (Orthorombic)
  - UD_3
- $YBCOD_{.1}$ (Perovskite superconductor)
  - $YBa_2Cu_3O_{7-x}D_{.1}$









LCF is repeatable with different lattice materials

Physical Review C Papers: Bremsstrahlung-induced Nuclear Reactions in Electron Screened, Deuterated Metal Lattices

Theoretical

APS physics

PHYSICAL REVIEW C
covering nuclear physics

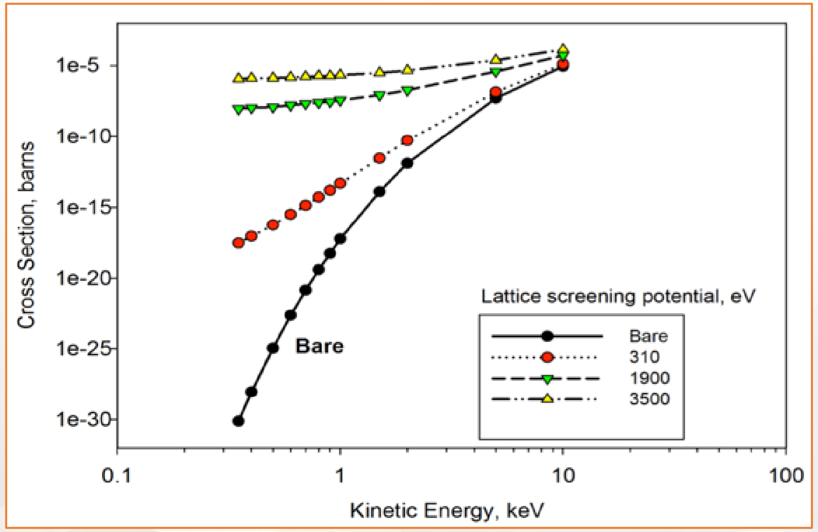
Accepted Paper

Nuclear fusion reactions in deuterated metals

Phys. Rev. C

Vladimir Pines, Marianna Pines, Arnon Chait, Bruce M. Steinetz, Lawrence Forsley, Robert C. Hendricks, Theresa L. Benyo, Gustave C. Fralick, Bayarbadrakh Baramsai, Philip B. Ugorowski, Michael D. Becks, Richard E. Martin, Nicholas Penney, and Carl E. Sandifer II

Accepted 10 December 2019



Electron Screened Enhanced Cross Sections

Experimental

APS physics

PHYSICAL REVIEW C
covering nuclear physics

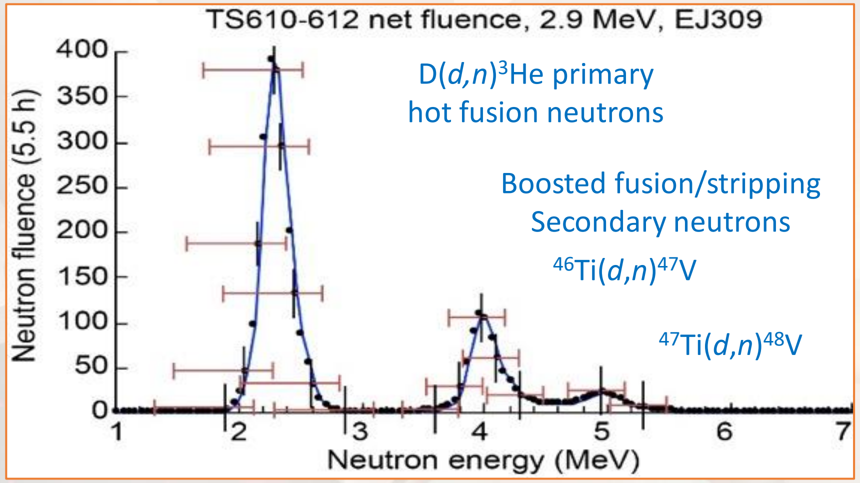
Accepted Paper

Novel nuclear reactions observed in bremsstrahlung-irradiated deuterated metals

Phys. Rev. C

Bruce M. Steinetz, Theresa L. Benyo, Arnon Chait, Robert C. Hendricks, Lawrence Forsley, Bayarbadrakh Baramsai, Philip B. Ugorowski, Michael D. Becks, Vladimir Pines, Marianna Pines, Richard E. Martin, Nicholas Penney, Gustave C. Fralick, and Carl E. Sandifer II

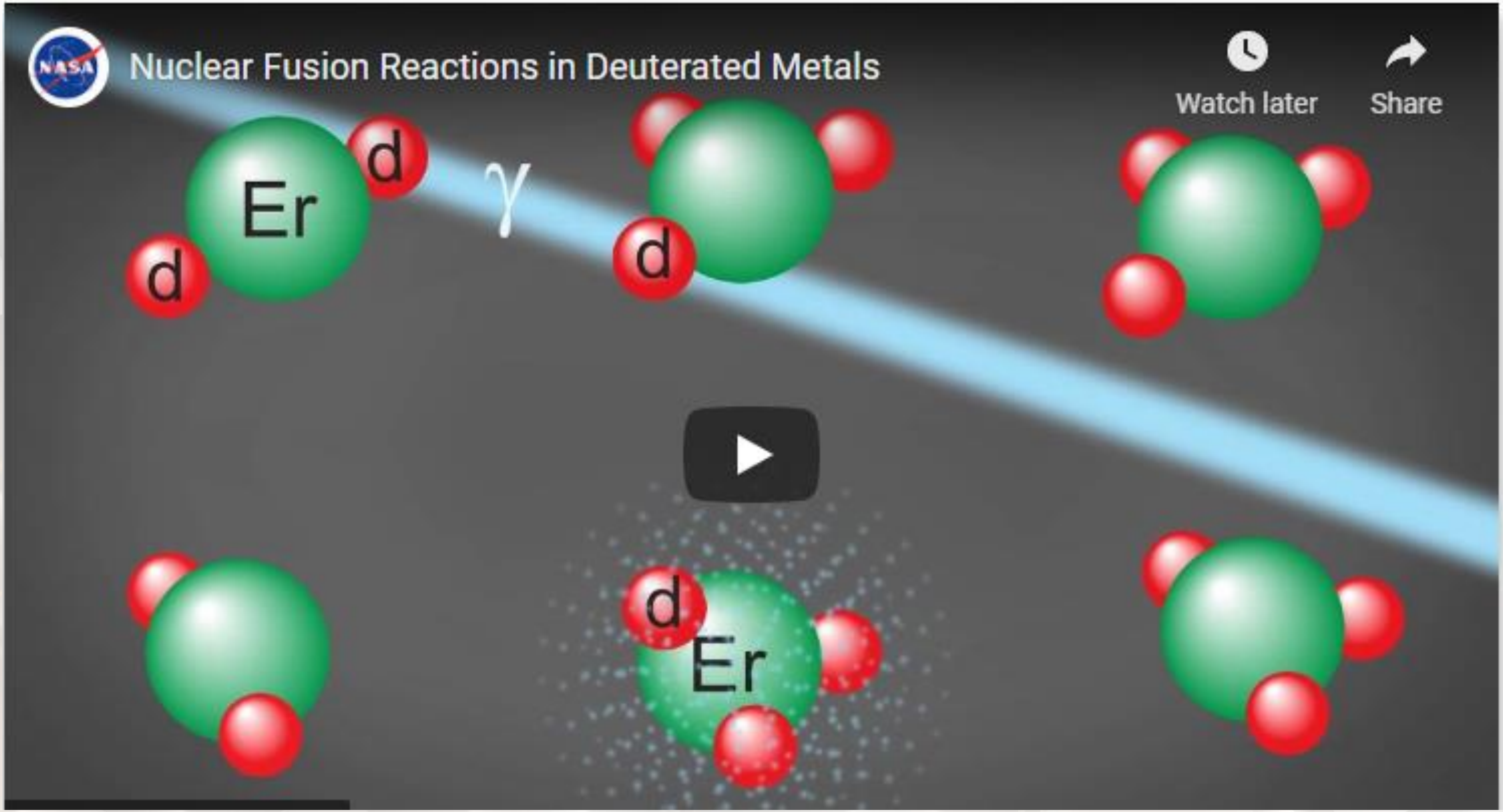
Accepted 6 December 2019



Fast Neutrons Observed

Lattice Confinement Fusion

LCF basic research has demonstrated nuclear reactions in deuterated metals



Lattice Confinement Fusion Fast-Fission Overview

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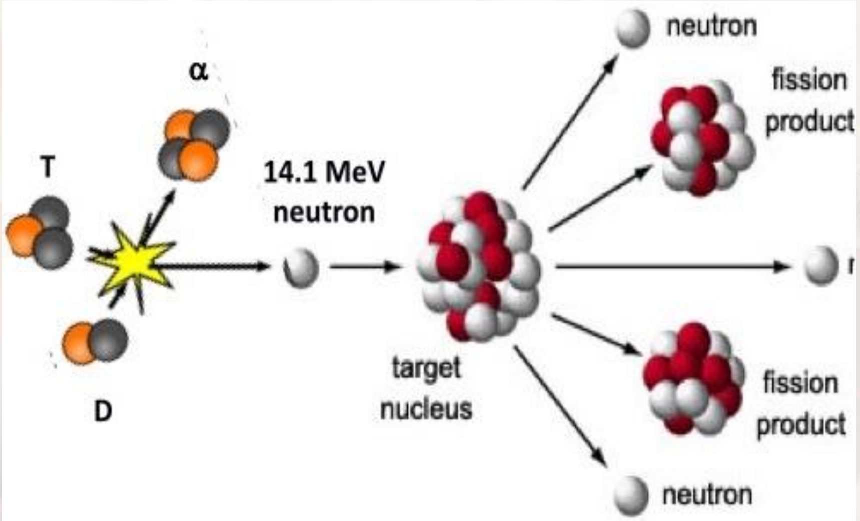
- Takes advantage of both nuclear processes
  - Fusion reactions provide the neutrons to fission non-fissile material
- Neutrons must be > 2 MeV to fission ^{238}U or ^{232}Th.
- LCF Fast-Fission generates an average of 6.4 MeV neutrons up to 15.6 MeV
- The Hybrid Fusion Technology generates energetic neutrons to fission
  - ^{238}U (99.7% DU, 99.3% natural Uranium)
  - ^{232}Th (100%, natural thorium)

Fusion Reaction	MeV	Occurrence	useful particle energy (MeV)
$D(d,n)^3He$	4.00	primary ≈ 50%	n=2.45
D(d,p)T	3.25	primary ≈ 50%	p=3.00
$D(^3He,p)\alpha$	18.30	secondary	p=15.00
$D(t,n)\alpha$	17.60	secondary	n=14.10
$T(t,\alpha)2n$	11.30	low probability	n=1 to 9
$^3He(^3He,\alpha)2p$	12.86	low probability	p=1 to 10
Fission Reaction	**MeV**	**Occurrence**	**useful particle/energy (MeV)**
$^{232}Th(n,\gamma)f$	200	high probability	n=1 to 9
$^{232}Th(p,\gamma)f$	200	some probability	p=1 to 10
$^{238}U(n,\gamma)f$	200	high probability	n=1 to 9
$^{238}U(p,\gamma)f$	200	some probability	p=1 to 10



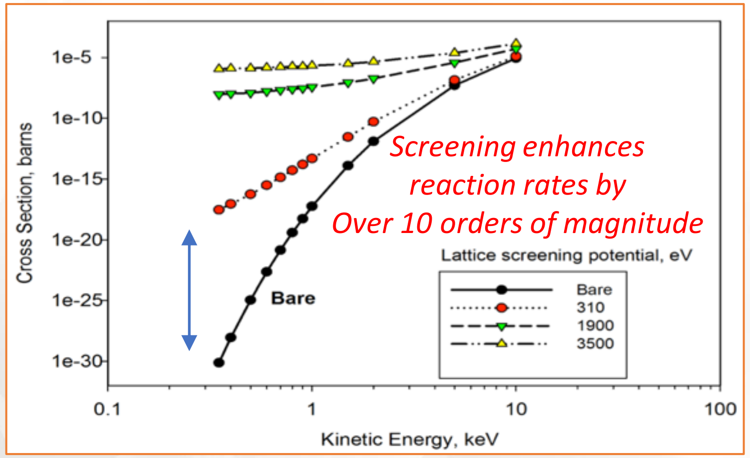
Conclusion

- **Demonstrated**
  - Bremsstrahlung photoneutron-initiated fusion in a "Globally Cold - Locally Hot" environment.
  - Process is repeatable and works with different lattice materials holding the deuteron fuel.
  - Observed boosted fusion or nuclear stripping reactions indicate a path to scaling.
- **Calculated**
  - Electron screening increases localized fusion rates in dense fuel.
  - Neutrons and screened charged particles most efficiently heat the dense fuel.
  - Electron screening increases large angle scattering between charged particles enhancing quantum tunneling and increased fusion rates.
- **Predicted**
  - Fusion rates consistent with observed neutron flux.
- **Extended**
  - Hybrid LCF Fast Fission takes advantage of fast neutrons created under LCF to fission natural U
- **Website**
  - https://www1.grc.nasa.gov/space/science/lattice-confinement-fusion/

Backup

The Path: Electron Screening [1]

- Electron screening results in a *more transparent Coulomb Barrier*, *shifting the Gamow Factor,* as if deuterons were at far higher energies.
- This exponentially increases fusion rates.
- Laboratory astrophysics using accelerated deuteron beams across the Periodic Table show lattice and plasma screening provide up to 3+ keV screening.
- The *PRC* Theory Paper indicates a *higher probability of large angle scattering of screened charged particles* on screened deuterons.



Electron Screened Enhanced Cross Sections

However, screening is only effective below 10 keV.

$$\sigma_{\mathrm{bare}}(E) = \frac{S(E)}{E} \exp\left[-G(E)\right]$$

The Path: Electron Screening [2]

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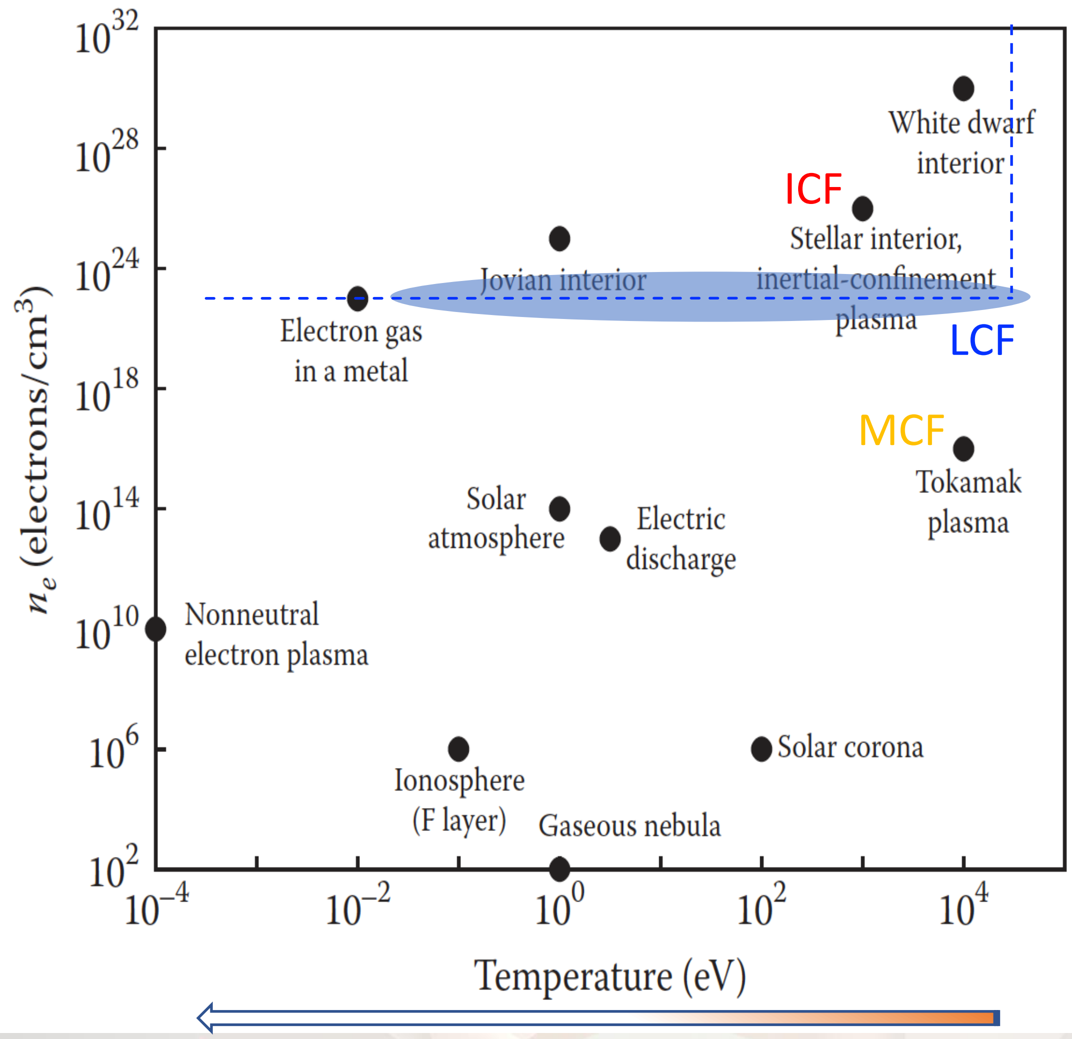
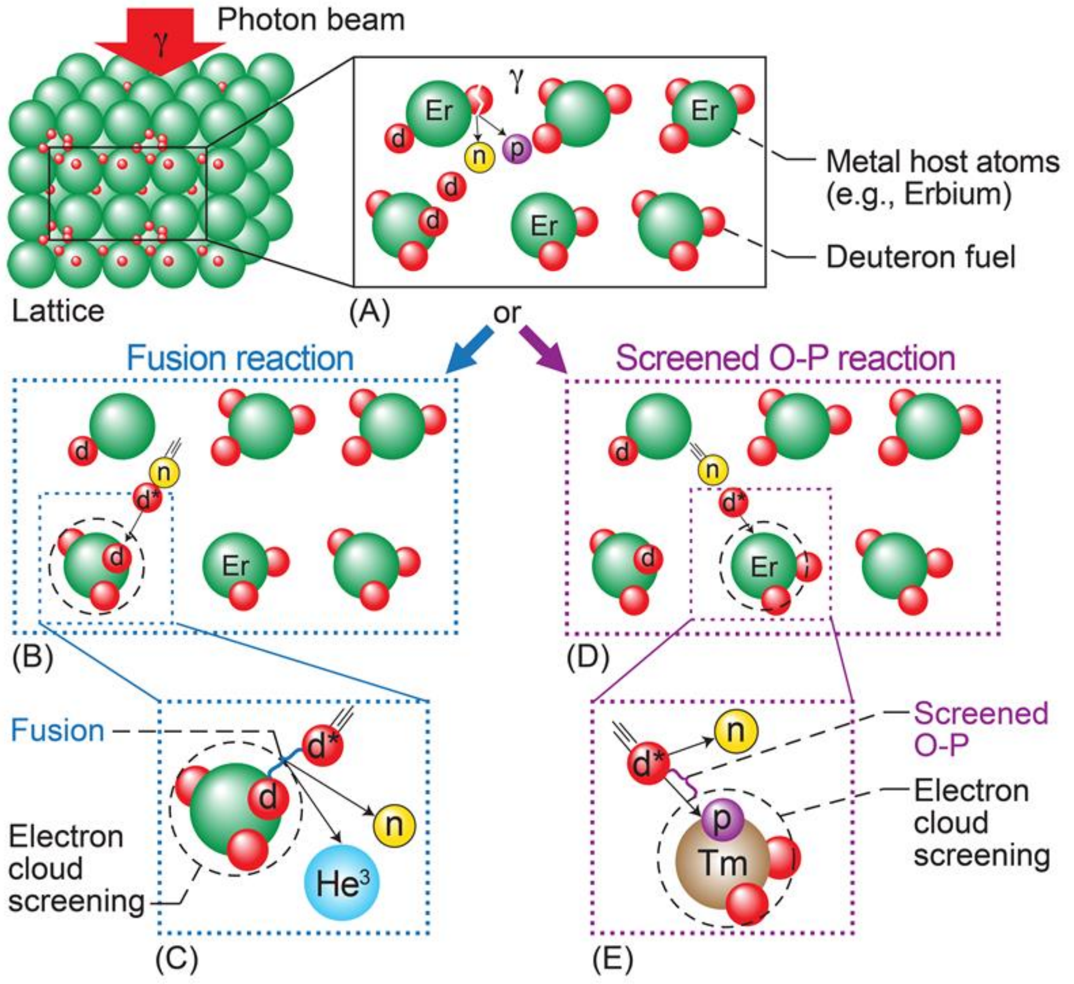
- Fermi Degeneracy occurs with $> 10^{23}$ electrons/cm^3:
  - White Dwarf stars
  - Gas giant planets
  - Metal conduction bands
  - LCF deuterated lattices
- Fermi Degeneracy is relatively temperature insensitive
- LBNL results published in *Nature* and the *Journal of Applied Physics* attribute a *100 to 1000-fold increase in fusion rates* to *electron screening* occurring at only 1.2 keV
- *Screening is effective < 10 keV*
- *LCF Straddles both hot fusion and electron screened regimes*

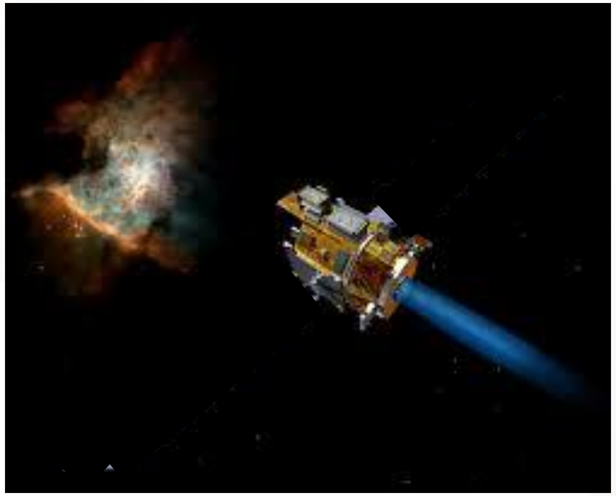
Examples of electron density vs temperature



Increasingly effective electron screening

LCF Reaction Mechanisms





- Er Erbium
- d static deuteron
- photodissociated deuteron
- d* accelerated deuteron
- p proton
- --- electron cloud
- n neutron
- He3 Helium-3
- Tm Thulium