The Science of Fusion Energy

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Video from the COMPASS Tokamak experiment at the Institute of Plasma Physics of the Czech Academy of Science (https://bit.ly/3C3rwVQ)

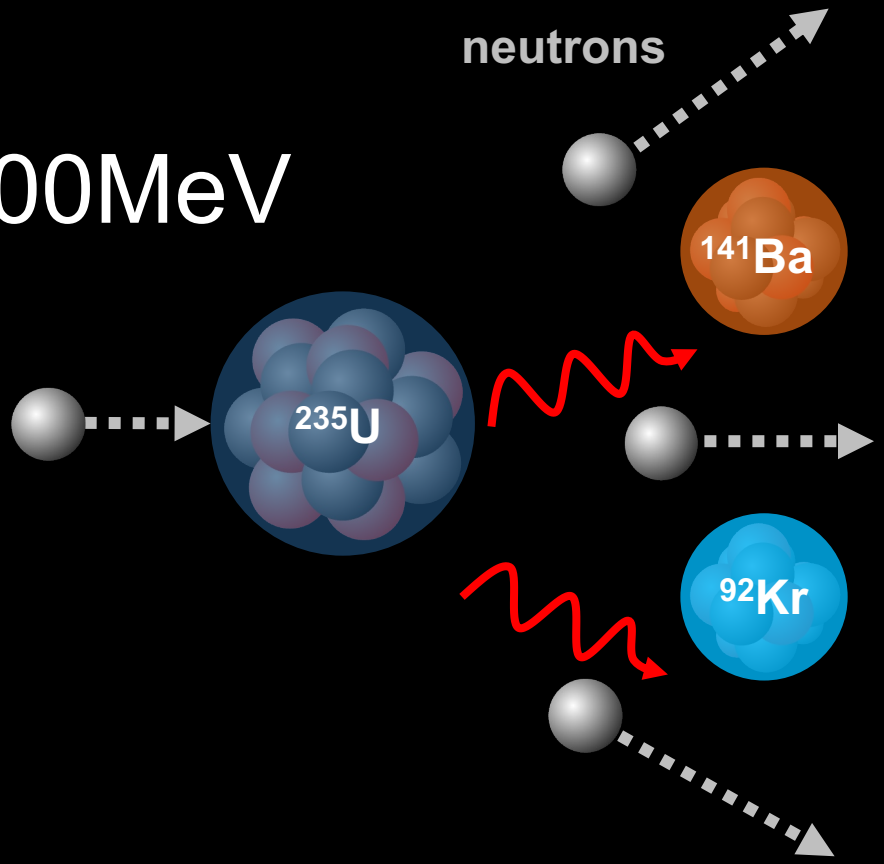
The Science of Fusion Energy

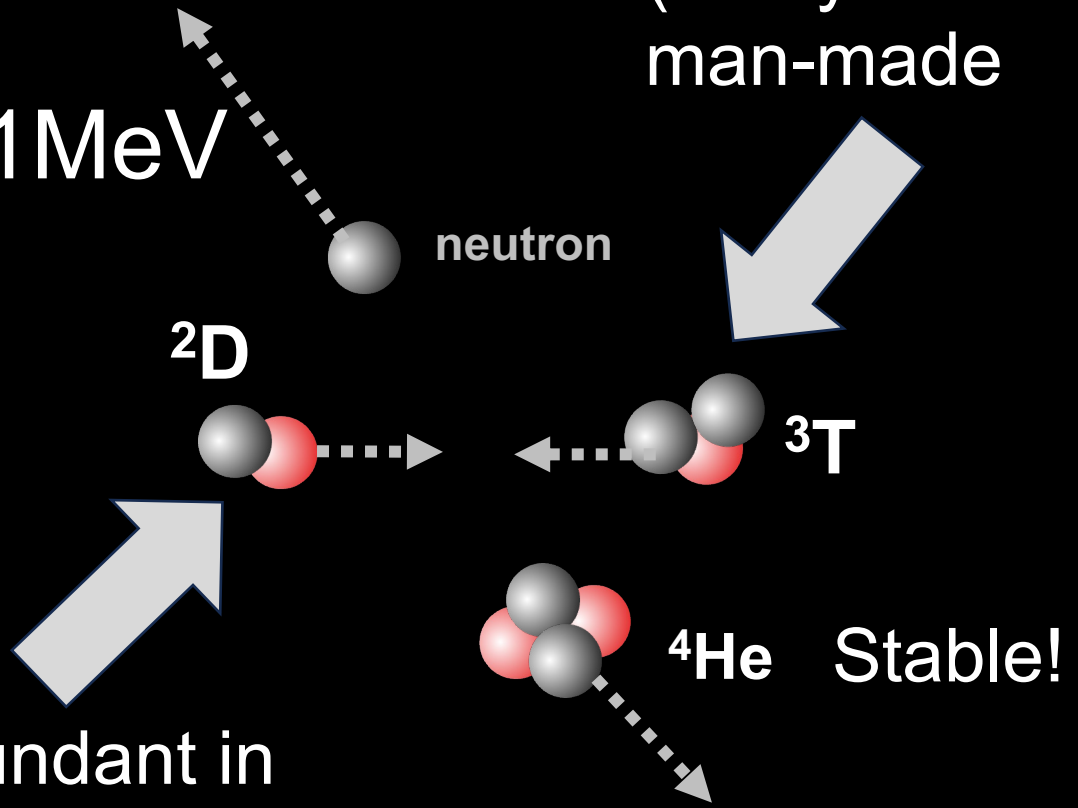
The what - Physics concepts

The how - Challenges & Strategies

The what - Physics concepts

Fusion vs. Fission



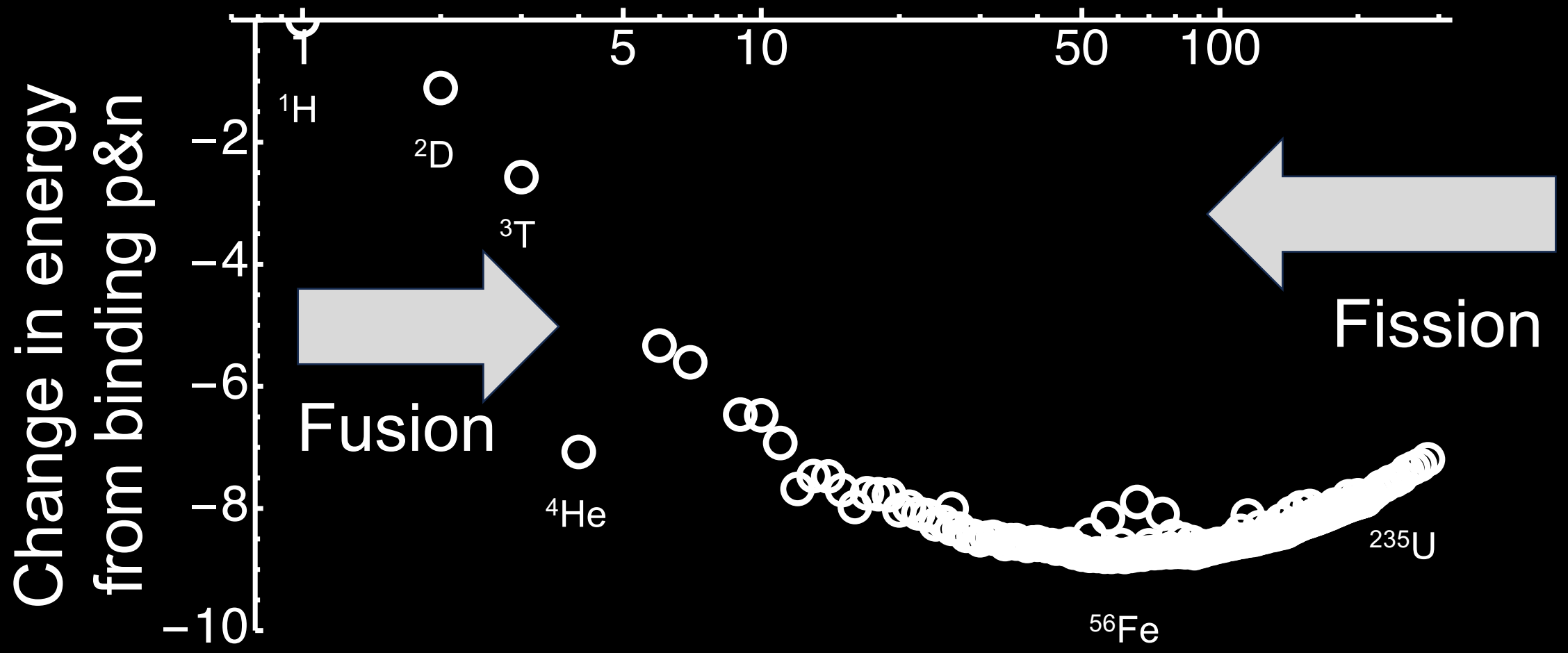


^{3}T radioactive (12.3y half-life) man-made

^{2}D abundant in ocean water (0.02%)

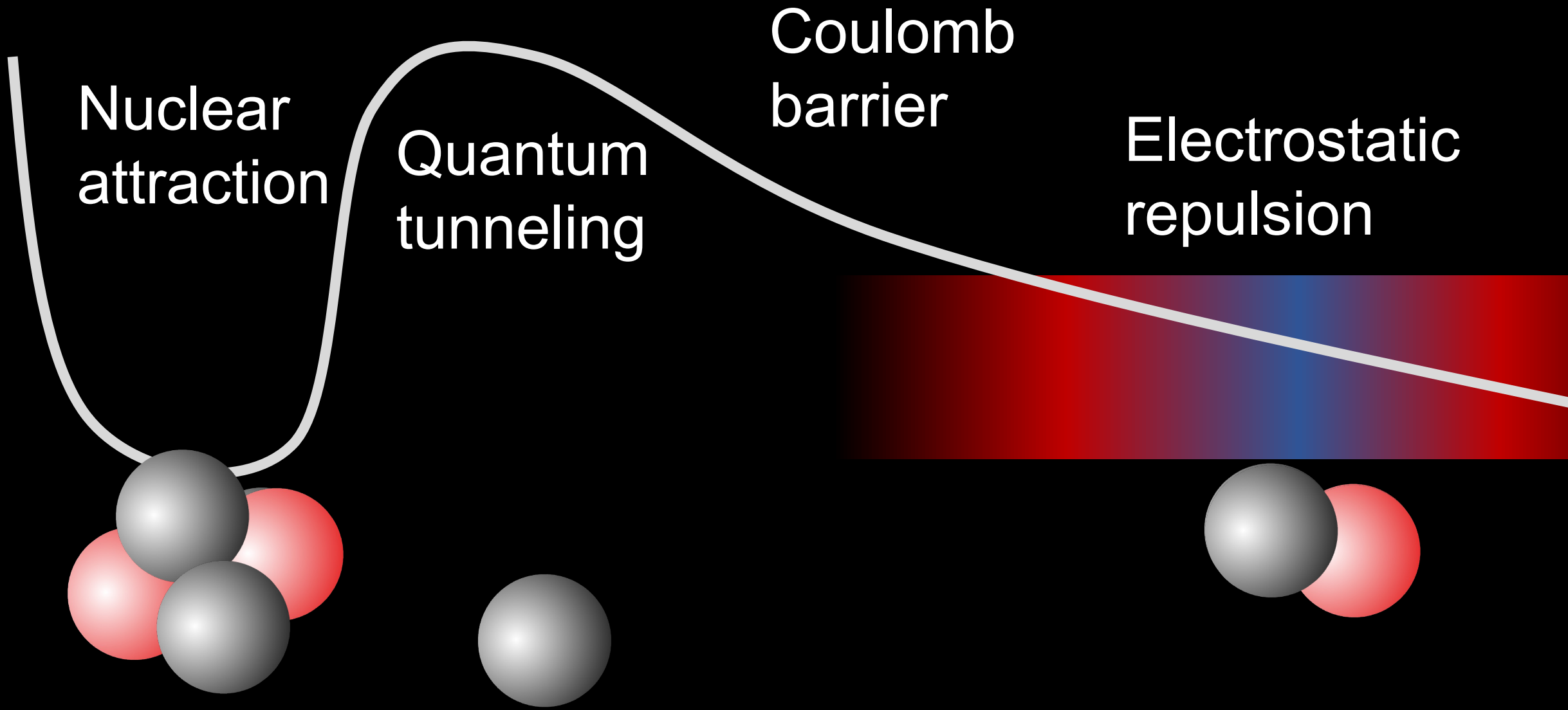
Fusion: 4x more energy per kilogram fuel than fission

Where does the Energy come from?

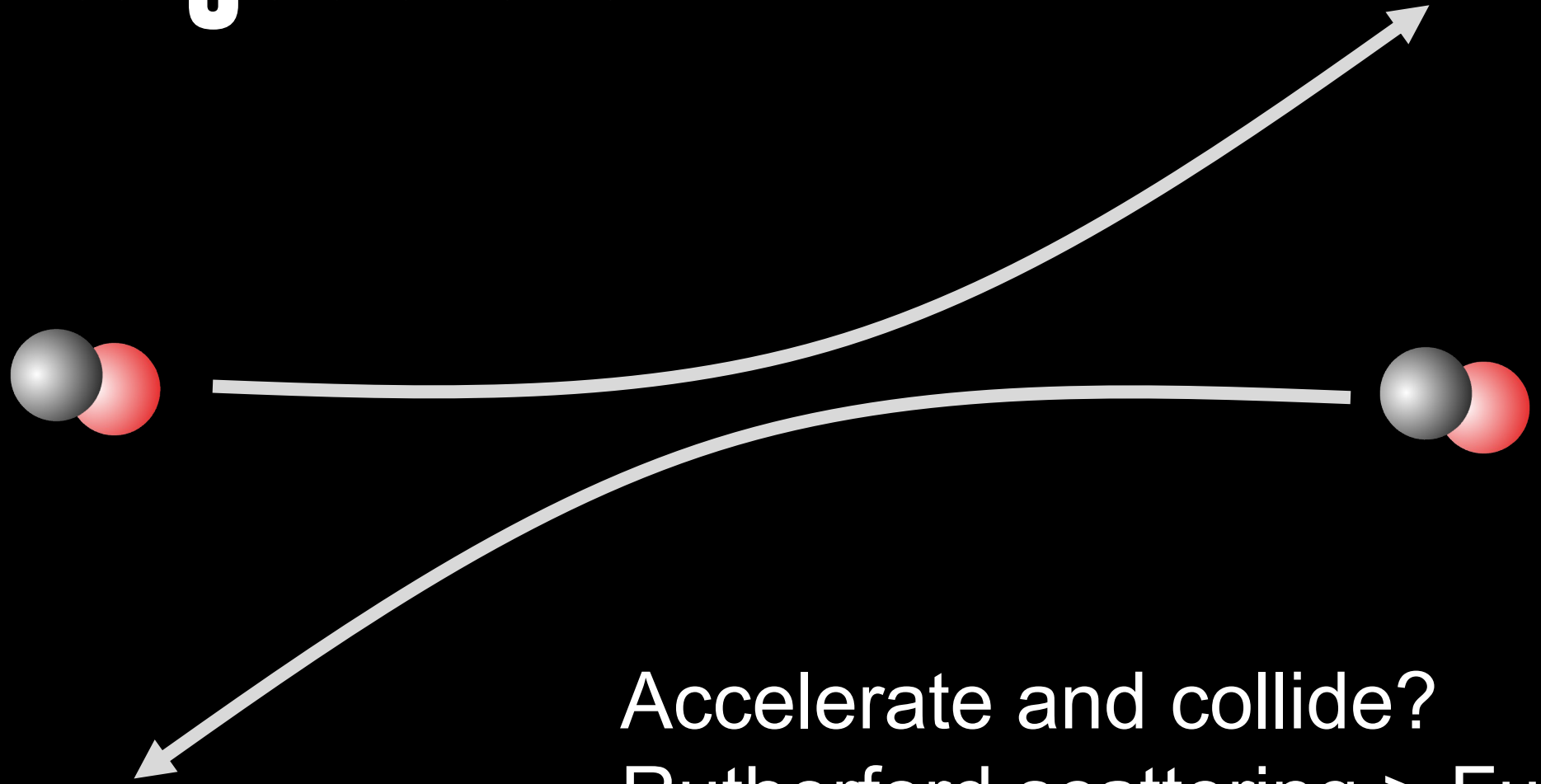


Fusion holistics: the sum is lighter than its parts

The fusion process



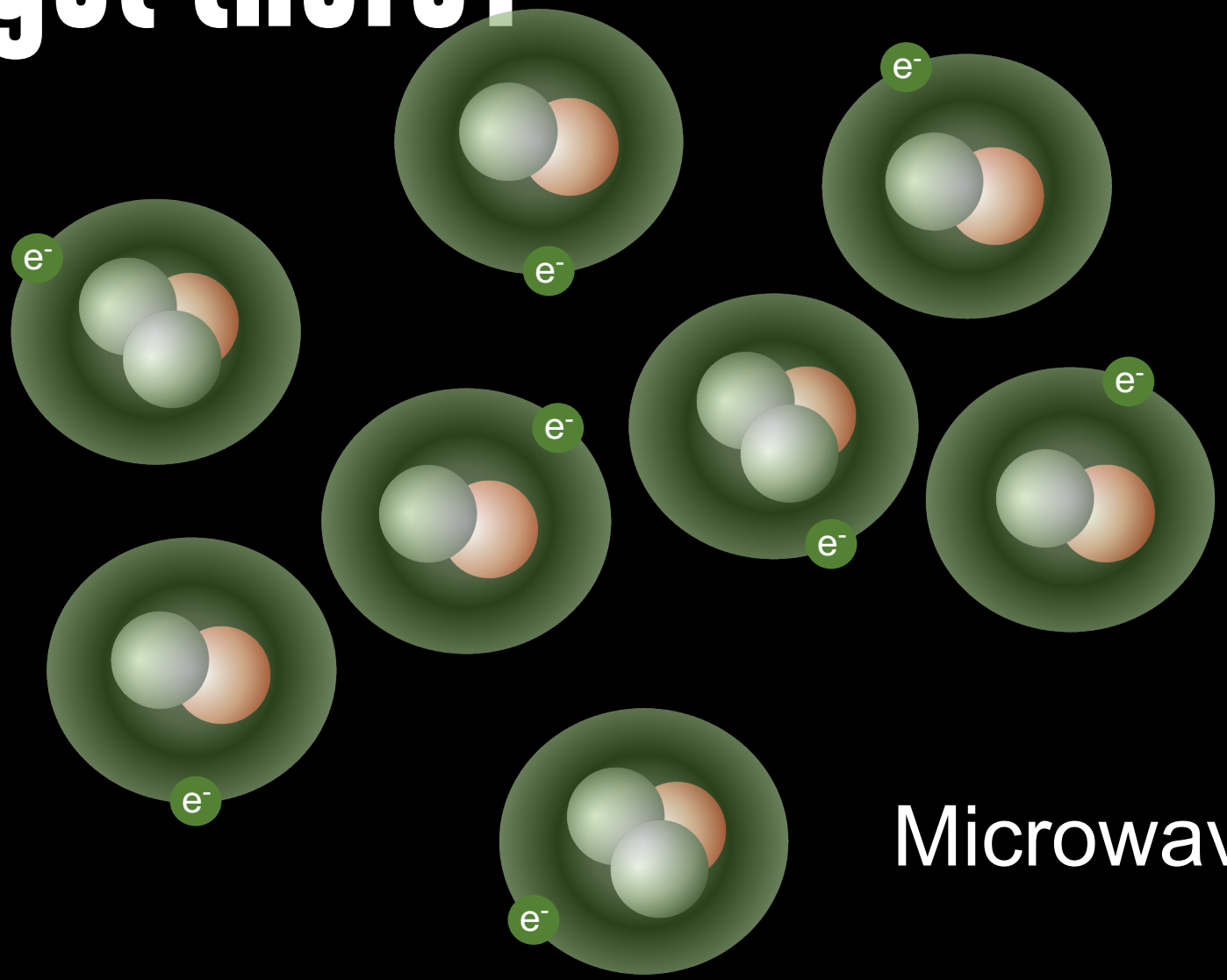
How to get there?



Accelerate and collide?
Rutherford scattering > Fusion

How to get there?

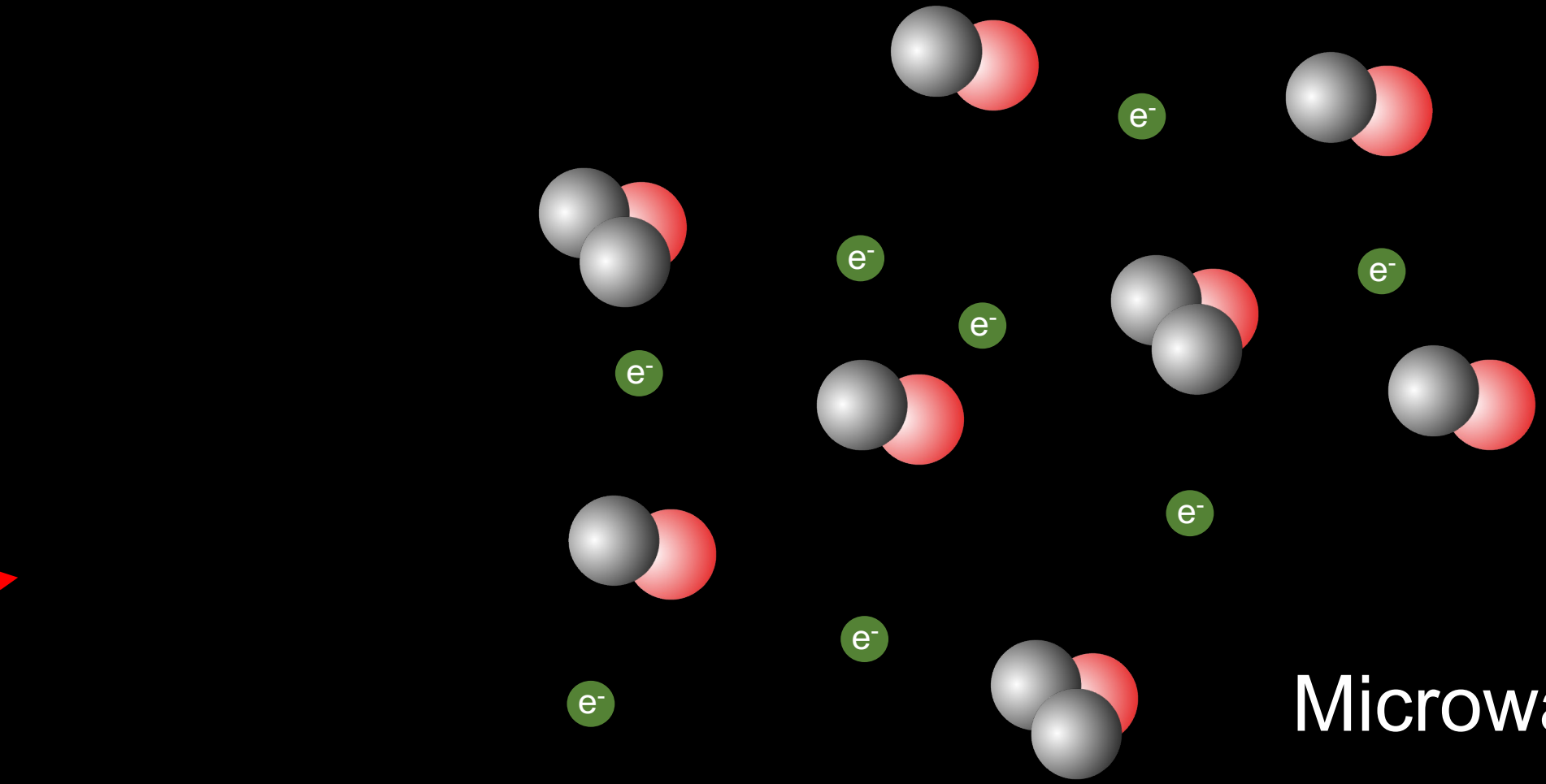
Deuterium – Tritium gas



Microwave heating

How to get there?

Deuterium – Tritium plasma



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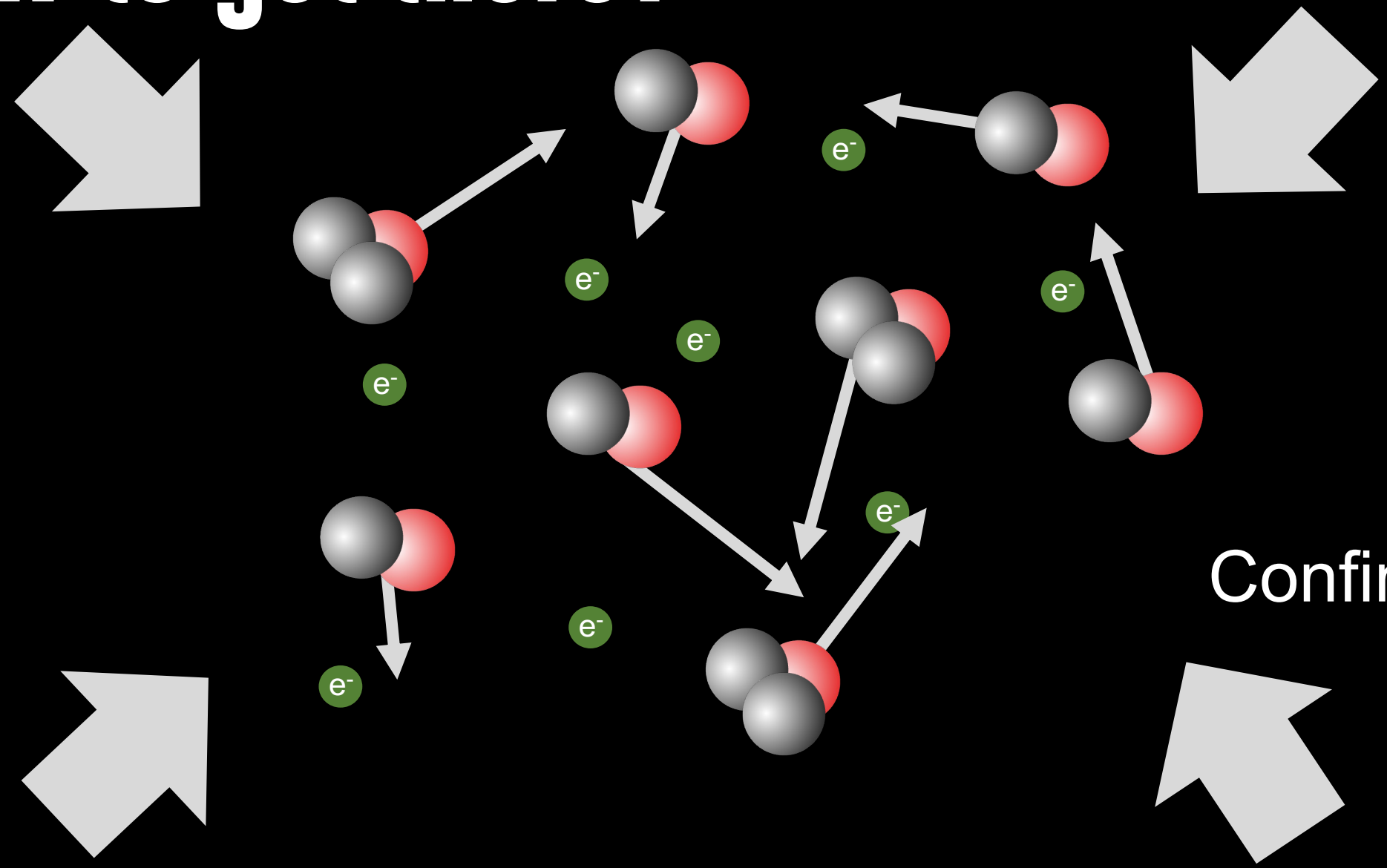
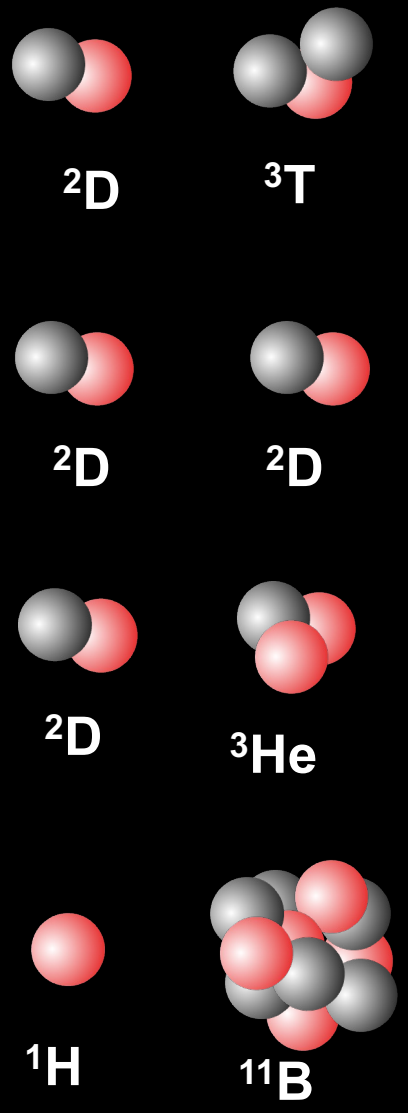
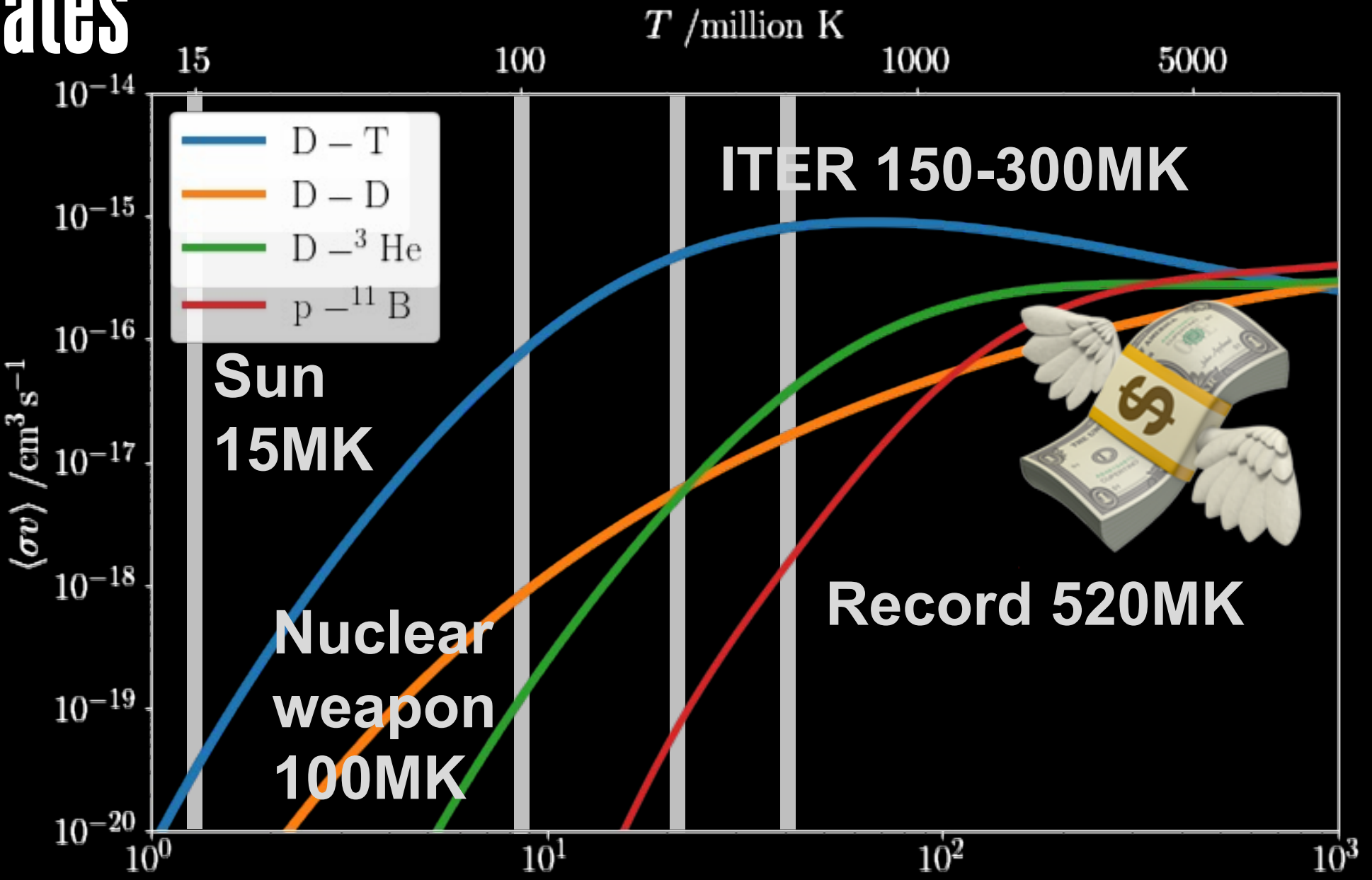


Confinement

Reaction Rates





The how - Challenges & Strategies

Fusion in your basement (electrostatic confinement)

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an achieve honest-to-goodness "hot fusion" right at home by making a Farnsworth-Hirsch fusion

This mini fusor is a demonstration version — while it generates only insignificant quantities of fusion products, it does show how

MATERIALS

- 4 Nylon spacers – McMaster-Carr #94638A29 or 94639A089
- 4 Threaded rods – McMaster-Carr #91565A566
- 2 Barbed hose fittings
- Oil cup cylinder – McMaster-Carr #1176K27, mcmaster.com
- Spade terminals
- PVC pipe fittings
- Variable transformer – aka "Variac"
- PVC tubing – Braided reinforcement keeps it from collapsing under high vacuum.
- 2 Hose clamps
- AC power cord
- Mineral oil
- 2 Diodes – Search hvstuff.com and buy extra in case you accidentally fry your rectifier.
- Male plug with ground prong
- Insulated wire
- Standoff – McMaster-Carr #93330A493

Generating Fusion is EASY but generating electricity is HARD

The original

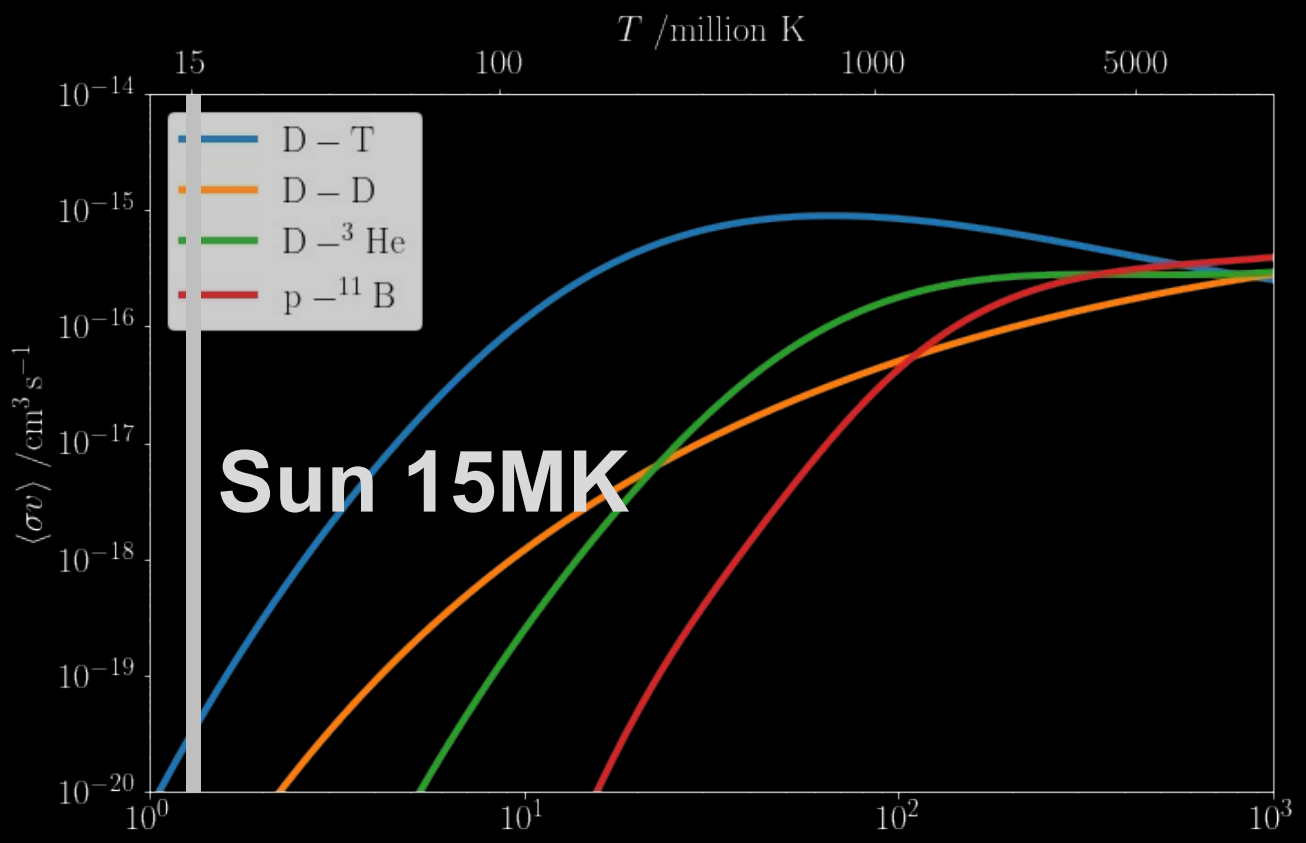
T_{core}=15 MK

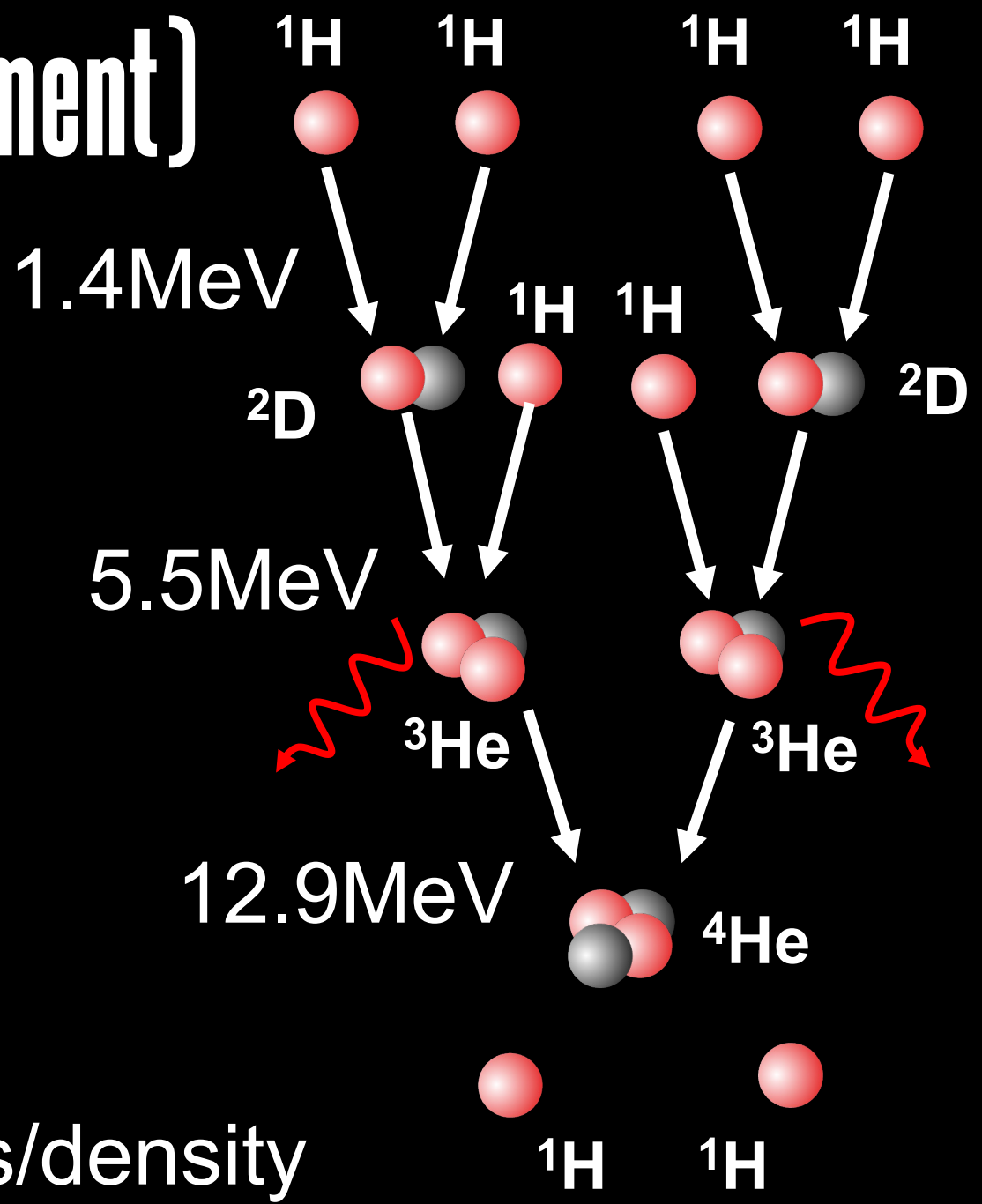
ρ=1.62 x 10^5 kg/m^3

$T_{surface}$= 5770K

Energy emitted as radiation

The sun (gravitational confinement)





Slow reactions, compensated
for by enormous volume/mass/density

Lawson criterion (Triple product)

Density x Temperature x Confinement time

Gain "Q"

Energy produced / Energy required

The holy grail: ignition (self-sustained fusion)

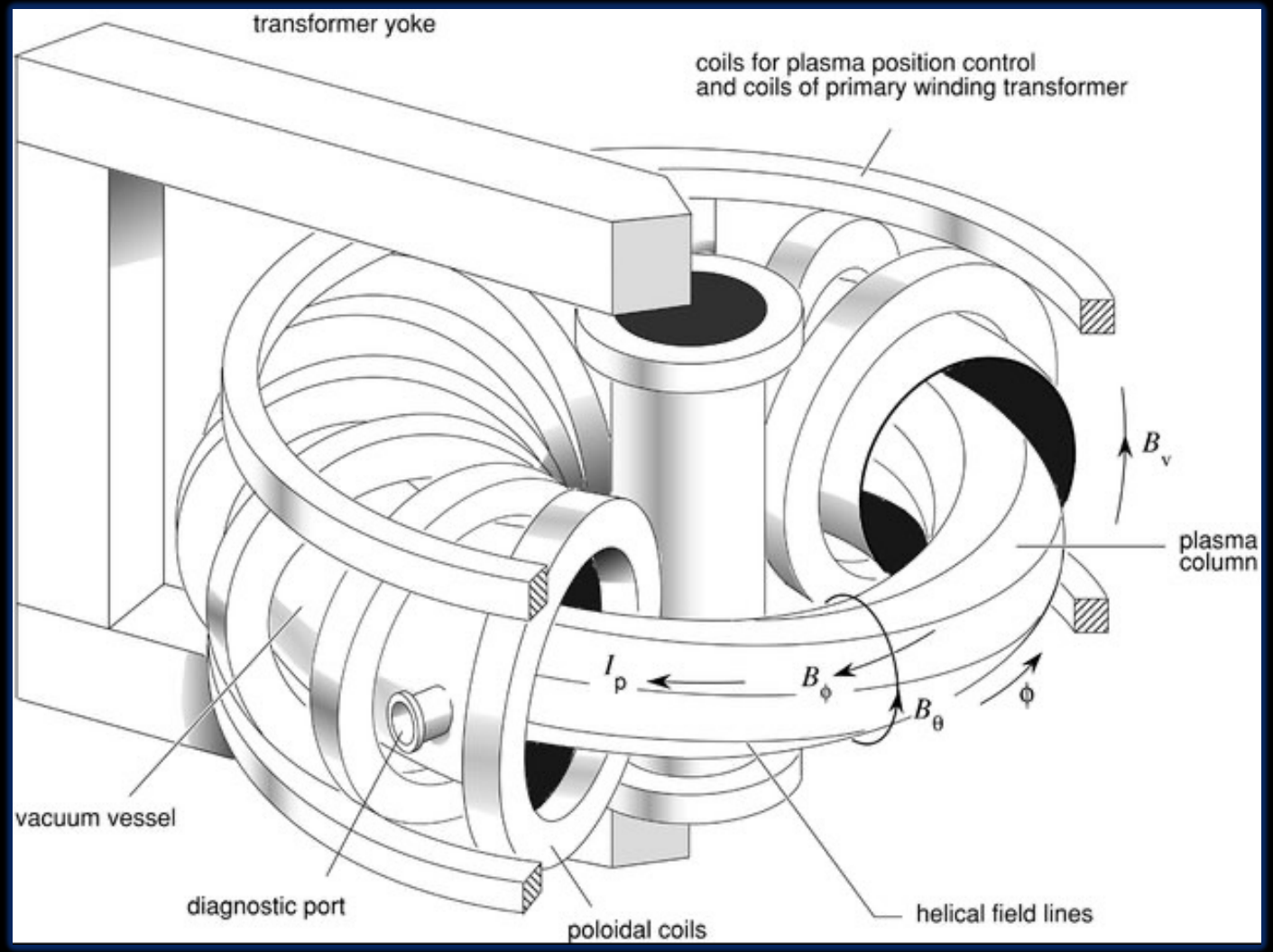
Fusion concepts: Tokamak (magnetic confinement)

Plasma challenge: instabilities

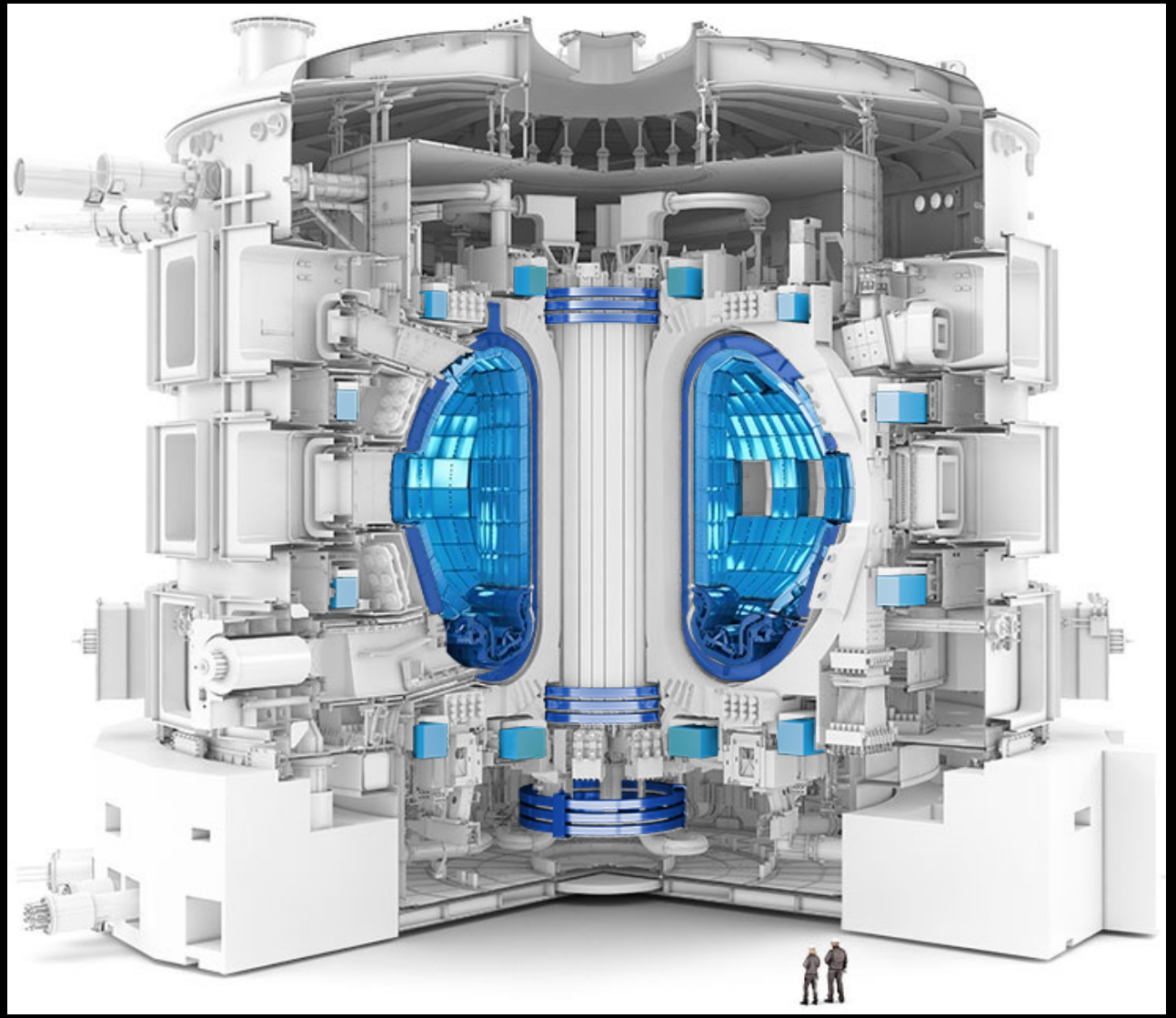
^{2}D-^{3}T challenge: Neutrons!

Recent records:

- T_{ion}~520MK
- t_c~7-100s
- E_f~59MJ



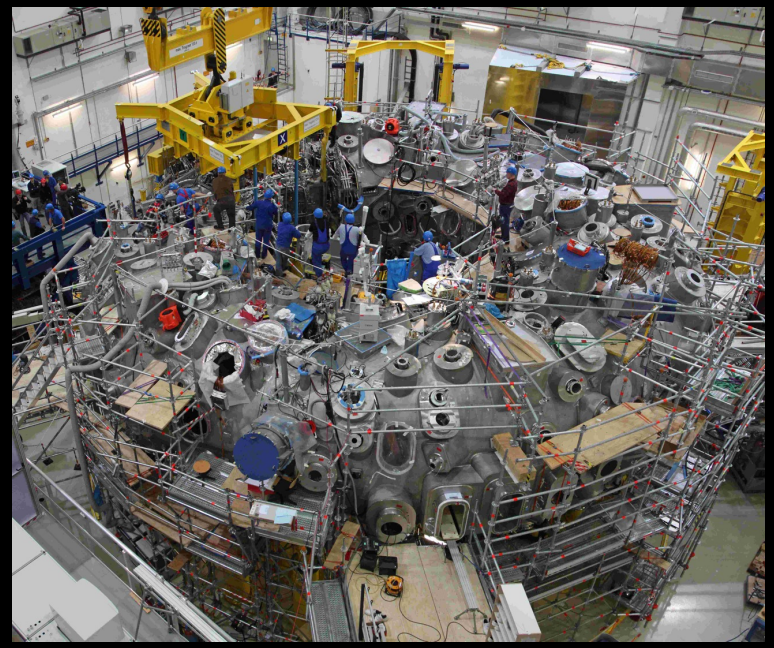
ITER: The largest Tokamak in preparation



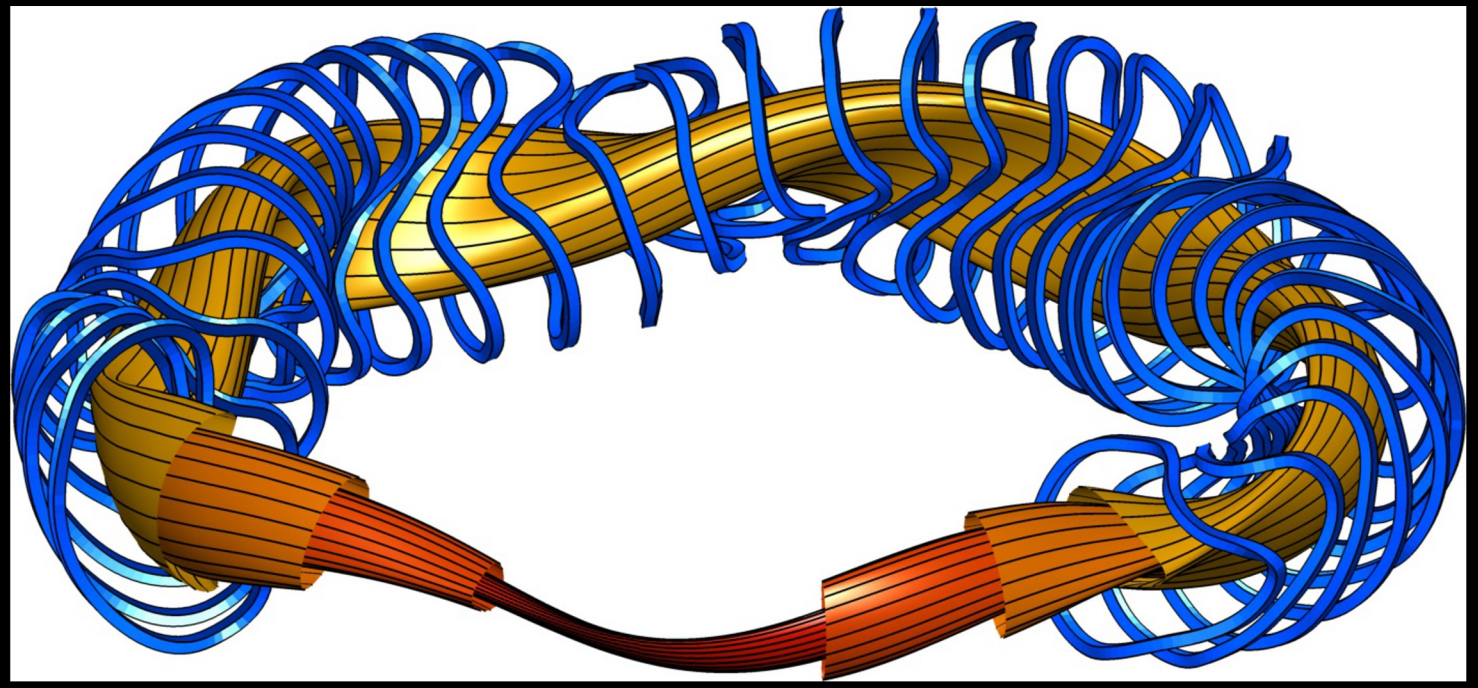
1) Boiling the kettle

2) Replenishing ^{3}T (Beryllium blanket)

Fusion concepts: Stellerator (magnetic confinement)



🇩🇪 Wendelstein 7-X

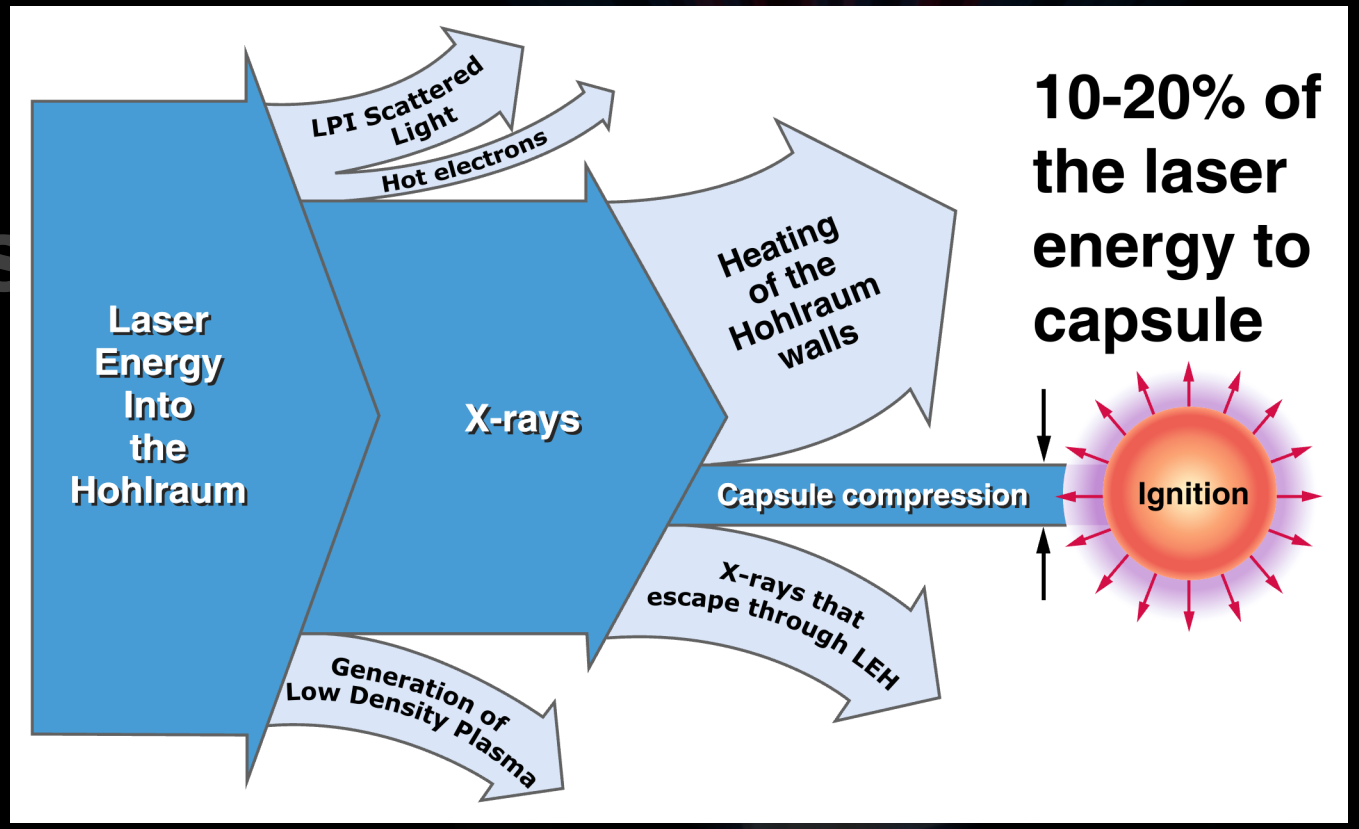


Fusion concepts: Laser fusion (inertial confinement)

Original intention:
Nuclear weapons res

Recent record:
Gain Q~1.5
and ignition!

But…



National Ignition Facility (NIF)

Many independent startups:

Magnetic confinement
Combined funding $ 3.3B

Kyoto Fusioneer · General Fusion · Tokamak Energy
TAE Technologie · Commonwealth Fu
Renaissance Fus · Pulsar Fusion · Deutelio
Type One Energy · Princeton Stell · Helical Fusion

Hybrid electrostatic confinement

CTFusion · Horne Technolog

Inertial confinement
Combined funding $ 92M

First Light Fus

Non-thermal laser fusion
Combined funding $ 54M

Focused Energy · HB11 · Marvel Fusion
Xcimer Energy · Ex Fusion

Pulsed non-ignition fusion
Combined funding $ 502M

Helion Energy

Sheared-flow stabilized (SFS) Z-pinch
Combined funding $ 184M

Zap Energy

Impact fusion

HyperJet Fusion

Hypervelocity Gradient Field Fusion

NearStar Fusion

Reactors Manufacturing

Princeton Satel · Fusion Reactors

Untitled
Combined funding $ 65M

Helicity Space · Compact Fusion · Avalanche Energ
Lawerenceville · Crossfield Fusi · NK Labs
Magneto-Inertia · Electricfusions

Must address: Reaction rates + Gain & extraction method

Conclusion: Fusion energy

Nuclear Physics ✅

Plasma physics 

Engineering 

Economics ⚠️