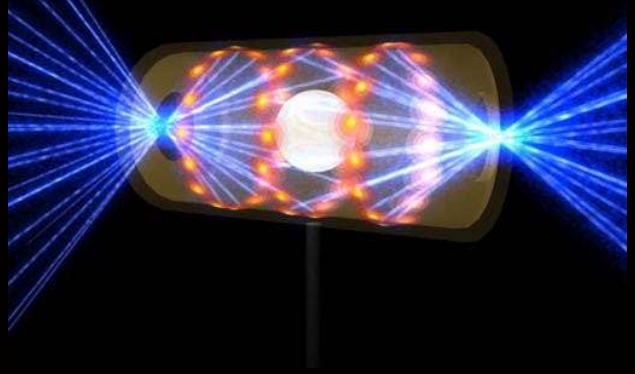
Harnessing Fusion: Building a Star on Earth



Presented by

Lawrence Livermore National Laboratory

Tammy Ma, PhD

LLNL Scientist, NIF & Photon Science

LLNL-PRES-681893

LLNL is one of 17 Department of Energy national laboratories

- Established in 1952
- Approximately 6,500 LLNS employees
- 1 square mile, 531 facilities
- Annual federal budget: ~ $1.9B
- Operated by LLNS, LLC
  (UC, Bechtel, BWXT, AECOM, Battelle)

Experimental Test Site
(11 miles^2 near Tracy, CA)

Our Mission: strengthen national security through world-class science, technology, and engineering

Stockpile Stewardship

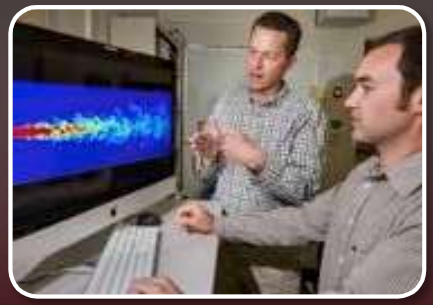
All-WMD Threat Reduction

Multi-Domain Deterrence

Energy and Climate Security

Science

Engineering

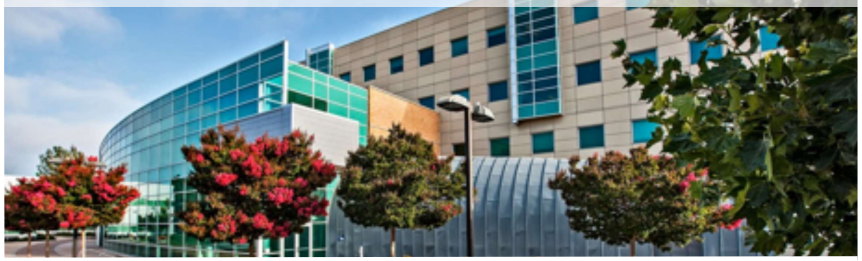


Computing

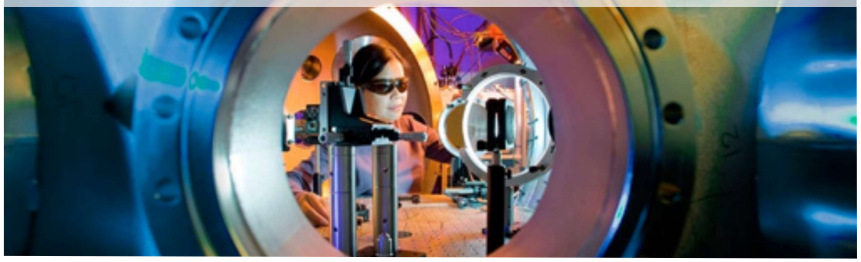
Unique R&D Facilities

National Ignition Facility (NIF)

Livermore Computing Complex B453



Jupiter Laser Facility



Center for Accelerator Mass Spectrometry

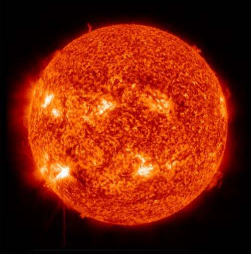
Forensic Science Center

High Explosives Applications Facility (HEAF)

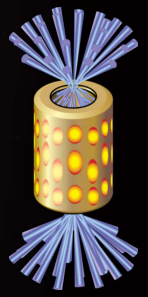
What are we going to talk about today?

What are we going to talk about today?

- We need more energy



- The sun uses fusion to make energy



- Here on earth, we use lasers to make fusion


Right now the world uses
13 TW of power

How much is 13 TW of power?

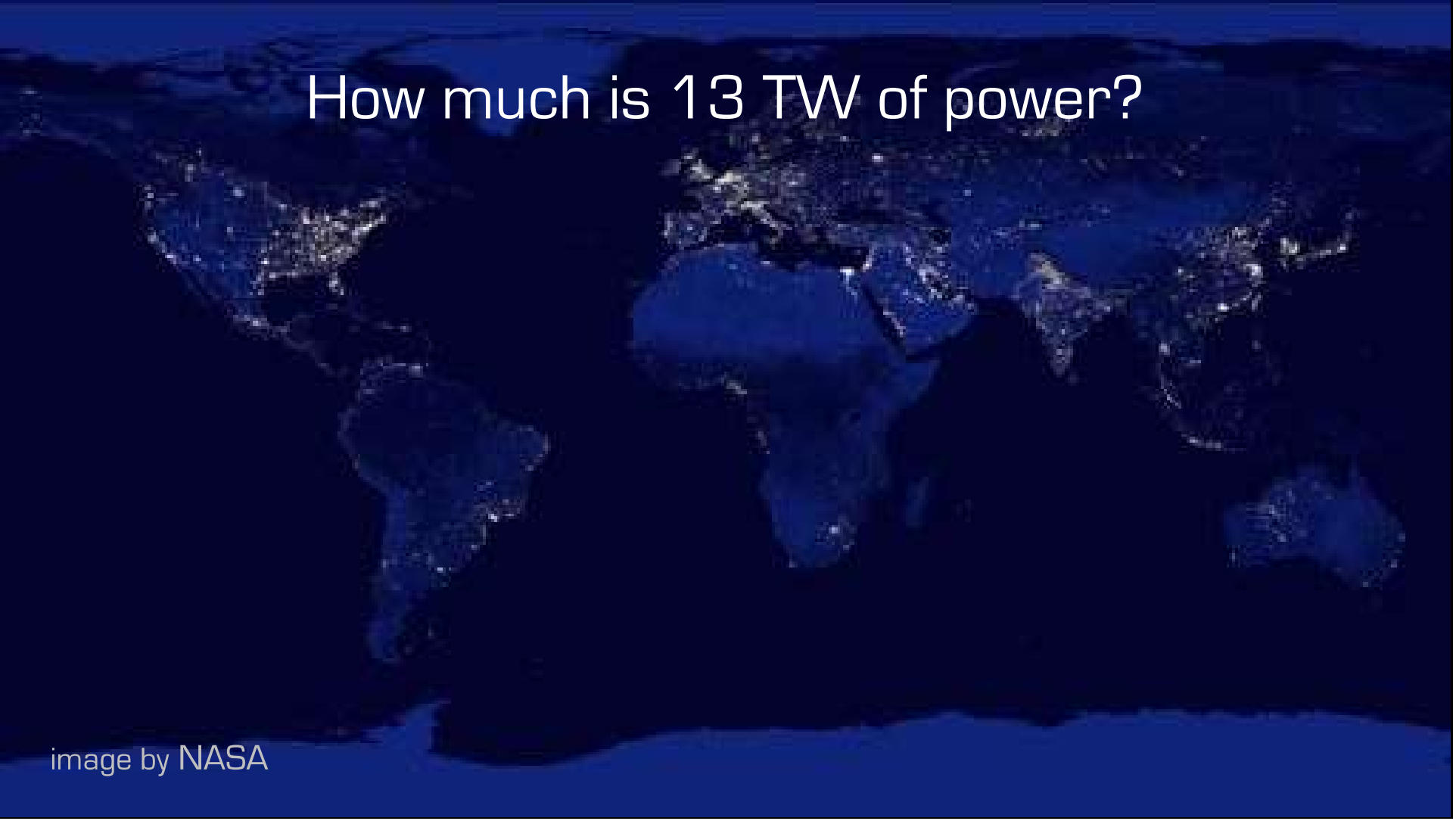


image by NASA

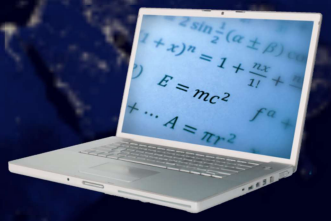

How much is 13 TW of power?
13,000,000,000,000 watts
image by NASA

How much is 13 TW of power?

Compact Fluorescent Bulbs
670 billion

How much is 13 TW of power?

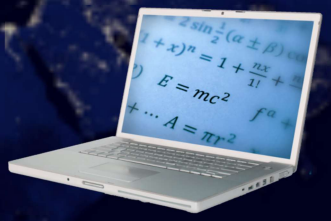
Compact Fluorescent Bulbs
670 billion



Laptops
300 billion

How much is 13 TW of power?

Compact Fluorescent Bulbs
670 billion

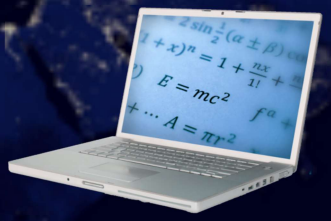


Laptops
300 billion

Refrigerators
24 billion

How much is 13 TW of power?

Compact Fluorescent Bulbs
670 billion



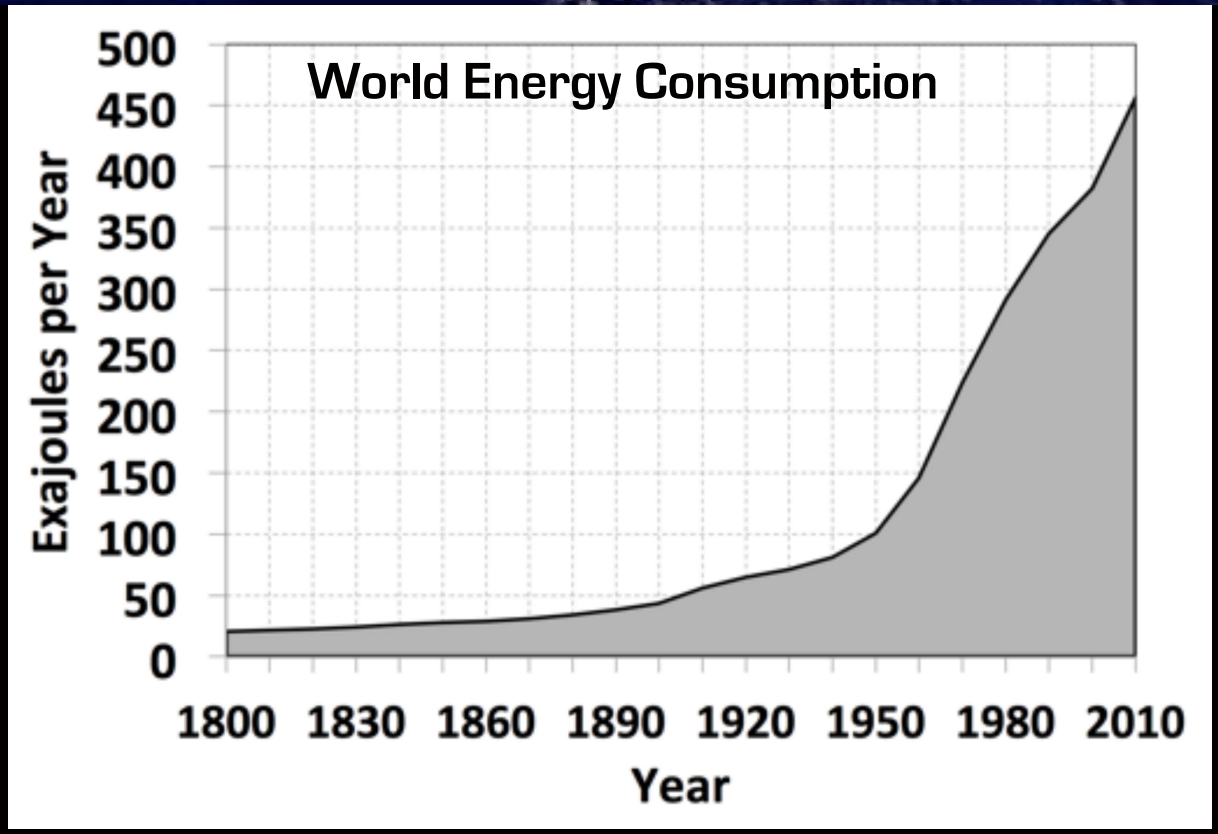
Laptops
300 billion

Refrigerators
24 billion

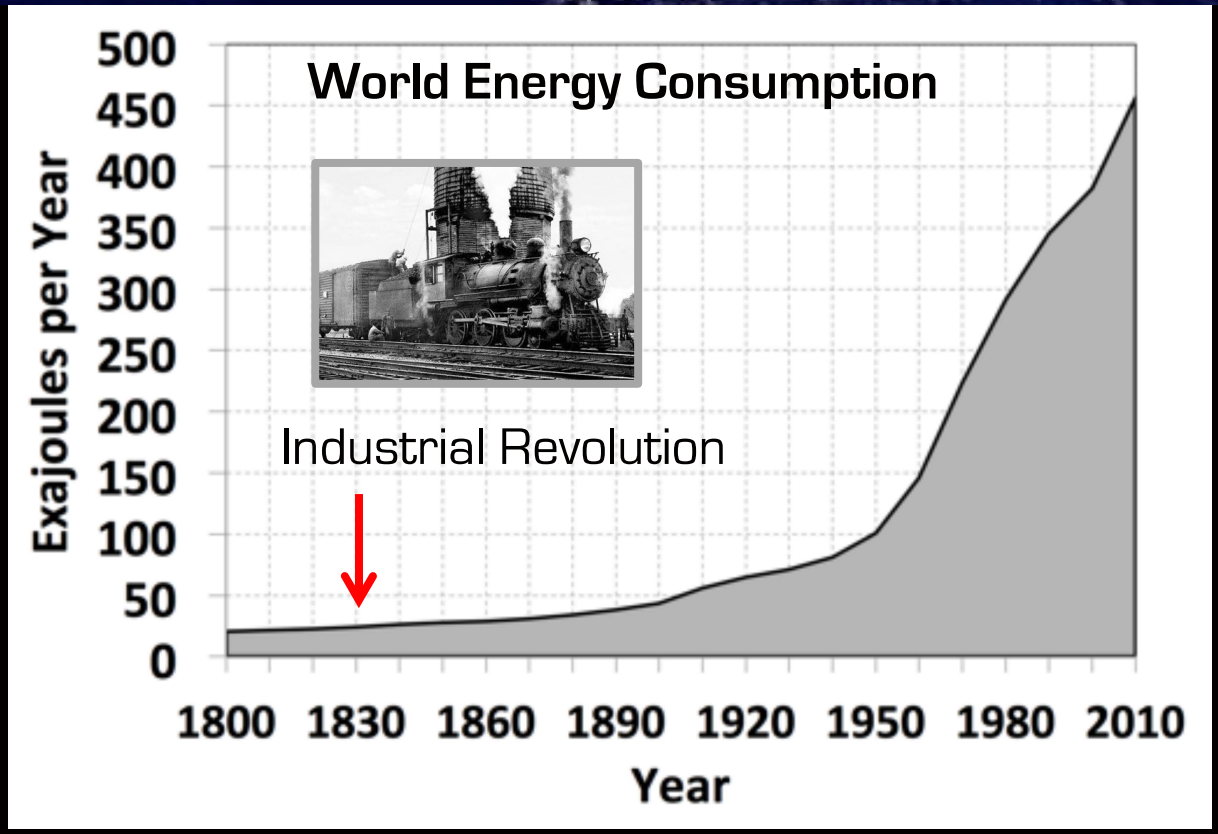
Smart Phones
2.6 trillion

But the world will need more energy!

But the world will need more energy!



But the world will need more energy!



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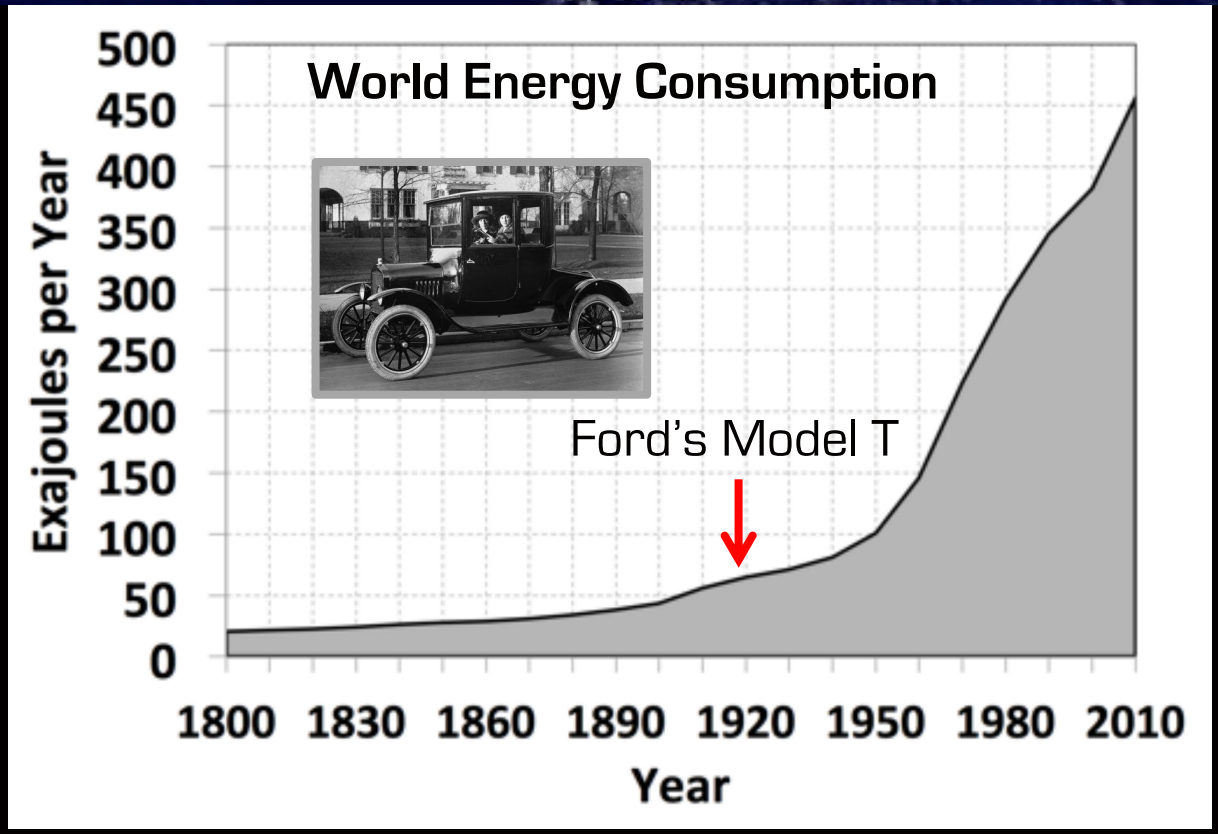

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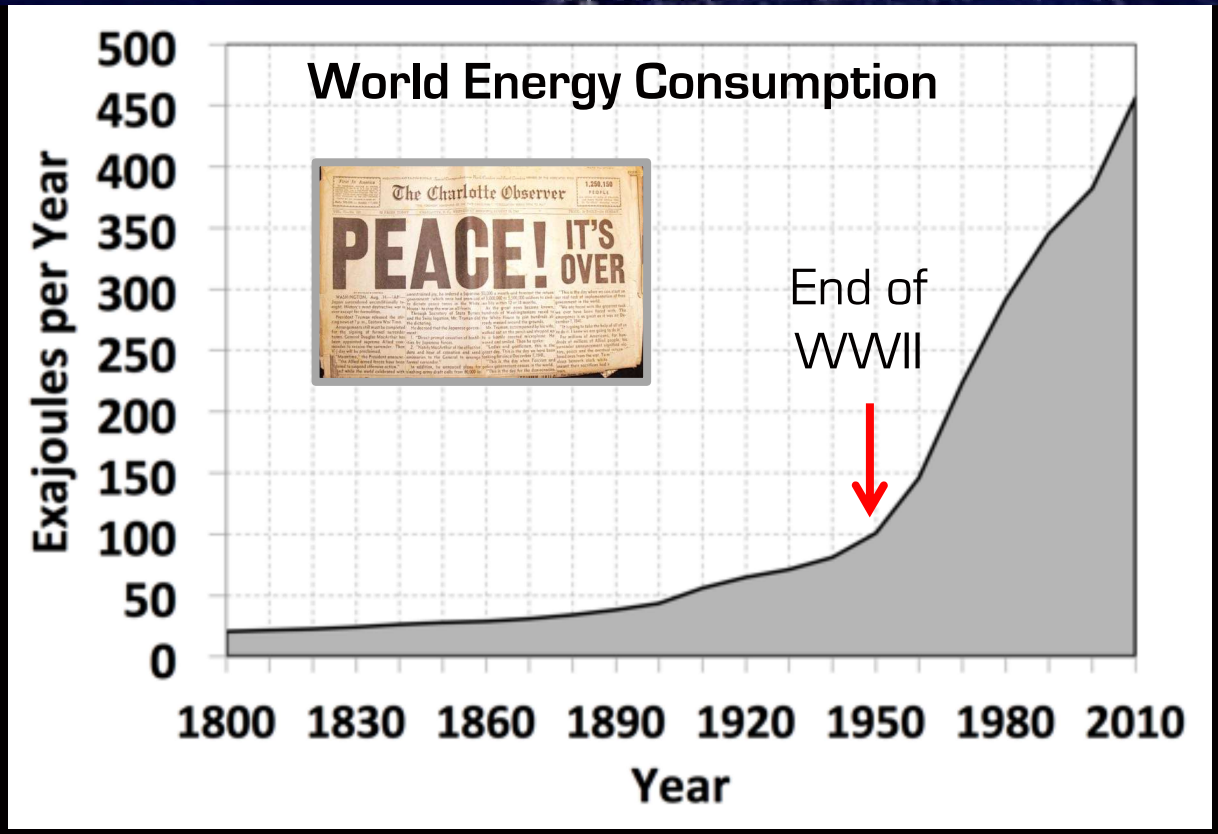

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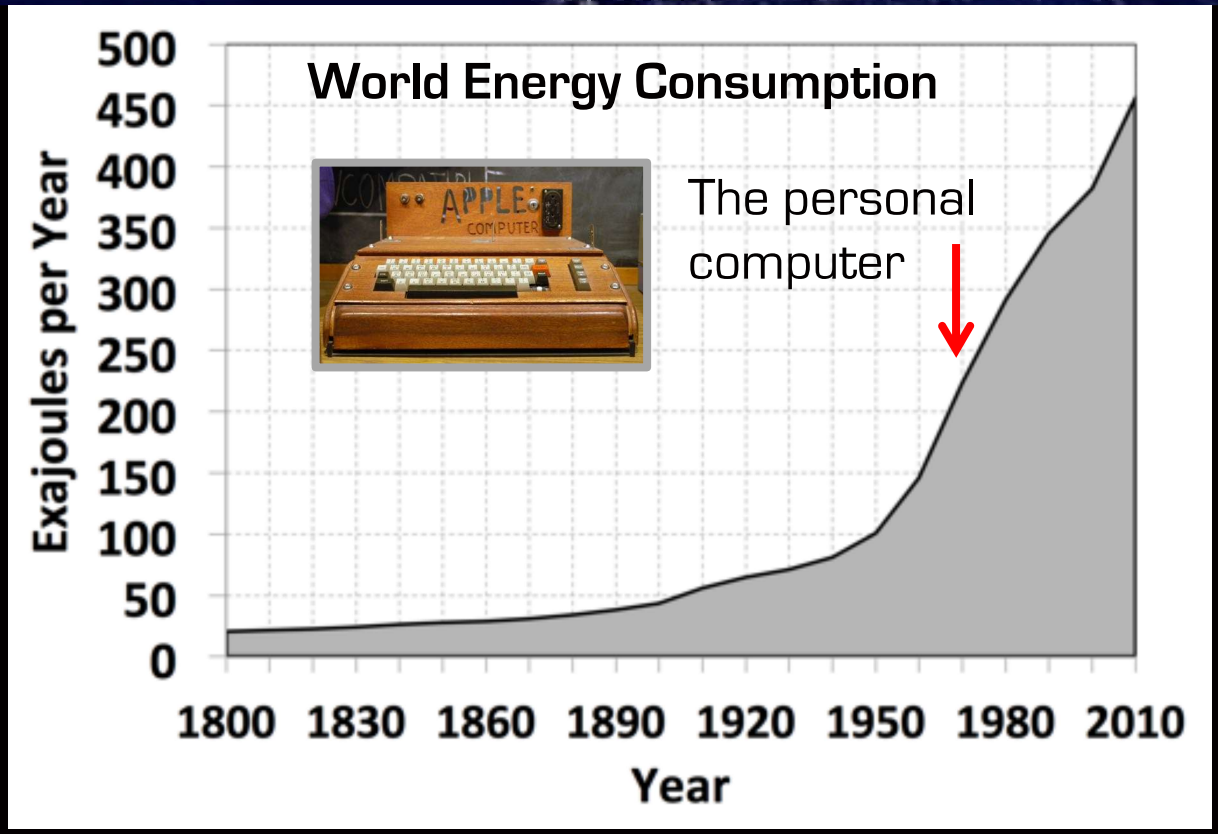

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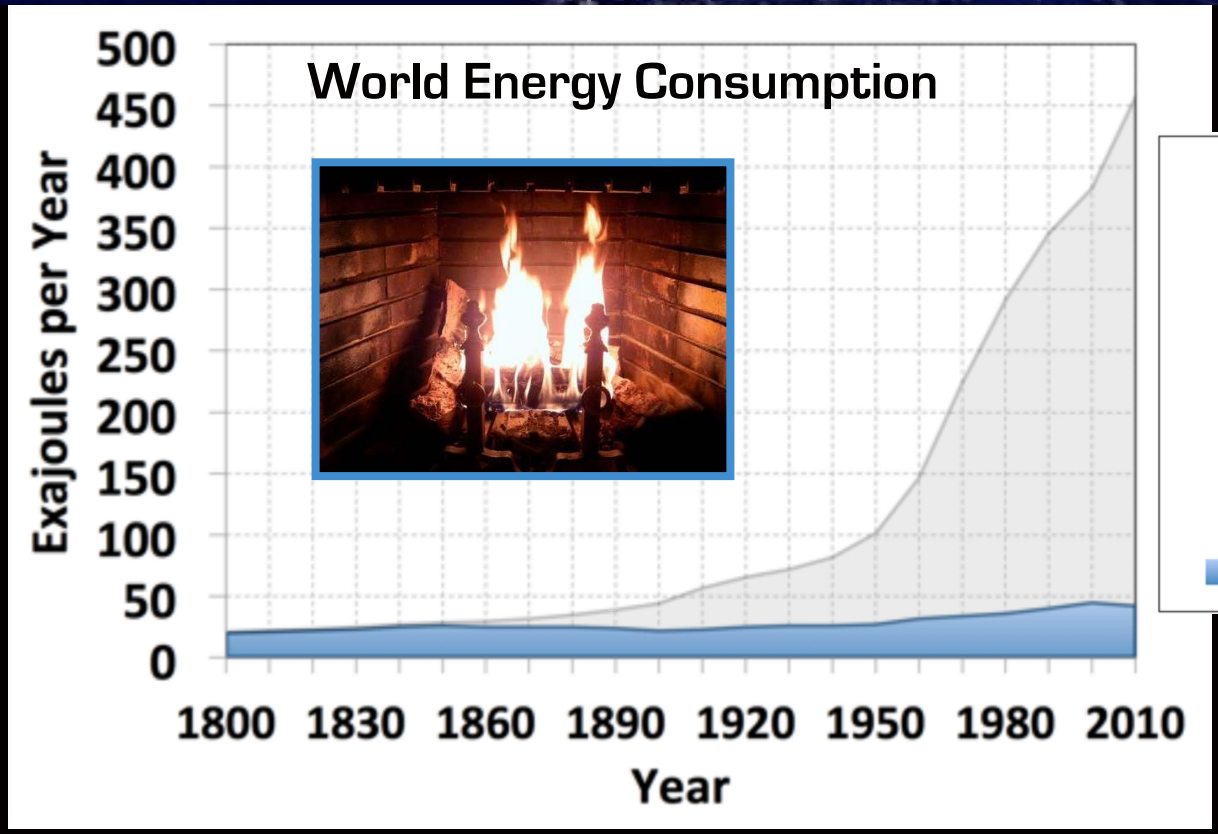

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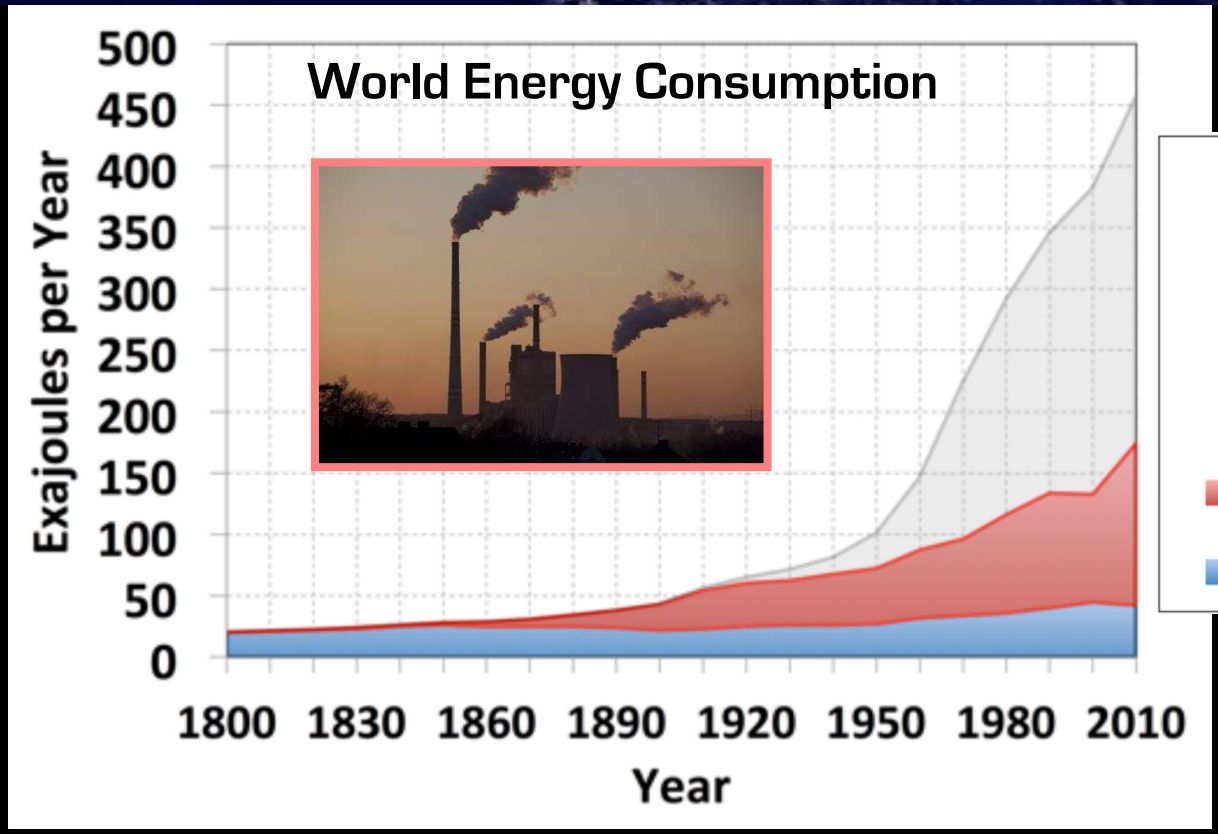

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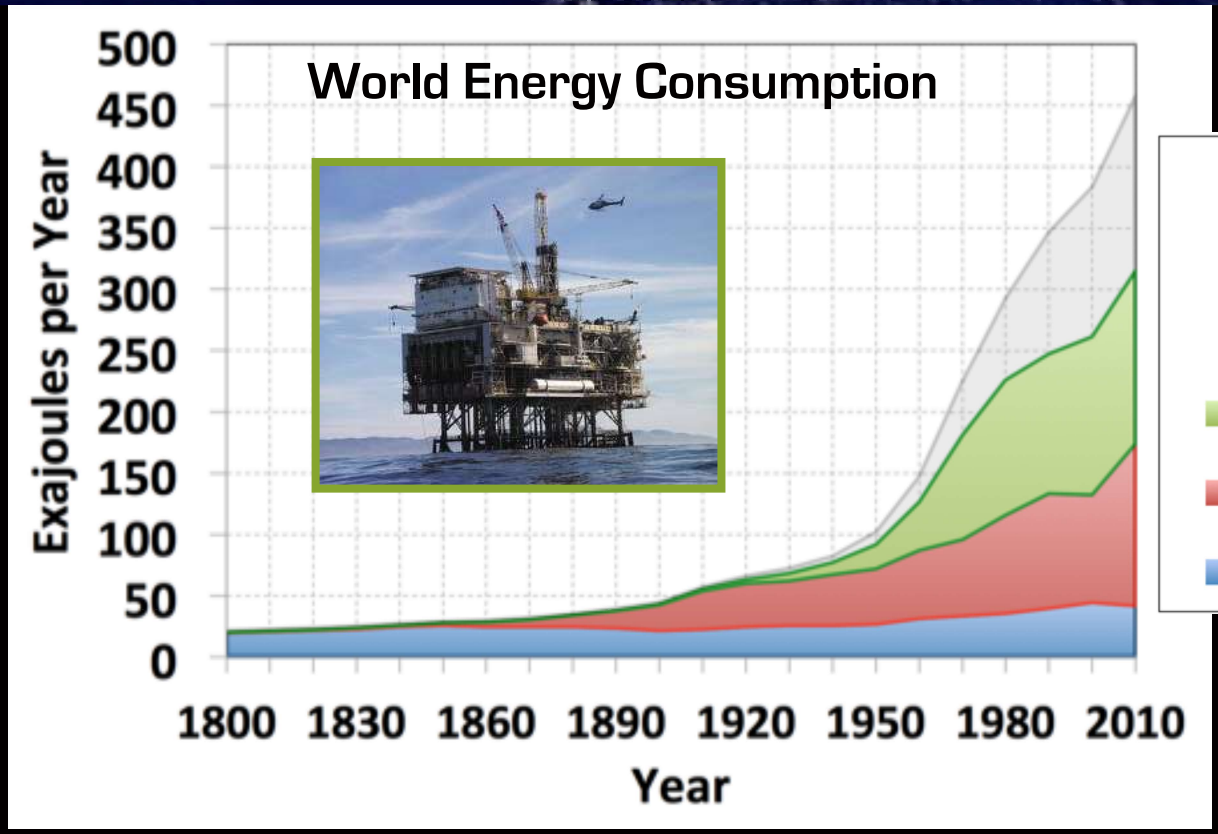

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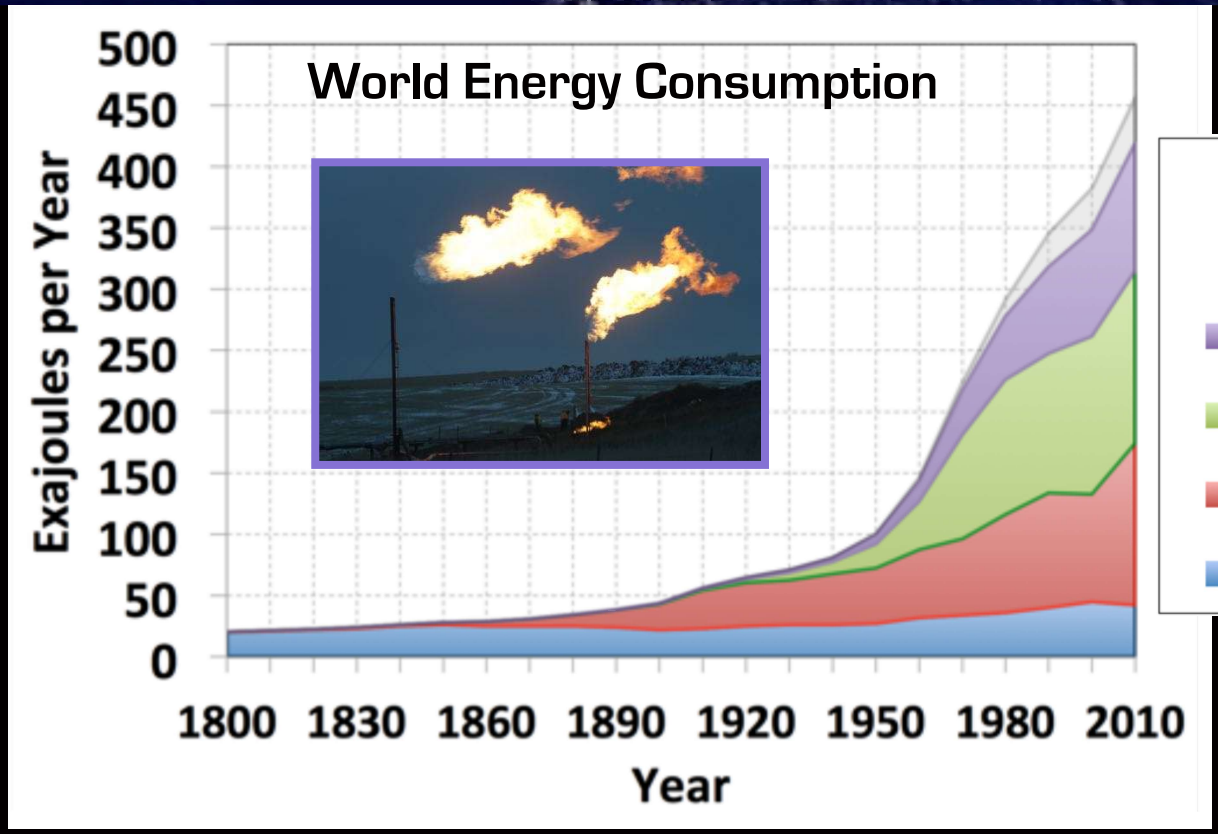

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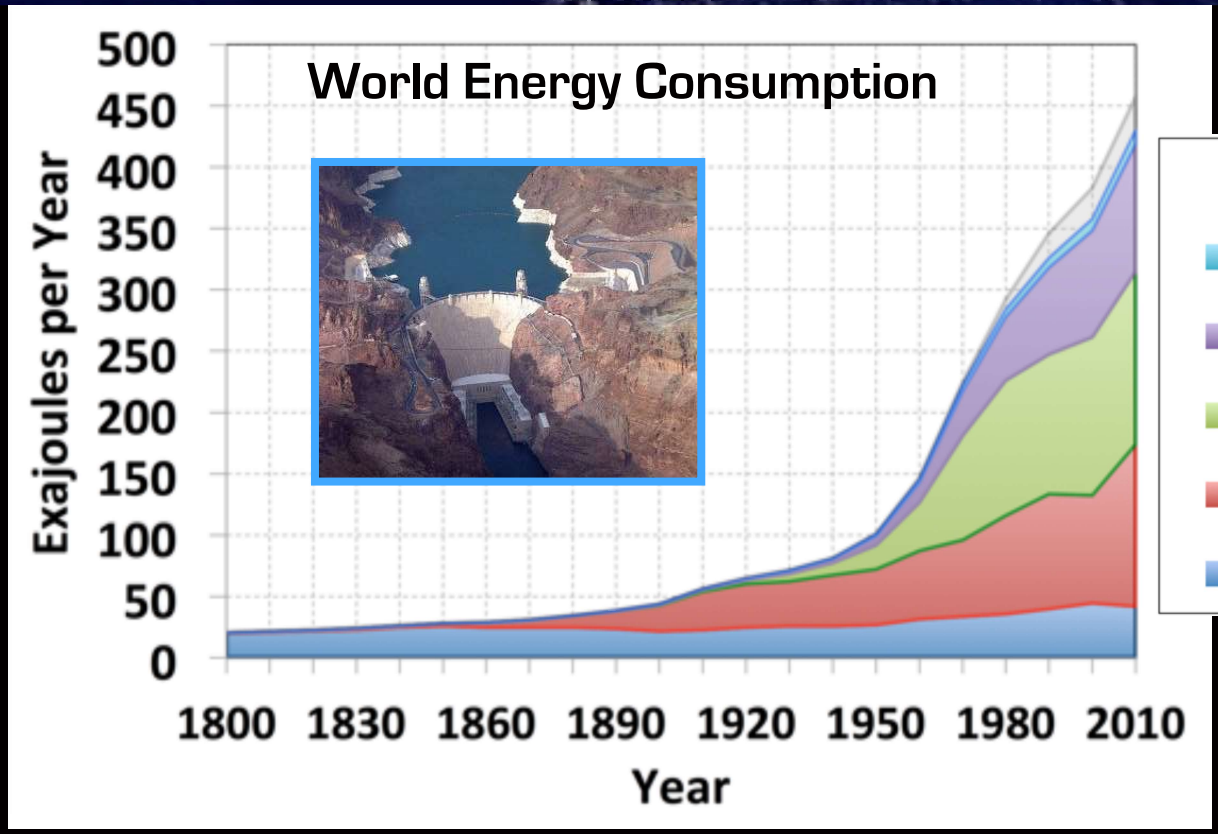

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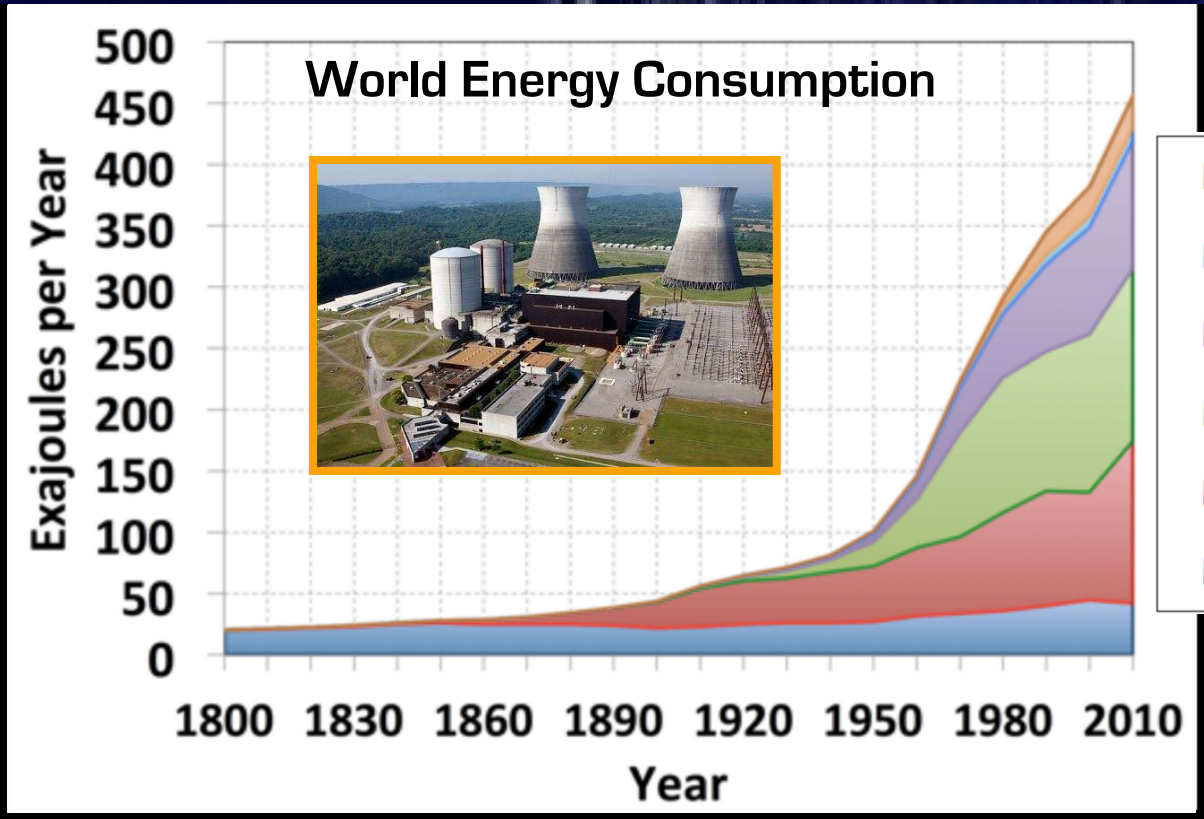


Data from Vaclav Smil (2010)

Fossil fuels are carbon based

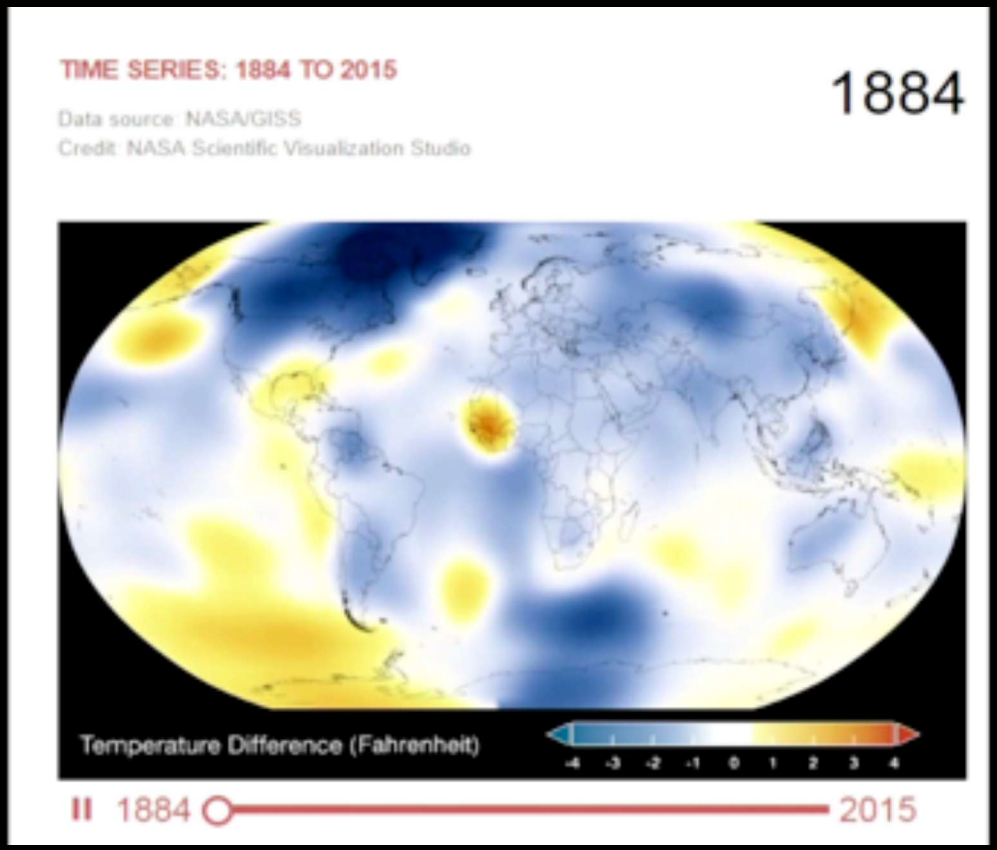
coal

natural gas

oil

We are burning 10 million years of carbon fossil fuel each year

Fossil fuels can affect the climate



Future non-carbon energy sources?

Hydro

Geothermal

Solarthermal

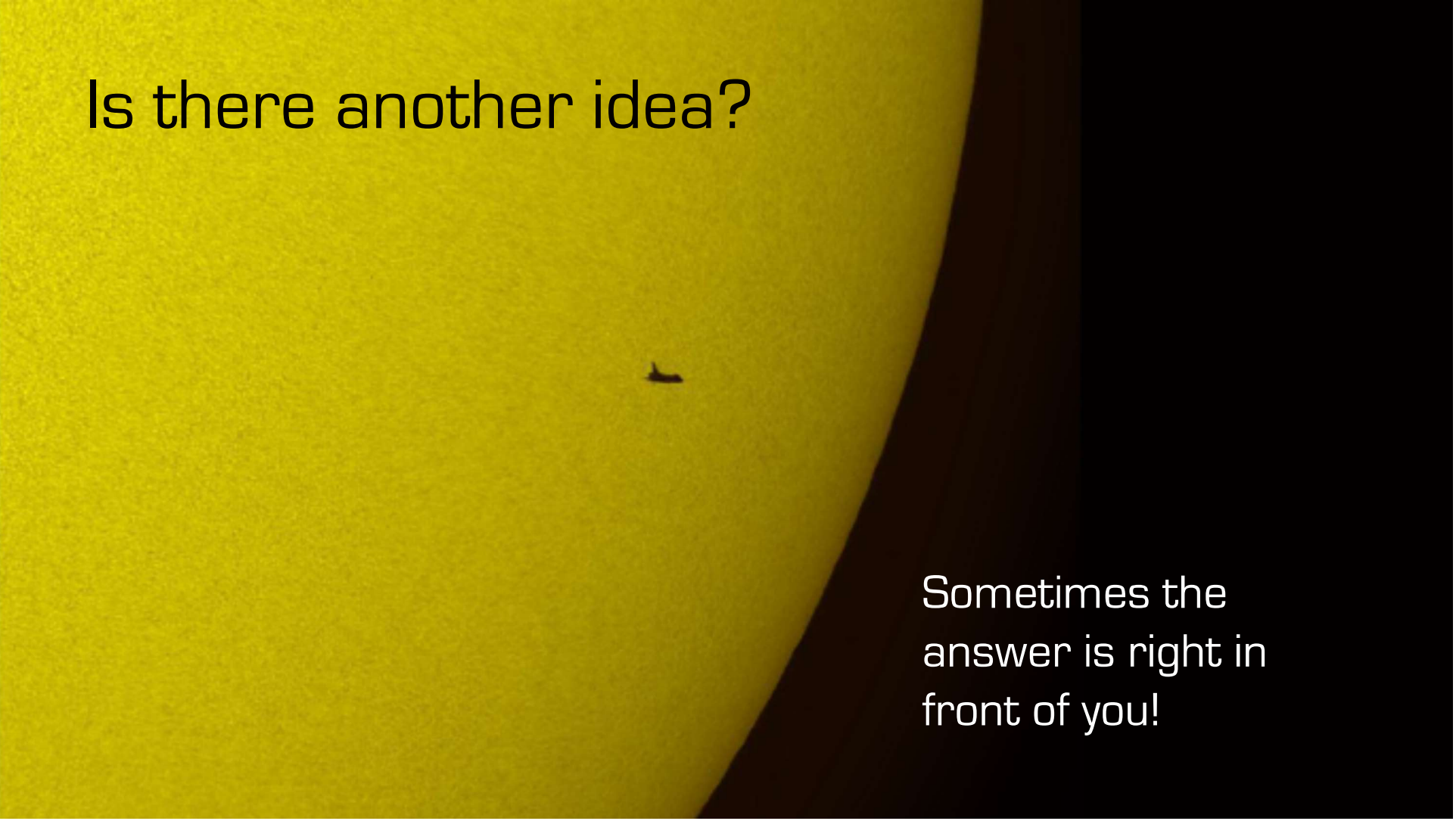
Photovoltaic

Wind

Nuclear

Is there another idea?

NASA/Thierry Legault


Is there another idea?
Sometimes the answer is right in front of you!

What if we could build a miniature sun on earth?

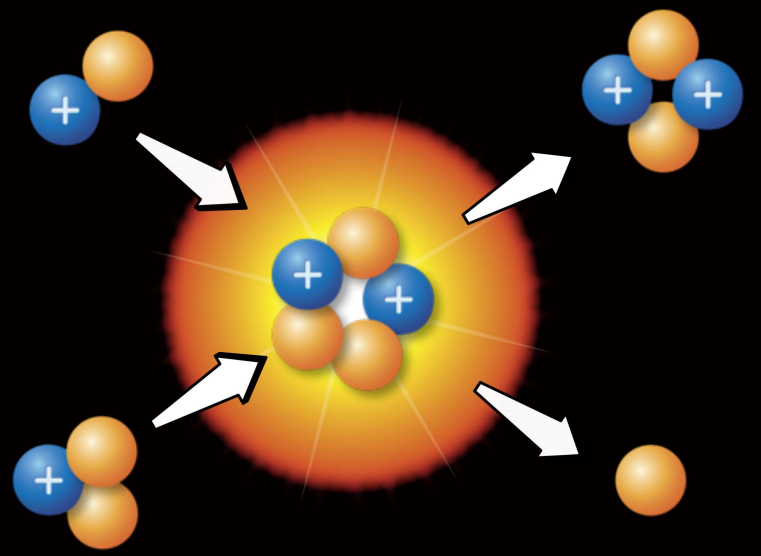
And harness that energy?

NASA's Goddard Space Flight Center

The sun and the stars are powered by fusion

^{2}H - Deuterium

^{4}He – Helium

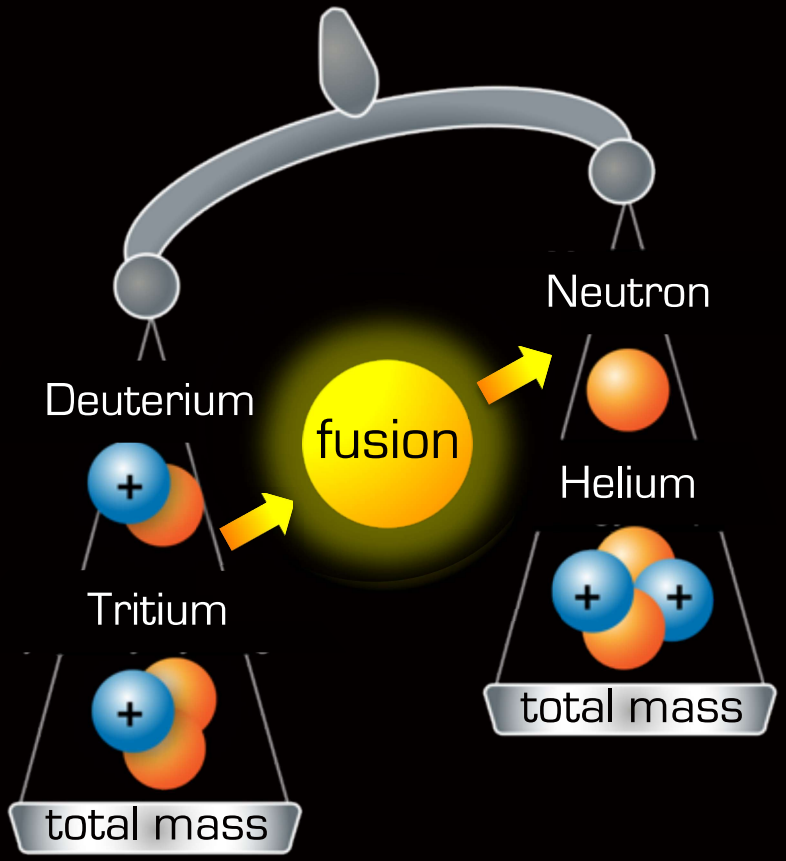


^{3}H - Tritium

neutron

+ Energy

Fusion occurs when light ions are joined together to make a heavier ion and energy is released



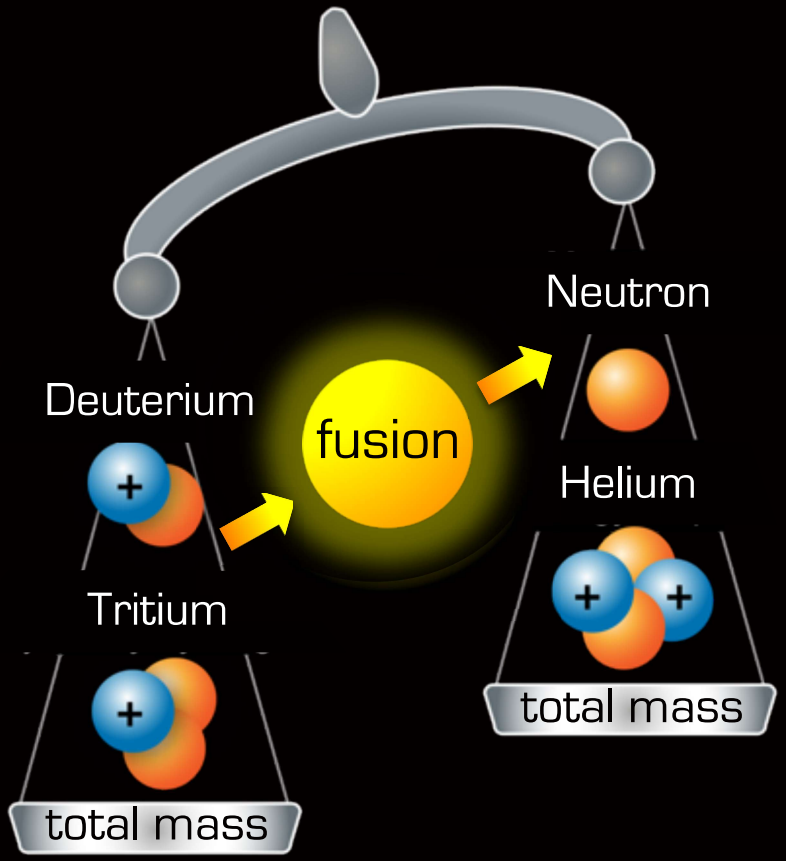
$E=mc^2$
a very powerful equation

E = energy

m = mass

c = speed of light

$(3 \times 10^8$ m/s)



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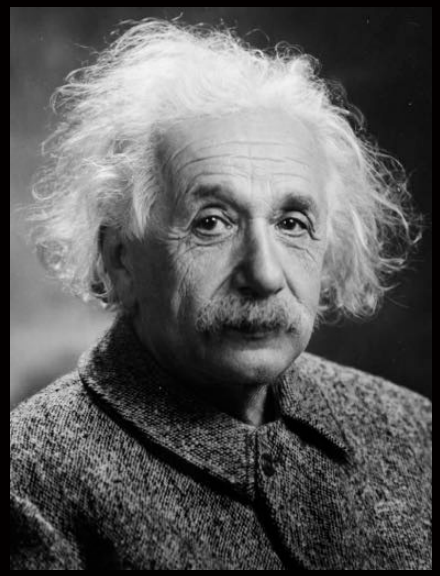
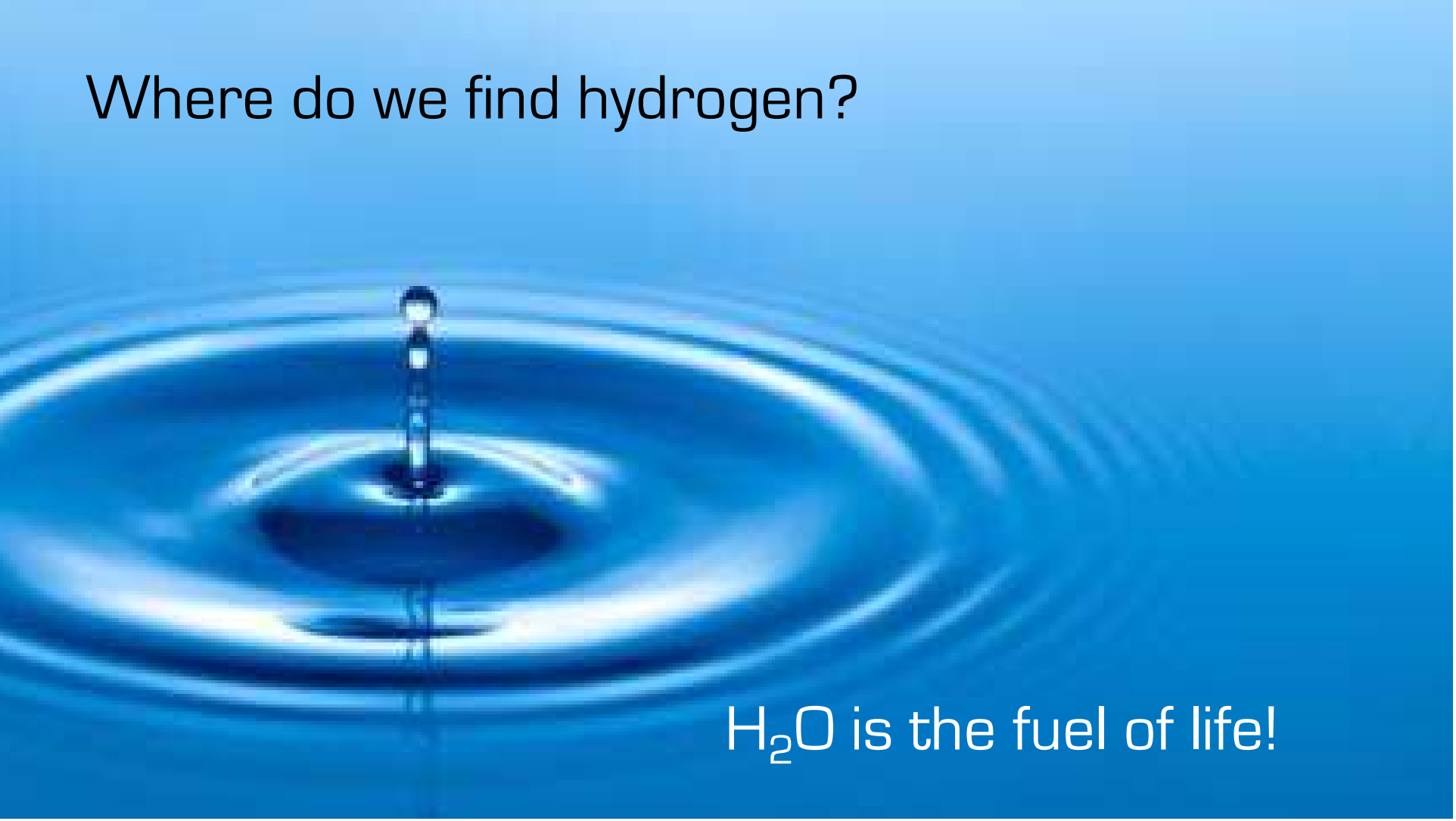


Where do we find hydrogen?

Where do we find hydrogen?



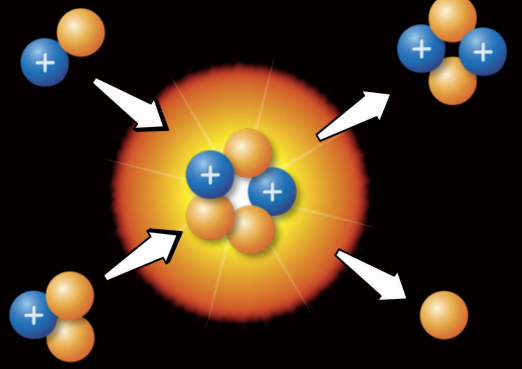
H_2O is the fuel of life!

Fusion fuel is plentiful

1 pound of fusion fuel

^{2}H - Deuterium

^{4}He - Helium

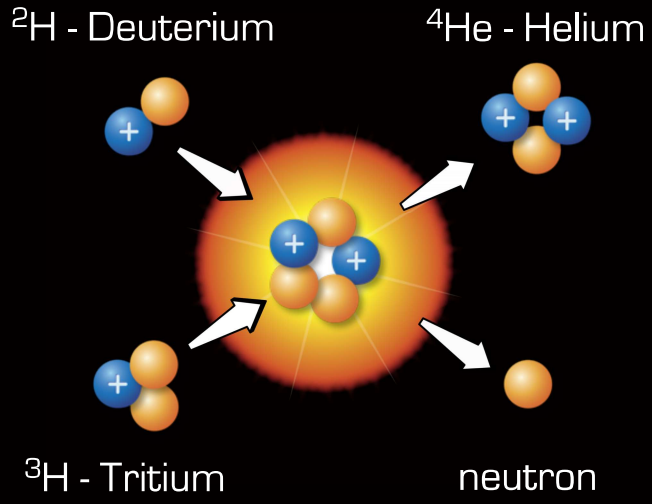


^{3}H - Tritium

neutron

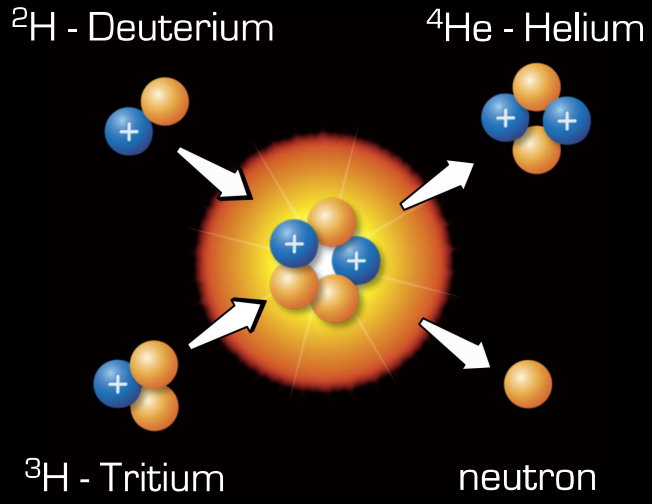
Fusion fuel is plentiful

1 pound of fusion fuel = 5,000 barrels of oil



Fusion fuel is plentiful

1 pound of fusion fuel = 5,000 barrels of oil = 3.5 million pounds of coal



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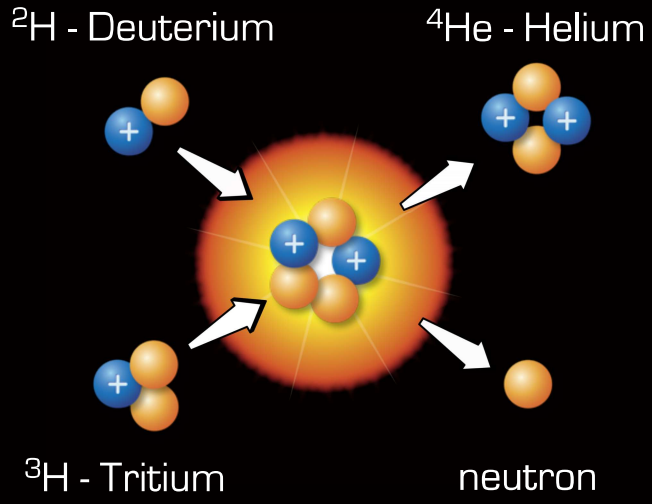
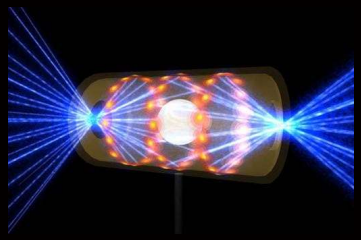


Potentially, we have fusion fuel for 30 million years!

Fusion energy is attractive for many reasons

Safe



Sustainable

Energy Security

Baseload

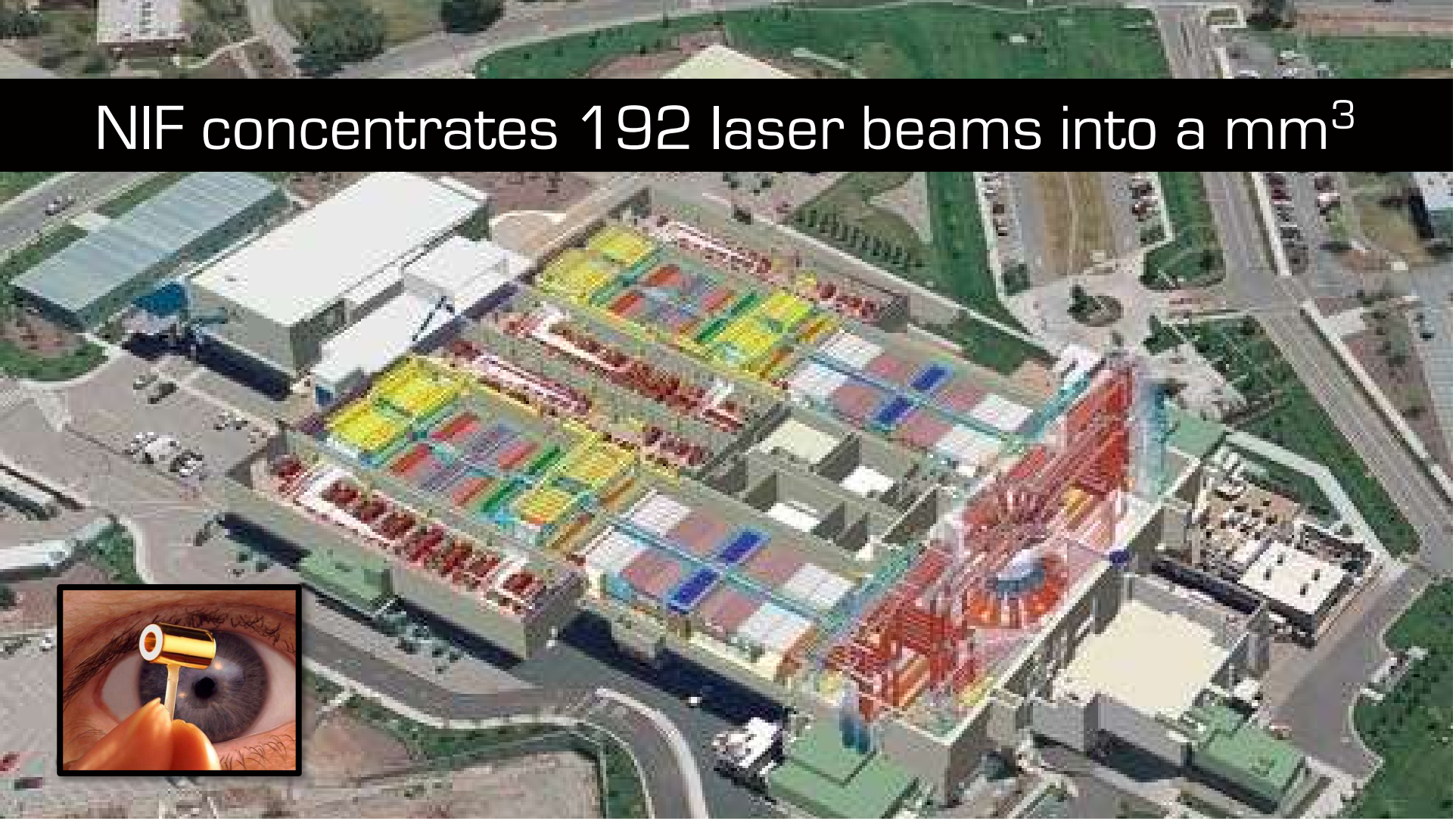
Carbon-Free

No Geologic Storage

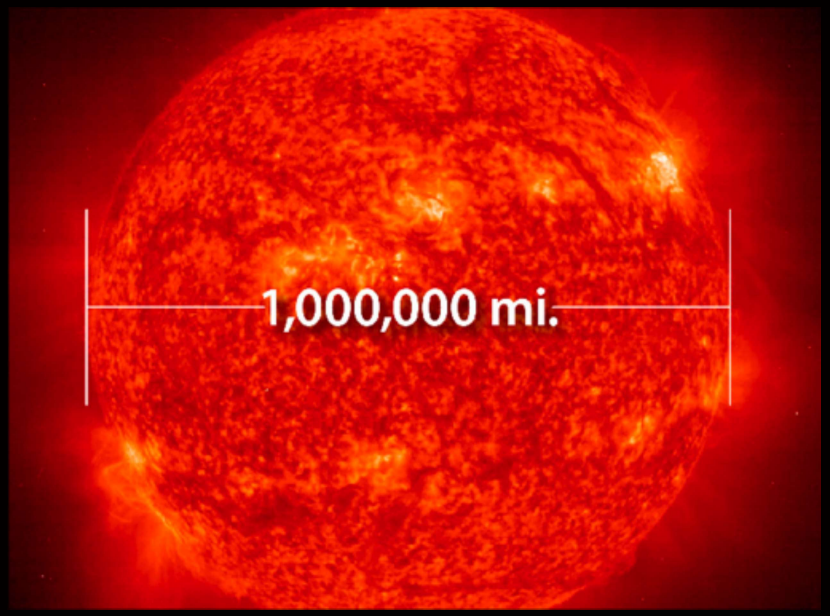
At the National Ignition Facility (NIF), we are building our own miniature sun

NIF is the world's largest and most energetic laser system

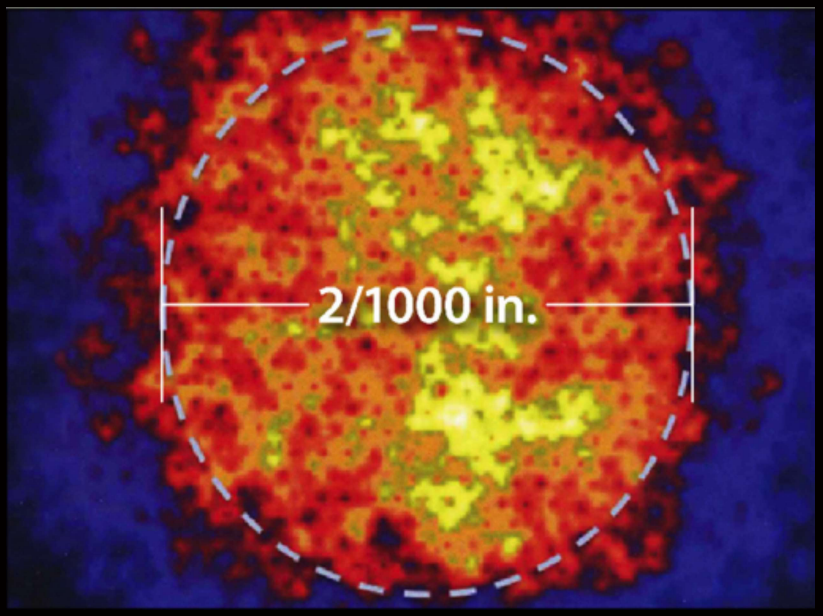
NIF concentrates 192 laser beams into a mm^3



We use Inertial Confinement Fusion (ICF) to bring star power to earth



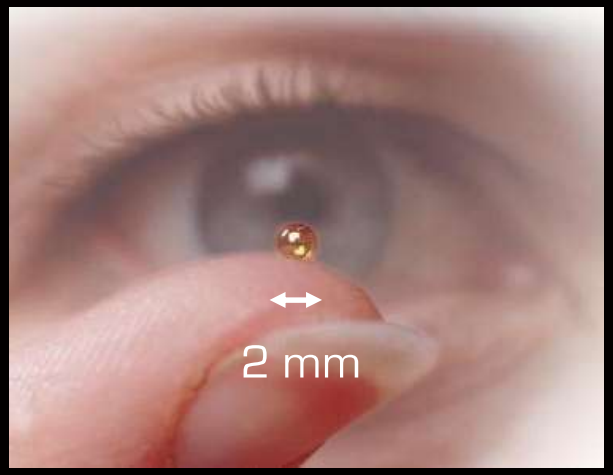
Sun



ICF experiment

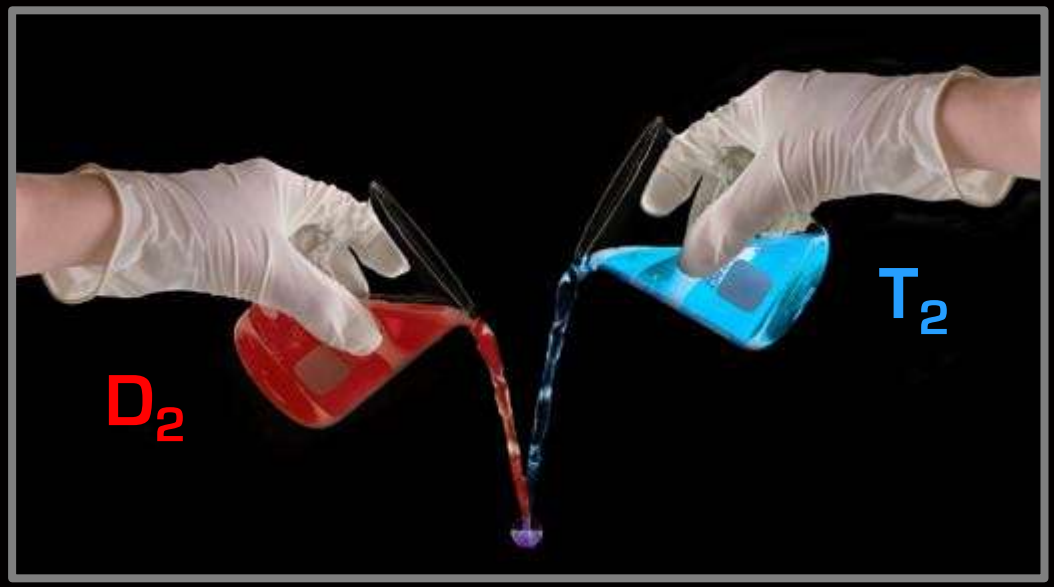
Recipe for a small star

1. Take a hollow spherical plastic capsule
   2 mm in diameter
   (about the size of a small pea)



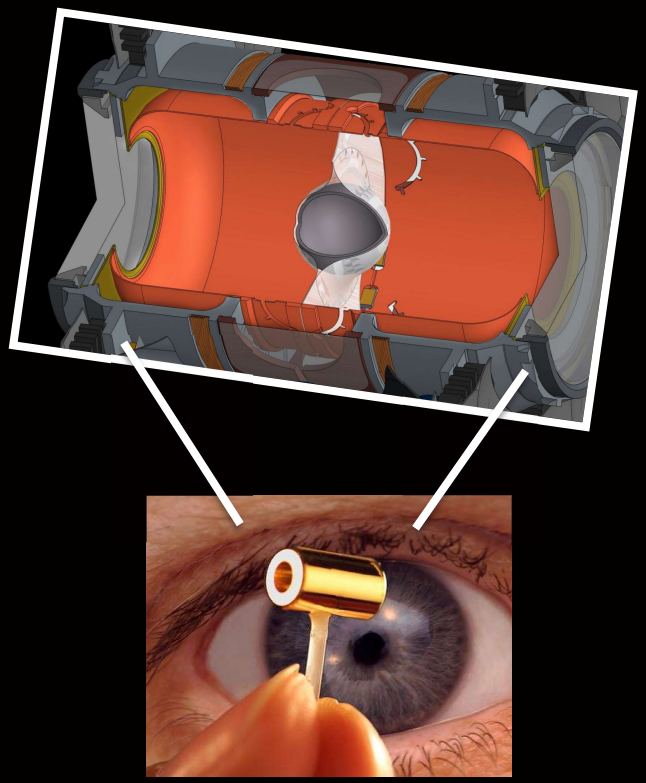
Recipe for a small star

2. Fill with deuterium and tritium



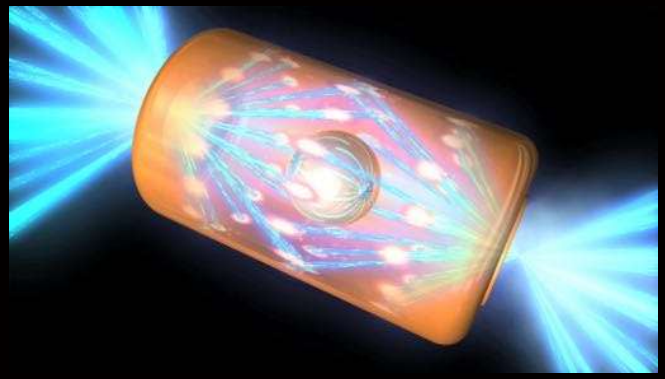
Recipe for a small star

3. Place the fuel capsule in a hohlraum



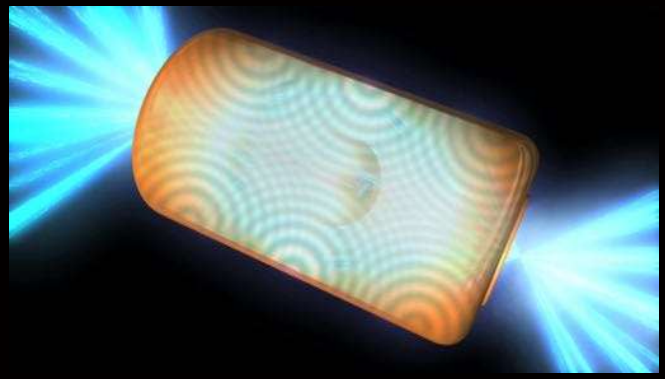
Recipe for a small star

4. Focus the light from the biggest laser in the world onto the inside of the hohlraum



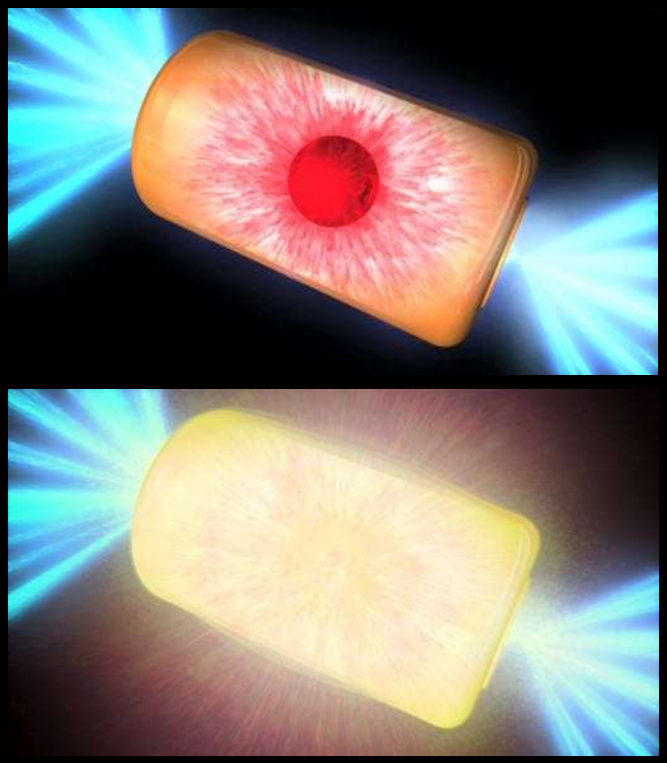
Recipe for a small star

5. Create very energetic x-rays with the laser light that can then compress the capsule



Recipe for a small star

6. Get the capsule to:
    - Densities > 100x solid lead
    - 100 million degrees C
      (hotter than the center of the sun)
    - For 1 billionths of a second

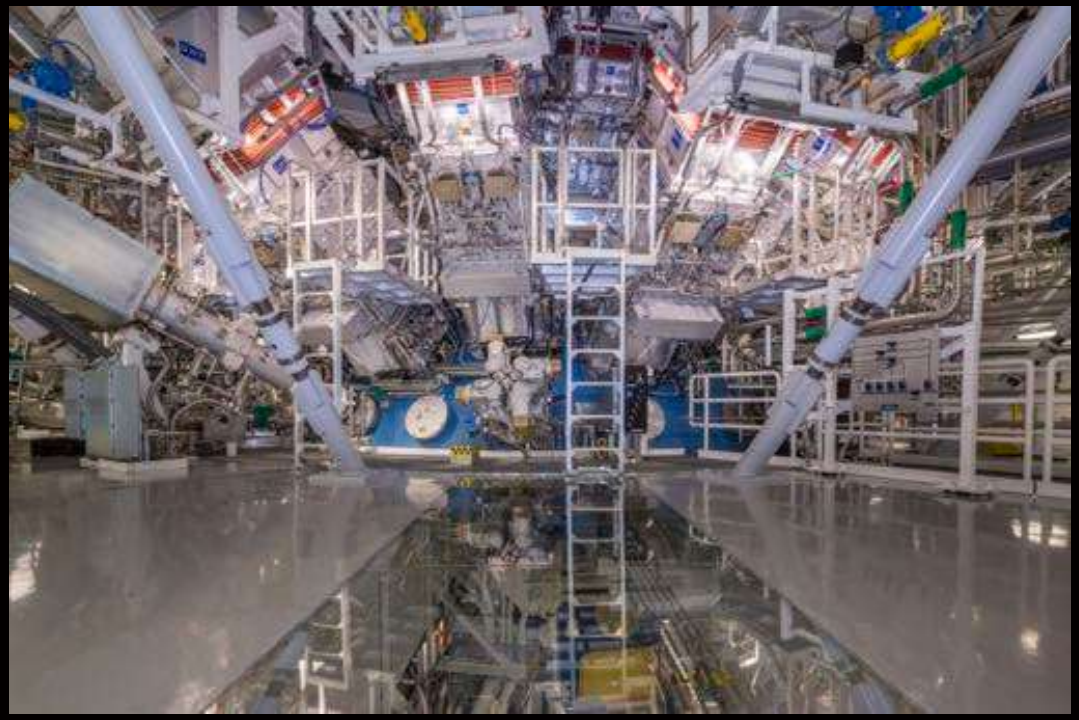


ICF capsules must shrink in volume by greater than 40,000x

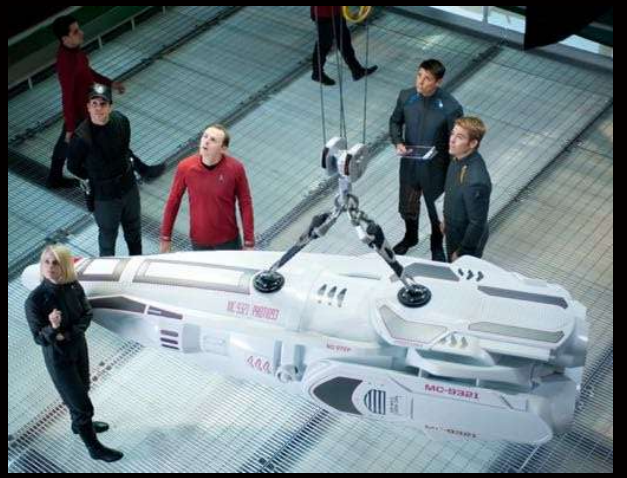
This is equivalent to compressing
a basketball down
to a marble in < 1 μs
while keeping it round


Movie:
MISSION IGNITION

NIF in Star Trek

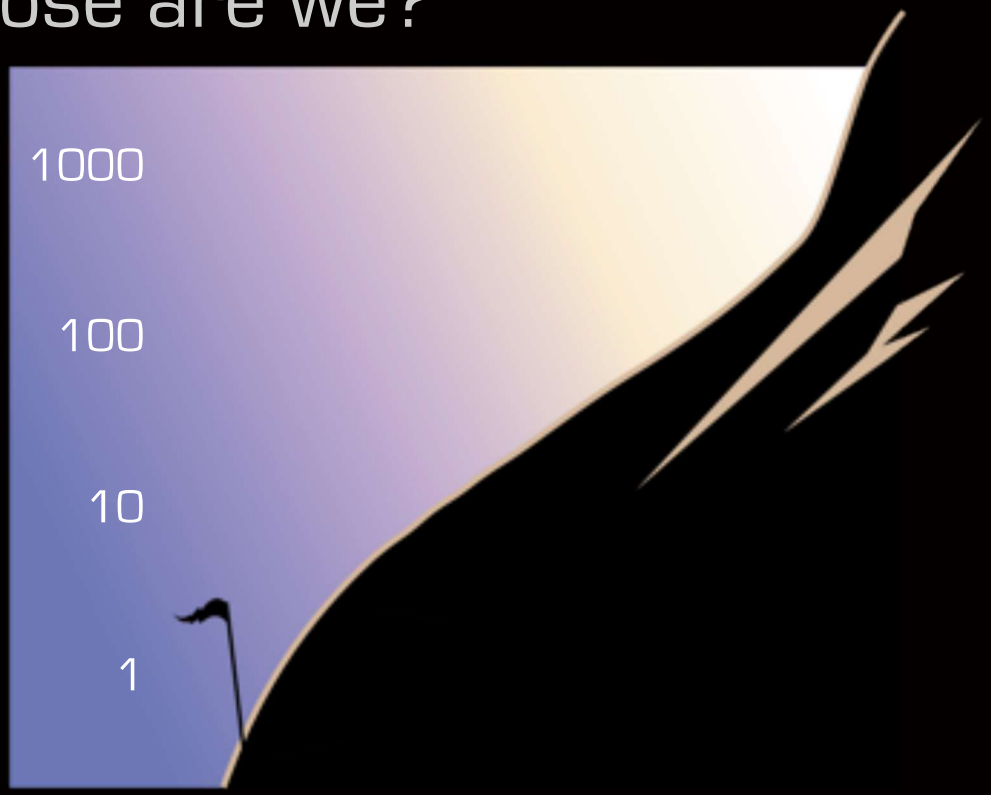


LLNL NIF target chamber



Paramount Pictures

How close are we?



Energy Produced [kJ]

Temperature x Density x Confinement of DT

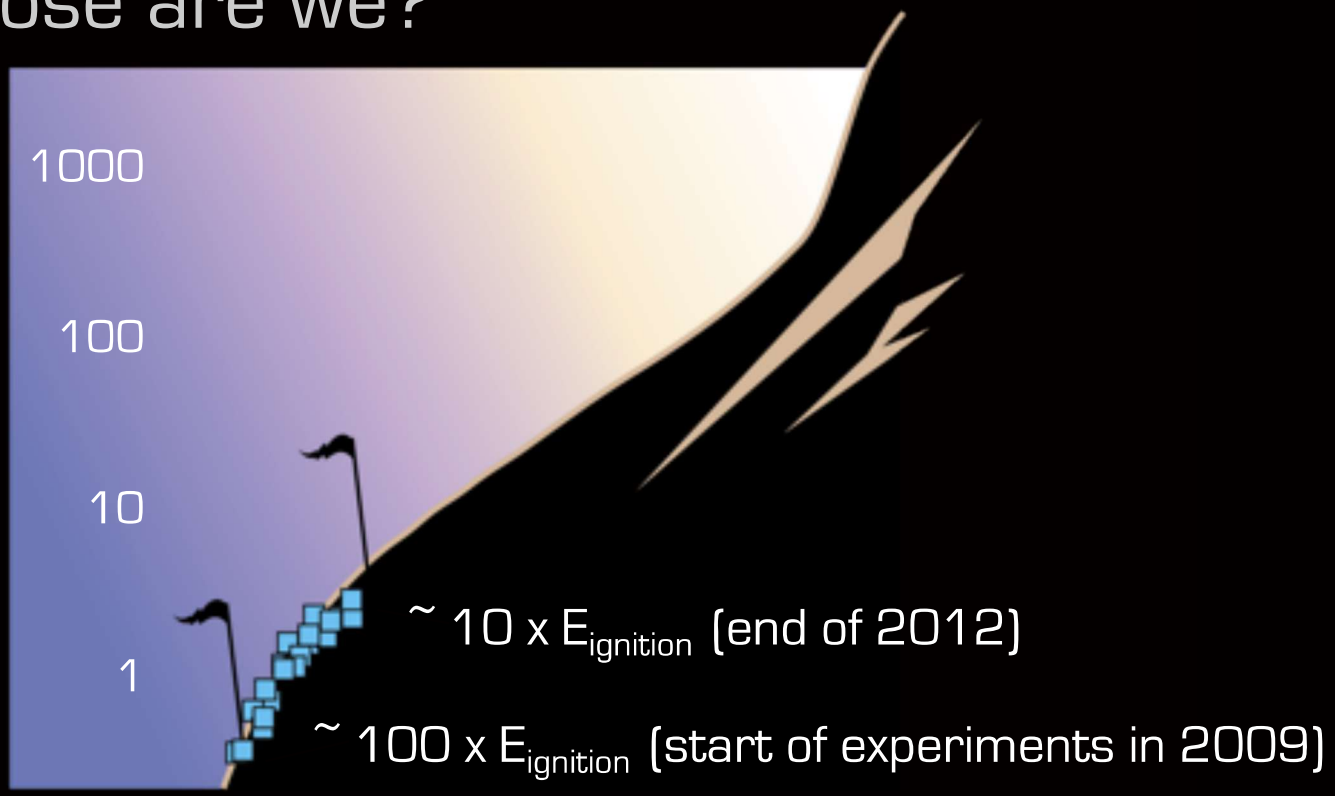
How close are we?

Energy Produced [kJ]

~ 100 x $E_{ignition}$ (start of experiments in 2009)

Temperature x Density x Confinement of DT

How close are we?



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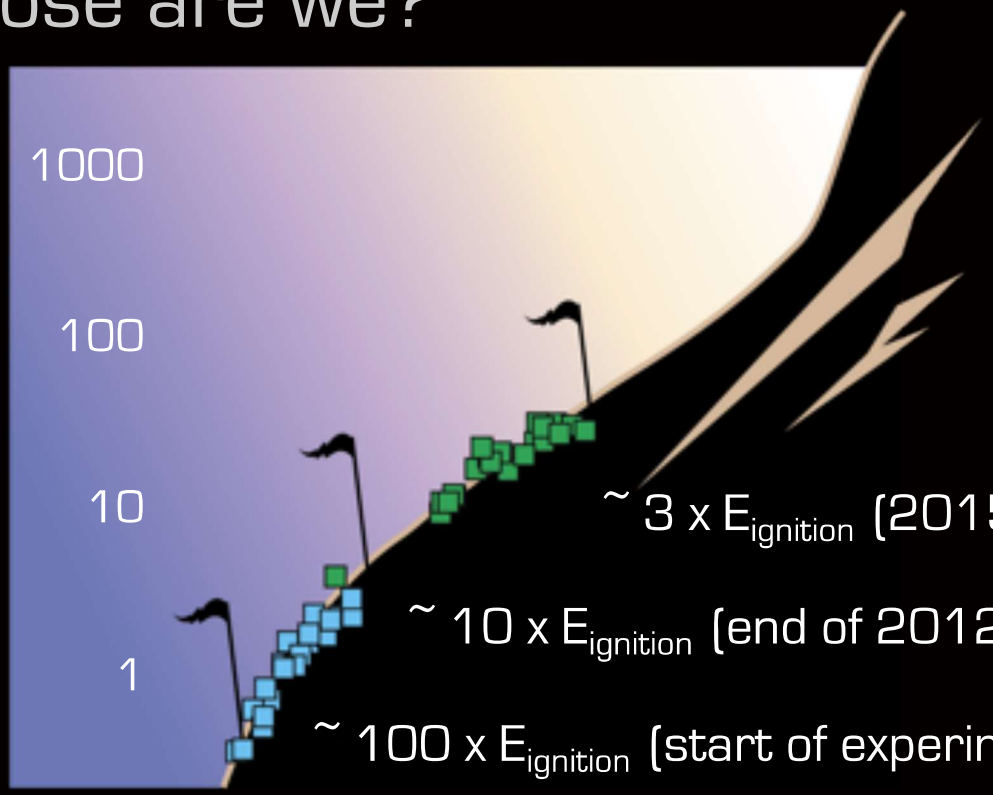

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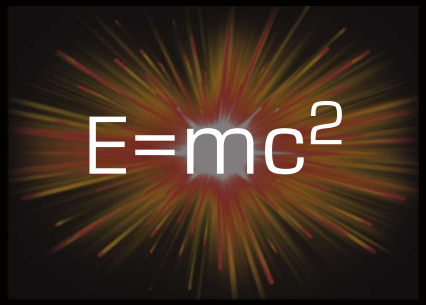


Energy Produced [kJ]

1000 Ignition (G > 1)

100 Alpha-heating

~ 2 x $E_{ignition}$ (today)

10

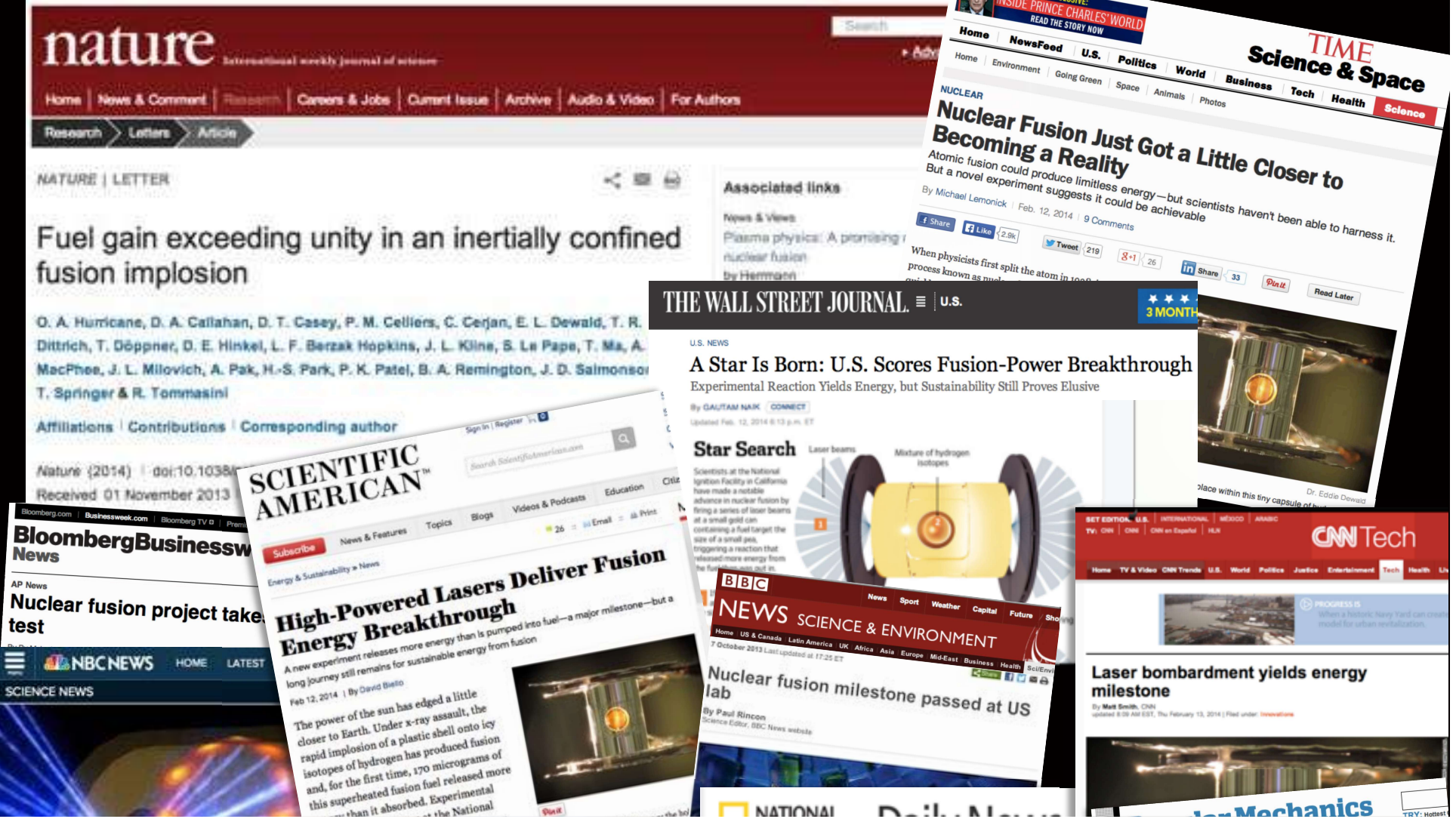
~ 3 x $E_{ignition}$ (2015)

~ 10 x $E_{ignition}$ (end of 2012)

1

~ 100 x $E_{ignition}$ (start of experiments in 2009)

Temperature x Density x Confinement of DT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Fuel gain exceeding unity in an inertially confined fusion implosion
O. A. Hurricane, D. A. Callahan, D. T. Casey, P. M. Celliers, C. Cerjan, E. L. Dewald, T. R. Dittrich, T. Döppner, D. E. Hinkel, L. F. Berzak Hopkins, J. L. Kline, S. Le Pape, T. Ma, A. MacPhee, J. L. Milovich, A. Pak, H.-S. Park, P. K. Patel, B. A. Remington, J. D. Salmonson, T. Springer & R. Tommasini
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Received 01 November 2013
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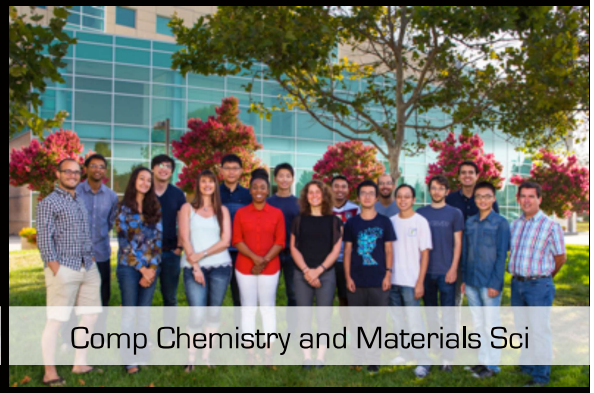
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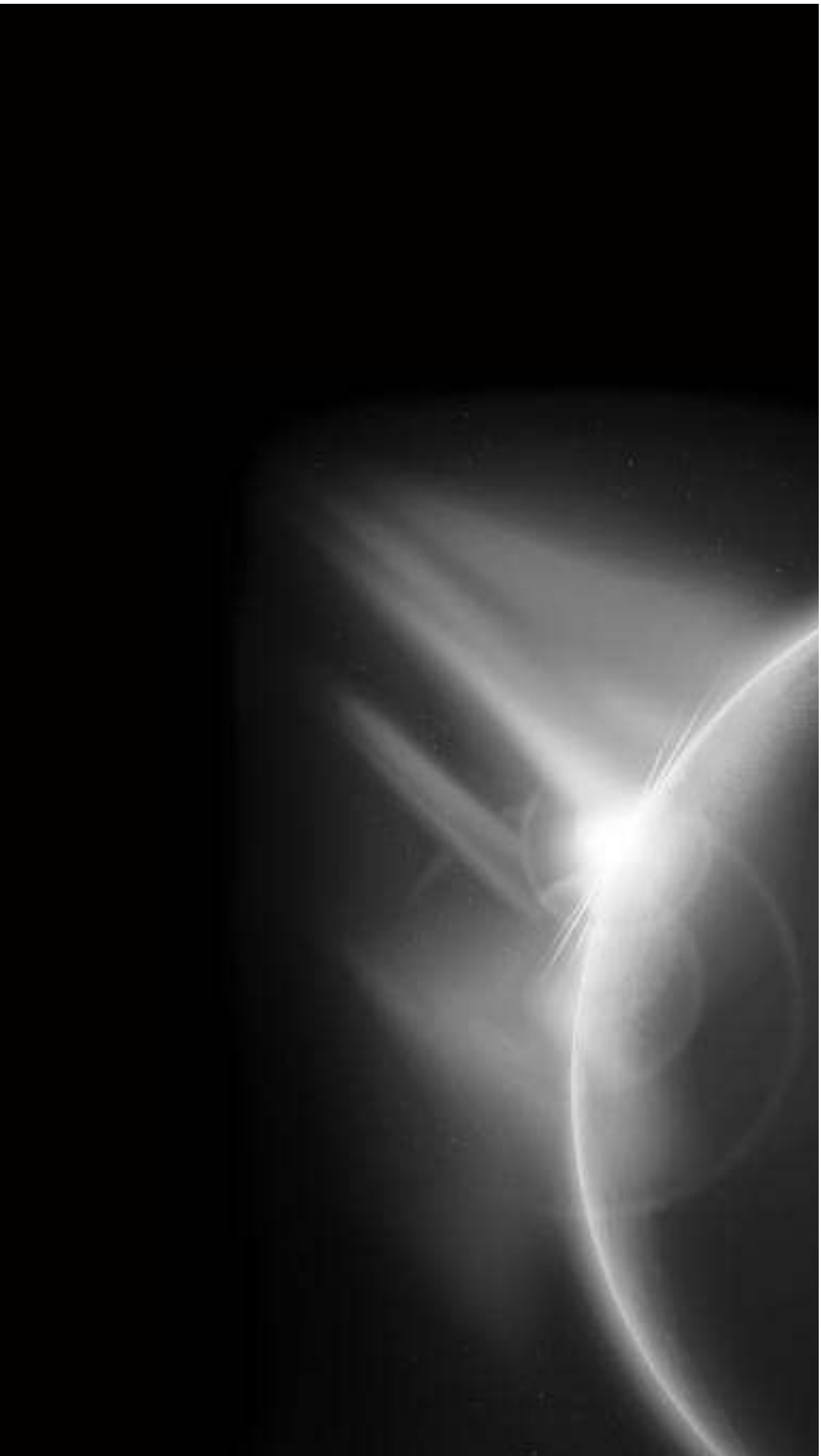

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC.