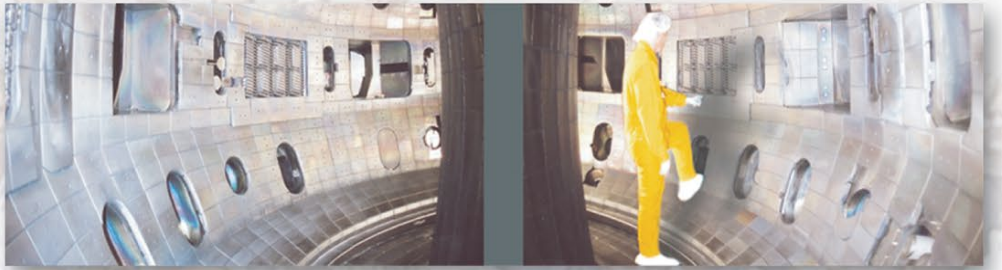
Plasma & Fusion on Earth: merging age-old natural phenomena into your present and future



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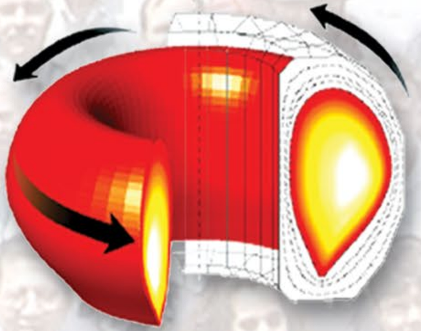

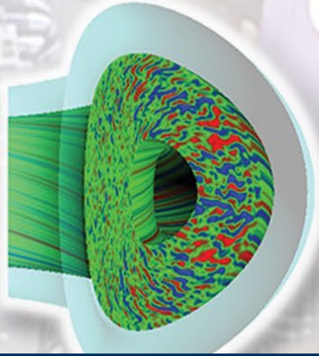

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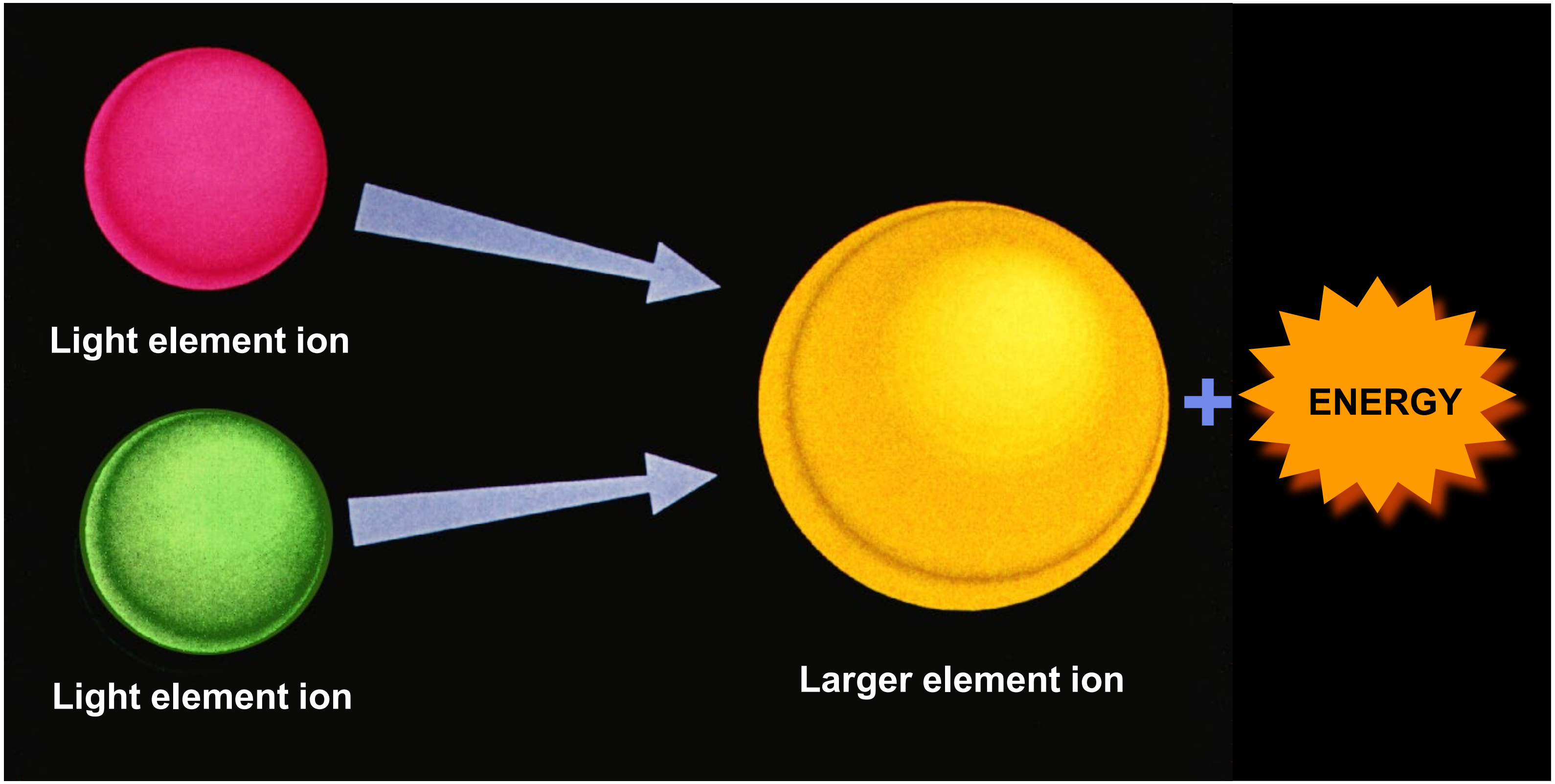
Fusion – the basic idea



DIII-D NATIONAL FUSION FACILITY

GENERAL ATOMICS

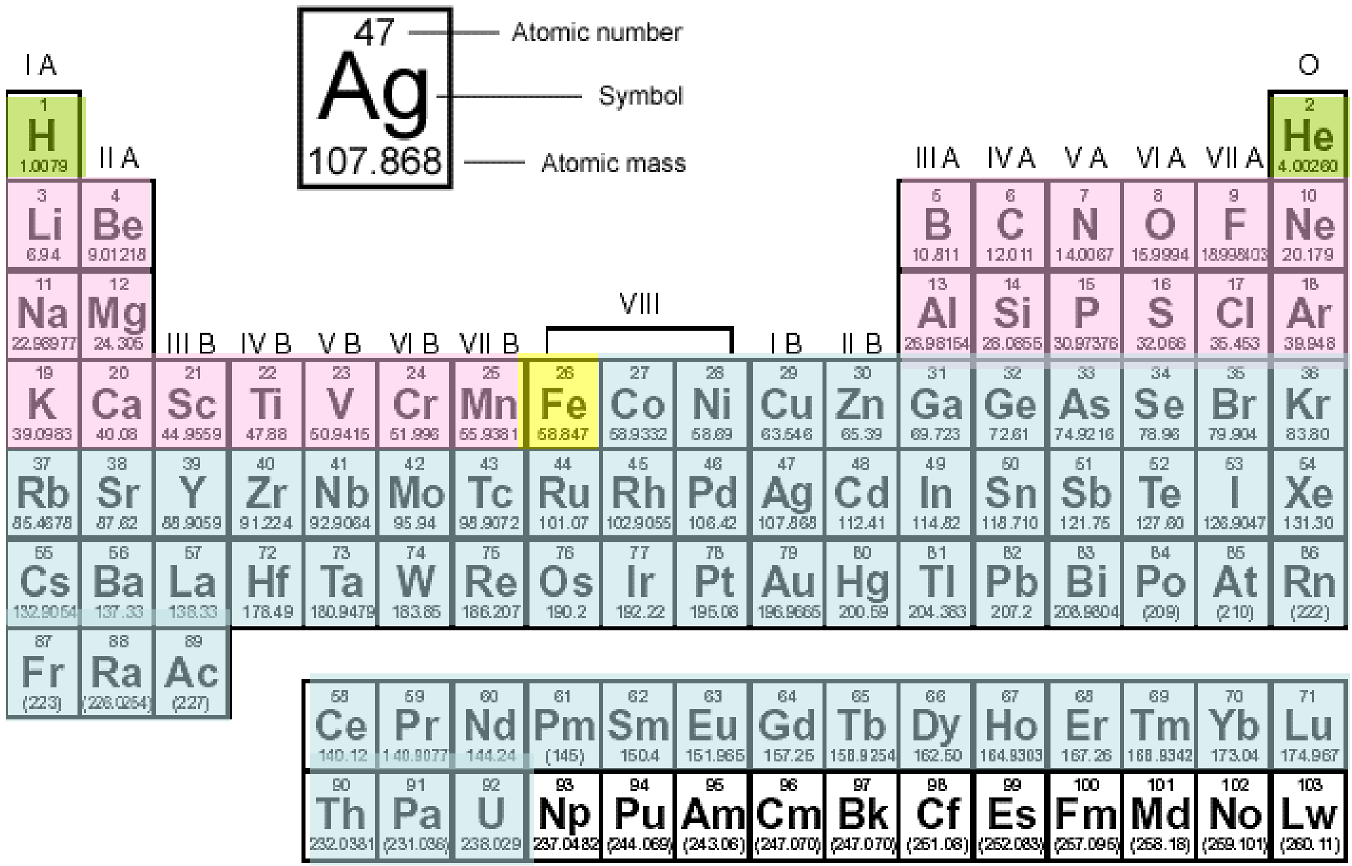
Inside massive stars: fusion builds the first quarter of the periodic table of the elements. Fast and slow neutron capture rxns after supernova builds the rest: a self-portrait of you and me!

Mostly of BB origin

Mostly of H/He fusion origin

Mostly of SN origin

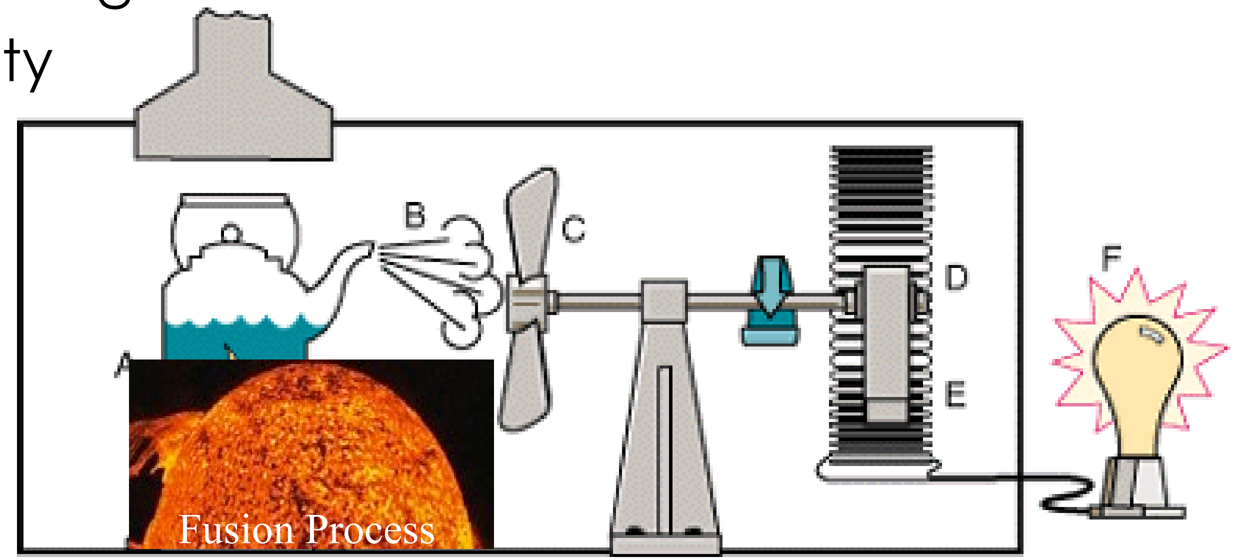
Nucleus stable against fusion



An important goal of fusion research includes an increased understanding of the associated plasma physics adequately to be able to design a reasonable reactor for electrical energy production.

To use energy from the process of fusion to

1. heat water
2. make steam
3. turn a turbine (propeller set)
4. turn an electrical generator
5. make electricity



Why do we need new sources of energy?

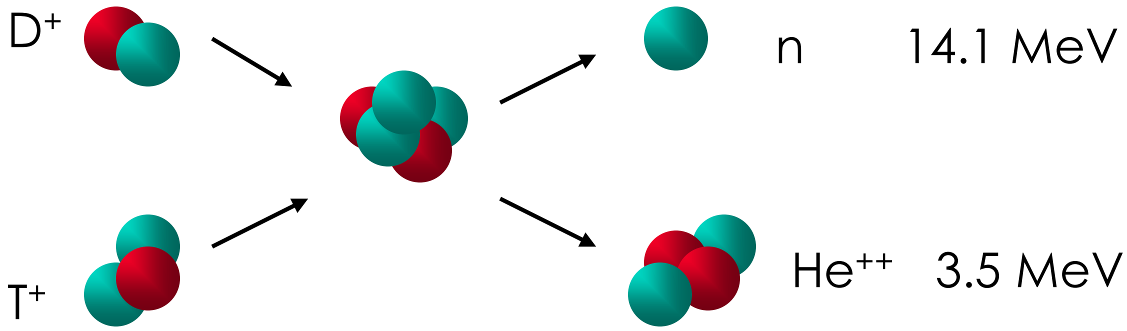
- The cost of mining coal and oil will eventually be prohibitive (reduced supply; need for fracking). And, there are other important uses for these resources beside burning.

- Water, wind, solar may not satisfy needs in all locations throughout the next 100,000+ years

- Fission may be supply-limited, and has weapons concerns

- Demand for electrical energy increases as population increases (electrical energy for water pumps, refrigeration, other large-scale industrial uses.)

Mass ‘goes’ into energy in fusion reaction; an example



The above reaction will be typical of fusion power plants. Fusion reactions in nature use H and many other low-mass atoms found in the periodic table.

Although we say the process “turns mass into energy,” a more understandable way to put it is: the origin of the released energy is the rearrangement of nuclear bonds.

Much energy is needed to overcome the repelling forces of the reactant ions. High temperature (≈ 10 -100^{+} million K) conditions are required.

High energy neutron will be used to heat fluid (water) to gas to turn turbine, while energy from alpha particle (He^{2+}) is used to sustain reaction

Matter exists in a wide temperature range: a few examples

Celsius

100,000,000 D, T nuclei fuse in tokamak

16,000,000 center of sun (H fusion)

100,000 lightning (no fusion, but ionized O, N)

10,000 fluorescent light (Argon & mercury ions)

6,000 surface of sun (what we see)

3,400 W (tungsten) melts

1,500 Fe (iron) melts

100 water boils

23 room temp

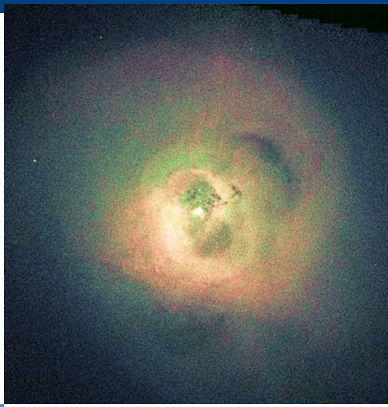
0 water ice

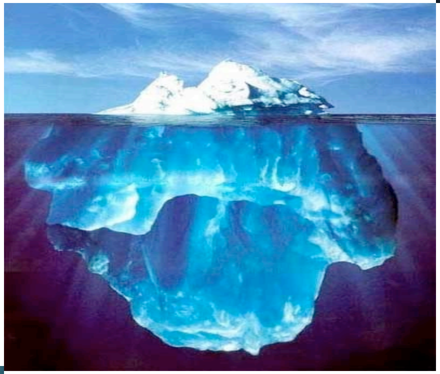
Dry Ice (CO_2) -78

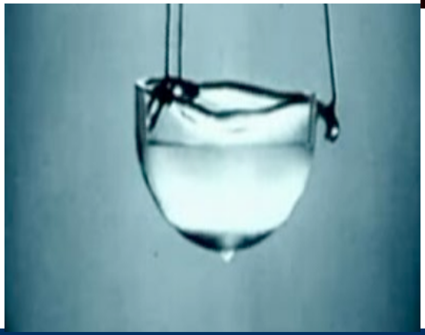
LN_2 -196

LHe -269

Abs. Zero -273





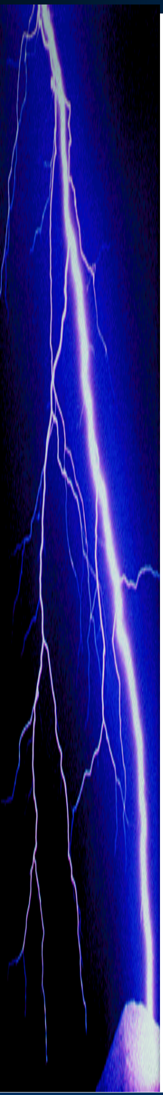


Plasma is the 4th state of matter and the 1st step toward fusion

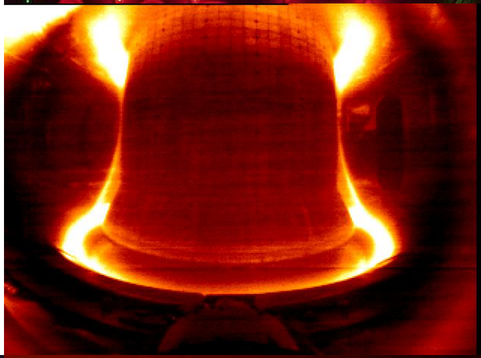
- A plasma is an ionized gas (1 or more e- removed from or added to a neutral atom).
- Plasma is called the "4th state of matter." Why?
- About 99% of the visible mass of the universe is in a plasma state of matter. (However, this is relatively little of the overall matter of the universe – about 96% of the universe is dark energy + dark matter!)
- 'Plasma' was coined by Tonks and Langmuir in (1929):

"...when the electrons oscillate, the positive ions behave like a rigid jelly..."

Where do we find plasmas?



- **Examples of plasmas on Earth:**
  - Lightning
  - Neon and Fluorescent Lights
  - Laboratory Experiments
- **Examples of astrophysical plasmas:**
  - The sun and the solar wind
  - Stars, interstellar medium

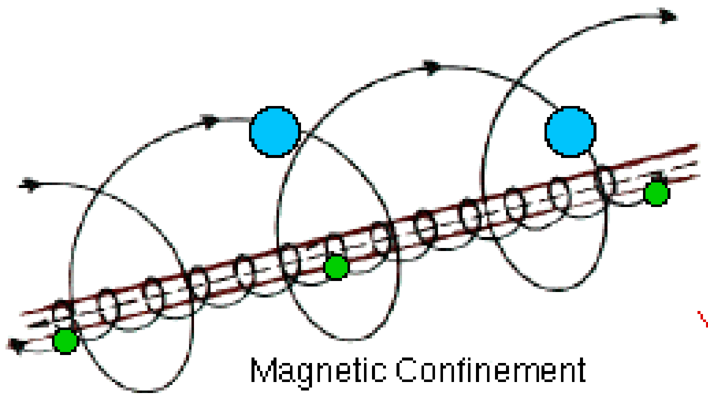


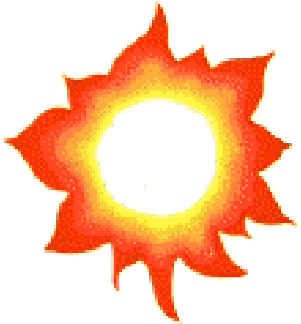
Why are we interested in plasmas?

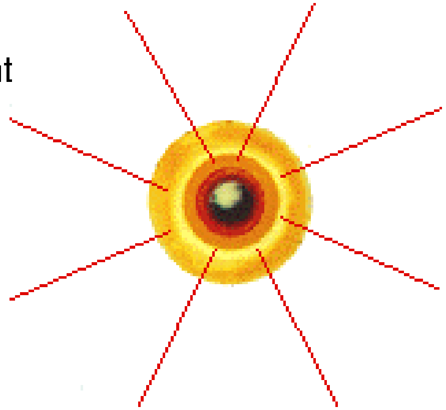
- **Fusion Energy**
  - Potential source of safe, clean, and abundant energy.
- **Astrophysics**
  - Understanding plasmas helps us to understand stars and stellar evolution. Interaction of solar wind particles and Earth's magnetic field.
- **Upper atmospheric dynamics**
  - The ionosphere is a plasma.
- **Plasma Applications**
  - Plasmas can be used to build computer chips, to clean up toxic waste, and drive space craft.

Methods for confinement – or, how do you hold on to something that is > 5,000 K?

- **Hot plasmas are confined with gravitational fields in stars.**
- **In fusion energy experiments magnetic fields are used to confine hot plasma, and inertial confinement uses lasers.**



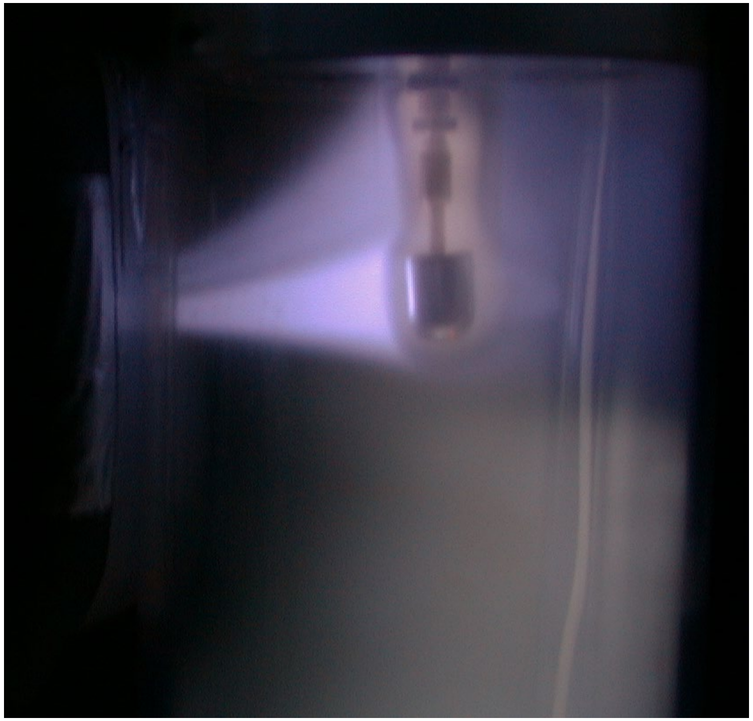




Magnetic fields cause charges to move in circles

- **To notice**
  - Plasma Colors
  - Shape
  - Attraction

Magnet



- **Magnetic fields have an effect on moving charged particles**
- **F=**q(**v** x **B)** causes circular motion
- **F** = q(**E** + **v** x **B**) What type of motion results?

Advantages of fusion as an energy producer

- Fusing deuterium and tritium to produce significant energy is achievable

- No CO_2 (or other greenhouse gas) output

- Fuel resource will last many millions of years
    - Deuterium, a hydrogen isotope, is found in all water
    - Tritium is a byproduct of the process and is harvested for reuse

- No radioactive wastes - although there will be local activation of structural materials

- Can be used day or night, with or without the presence of wind or waves

Disadvantages of Fusion

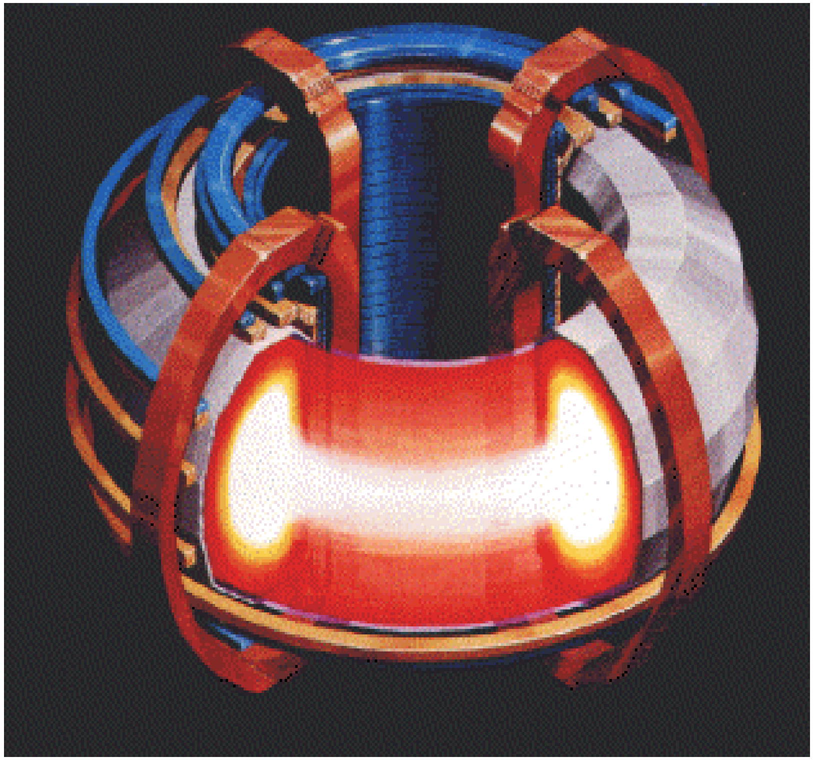
- Limited helium supply on Earth - He is used to cool magnets (superconducting) and as a cryo-pumping resource
- Fusion is a difficult science; some have said it is the most ambitious and difficult undertaking ever
- Technology is advanced (read: NOT cheap)

The Magnetic Confinement Fusion Reactor

- **How can we fuse these light atoms?**
  - ✓ Make a plasma---ionize the gas atoms
  - ✓ Hold on to the plasma---use a magnetic field
  - ✓ Heat the plasma---use particle beams and electromagnetic energy (RF, microwave)
  - ❑ Harness the energy---use a series of heat exchangers involving liquid metals and other fluids

Controlling fusion with magnetic fields

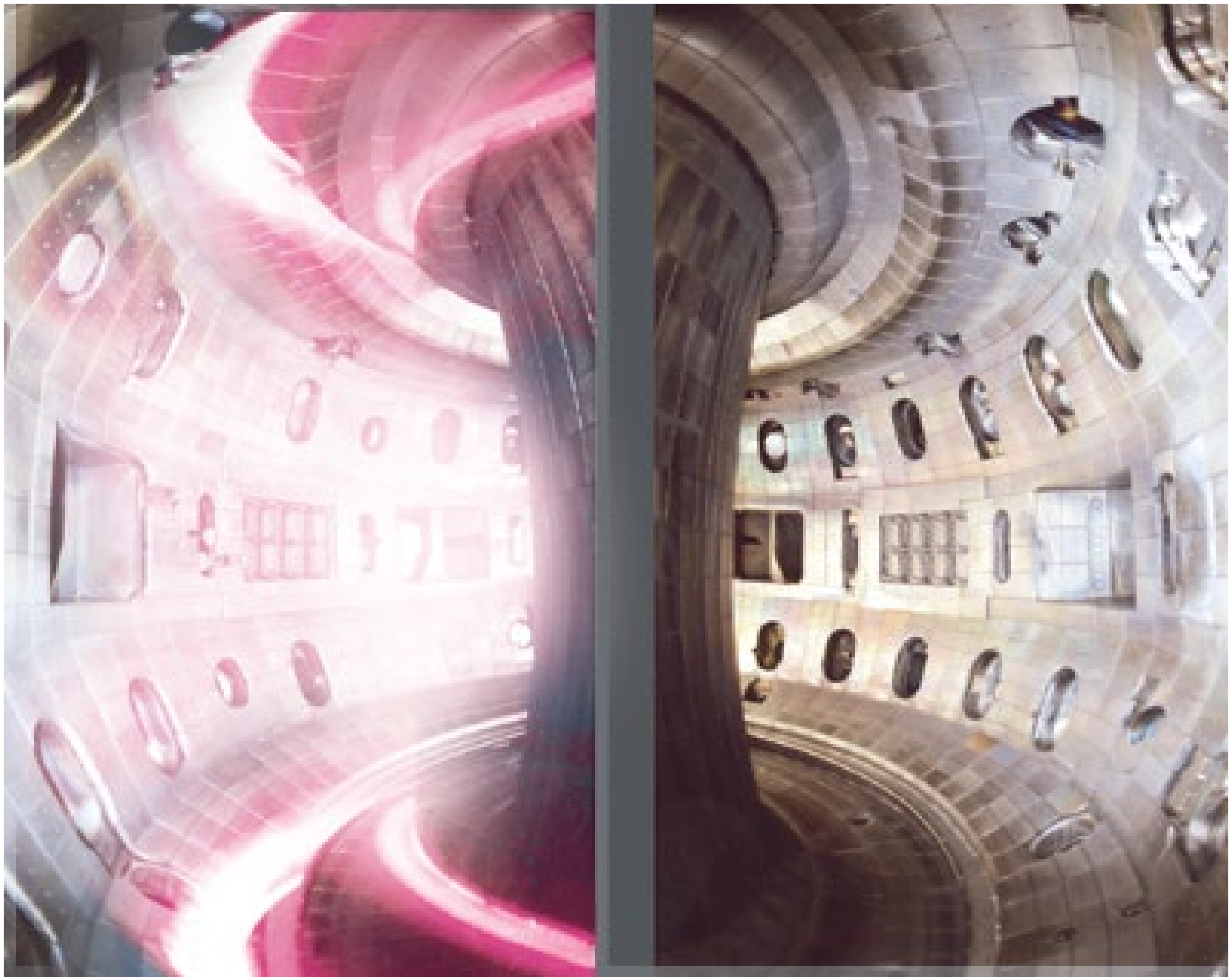
- **Most magnetic confinement devices in use today have a toroidal shape.**
- **Large magnetic fields are created by driving currents through coils wrapped around the torus.**



http://demo-www.gat.com/

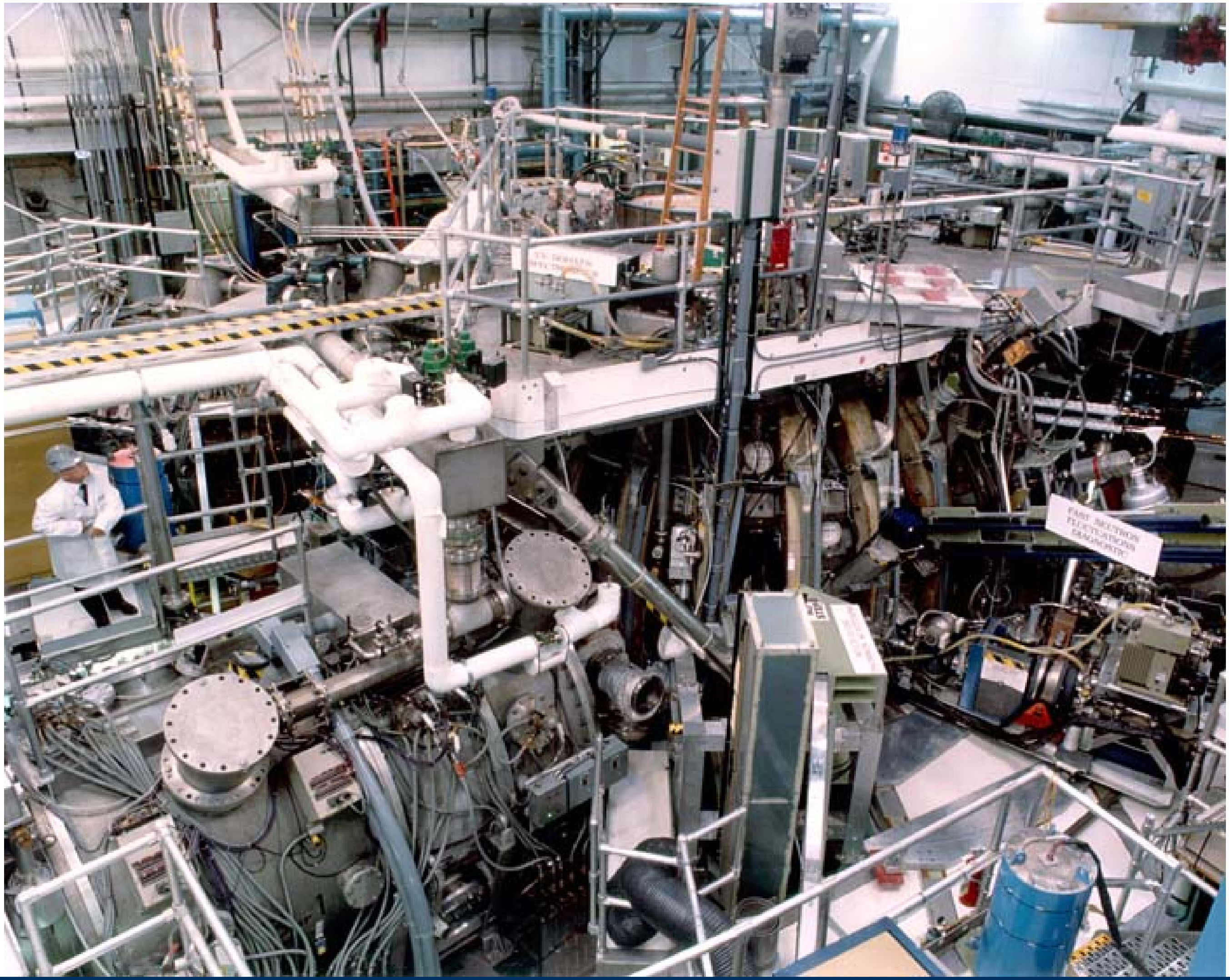
DIII-D, a mid-size tokamak, is operated by General Atomics for the US Department of Energy and is located in San Diego, CA

plasma

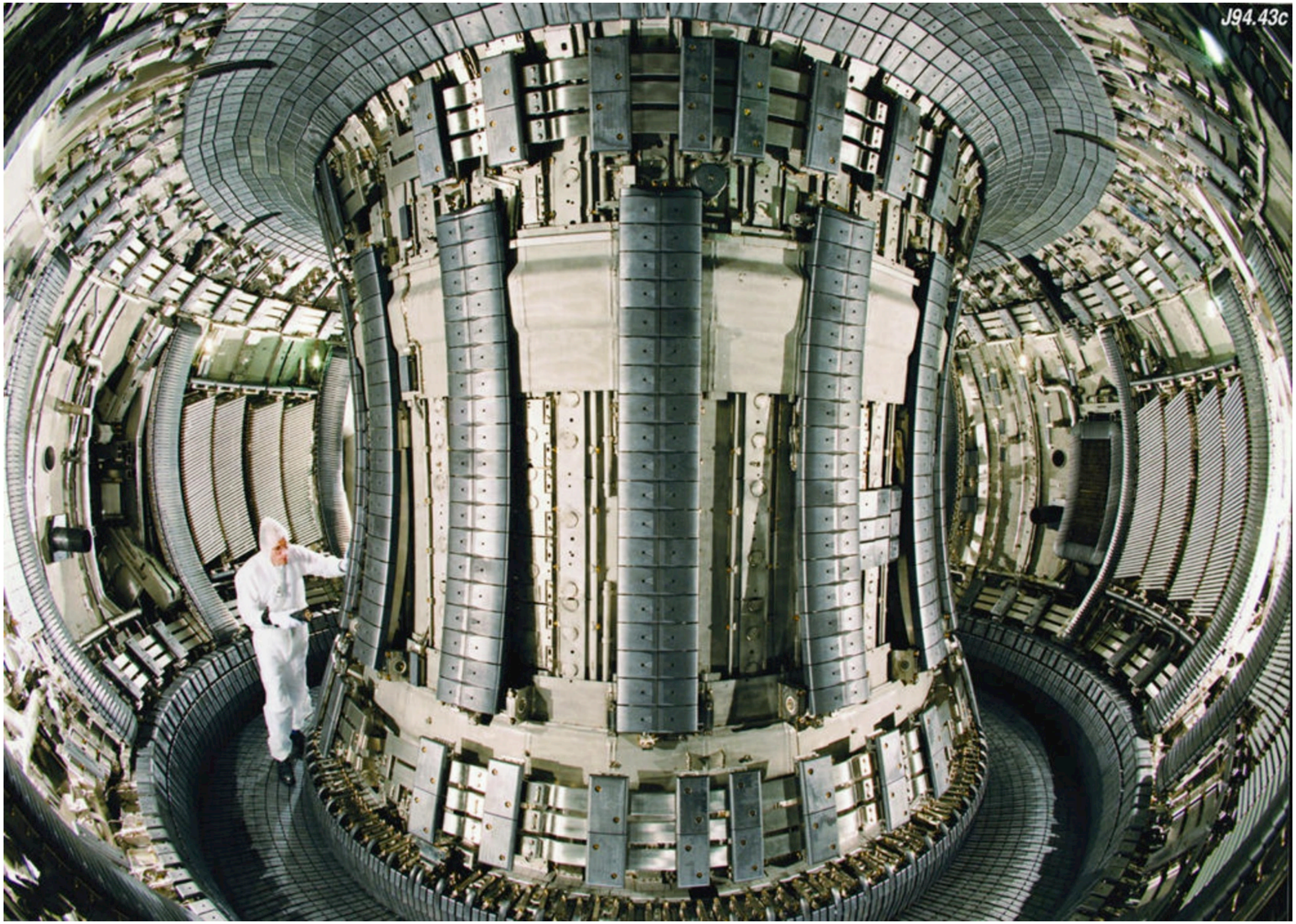


No plasma

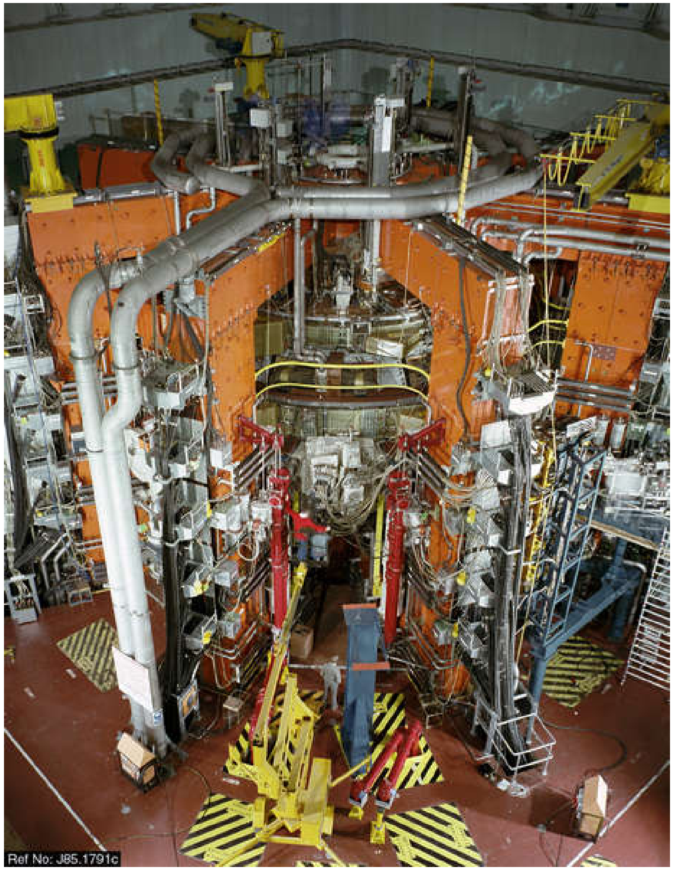
Outside DIII-D… an industrial-scale experiment

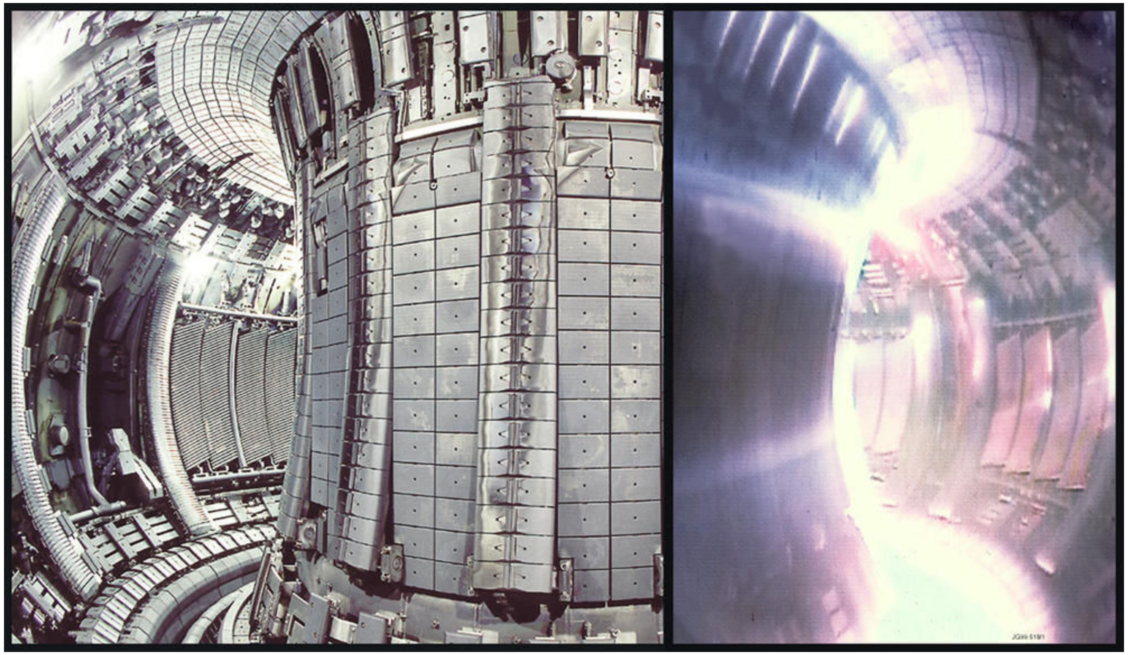


Inside the largest tokamak: Joint European Torus - JET



Joint European Torus: outside and inside





The next step: ITER - "The Way" is being built now in Southern France

- International
- Large scale tokamak design
- Produce fusion energy (500 MW)
- But, no electricity production
- One of humankind's biggest science projects