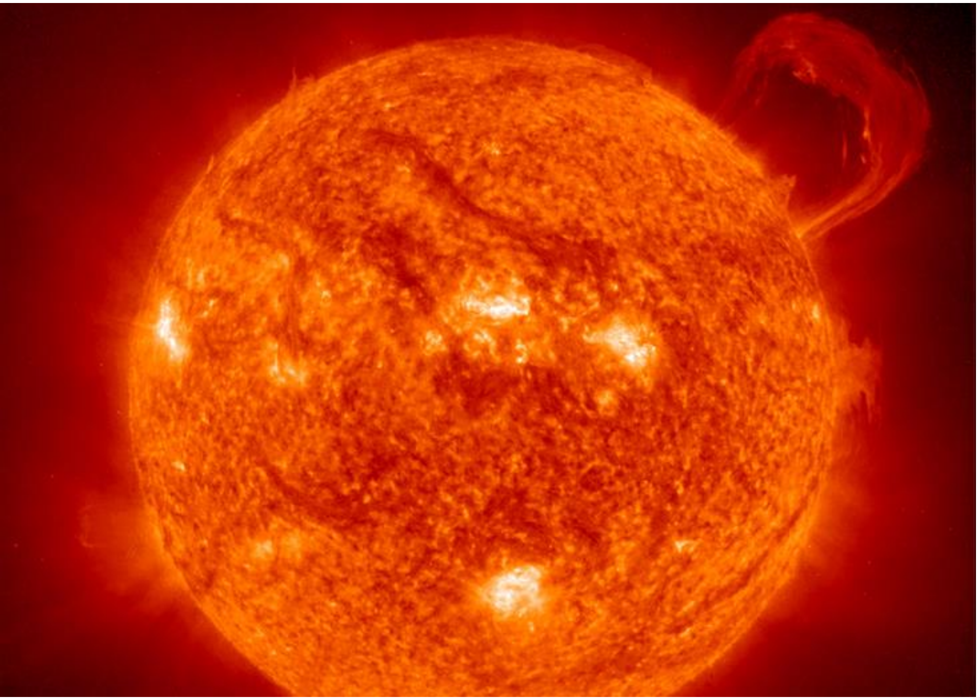
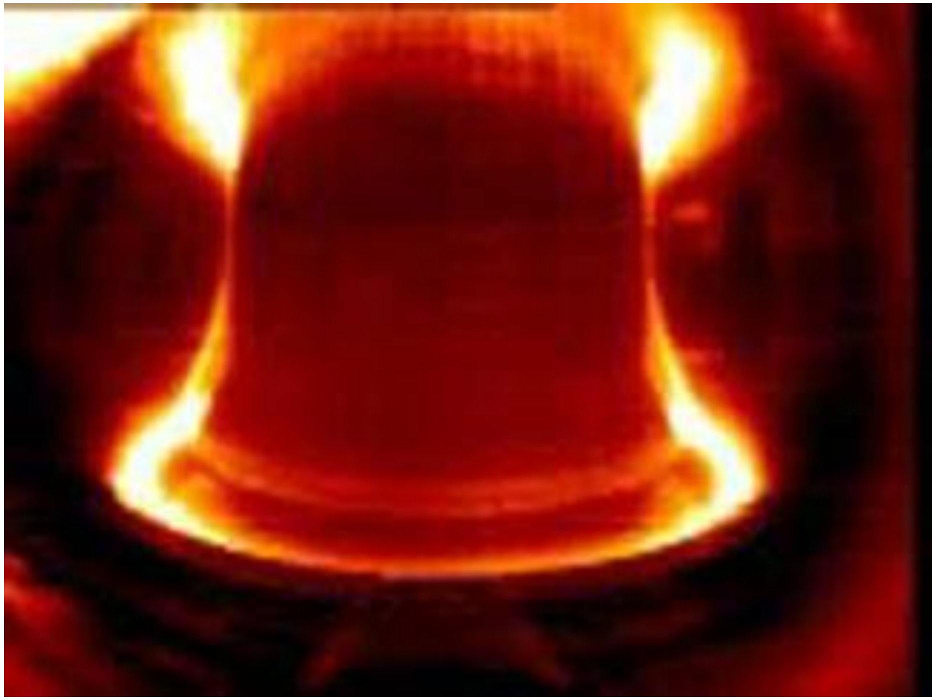
# Containing a star on earth: PPPL and the promise of fusion energy





**Walter Guttenfelder**

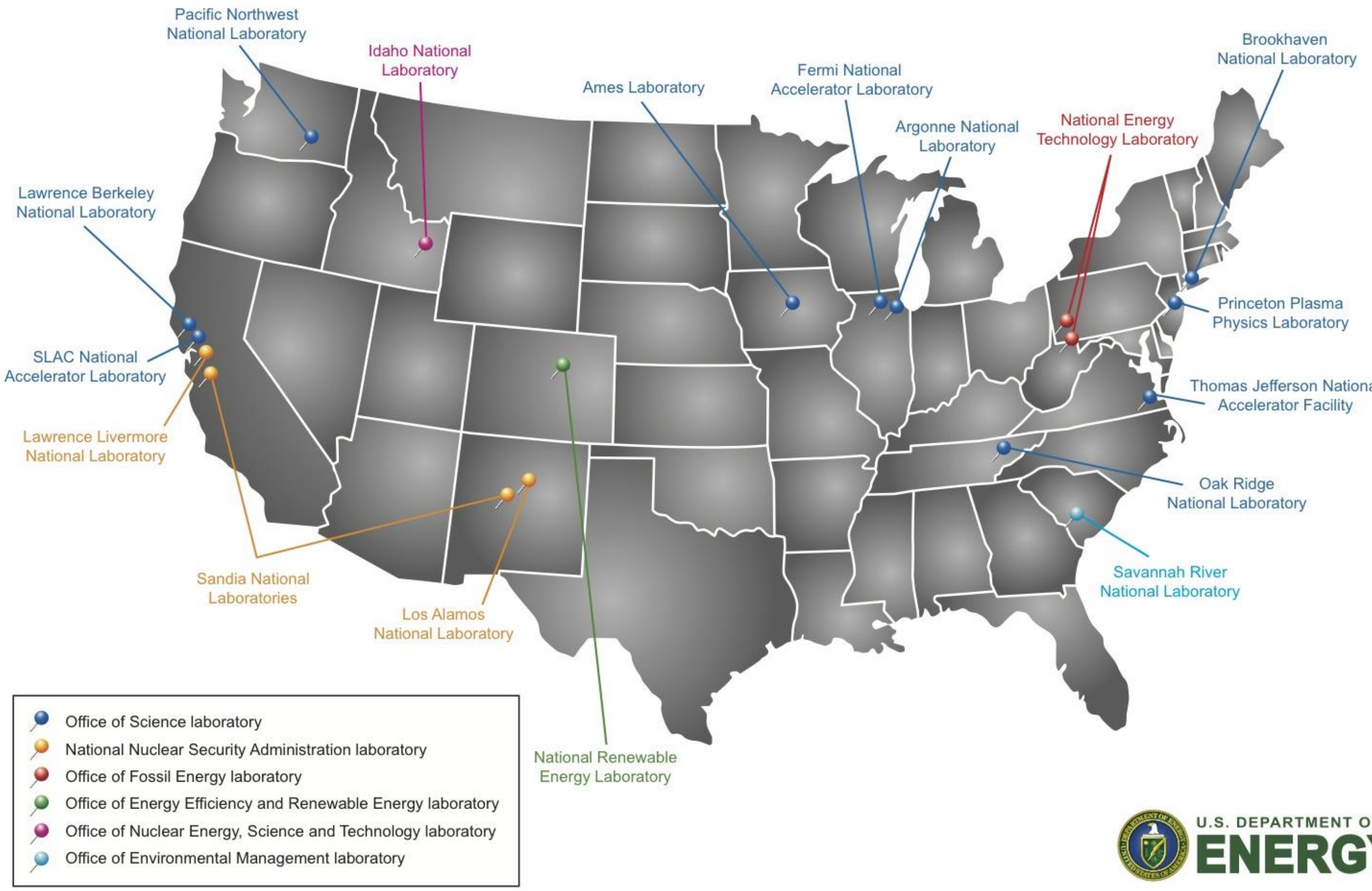
U.S. DEPARTMENT OF ENERGY | Office of Science

PPPL PRINCETON PLASMA PHYSICS LABORATORY

# Princeton Plasma Physics Laboratory (PPPL)
# Plainsboro, New Jersey

# PPPL is 1 of 17 Department of Energy (DOE) National Laboratories

- **PPPL Vision: Enable a world powered by safe, clean and plentiful fusion energy while leading discoveries in plasma science and technology.**

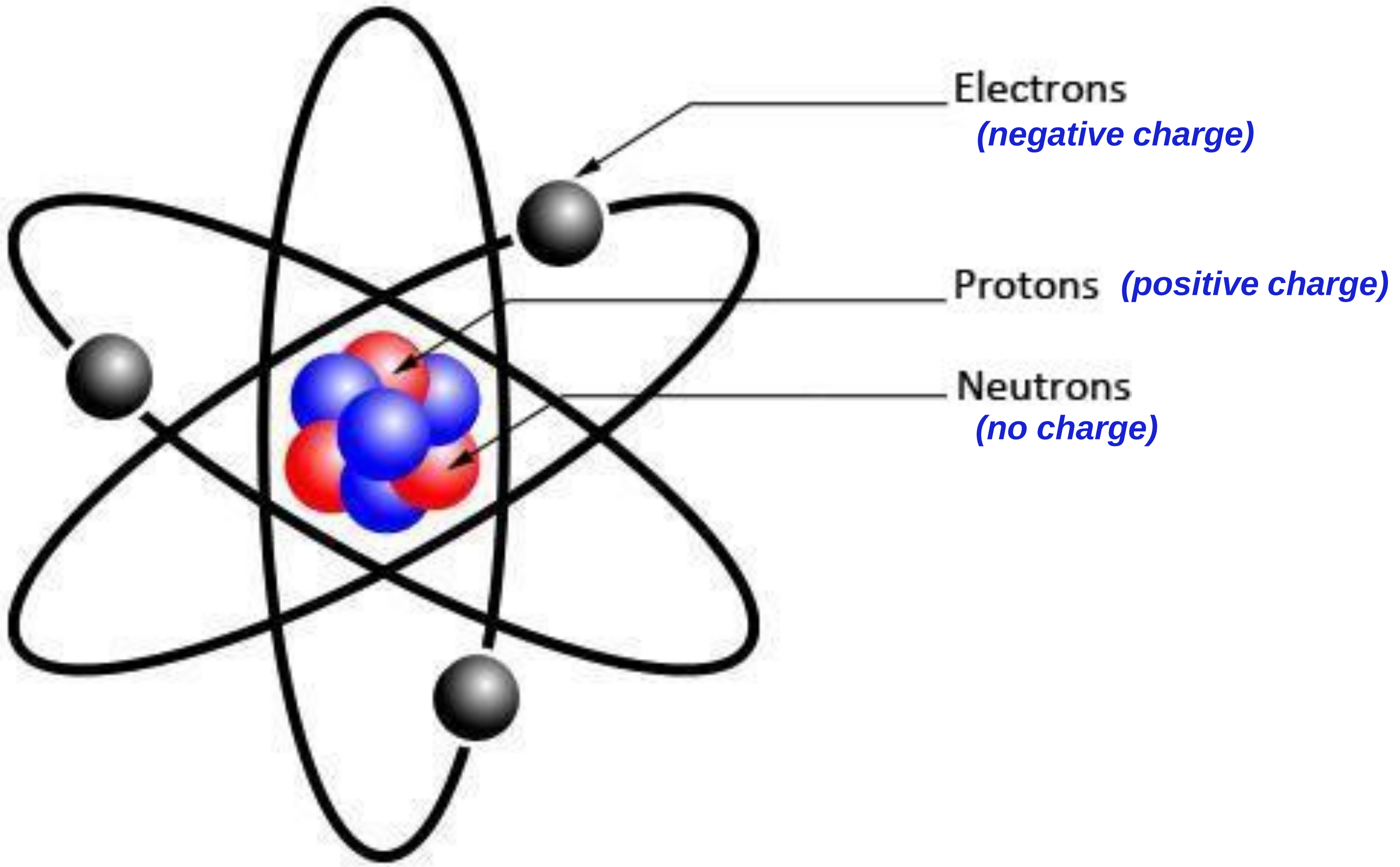



U.S. DEPARTMENT OF ENERGY

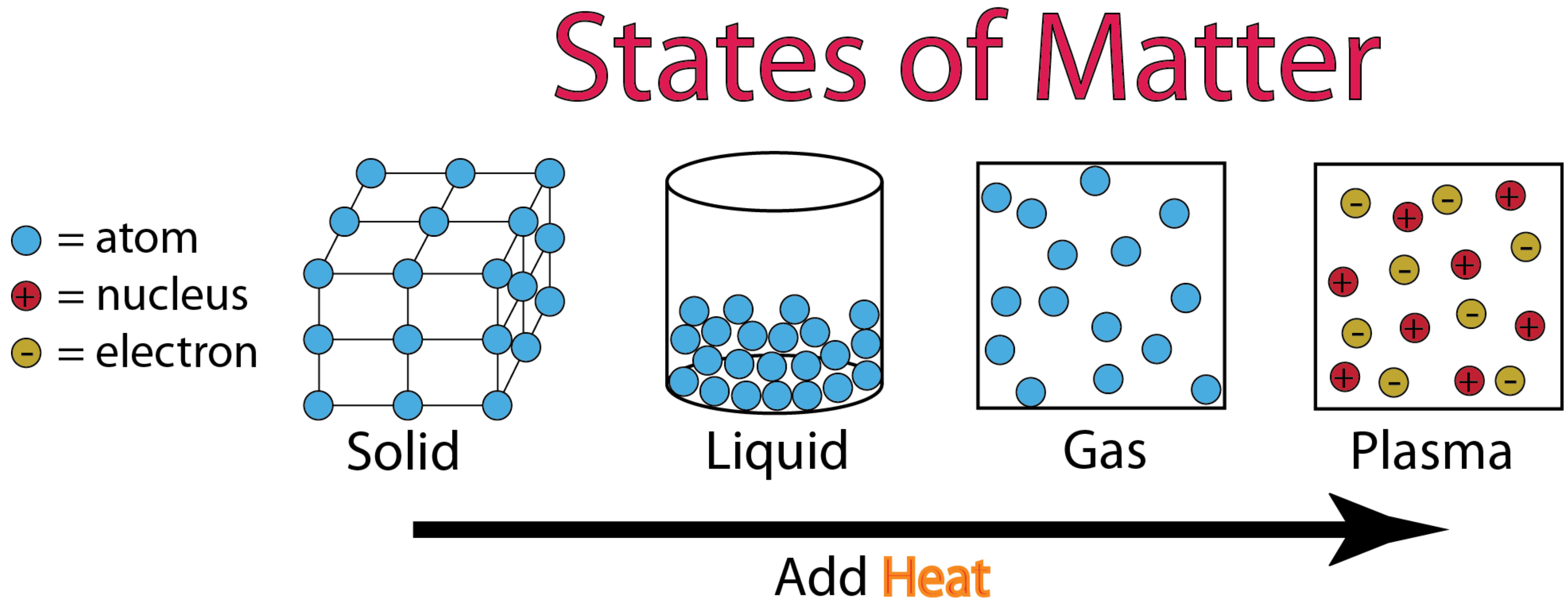
# What is a plasma?

# (Not the blood kind)

# Let’s review atoms



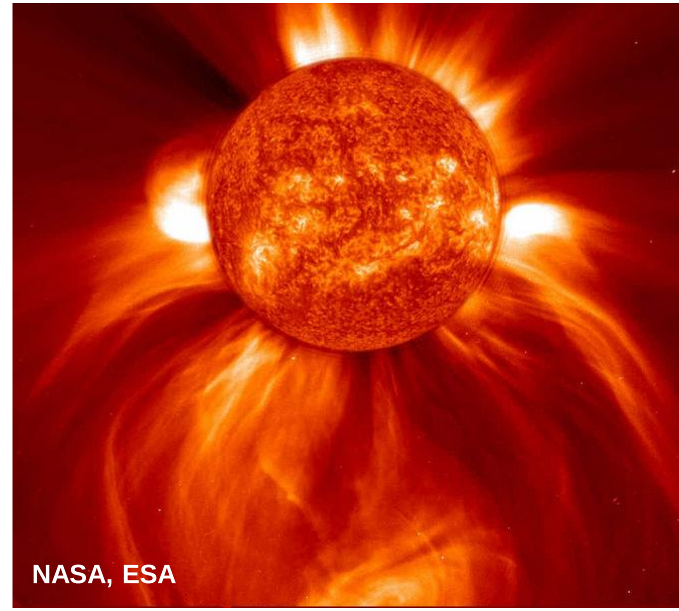
# Plasma – the 4th state of matter ("super heated gas")



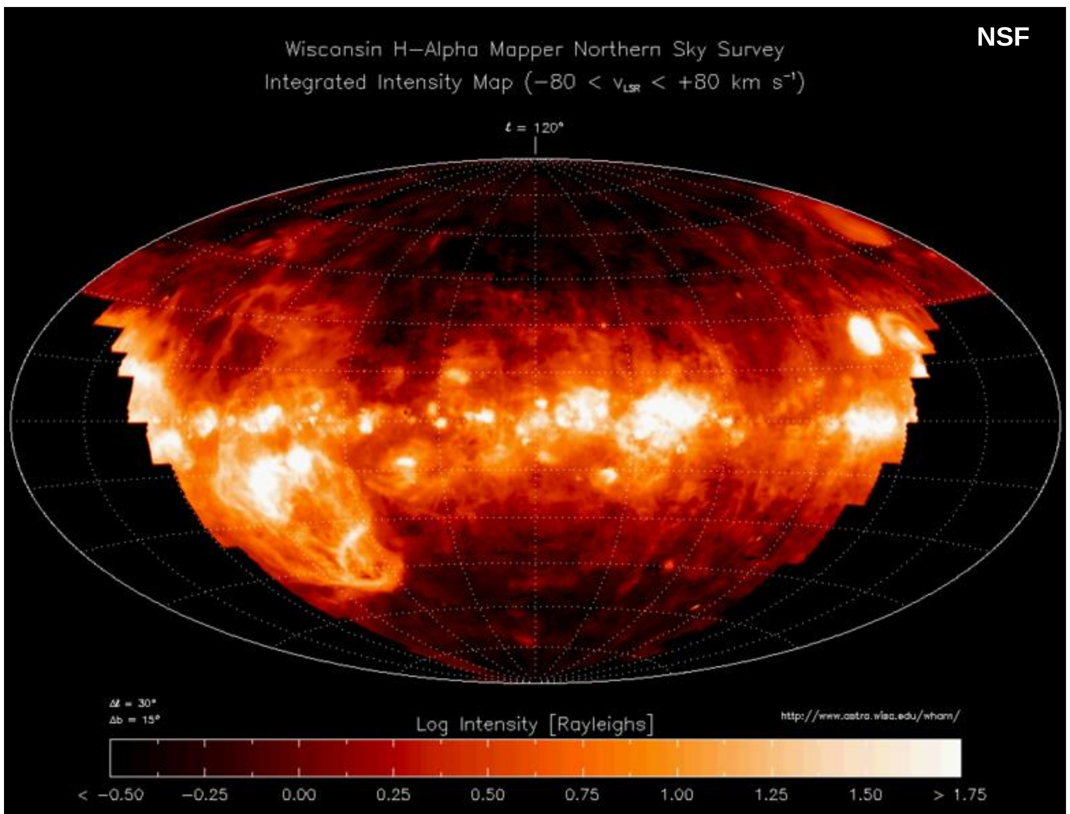

- Water: 0 °C 100 °C 160,000 °C

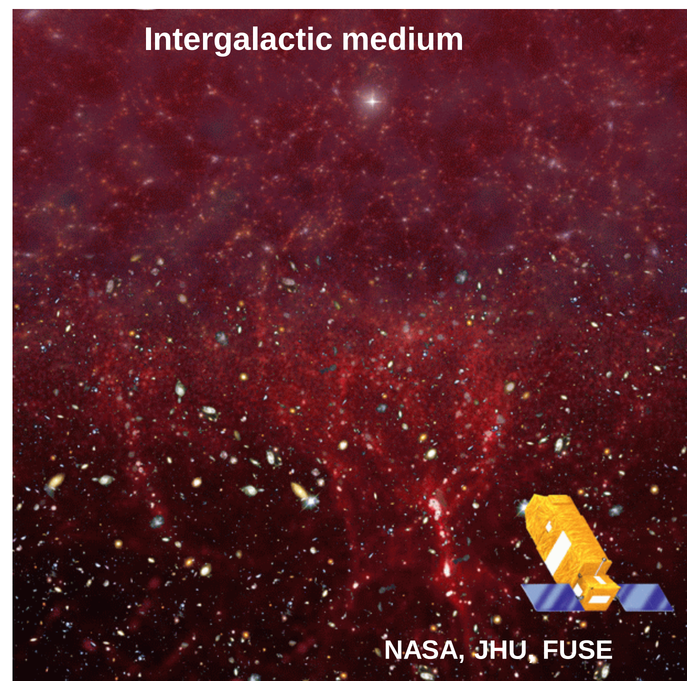
# 99% of (known) matter in universe is plasma

- Sun, stars, interstellar and intergalactic medium account for most mass and are largely plasma




**Ionized gas in the Milky Way**



# Numerous examples of plasmas on or near earth

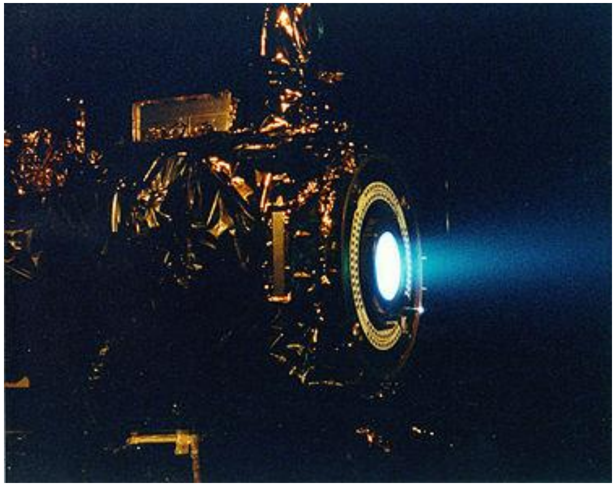
lightning

neon signs

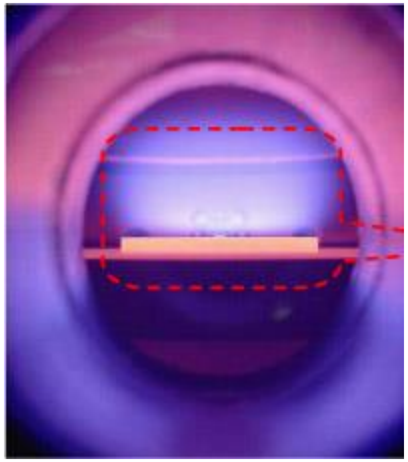

tv

aurora

satellite plasma thrusters



semiconductor processing

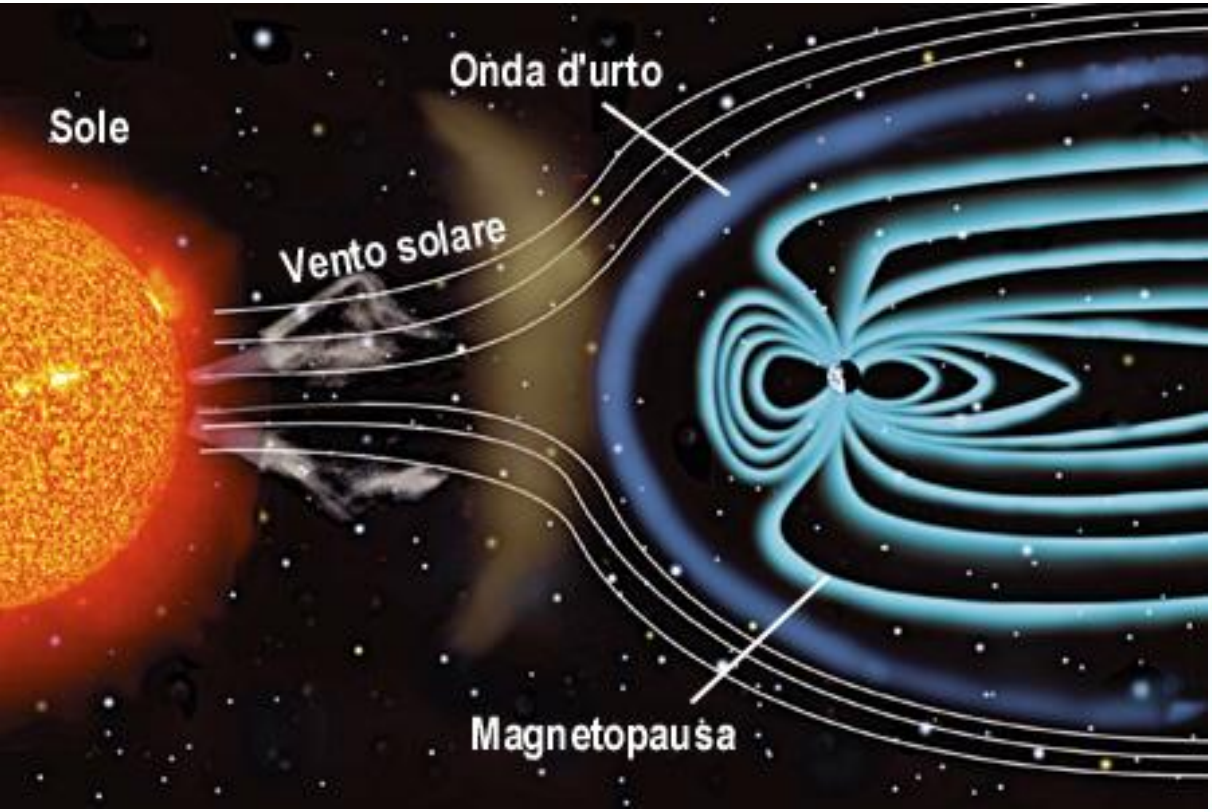


**At PPPL, we try to understand many aspects of plasmas**

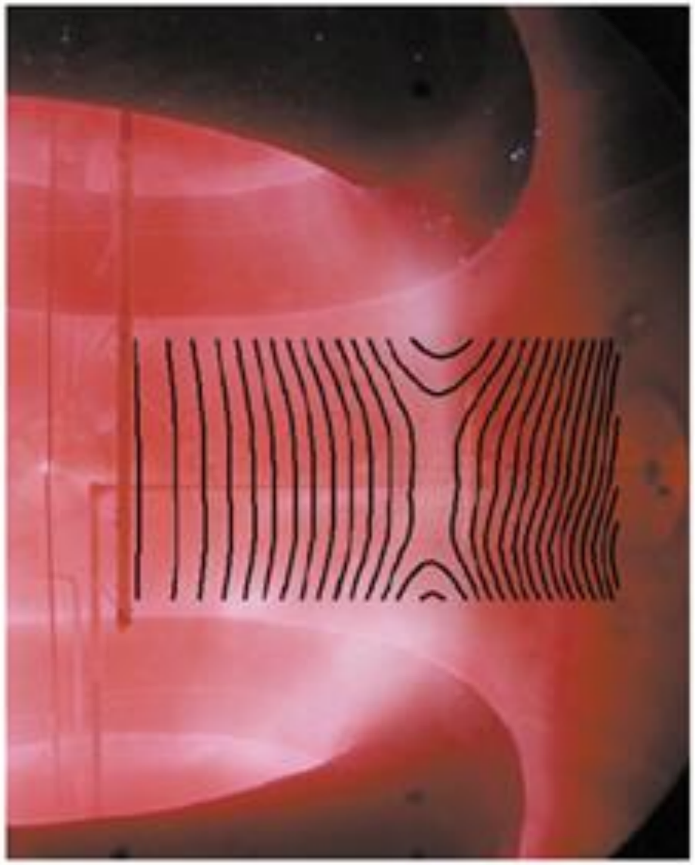
**For example…**

# Experiments to study astrophysical “reconnection” (solar flares)

- Laboratory experiment to mimic interaction of solar flare impinging on earths magnetic field (relevant to telecommunications)

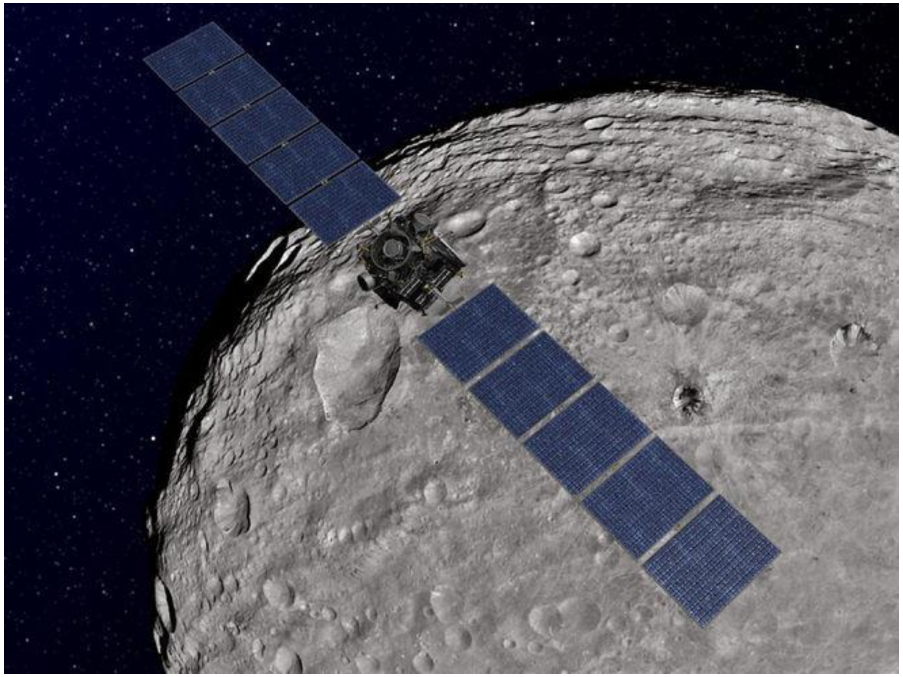



**MRX**
**Magnetic Reconnection Experiment**

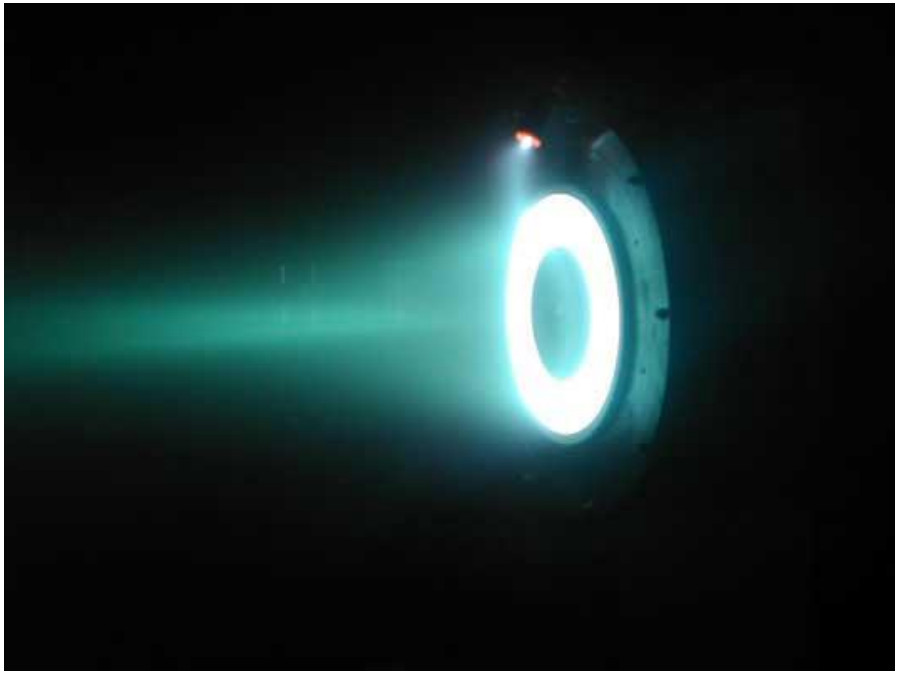


# Experiments to study plasma thrusters for satellites and deep space exploration

**The success of NASA's Dawn mission to orbit two asteroids depended on plasma thrusters**



**HTX**
**Hall Thruster Experiment**



# Additional plasma research at PPPL

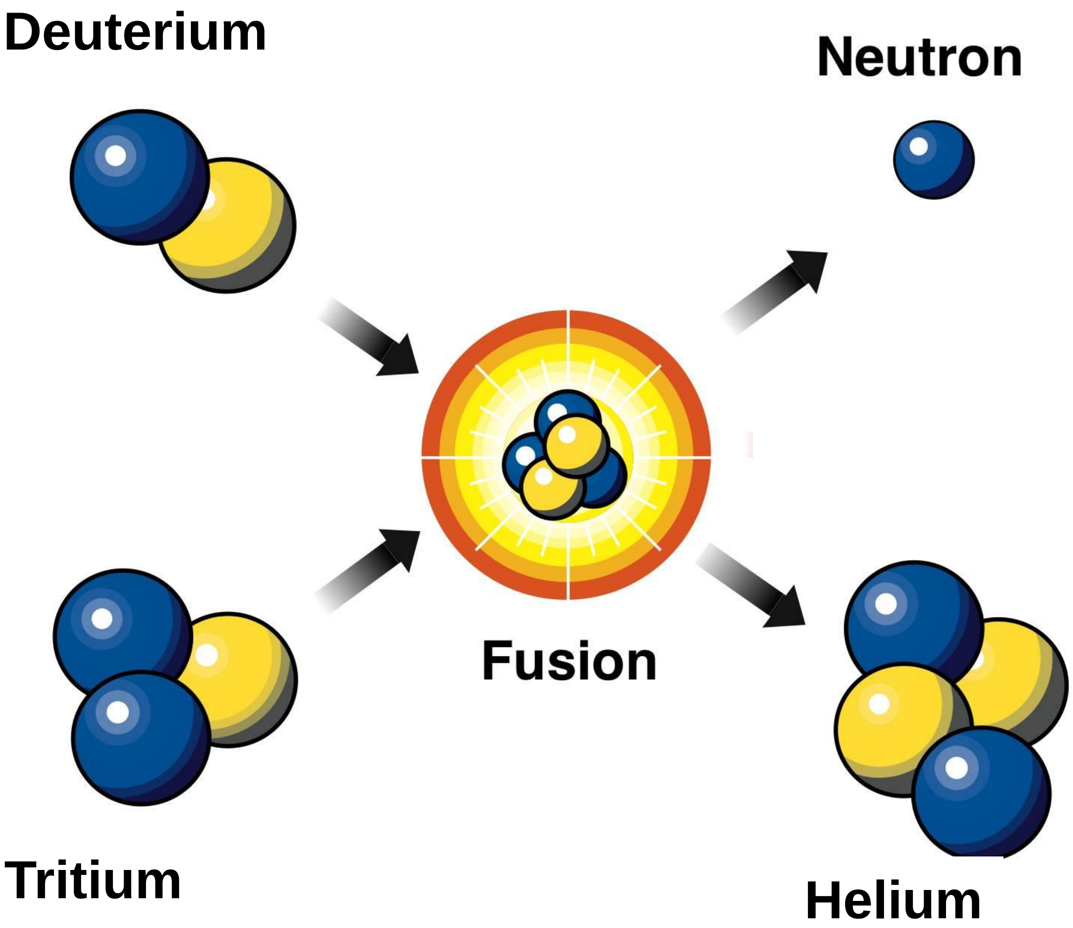
- Astrophysics
- Plasma thrusters
- Basic plasma physics
- Nanotechnology
- Plasma-surface chemistry interaction
- Developing medical isotopes
- Plasma theory and simulation

➢ **Plasmas for nuclear fusion energy research**

# What is nuclear fusion?

# <u>Nuclear Fusion</u>: Energy release occurs due to fusing two small nuclei

| mass of deuterium + tritium | > | mass of Helium + neutron |
|---|---|---|



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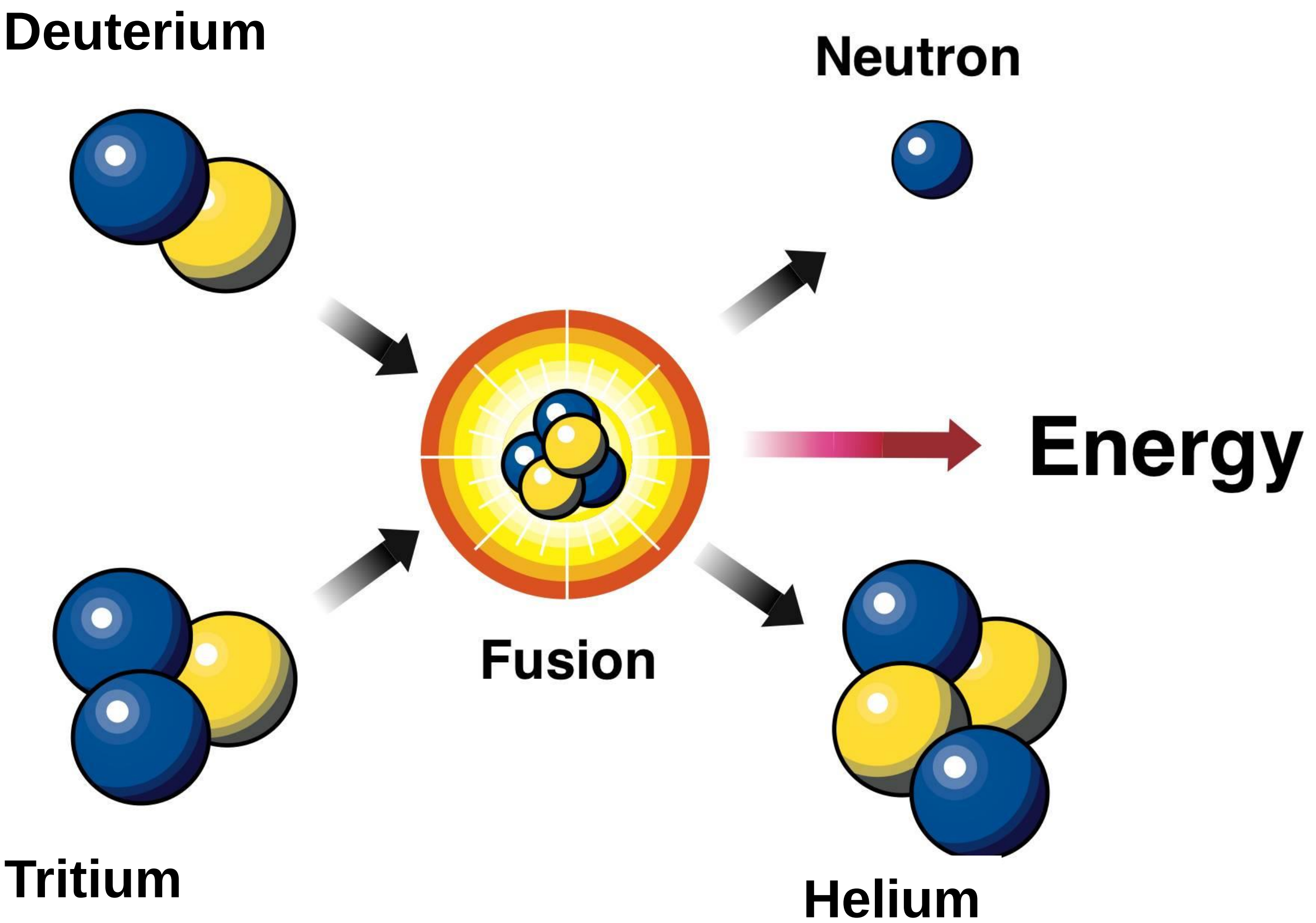
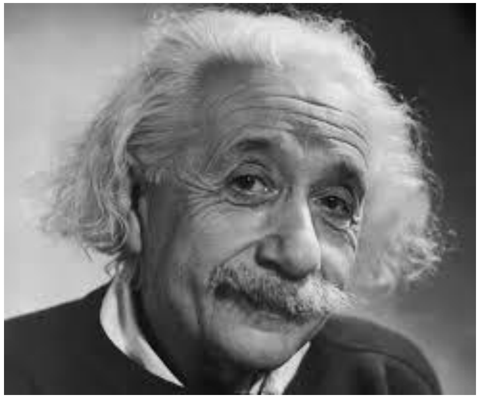



Tiny difference in mass is converted into energy

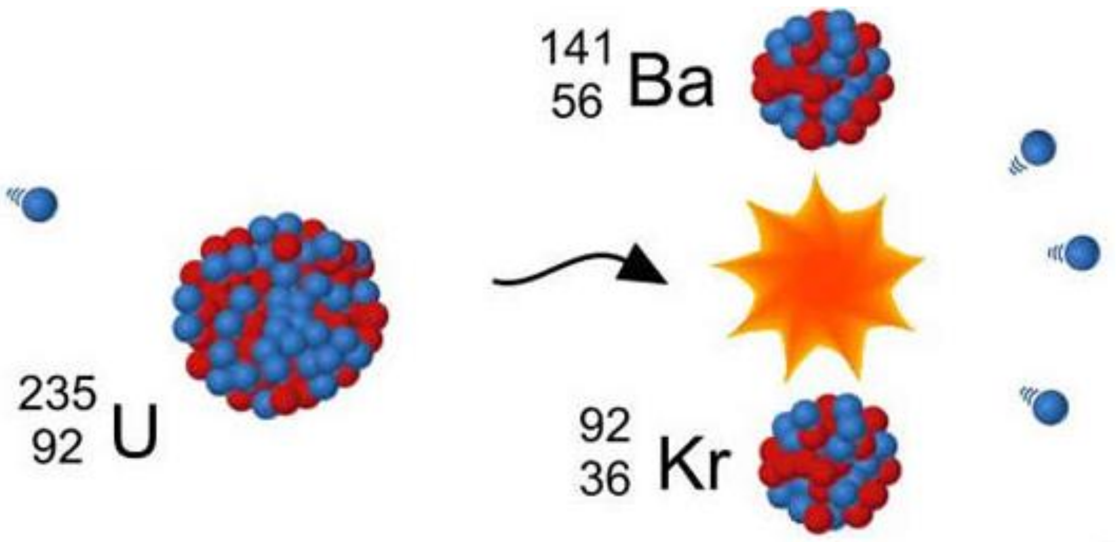
$$E = mc^2$$



# Opposite of nuclear fission that powers today's "nuclear" reactors

- Splitting large atoms also leads to energy release

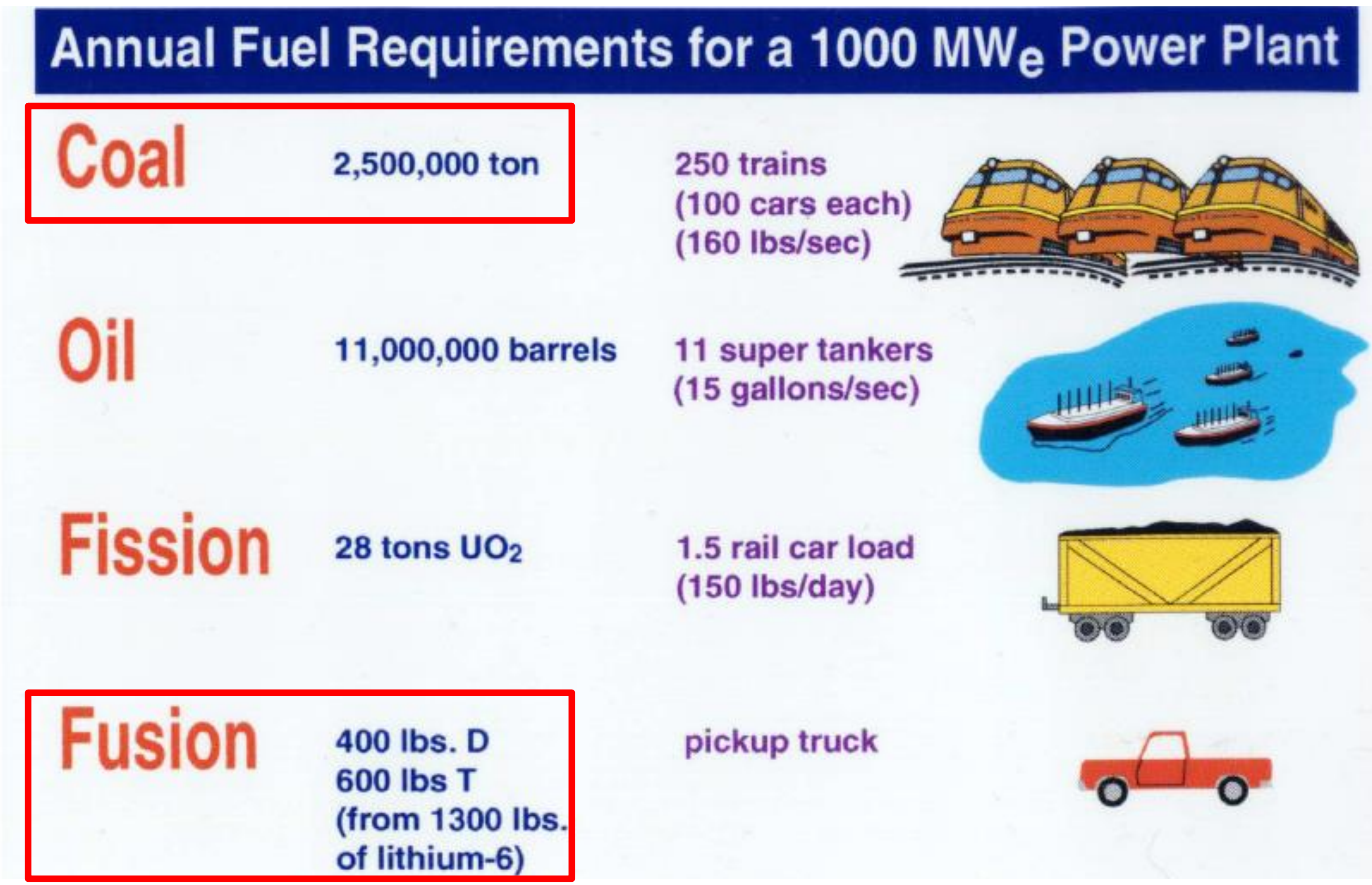
| mass of Uranium + neutron | > | mass of Products |
| --- | --- | --- |




Indian Point Nuclear Power Plant

# Why study fusion energy research?

- No carbon emission
- Fuel is available for thousands of years



# Why study fusion energy research?

- No carbon emission
- Fuel is available for thousands of years

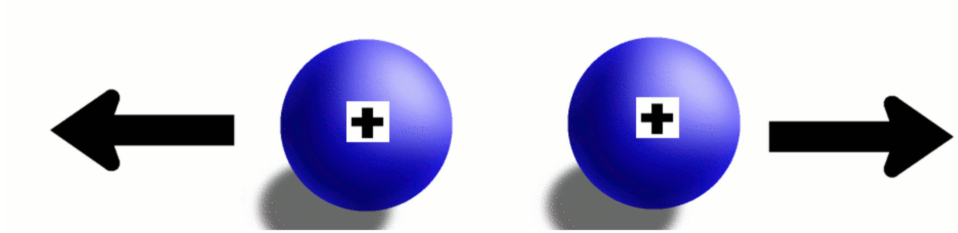
- Inherently safe – only grams (<minute) of fuel in the device
  - no melt down/runaway concerns
- Very little (and short lived) radioactive material compared to nuclear fission

- Compared to non-carbon renewables (solar, wind) fusion is compact and continuous (not intermittent)

- **Disadvantages: Hard to do!**

# Must overcome repulsive electrostatic force to fuse atomic nuclei

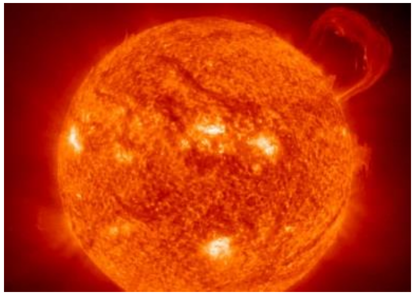
- Force between two charged particles increases as they get closer



- **Temperatures must be ~150 million degrees Celsius**

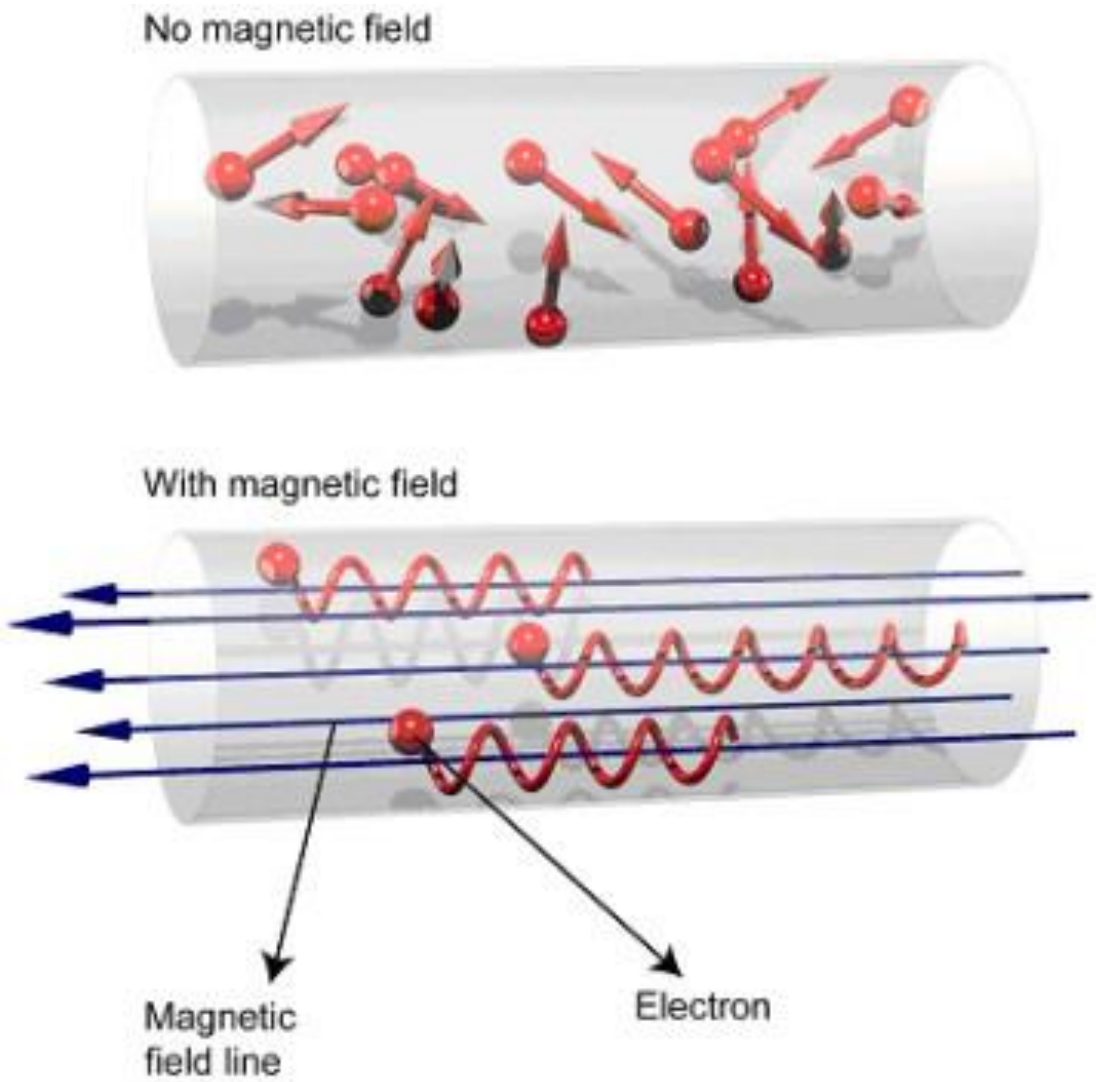
**→ no longer a gas, but a <u>plasma</u>**

**(Core of the sun ~15 million C)**

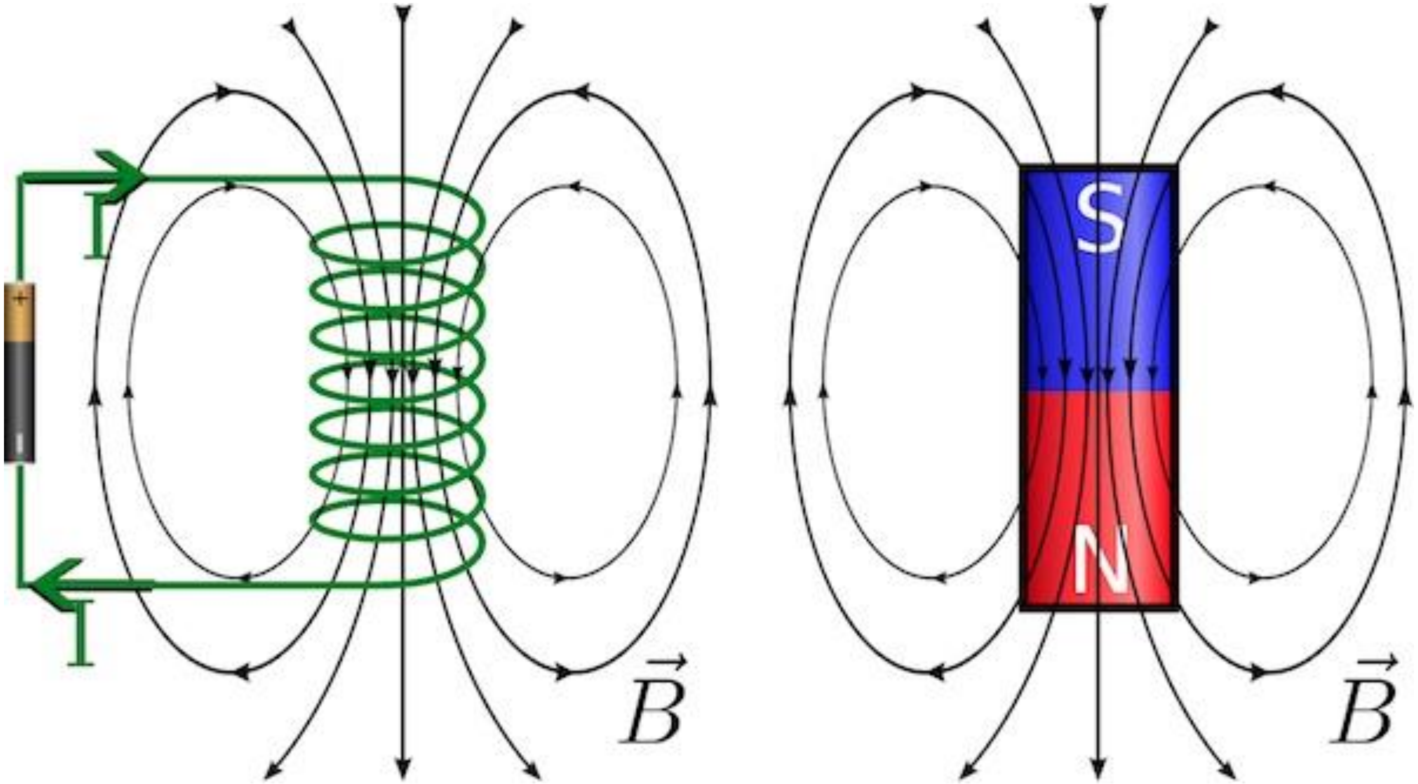


# How do we contain a *hot* plasma on earth?

# Magnetic field confines charged particles (plasma) away from boundaries

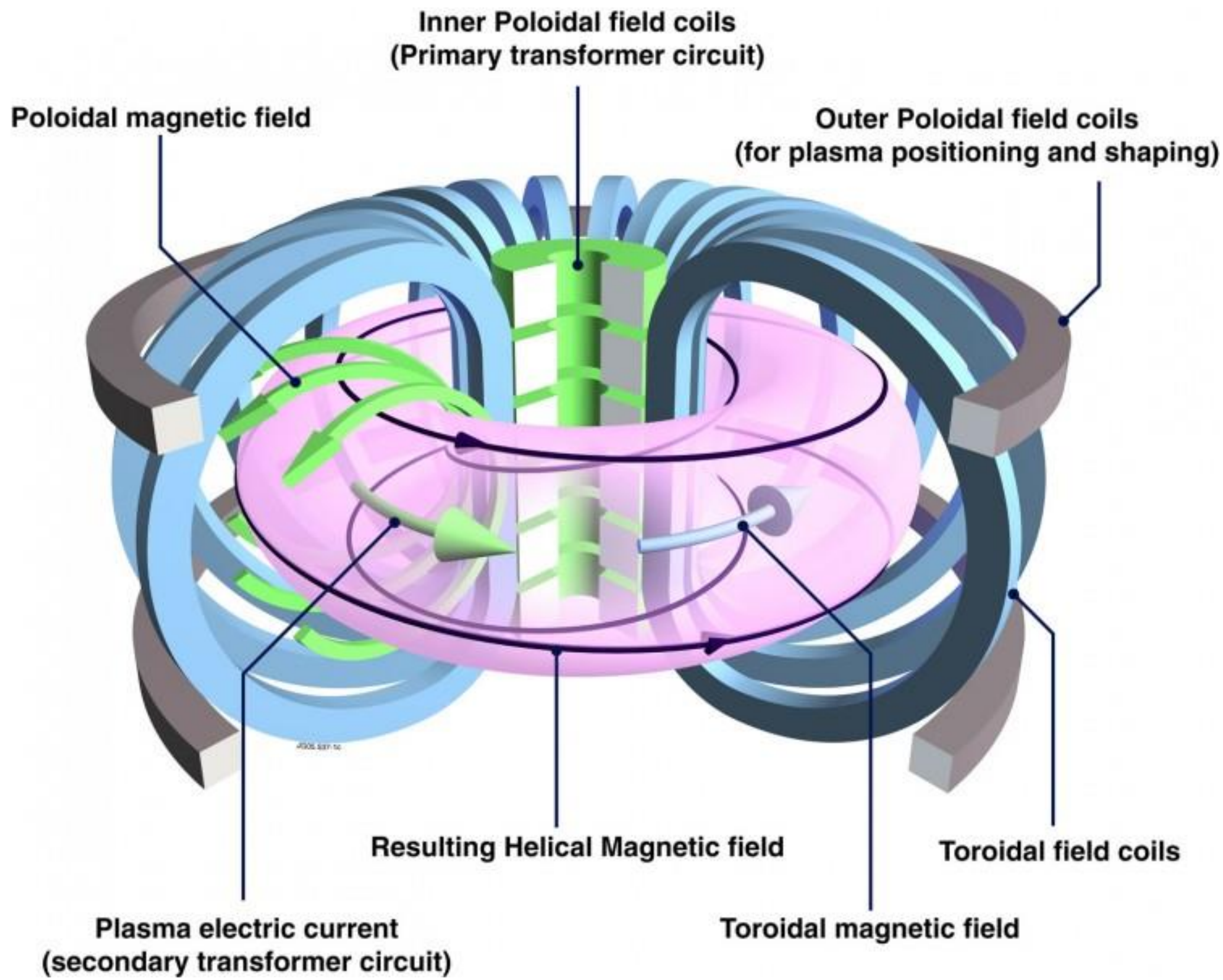


# We use strong electromagnets to generate the magnetic field

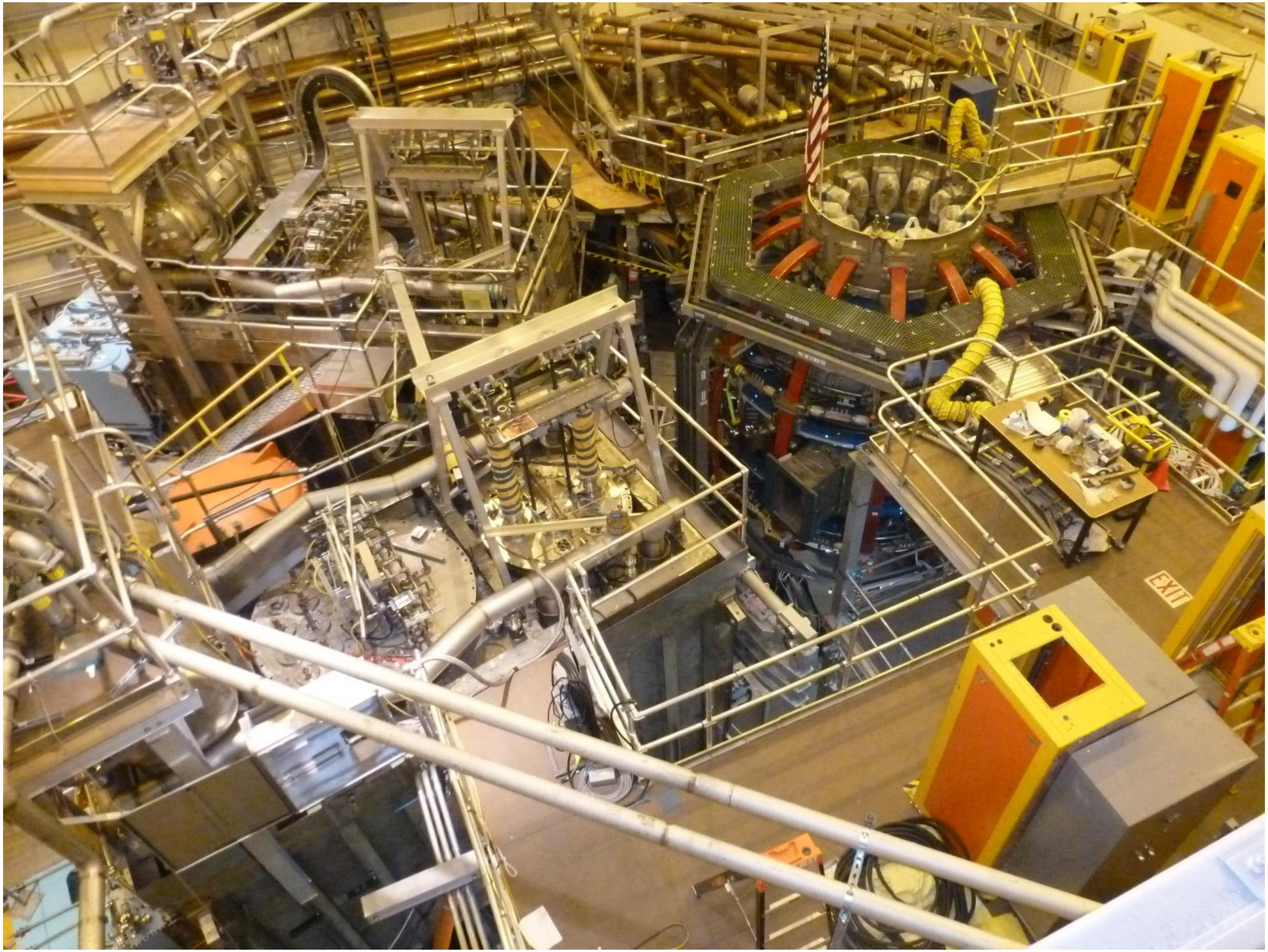



- But hot particles can easily leak out the ends of a straight magnetic field…

# The Tokamak (Russian acronym for "toroidal chamber with magnetic coils")



# At PPPL:
# National Spherical Torus Experiment-Upgrade (NSTX-U)



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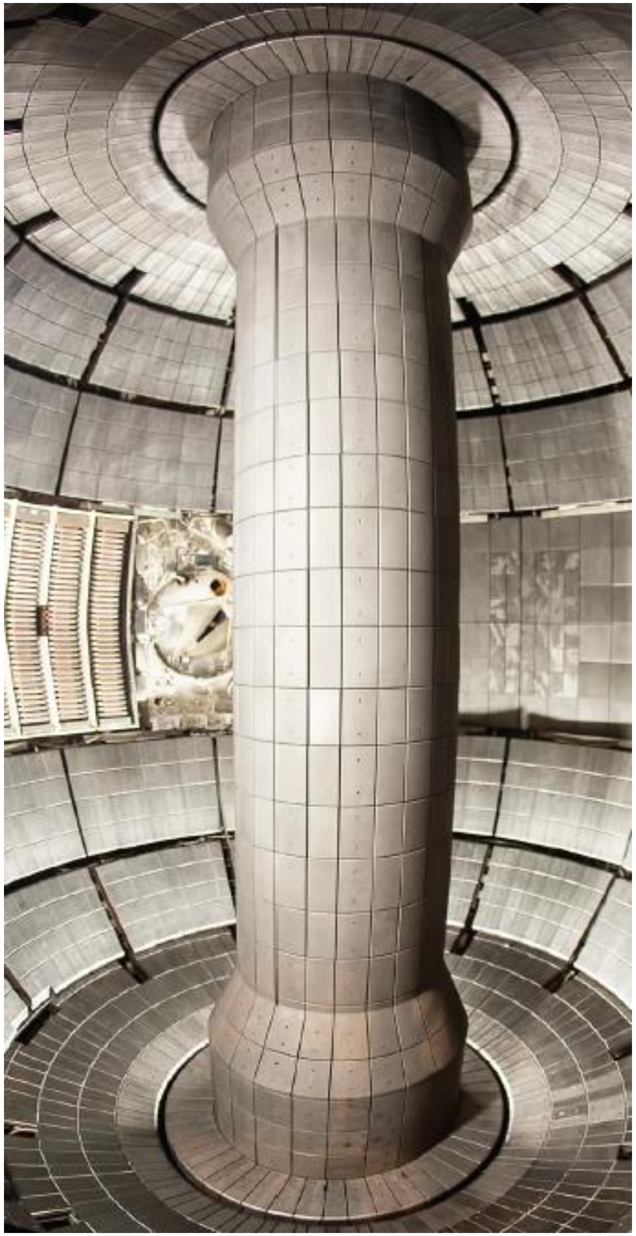
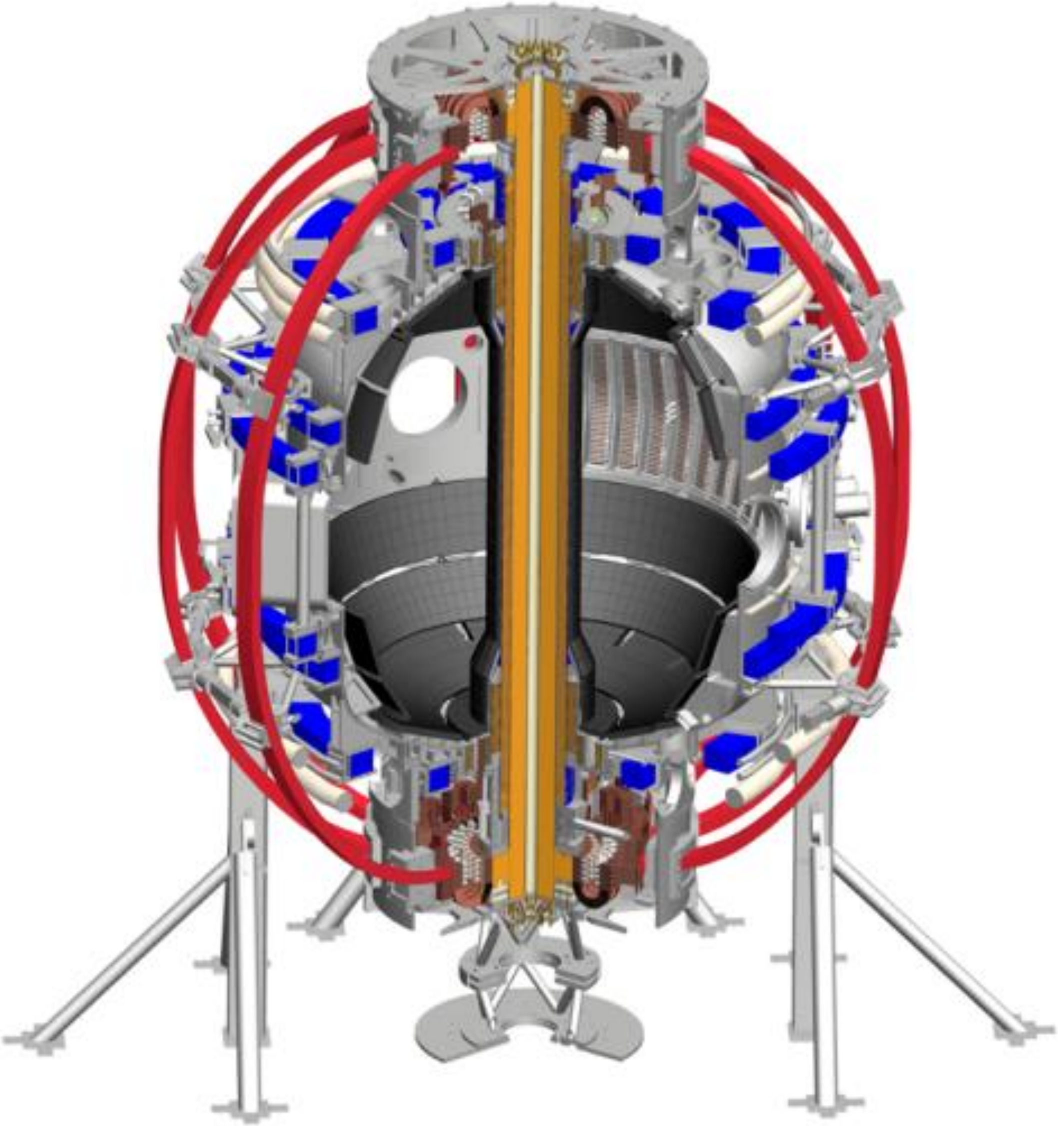
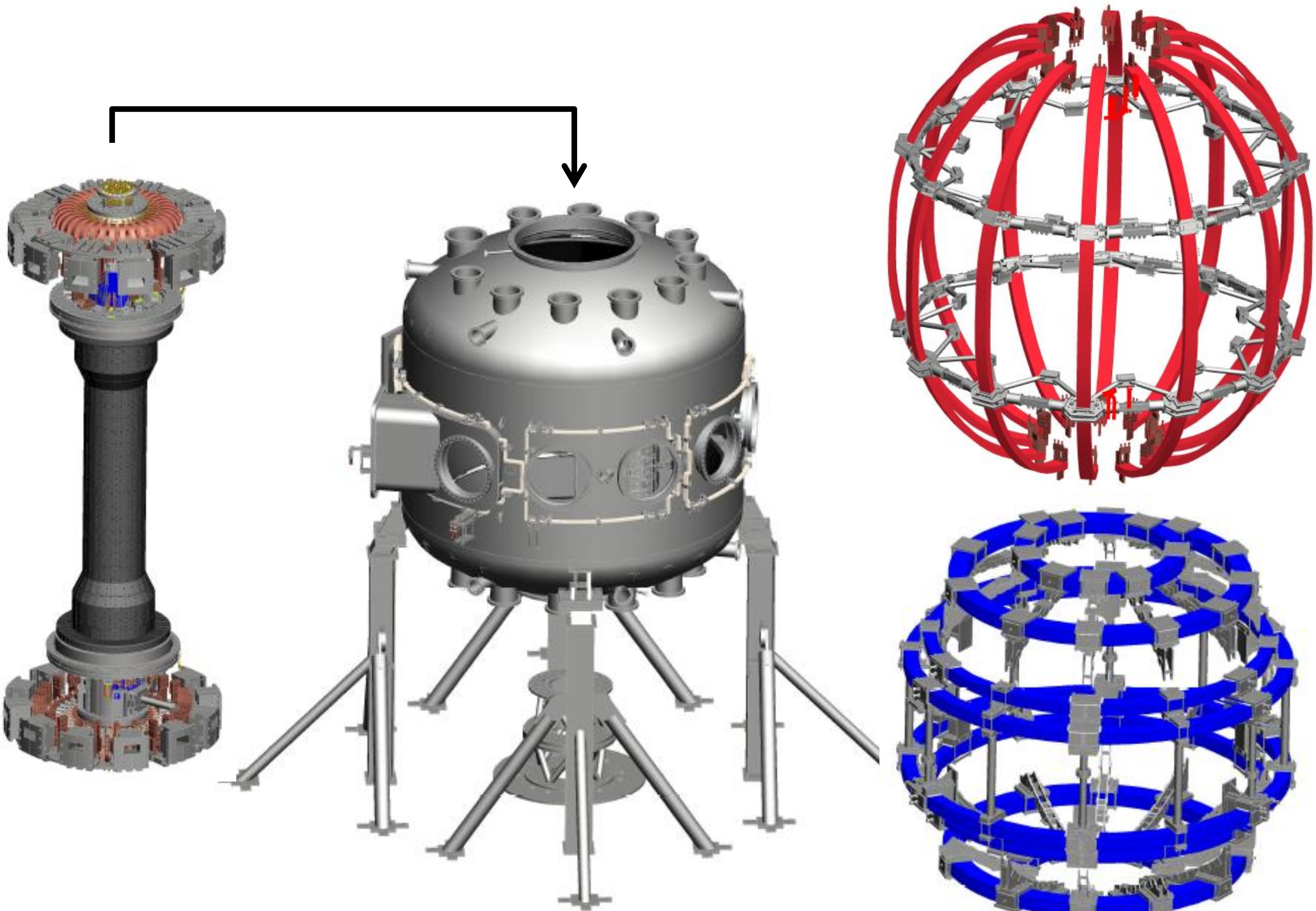




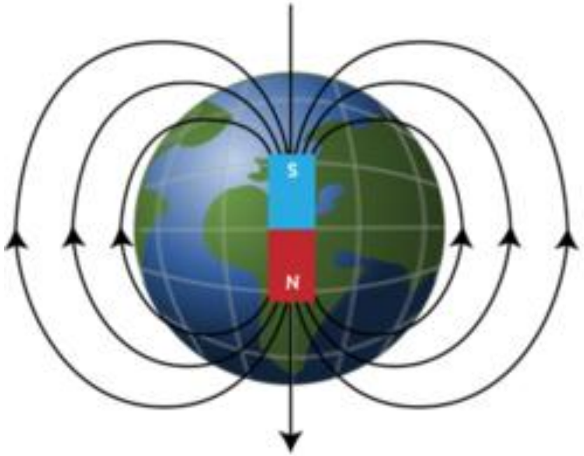


# Secretary of Energy Ernest Moniz, Sen. Cory Booker and Rep. Bonnie Watson Coleman dedicated the NSTX-U project just last Friday!

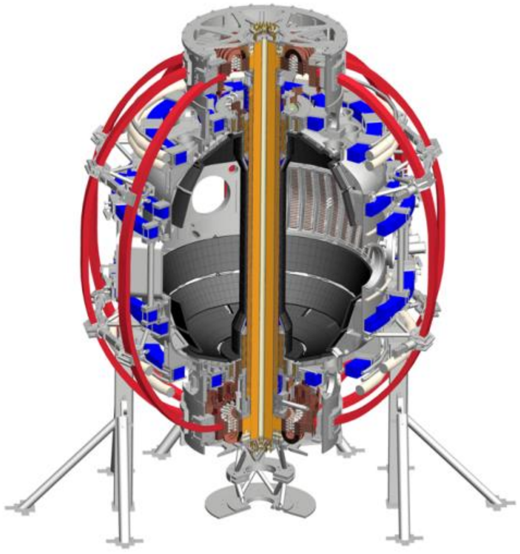

http://www.nj.com/

# Example magnetic fields, measured in units of Tesla [T]

**Earth:**
**0.00005 T**



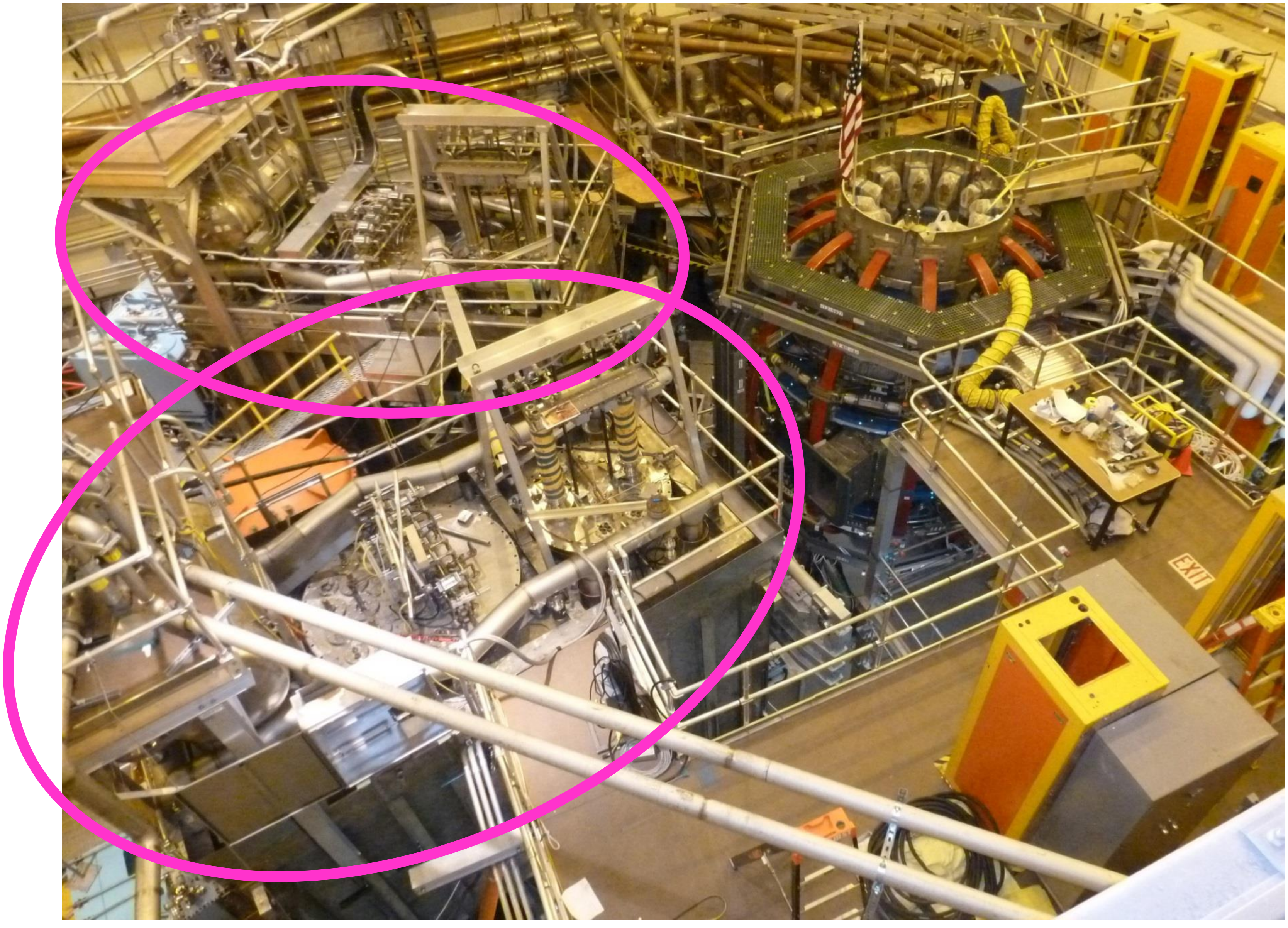

**PPPL's NSTX-U:**
**1 T**



**MRI:**
**0.5-3 T**

# We’ve created a magnetically confined plasma – how do we heat it?

# Mini particle accelerators (Neutral Beam Injectors) are used to heat the plasma



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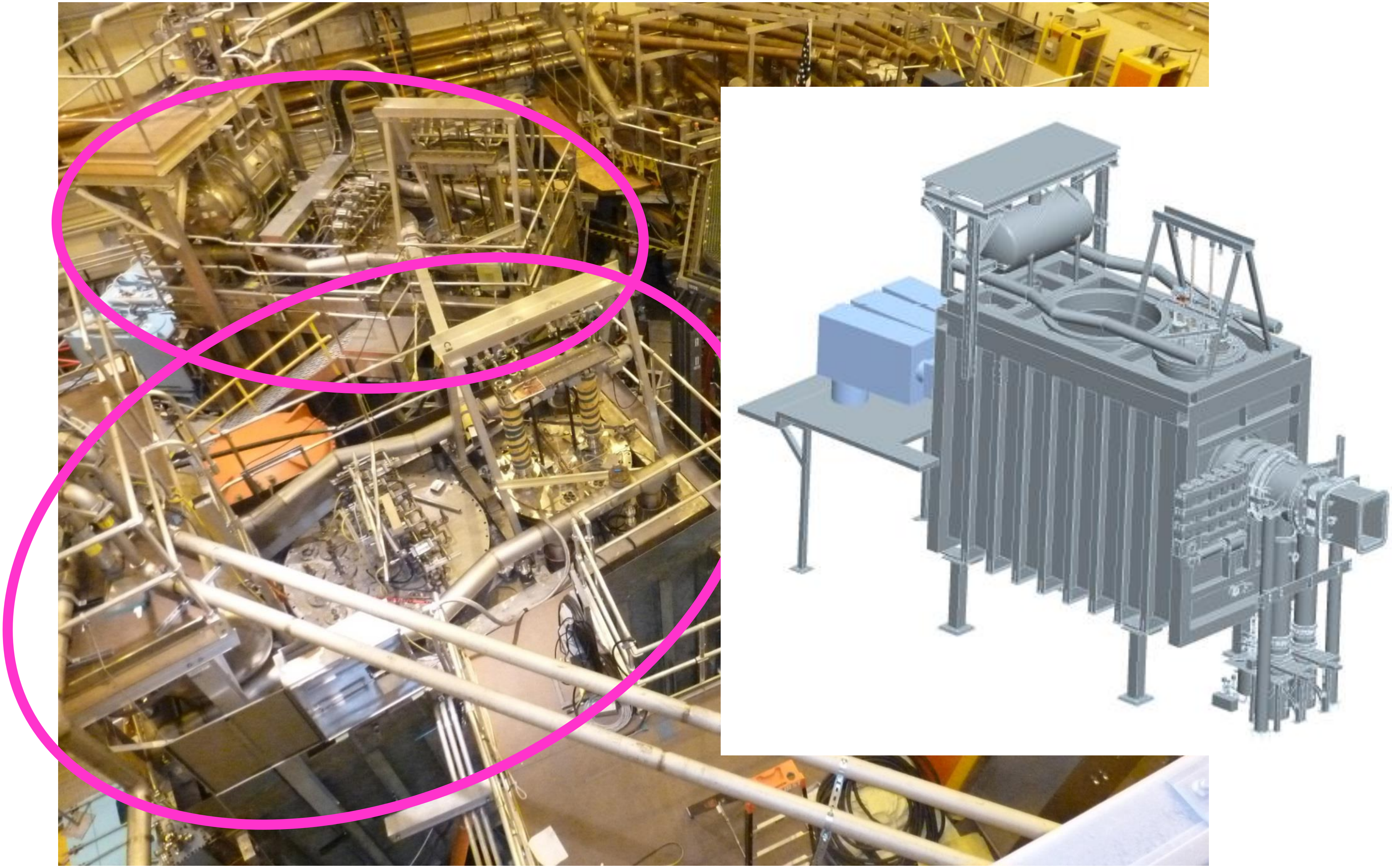
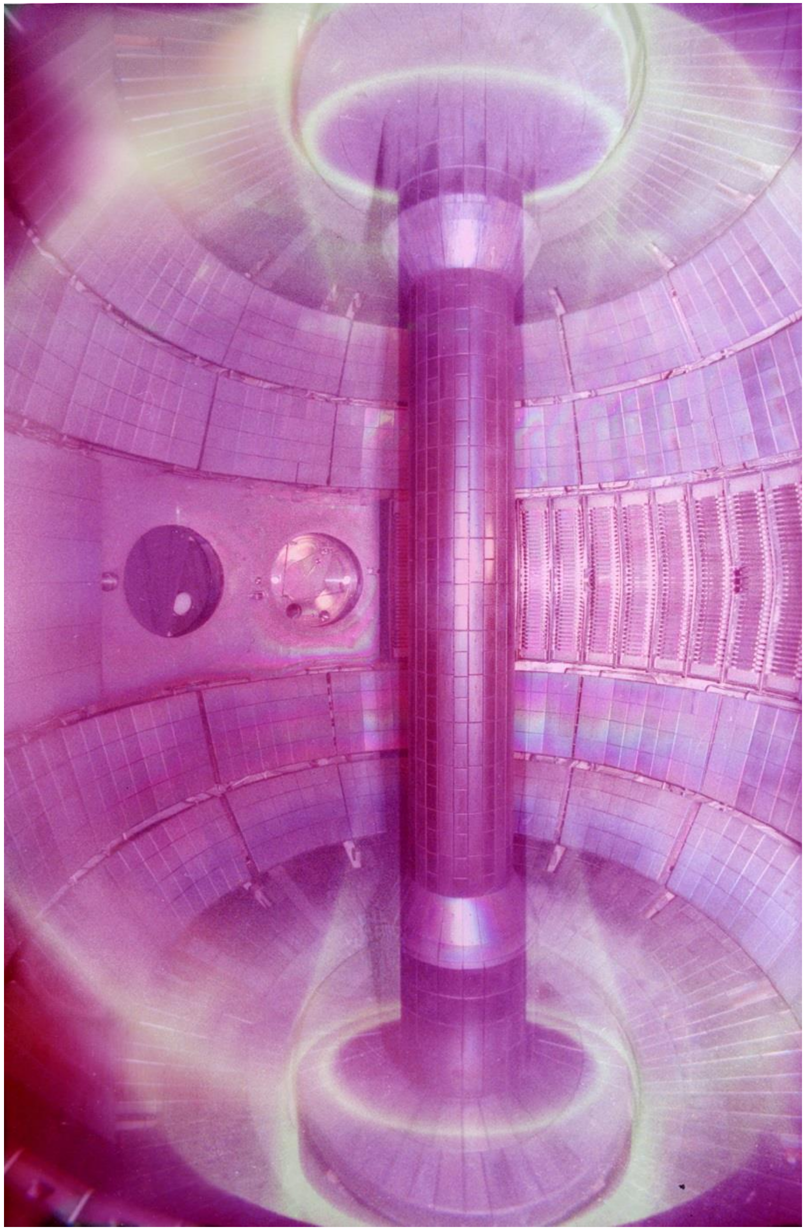


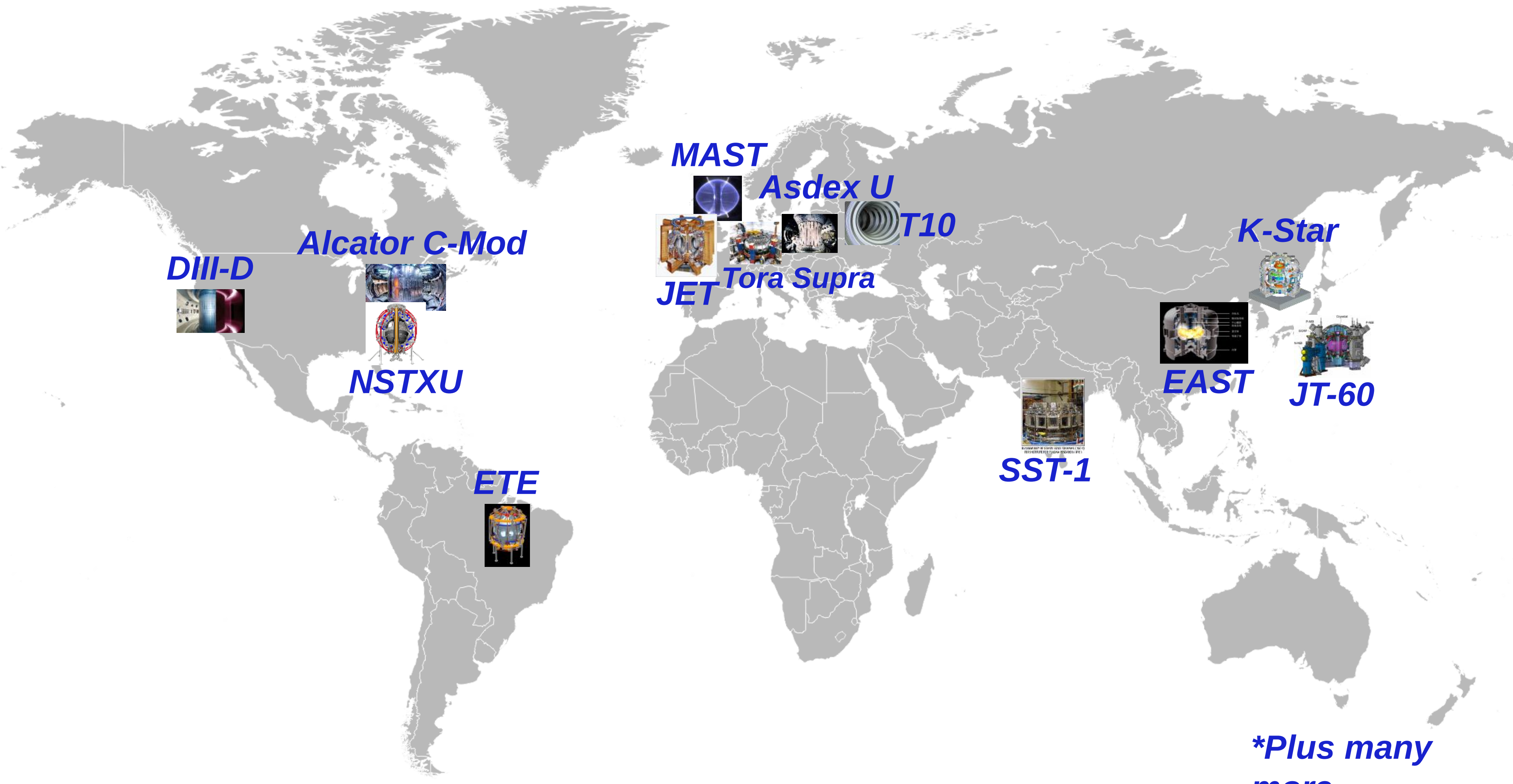
# Microwave heating is also used (works similar to microwave ovens)

RF antenna

# Video of NSTX-U plasma



# There are many tokamaks around the world studying different plasma parameters & shapes

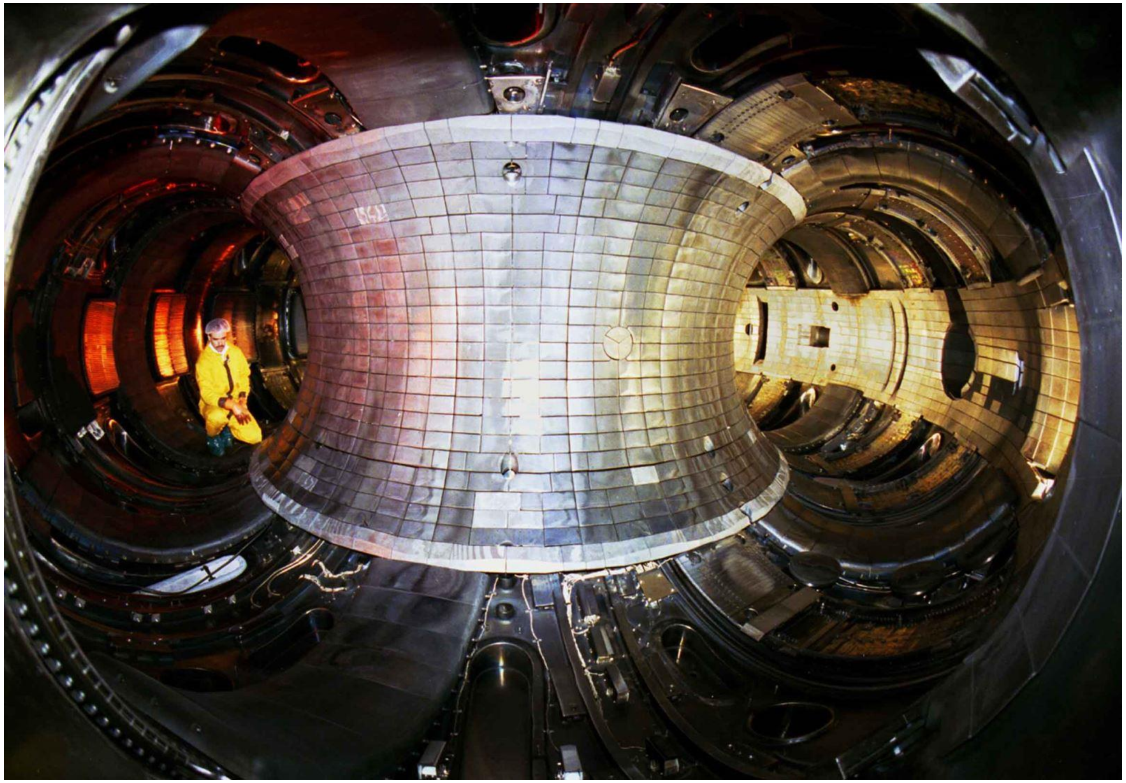


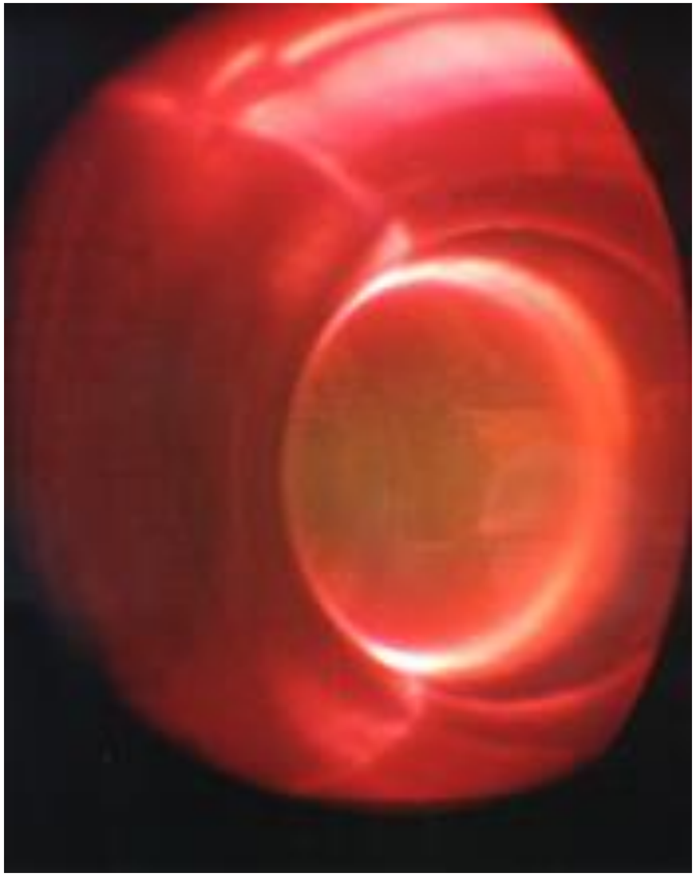

*Plus many more

# Previous experiments have demonstrated sufficient temperatures!

**Tokamak Fusion Test Reactor (PPPL, 1982-1997)**

**Reached 500 million degrees Celsius!**





**10 MW of fusion power using**
**46 MW of heating power**

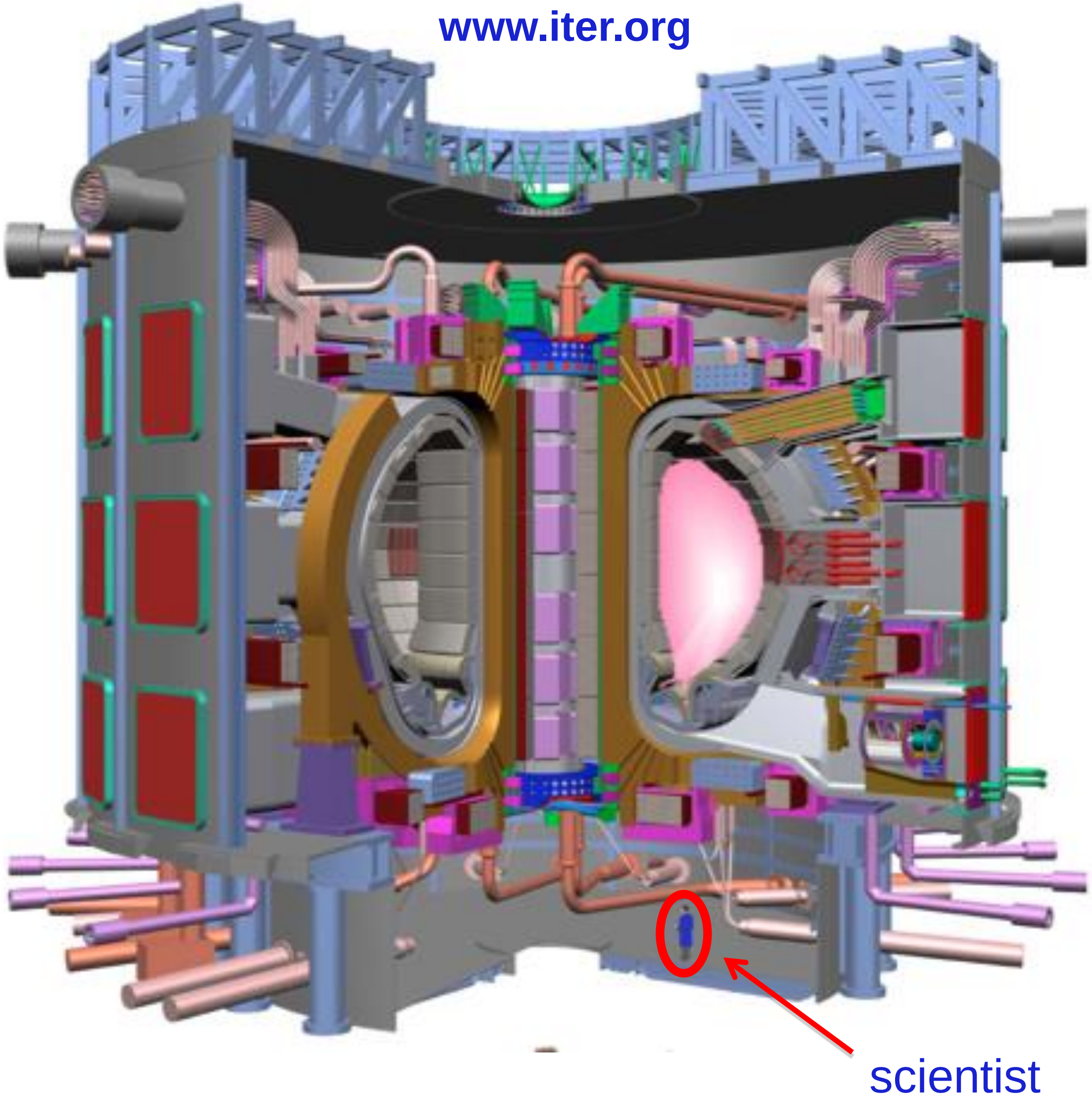
# Next step: ITER is being built to study "burning plasmas"

- **Goal:** 500 MW fusion power using 50 MW heating power

  **→large fusion gain Q = 10**

  <u>Seven partners</u>

  China, EU, India, Japan, Korea, Russia, US



# ITER is being constructed in France, just north of Marseille

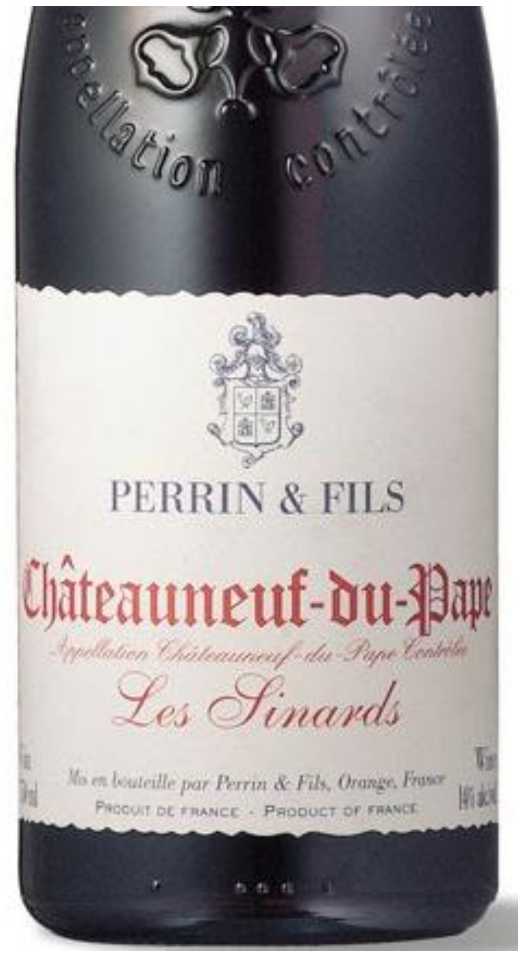

- First plasma ~ 2025
- D-T fusion ~ 2032

~$30 Billion ???

# Government bureaucracy, time delays & large costs leads to much stress

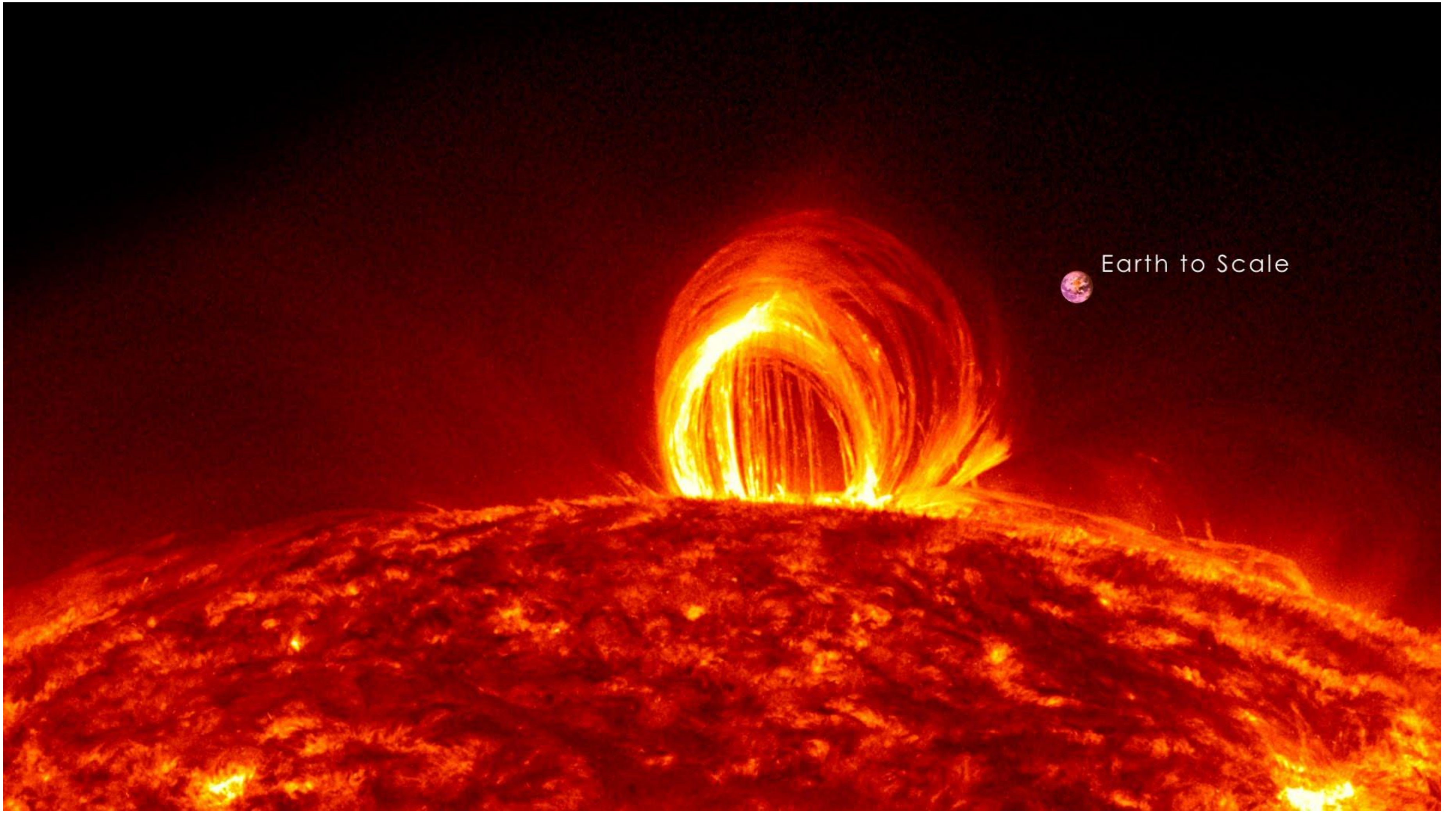
**Thankfully, the lavender is plentiful…**

**and the wine isn't *too* expensive**



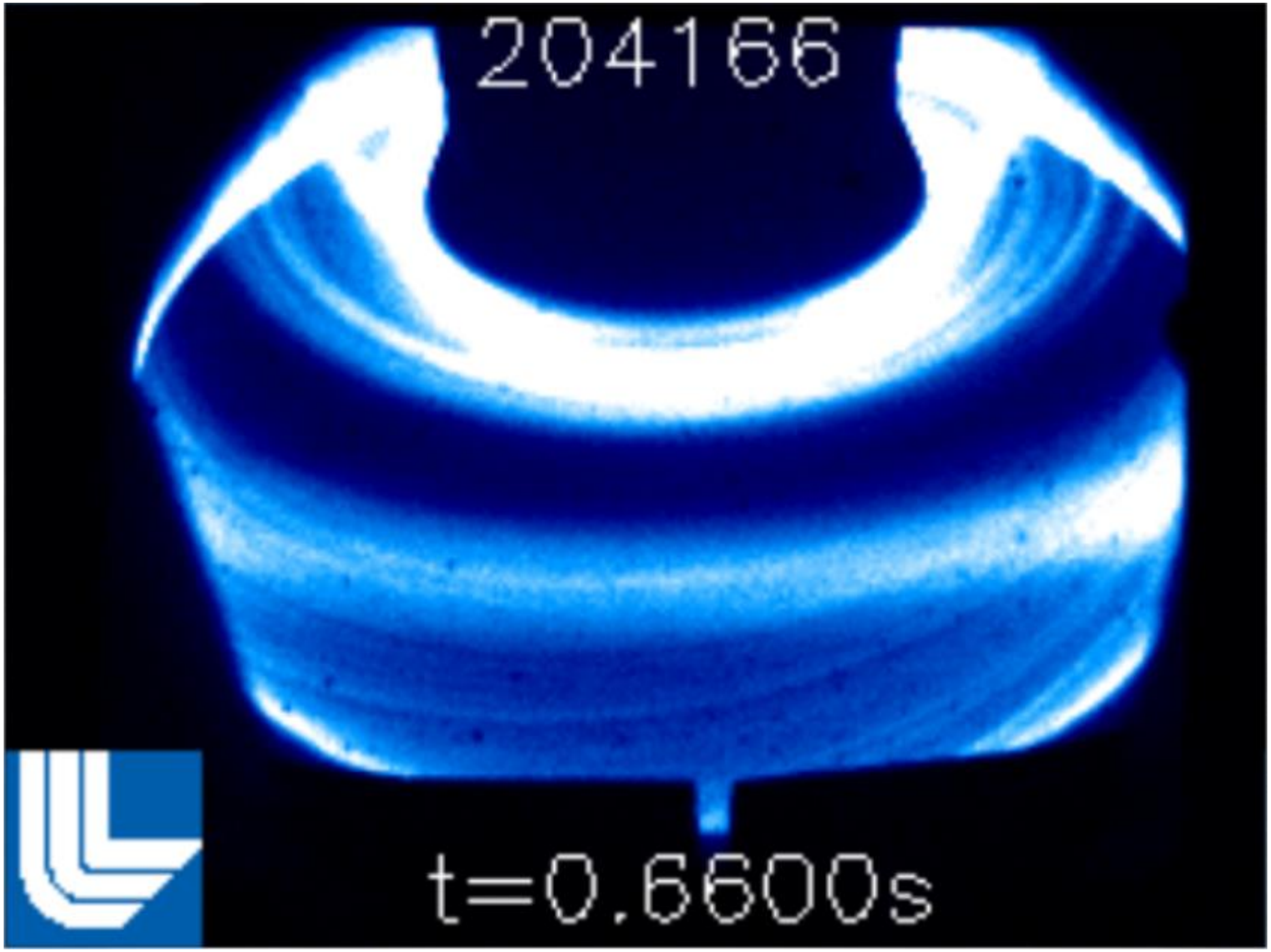
# So why is ITER so big (and expensive)?

# Video of sun

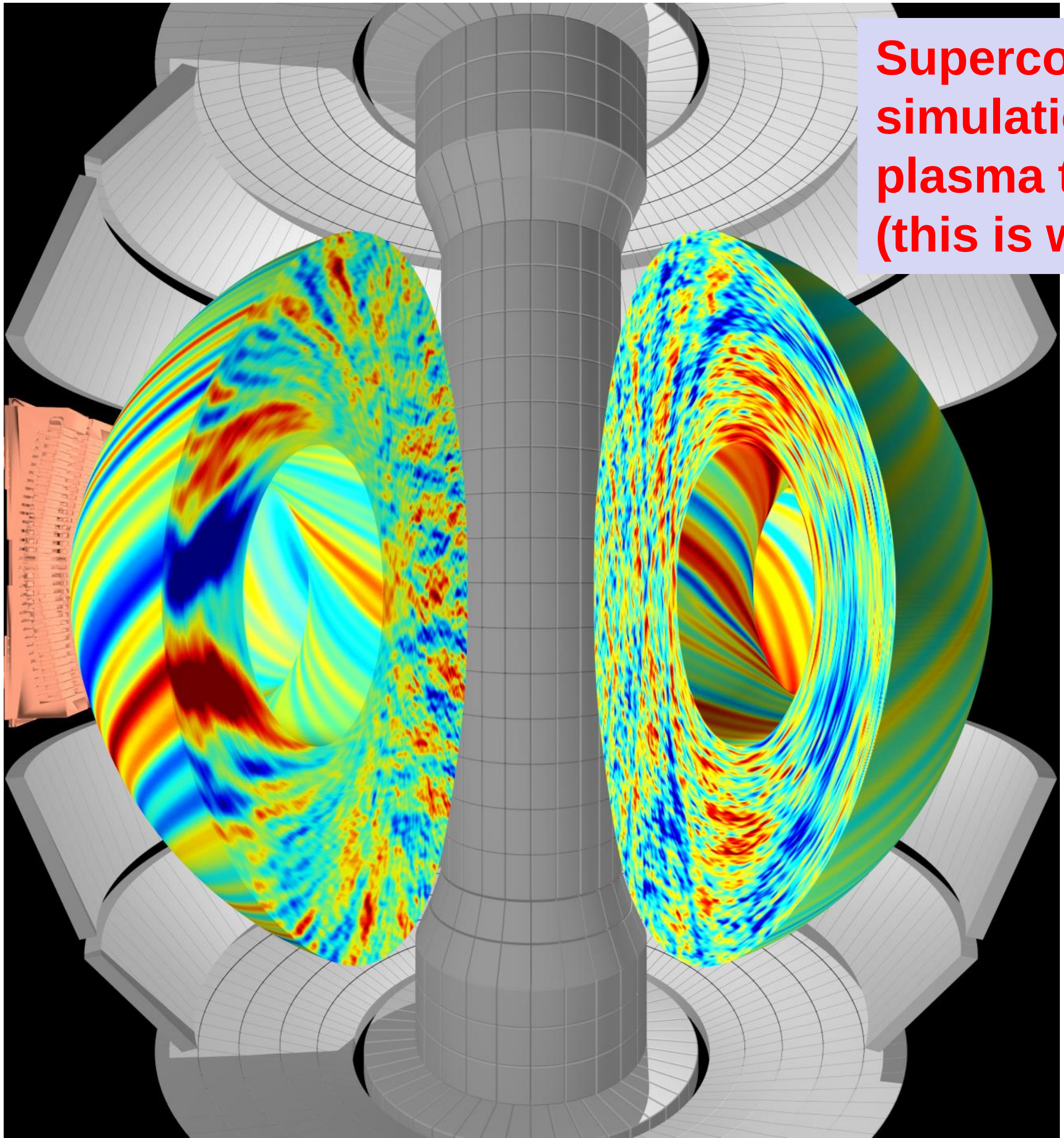



NASA Solar Dynamics Observatory

# Video of NSTX-U

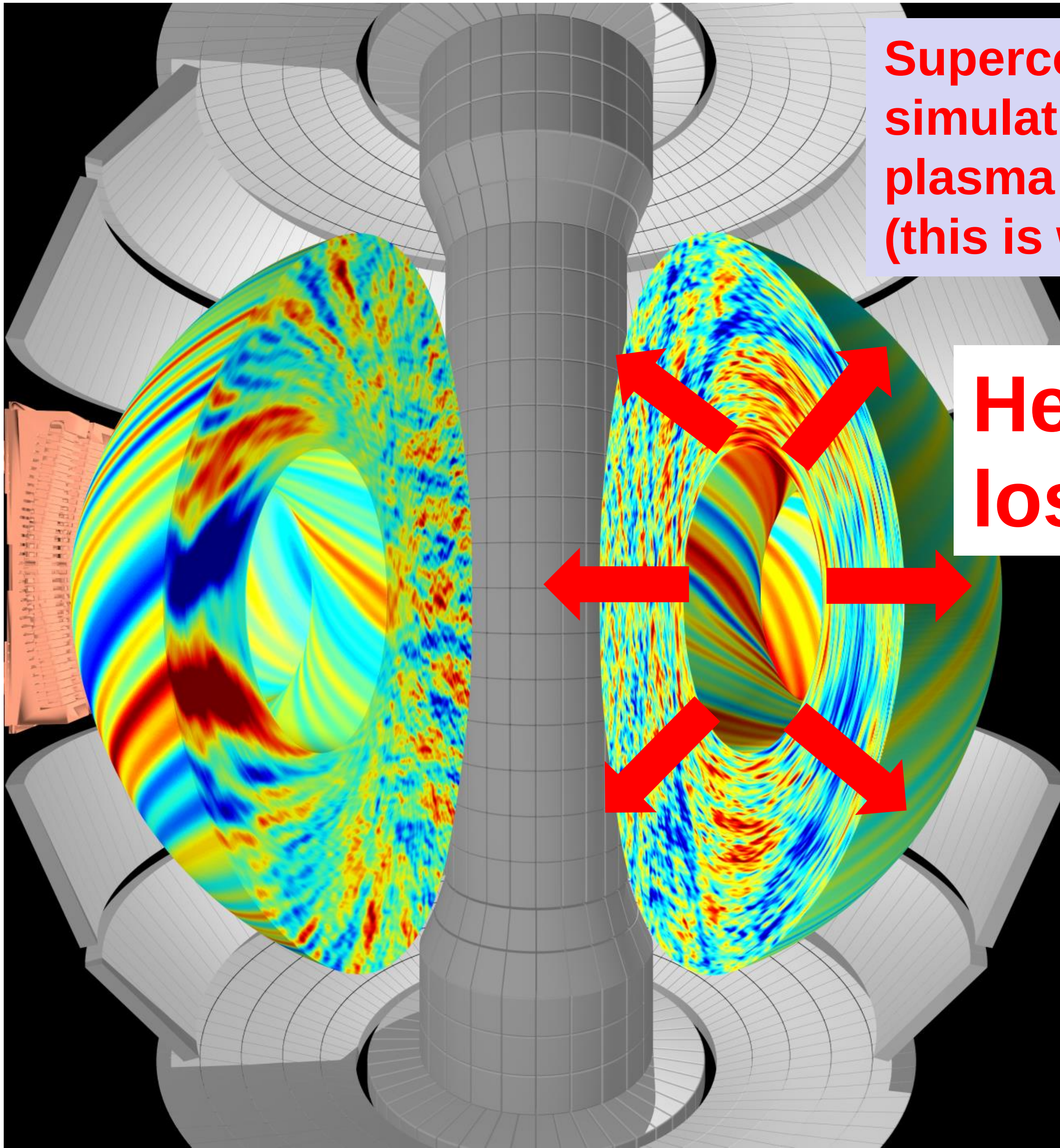


# Turbulence in the plasma is very efficient at taking away the heat



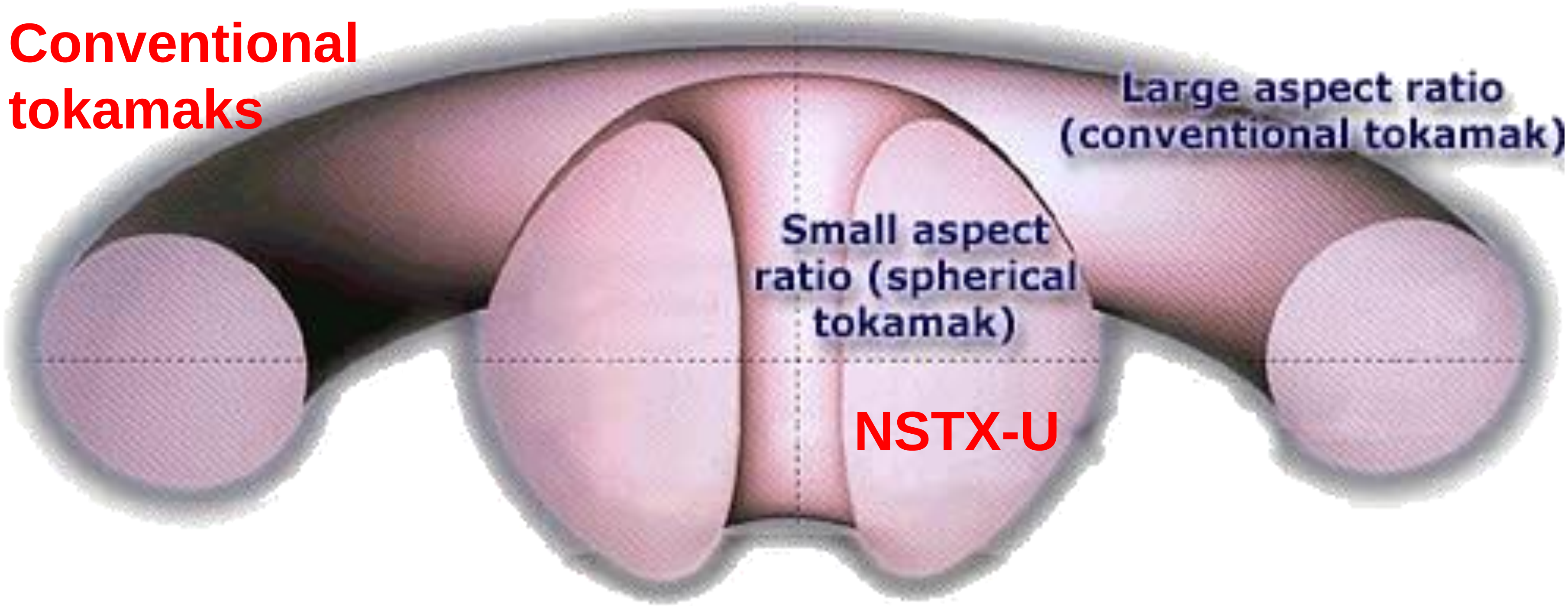
**Supercomputer simulation of plasma turbulence (this is what I do 🙂 )**

# Turbulence in the plasma is very efficient at taking away the heat



# Analogous to convective bubbles when heating a fluid from below … boiling water (before the boiling)

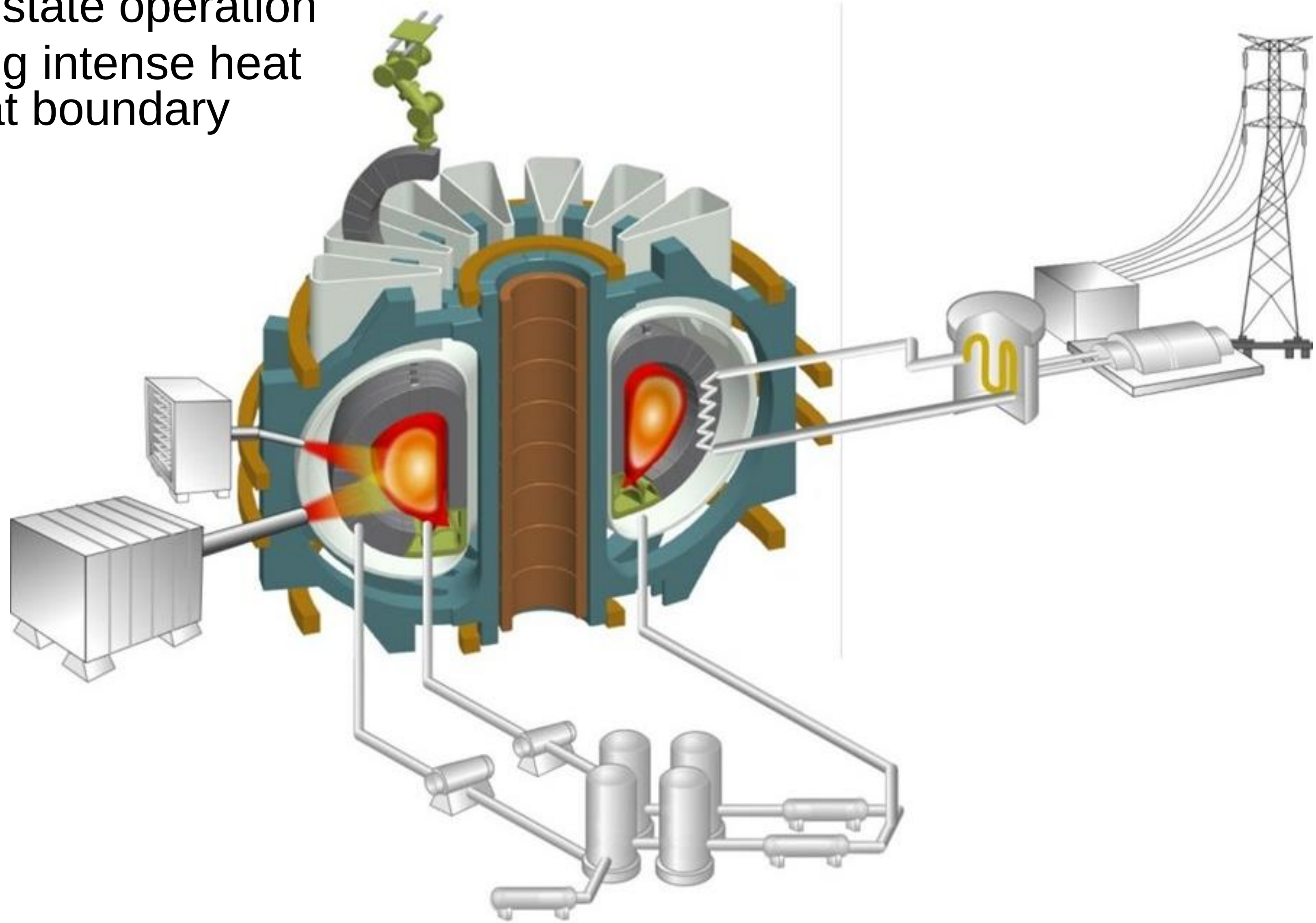
# NSTX-U built to study more compact (spherical) configuration




- **More compact ⇒ cheaper!**

# What problems remain to generate electricity from fusion?

- Steady state operation
- Handling intense heat fluxes at boundary



# Summary

- Nuclear fusion offers a promising solution for clean, global energy demands
- PPPL is studying many aspects of plasma (super-heated gas of charged particles) including magnetic fusion
- More information at **www.pppl.gov**
  - Lab tours are available first and third Friday of every month

# Thank you!