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Fusion Energy

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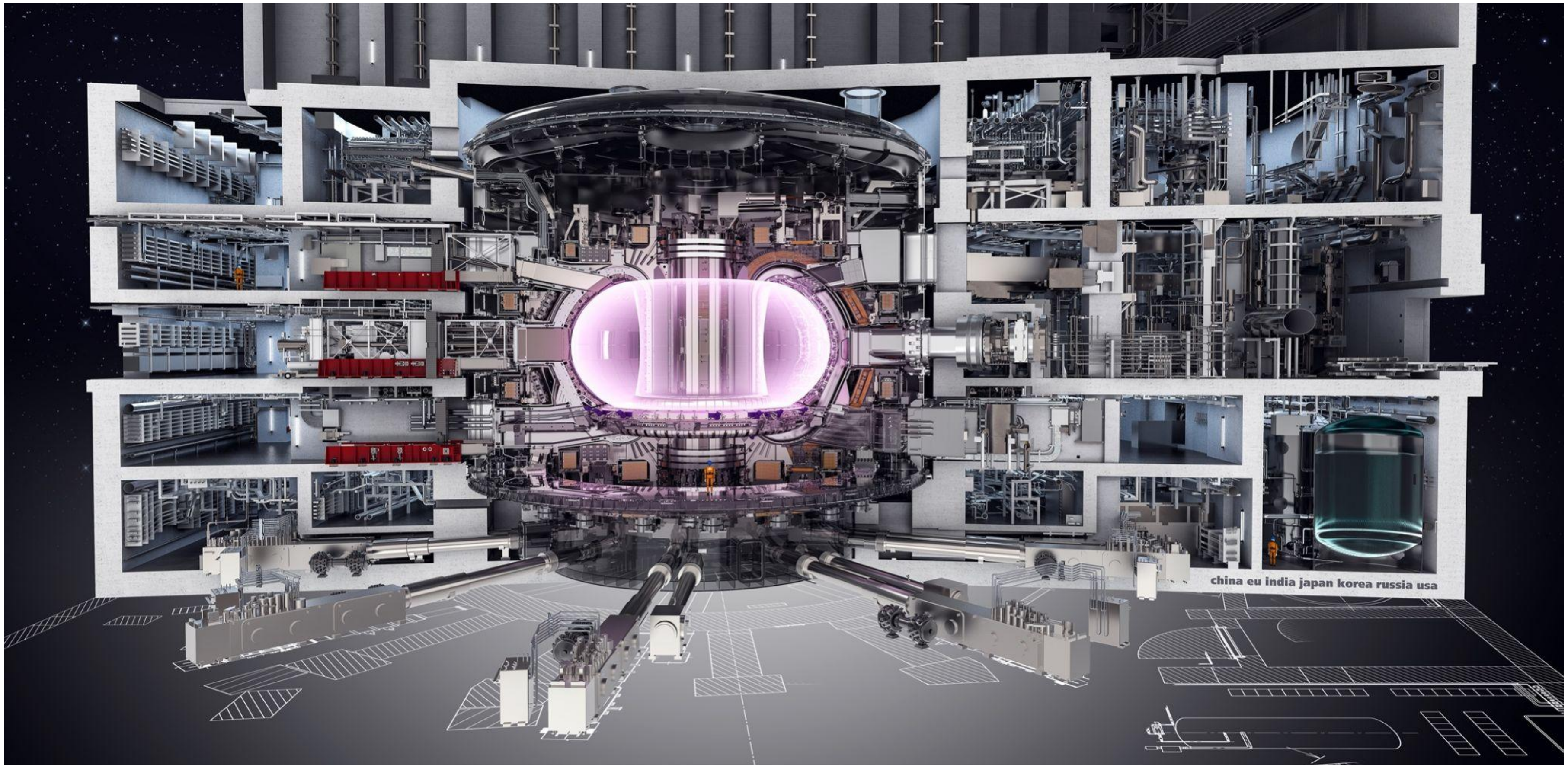
NuSTEAM 2025

Topics

- Fusion Basics
- Challenges
- Tritium

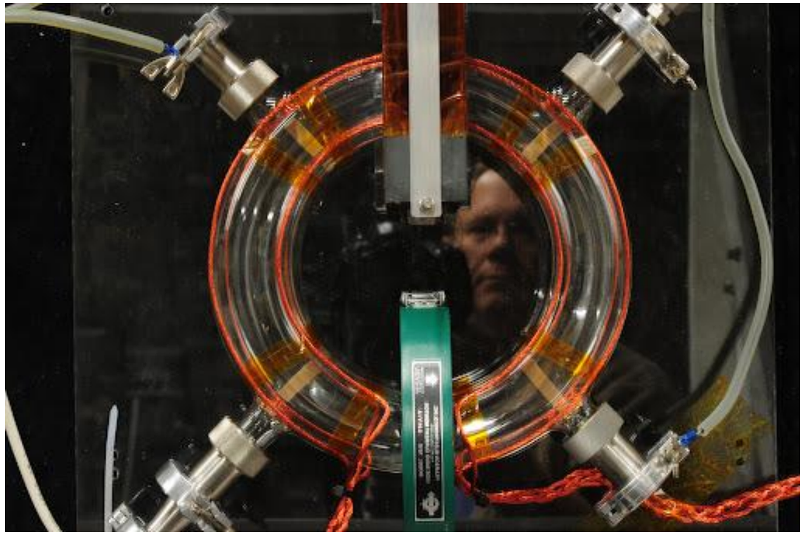


History

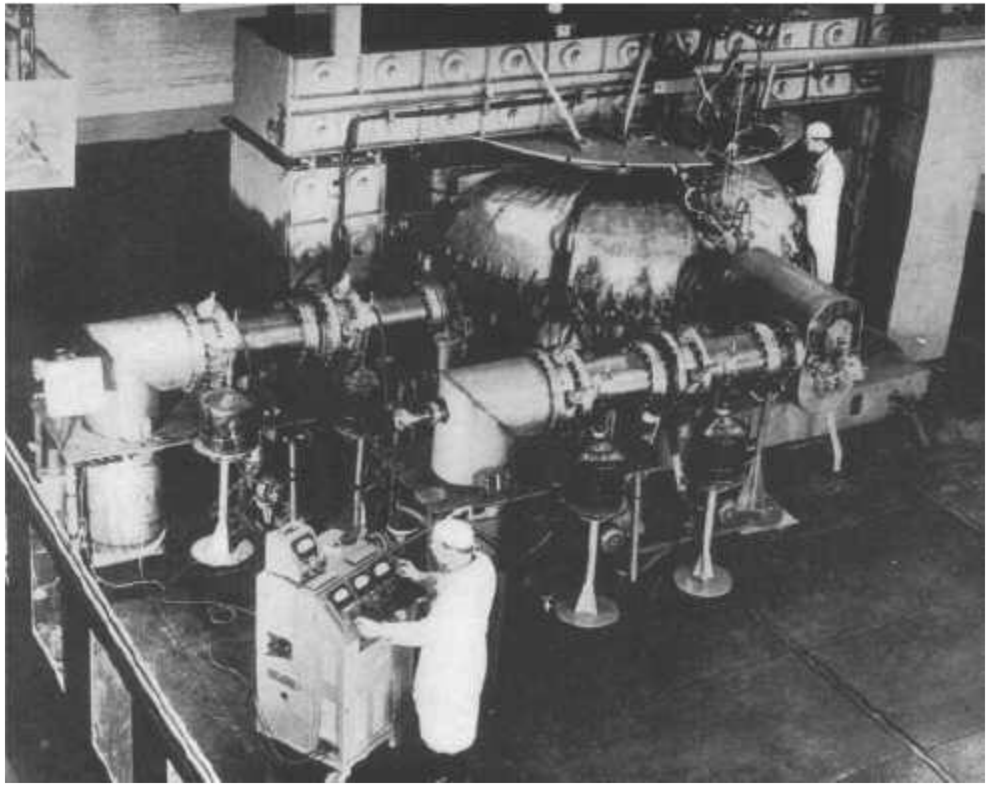
1920 - Arthur Eddington proposes fusion of hydrogen and helium powers the sun

1930s through 1950 - Early accelerator and pinch fusion experiments

1950s - countries declassift their fusion research



> If, indeed, the sub-atomic energy in the stars is being freely used to maintain their great furnaces, it seems to bring a little nearer to fulfilment our dream of controlling this latent power for the well-being of the human race — or for its suicide.
>
> - Sir Arthur Stanley Eddington



History

1960s - First tokamak constructed by Kurchatov Institute

- laser invented in 1960 also used in fusion research

1980s - Europe and US invest more in fusion

- JET in the UK

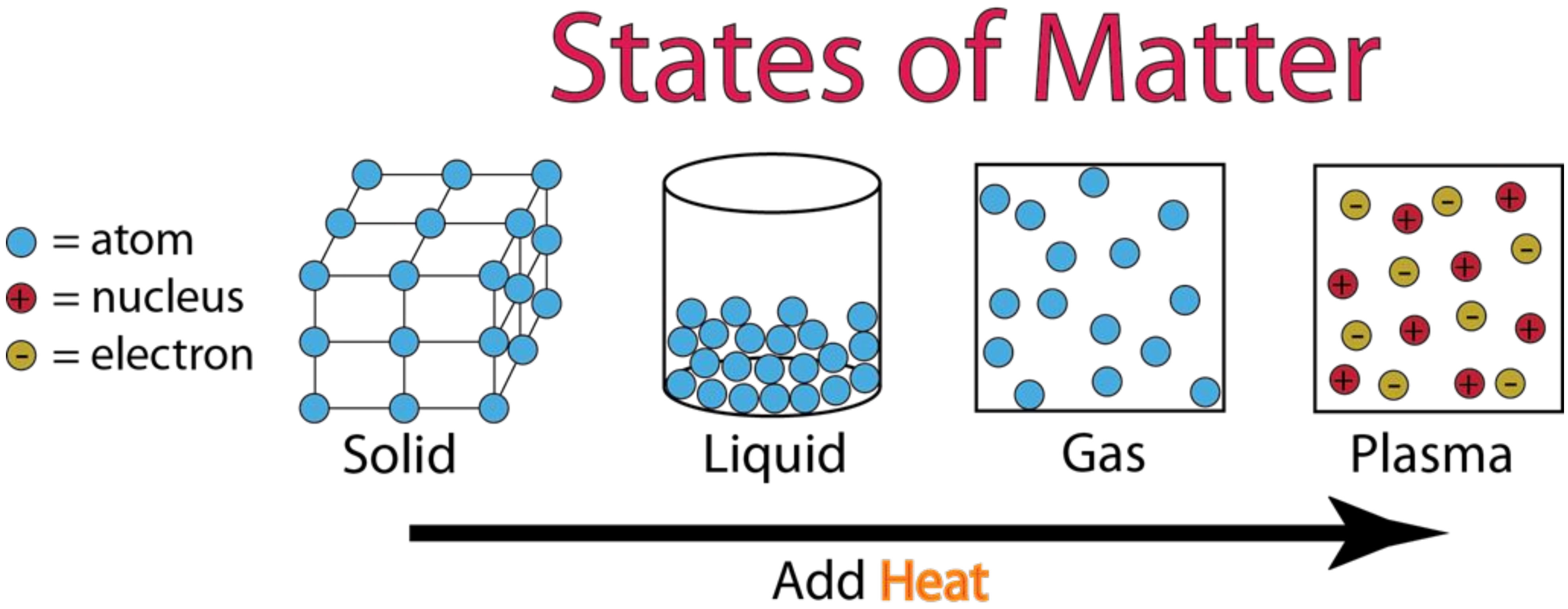
1985 - ITER project agreed to

2010 - ITER Construction Begins

2020 - NIF achieves ‘burning plasma’

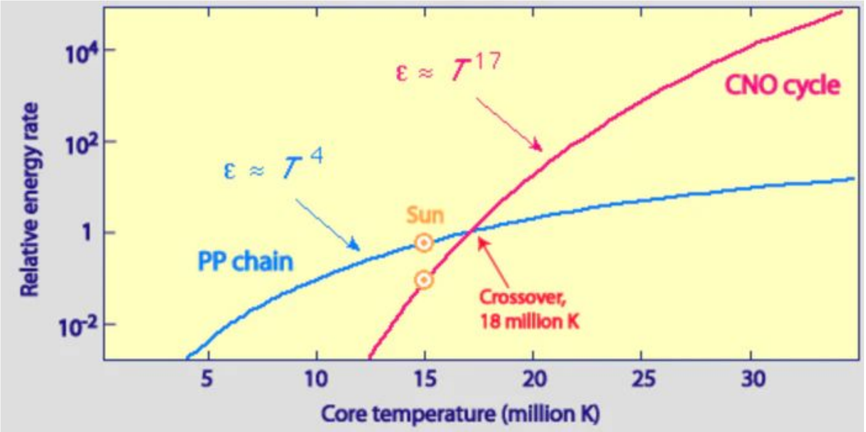
Fusion Basics

Where does fusion start? We need Plasma



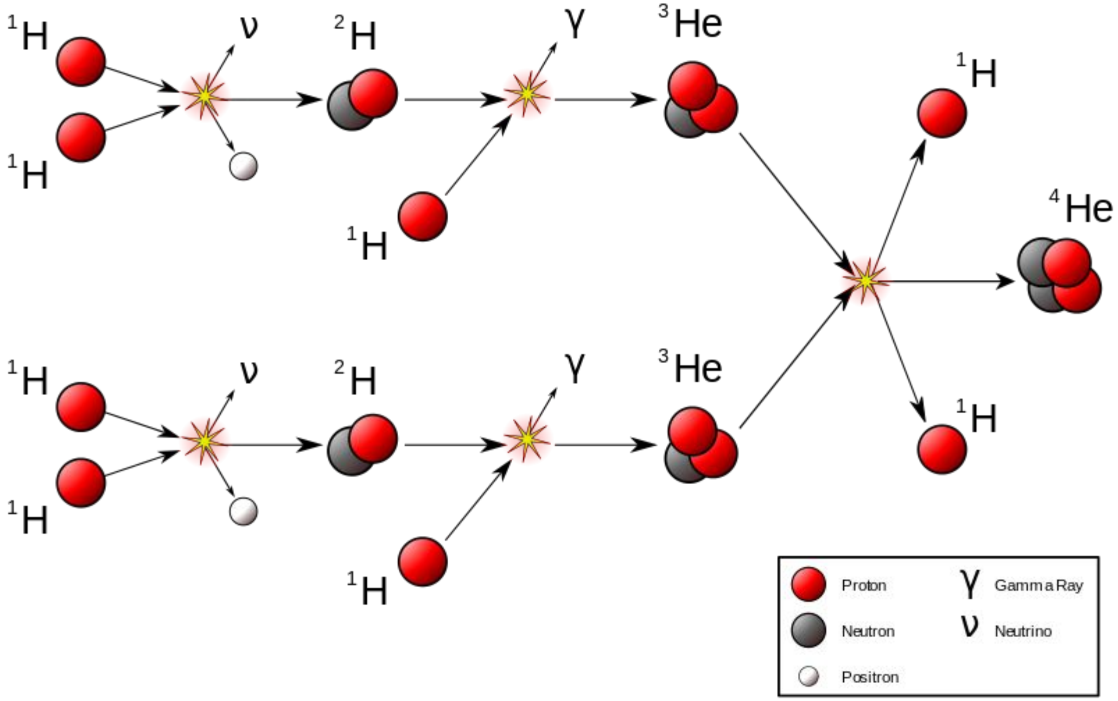
Fusion

- Fundamentally we just need to overcome the electrostatic force between similarly charged particles



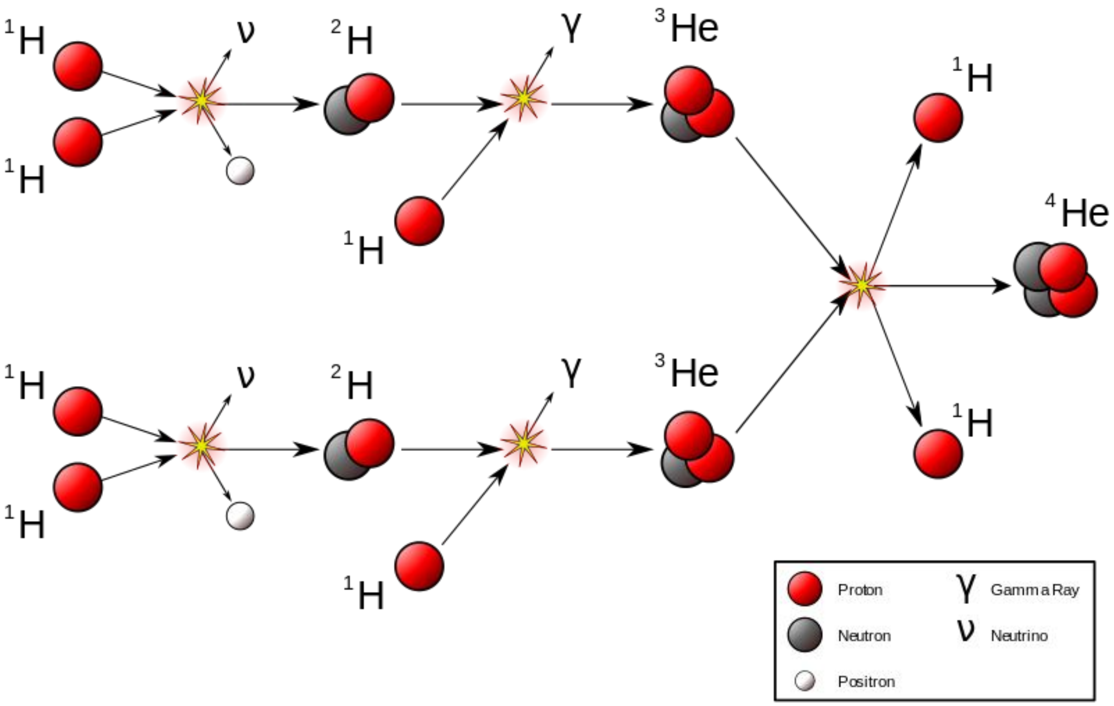
Fusion in Stars

- Primarily P-P interactions
- Hydrogen fusion begins around 10^7 K

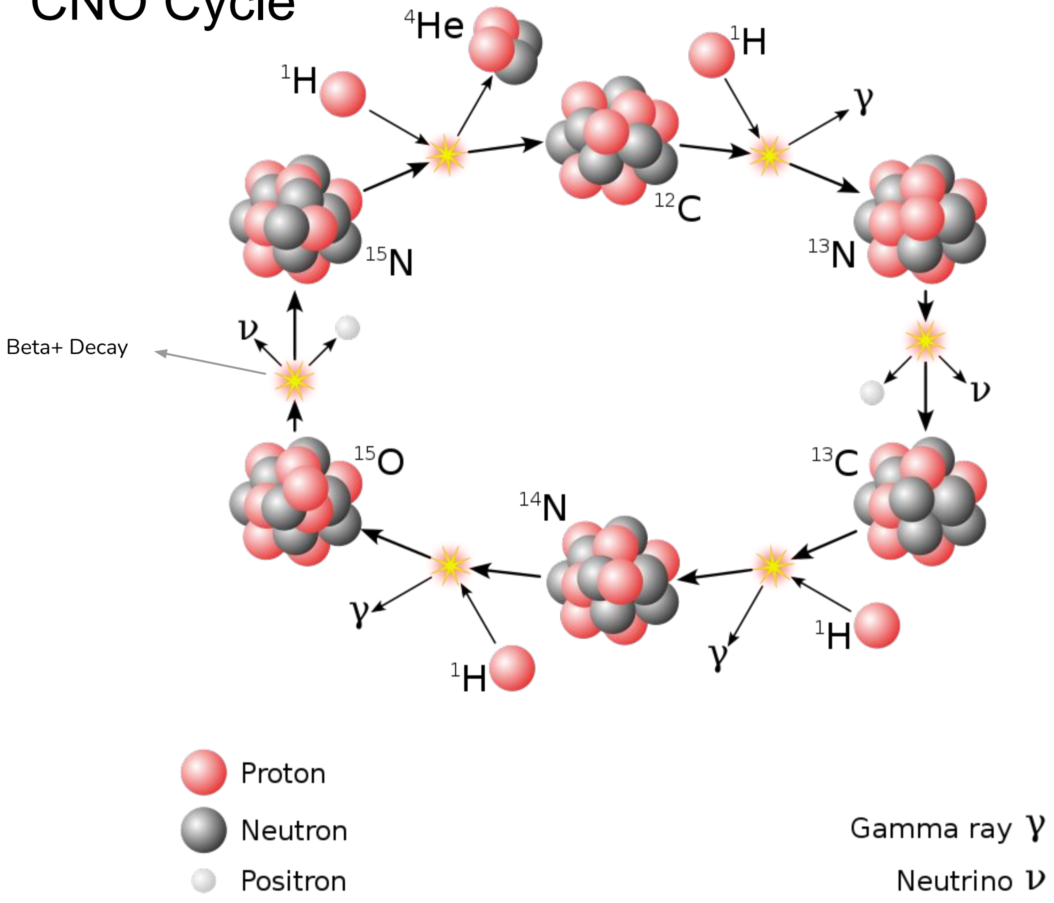


Fusion in Stars

- Proton - Proton Chain



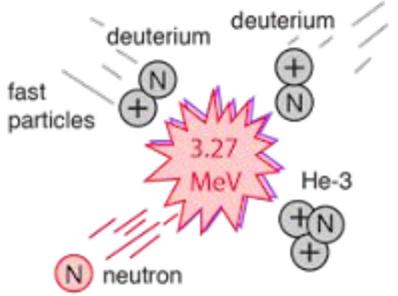
- CNO Cycle



Fusion on Earth

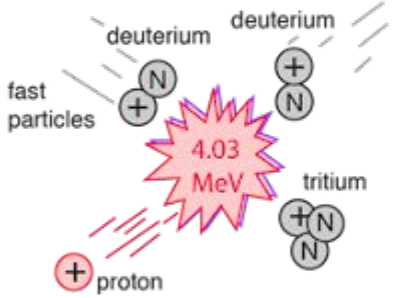
- WAY hotter - 15 x 10^8
- Mostly Deuterium-Tritium reactions
  - DT fusion has been found to be the most efficient reaction
  - related to the reaction speeds achievable
- Deuterium is stable and very common
  - harvested from seawater
  - 33g of deuterium / m^3 of sea water
- Tritium decays and must be produced through difficult means
  - half-life of 12.32 years

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + ^{1}_{0}n + 3.27MeV$$



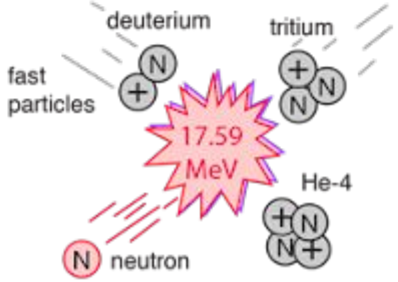
Deuterium-deuterium Fusion

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{1}H + ^{1}_{1}H + 4.03MeV$$



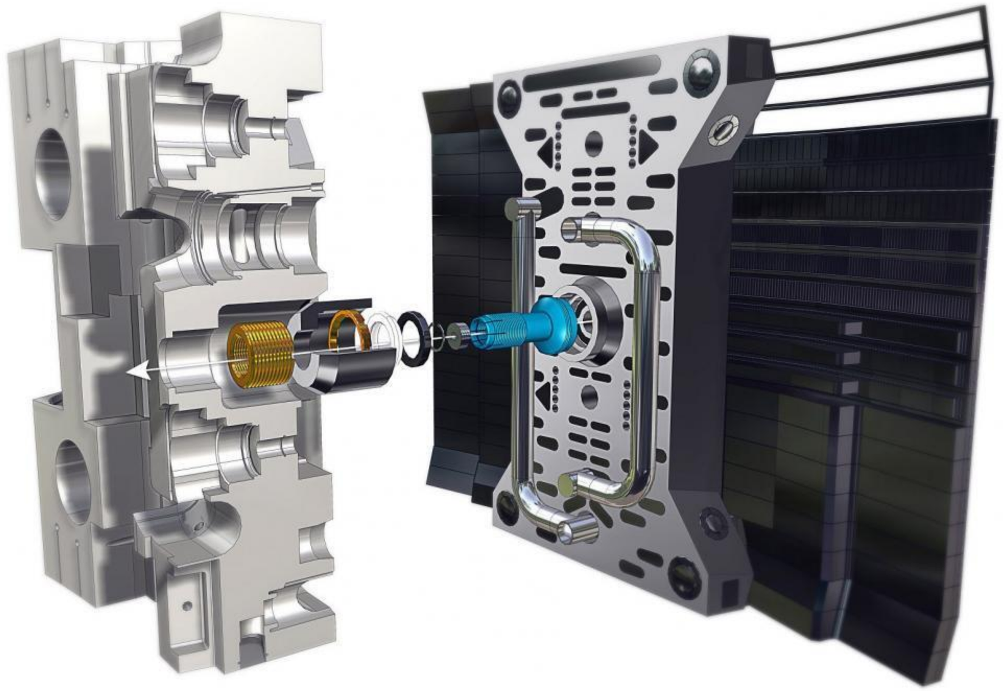
$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + 17.59MeV$$

Deuterium-tritium Fusion



Blanket Modules

- High energy neutrons are ejected from the plasma
- “Blanket”s will capture and protect the vacuum vessel



Containment Blanket

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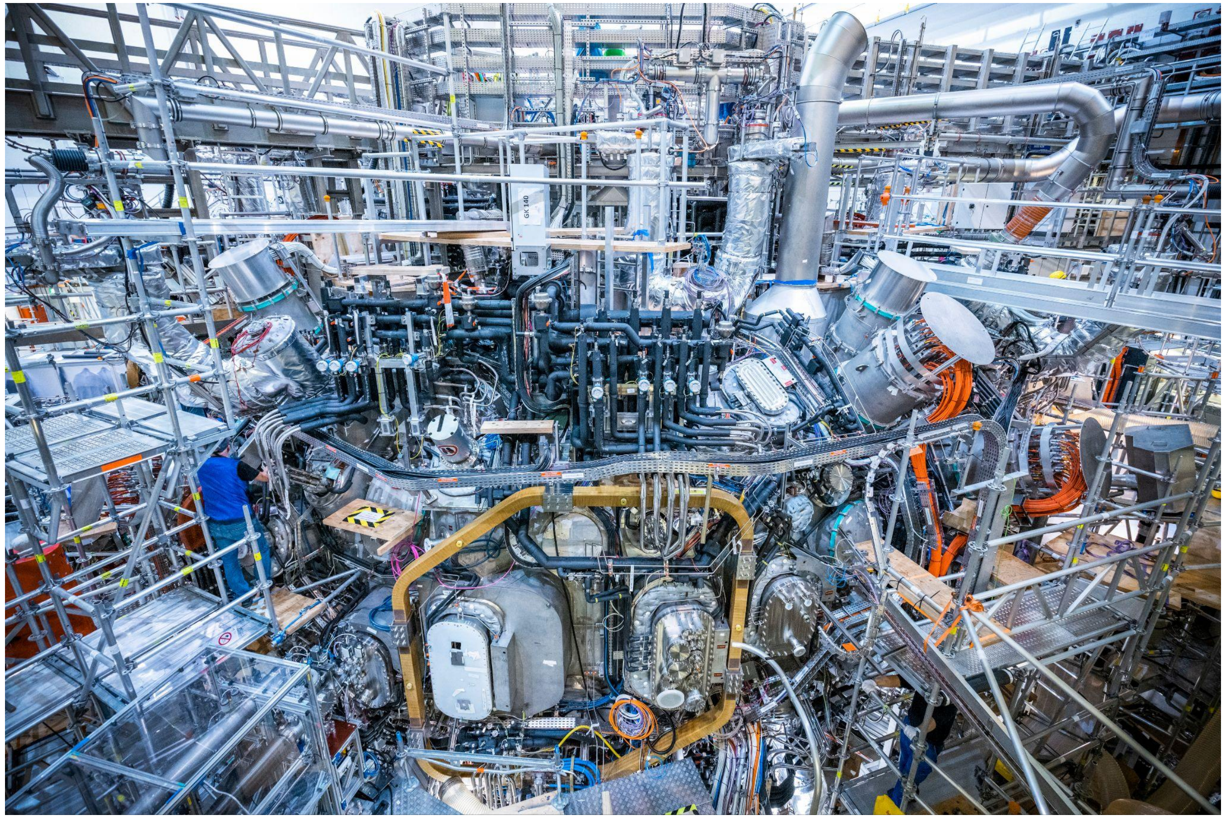
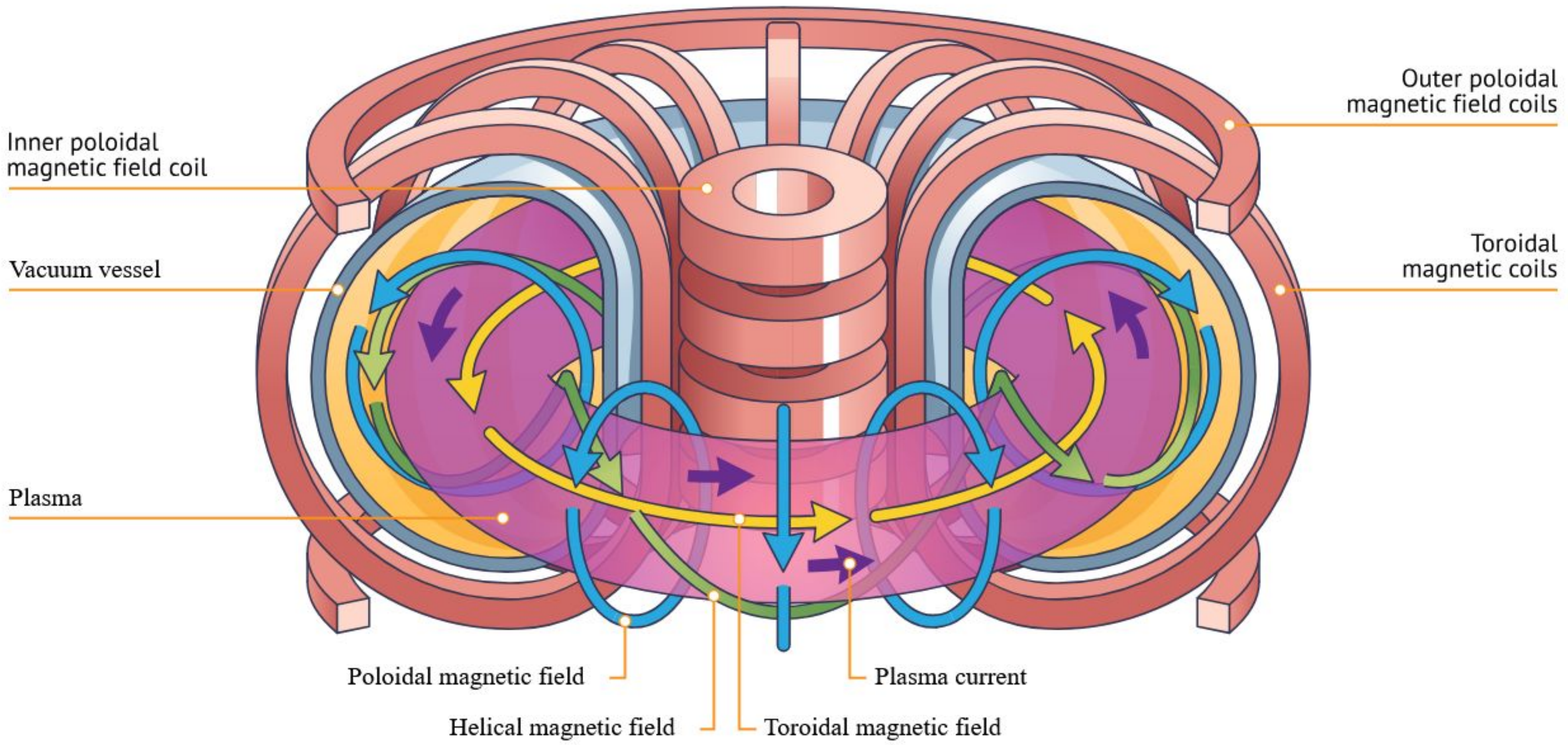
Magnetic Confinement

The process of containing plasma required for fusion - several approaches

- Tokamak
- Spherical tokamak
  - same principle as tokamak but smaller volume of plasma and easier to control
- Stellarators
  - twists plasma to reduce plasma leak
  - very complex to build



TOKAMAK



- Plasma confined by three magnets
  - trying to stop plasma from hitting the walls
- Energy is produced in the form of heat when neutrons come into contact with the containment walls

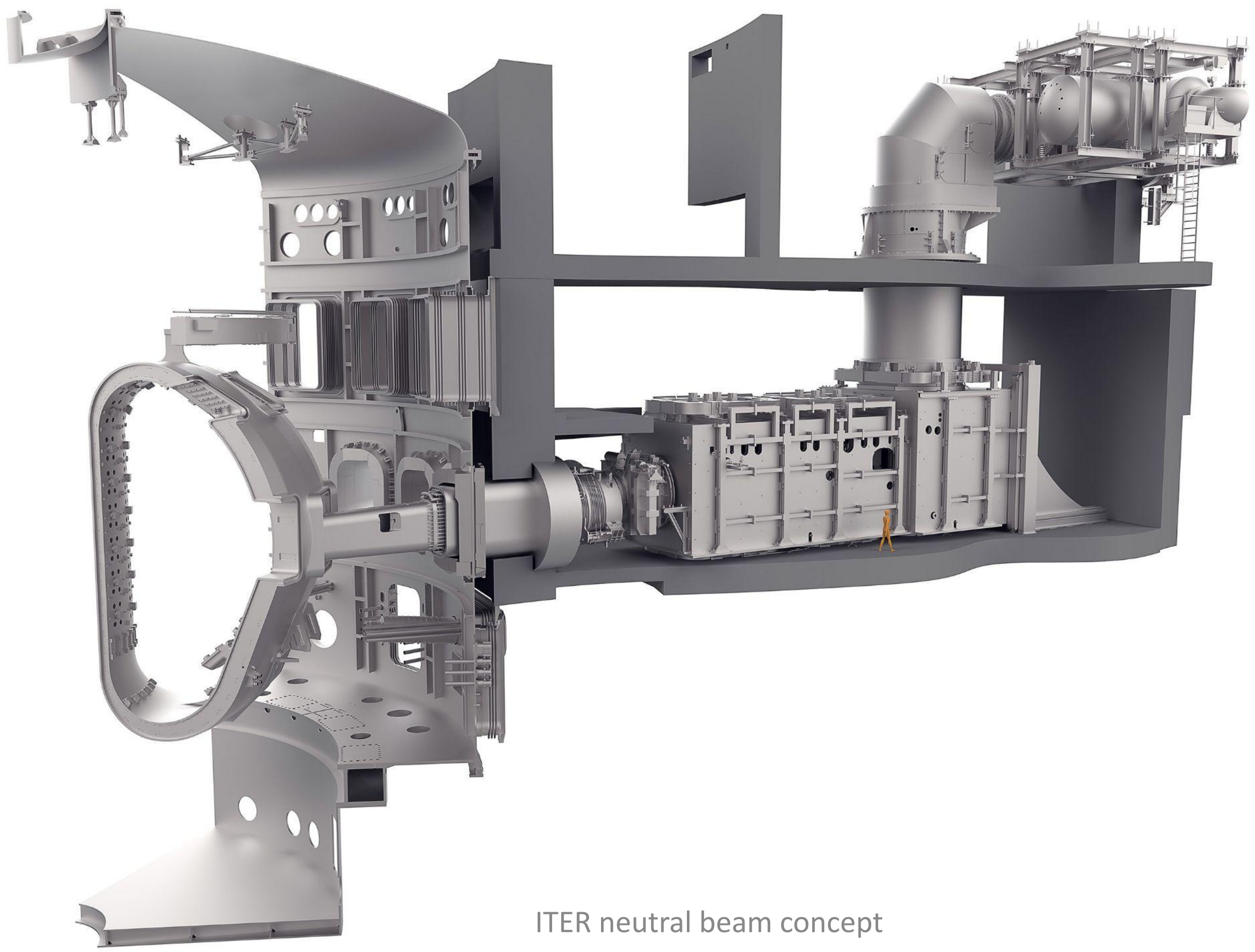
Fusion Challenges

Heating a Fusion experiment

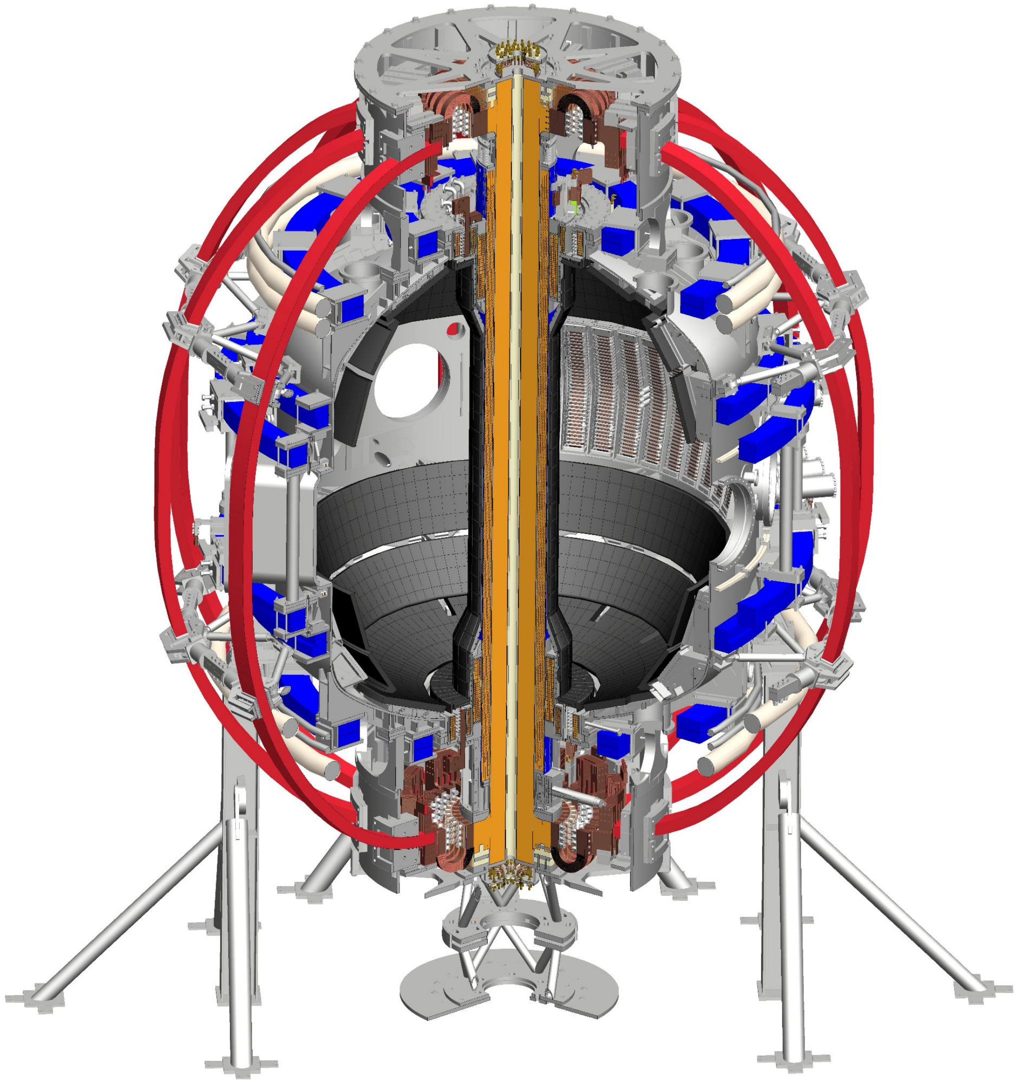
- Difficult to 'ignite' plasma
- Difficult to maintain temperatures upwards of 15 x 10^8 K

Major Factors

1. Ohmic Heating
   a. runs current through the plasma generating heat through resistance
2. Neutral Beam Heating
   a. a linear accelerator strapped to a fusion reactor
3. Burning Plasma
   a. Self heating fusion reaction



ITER neutral beam concept



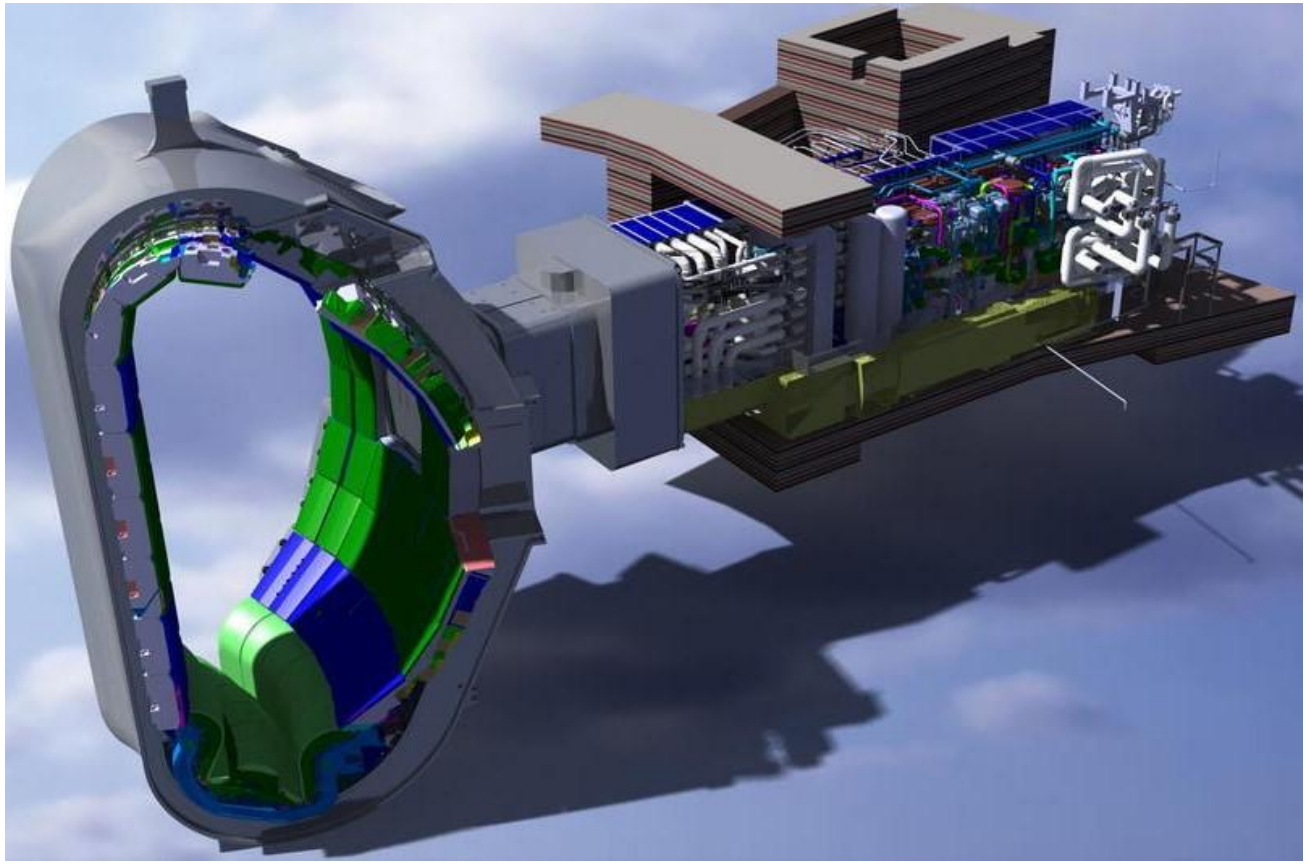
Spherical Tokamak

Other Difficulties

- General materials science
  - superconducting magnets, other rare or difficult to make materials
- Costs
  - Not only are massive experiments expensive, they often go over budget
- Damage
  - Production of neutrons and tritium will damage materials inside the reactor

Tritium

- Tritium is a finite resource
- Major focus of fusion research is to produce tritium during the fusion reaction



Tritium Blanket Breeder Concept

Most tritium now is produced by CANDU (Canada Deuterium Uradium) reactors

~20 kilograms / year

Major focus of ITER is to test tritium breeding 'modules' to produce tritium during fusion reactions using the interaction between lithium and a neutron

Tritium Breeding

- The process aims to sustain a breeding rate of >1
- ITER will never self sustain Tritium but test solutions through TBMs
  - will test various methods of producing tritium

TB Basics

- Lithium in reactor blanket
- neutrons strike lithium

$$^{6}Li + {}^{1}n \rightarrow {}^{4}He + T$$

Questions?

Conclusion

Experiments

ITER

- Construction began in 2010
- Hugely Collabroative
  - US-ITER just finished constructing the central solenoid

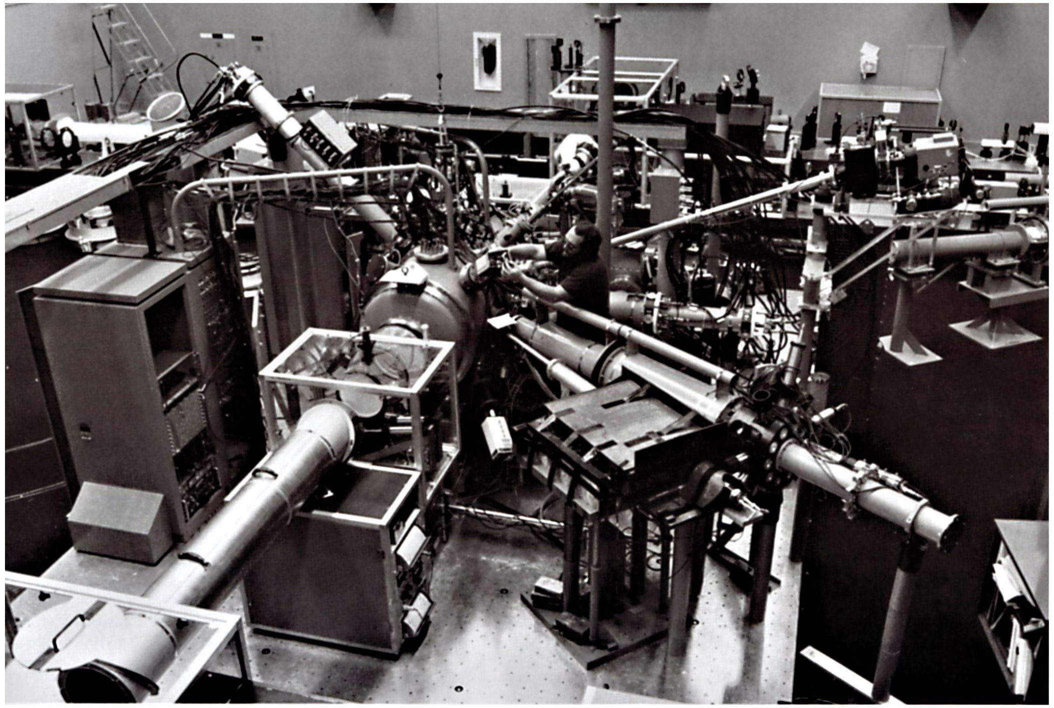
Major Experiment goals:

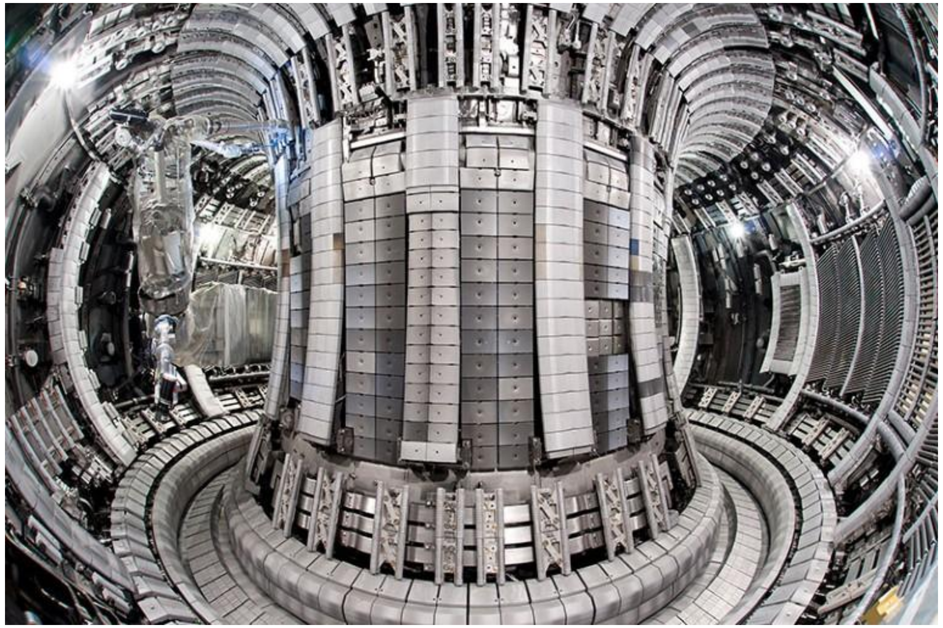
1. ‘Burning plasma’ self-sustaining fusion reaction
2. Tritium Breeding

ITER will **not** produce energy for the power grid it is strictly

NIF - National Ignition Facility

- Lawrence Livermore National Lab
- Inertial confinement (pellets)
- Achieved self sustaining fusion reaction in 2020





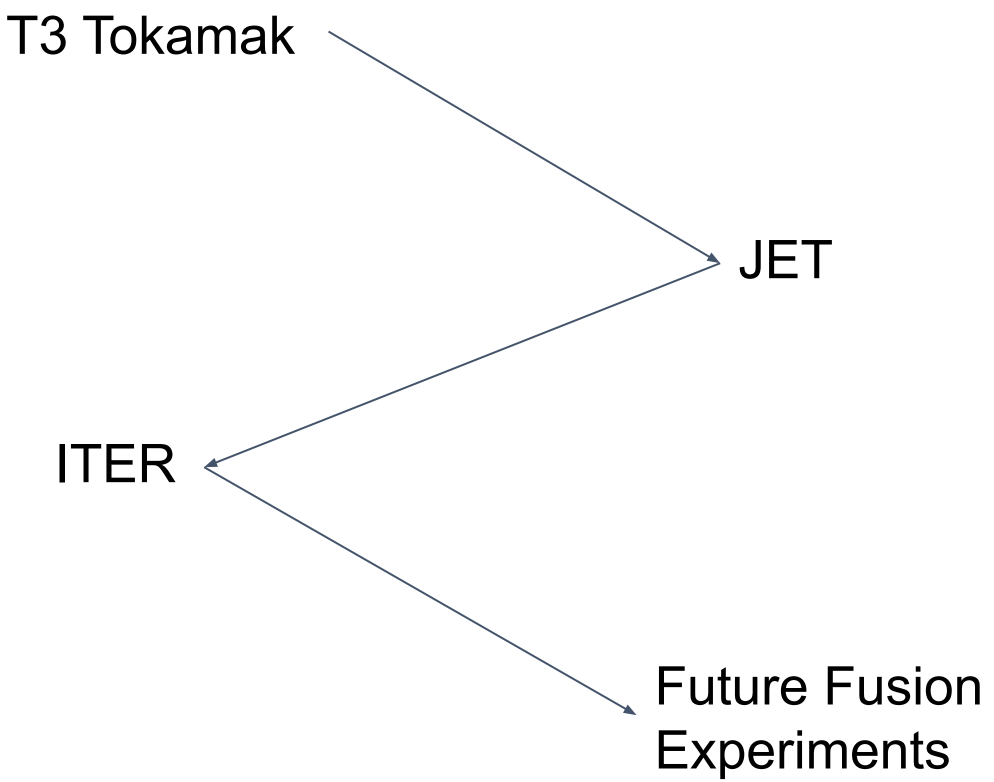
JET - Joint European Torus

- A blueprint for ITER
- Started D-T fusion research early
    - first controlled DT fusion
- Tokomak design

What we’ve learned

- Fusion is extremely difficult
- A lot of interesting challenges ahead
- Extremely multinational collaboration going back to the cold war

All interconnected:



backup slides

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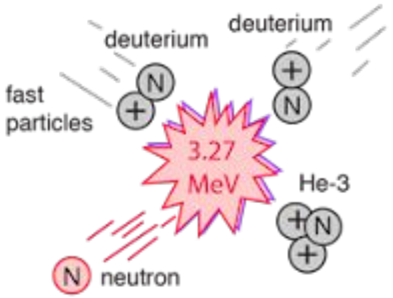
Deuterium-deuterium Fusion



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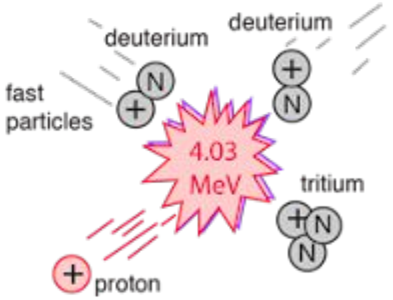

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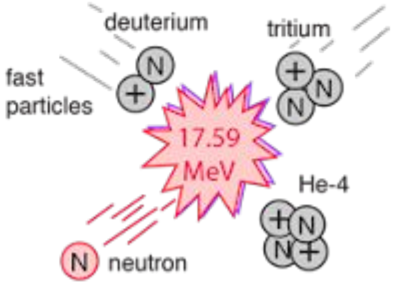

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Why DT Reactions?

High Reaction Rate