

---



**WOODRUFF • SCIENTIFIC**

## **Sun in a Bottle: Fusion Energy**

Simon Woodruff, Jennifer, K. Baerny

*Woodruff Scientific Inc, 4501 Shilshole Ave NW, Seattle, WA 98107*

ESS 495 – NASA Research Seminar

April 21<sup>st</sup> 2011

---

---

## Outline

I. Some history and context

II. Some space plasmas that are relevant to fusion

III. Golden age of fusion, just starting

---

---

## Outline

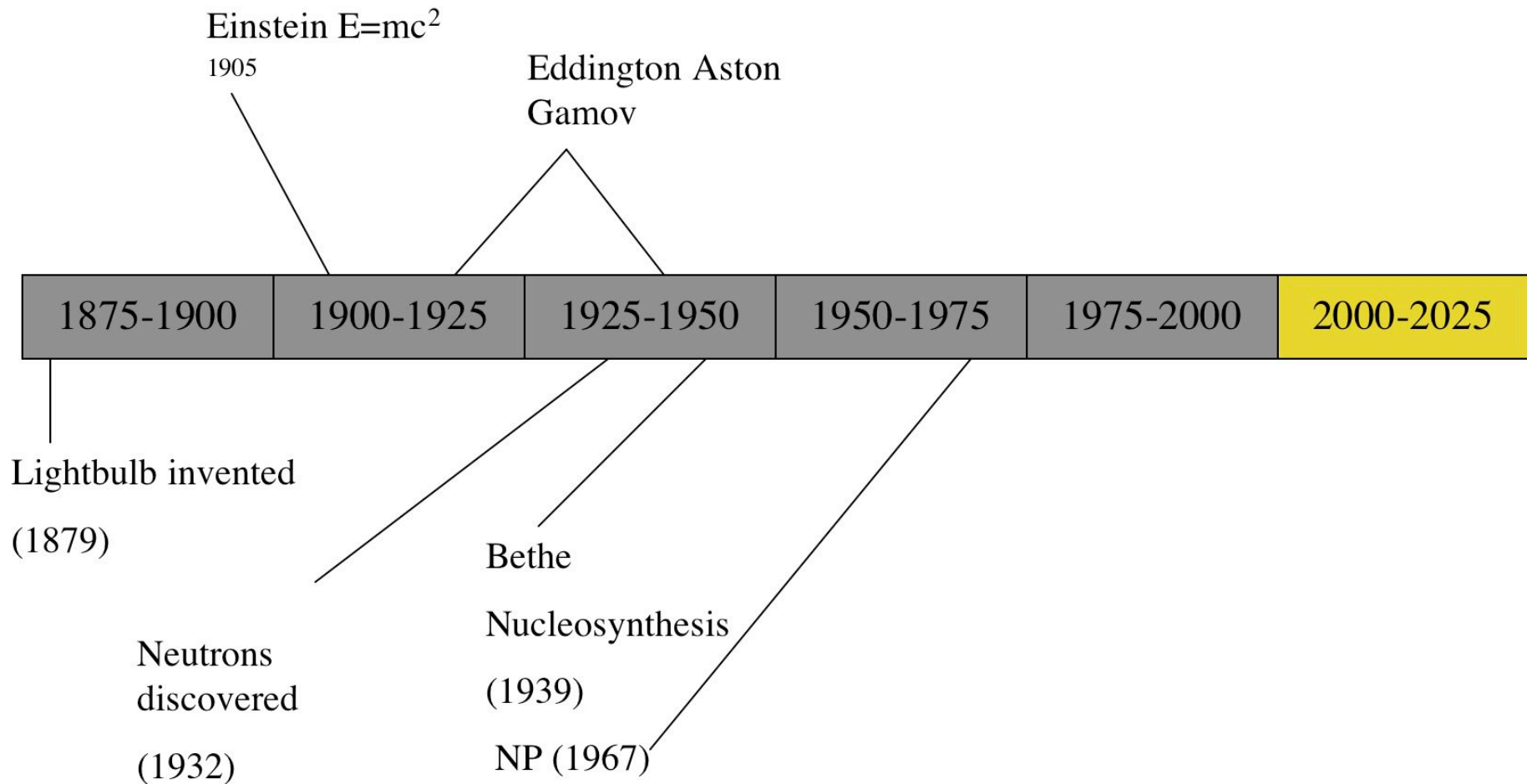
I. Some history and context

II. Some space plasmas that are relevant to fusion

III. Golden age of fusion, just starting

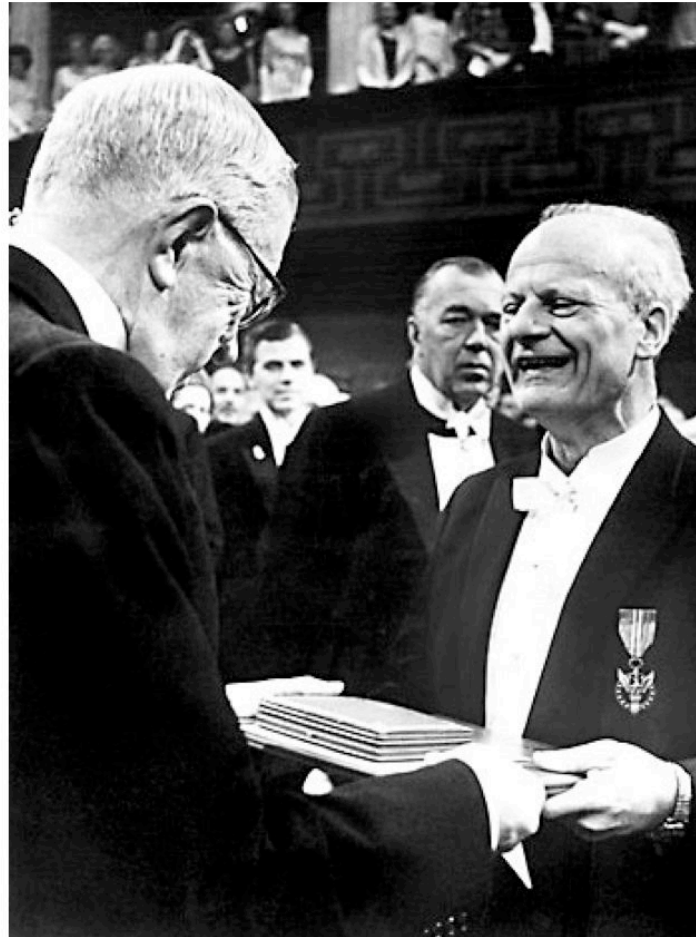
---

# 20th century riddle: energy source of the sun

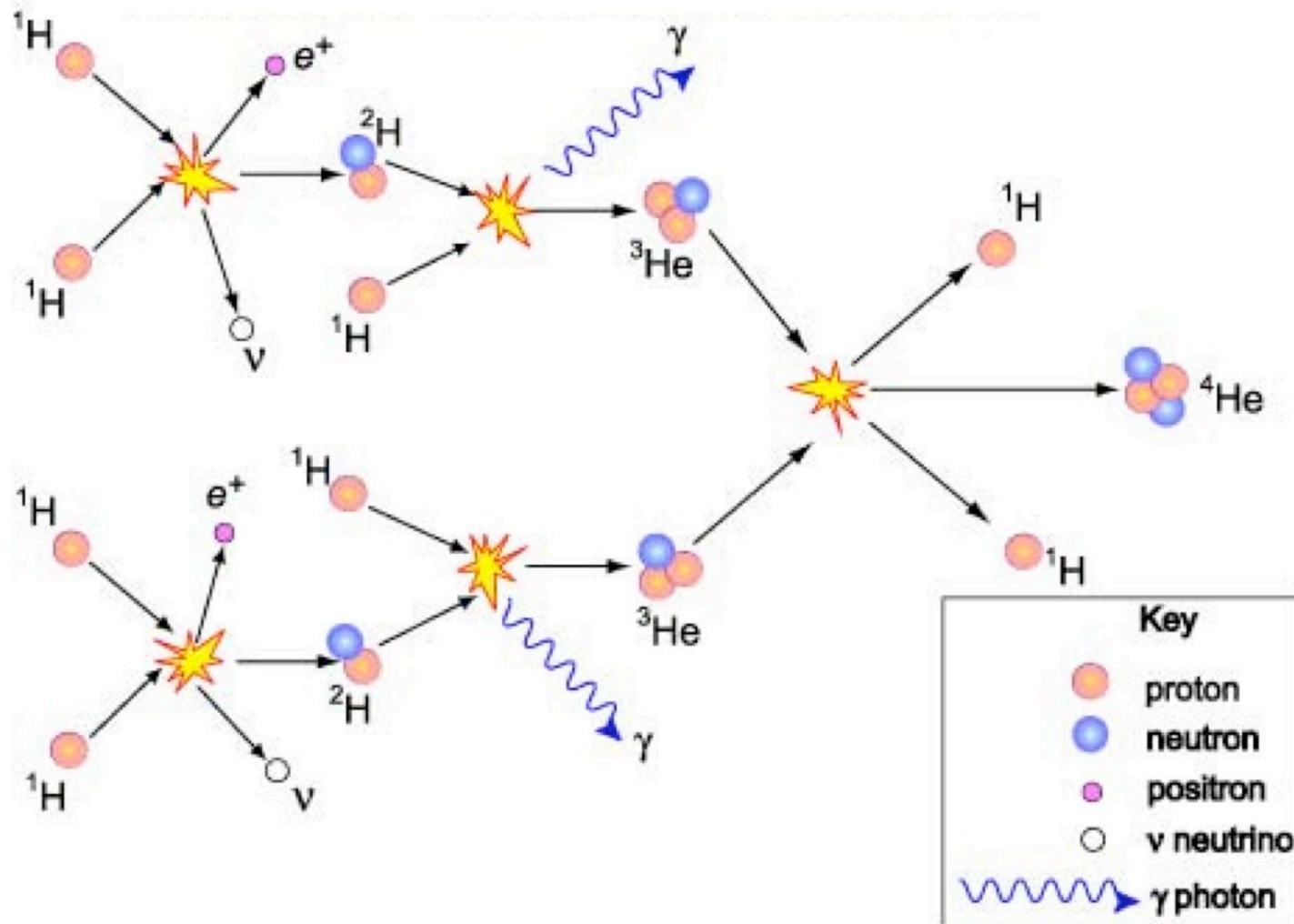


# Hans Bethe solved the problem of star's energy source

---



# Nucleosynthesis by nuclear fusion



---

## Outline

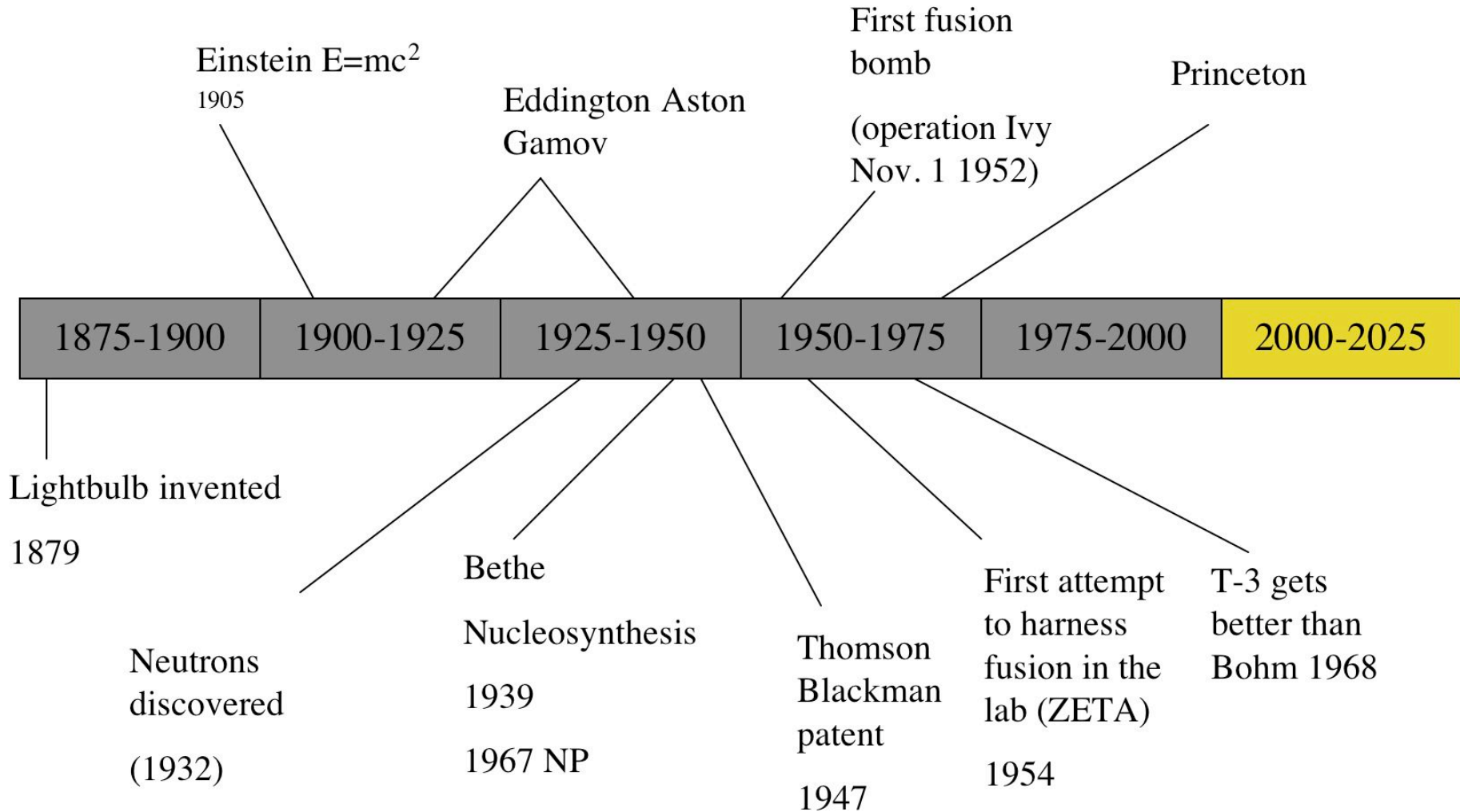
I. Some history and context

II. Some space plasmas that are relevant to fusion

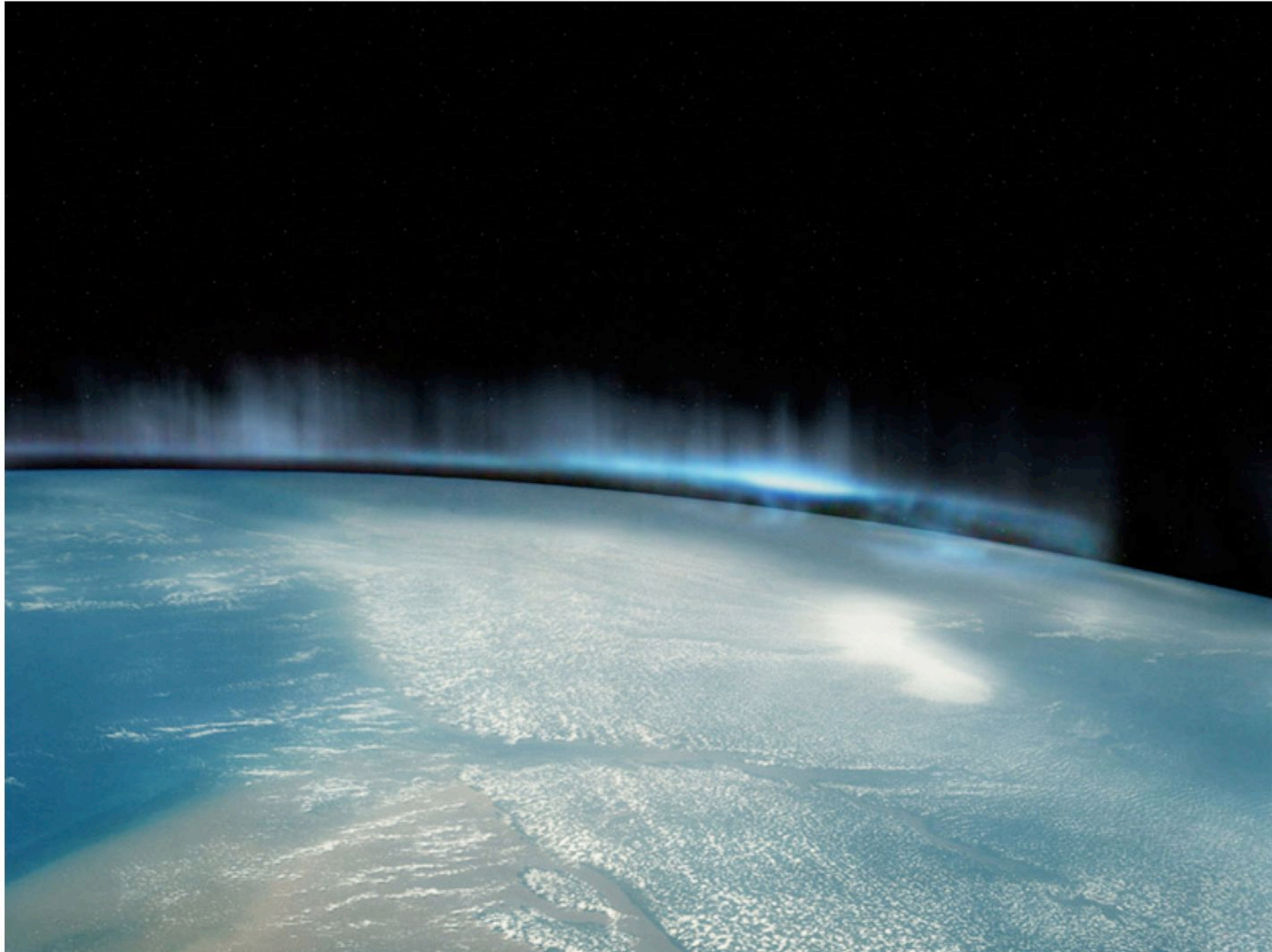
III. Golden age of fusion, just starting

---

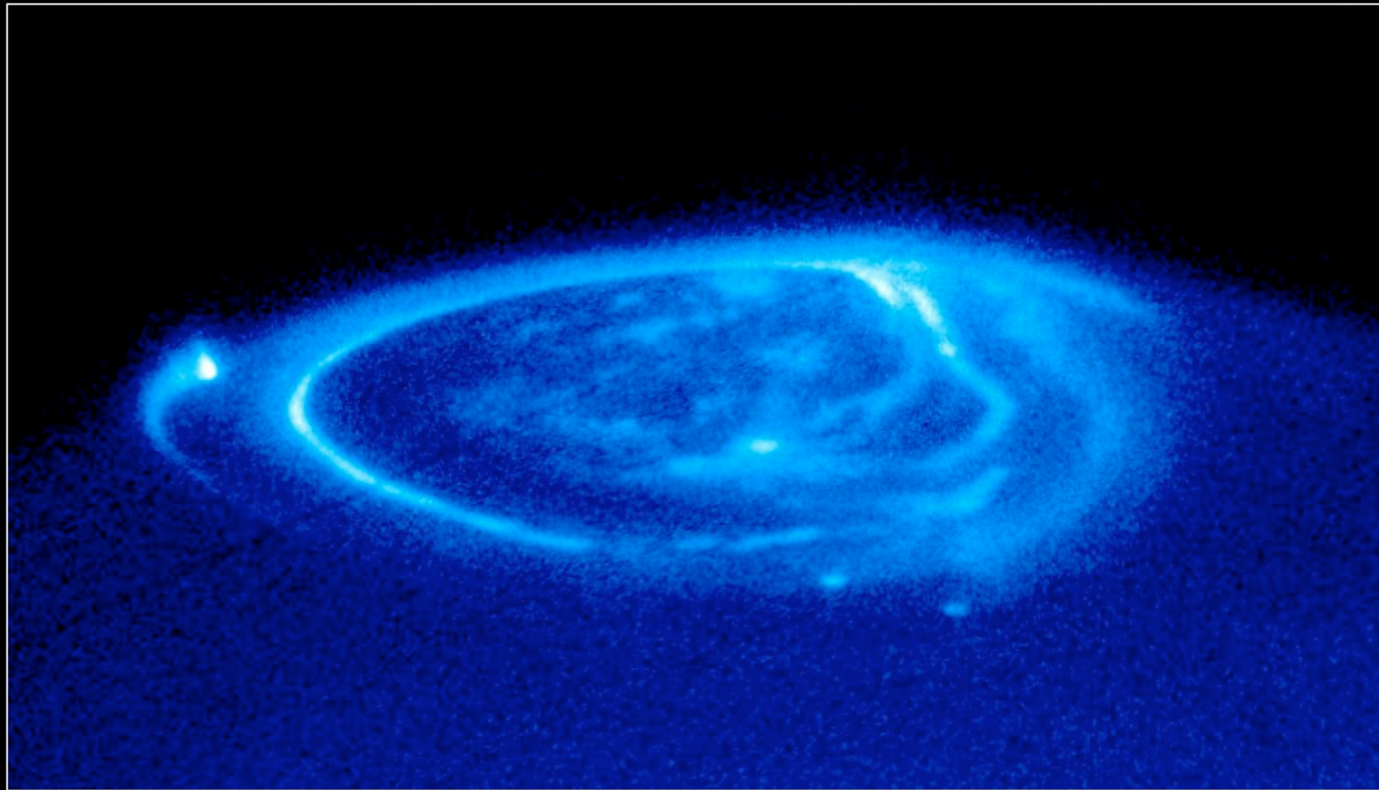
# Lab plasma physics



# Aurorae on Earth



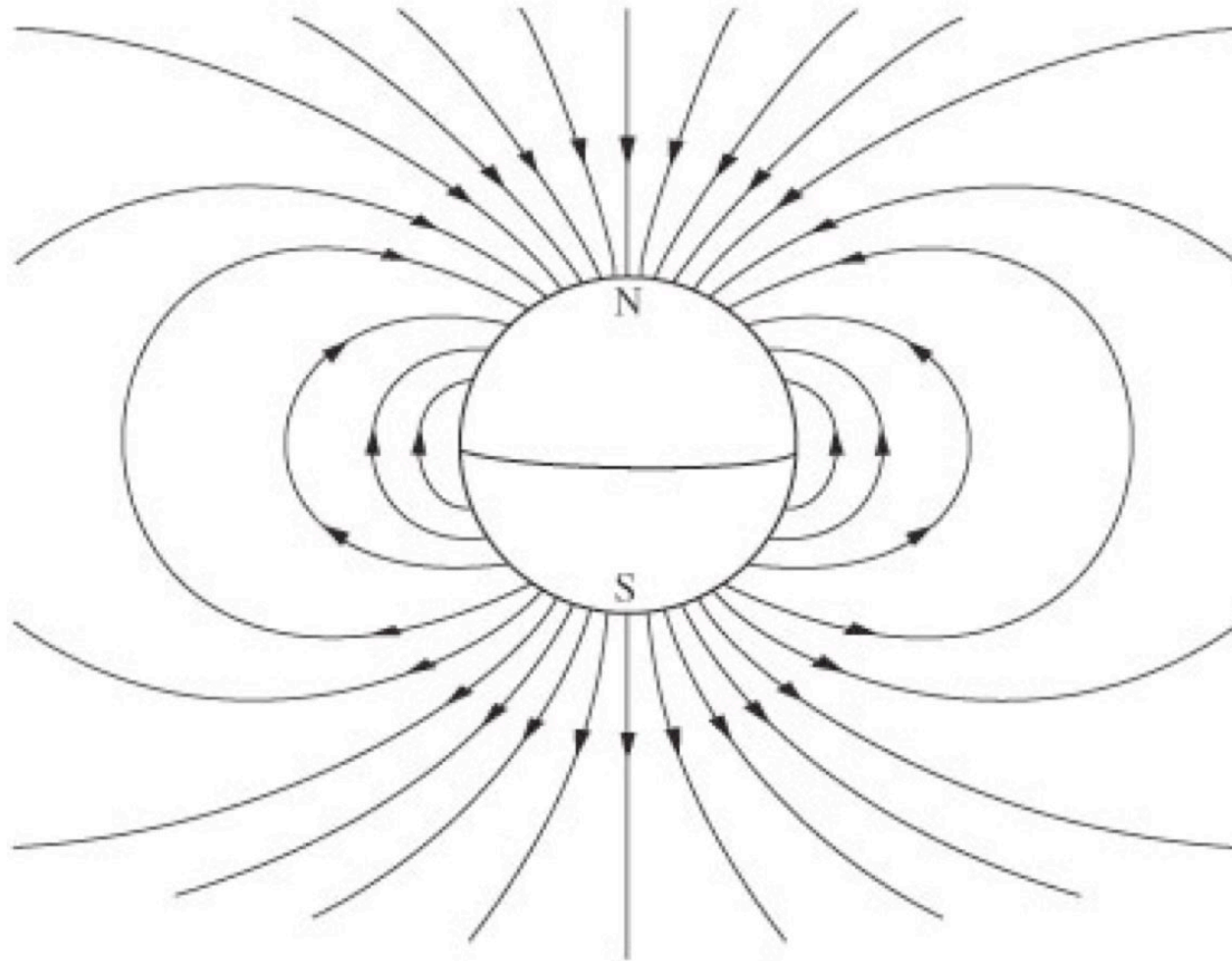
# Aurorae on Jupiter



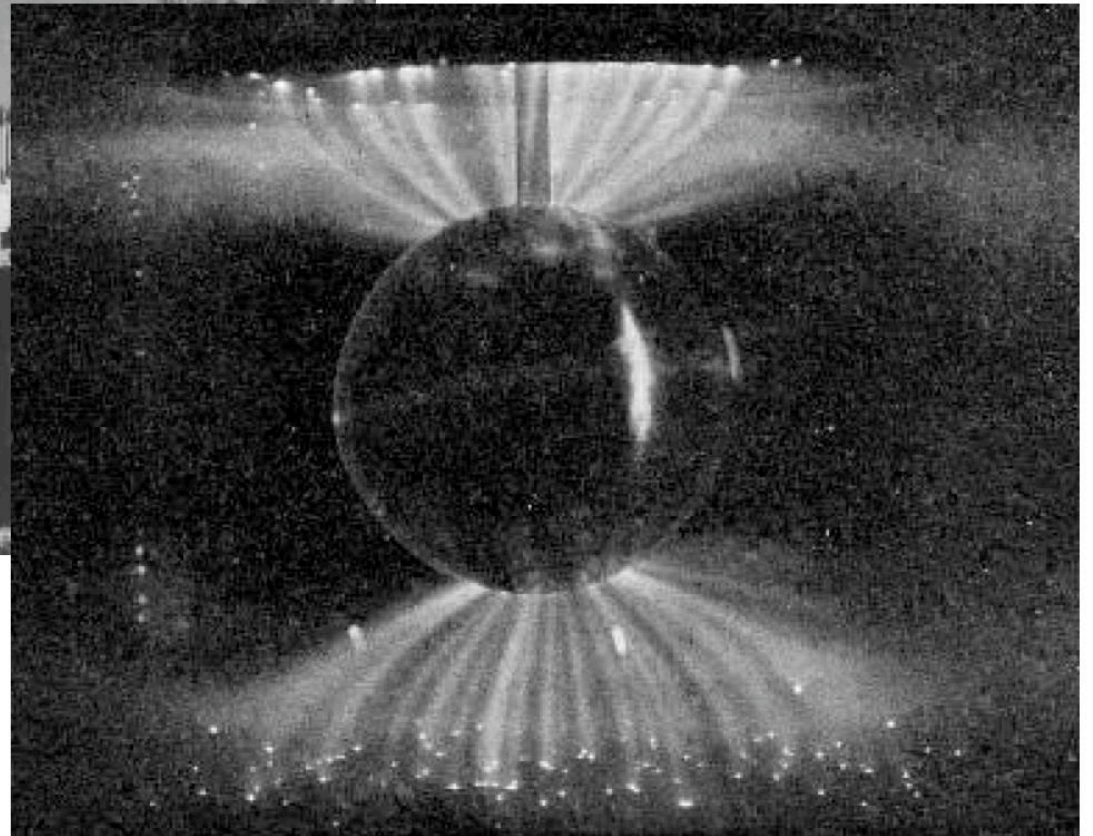
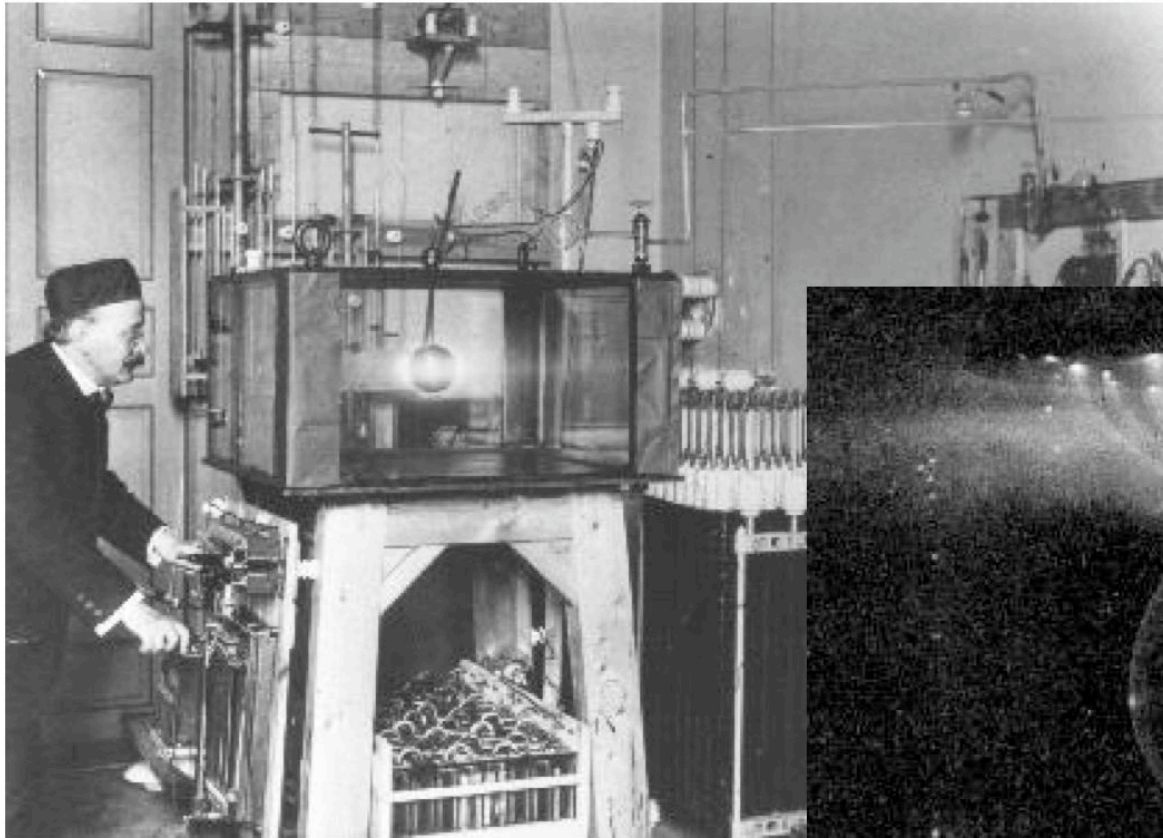
**Jupiter Aurora**  
**Hubble Space Telescope • STIS**

# Dipole magnetic fields

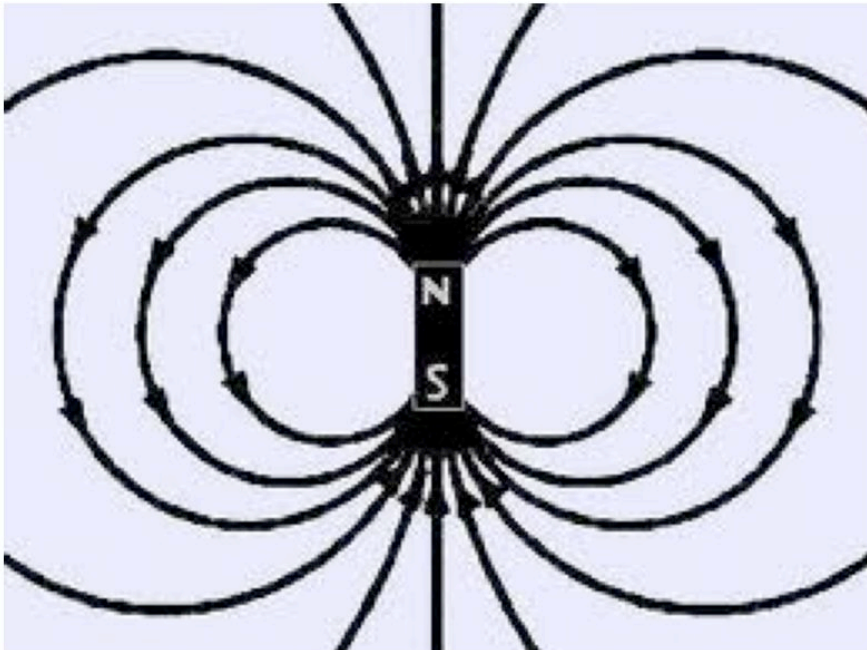
---



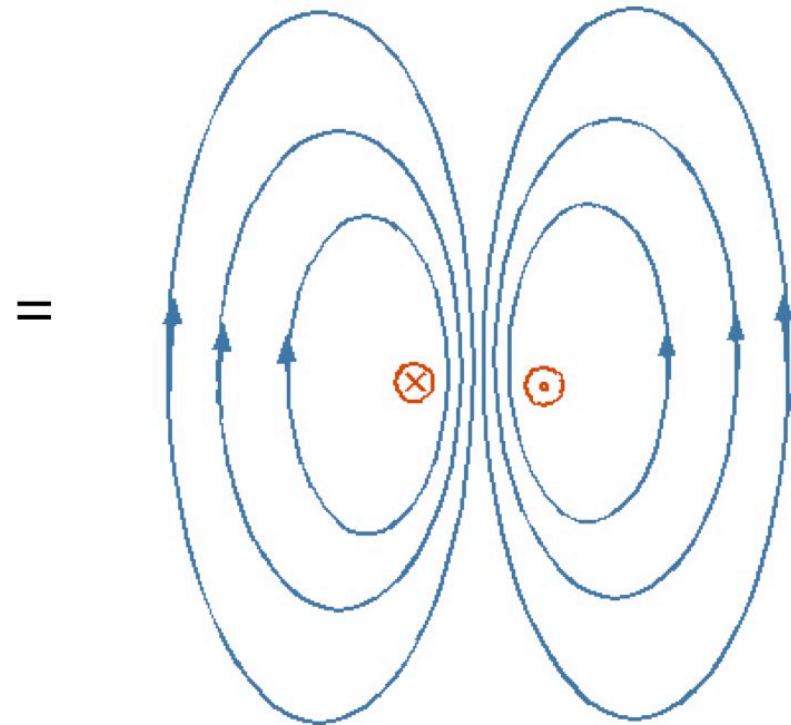
# Early lab plasmas



# Dipole magnetic field

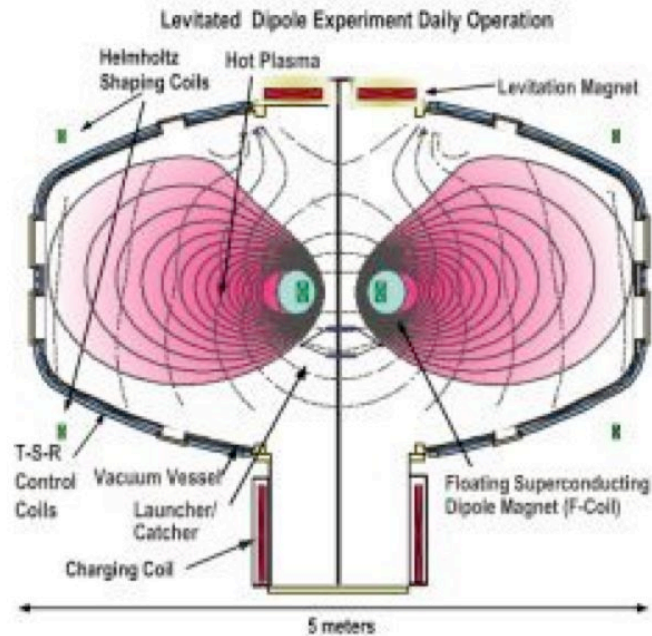
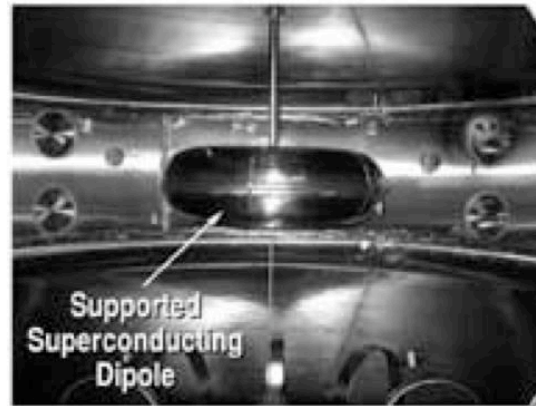


Bar magnet



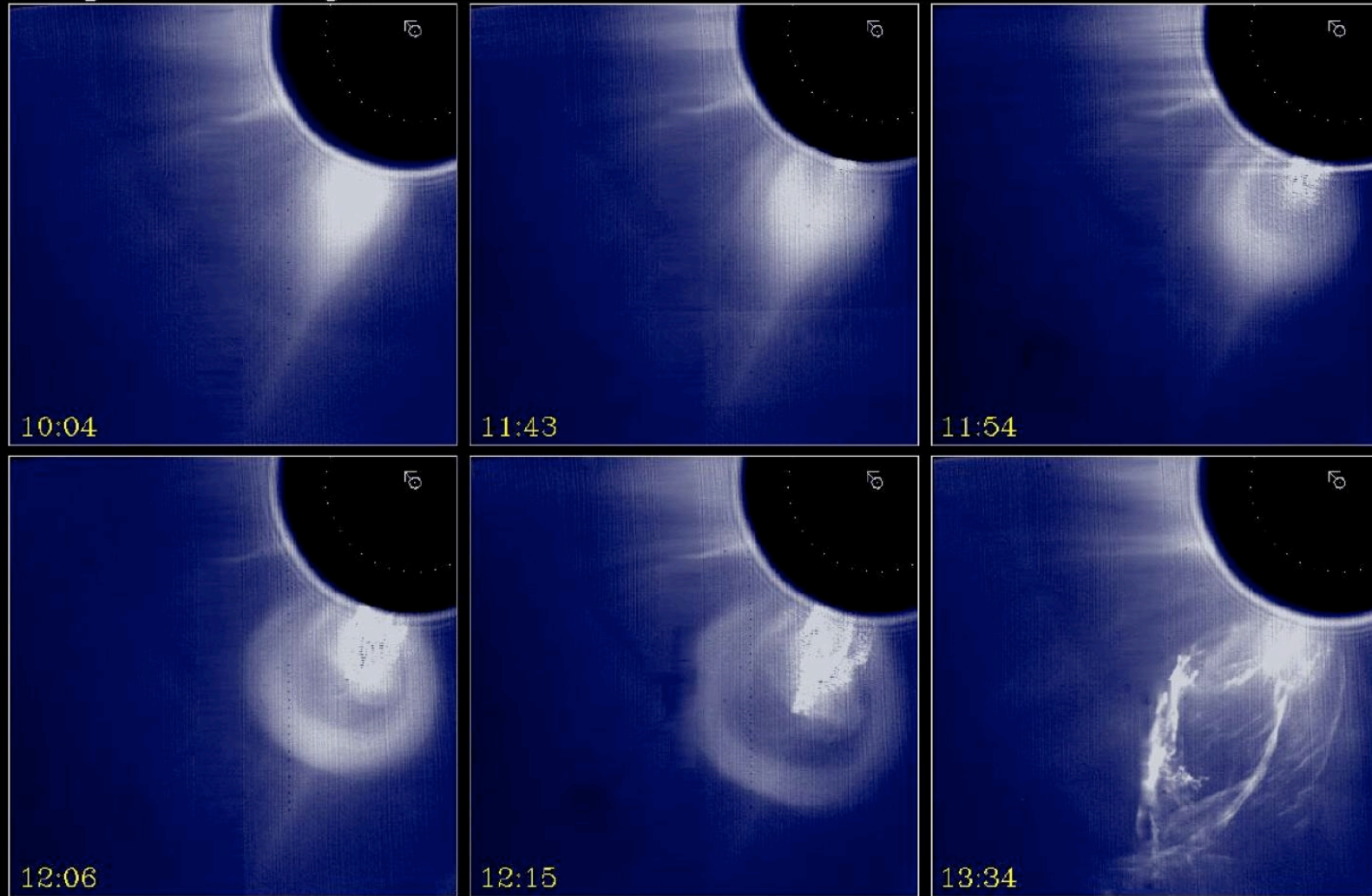
Current loop

# Dipole magnetic field



# Coronal mass ejections

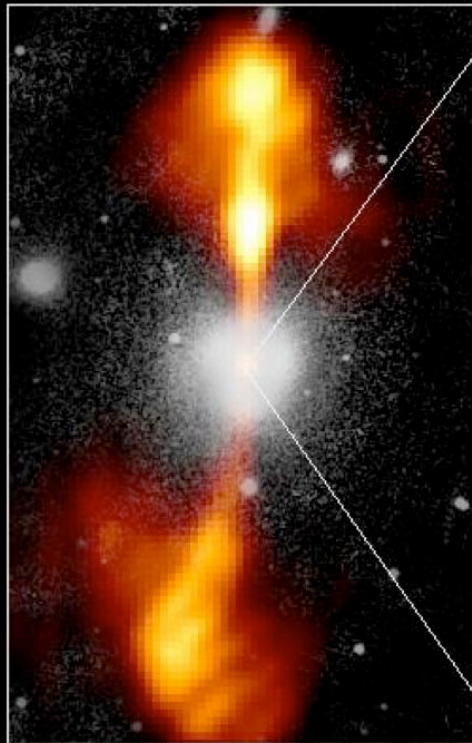
18 Aug 1980: White Light



## Core of Galaxy NGC 4261

Hubble Space Telescope  
Wide Field / Planetary Camera

Ground-Based Optical/Radio Image



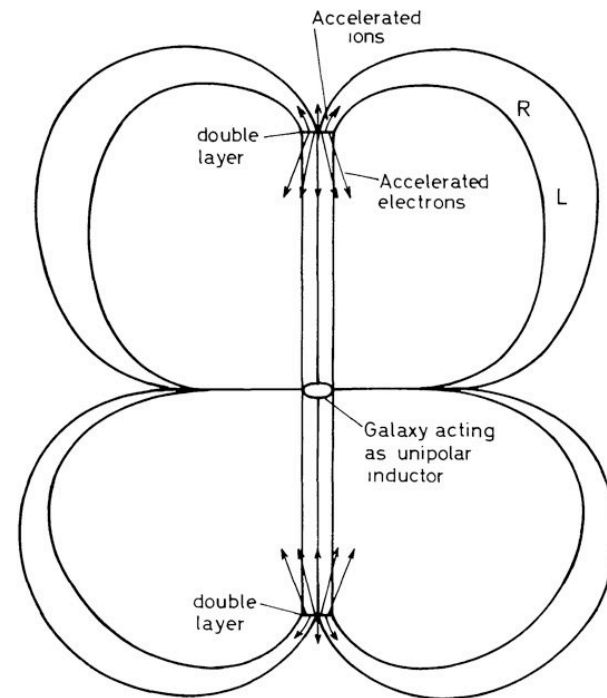
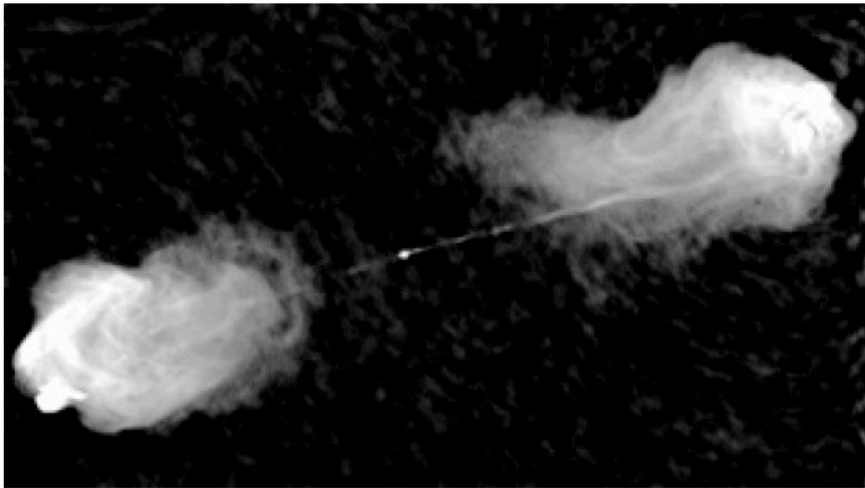
380 Arc Seconds  
88,000 LIGHTYEARS

HST Image of a Gas and Dust Disk



17 Arc Seconds  
400 LIGHTYEARS

# Galactic jets and Alfven

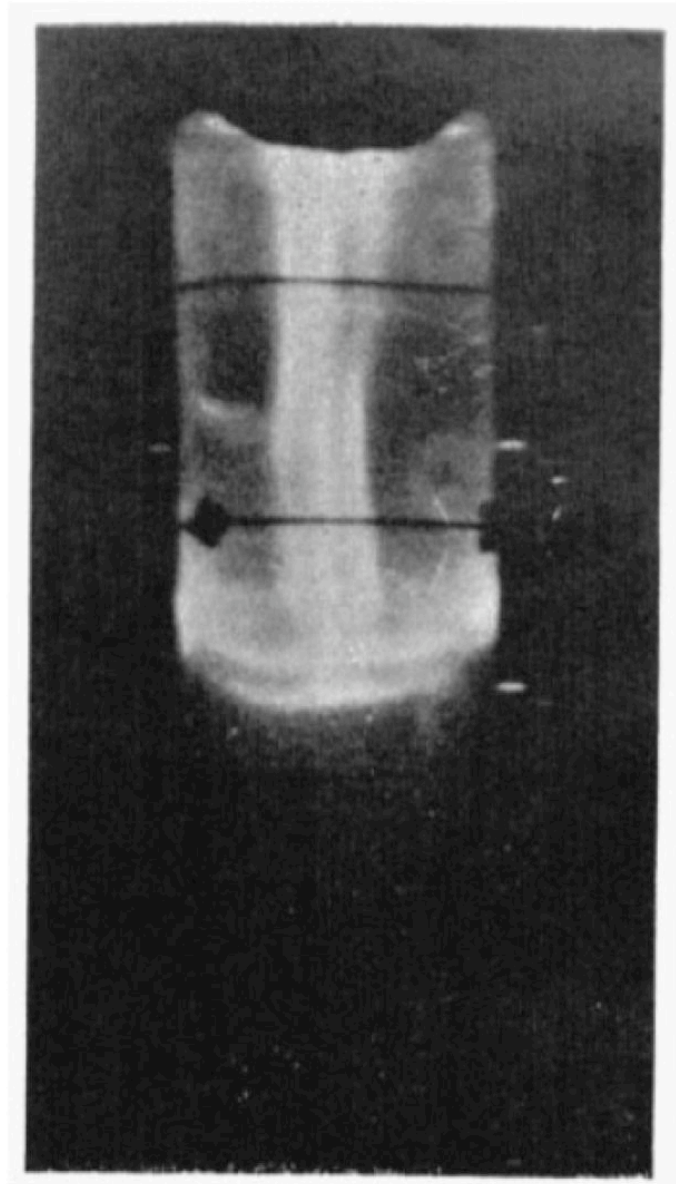
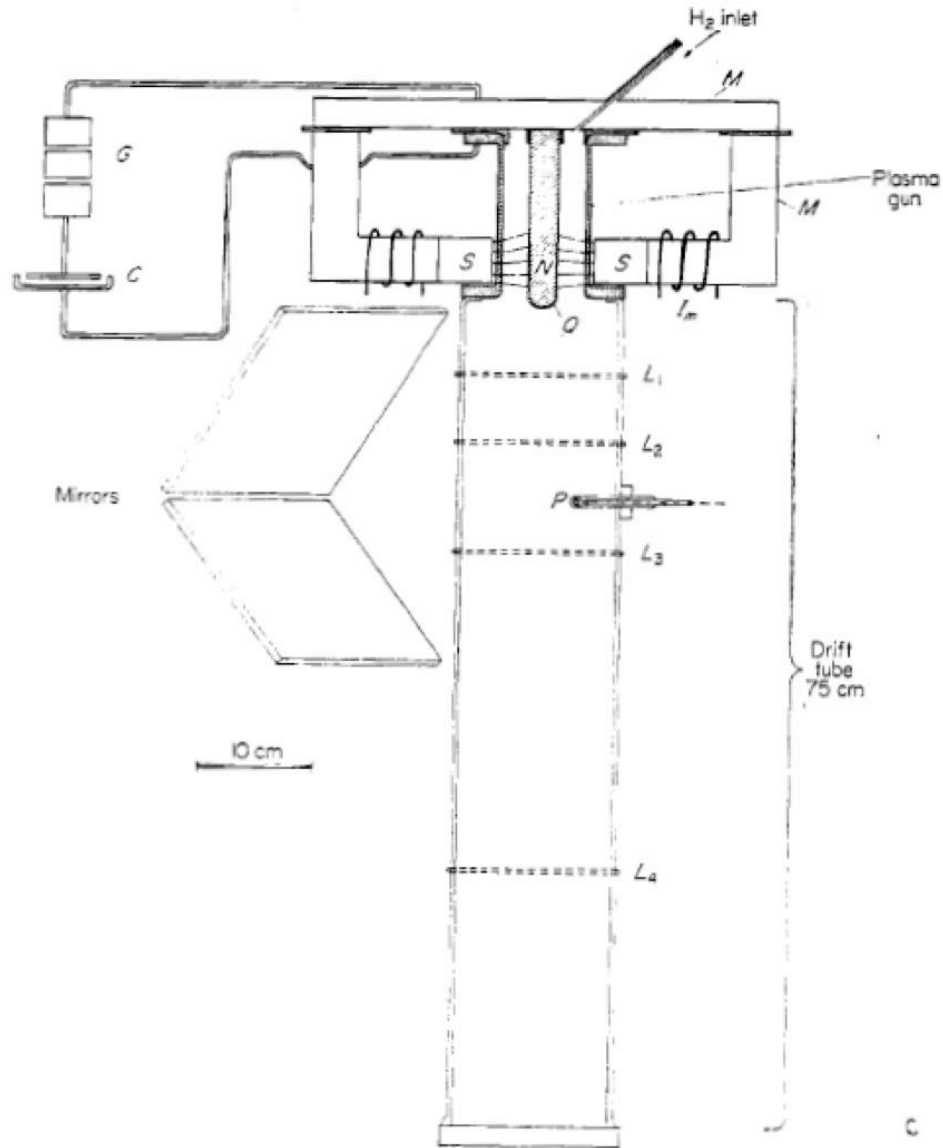


Galactic circuit, extra polated from heliosphere circuit.  
Current  $10^{17}$  A and double layer voltage  $10^{18}$  V



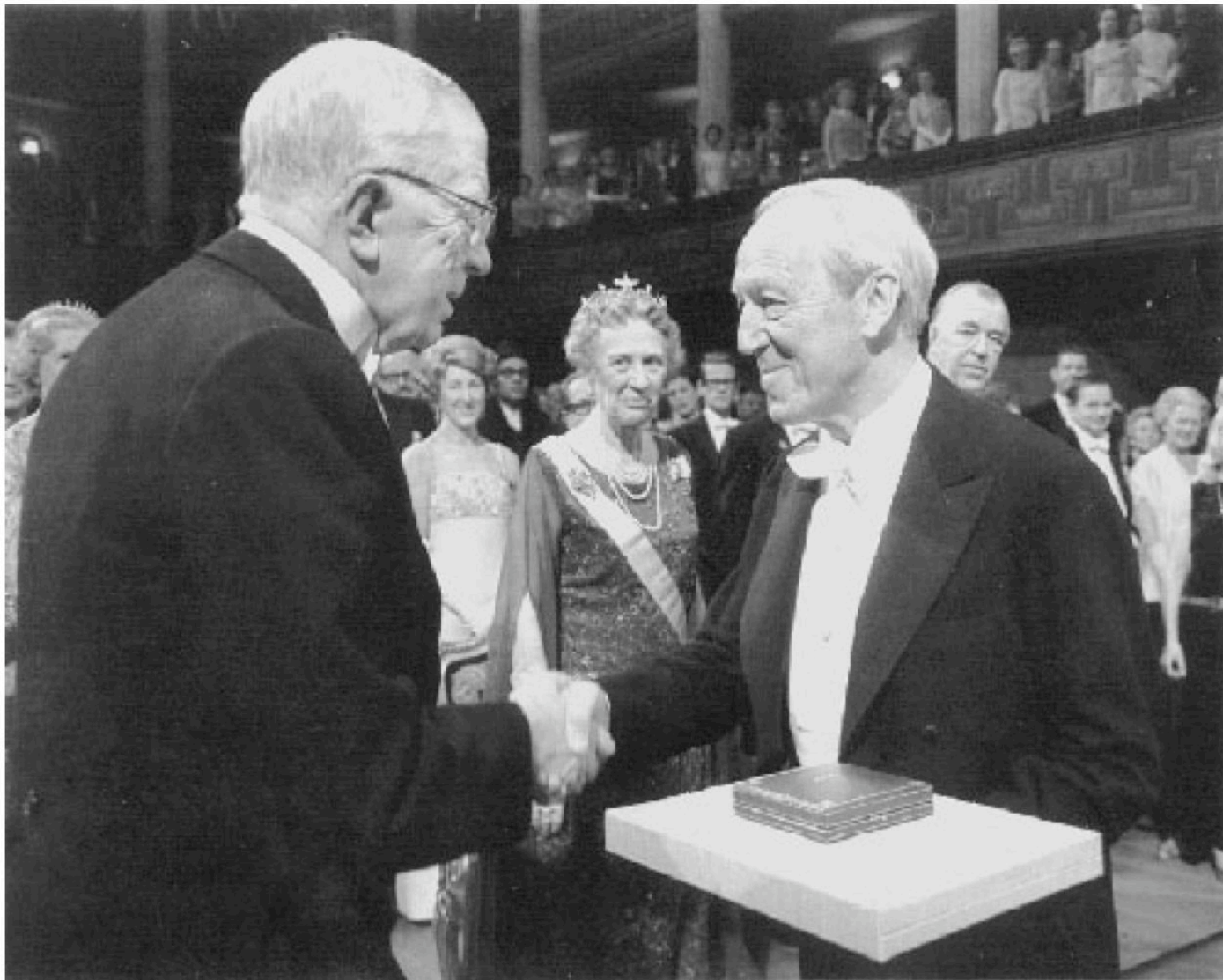
Radio astronomic observations by Hargrave and Ryle.

# Galactic jets and Alfven

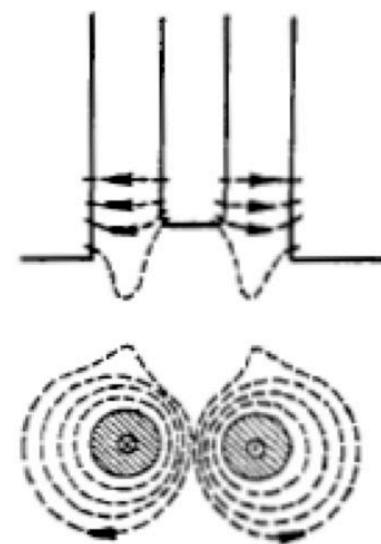
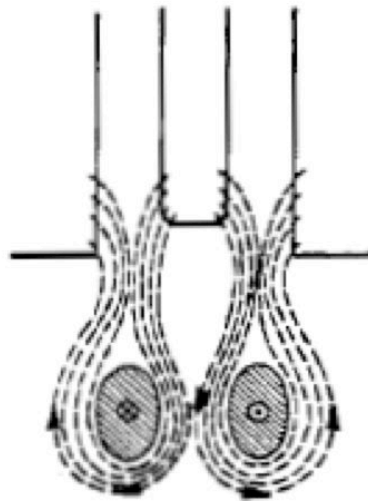
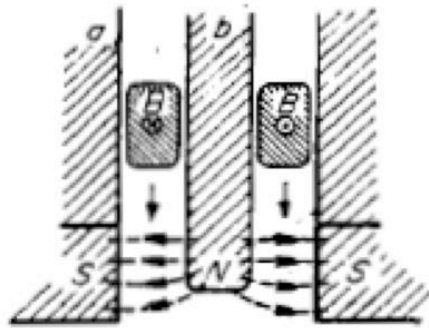


# Alfven's work on plasmas earned him NP

---

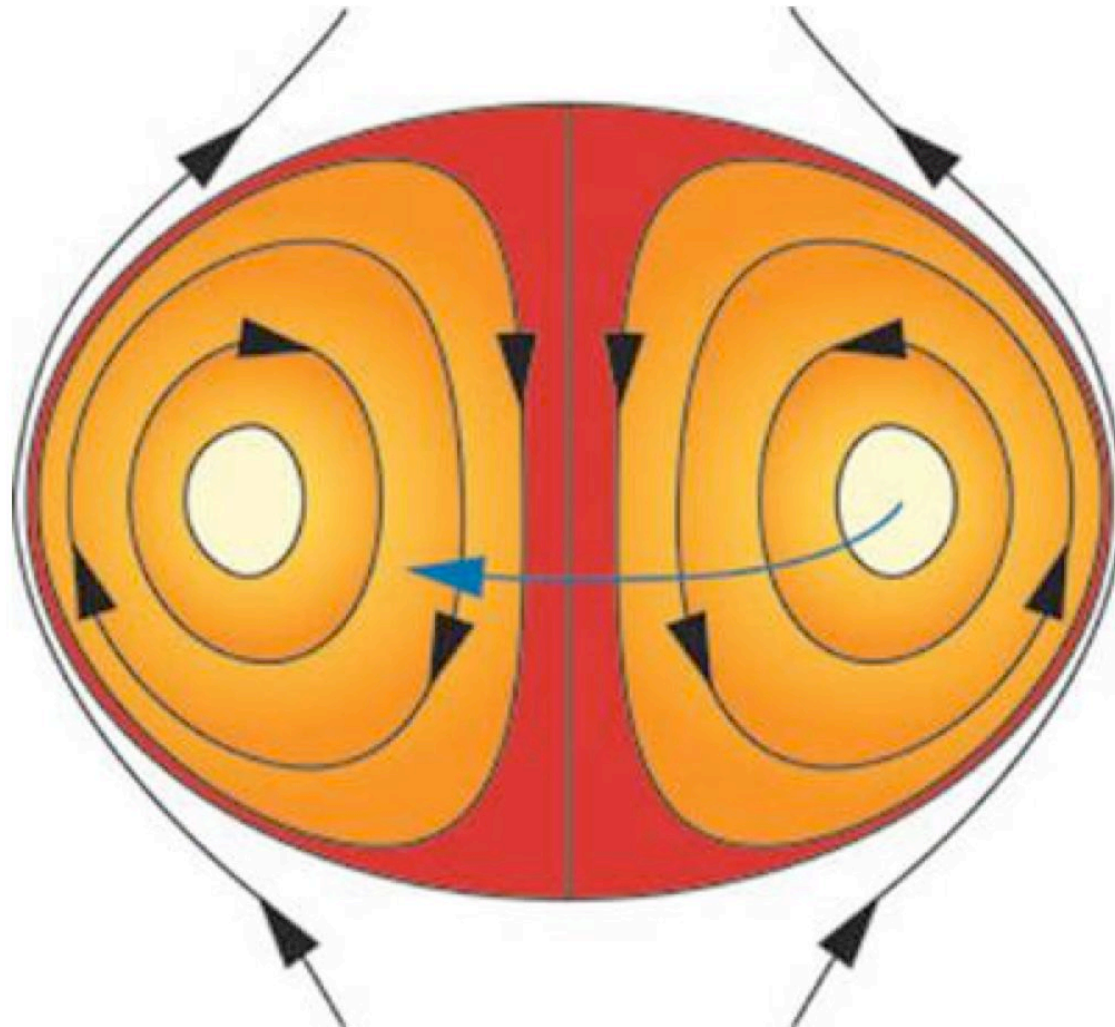


# Spheromaks - Alfven

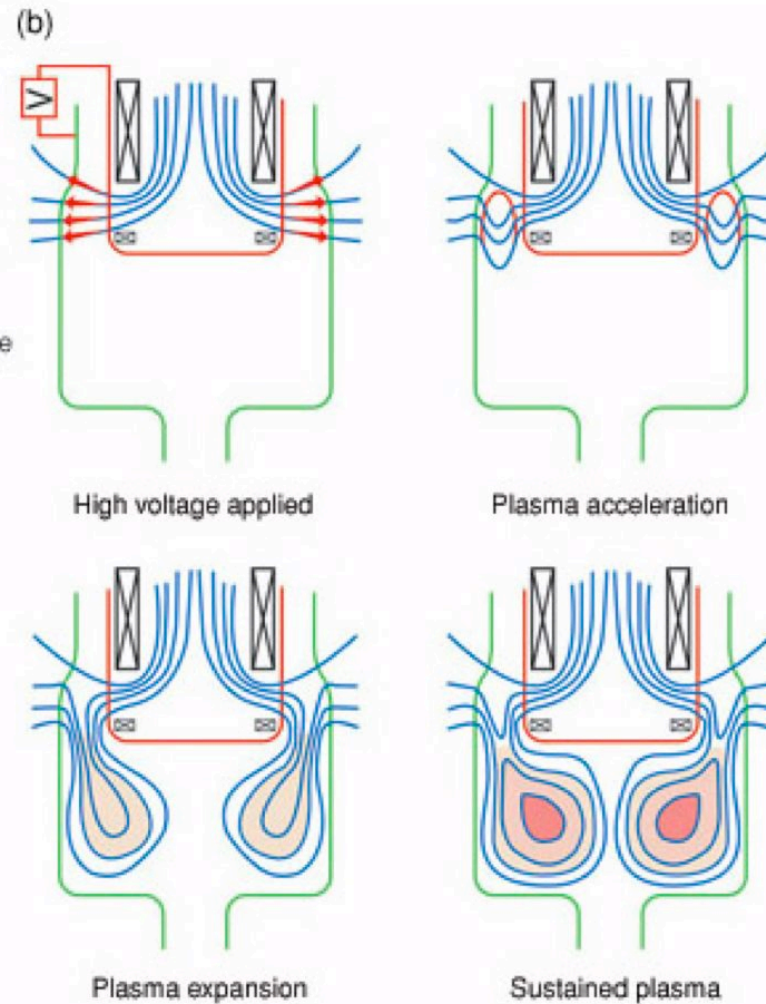
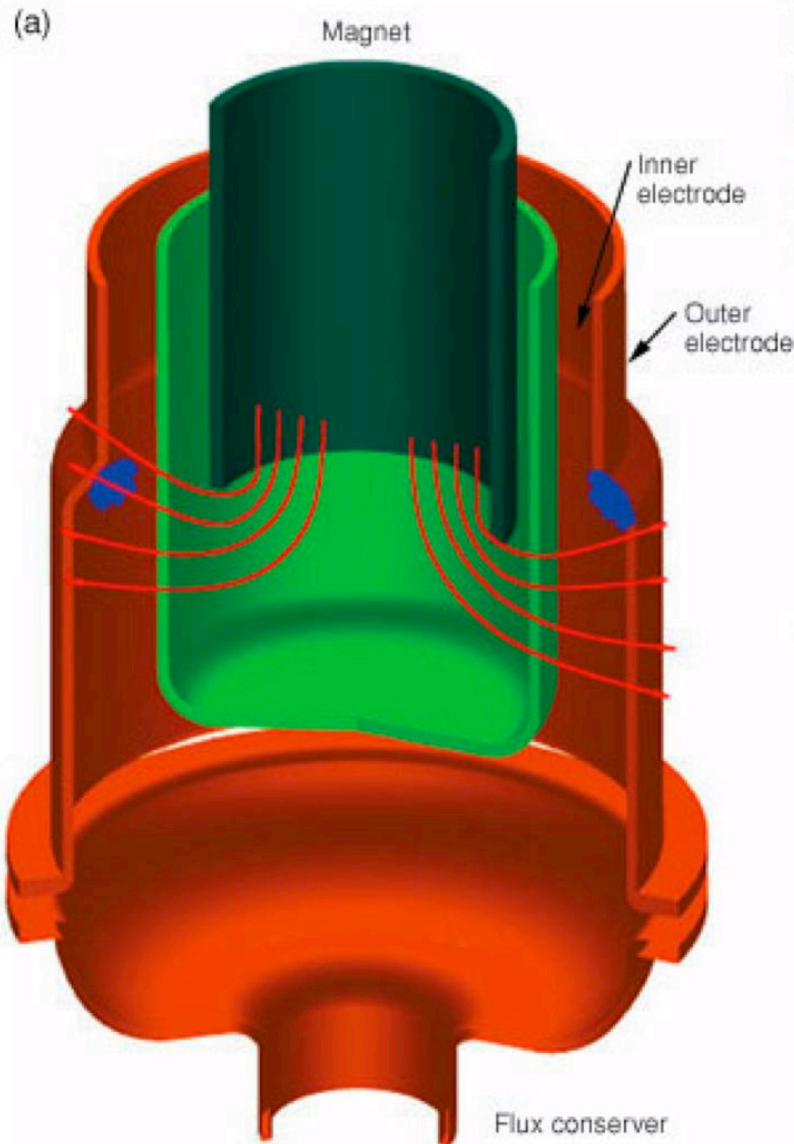


# Spheromaks: dipole current carried in plasma

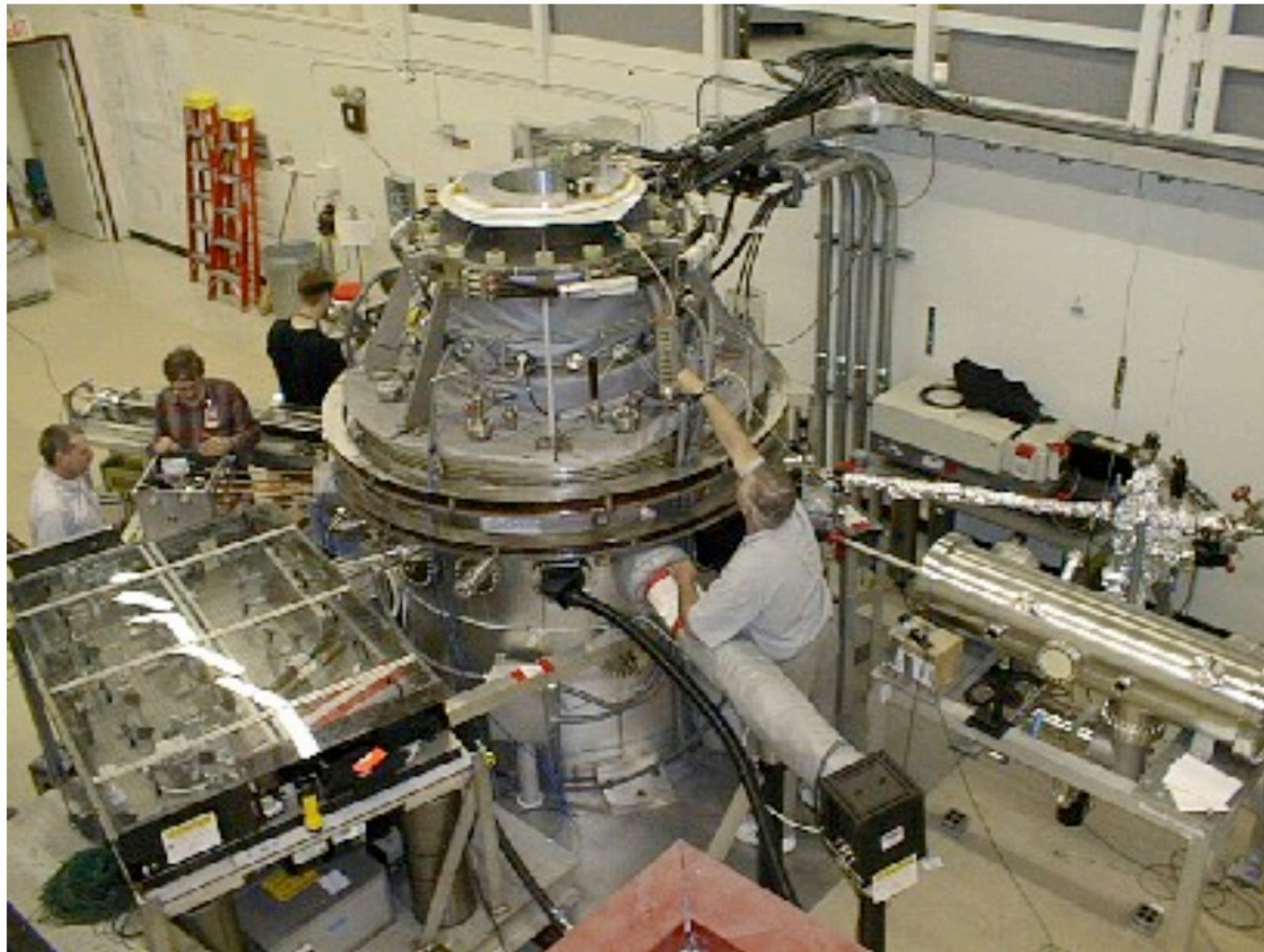
---



# Spheromaks today



# Spheromaks are the simplest of all fusion concepts



---

## Outline

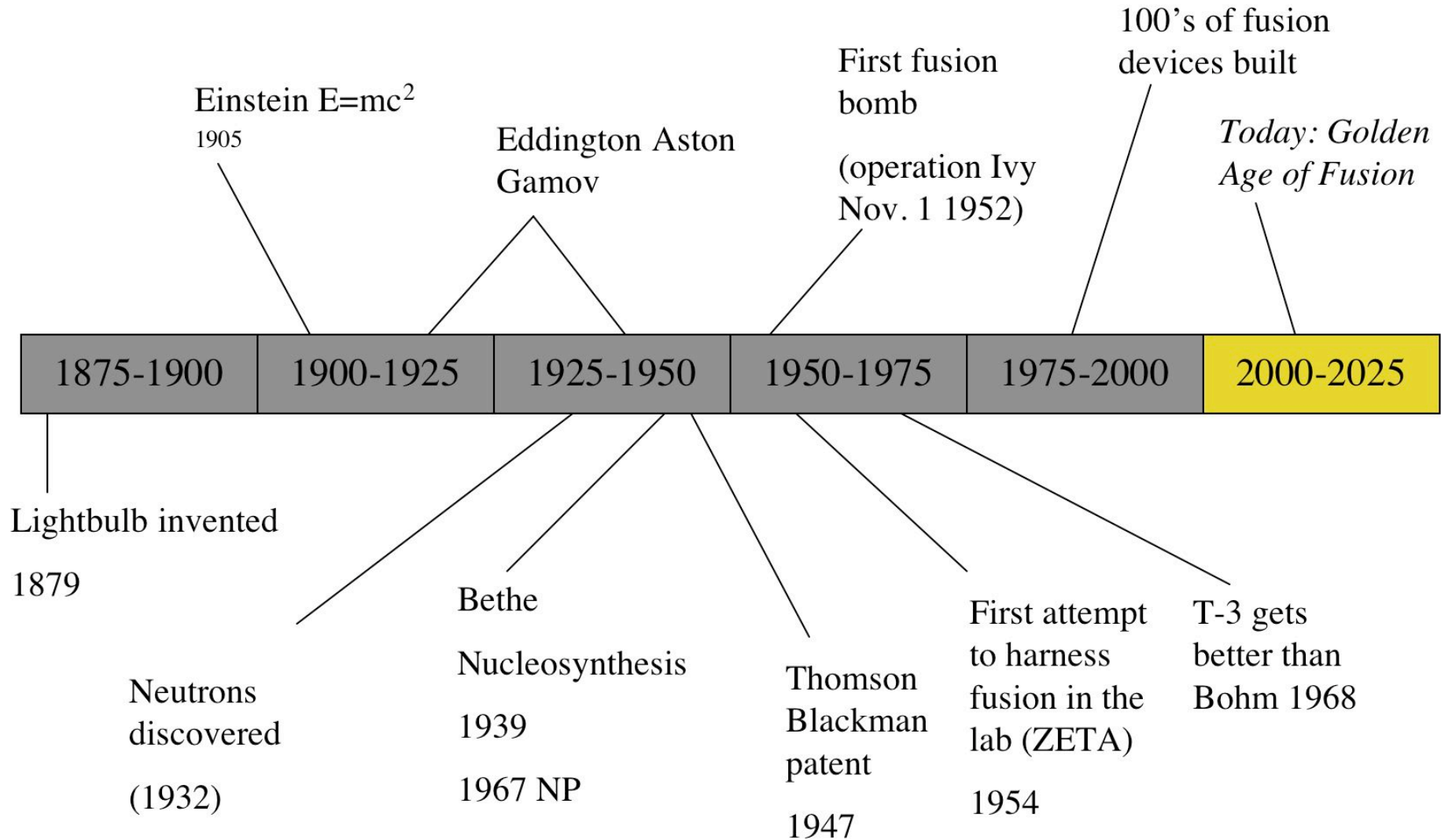
I. Some history and context

II. Some space plasmas that are relevant to fusion

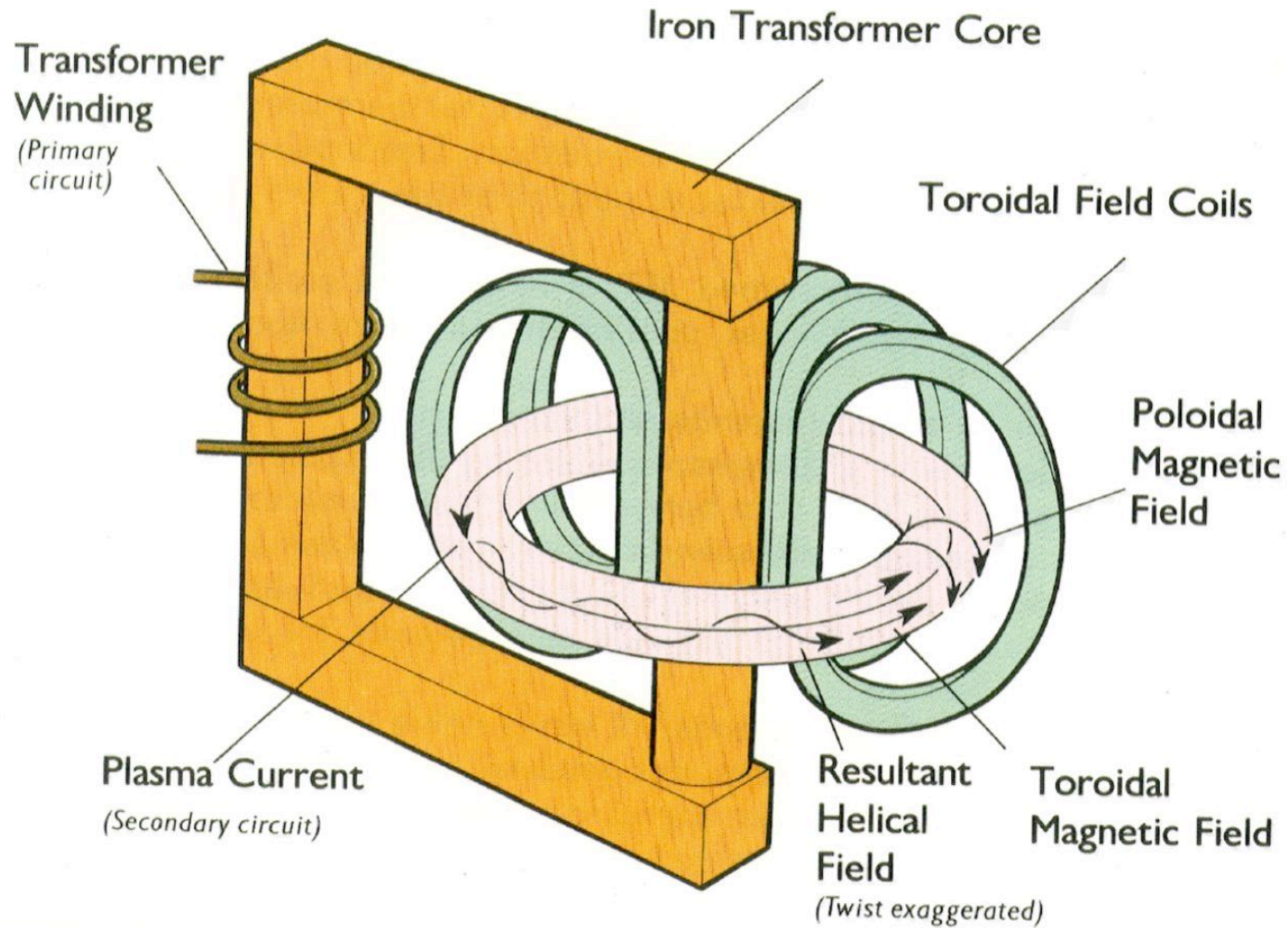
III. Golden age of fusion, just starting

---

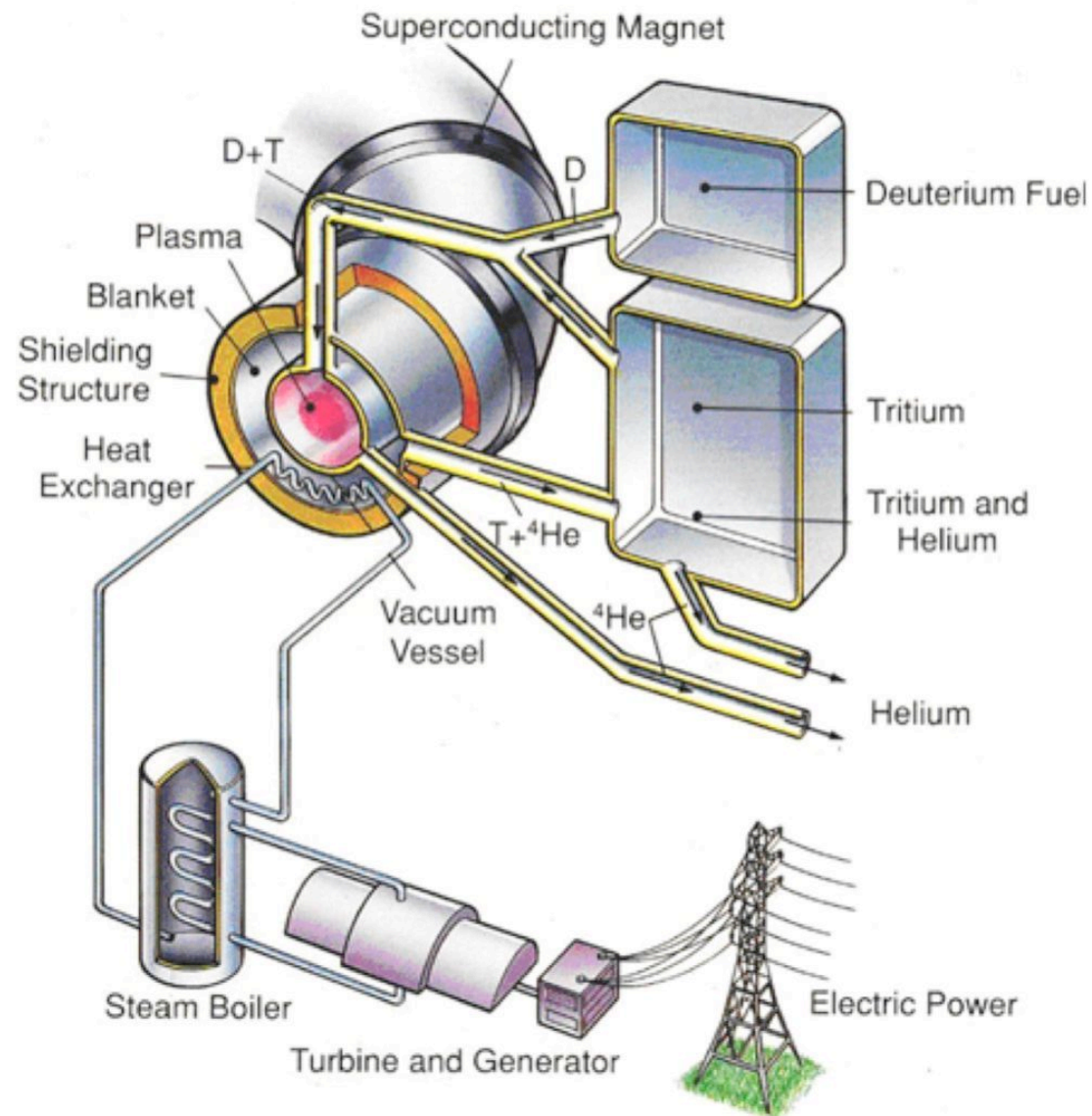
# Fusion golden age: now!



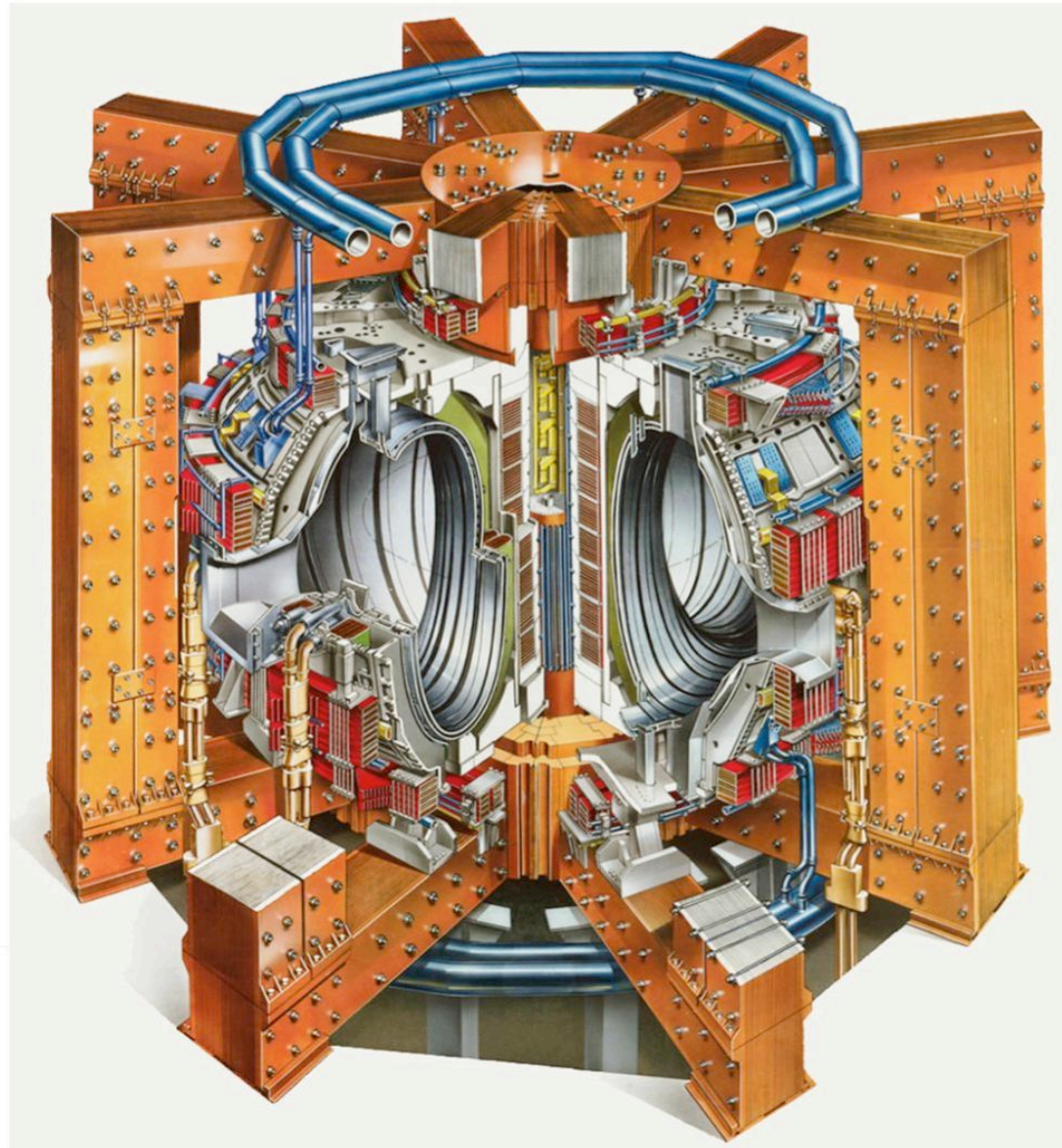
# Fusion fuel burns at 100M°C - suspended in magnetic fields



# Heat will be extracted to drive a steam turbine

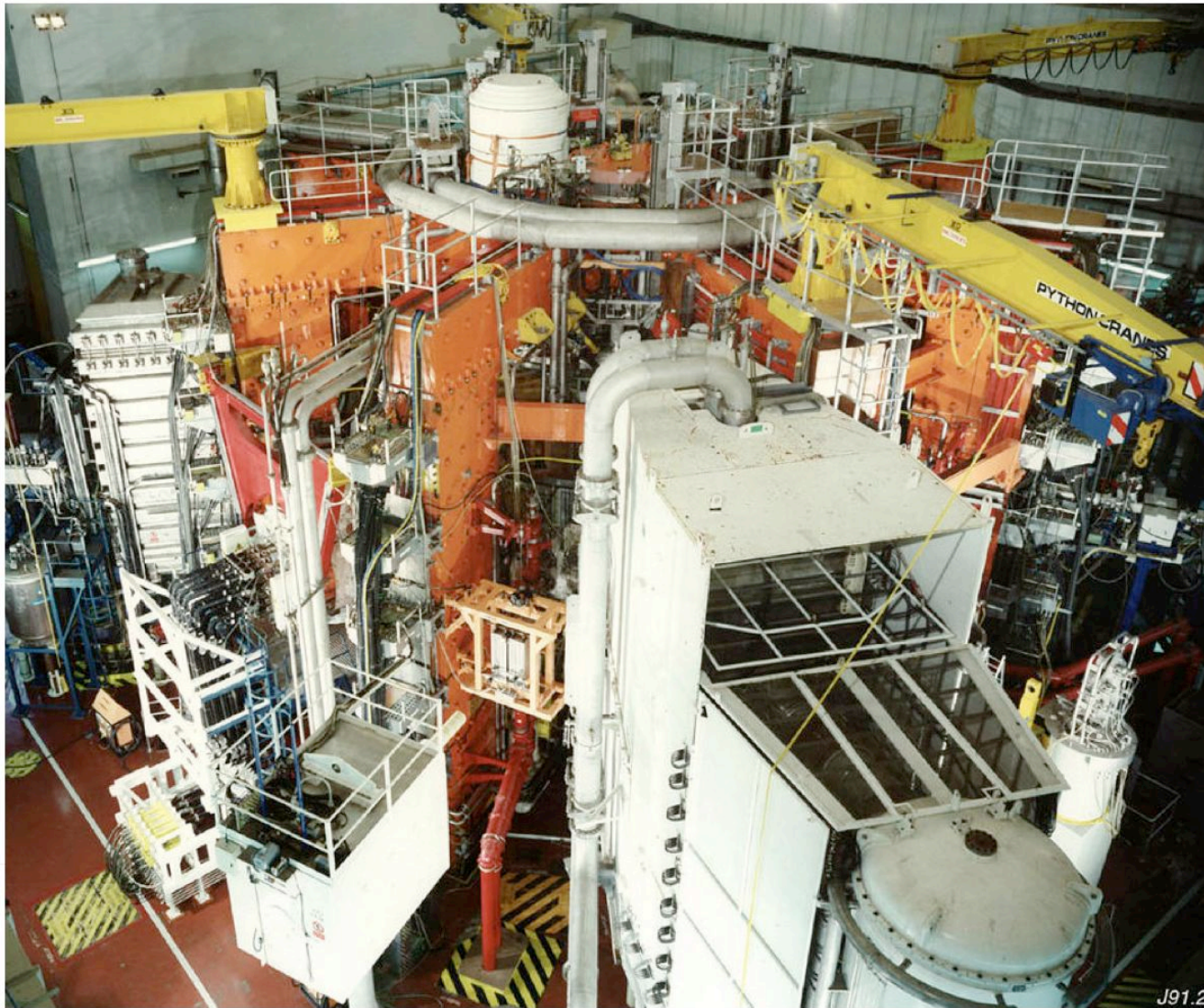


# Fusion chambers are marvels of engineering



**JET**

# Fusion chambers are marvels of engineering

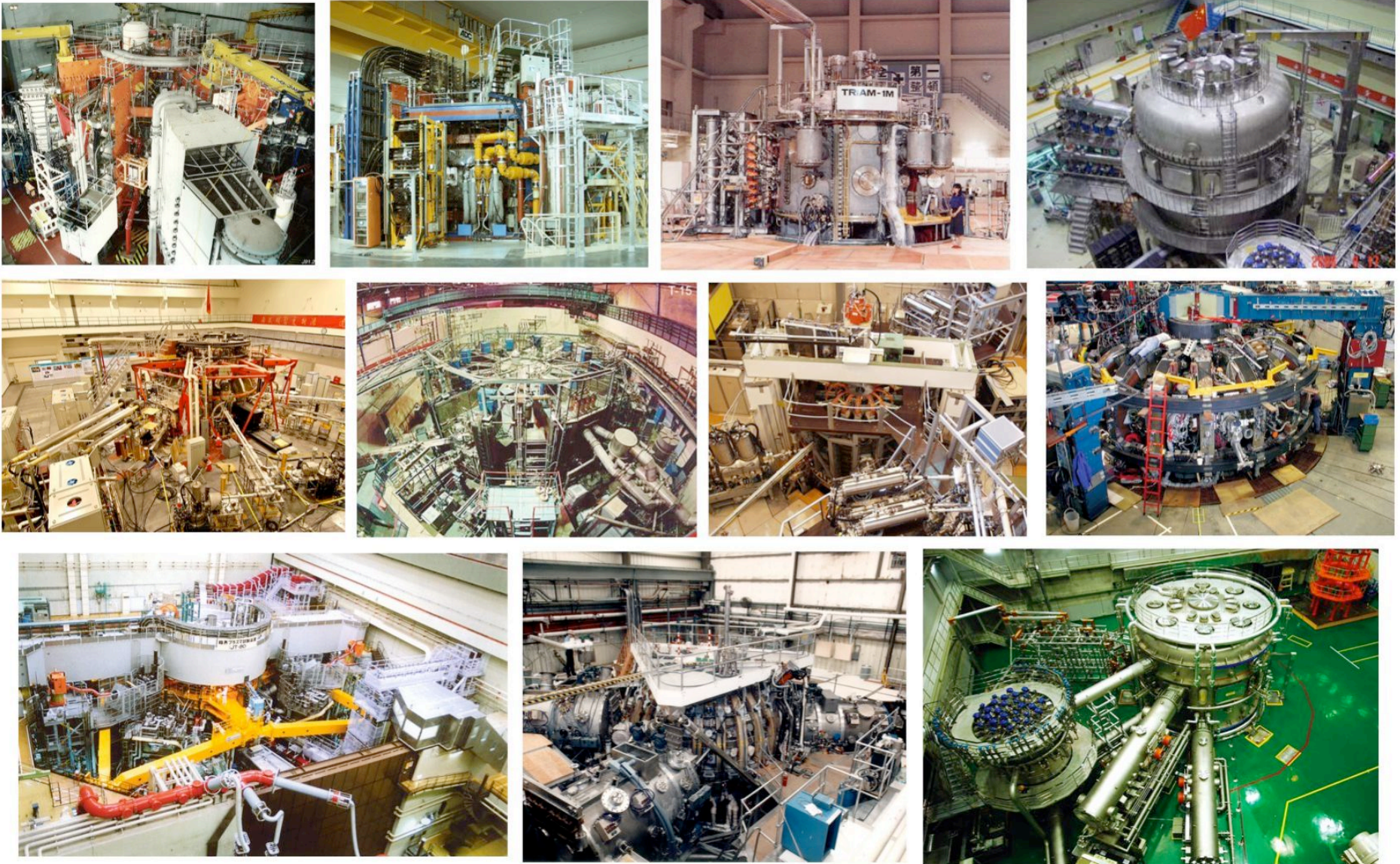


**JET**

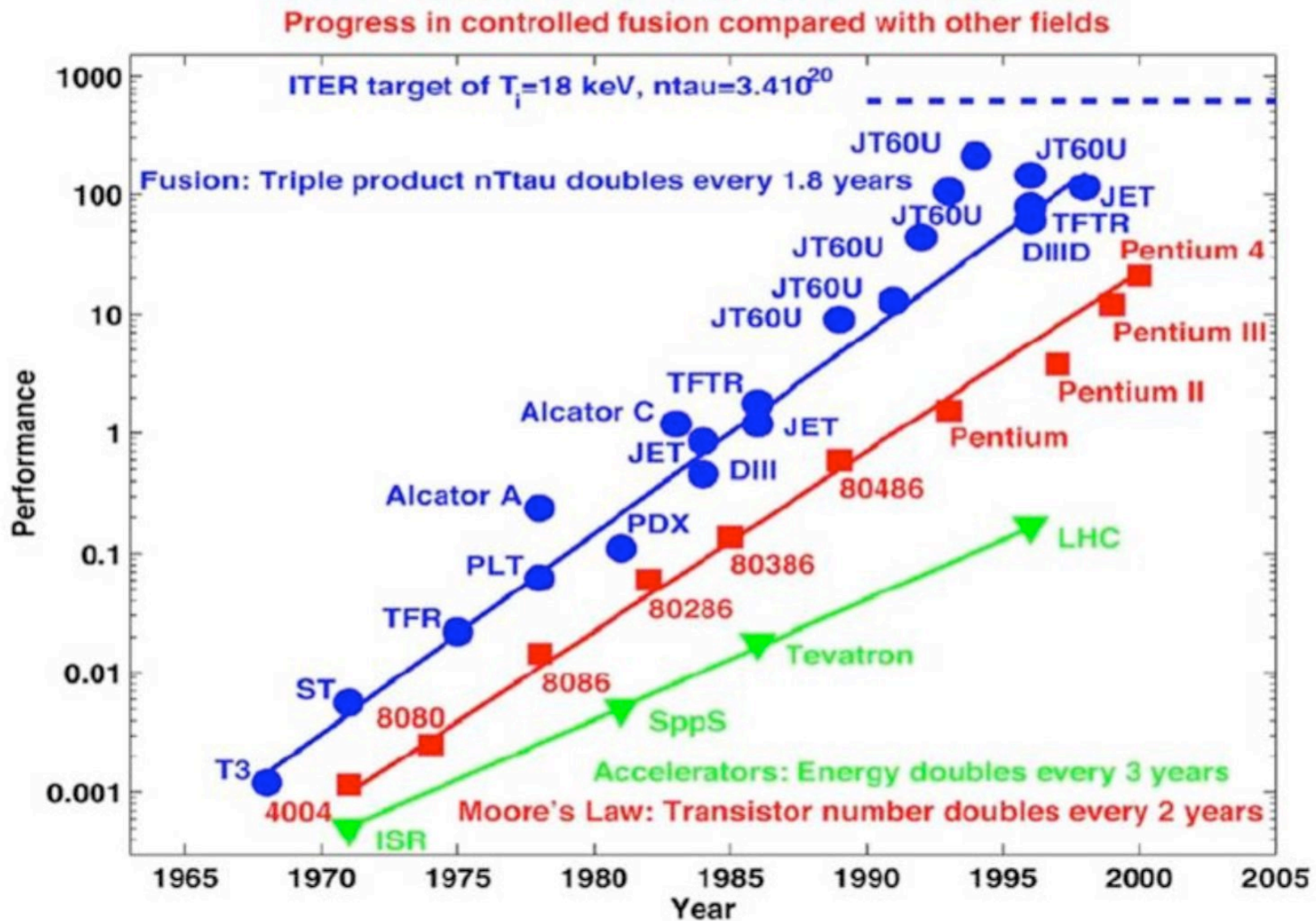
J91.2



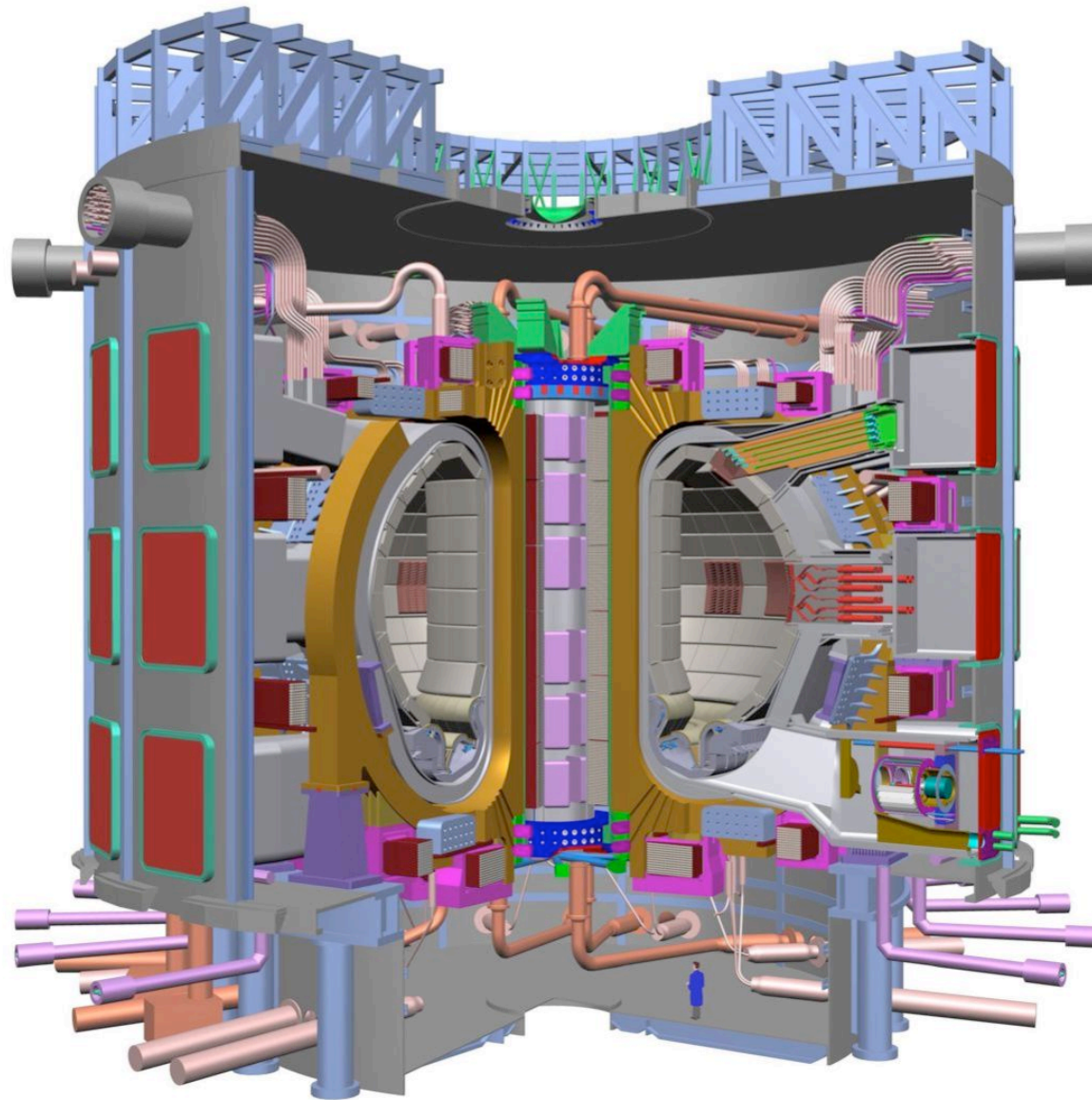
# Worldwide many fusion devices contribute understanding



# Fusion progress - faster than Moore's law



# Government-backed concepts: more power out than in soon

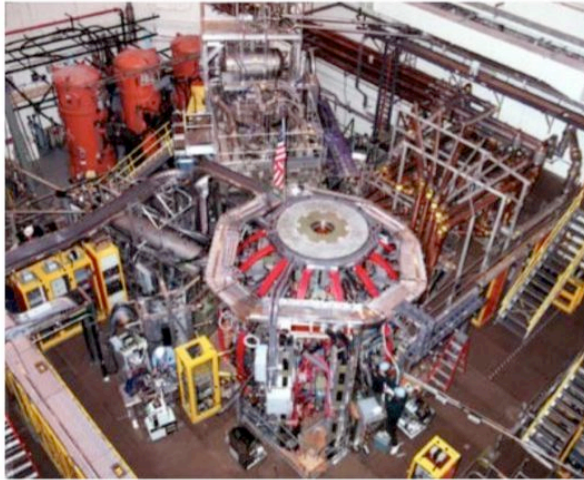


**ITER**

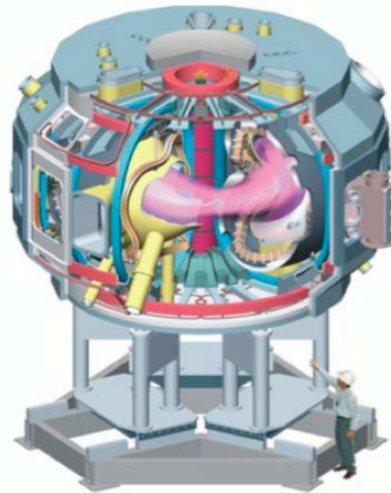
2020

# US government also backs alternative systems

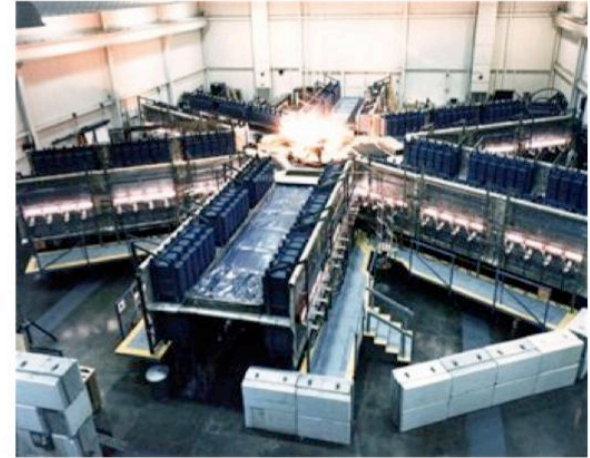
**Spherical tokamaks**



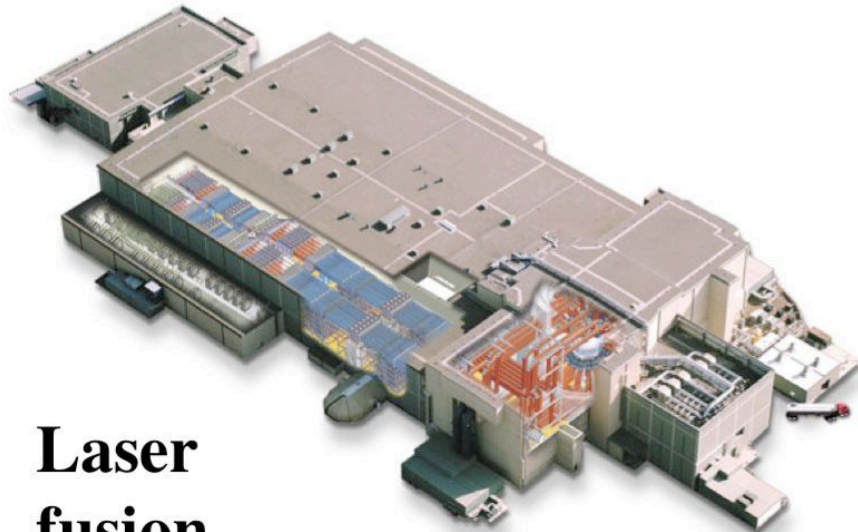
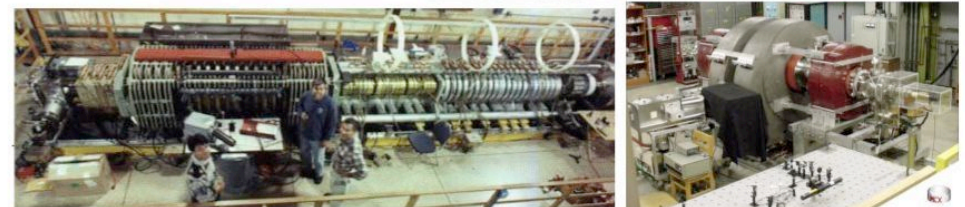
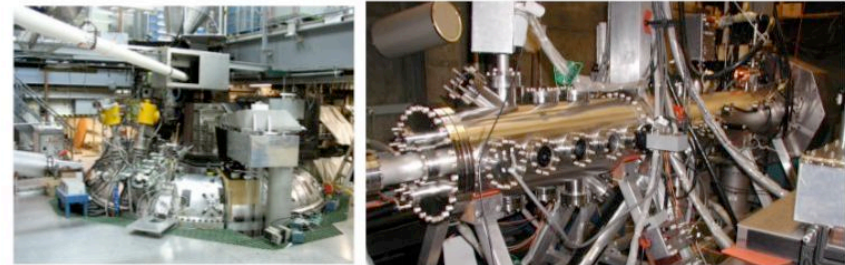
**Stellarators**



**Magnetized target fusion**

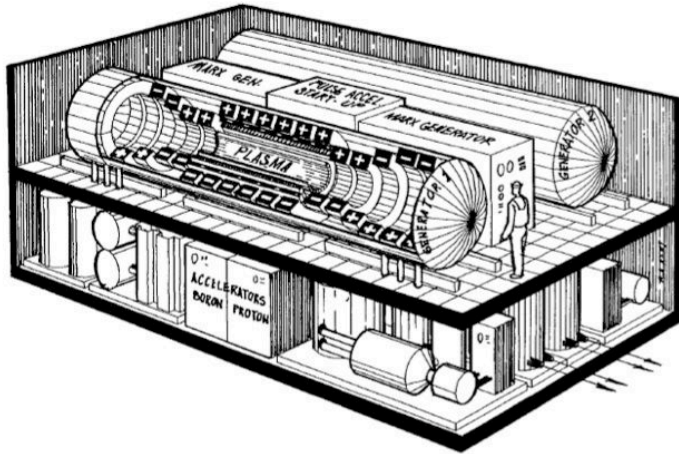


**Compact Fusion Concepts**

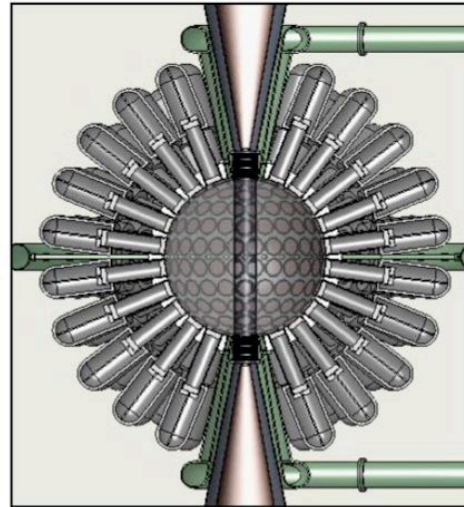


**Laser fusion**

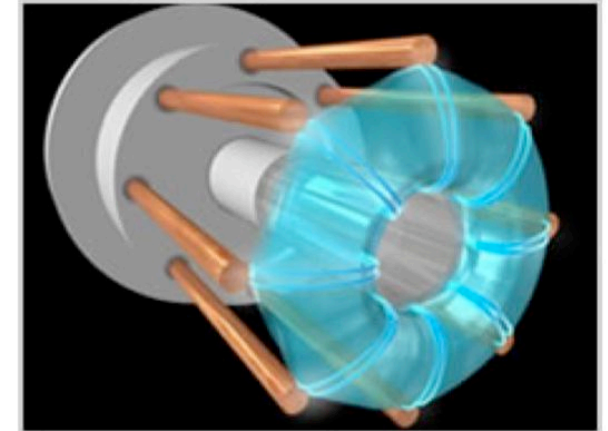
# Many companies think “Smaller is better!”



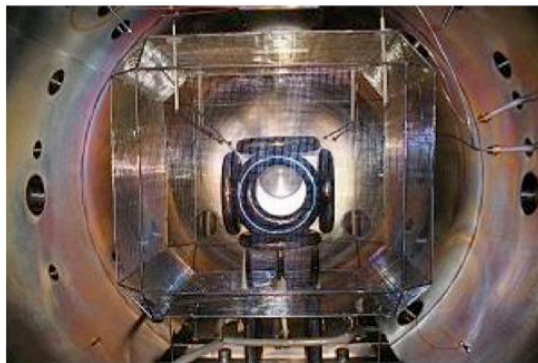
Tri-Alpha Energy (\$100M)



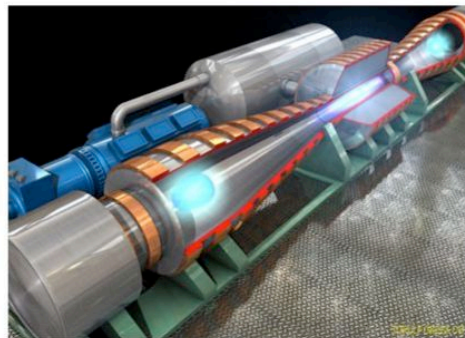
General Fusion (\$20M)



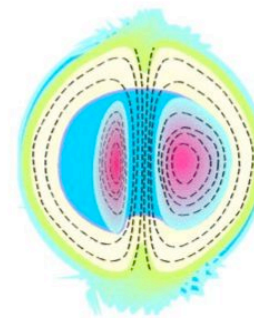
Lawrenceville (\$1.2M)



EMC2 (\$9M)



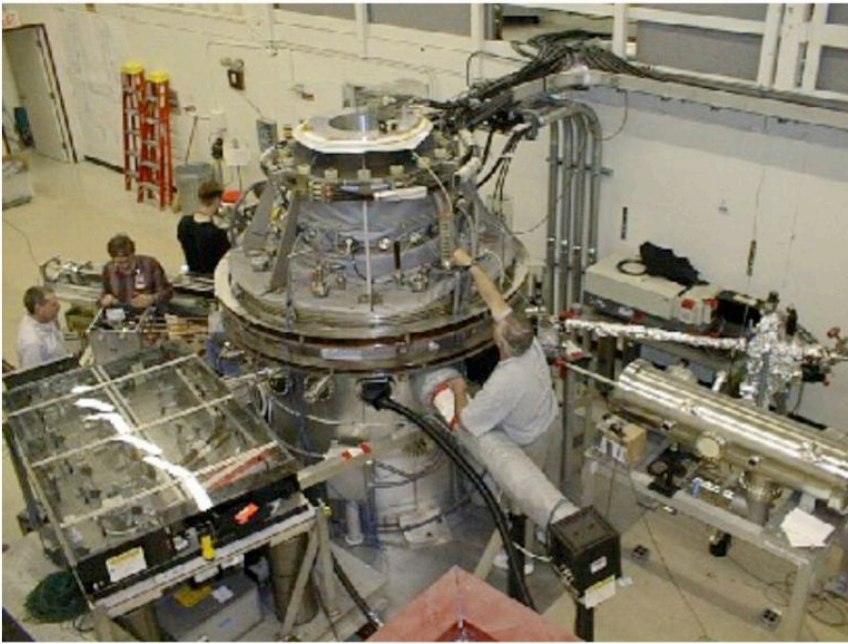
MSNW



PLASMAK

...

# Our system combines compact fusion with a large diesel



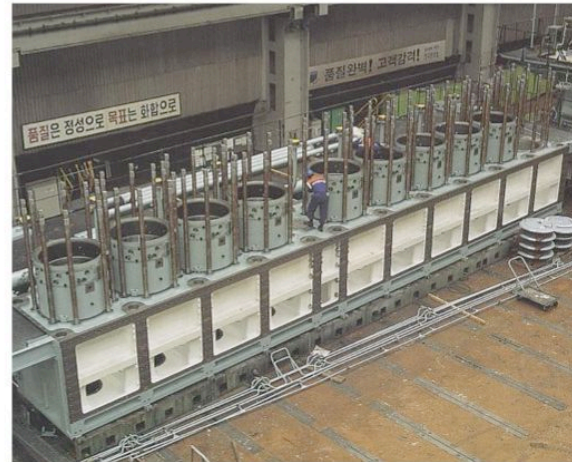
**Spheromak SSPX (1999-2009)**

**$R=0.3m, a=0.15m, B=1T, I_p=1MA$**

**Thomson Scattering measurement of temperature  $\sim 0.5keV$ .**

6/18/10

+



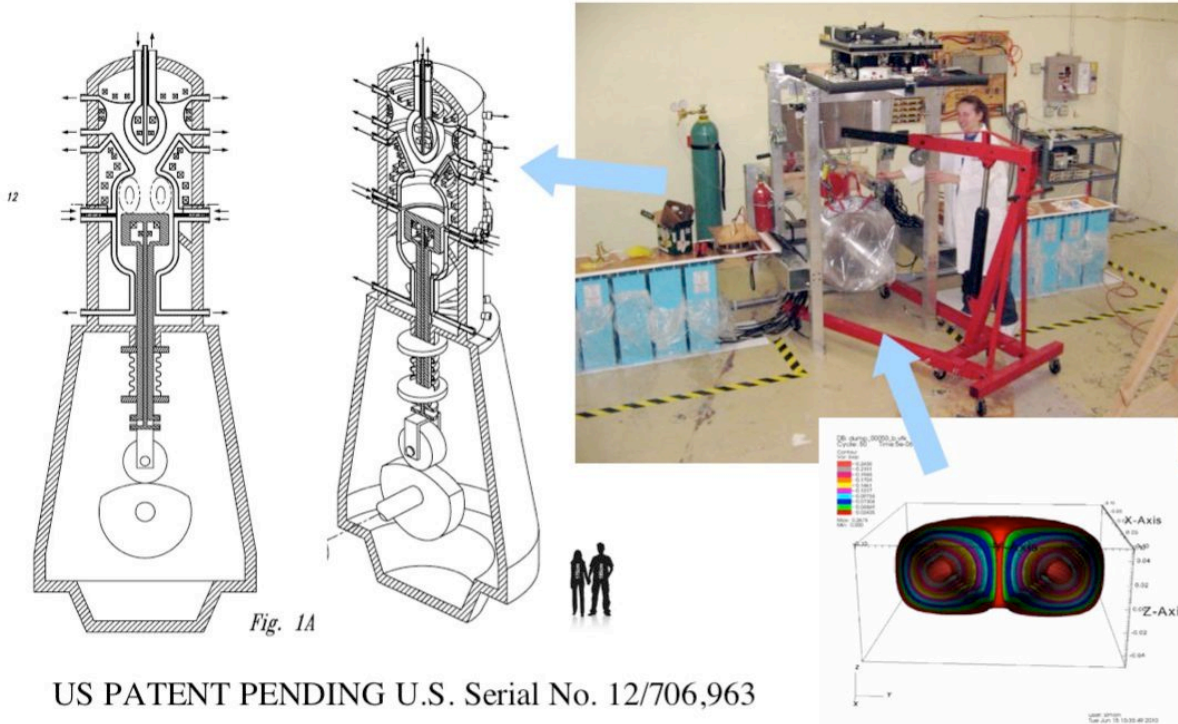
**Wartsila-Sulzer RTA96-C**

WSI

14



# We have patented the concept. Building a scale version (DOE)



## WSI Team



Woodruff



Mattor



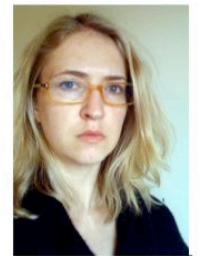
Marston



Woodruff

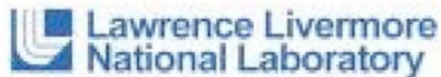


Stoullil



Woodruff

## Partners



## Scientific Advisory Board

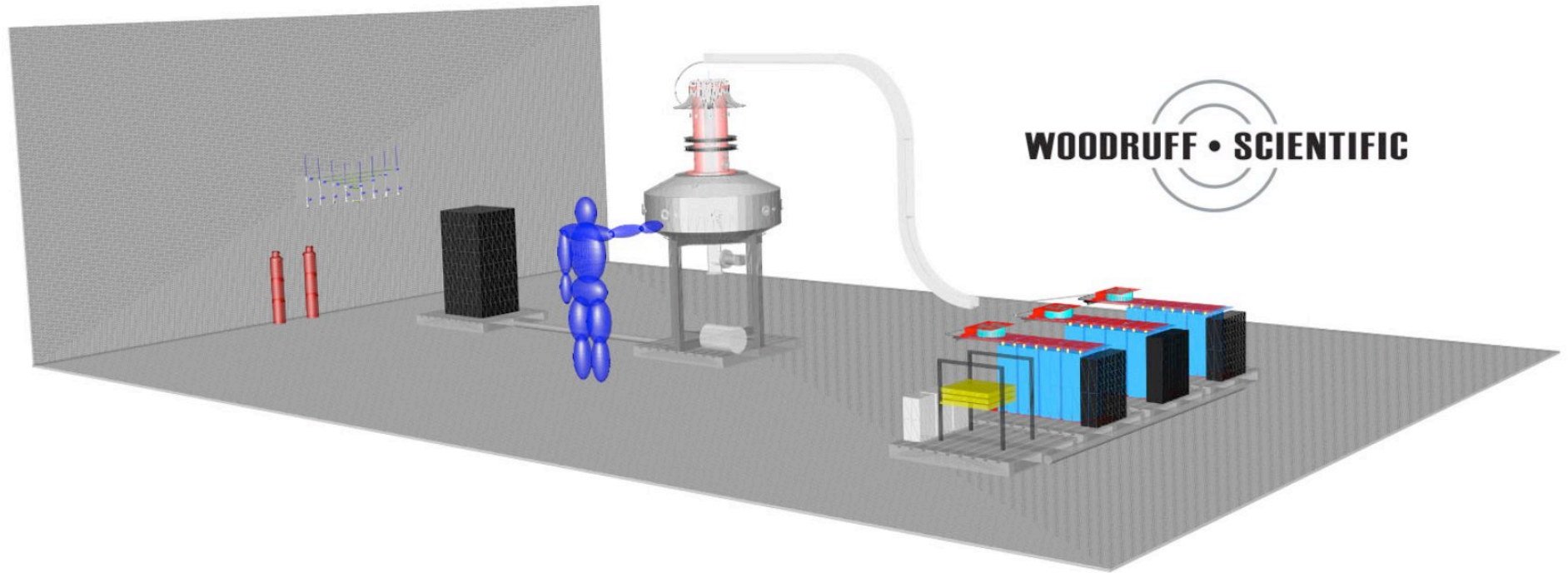


WSI



# We also build systems to spec

---



Critical discoveries for fusion have only been made in the last century.

MANY 100's of devices built in the lab have drawn inspiration from astro and space plasmas --> **fundamental physics understood.**

Technology development program now in race for goal of economic fusion energy.

(...we are also due another NP for fusion science!)