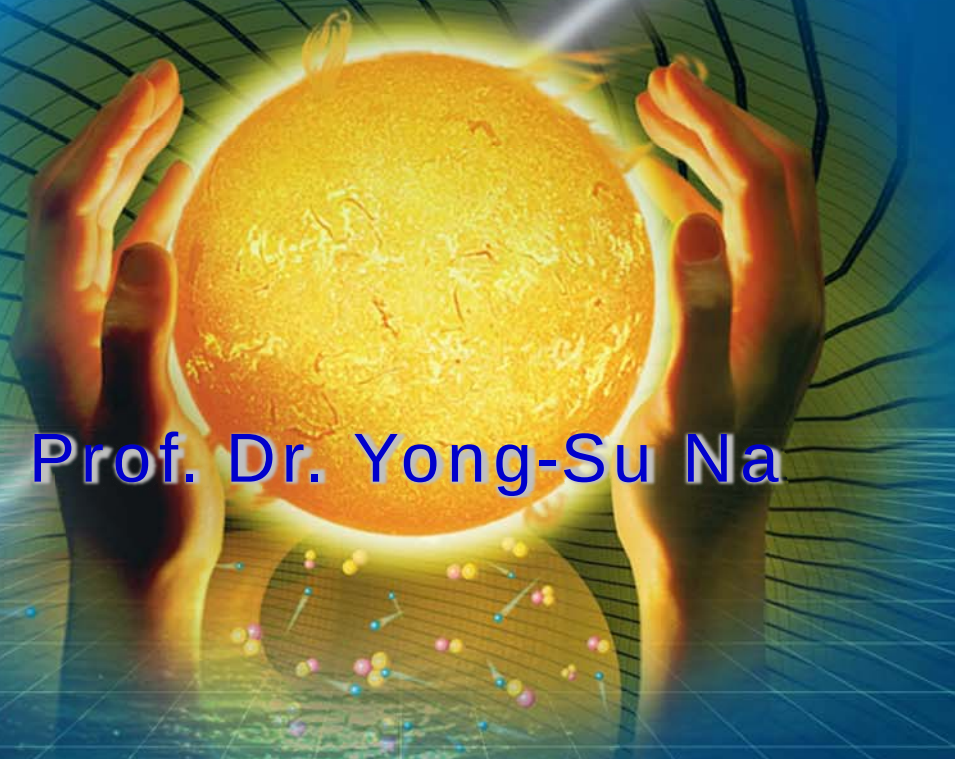
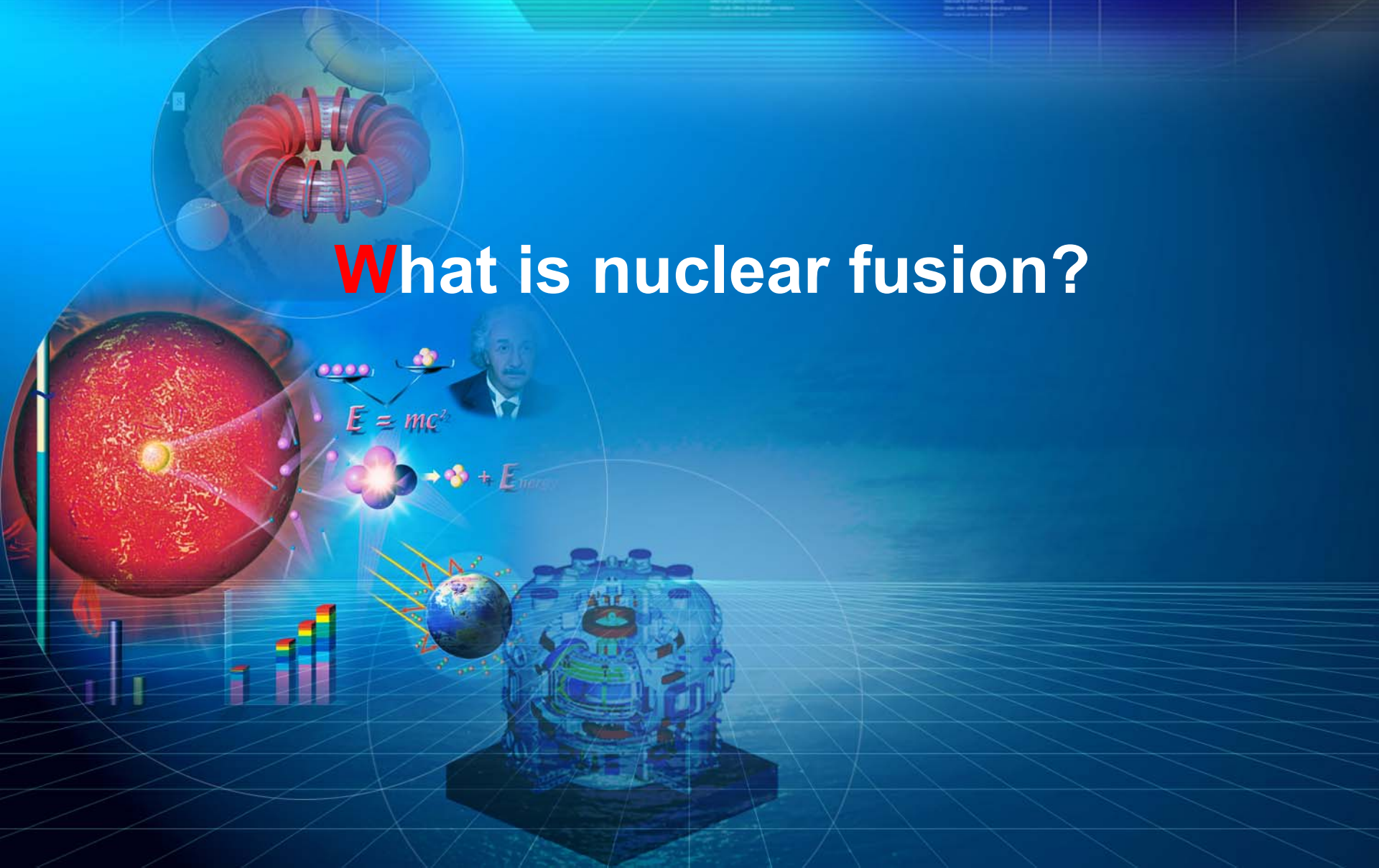
Present Status and Future Prospect of Nuclear Fusion



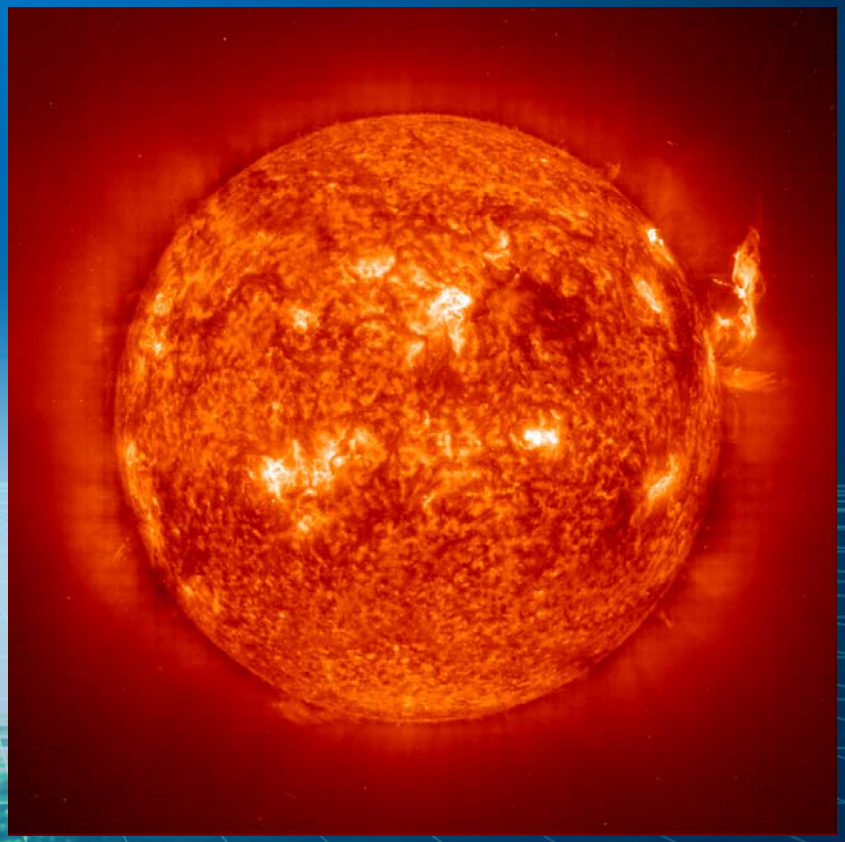
Prof. Dr. Yong-Su Na

Contents

What is nuclear fusion?

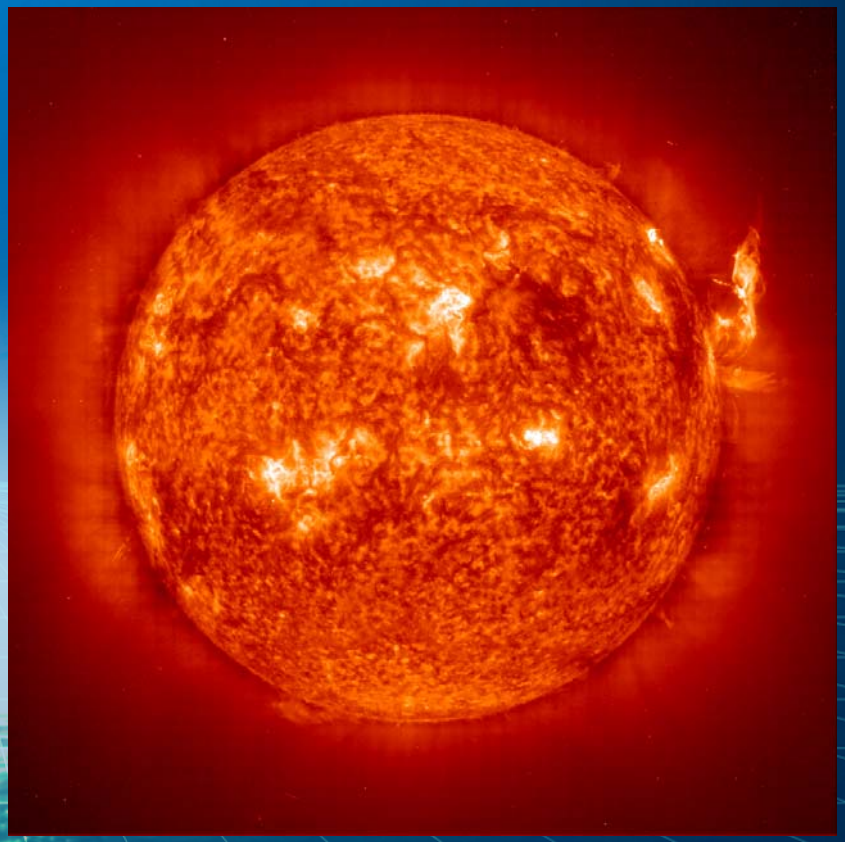


Origin of the Star Energy

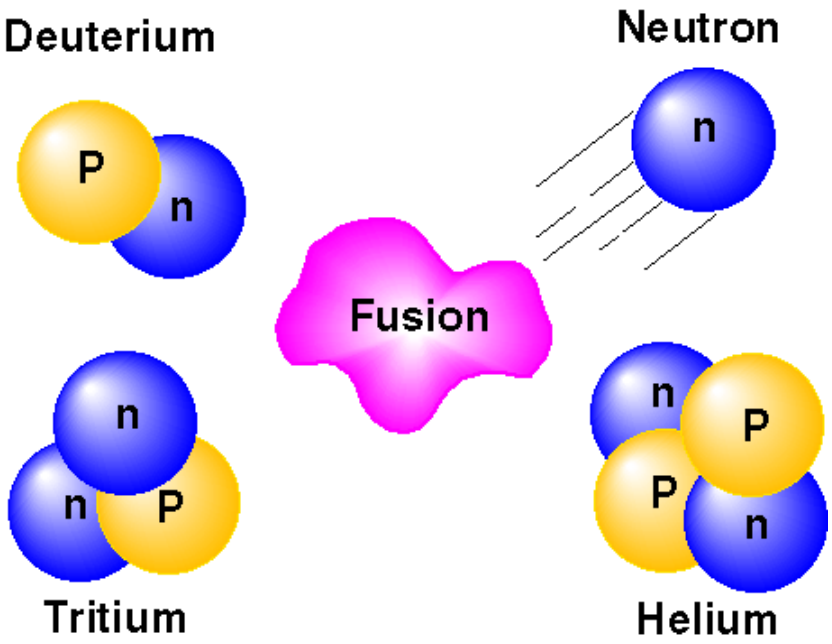


Origin of the Star Energy

Thermonuclear fusion



Nuclear Fusion Reaction

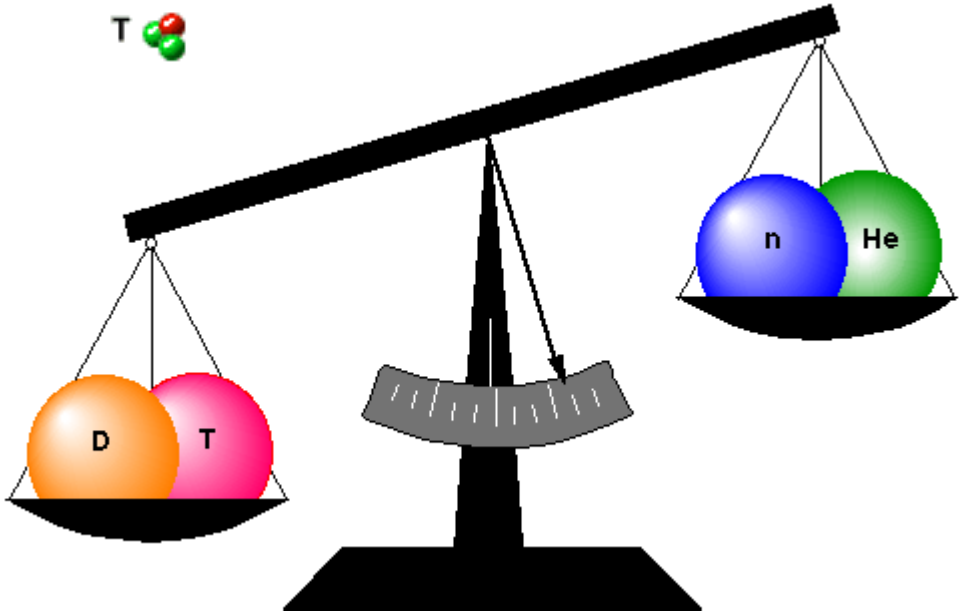


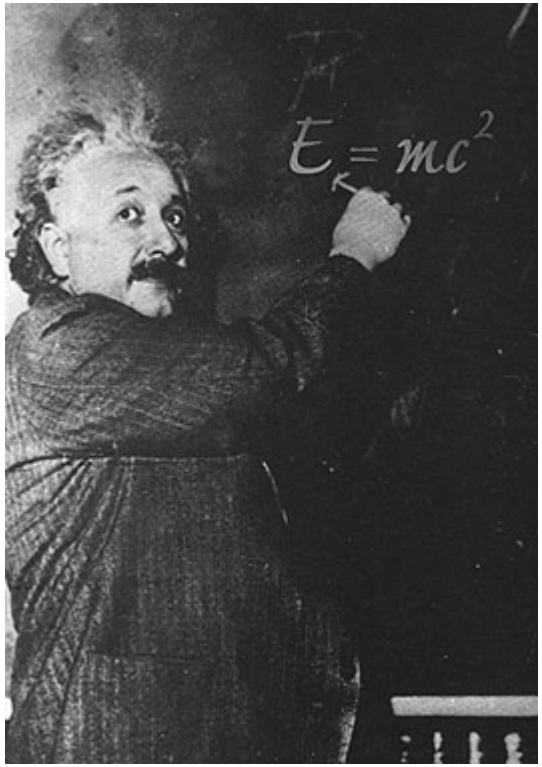
D

T

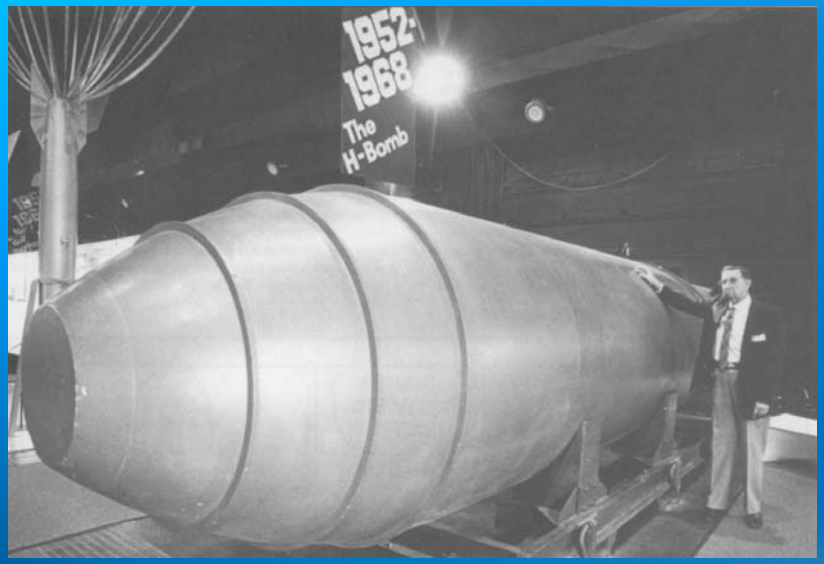
Nuclear Fusion Reaction

D





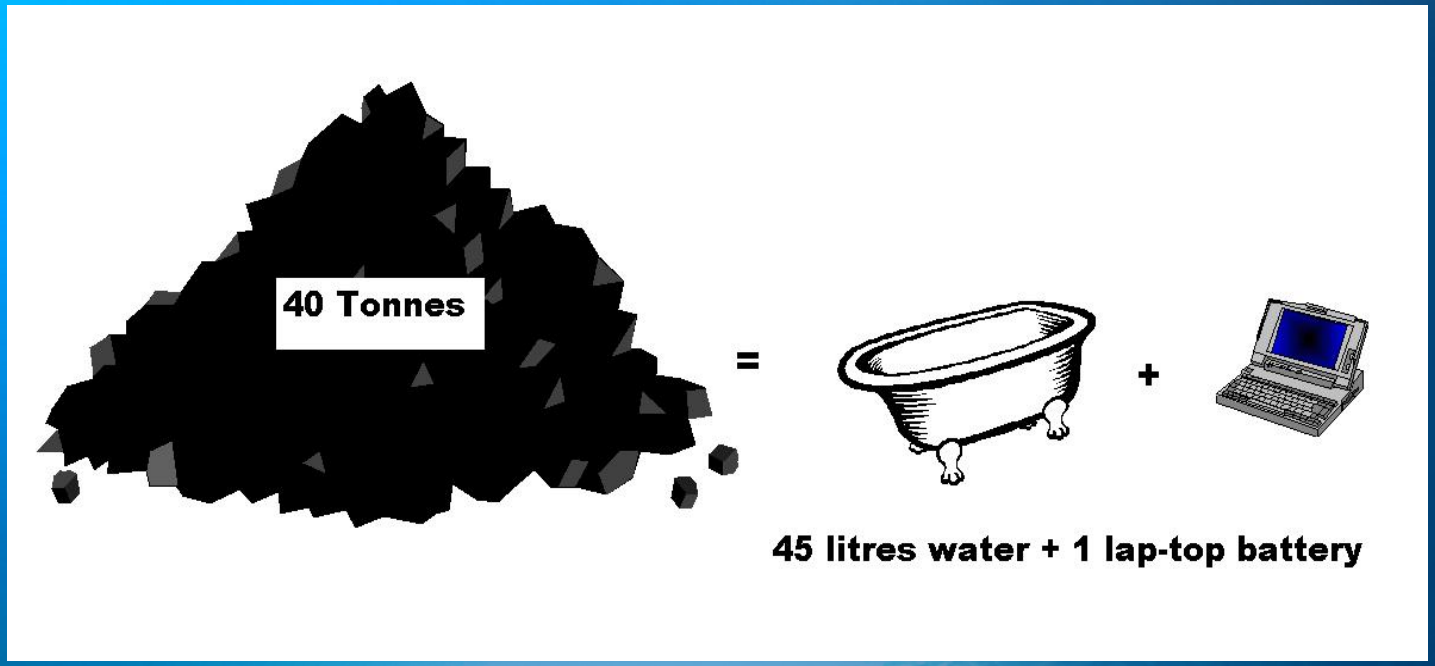
Utilisation of the Fusion Energy



A Mark-17 Hydrogen bomb at
the National Atomic Museum

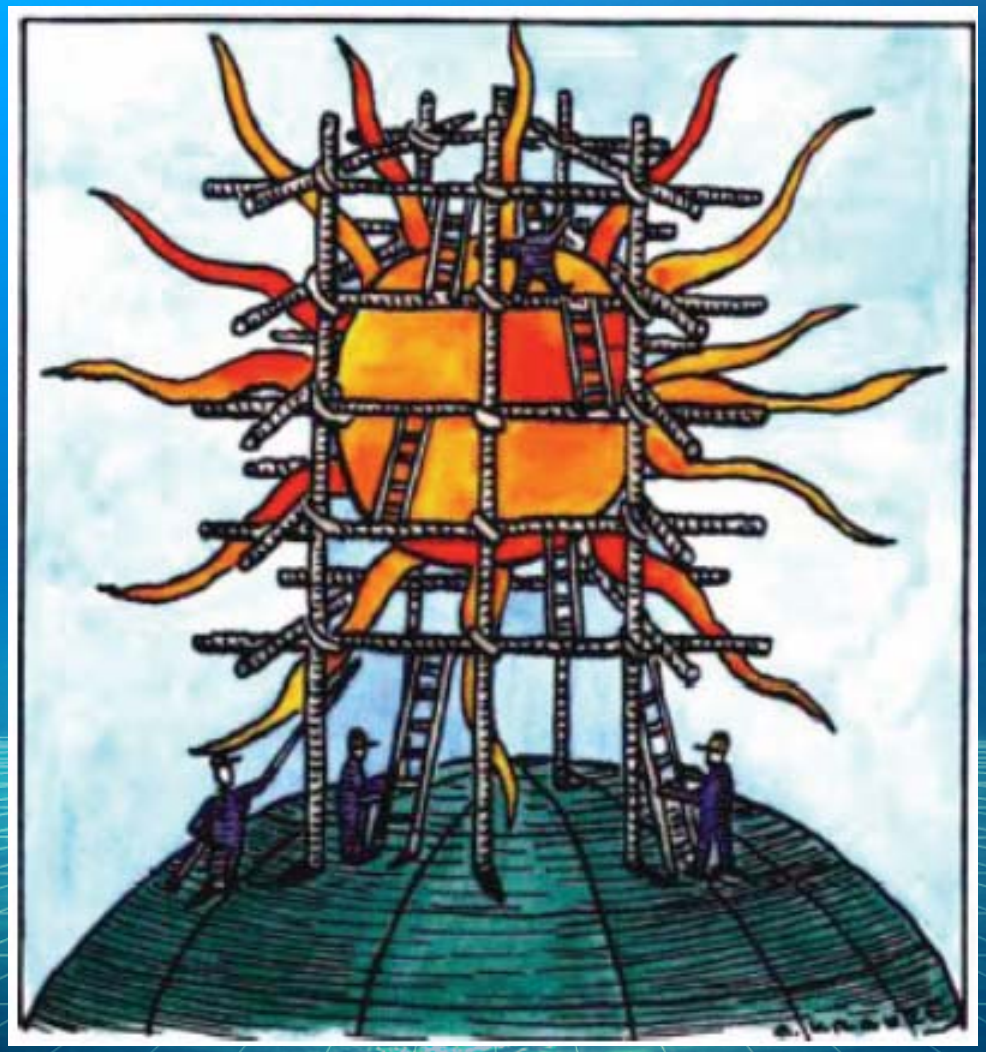
Peaceful use of the fusion energy?

Peaceful Use of the Fusion Energy

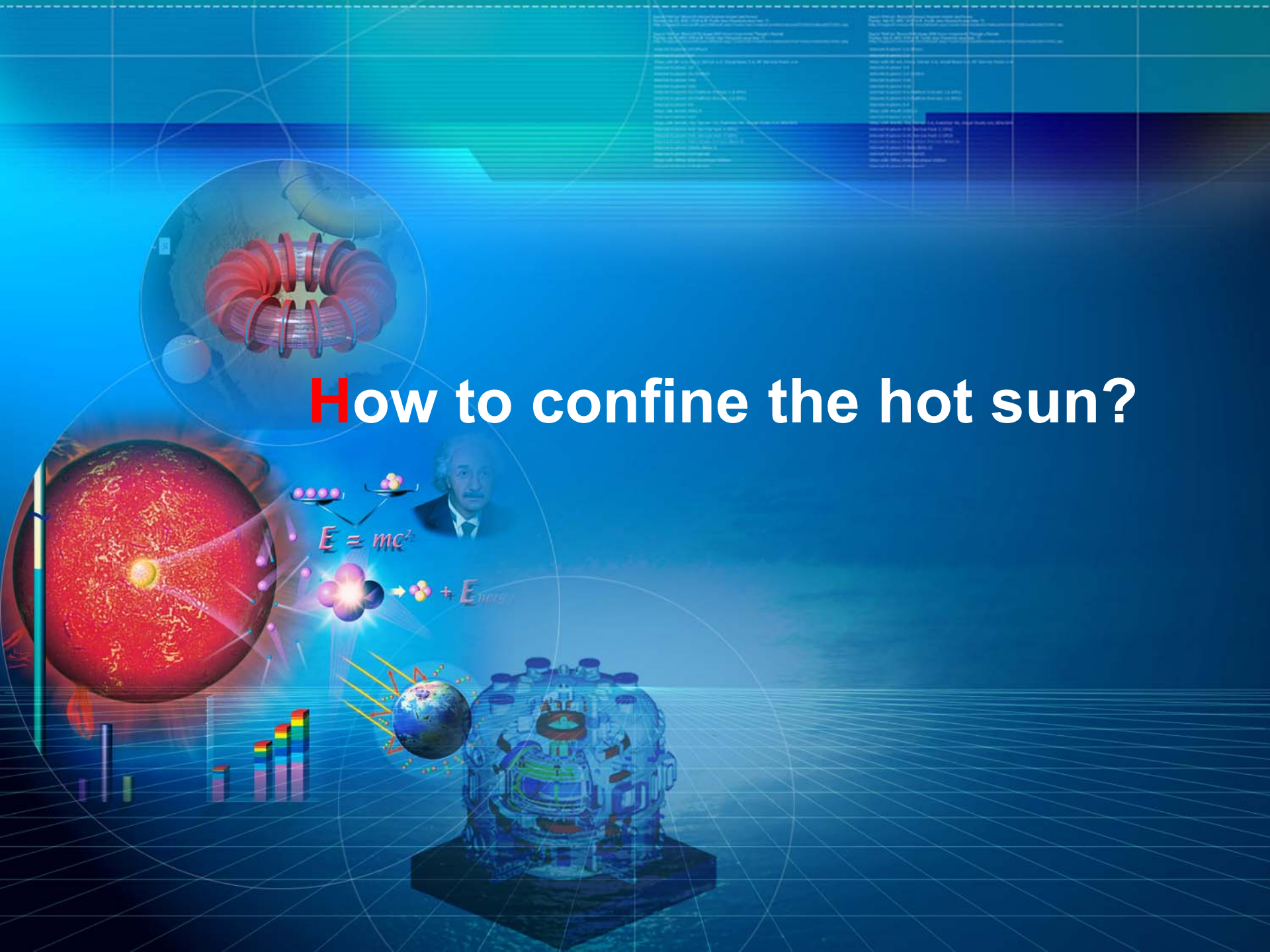


- Lithium in one laptop battery + half a bath-full of ordinary water (≥ one egg cup full of heavy water) = 200 MW

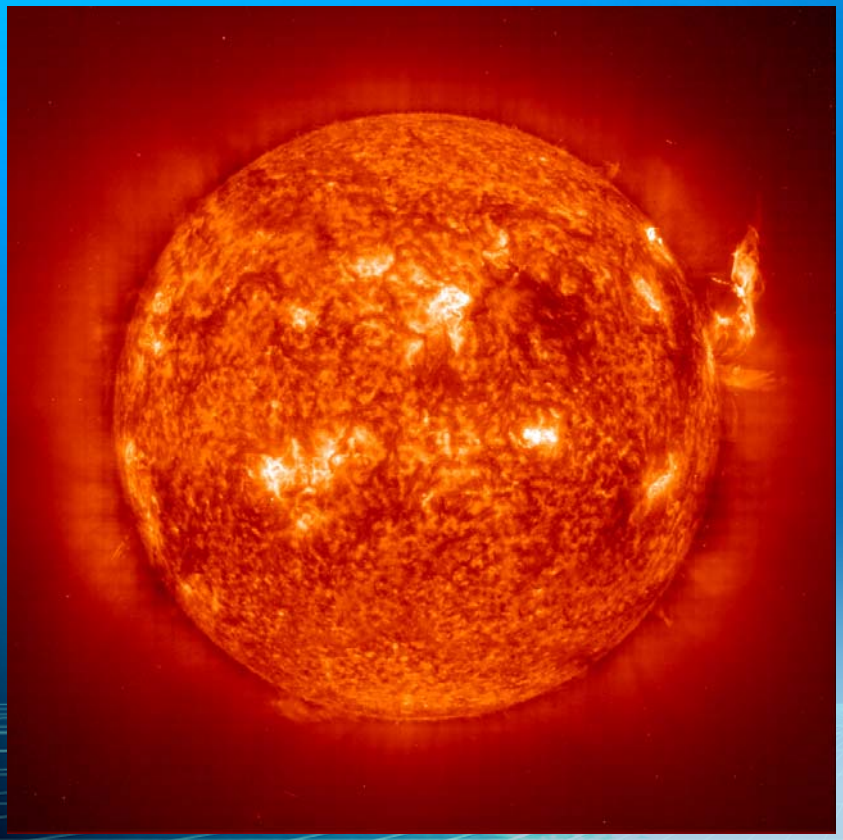
Build a Sun on the Earth



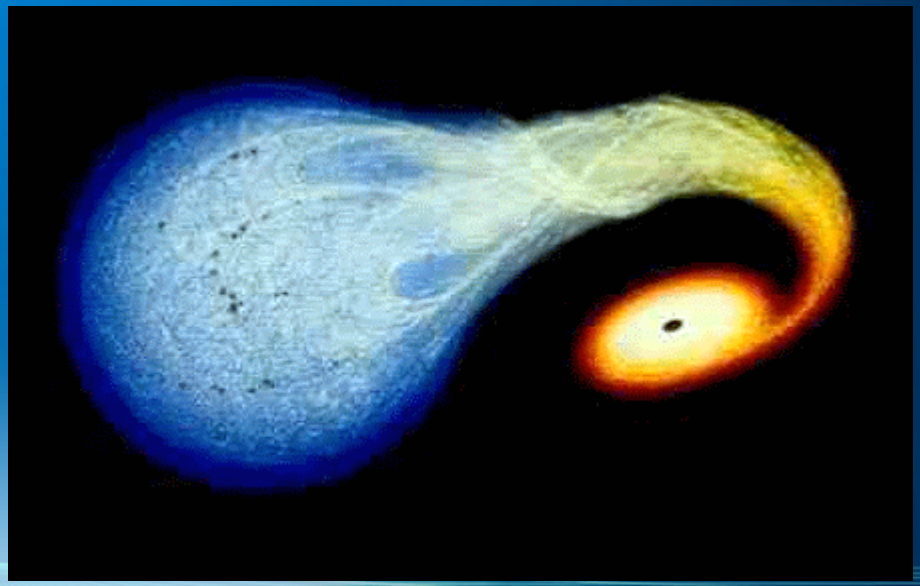
Iron Man


How to confine the hot sun?
E = mc²

Gravitational Confinement

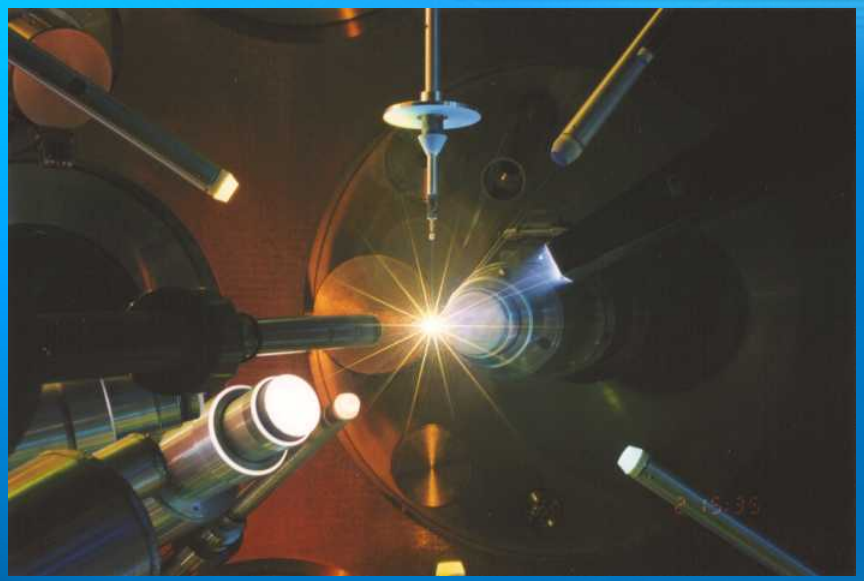


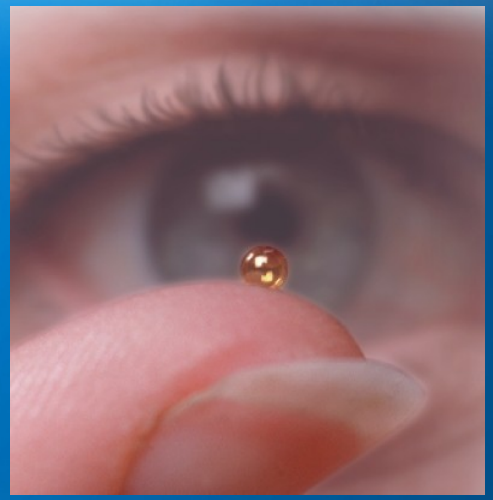
The sun



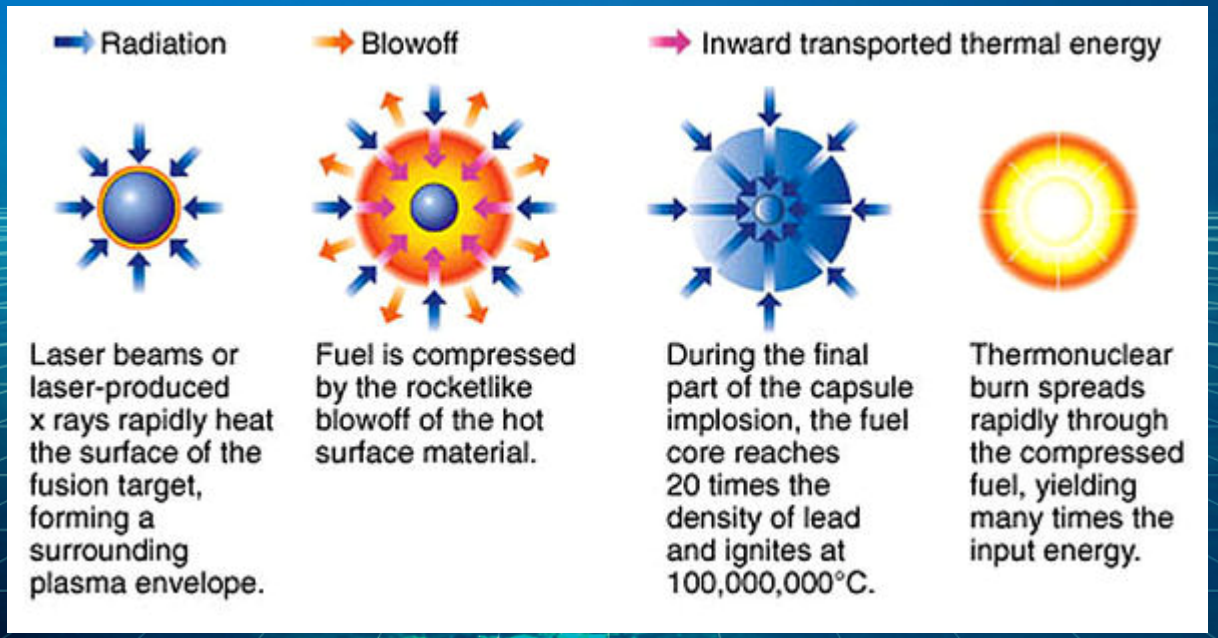
Black hole

Inertial Confinement

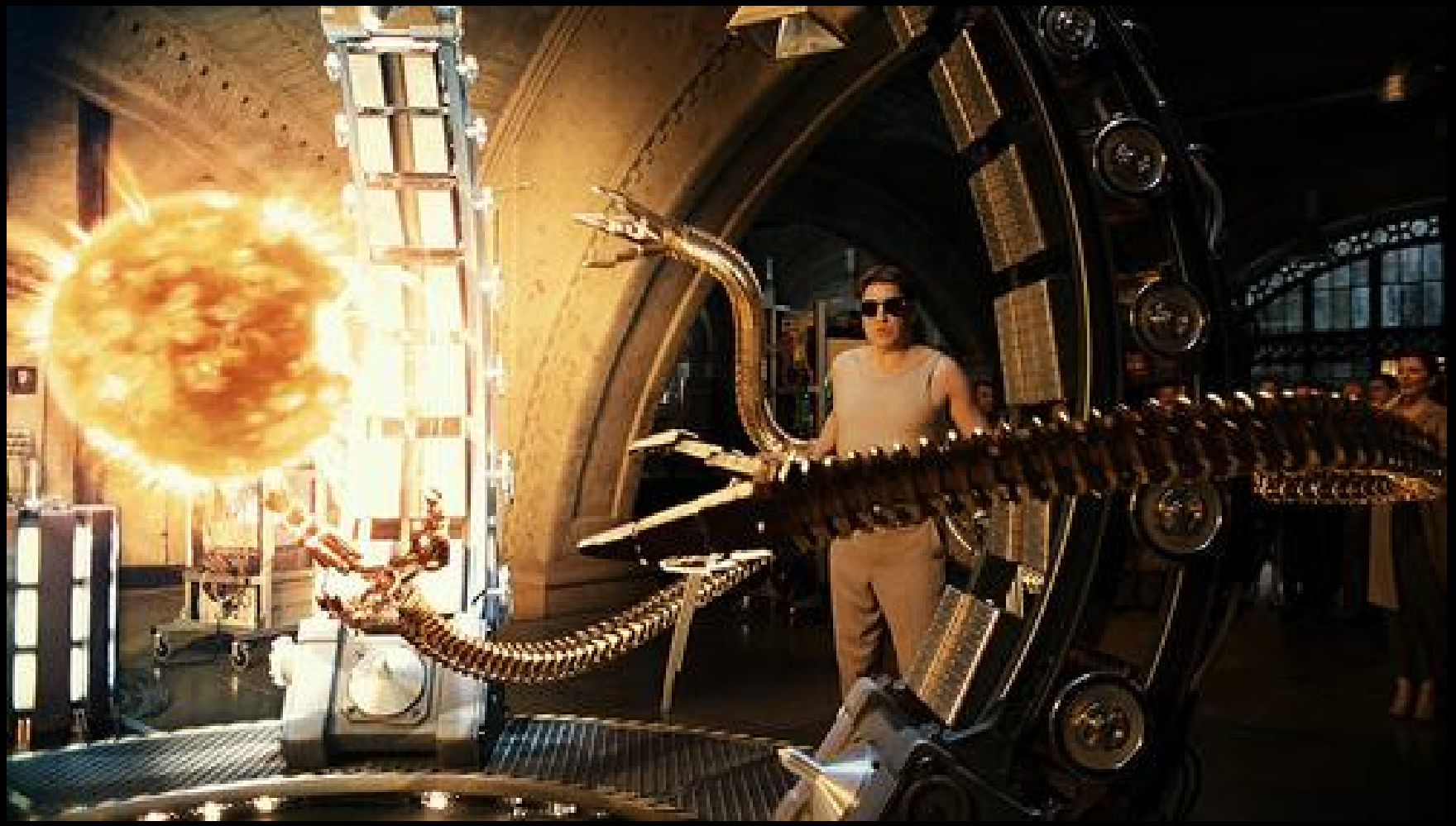




Fusion fuel microcapsule (microballoon)



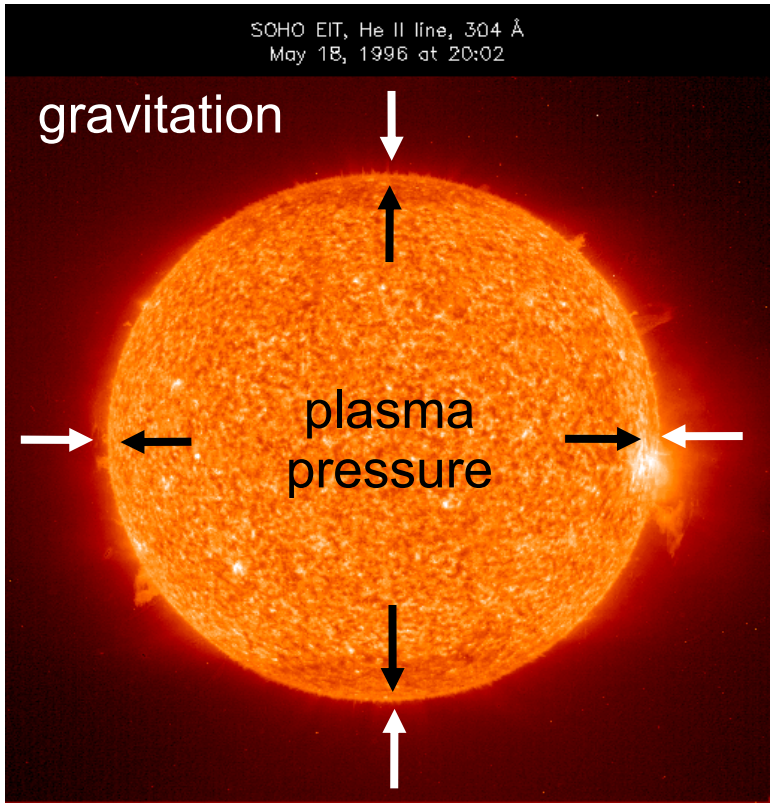
Spiderman II



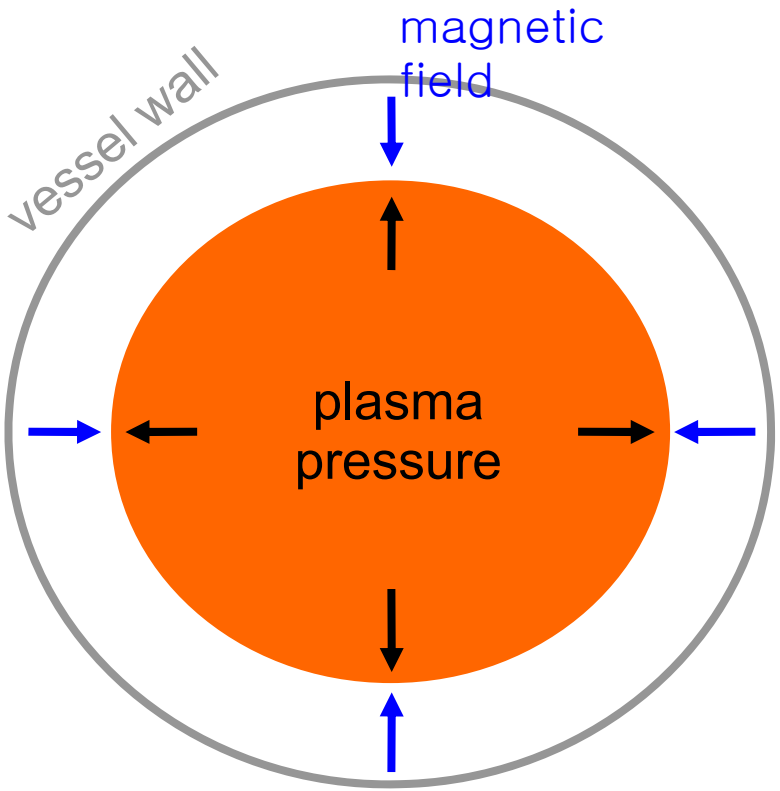
Spiderman II

Magnetic Confinement

- **Imitation of the Sun on Earth**

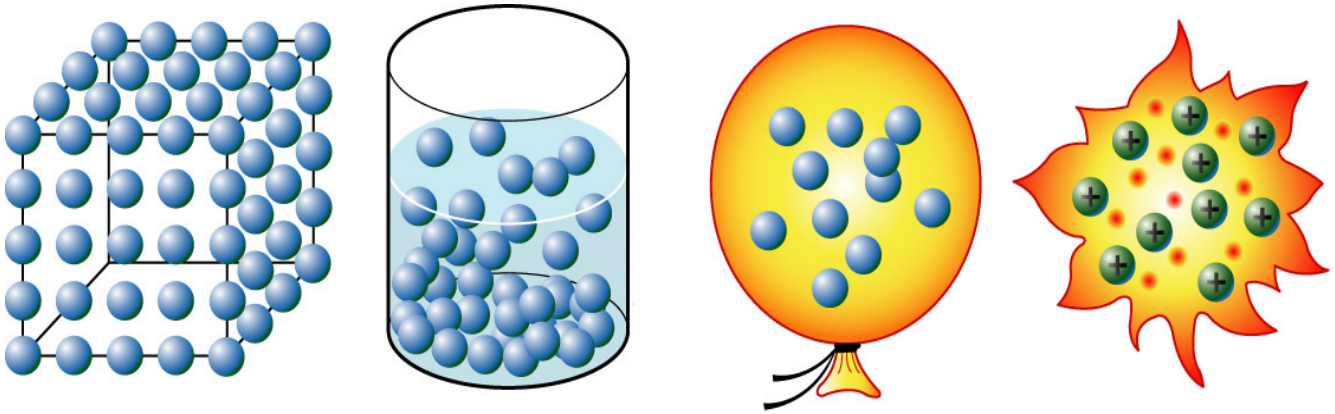


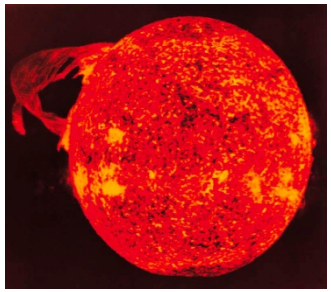
Equilibrium in the sun



Plasma on earth
much, much smaller & tiny mass!

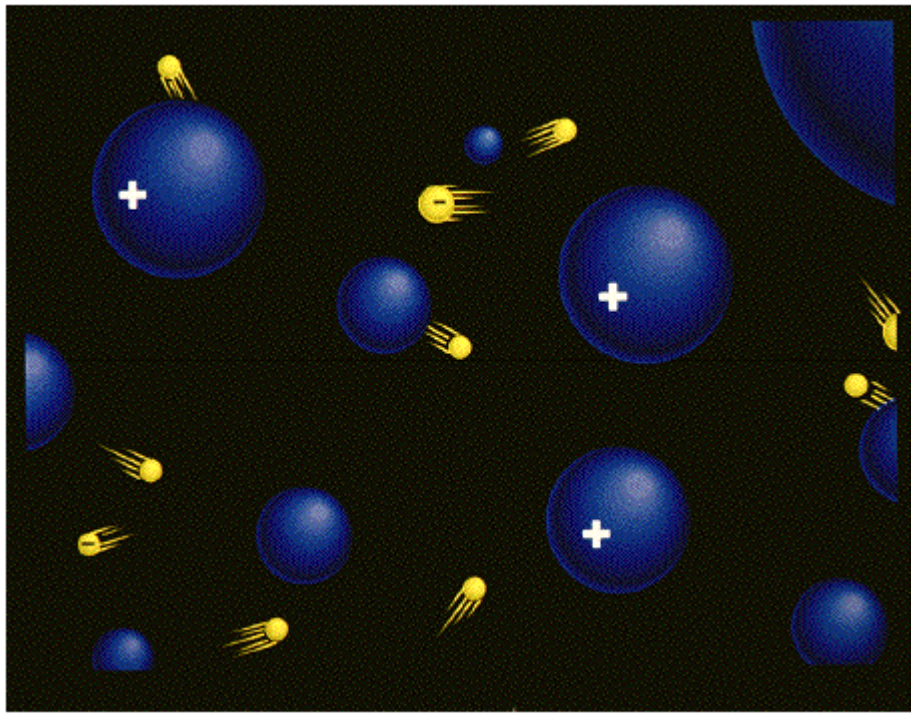
Plasma – The 4th State of Matter

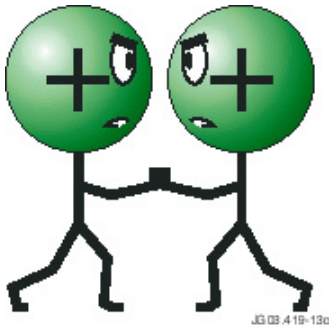




The 4th state of matter

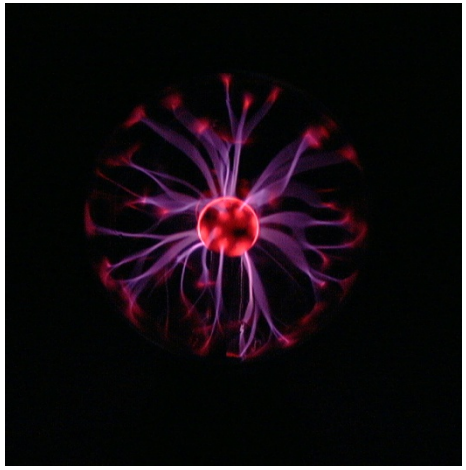
Plasma – The 4th State of Matter





Ions and electrons are separated.

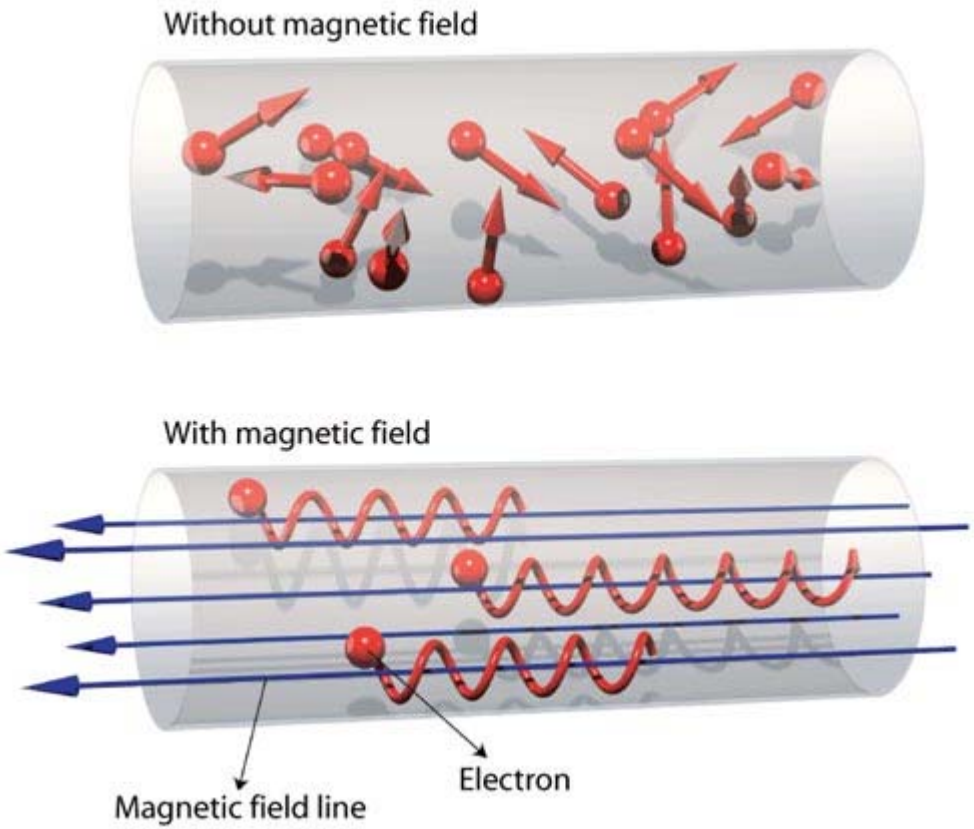
Magnetic Confinement

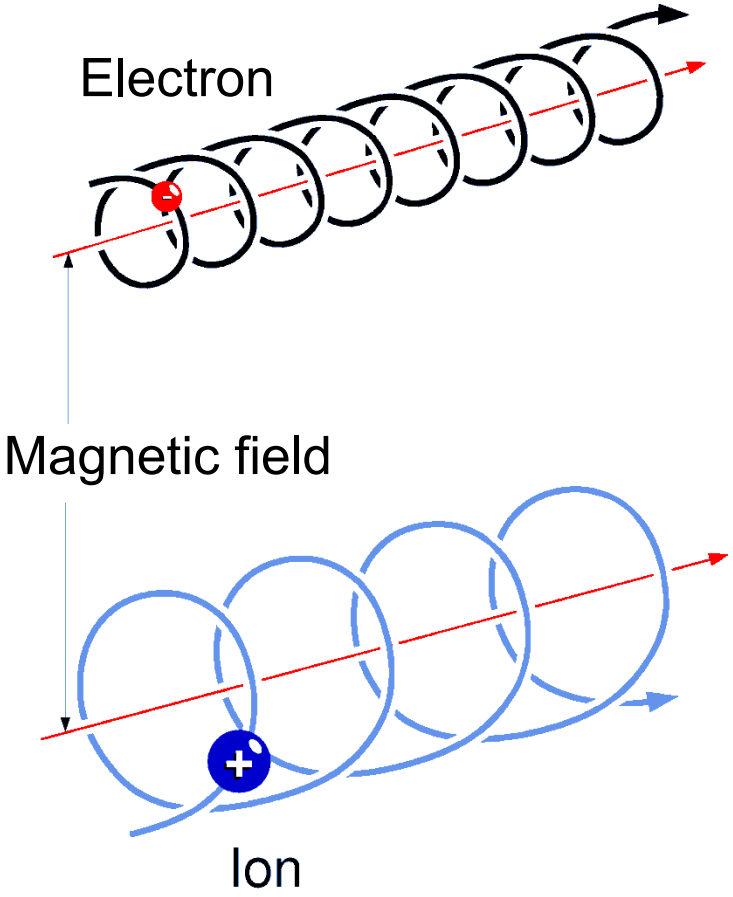


Magnetic field

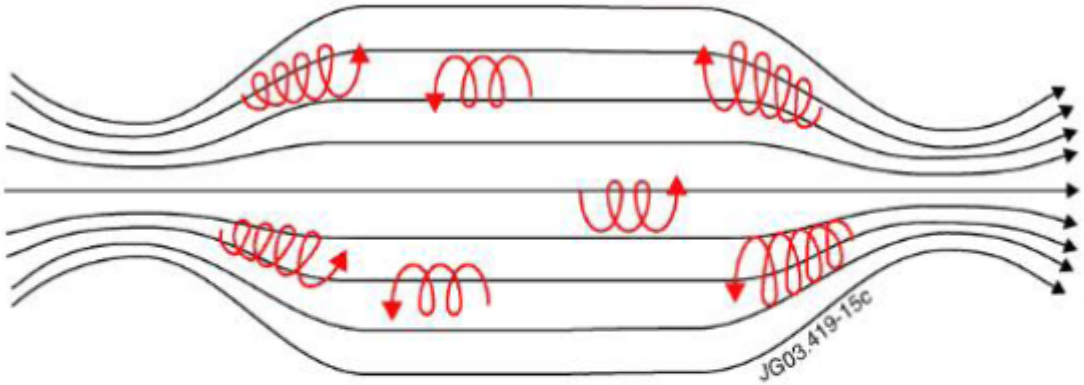
ion

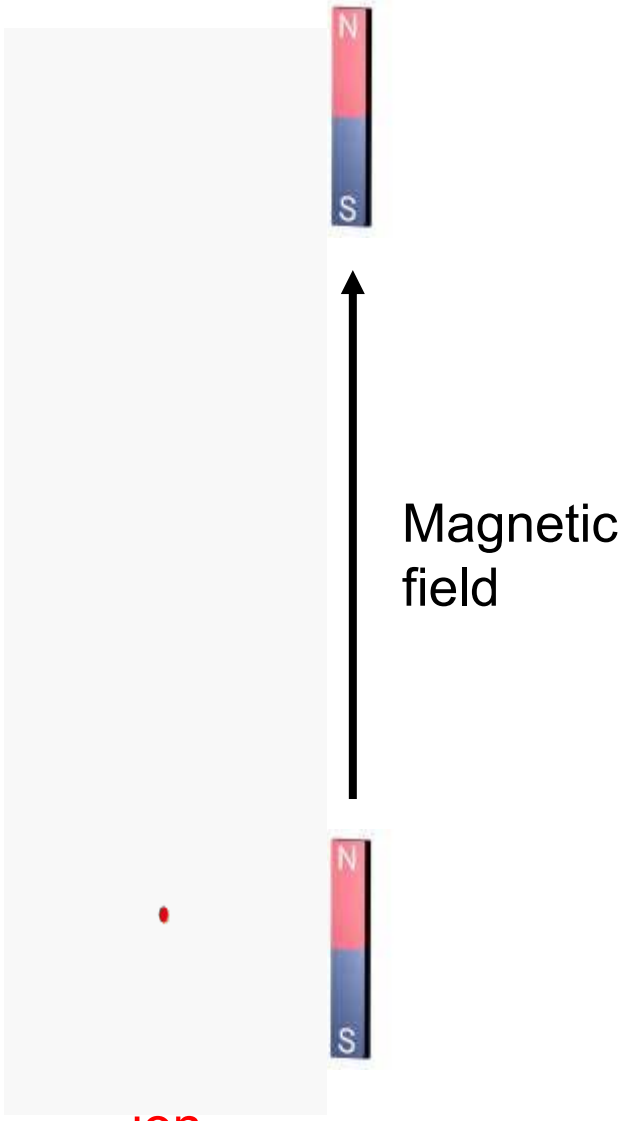
Magnetic Confinement



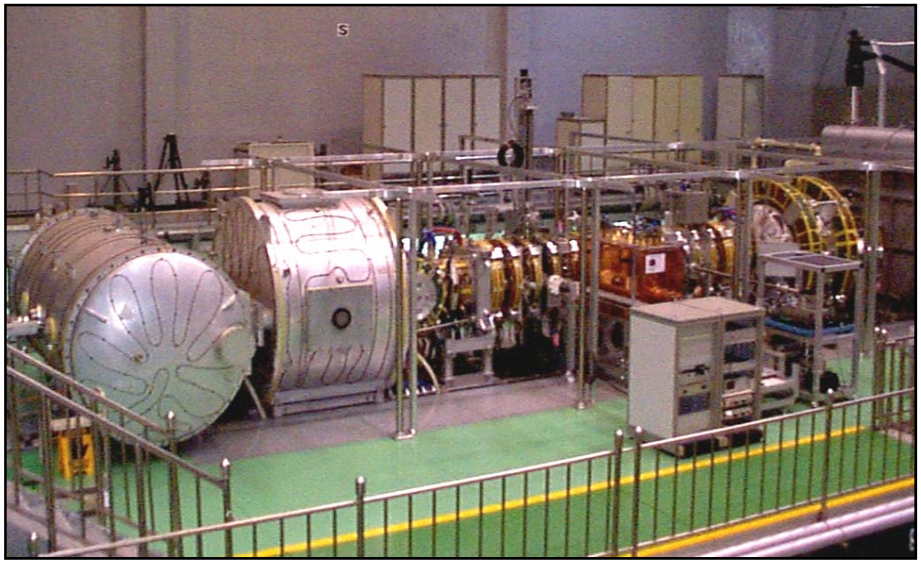


Magnetic Confinement



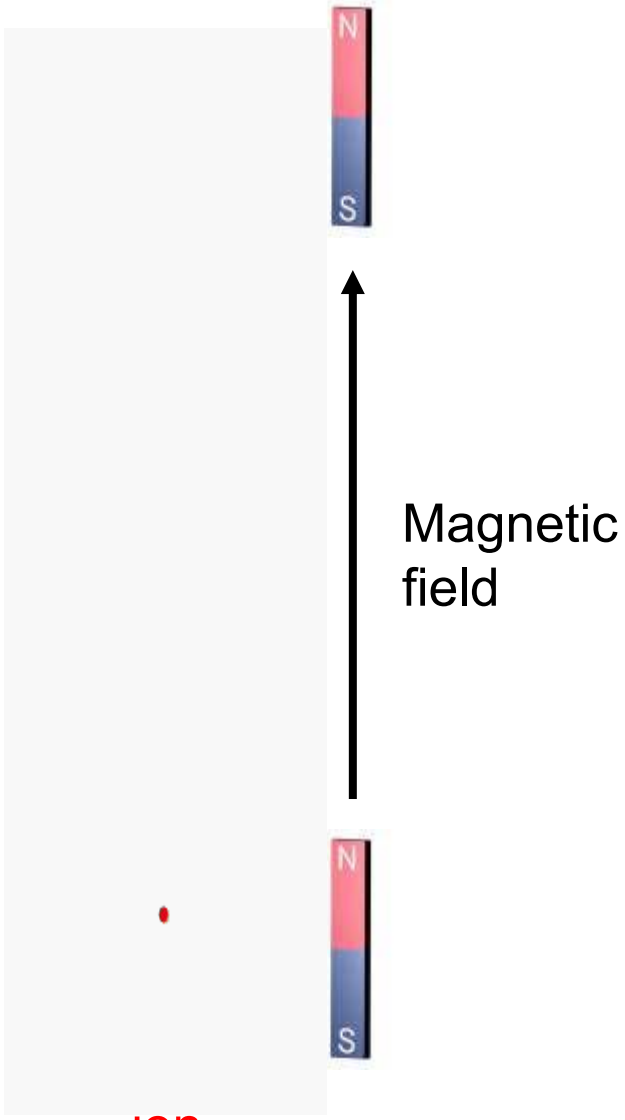


Magnetic Confinement

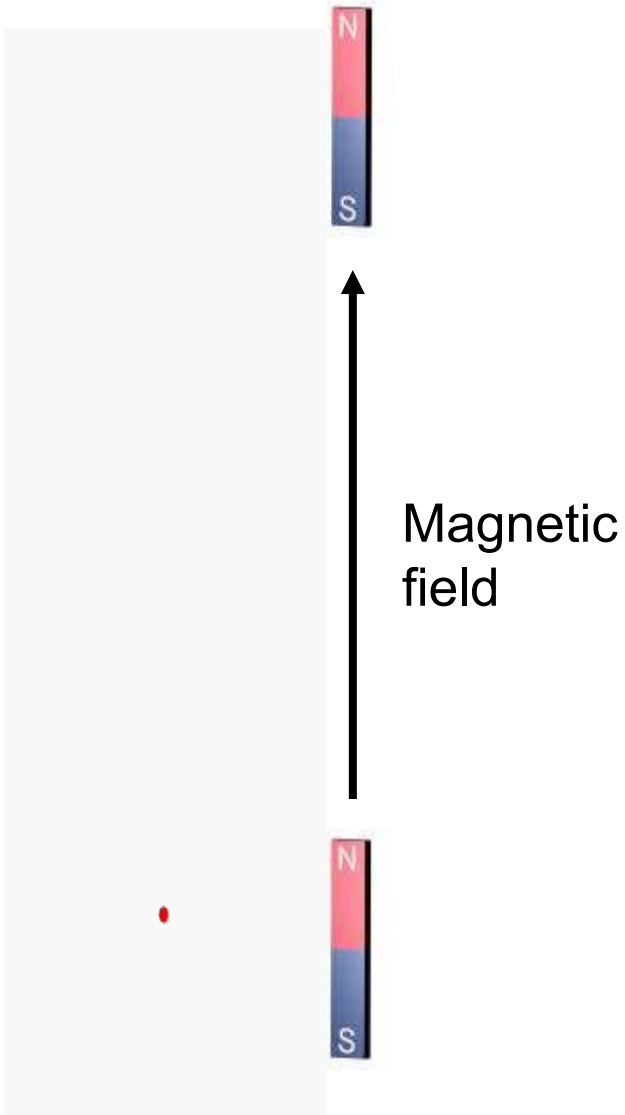


Mirror Machine

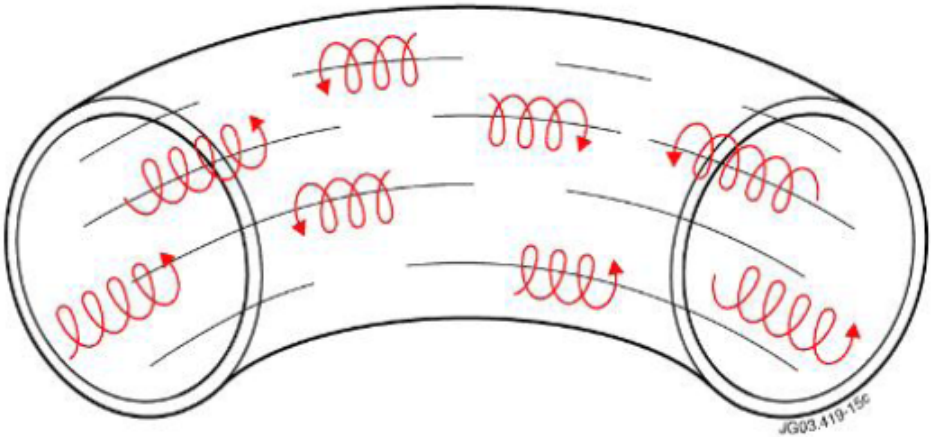
old Hanbit Device in NFRI

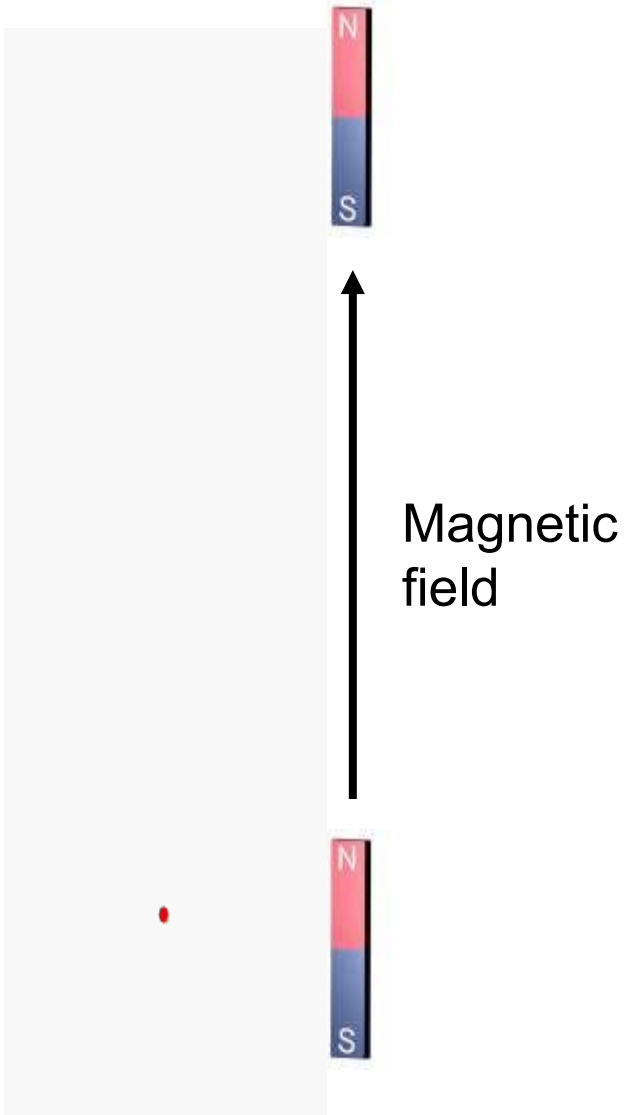


Magnetic Confinement



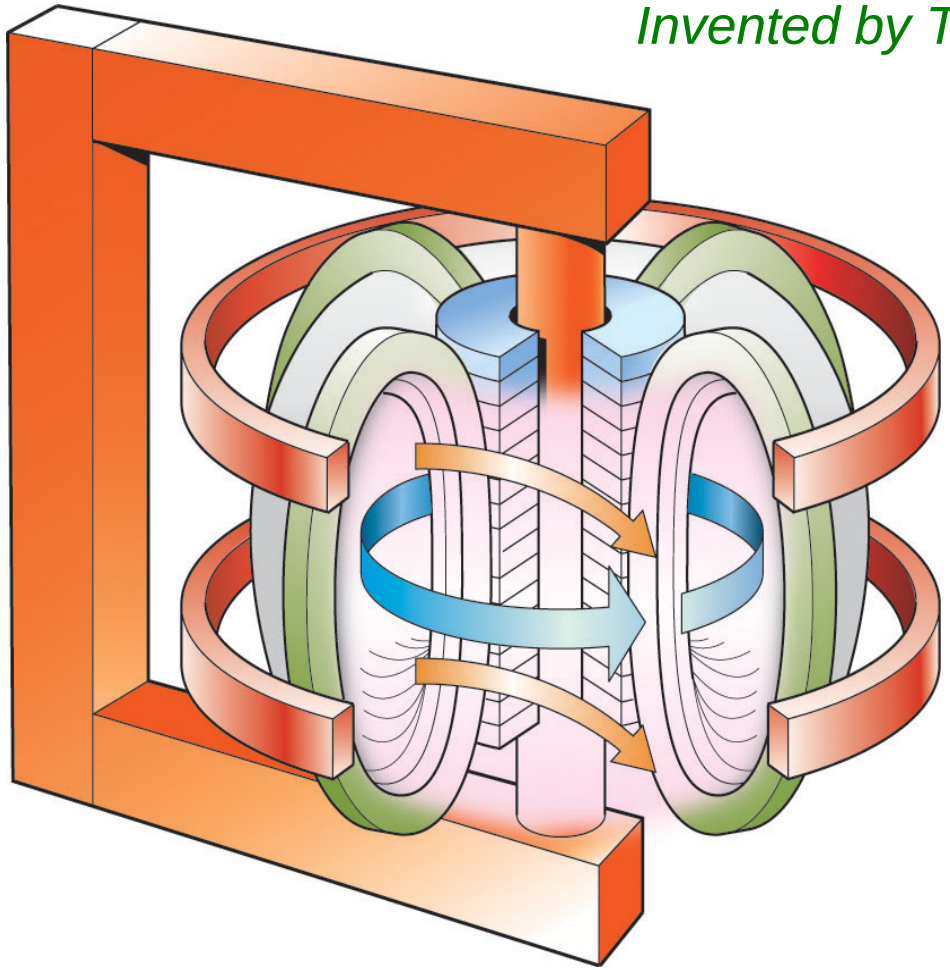
Magnetic Confinement





Tokamak

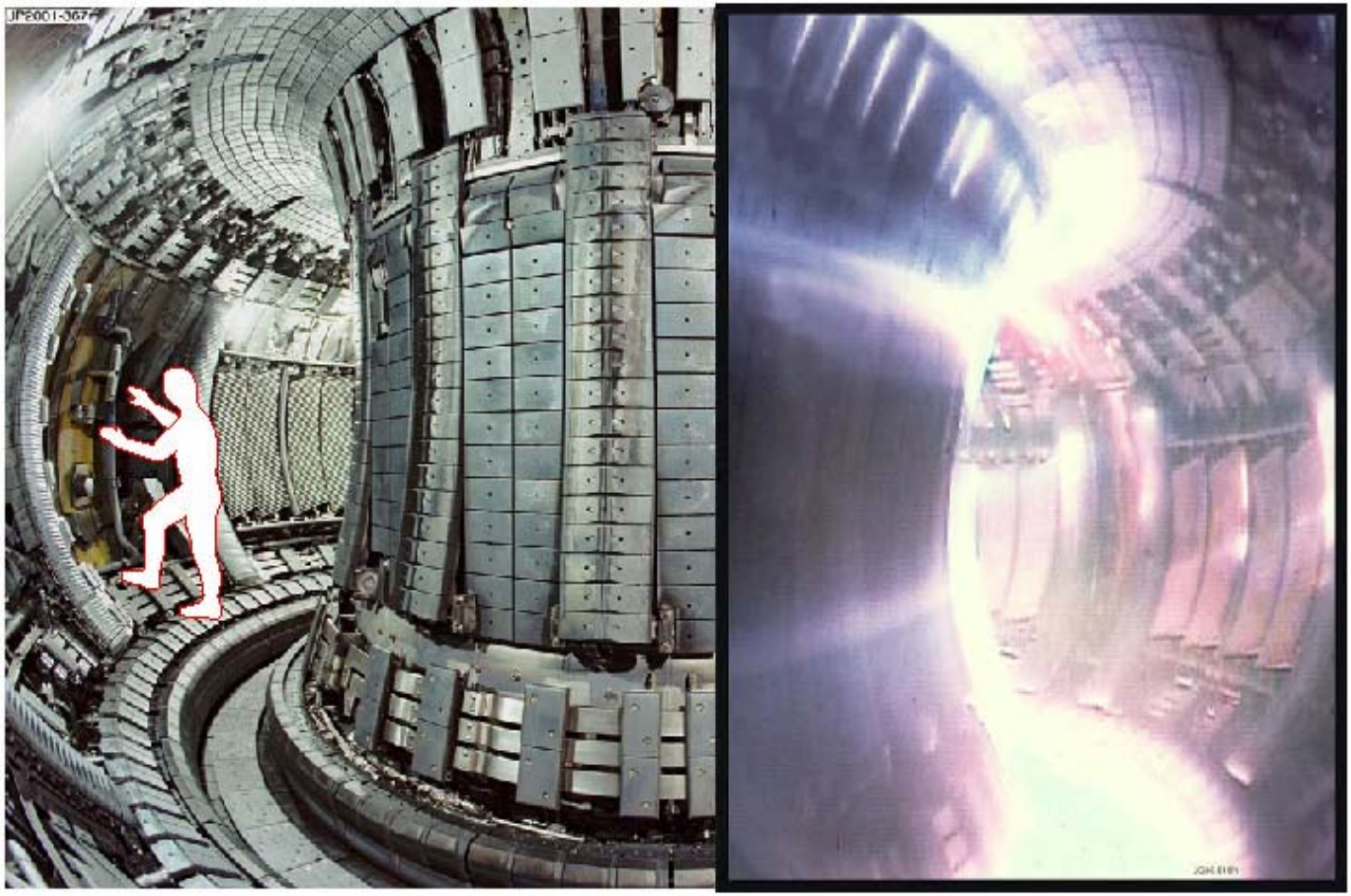
Invented by Tamm and Sakharov in 1952



Toroidalnaja **ka**mera **ma**gnitnaja **k**atushka
(Toroidal chamber magnetic coil)

Tokamak

JET (Joint European Torus): R_0 = 3 m, a = 0.9 m, 1983-today

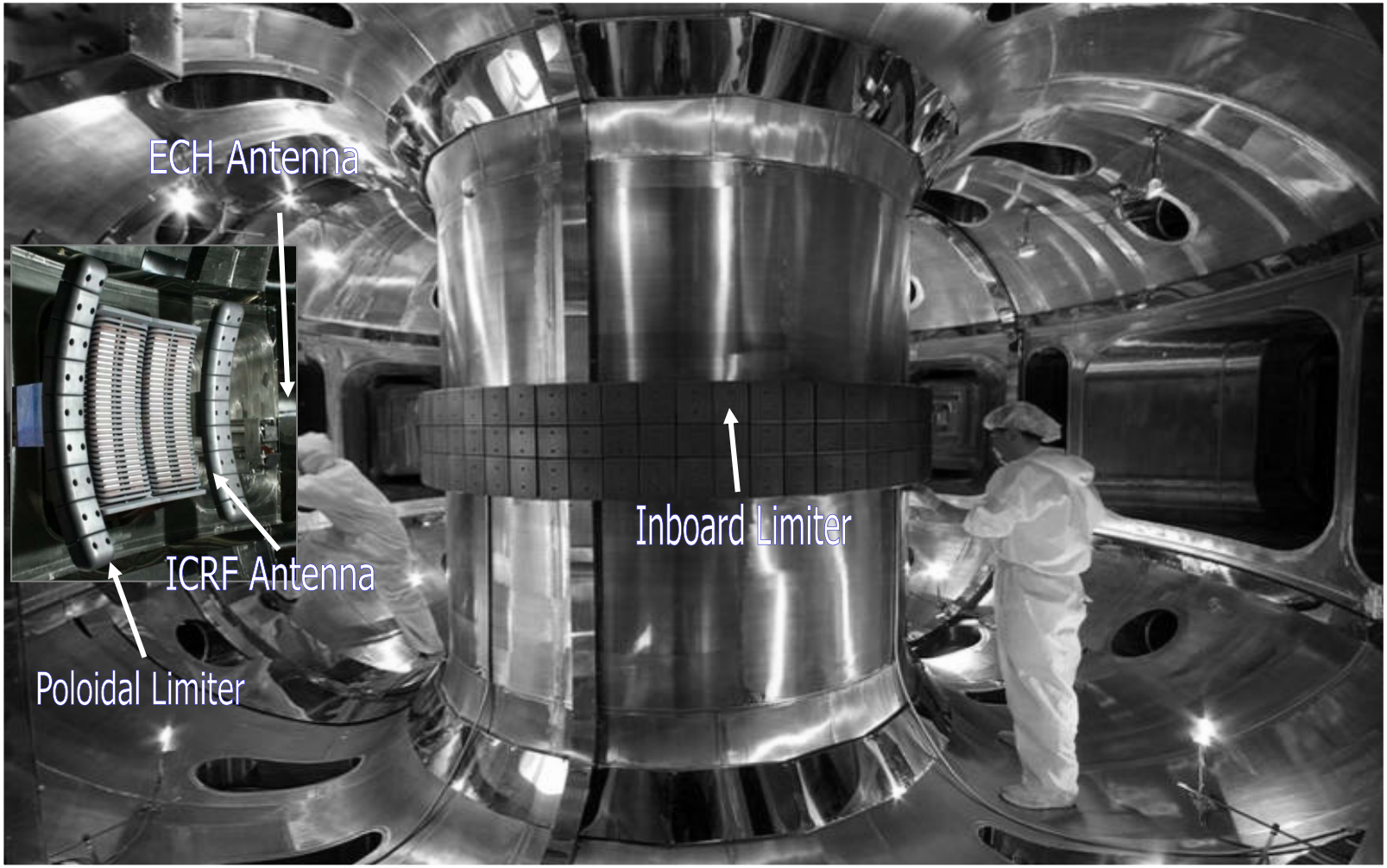


Tokamak

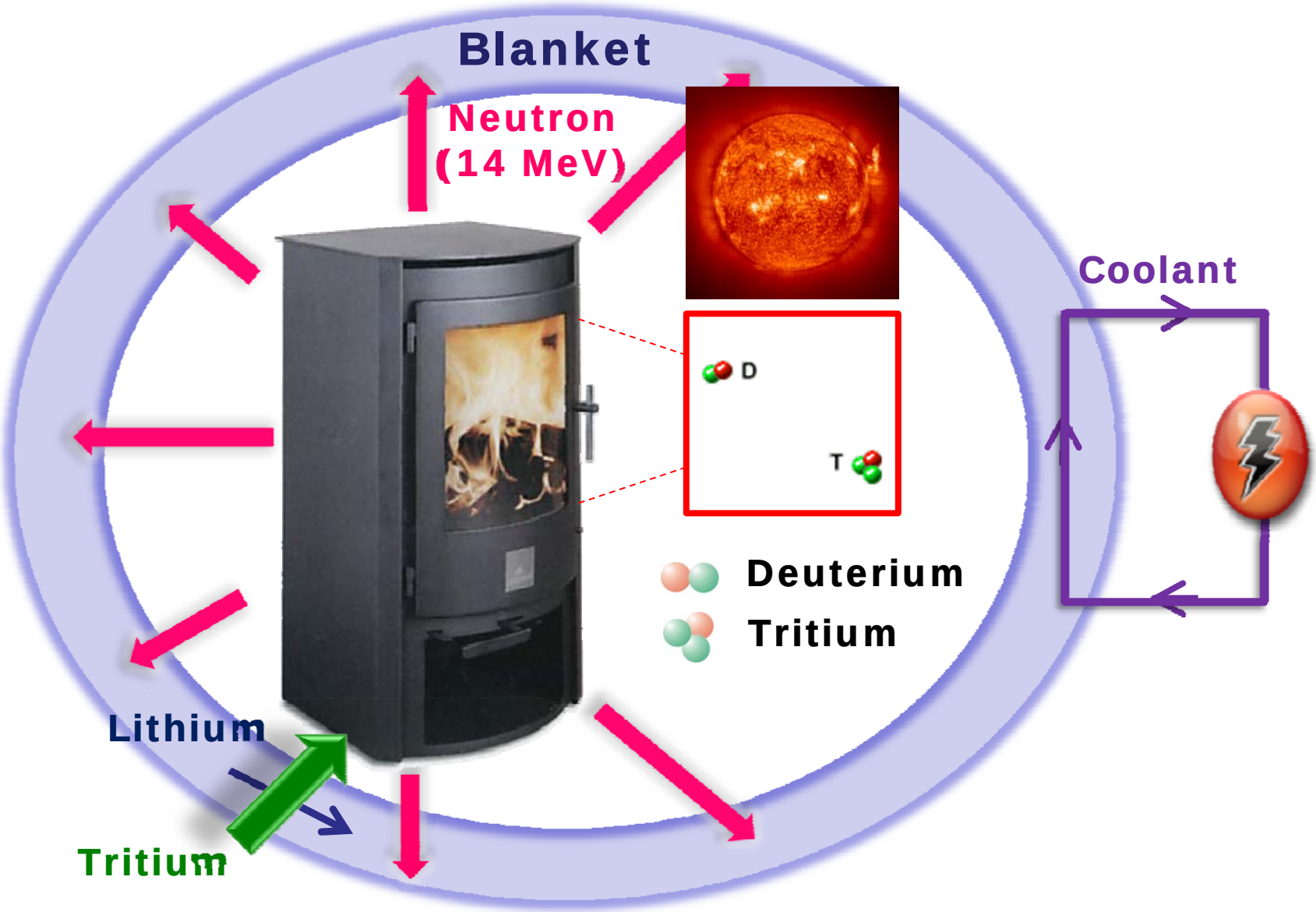
JET (Joint European Torus): R_0 = 3 m, a = 0.9 m, 1983-today

Tokamak

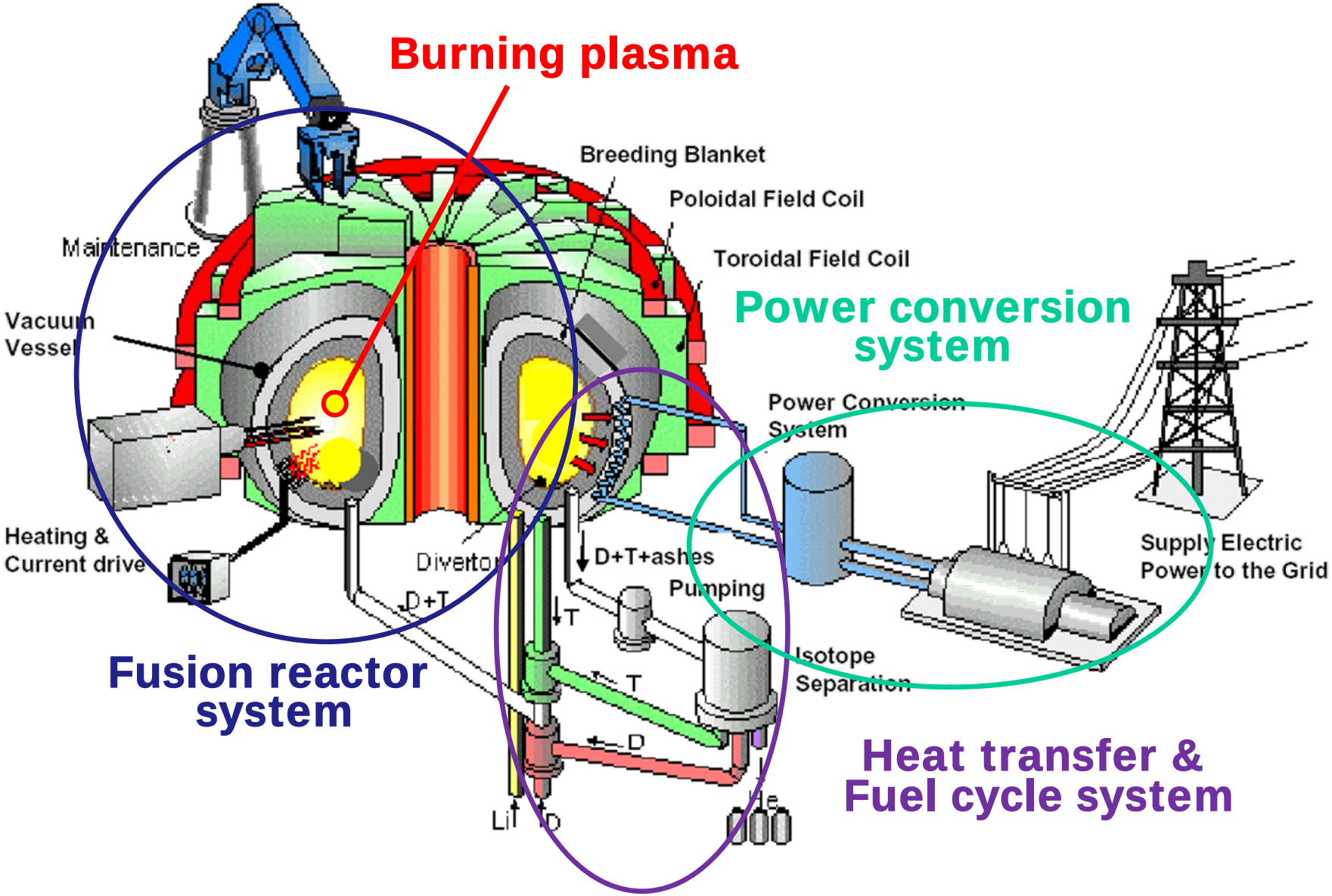
KSTAR (Korea Superconducting Tokamak Advanced Research):
R_0 = 1.8 m, a = 0.5 m, 2008-today



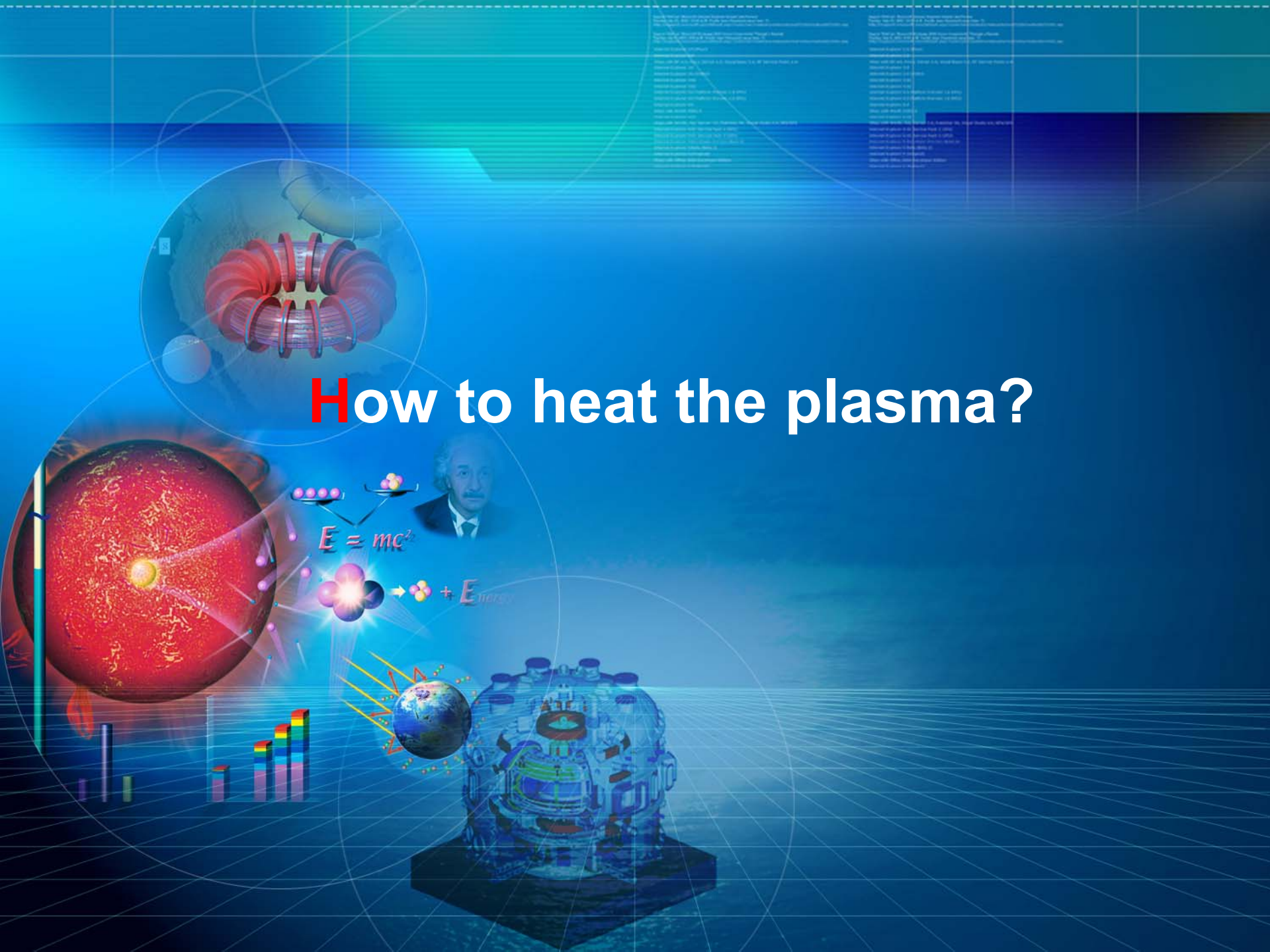
Fusion Power Plant System



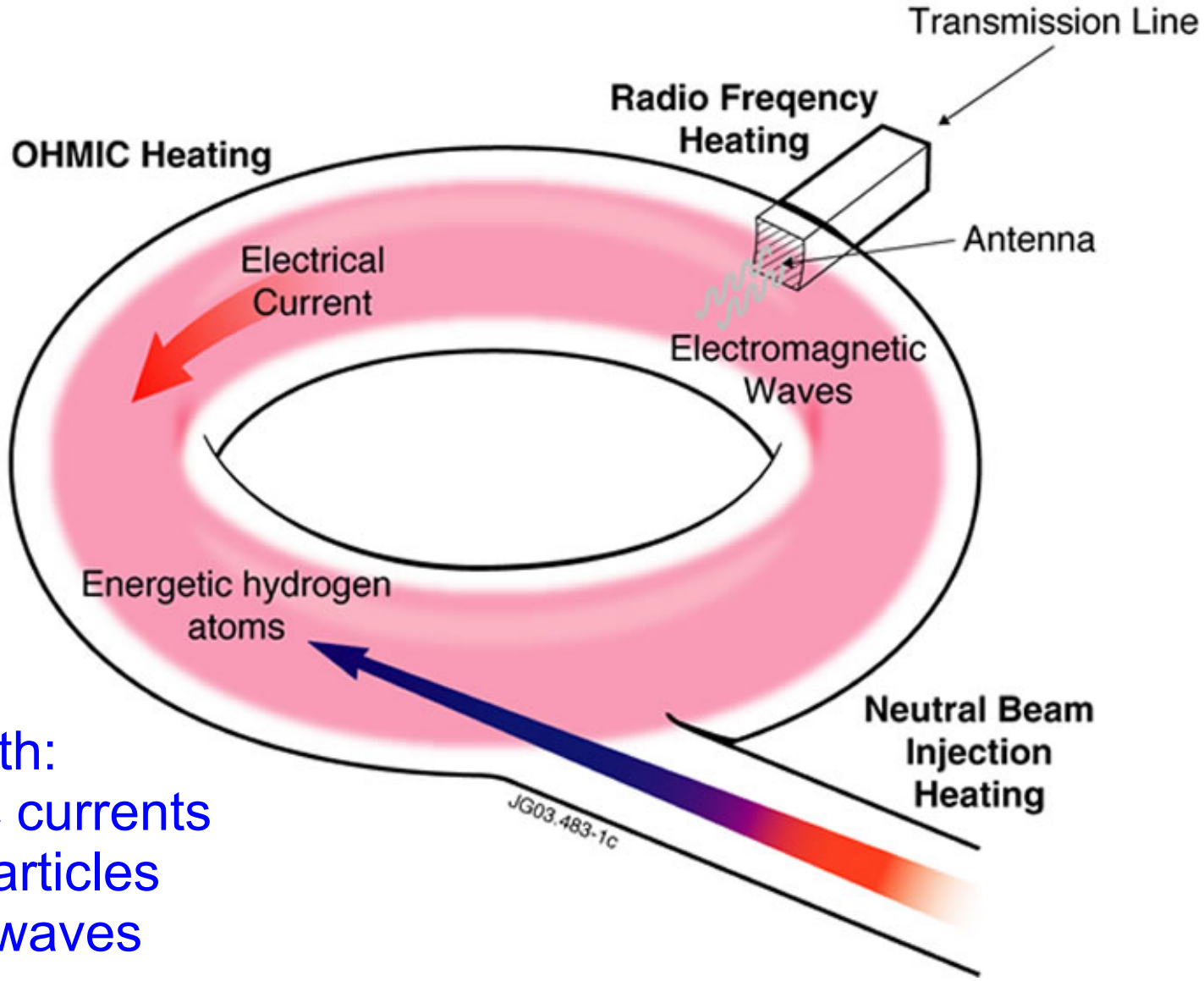
Fusion Power Plant System



How to heat the plasma?



Plasma Heating



Heating with:

- ohmic currents
- fast particles
- microwaves

Plasma Heating – Ohmic Heating

Electric blanket

Plasma Heating – Neutral Beam Injection (NBI)

Injection of a beam of neutral fuel atoms (H, D, T) at high energies (E_b > 50 keV)

⇓

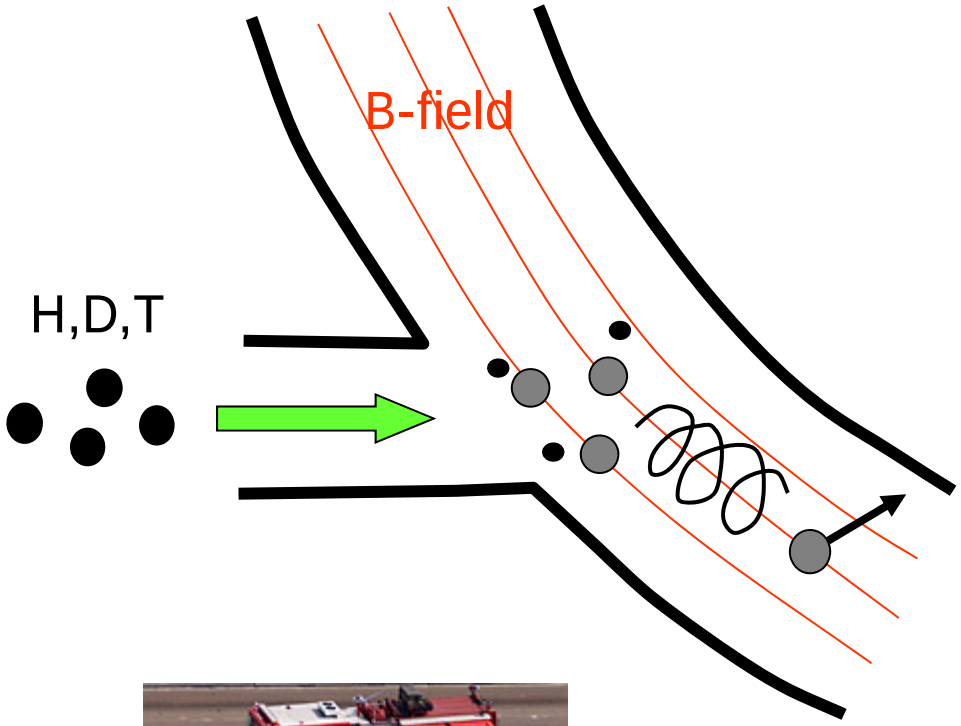
Ionisation in the plasma

⇓

Beam particles confined

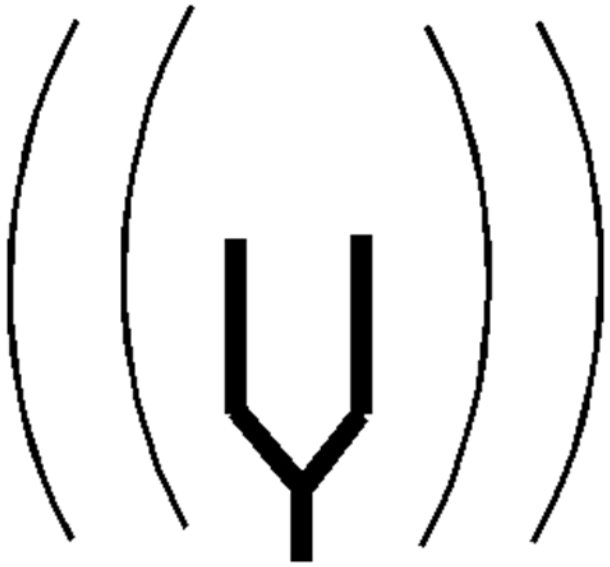
⇓

Collisional slowing down



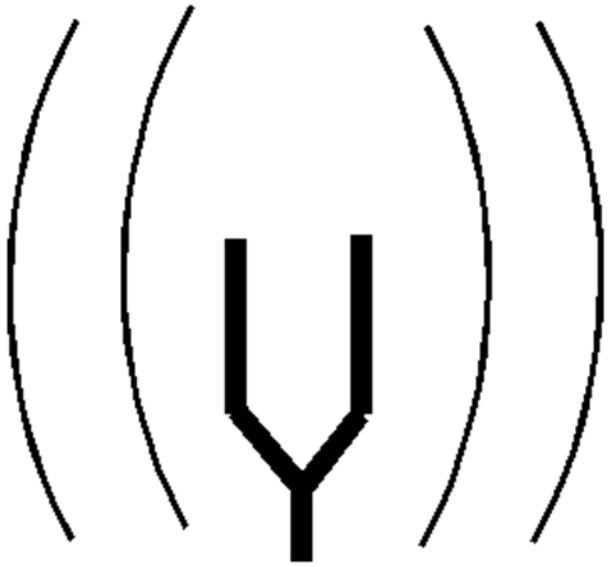
Plasma Heating – Wave (ICRH, ECRH, LHH)

Tuning fork

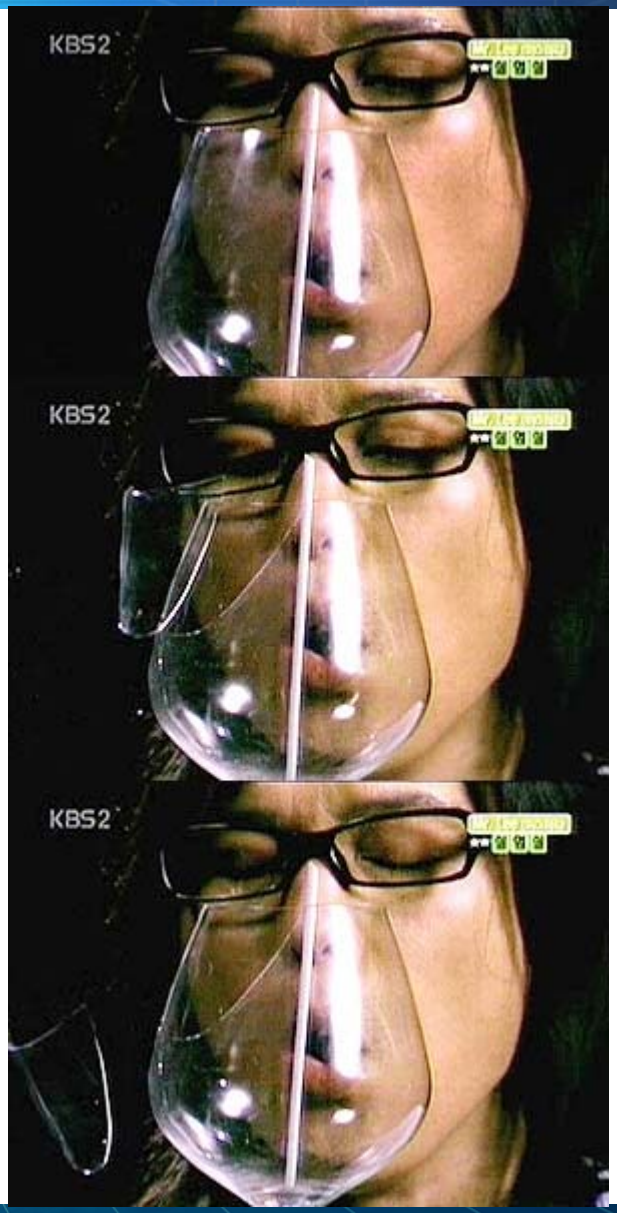


Plasma Heating – Wave (ICRH, ECRH, LHH)

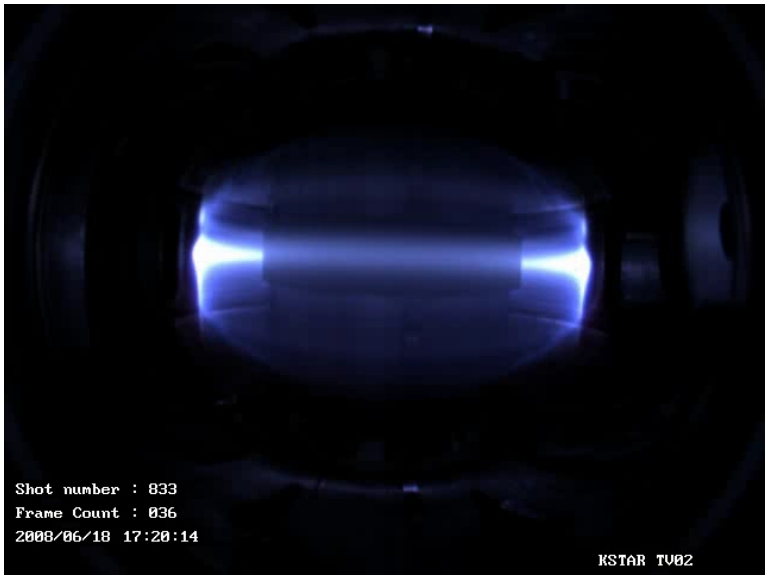
Tuning fork



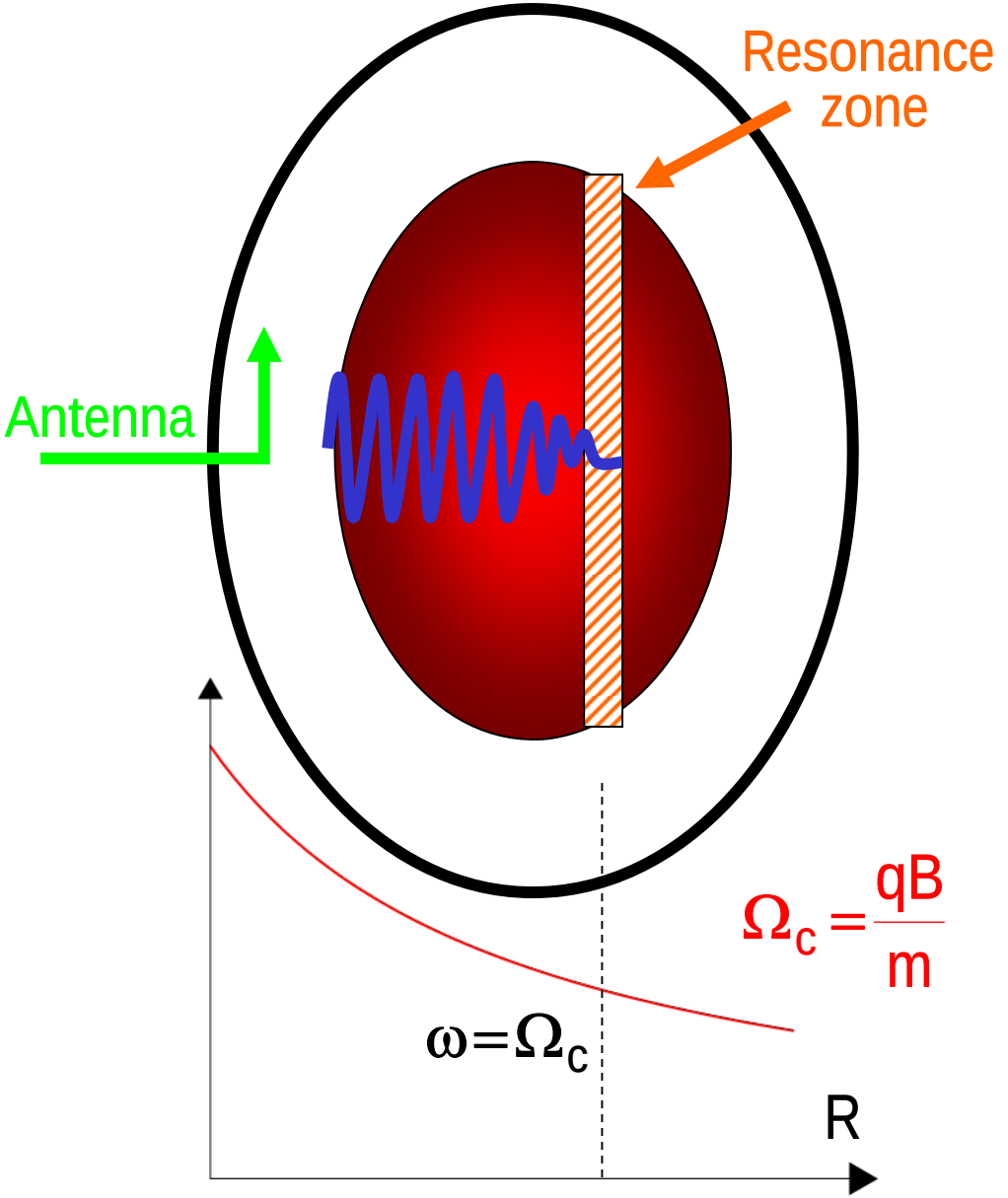
Resonance



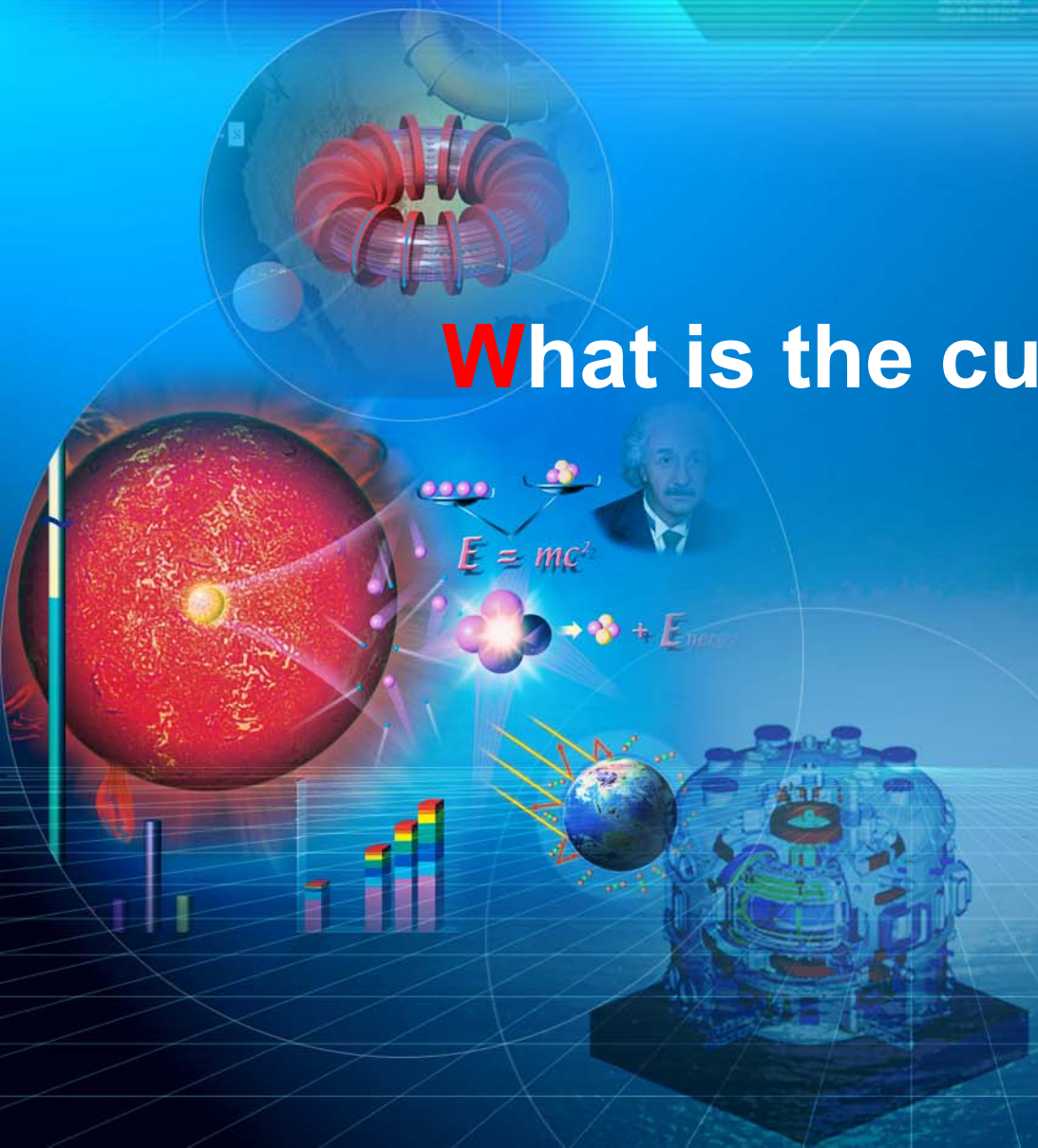
Plasma Heating – Wave (ICRH, ECRH, LHH)



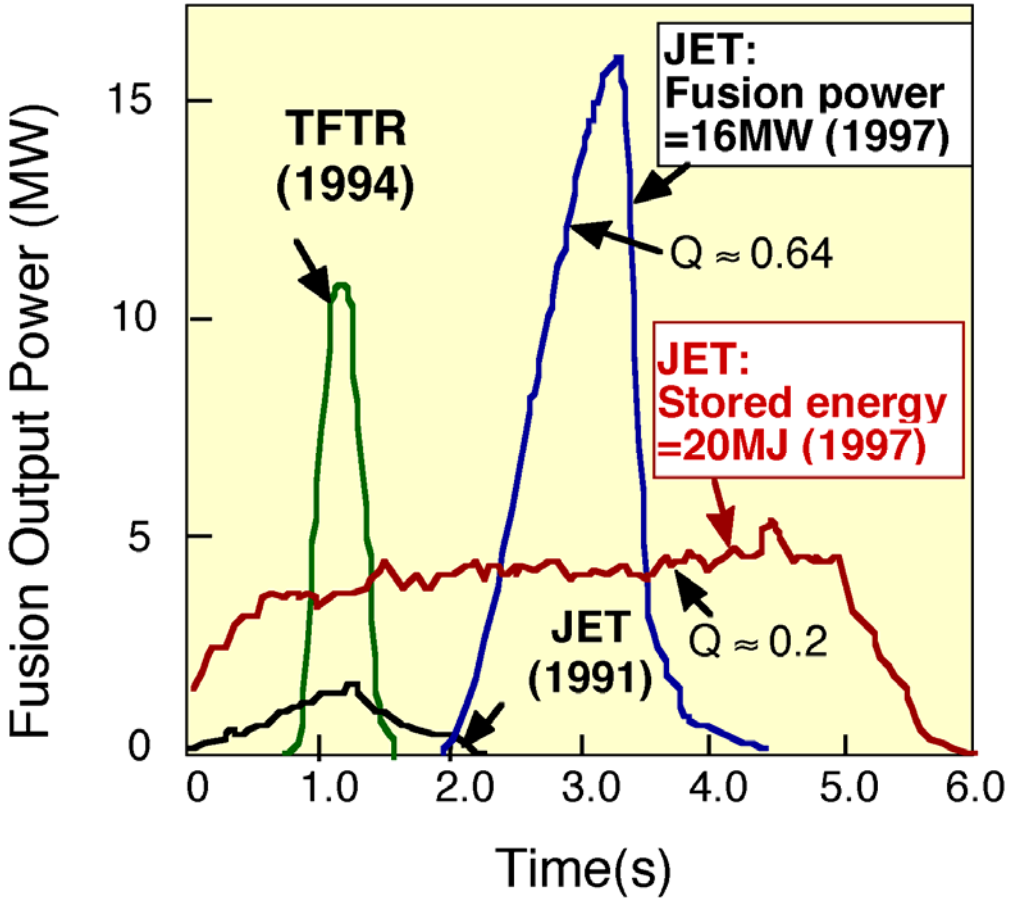
KSTAR first plasma



What is the current status?



Status of the Tokamak Research



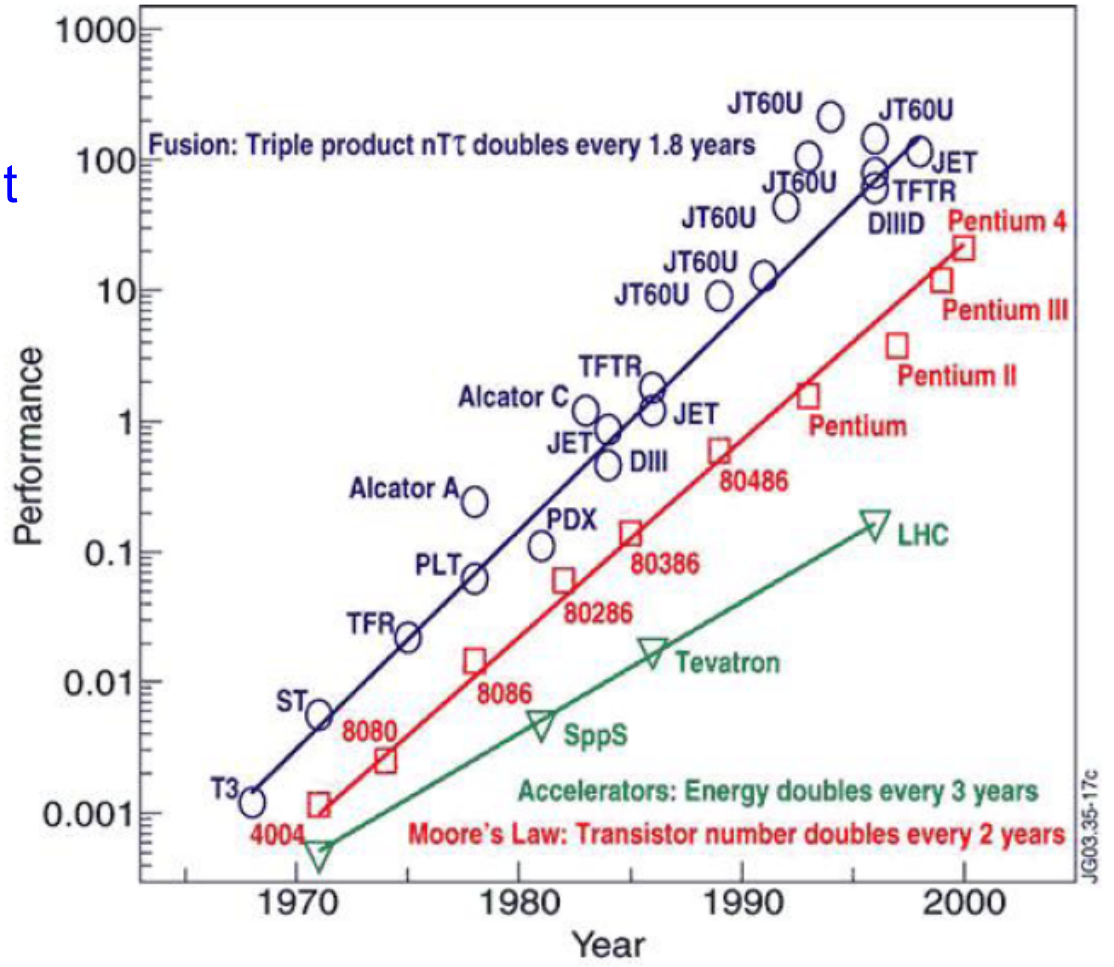
- Present machines produce significant fusion power:
  - TFTR (USA) ~10 MW in 1994
  - JET (EU) 16 MW (Q=0.64) in 1997

Status of the Tokamak Research

- Progress in fusion can be compared with the development of computer chips and particle physics accelerator energy.

- Present machines produce significant fusion power:

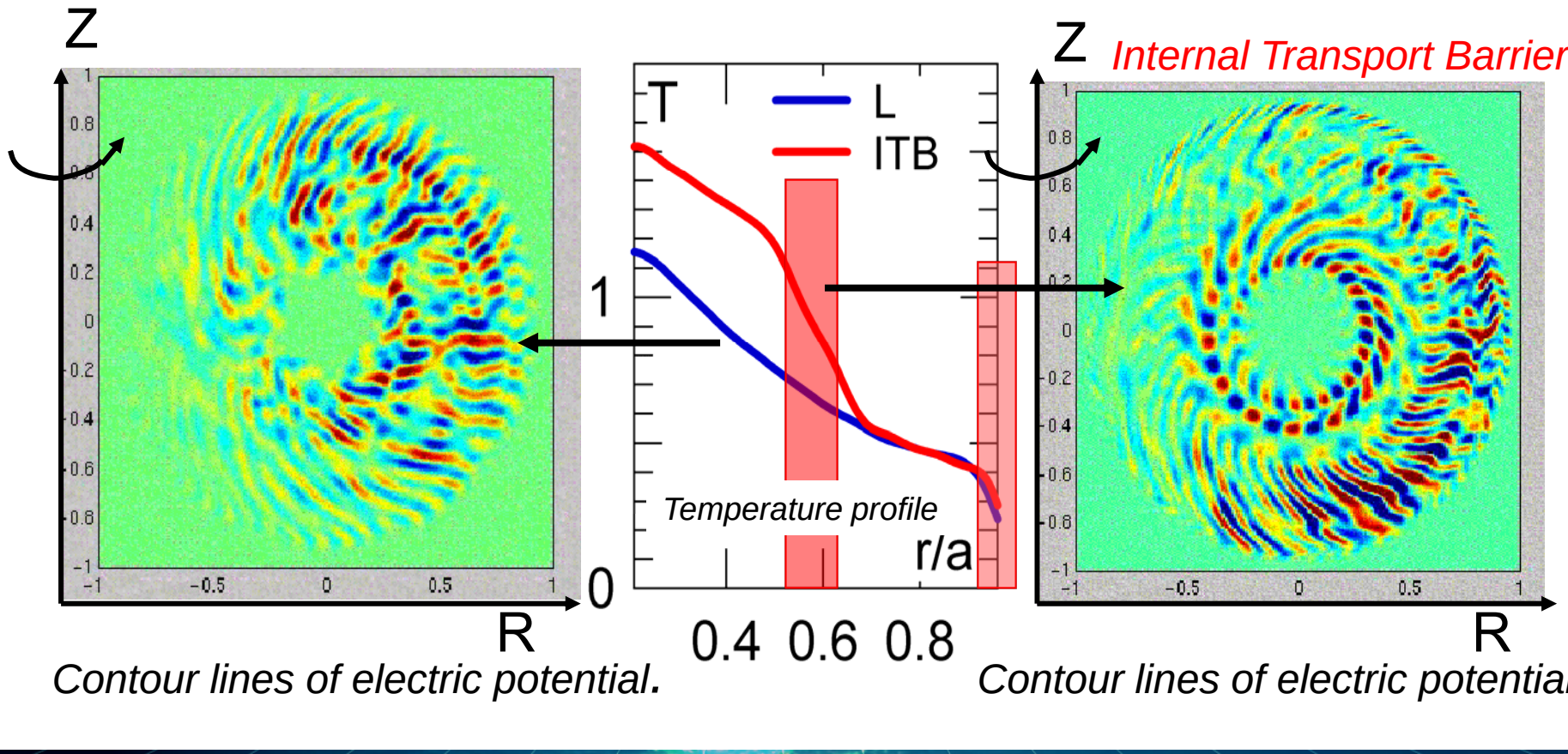
  - TFTR (USA) 10 MW (1994)
  - JET (EU) 16 MW (Q=0.7) (1997)



What are the critical issues?

Stabilisation of Plasma Turbulence

- **Turbulence stabilisation → Increase of plasma pressure**
  → High fusion power



Contour lines of electric potential.

Contour lines of electric potential.

Stabilisation of Plasma Turbulence

Gyrokinetic Simulations
of Plasma Microinstabilities

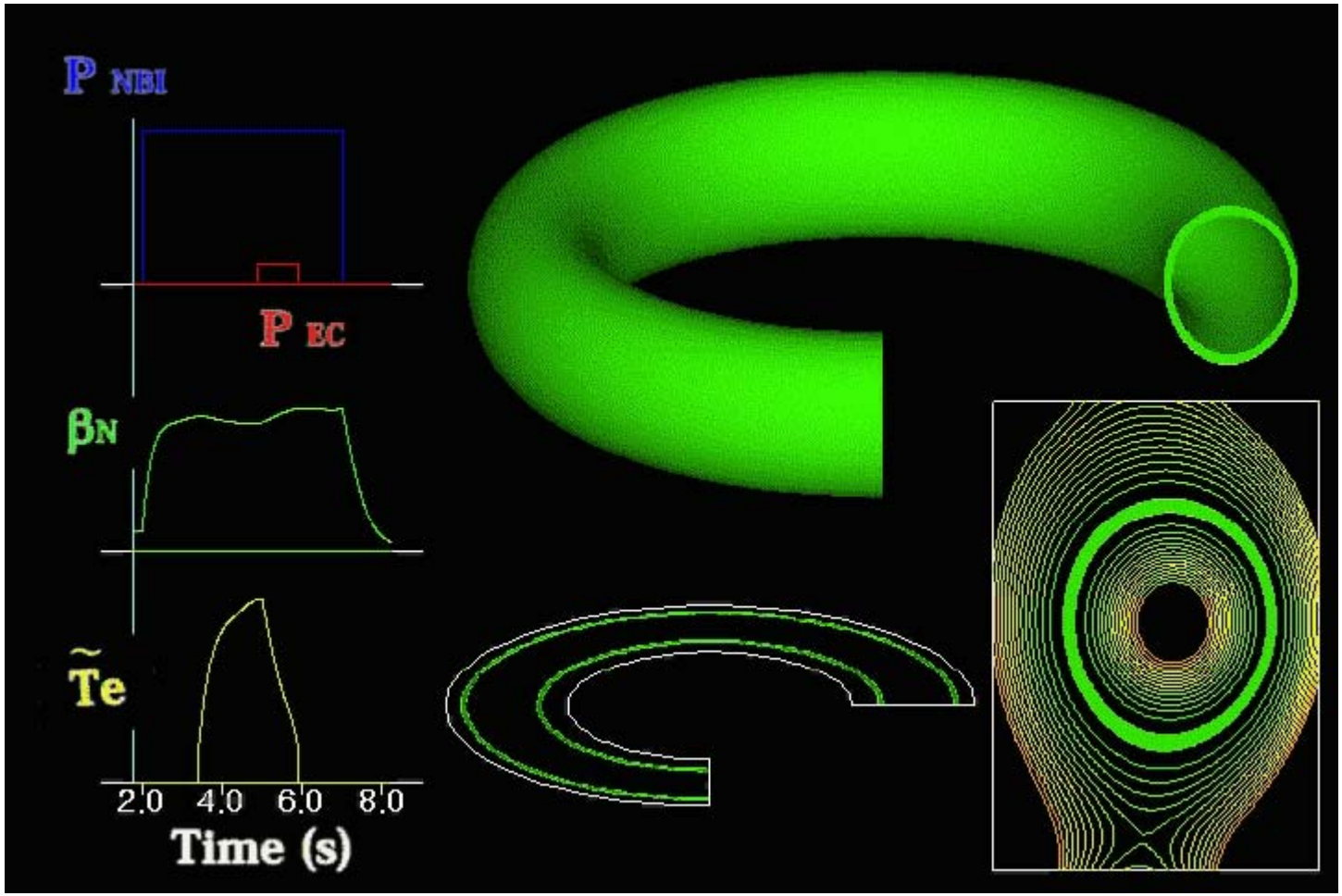
simulation by

Zhihong Lin et al.

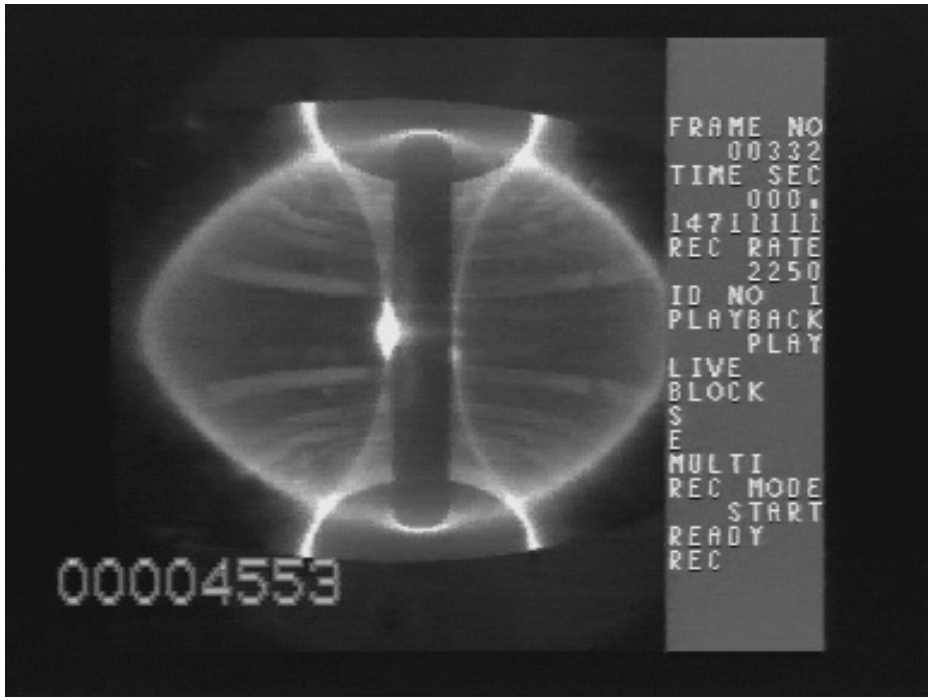
Science 281, 1835 (1998)

Suppression of Plasma Instabilities

- **Suppression of Neoclassical Tearing Mode by ECCD**



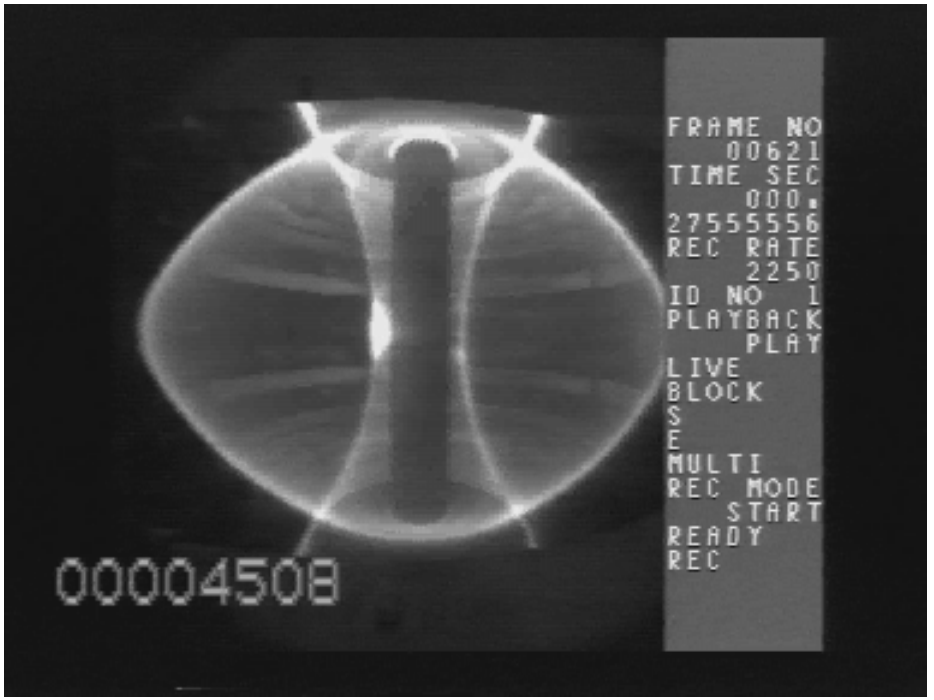
Edge Region Instability and Disruption



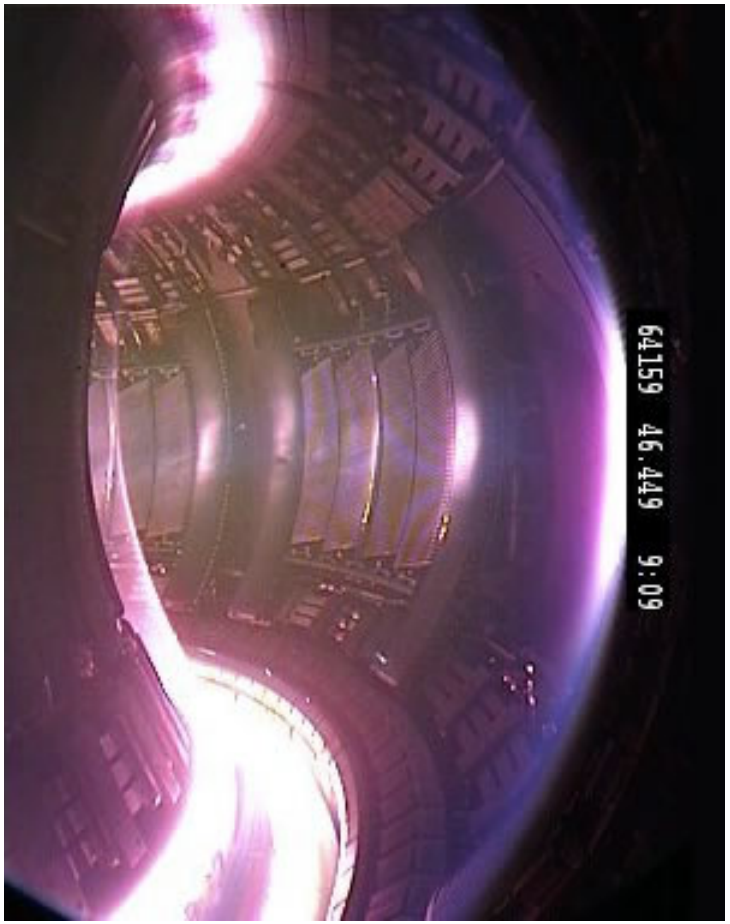
Edge Localised Mode

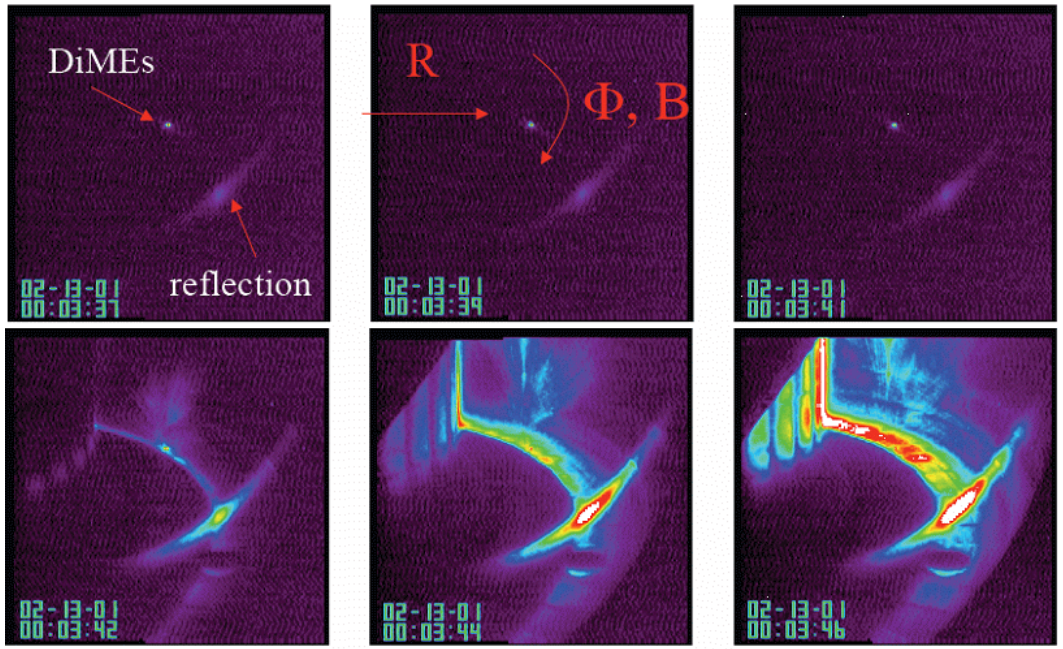
MAST
MEGA-AMPERE SPHERICAL TOKAMAK

Disruption



Plasma–Wall interactions



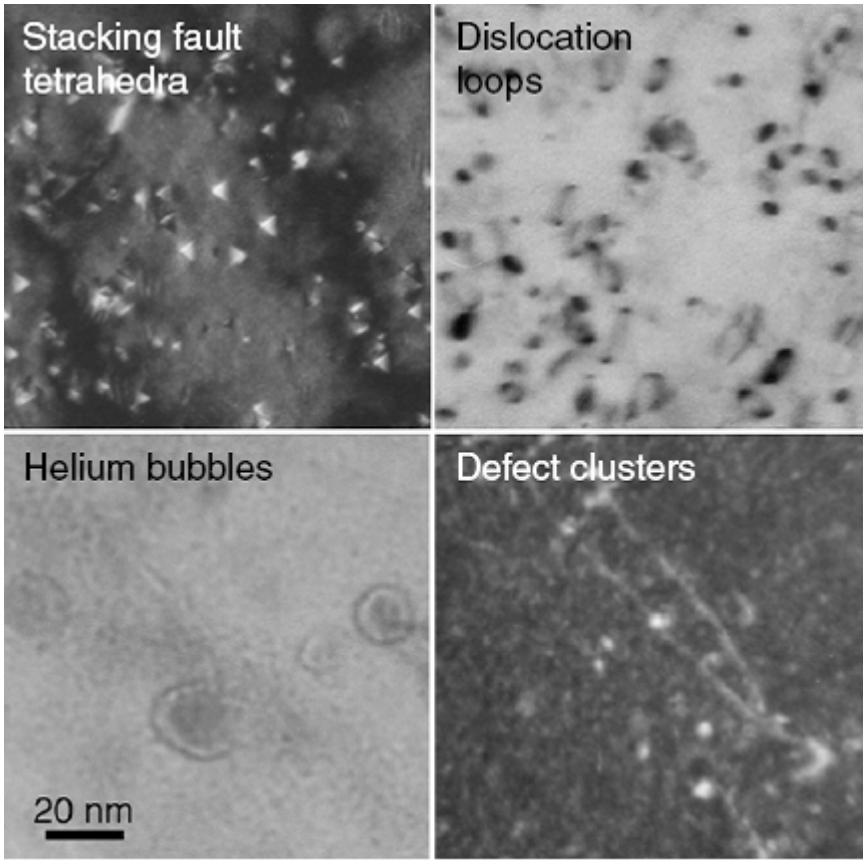


- High heat flux to the surrounding materials

The Underground

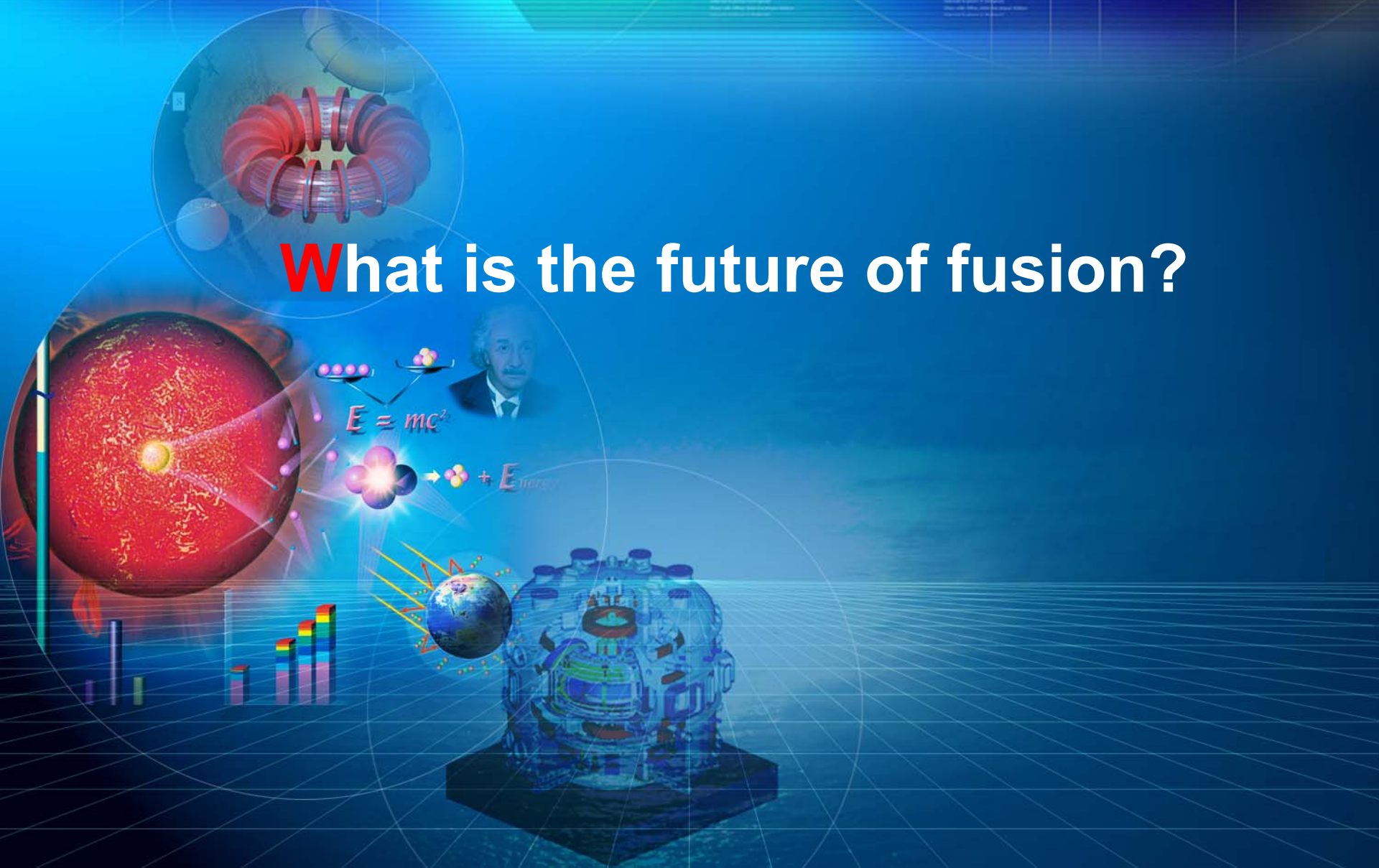
http://cafe.naver.com/gamebox26.cafe?iframe_url=/ArticleRead.nhn%3Farticleid=16140

Radioactivation of Materials



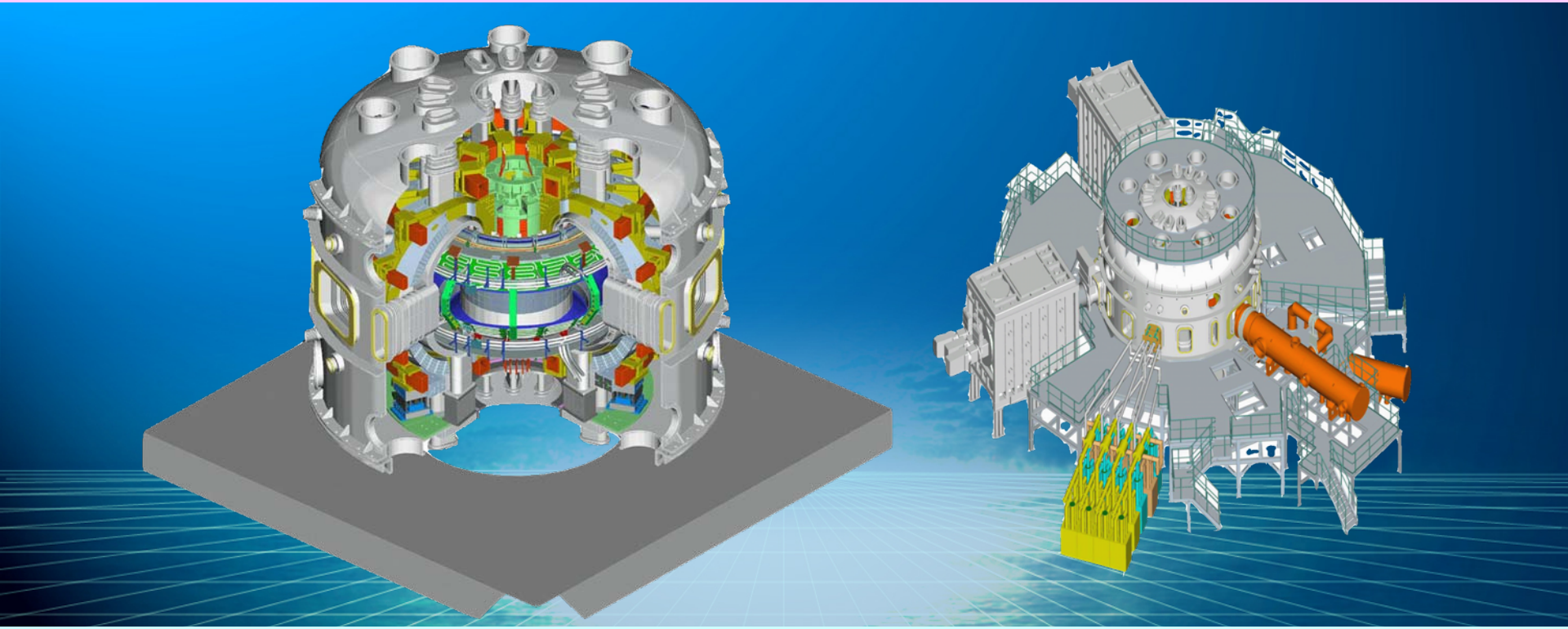
- Neutron impacts on materials

What is the future of fusion?



KSTAR Project

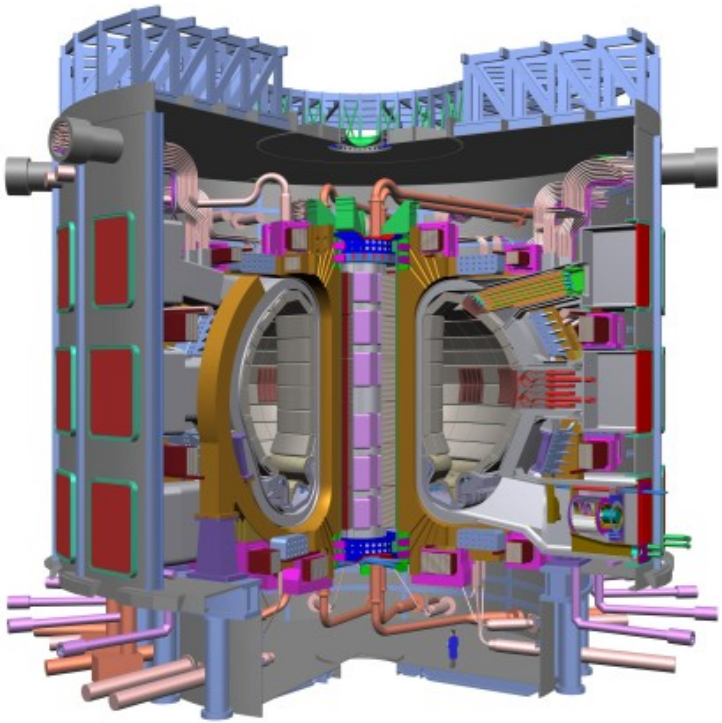
- **K**orea **S**uperconducting **T**okamak **A**dvanced **R**esearch
  - superconducting tokamak using ITER-relevant magnets
  - capability of reactor-relevant plasma performances



- Objective - To integrate optimised plasma performance and continuous operation as a step toward an attractive tokamak fusion reactor

ITER Project

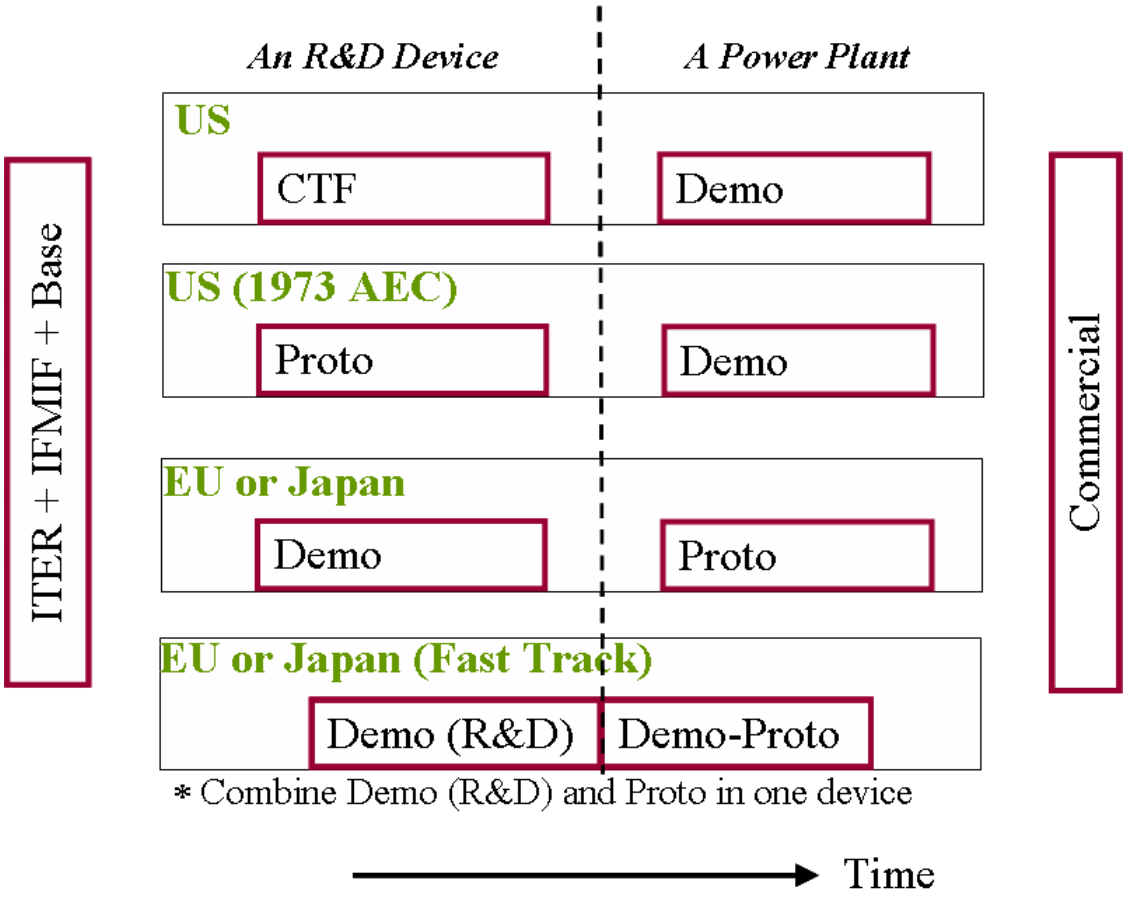
- International **T**hermonuclear **E**xperimental **R**eactor
  - "the way" in Latin
  - the essential next step in the development of fusion



- Objective - To demonstrate the scientific and technological feasibility of fusion power.
  - The world's biggest international research project

Fusion Energy Development

- **The Fast Track Approach**



Korean Plan for Fusion Energy Development

2007년 이후
KSTAR

- 고성능, 고효율 장시간 운전연구

2019
ITER

- 연료 연구
- 열이용 연구
- 재료 연구
- 공학 연구

2030년대 중반
DEMO

- 실질적인 발전 실현
- 시스템 최적화
- 경제성 구현

2040년대
상용화

- 대용량 전기생산

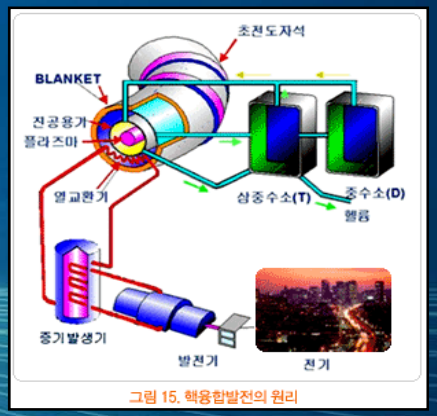


그림 15. 핵융합발전의 원리

Summary

I What is nuclear fusion?

II How to confine the hot sun?

III How to heat the plasma?

IV What is the current status?

V What are the critical issues?

VI What is the future of fusion?

VII Closing remarks

When he was asked how long it would take to build the first fusion power plant, the Soviet physicist Lev Artsimovich – one of the pioneers of tokamak research – replied that "fusion will be there when society needs it." That time is fast approaching, and with the construction of ITER finally about to start, efforts are now gearing up for the longer –term prospect of fusion energy.

- "Fusion: the way ahead, Physics World March 2006

“The entire cost of the fusion development programme is equal to only a week of spending in the international energy markets.”

- I. Cook, IAEA 2005