The Abdus Salam
International Centre
for Theoretical Physics

Alexander von Humboldt
Stiftung/Foundation

A journey to mysterious plasma world

Waleed Moslem
Port Said University
The British University

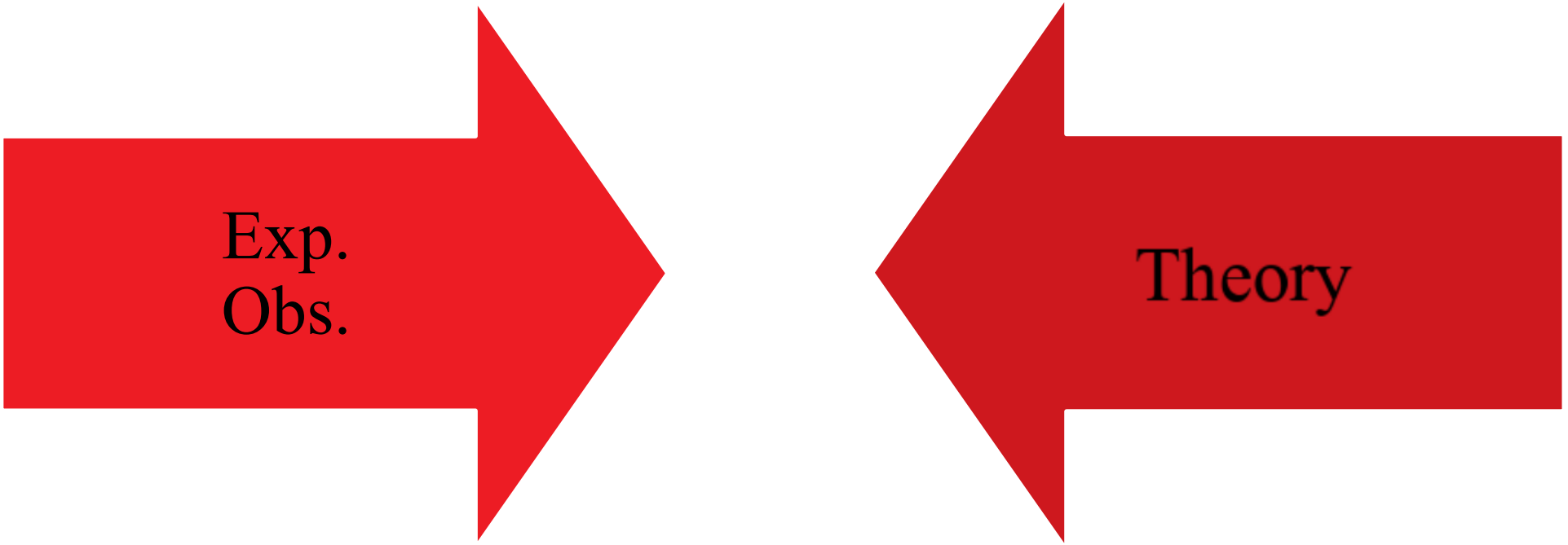
Outline

- **Plasma History**
- **Basic Plasma Physics**
- **Plasmas are Everywhere**
- **Plasma in the Universe**
- **Plasma in Technology**

Outline

- **Plasma History**
- Basic Plasma Physics
- Plasmas are Everywhere
- Plasma in the Universe
- Plasma in Technology

Plasma History

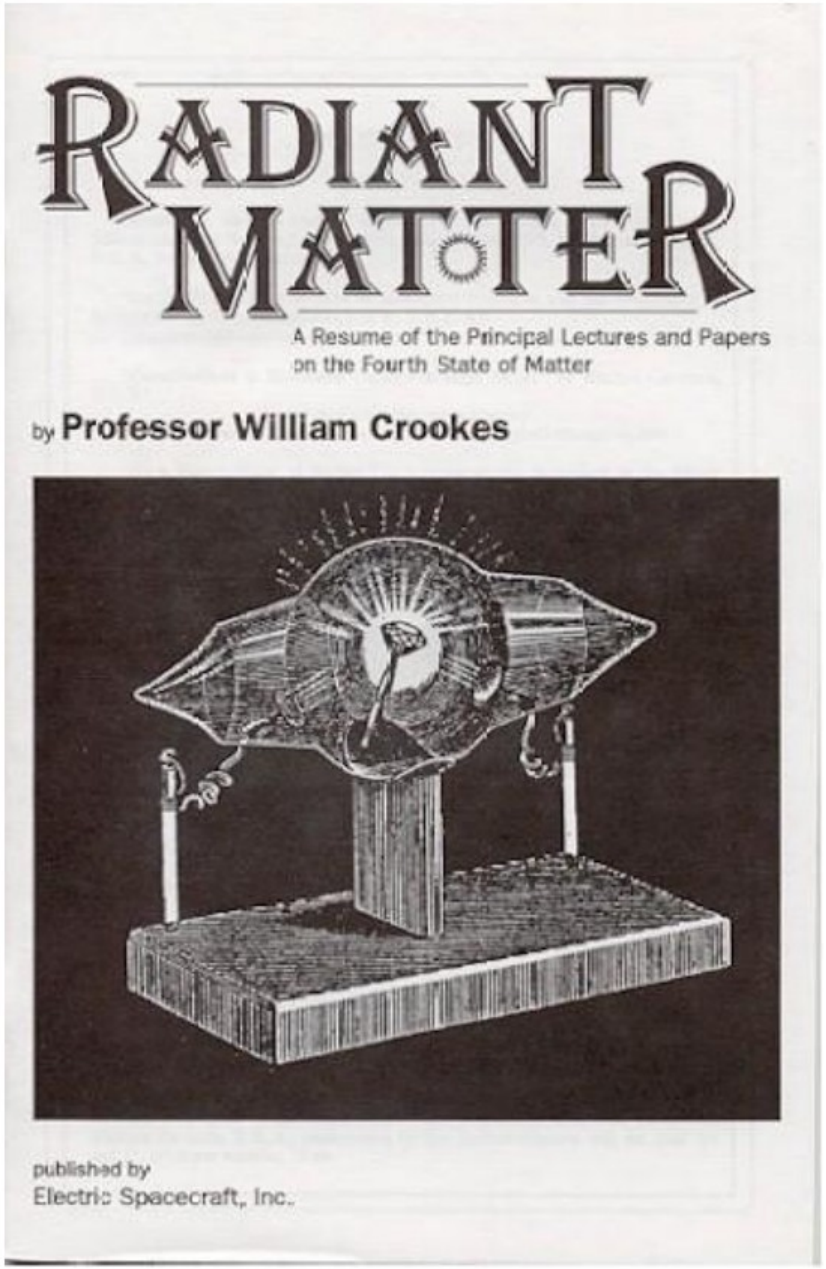


Plasma History, 19th century

William Crookes
(1832 – 1919)
1879 Radiation Matter

Studied the passage of the electrical discharge through rarefied gases (cathode rays)

Plasma History, 19th century



تختلف هذه الظواهر عن أي شيء يحدث في الهواء أو الغاز، حتى أننا نفترض أننا نواجه وجهاً لوجه مع مادة جديدة أو الحالة الرابعة، وهي حالة بعيدة كل البعد عن حالة الغاز ولكنها غاز مكون من سائل

Plasma History, 19th century

Discovered the subatomic nature of Crookes' radiant matter and proved that the cathode rays consist of streams of negative electrons

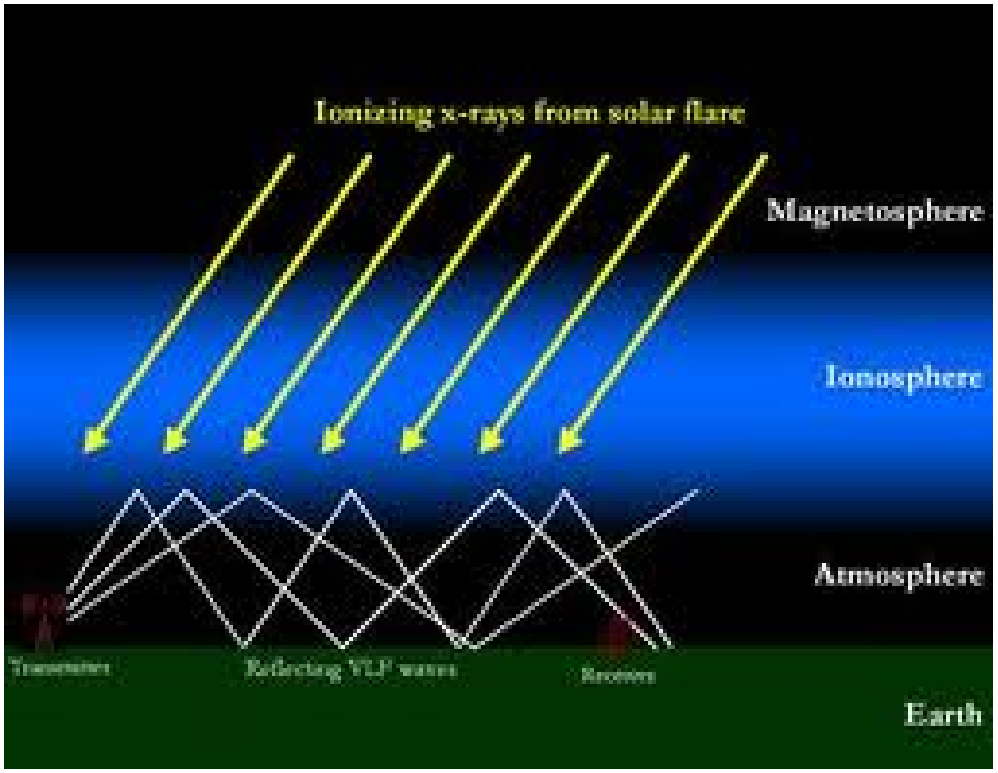
Joseph John Thomson
(1856 – 1940)
1897 Ionized Gas Properties

Plasma History, 1920s

Irving Langmuir
USA
(1881 – 1957)
Nobel Prize in Chemistry 1932

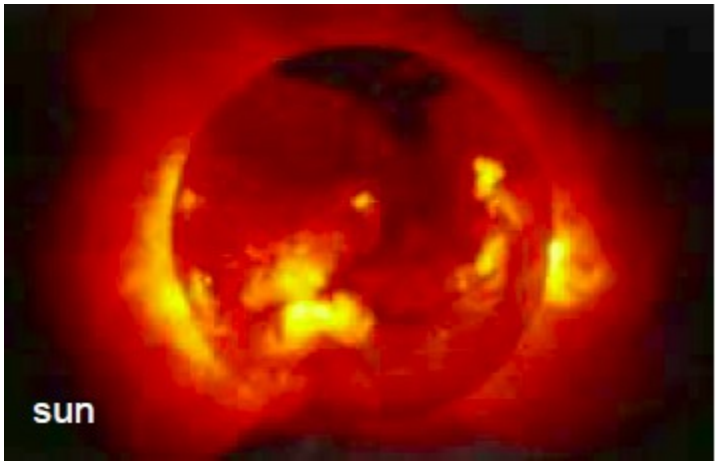
- In **1924** the concept of electron temperature and the method of local measurement of temperature and density of electrons in gas discharge with electrostatic probe (Langmuir Probe).
- The use of the term "**PLASMA**" for an ionized gas was first coined in **1927** by **Irving Langmuir** (1881-1957).

Plasma History, 1930s



The development of research led to the discovery of the Earth's *ionosphere*, a layer of partially ionized gas in the upper atmosphere which reflects radio waves, and is responsible for the fact that radio signals can be received when the transmitter is over the horizon.

Plasma History, 1930s cont.



- The astrophysicists quickly recognized that much of the Universe consists of plasma.
- To have better understanding of astrophysical phenomena requires a better grasp of plasma physics.

Plasma History, 1940s

Hannes Alfven
1908 – 1995 (Sweden)
Nobel Prize in Physics1970

- The pioneer in this field was Hannes Alfvén, who around 1940 developed the theory of *magnetohydrodyamics*, or MHD, in which plasma is treated essentially as a conducting fluid.
- This theory was used to study sunspots, solar flares, the solar wind, star formation, and a host of other topics in astrophysics.

Plasma History, 1950s


The Boston Daily Globe

HAIL TRUMAN H-BOMB ORDER

Bishop Wright Appointed to Worcester

Heads New Diocese of the Country

Driving Tough Today; More Snow on Way

3 Brink's Employees Called in New Quiz

- The creation of the hydrogen bomb in 1952 generated a great deal of interest in *controlled thermonuclear fusion* as a possible power source for the future. (USA, UK, USSR).

- In 1958 thermonuclear fusion research was *declassified*. Thus, theoretical plasma physics first emerged as a mathematically rigorous discipline in this years.

Plasma History, 1950s

Eugene Newman Parker
(born June 10, 1927)

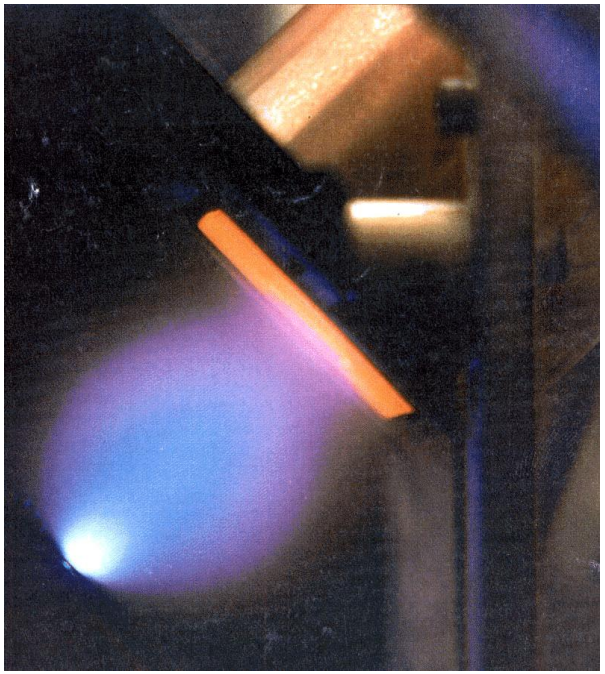
- American solar astrophysicist.
- In the mid-1950s, he developed the theory of the supersonic solar wind and predicted the Parker spiral shape of the solar magnetic field in the outer Solar System.
- In 1987, Parker proposed a mechnism of the solar corona heating by tiny "nanoflares" that found all over the Sun surface.
- In 2018, NASA named Parker Solar Probe in his honor

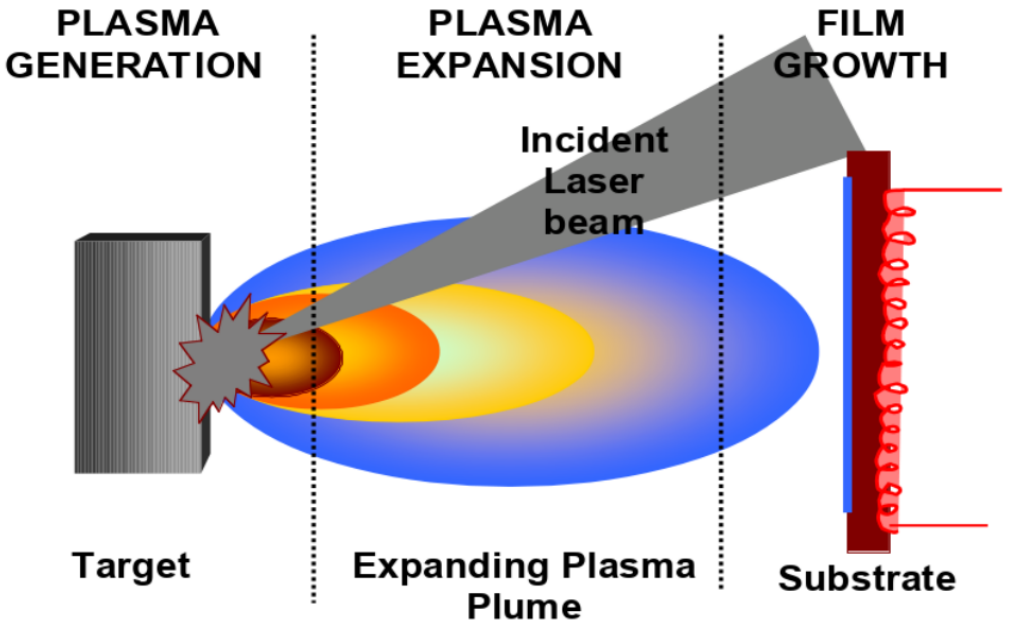
Plasma History, 1950s cont.

James A. Van Allen
1914 – 2006 (USA)

- Fourthly, James A. Van Allen's discovery in 1958 of the Van Allen radiation belts surrounding the Earth, using data transmitted by the U.S.
- Explorer satellite, marked the start of the systematic exploration of the Earth's magnetosphere via satellite, and opened up the field of *space plasma physics*.
- Movie

Plasma History, 1960s





- The development of laser in the 1960's opened up the field of *laser plasma physics*.
- When a laser beam strikes a solid target → material is immediately ablated, and a plasma forms at the boundary between the beam and the target.

Plasma History, 1970s-1980s

- Nonlinear plasma era → last day lecture
- Plasma basic theory → Plasma interactions with waves and beams
- Plasmas in nature → Space & Astrophysical plasma & Geophysics
- Industrial plasmas → Plasma chemistry & etching...etc
- Plasma applications → fusion power & plasma medicine & plasma torches...etc

Plasma History, 1990s - 2010s

- Dusty (complex) plasma → tomorrow lecture
- Quantum plasma → tomorrow lecture
- How plasma affect to our life?

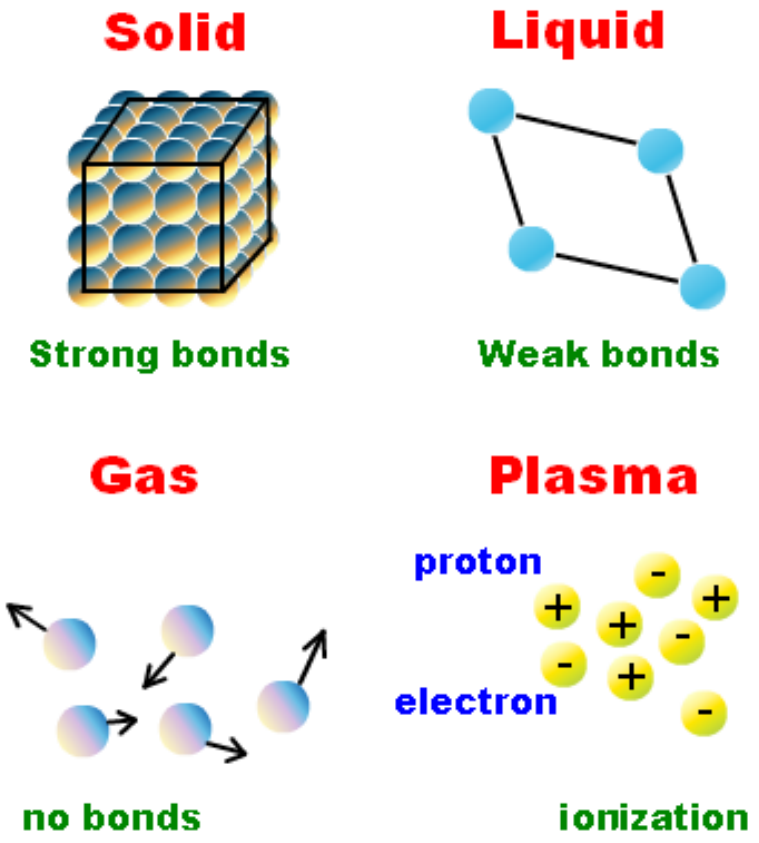
Plasma History, 1990s - 2010s

1) TV **2)** Coated jet turbine blades **3)** LED **4)** Coating
5) Artificial hip
6) Plasma laser cutting clothes
7) HID headlight
8) Produce H2 in full cell
9) Plasma aided conbustion
10) Plasma muffler
11) Water purification
12) LCD screen **13)** Solar cell
14) Microelectronics
15) Pharmaceutical production
16) Treated polymers
17) Textile
18) Treated heart stent
19) Plasma deposition
20) Window glazing
21) Plasma lamp

Outline

- Plasma History
- **Basic Plasma Physics**
- Plasmas are Everywhere
- Plasma in the Universe
- Plasma in Technology

Basic Plasma Physics



- 96 % of the universe → dark energy & dark matter
- 4% normal matter
- 99% of the visible matter is in the plasma state

Basic Plasma Physics, cont.

- Degree of ionization $\chi = \dfrac{n_e}{n_e + n_n}$
- Range 10^{-8} – 1
- Partially or weakly ionized plasma $\chi \ll 1$
- Fully ionized plasma $\chi \sim 1$
- Saha equation $\dfrac{N_i}{N_n} = 2.405 \times 10^{21} \dfrac{T^{3/2}}{N_i} e^{-U/(k_B T)}$

Estimate the degree of ionization of air at 1 atm pressure and room temperature (300 K). Repeat the calculation for a temperature of 8000 K. The main component of air is nitrogen, with an ionization potential of 14.5 eV.

Basic Plasma Physics, cont.

Three fundamental parameters characterizes a plasma:

1. The particle density n (particles per cubic meter)

2. The temperature T of each species (eV)
   1 eV = 11,605 K

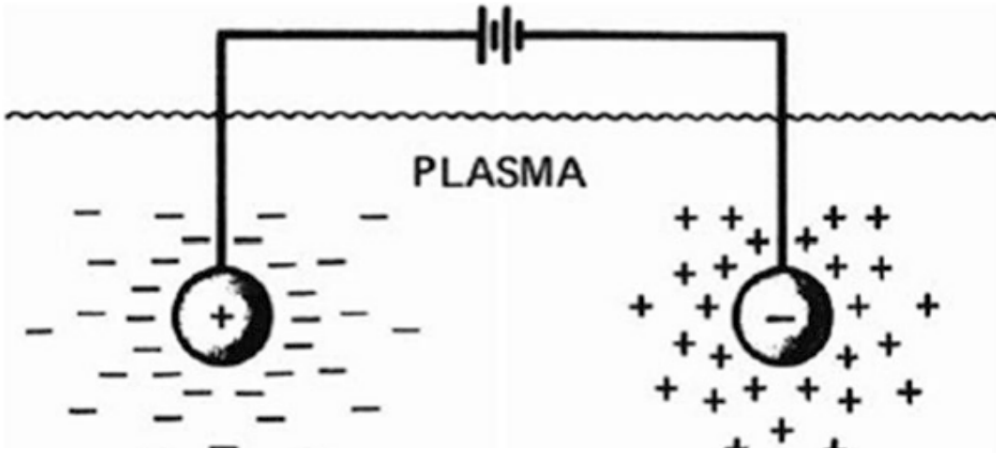
3. The steady state magnetic field B (Tesla).

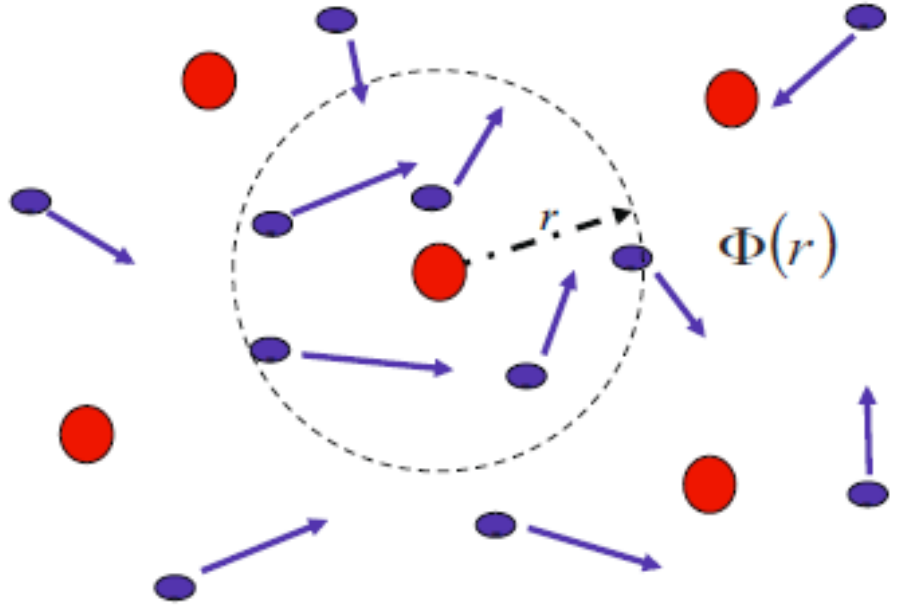
Basic Plasma Physics, cont.

- Debye shielding length

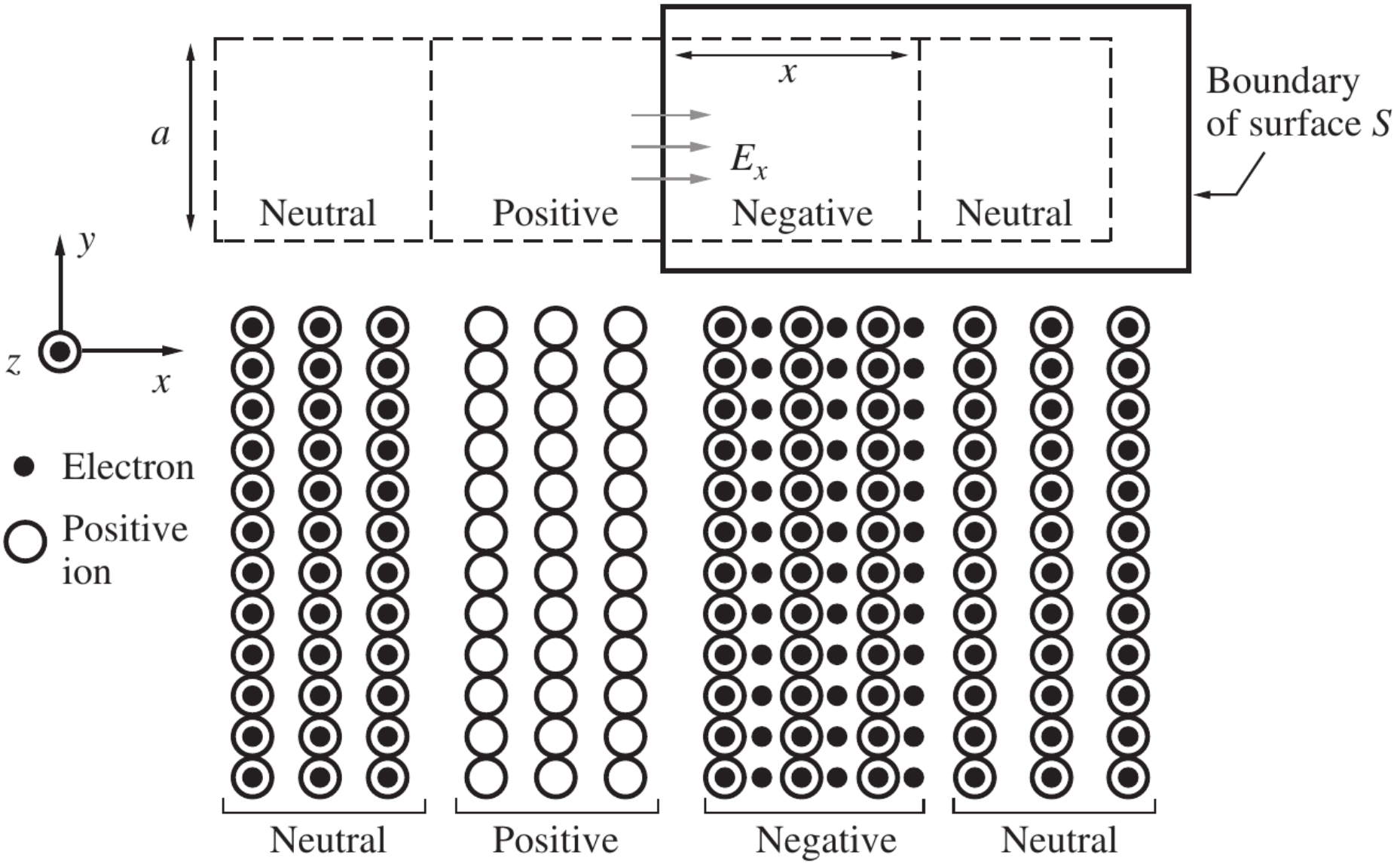
$$\lambda_D \equiv \left(\frac{\varepsilon_0 K T_e}{n e^2} \right)^{1/2}$$

$$\lambda_D = 69 (T_e / n)^{1/2} \mathrm{m}$$





Basic Plasma Physics, cont.



Basic Plasma Physics, cont.

- Electron plasma frequency

$$\omega_p = \sqrt{\frac{N_e q_e^2}{\epsilon_0 m_e}}$$

Compute the Debye length for the plasma found in a typical plasma television cell with the following parameters: $N_e = 10^{19}$ m^{-3}, $k_B T = 1$ eV. The cell dimensions are on the order of 100 μm and the plasma is excited using a 250 V signal at 100 kHz.

Basic Plasma Physics, cont.

- Quasi-neutral gas & Collective behavior
- Plasma critria

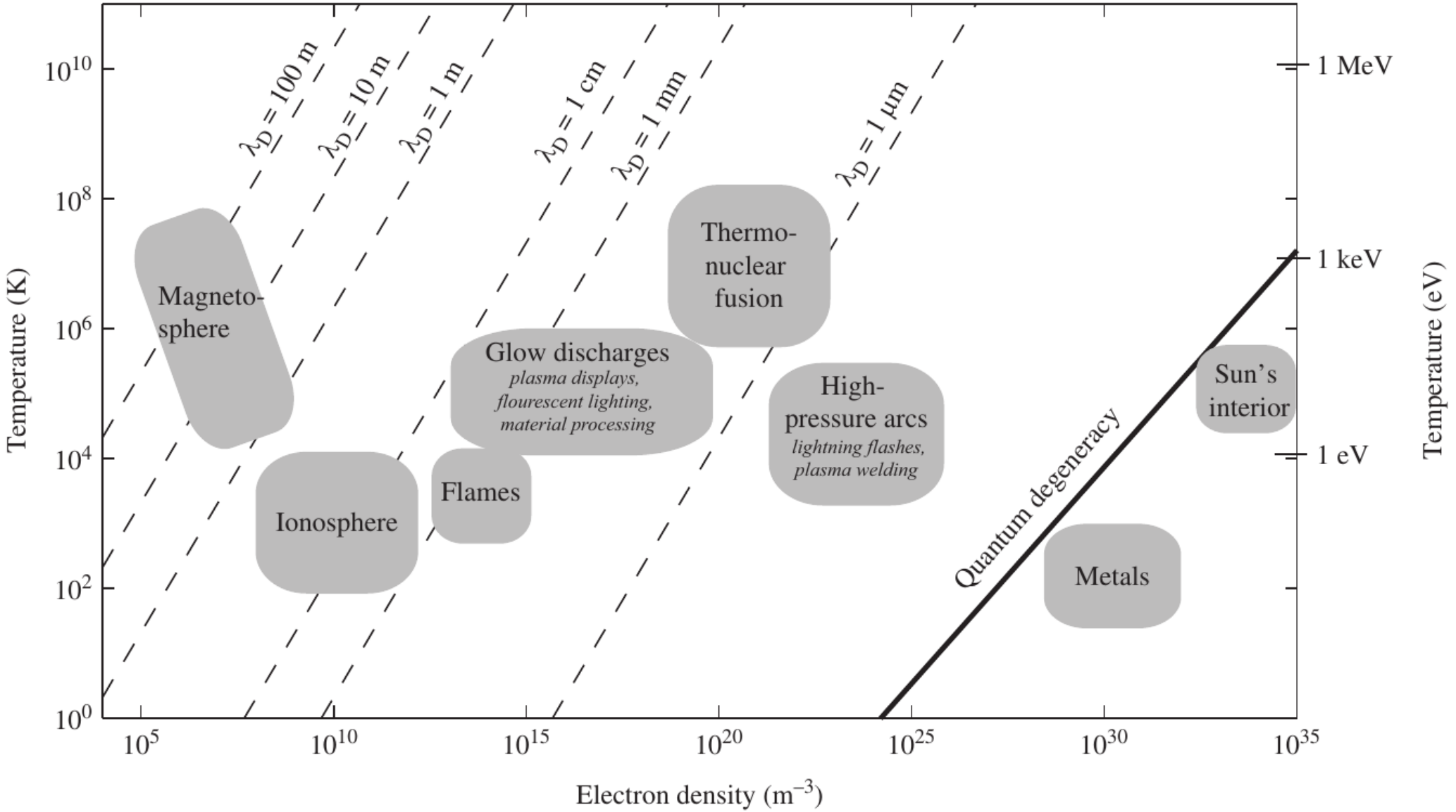
  The three conditions a plasma must satisfy

1. $\lambda_D \ll L$.
2. $N_D \ggg 1$.
3. $\omega\tau > 1$.

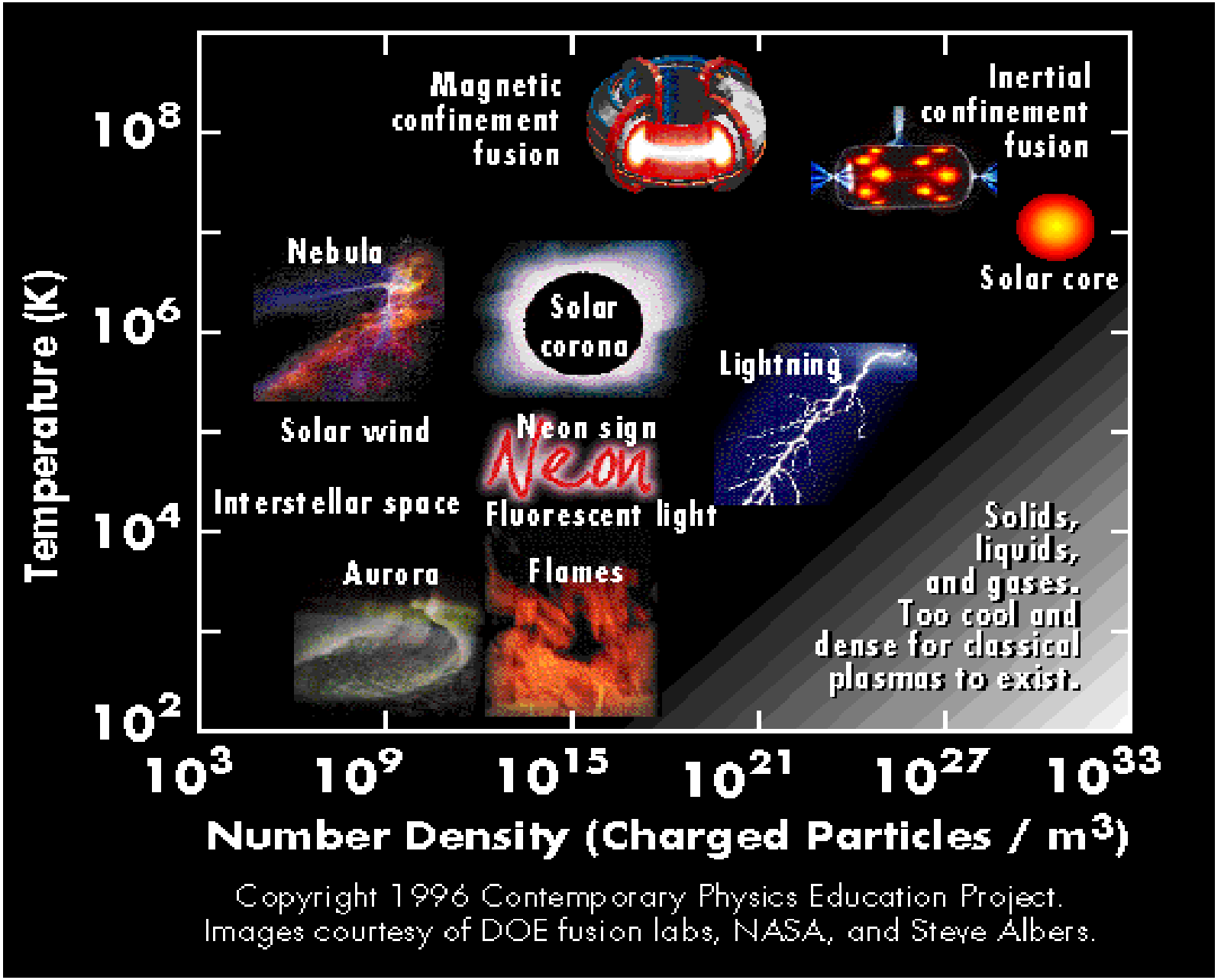
Outline

- Plasma History
- Basic Plasma Physics
- **Plasmas are Everywhere**
- Plasma in the Universe
- Plasma in Technology

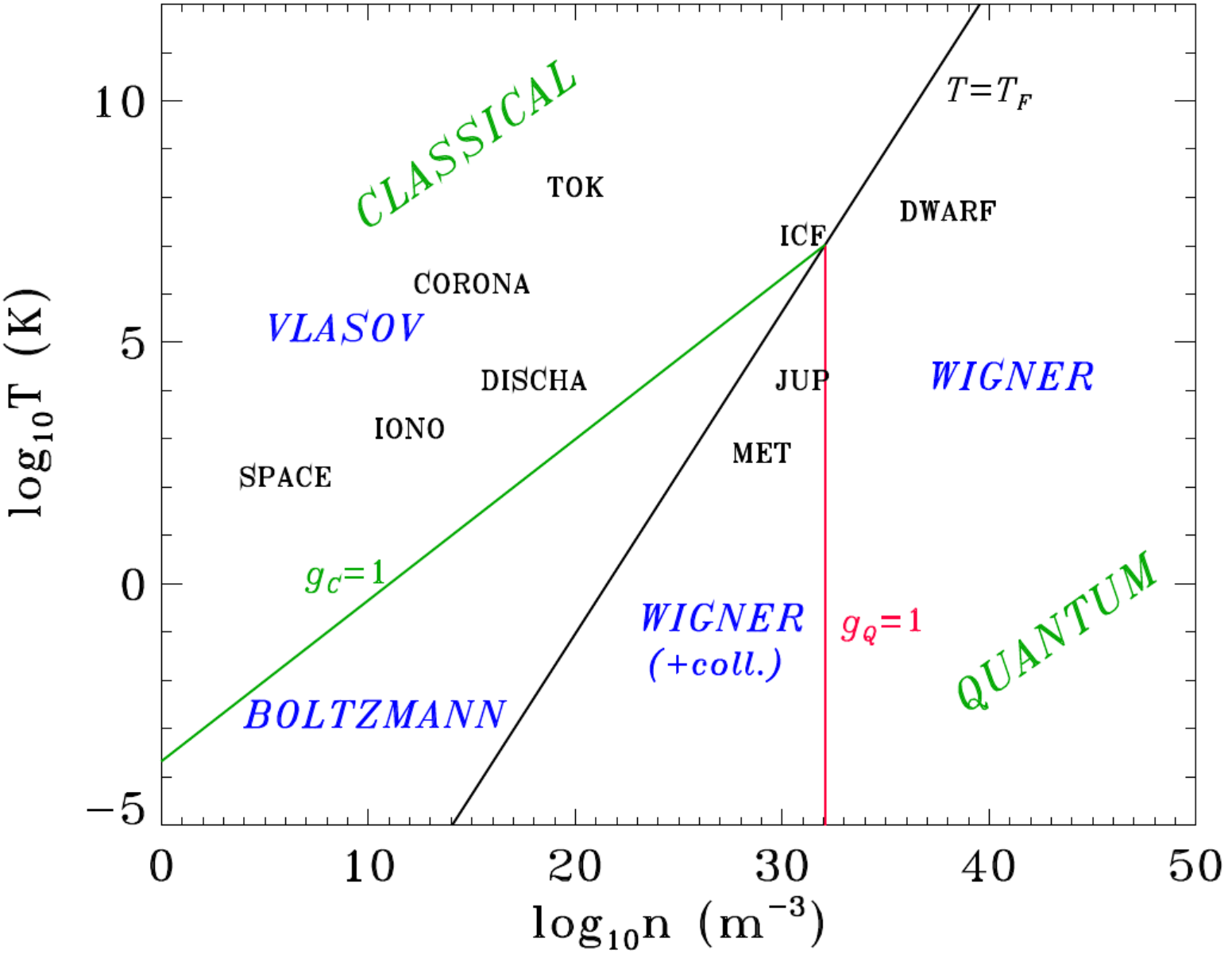
Plasmas are Everywhere



Plasmas are Everywhere, cont.



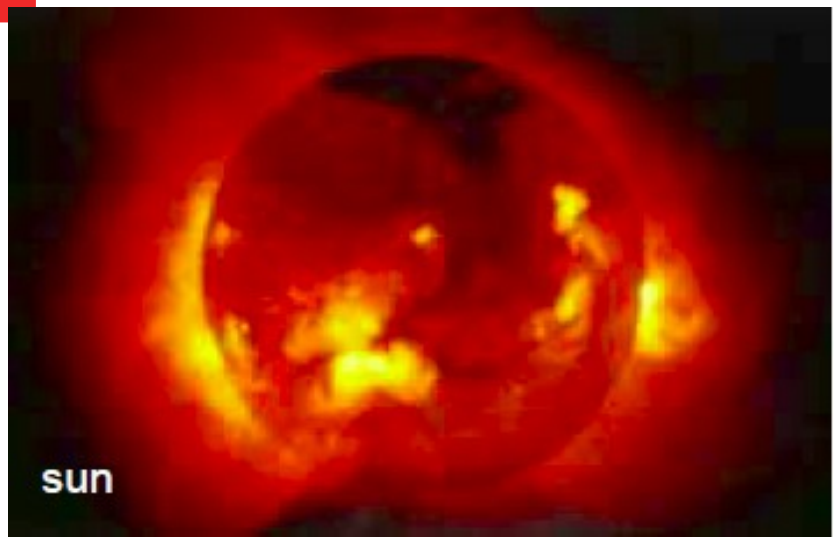
Plasmas are Everywhere, cont.



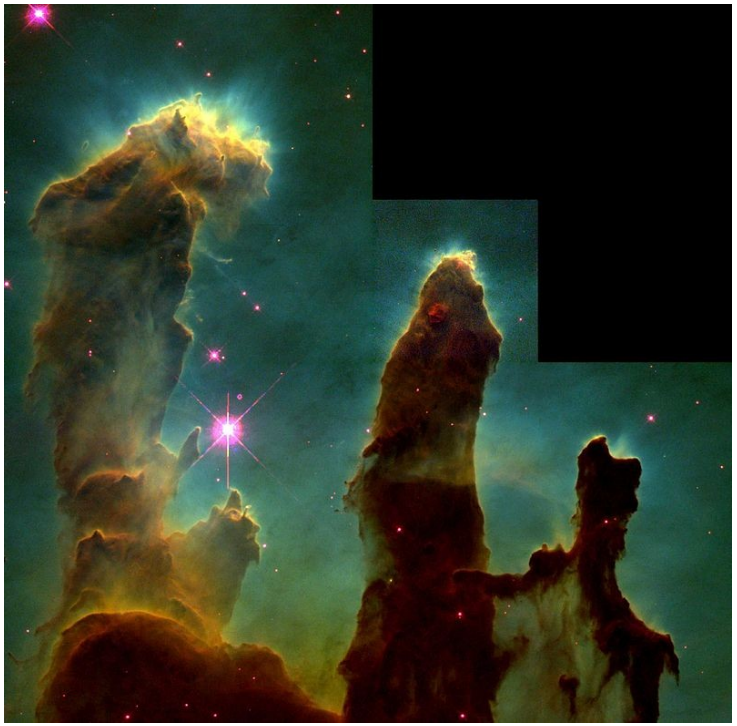
Outline

- Plasma History
- Basic Plasma Physics
- Plasmas are Everywhere
- **Plasma in the Universe**
- Plasma in Technology

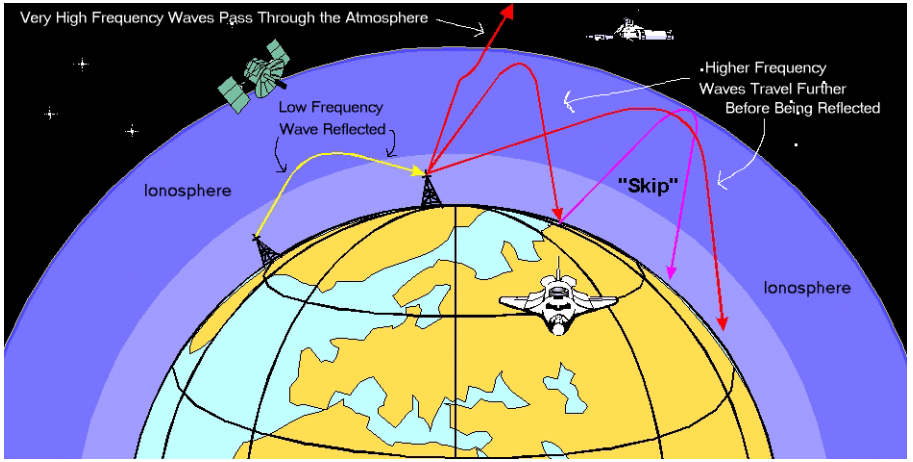
Plasma in the Universe



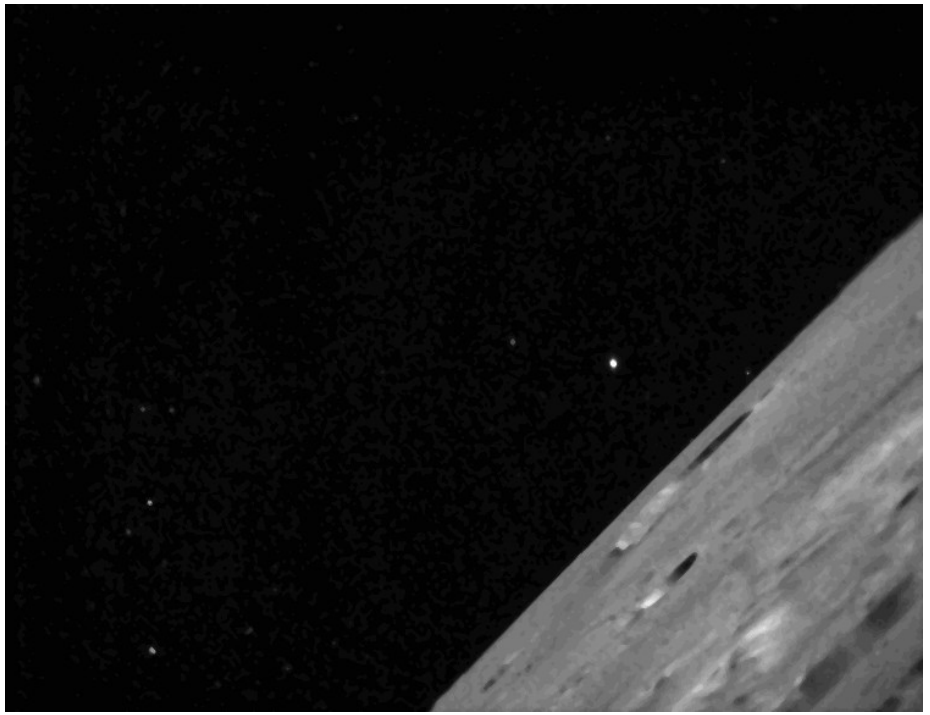
Movie

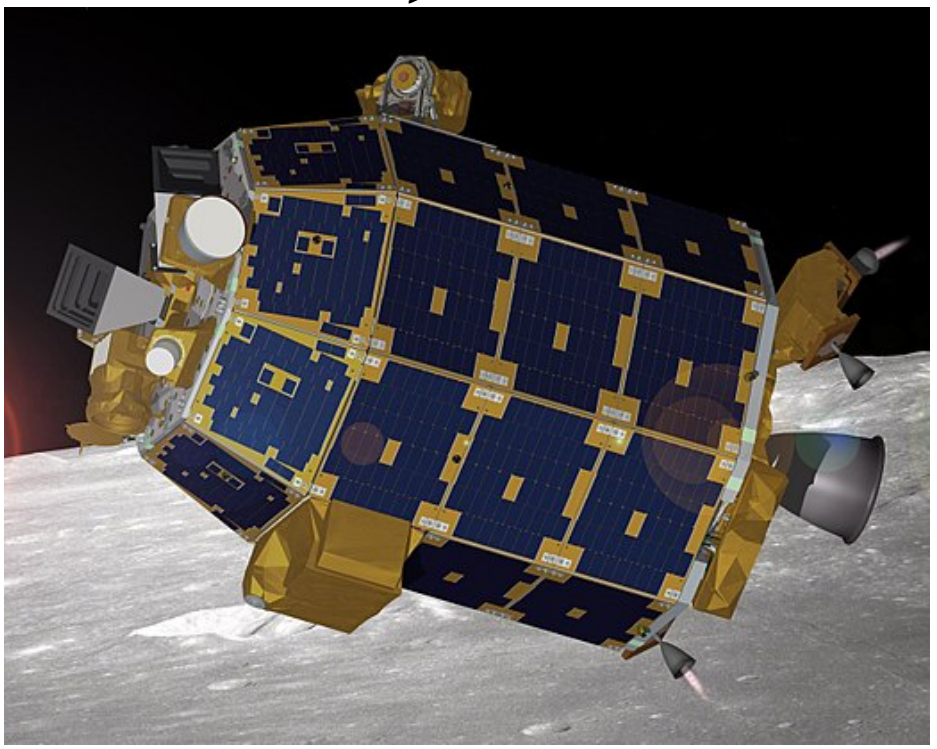


Plasma in the Universe, cont.



Plasma in the Universe, cont.



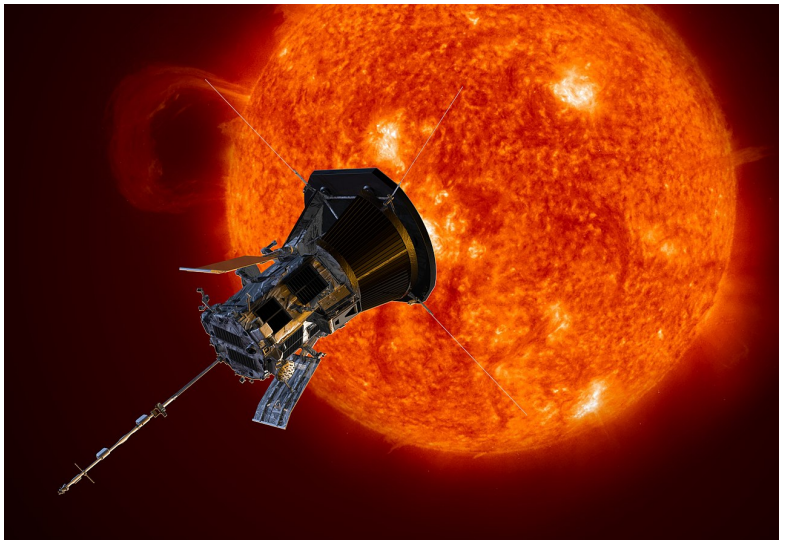


In September 2013, NASA launched the **LADEE** mission (**L**unar **A**tmosphere and **D**ust **E**nvironment **E**xplorer). One of the purposes of this mission is to study the nature of the **dust lofted above the lunar surface** and reported by the Apollo astronauts as "moon clouds"

Plasma in the Universe, cont.

Parker Solar Probe

- 12 August 2018

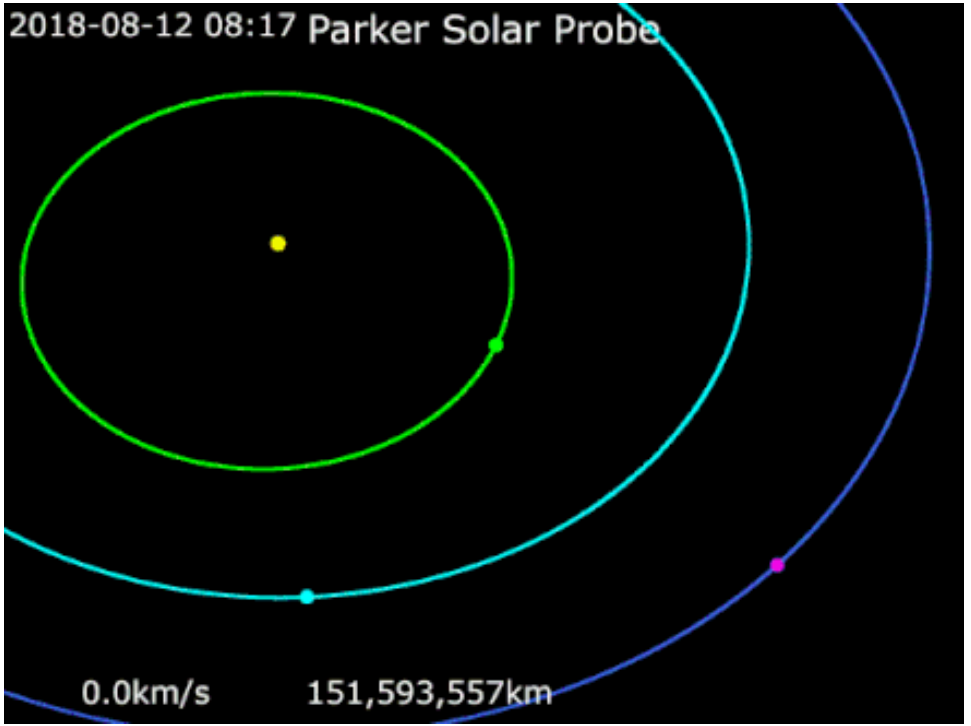


Missions

a) Corona and accelerates the solar wind,

b) Magnetic fields at the sources of solar wind,

c) Mechanisms accelerate and transport energetic particles.



Movie & Movie

Outline

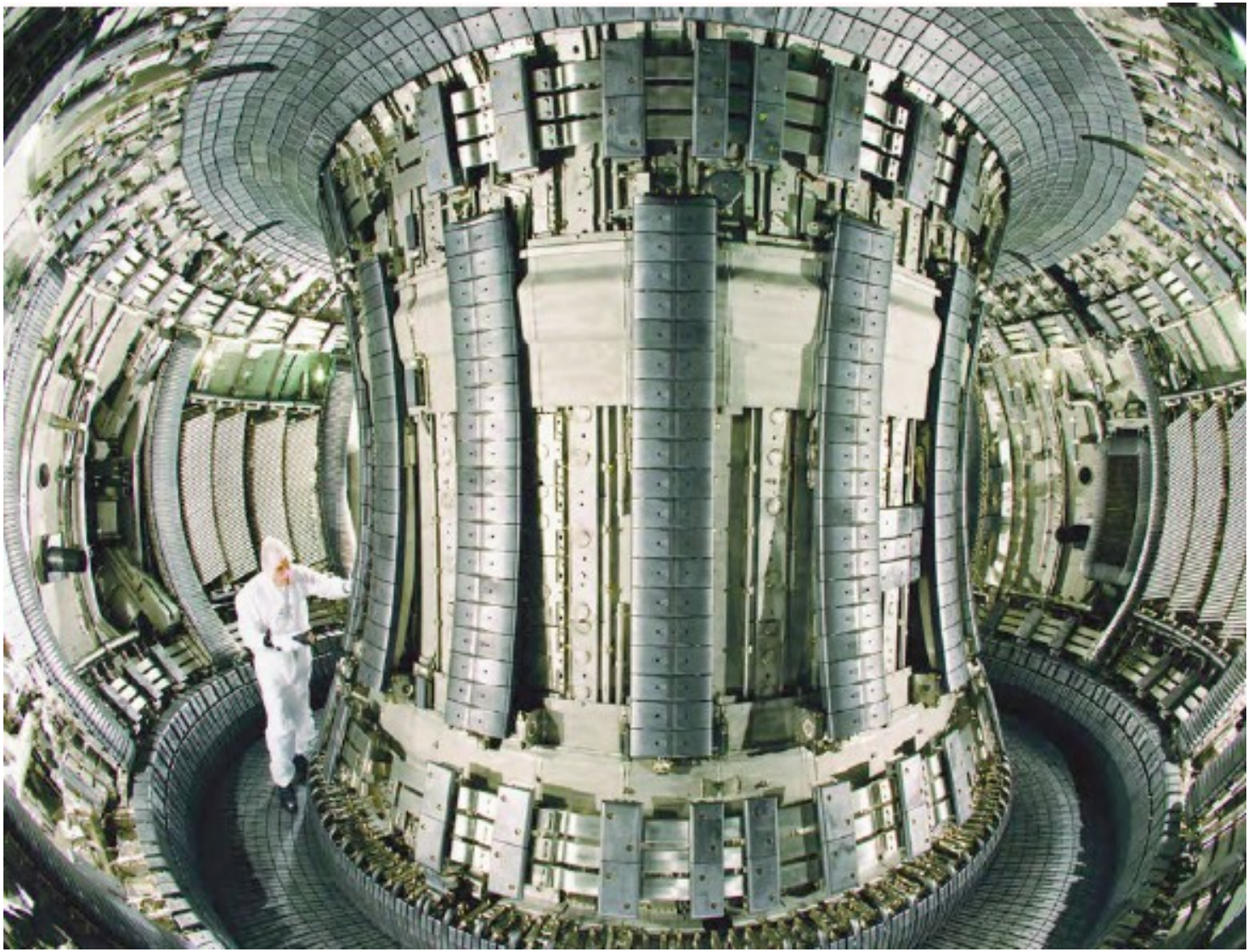
- Plasma History
- Basic Plasma Physics
- Plasmas are Everywhere
- Plasma in the Universe
- **Plasma in Technology**

Plasma in Technology

The situation is further complicated due to the fact that reactive plasmas represent a cross-disciplinary field which requires knowledge in a wide variety of fields in:

- Physics (statistical, quantum, electrodynamics, material science, laser, space, astronomy...)
- Chemistry
- Mathematics (differential equations…..)
- Programming (C++, Fortran, Paython, MatLab...)
- Biology

Plasma in Technology, cont.



Joint European Torus (JET) is currently World's Largest Tokamak 16 MW

Plasma in Technology, cont.

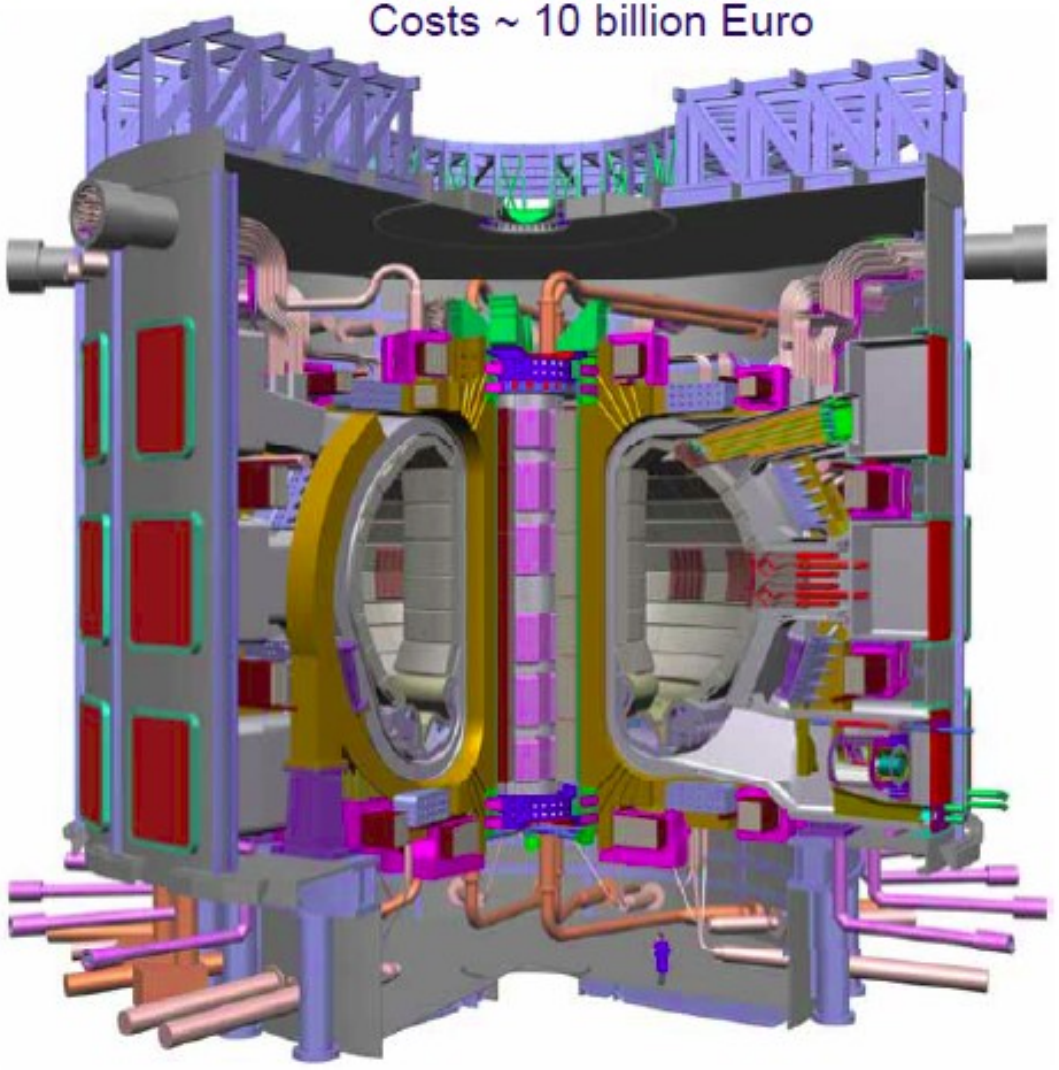
ITER

European Union
Japan
China
India
Korea
Russia
USA

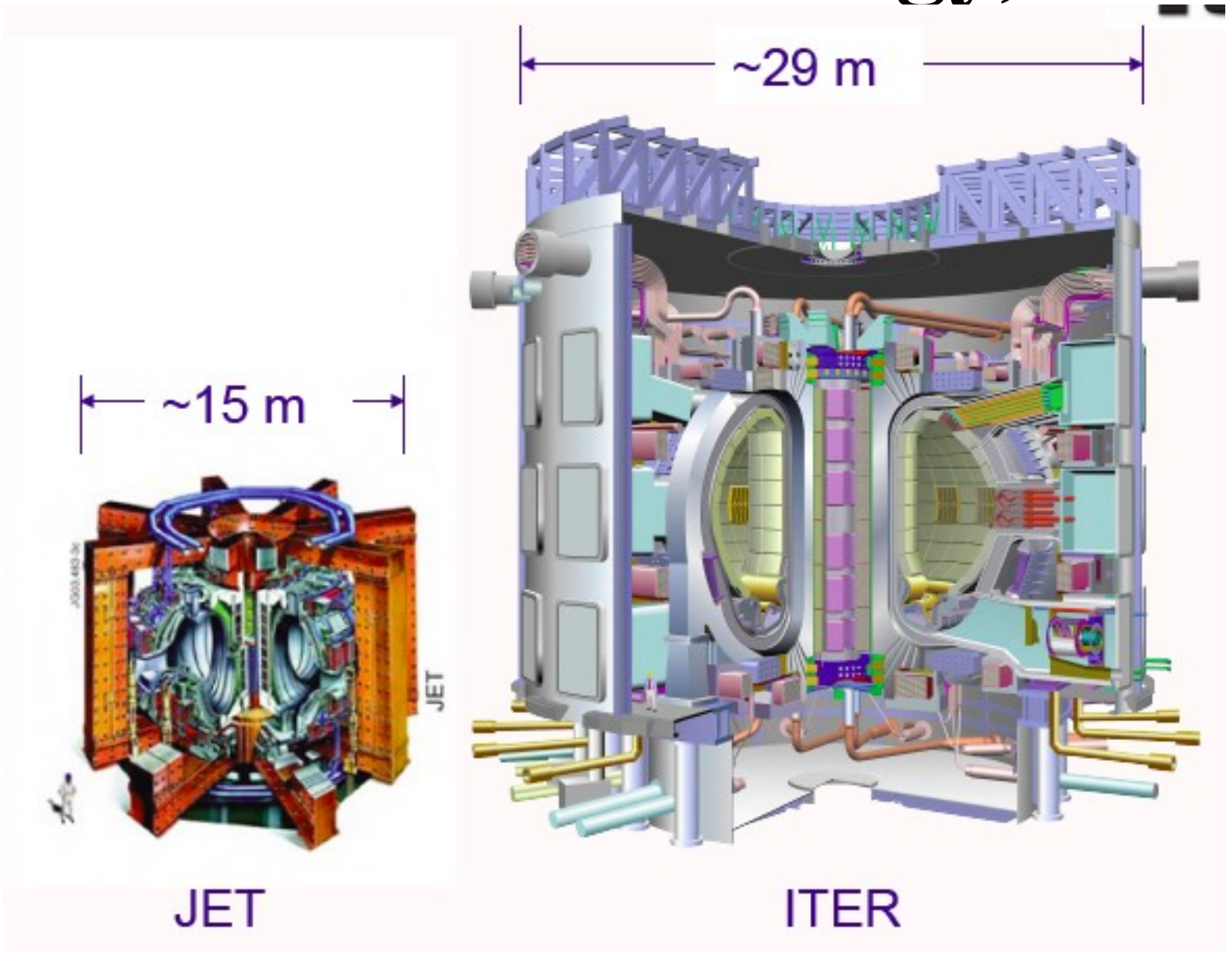
Cadarache, France

Goals:

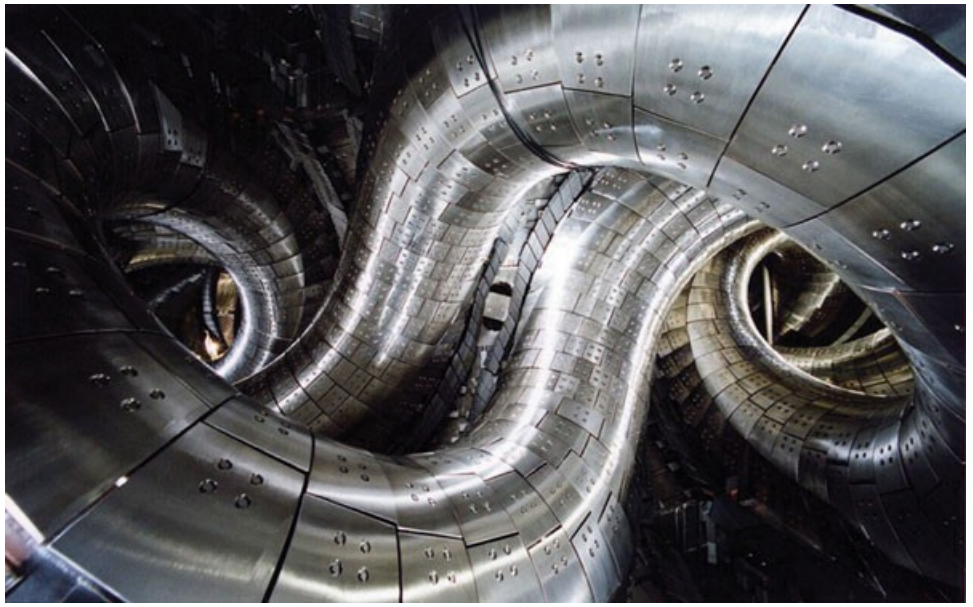
- Q=10
- α-physics
- Tritium-cycle
- Neutrons
- cont. operation
- Material science
- Technology

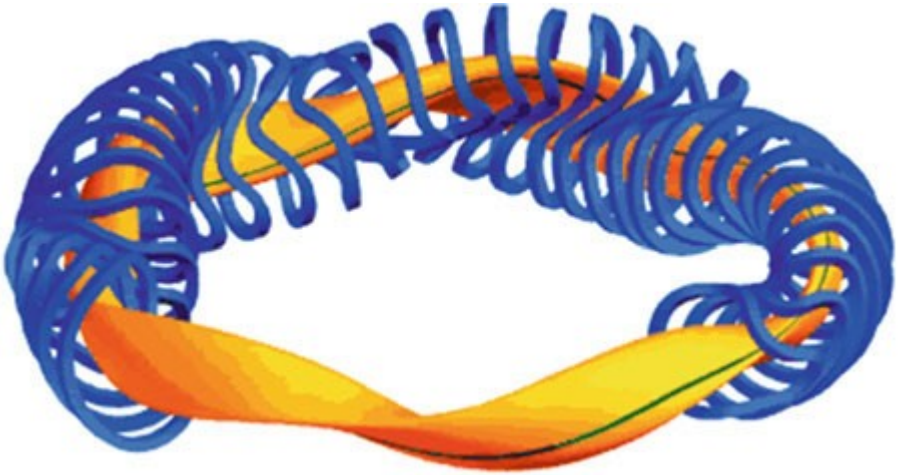


Plasma in Technology, cont.

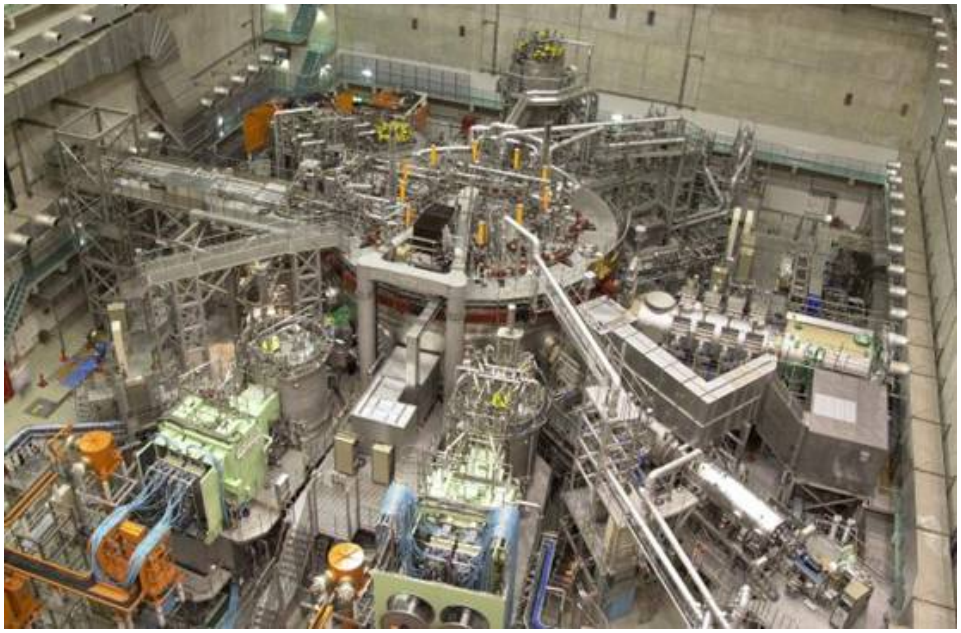


Plasma in Technology, cont.

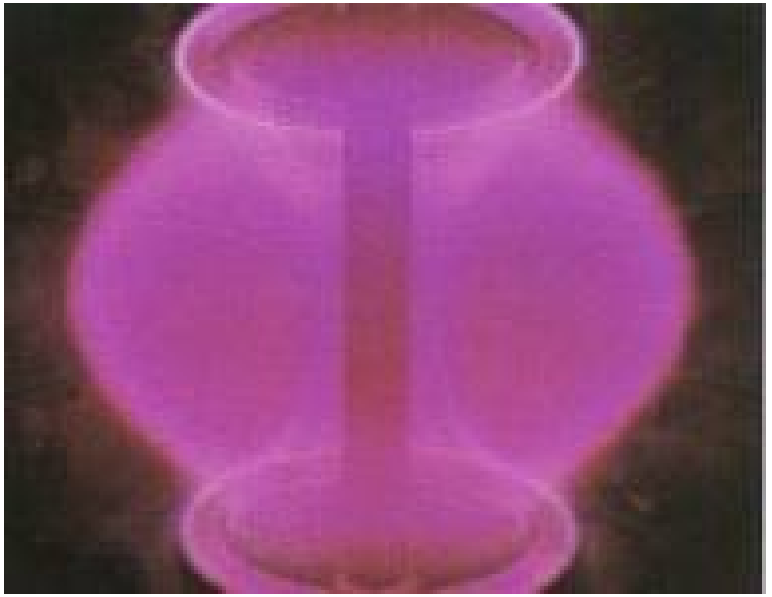


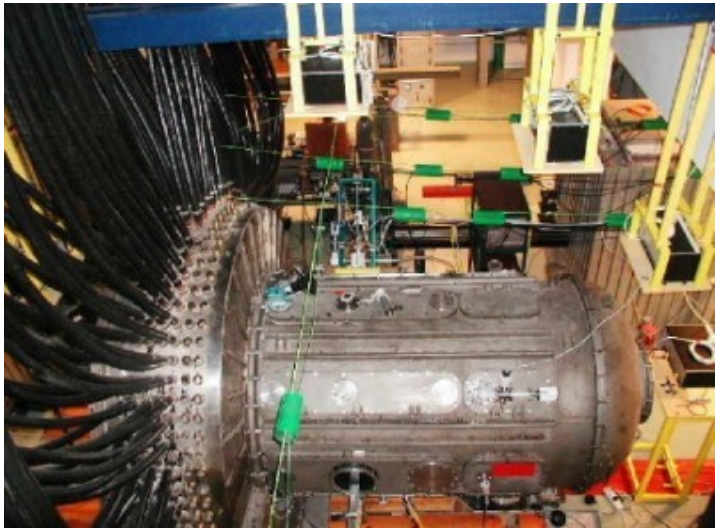


Stellarator

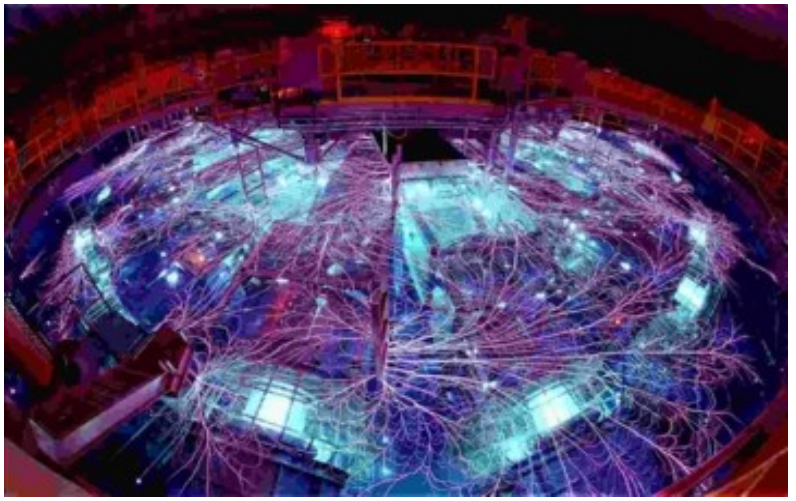


Plasma in Technology, cont.





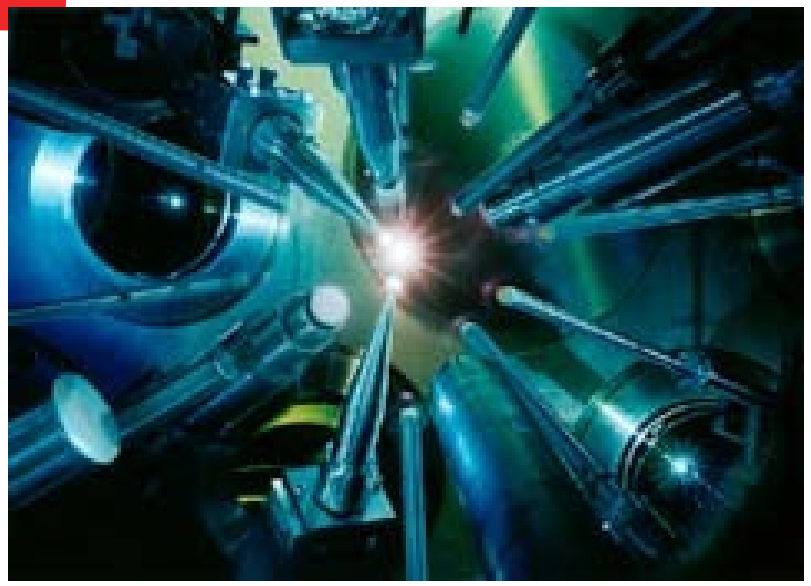
PF1000 Warsaw



Z-Machine Sandia

Other Fusion Devices

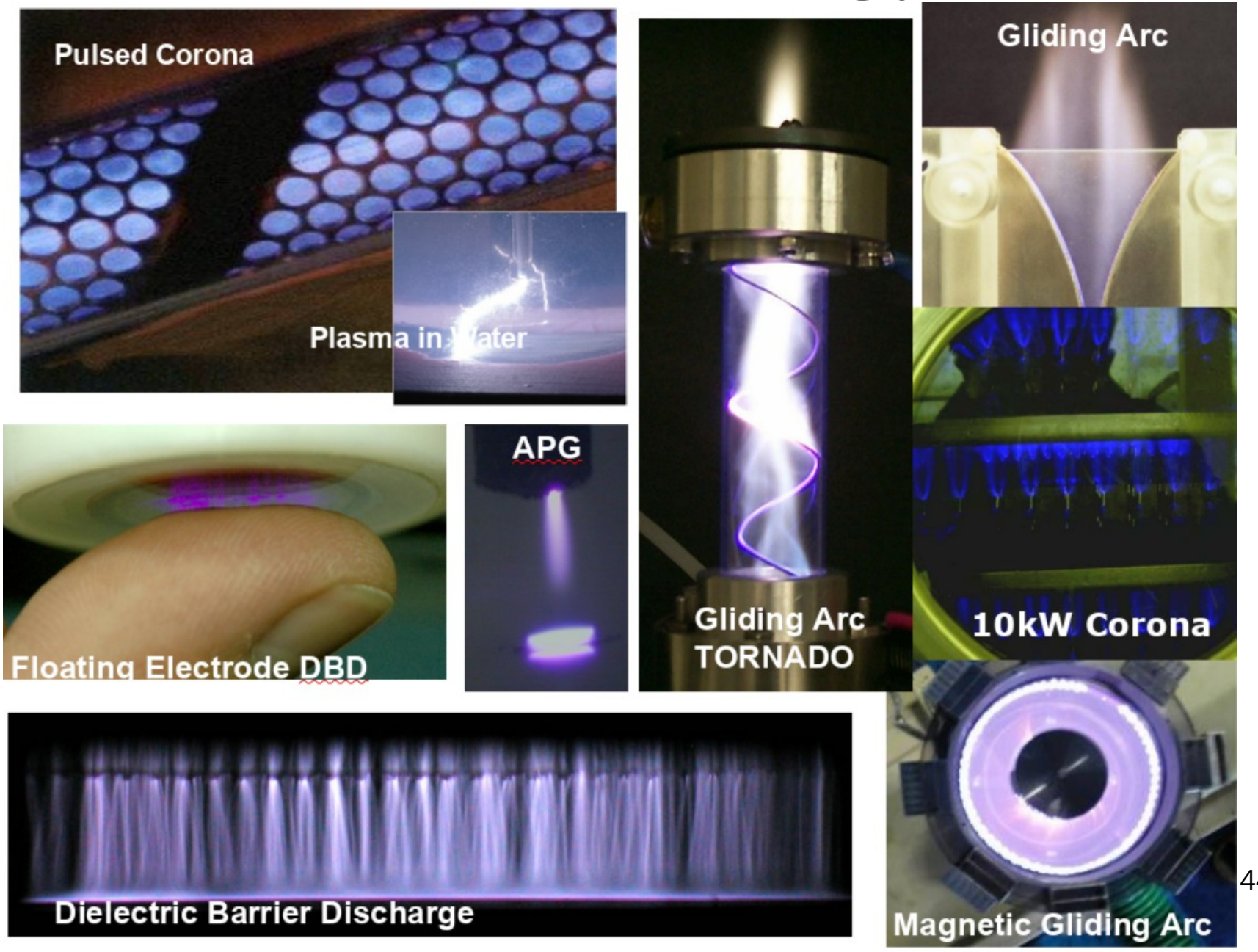
Plasma in Technology, cont.



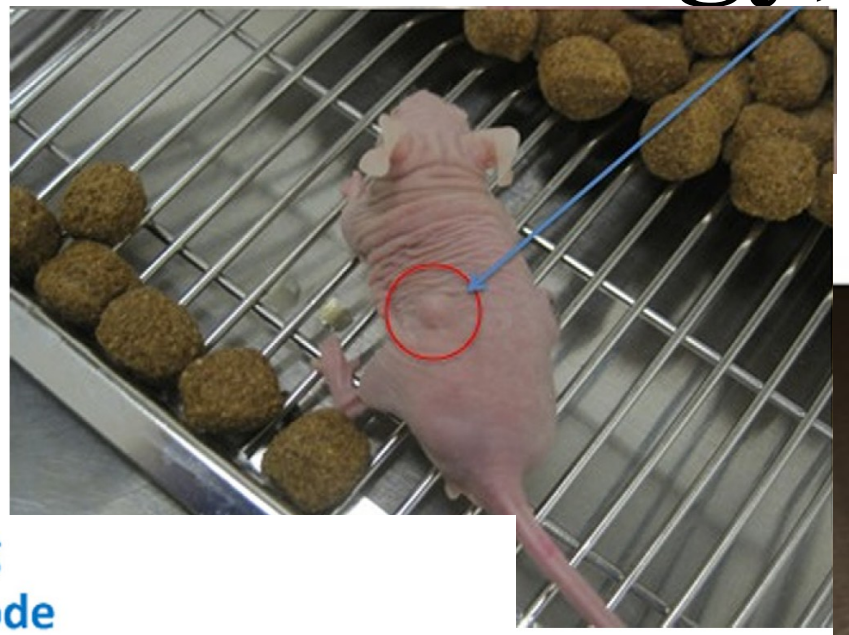
- **Inertial confinement fusion**

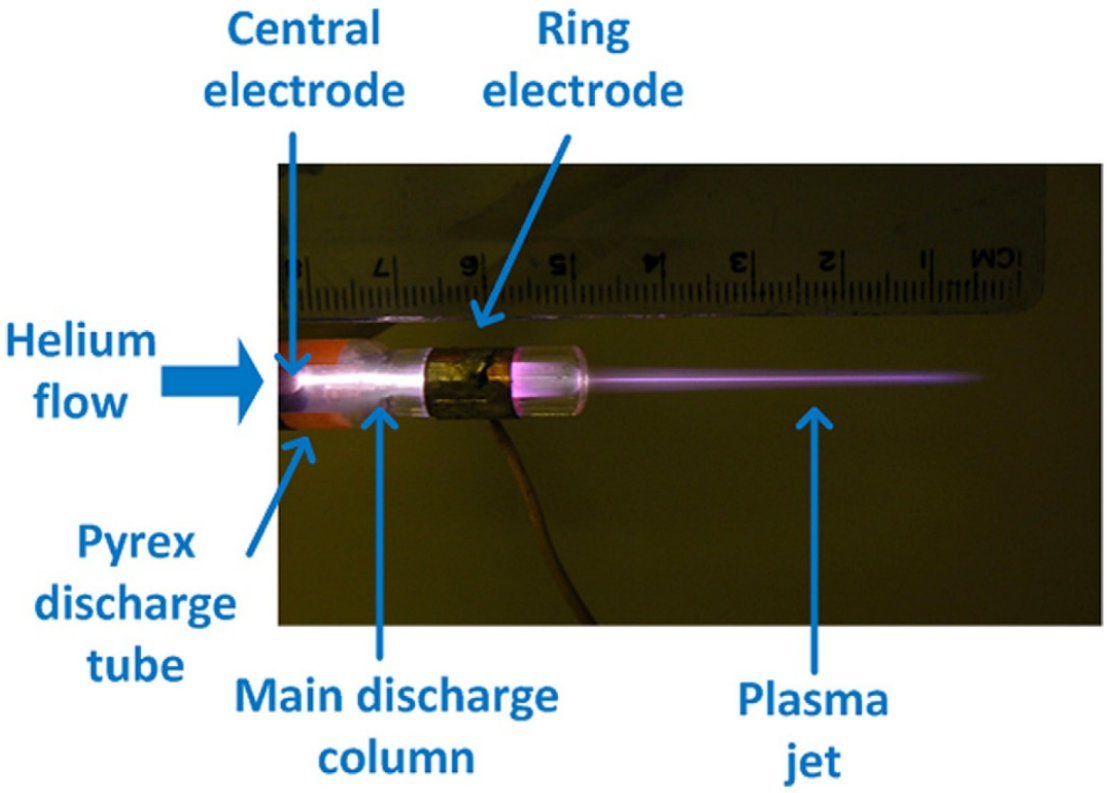
- In this approach, tightly focused laser beams are used to implode a small solid target until the densities and temperatures characteristic of nuclear fusion (*i.e.*, the center of a hydrogen bomb) are achieved.

Plasma in Technology, cont.



Plasma in Technology, cont.





Plasma in Technology, cont.

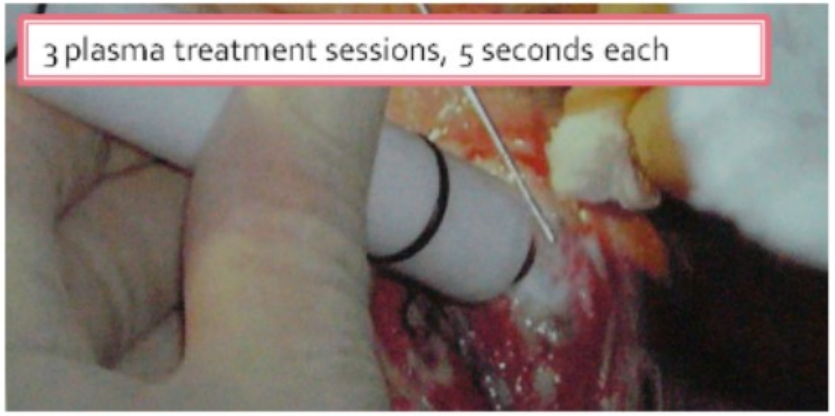
Wound Healing: Suppurated Burns

Plasma Technologies, Inc

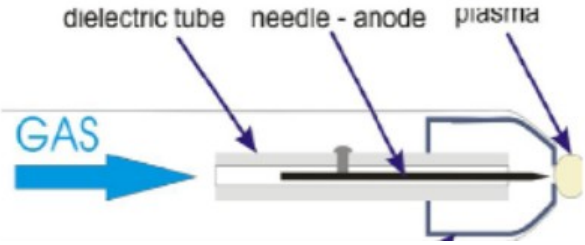
Wound Healing: Trophic Venous Ulcers

Broad Necrotic Suppurated Ulcer (Diabetic Peripheral Neuropathy)

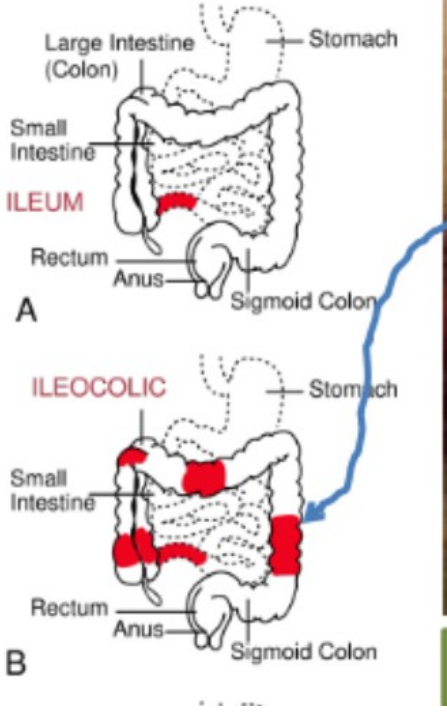
Plasma in Technology, cont.

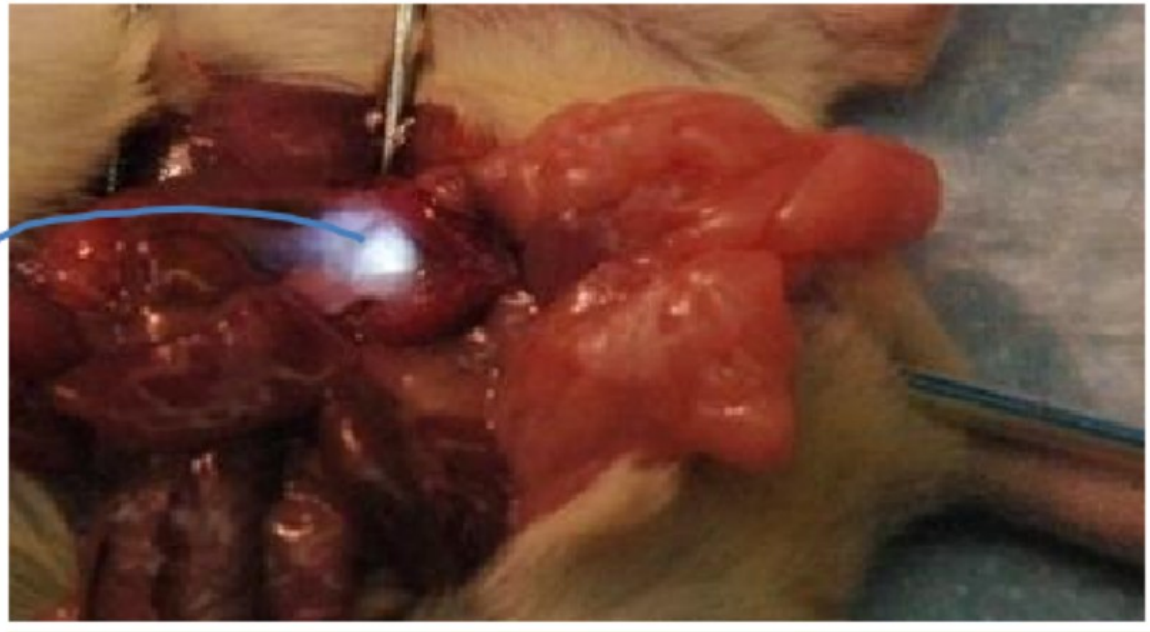


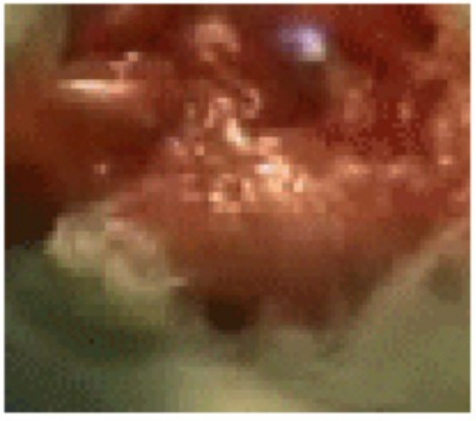
- Discharge voltage: 1 – 5 kV
- Plasma diameter: 3 – 5 mm
- Frequency: 1 – 7 Hz
- Pulse duration: ~30 ms
- Energy per pulse: 0.5 - 1 J



Plasma in Technology, cont.

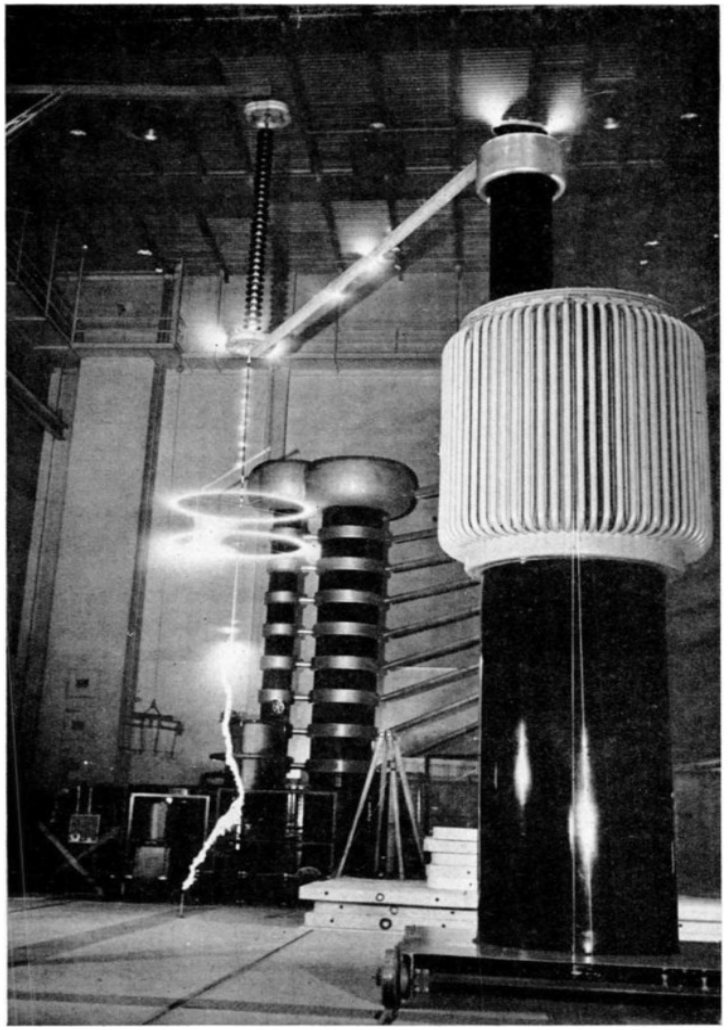


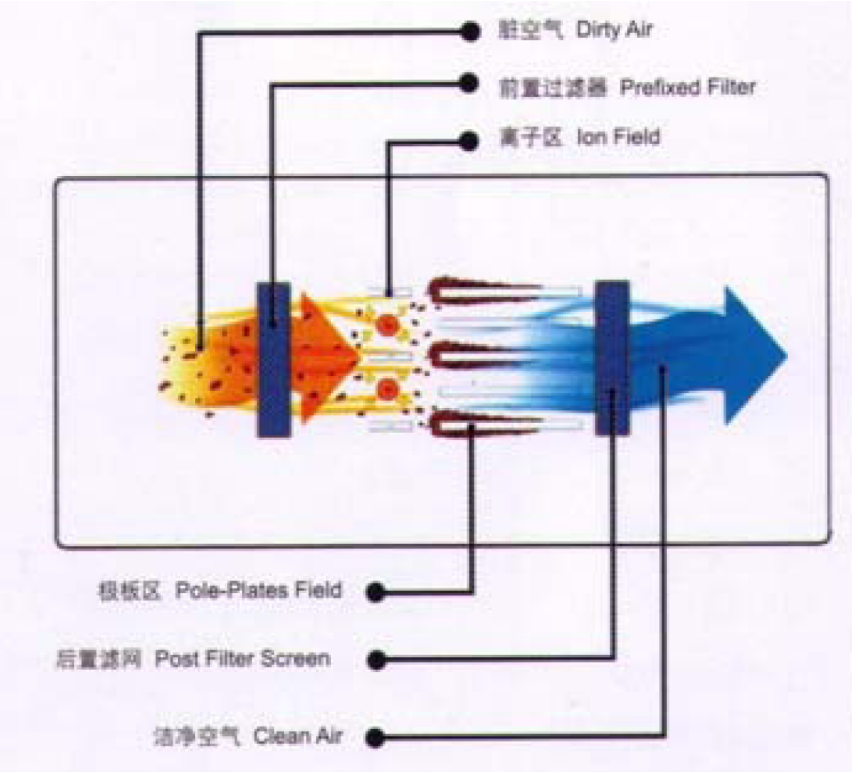




Plasma can be safely applied to treatment of gastrointestinal diseases.

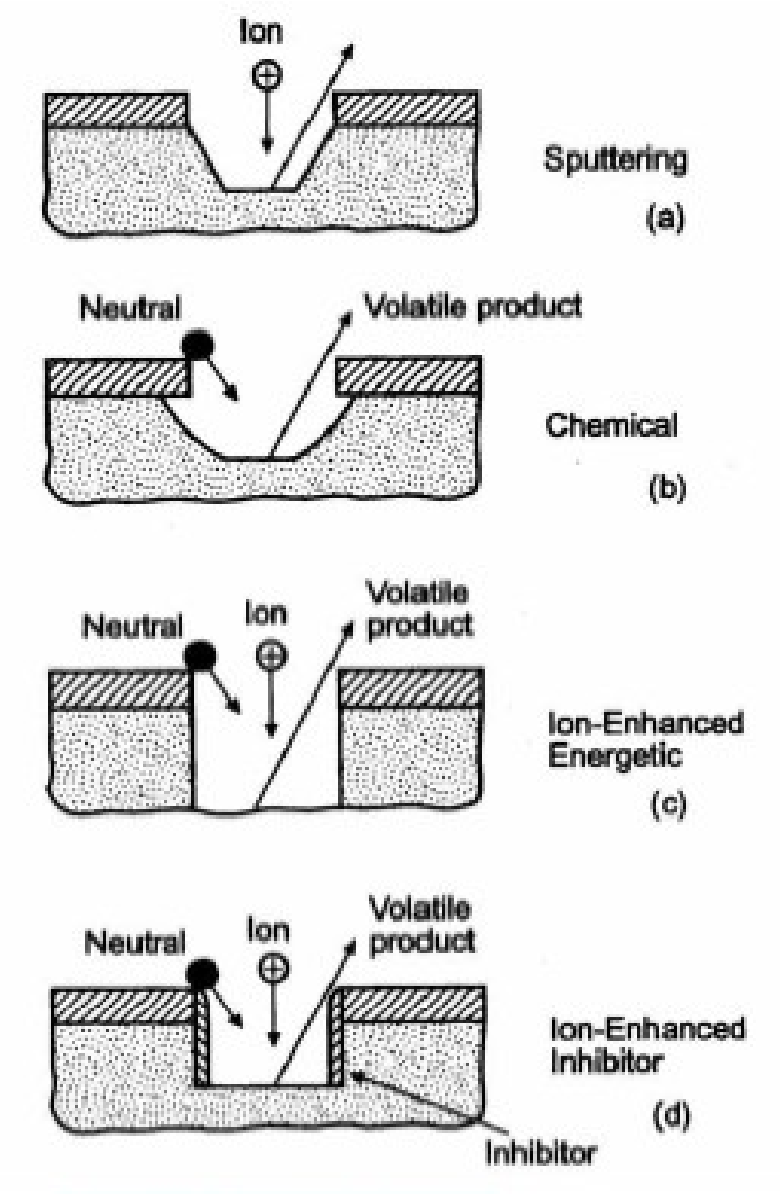
Plasma in Technology, cont.



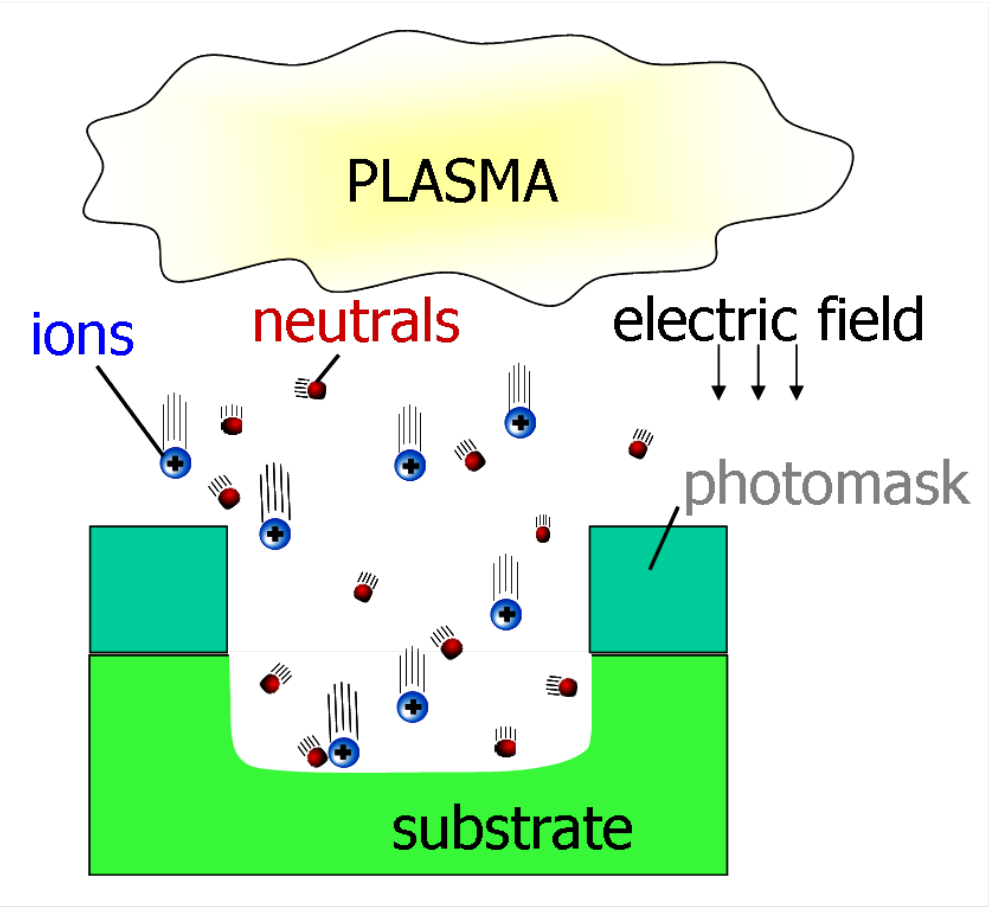


Large corona discharges *(white)* around conductors energized by a 1.05 million volt transformer in a U.S. NIST laboratory in 1941
Movie & Movie

Plasma in Technology, cont.



Plasma Etching, (1989) p.93



Plasma in Technology, cont.

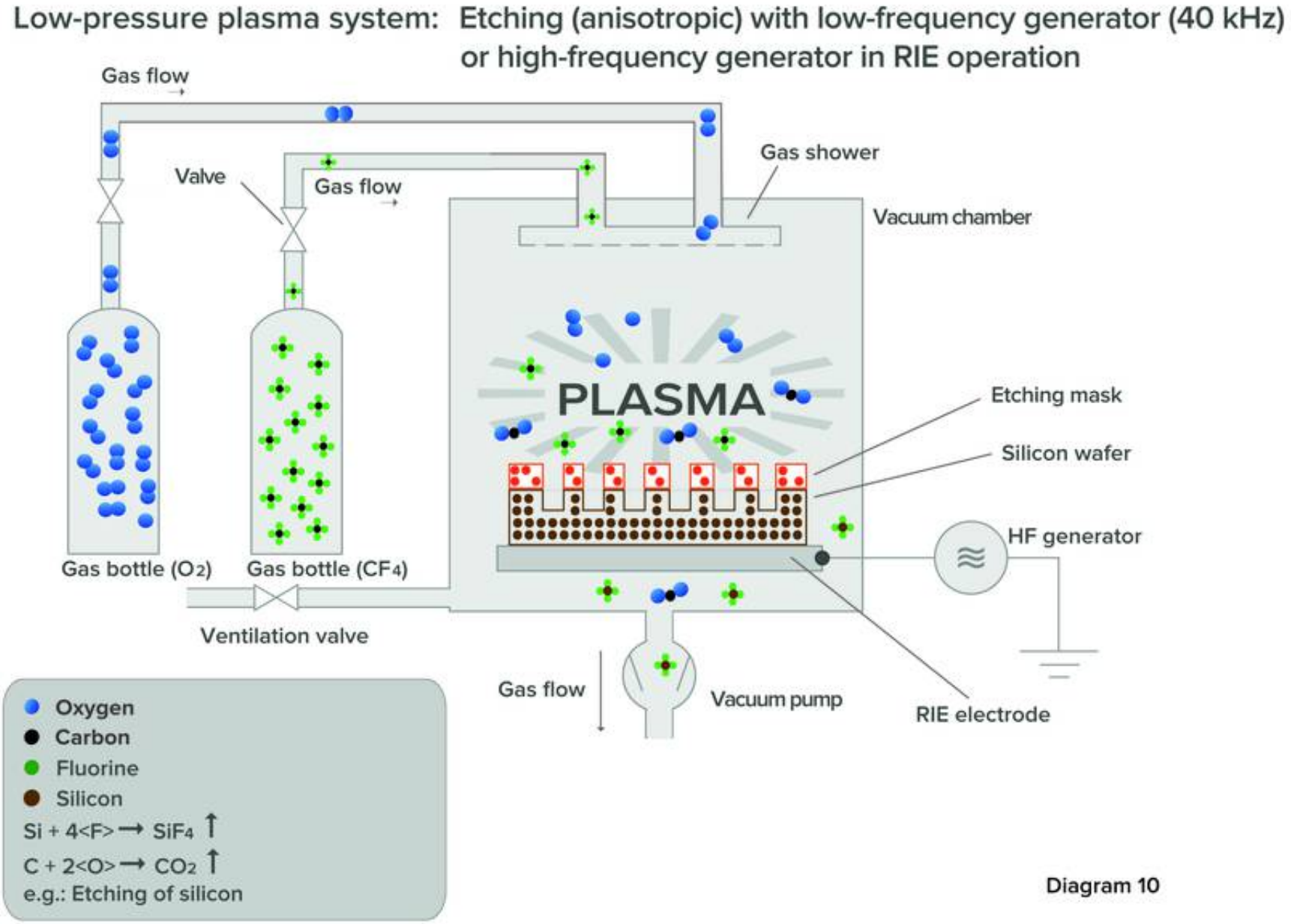
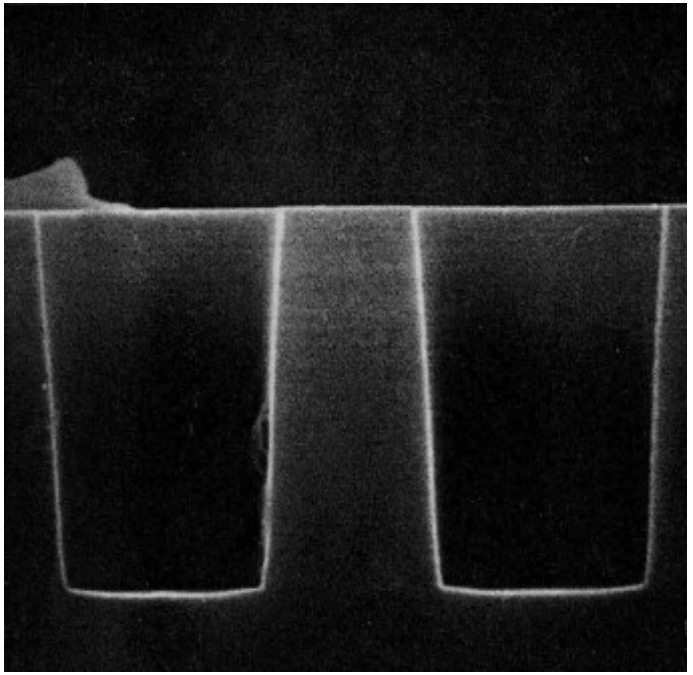
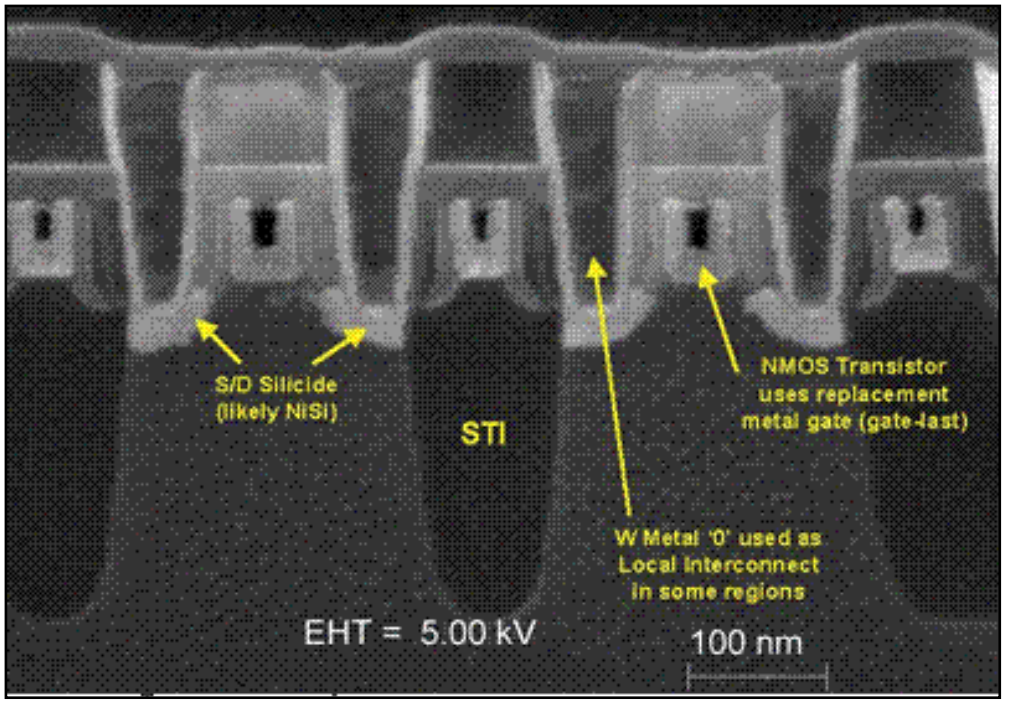


Diagram 10

Plasma in Technology, cont.





Thank You