Fusão Nuclear: Utilizando na Terra a Energia das Estrelas

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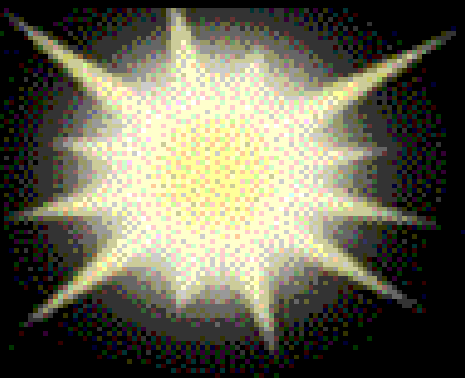
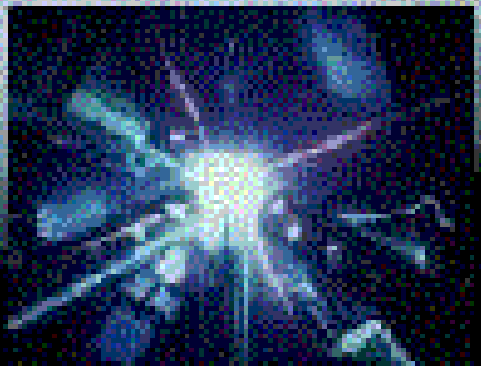
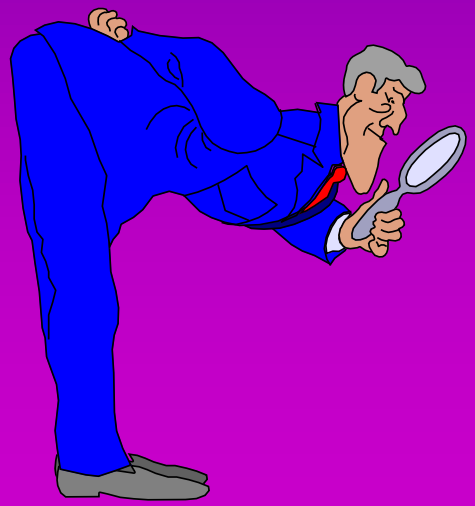
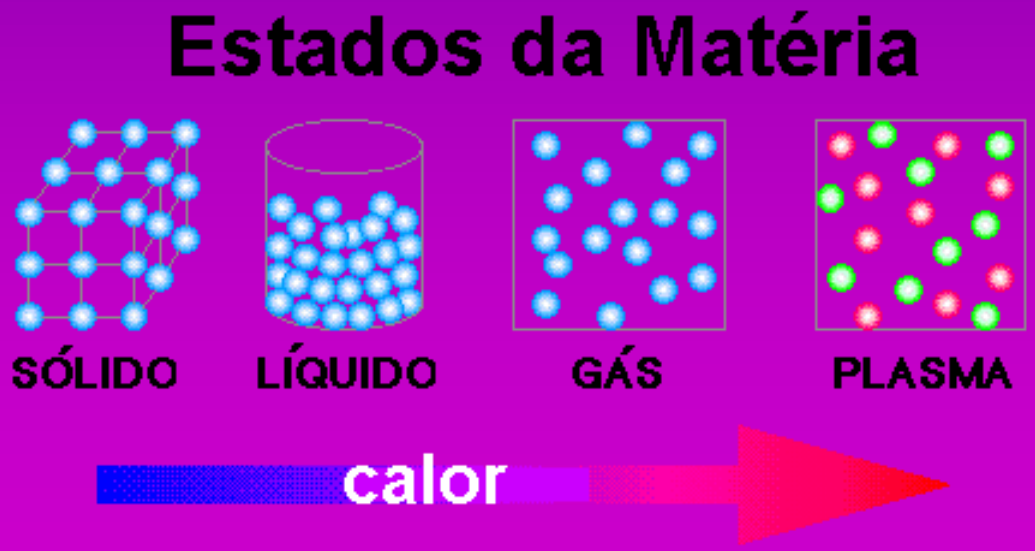




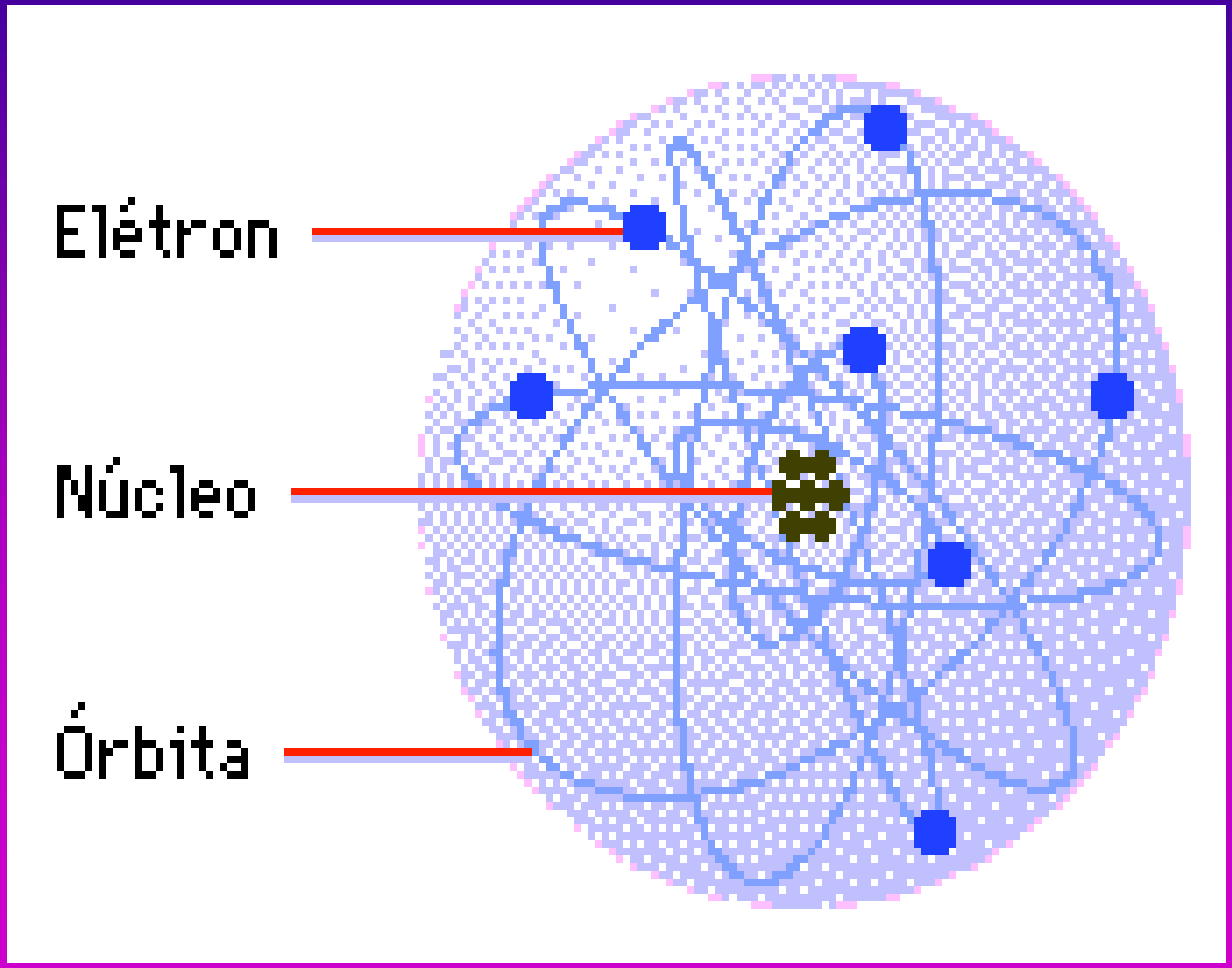
Plasma

- Gás a temperaturas elevadas (átomos ionizados)
- Número de cargas + e – aproximadamente o mesmo
- É usualmente denominado o 4º Estado da Matéria

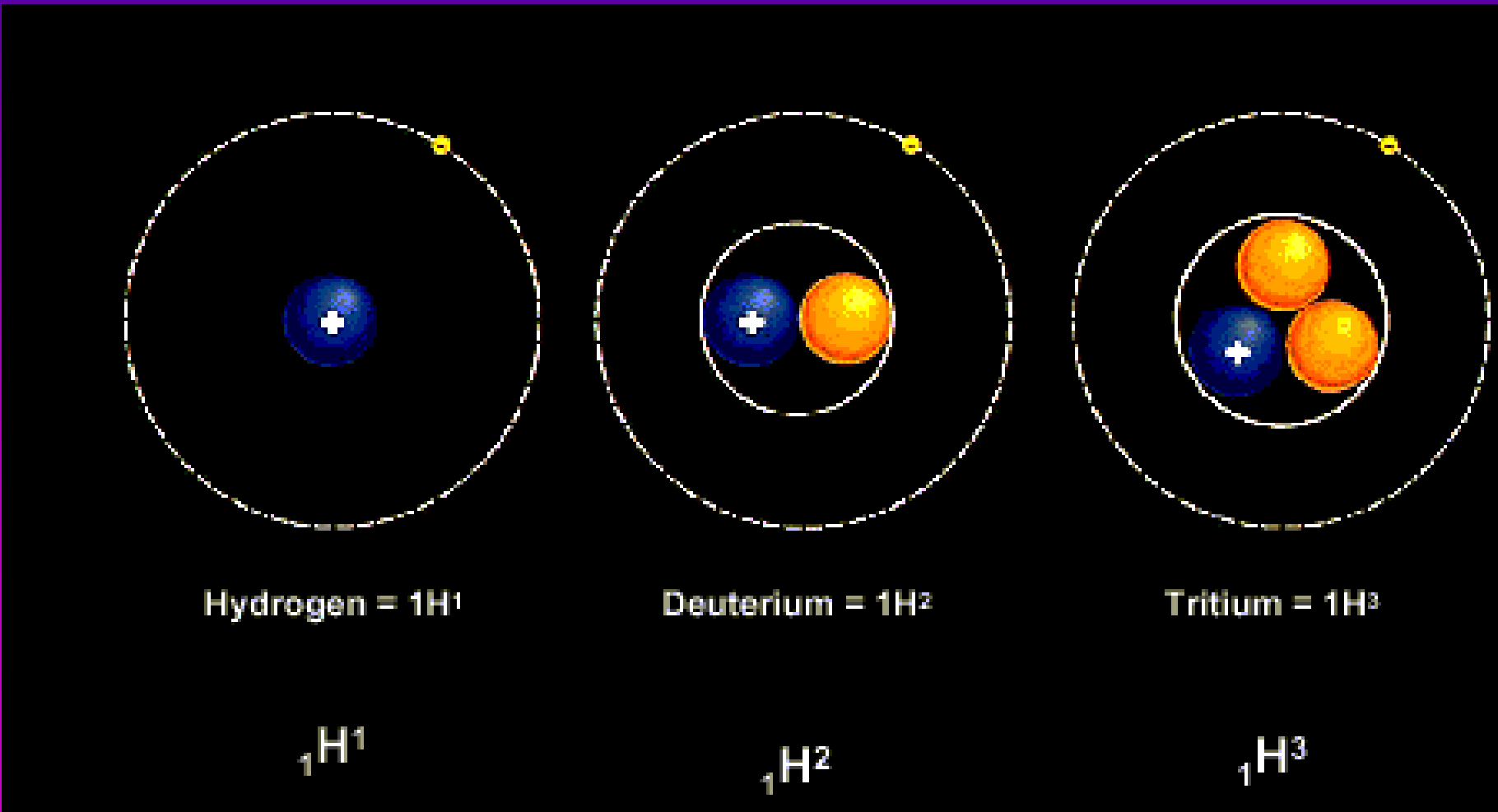




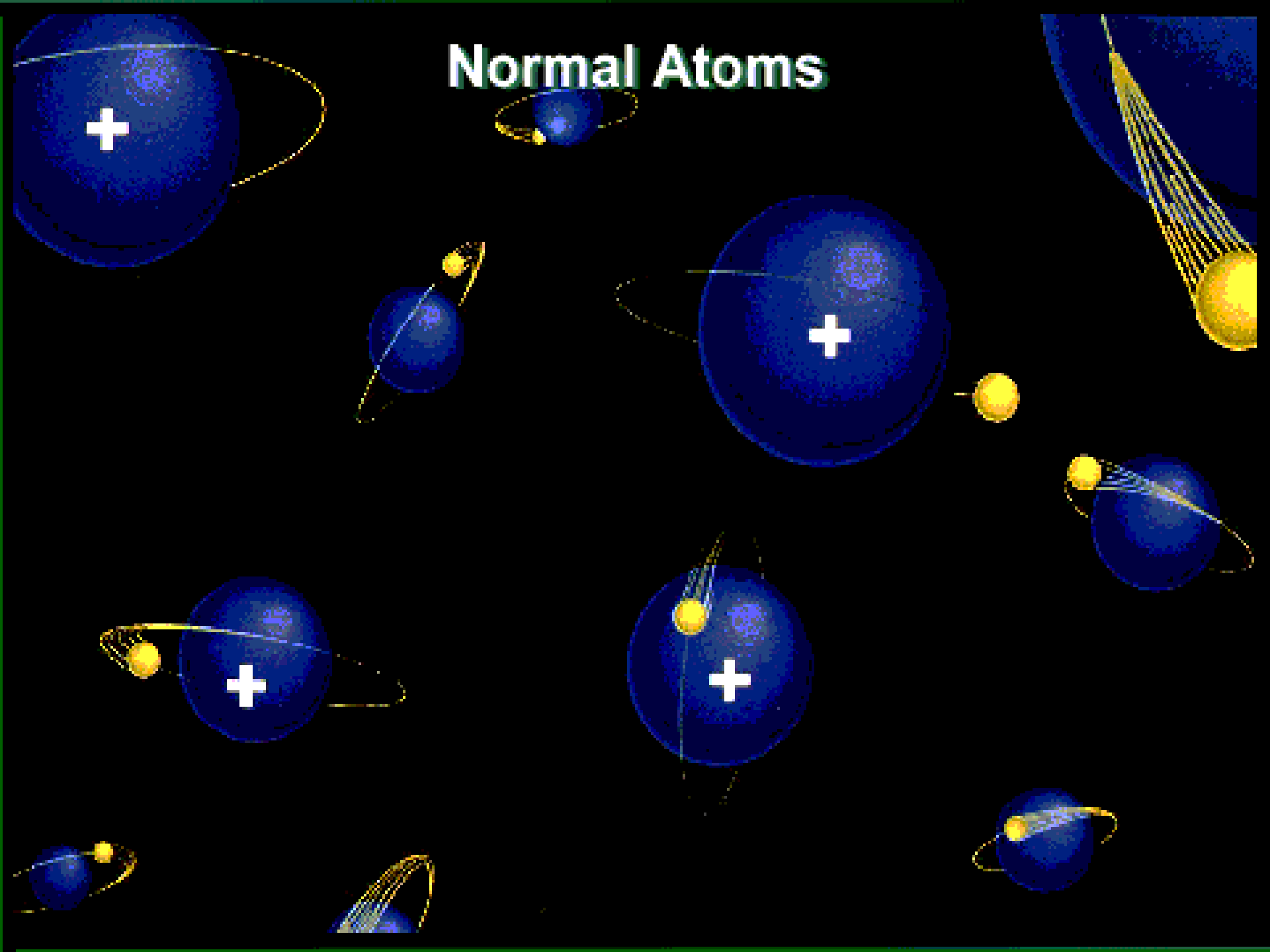
Modelo Atômico (clássico)

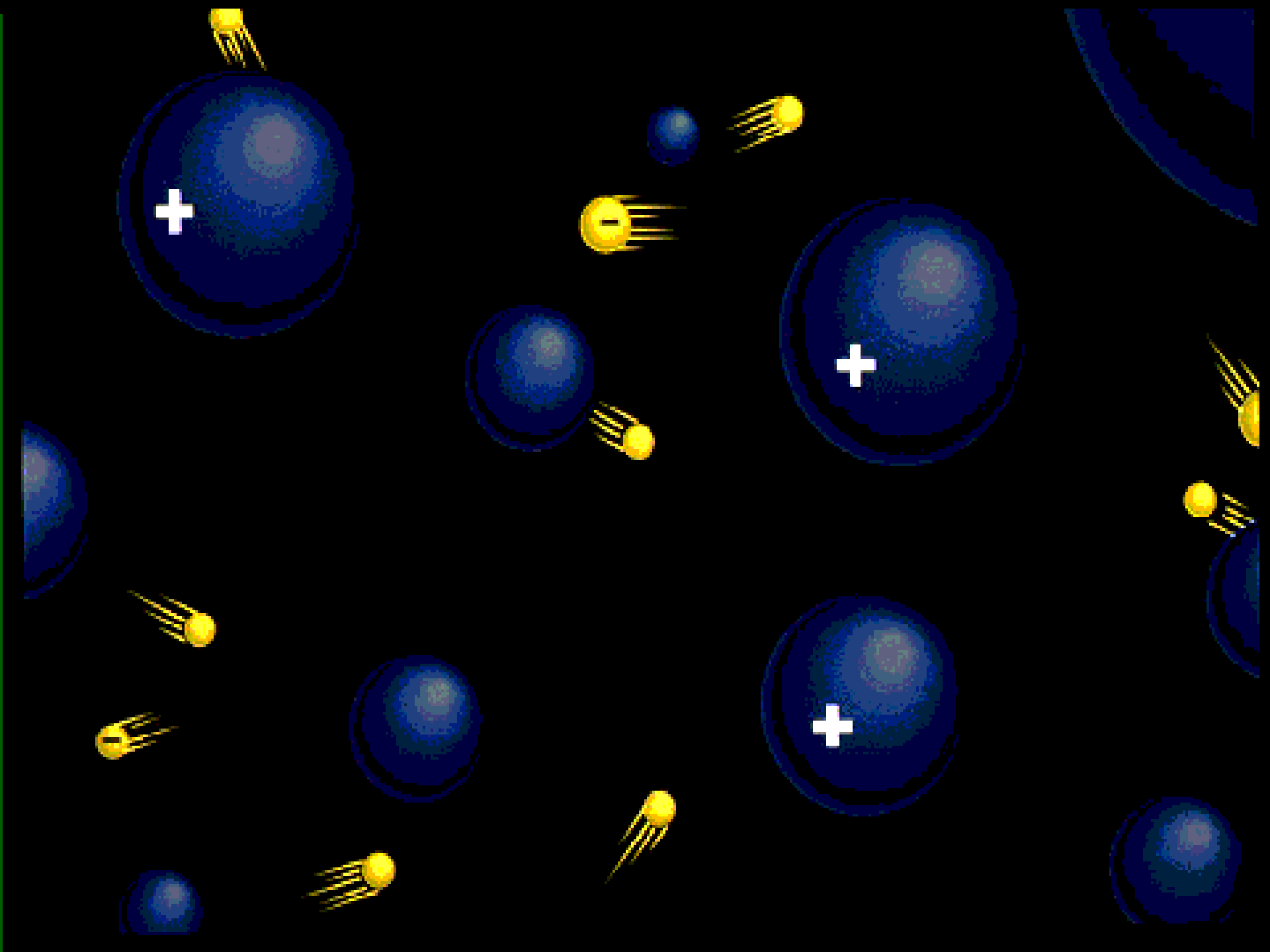


Isótopos do Hidrogênio



Normal Atoms





Motivação

Estima-se que 99% da matéria conhecida no Universo encontra-se na forma de Plasma

Lembrando que a *Velocidade da Luz*:

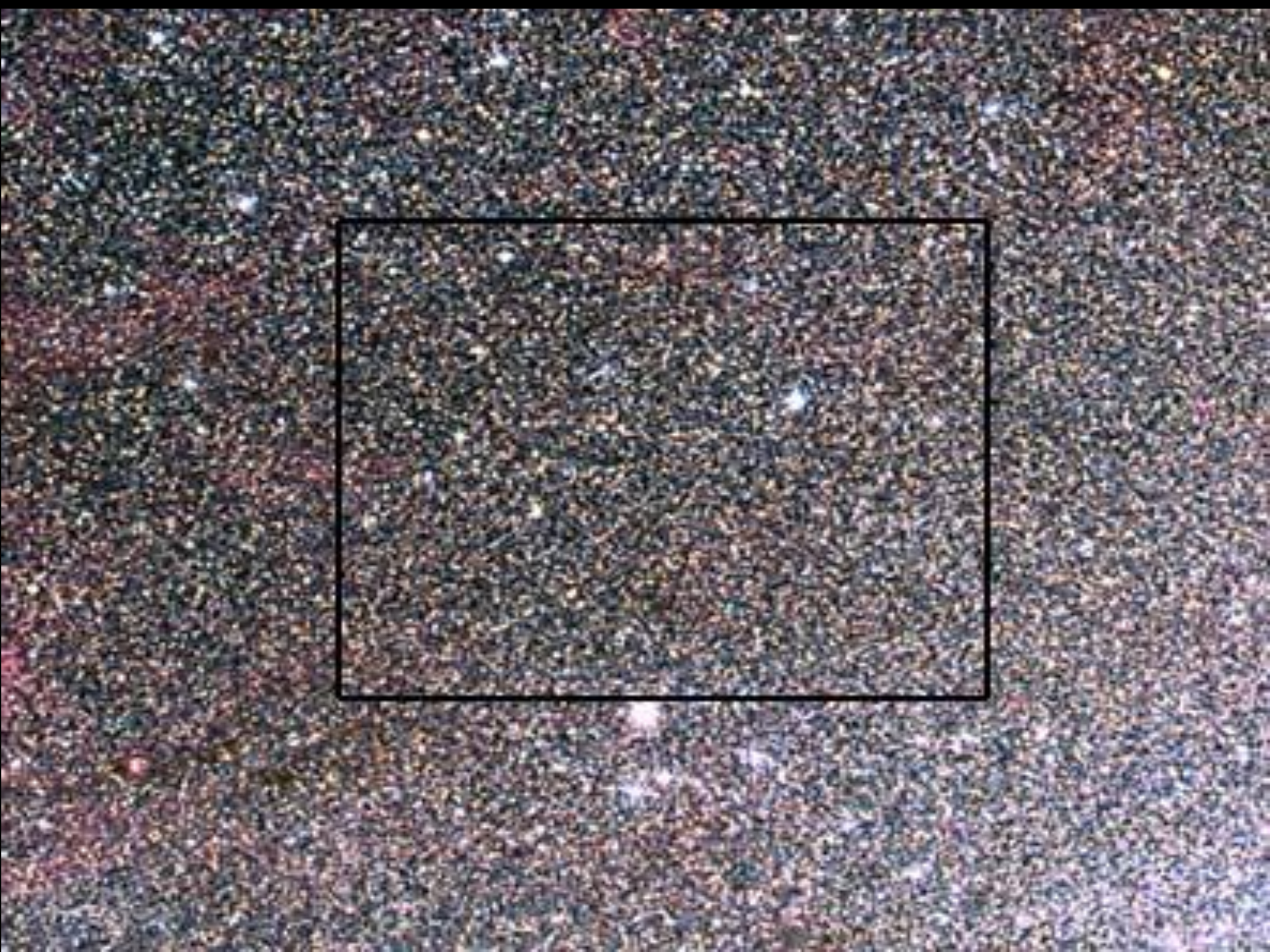
c = 300.000 km/s

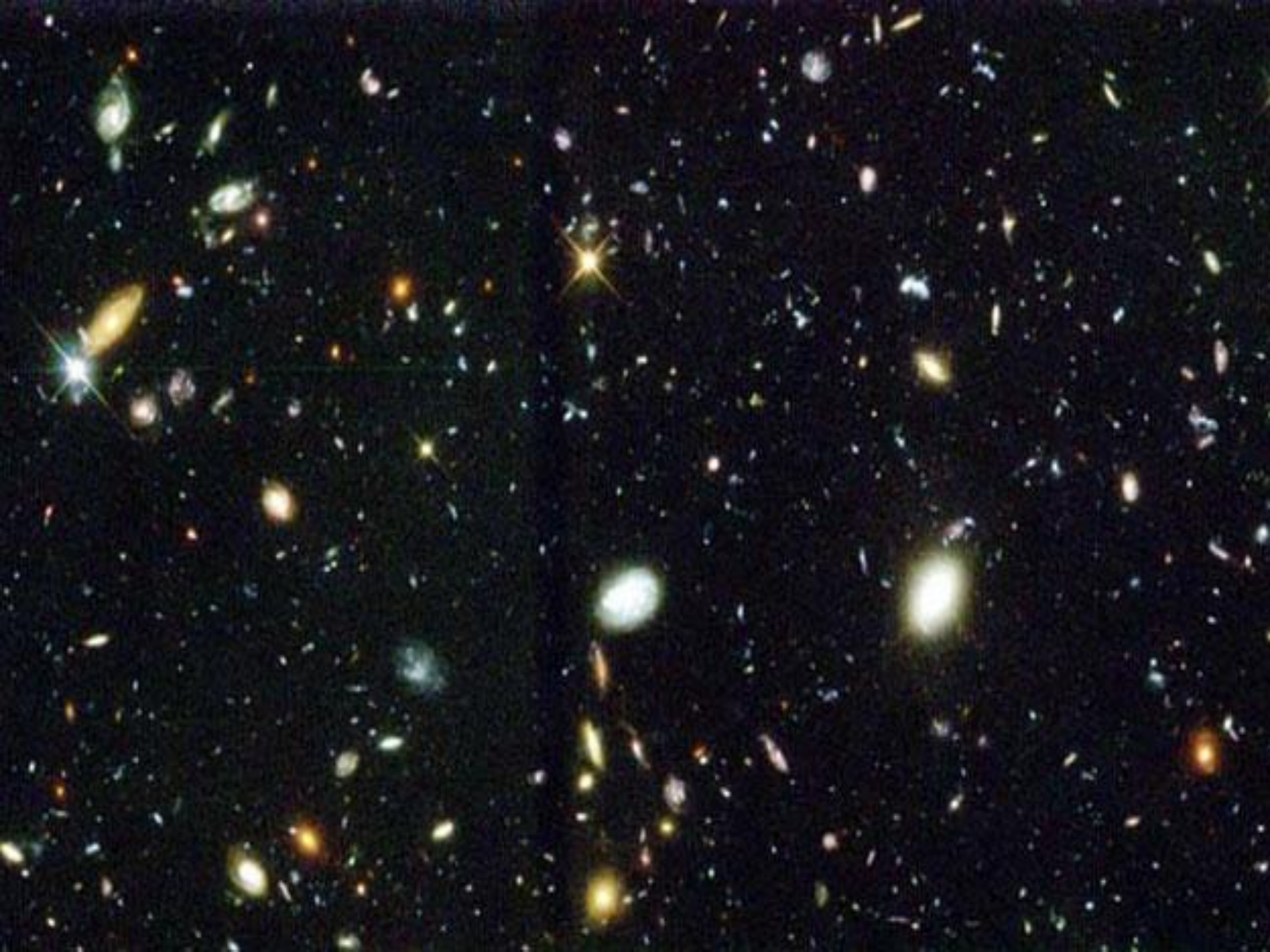
Via Láctea:

* 200 bilhões de Estrelas! - *Ainda existem?*
* 100.000 anos-luz de diâmetro.
* Sol encontra-se a 30.000 anos-luz do centro.
* Período de translação do Sol: 200 milhões de anos.

A Grande Nuvem de Magalhães

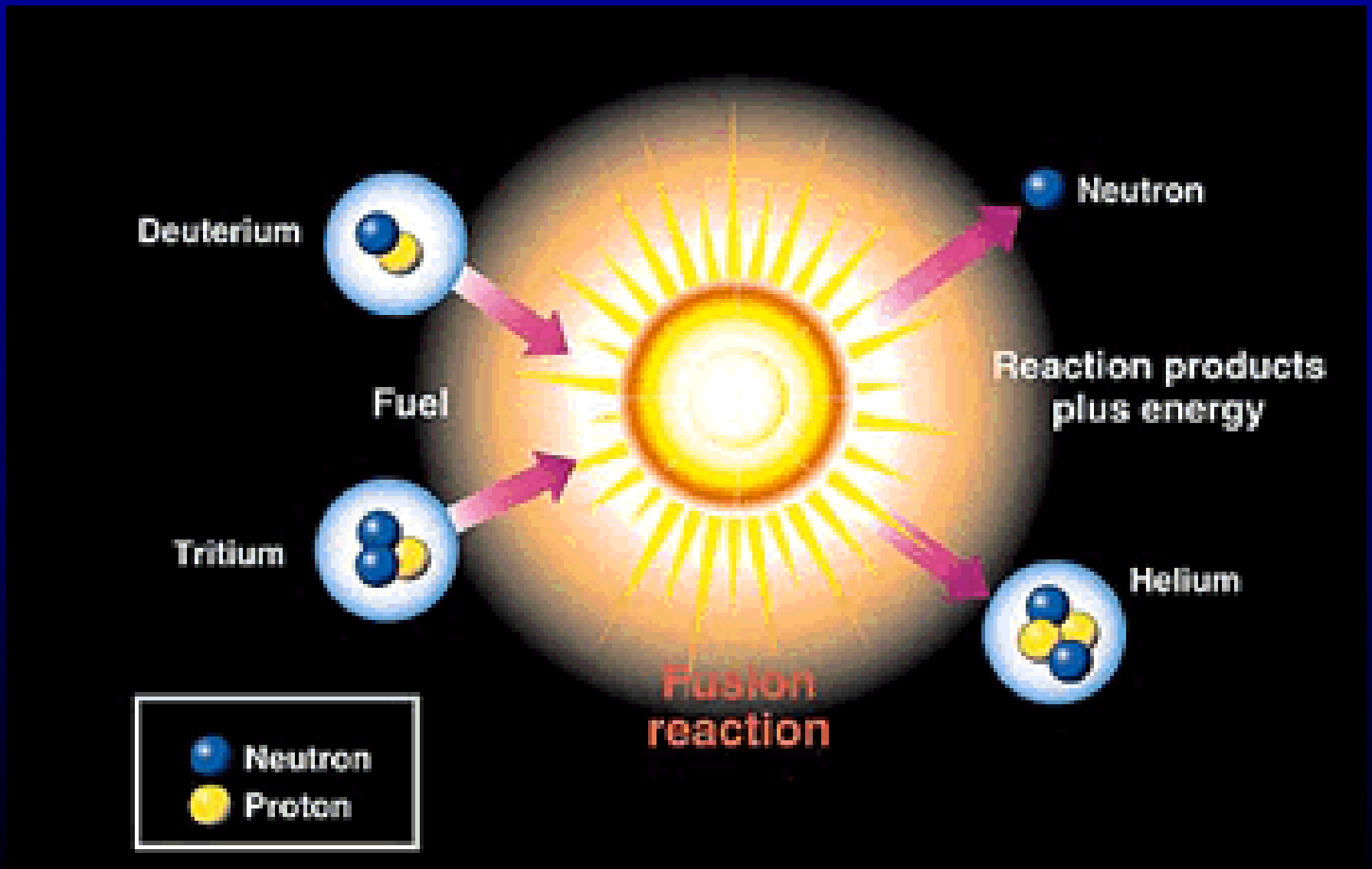
É a galáxia mais próxima da Terra (160 mil anos-luz)



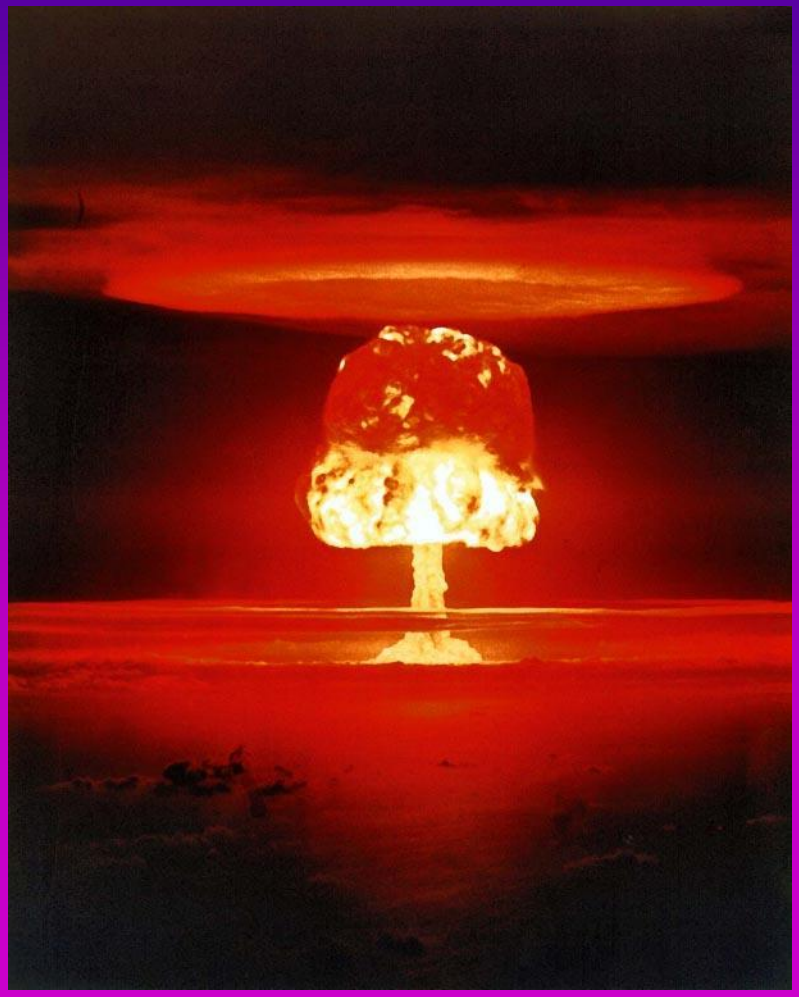


Principal Objetivo

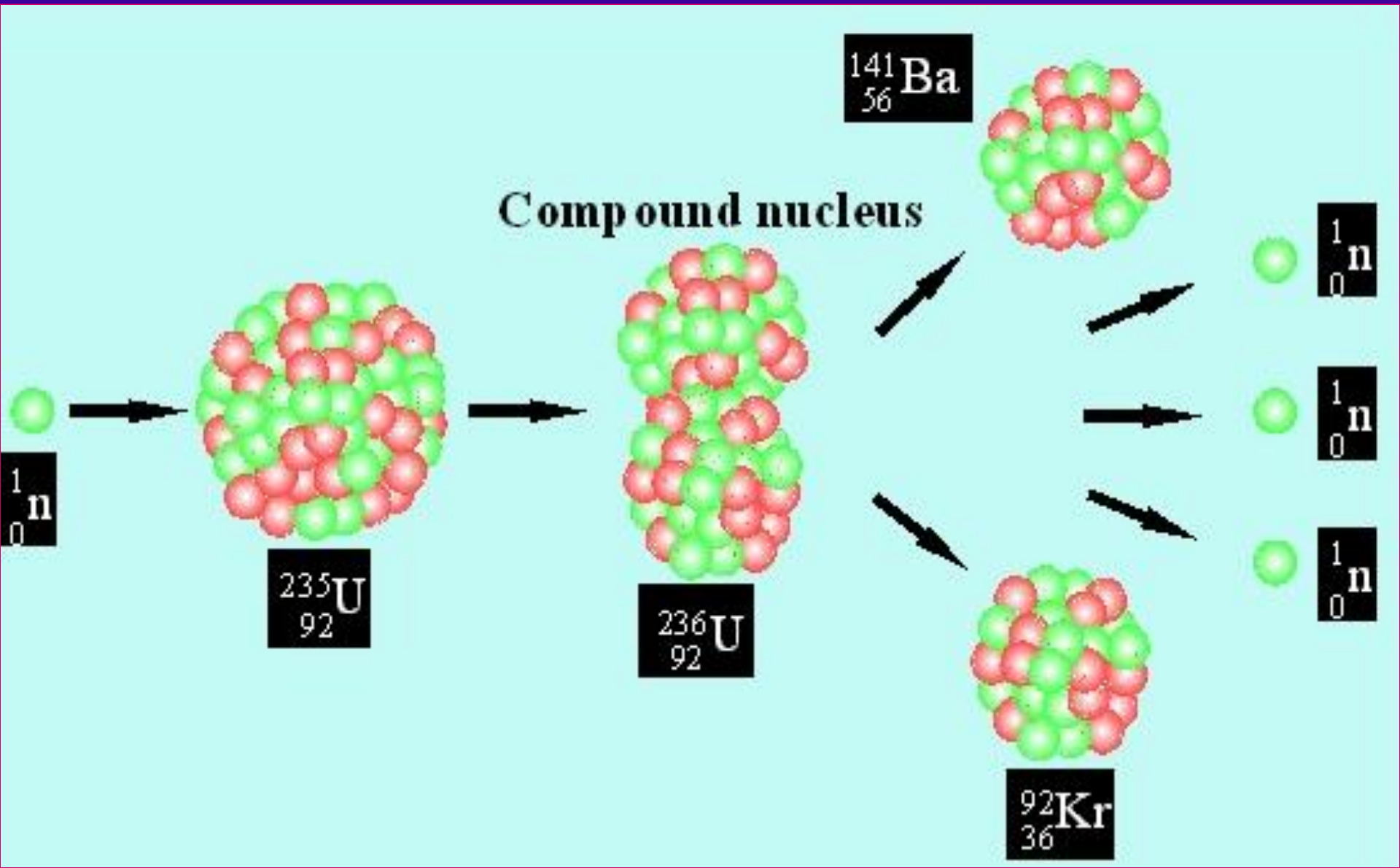
- Obtenção da *Fusão Termonuclear Controlada*

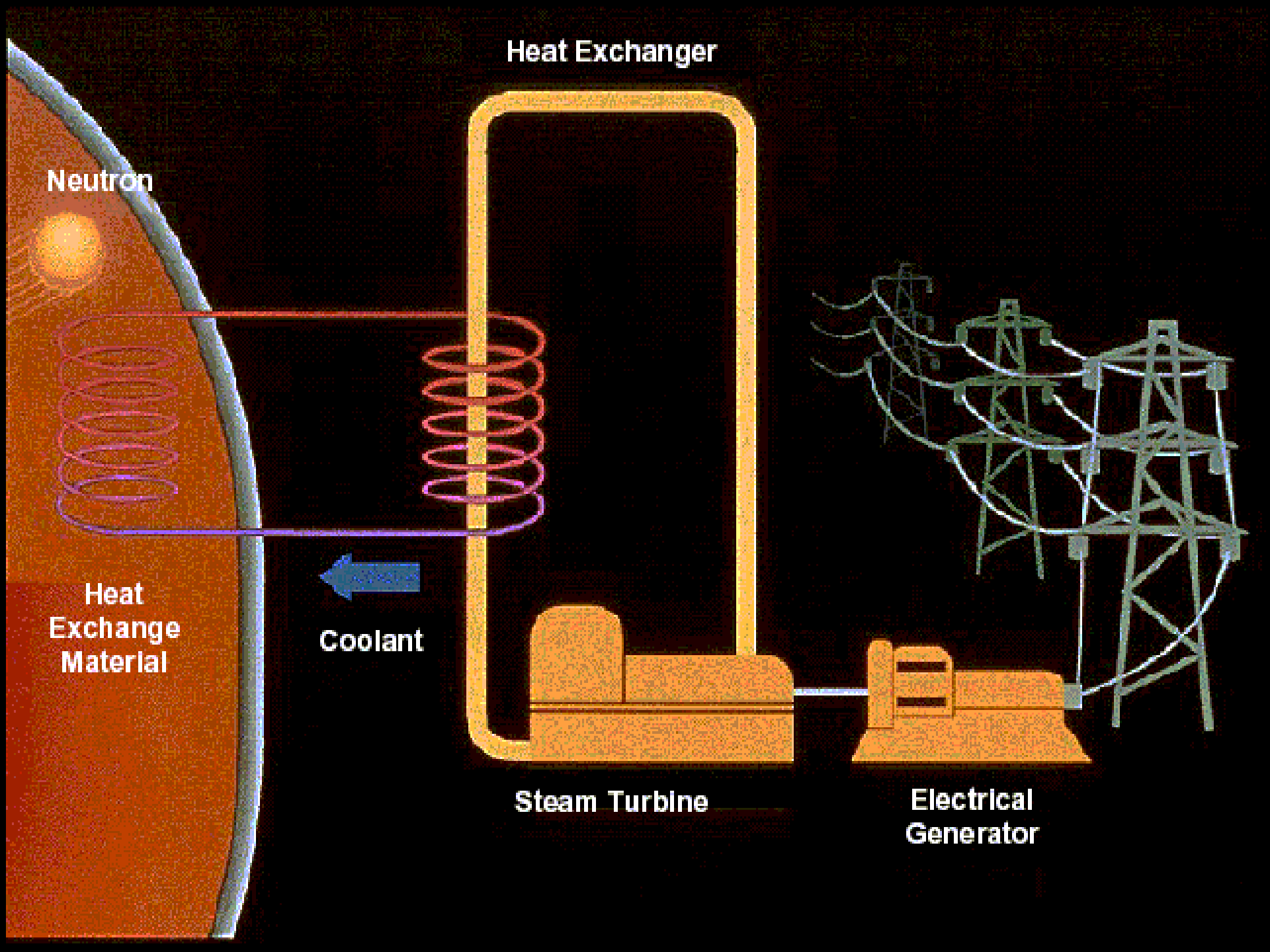


Fusão Termonuclear Descontrolada:



Fissão Nuclear

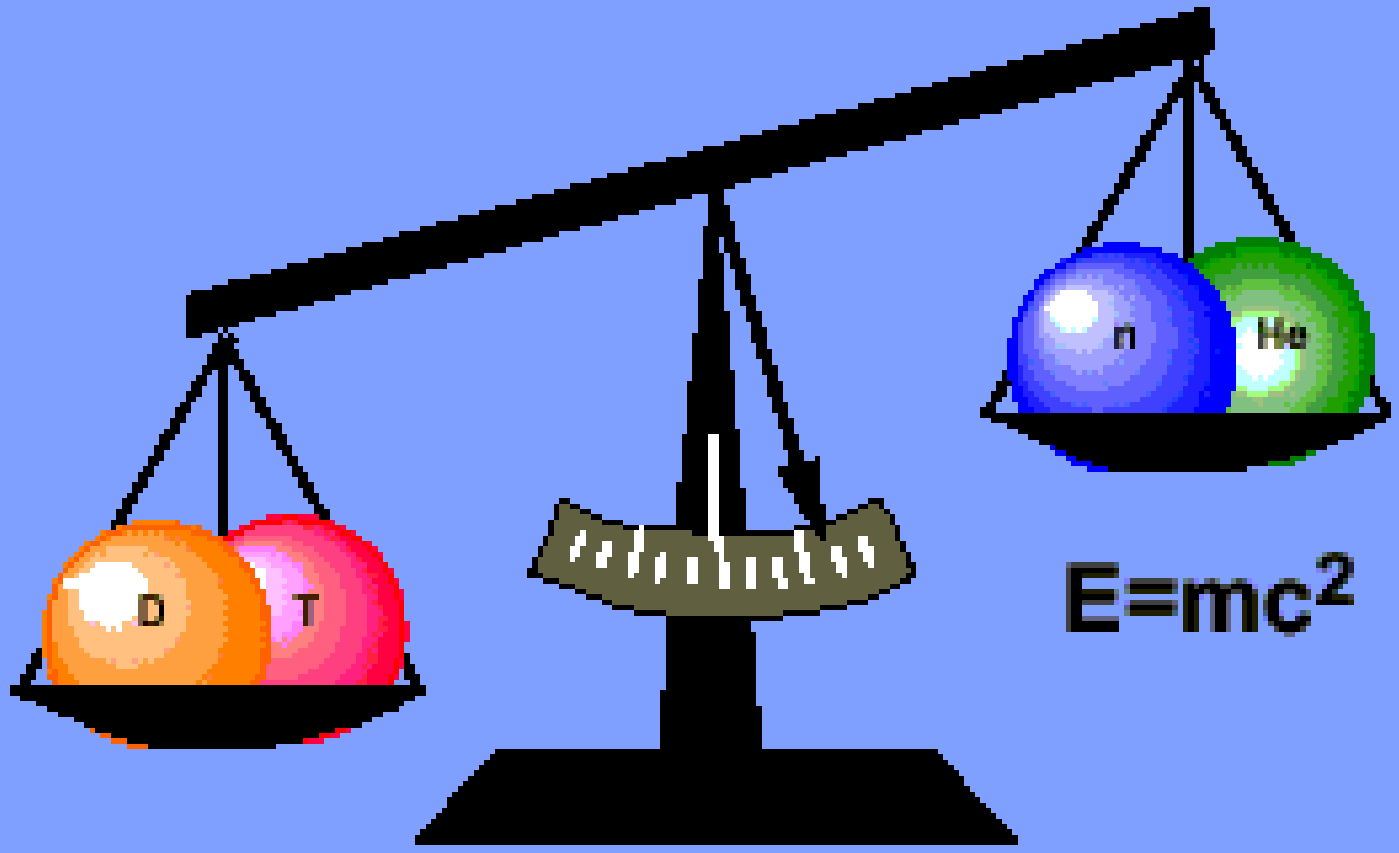


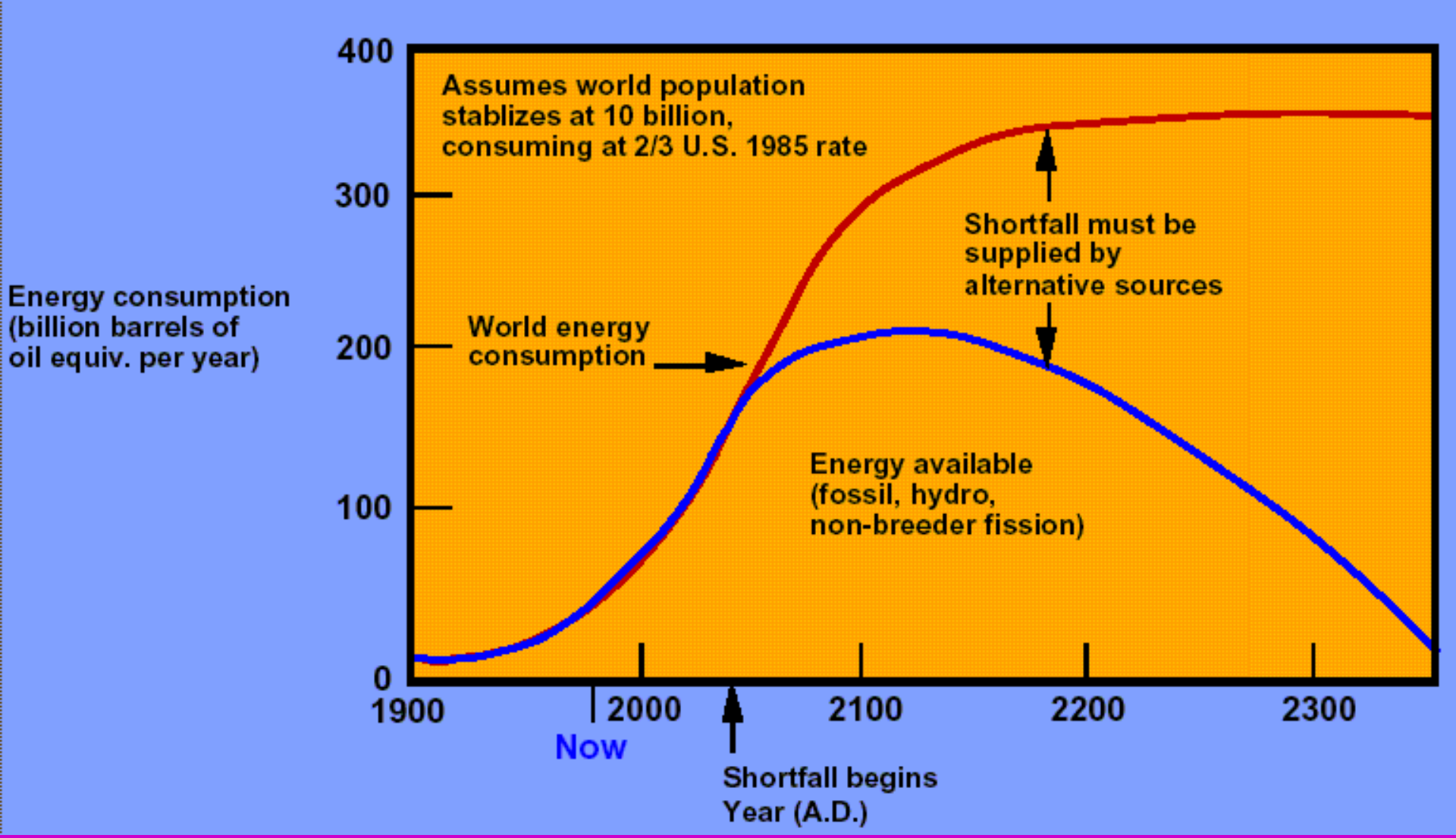

Heat Exchanger
Neutron
Heat
Exchange
Material
Coolant
Steam Turbine
Electrical
Generator

Vantagens da Fusão Nuclear sobre a Fissão

- É uma fonte de energia razoavelmente "limpa": não produz lixo radiativo
- É praticamente nula a probabilidade de acidentes
- A água do mar praticamente corresponde a uma fonte inesgotável de deutério!

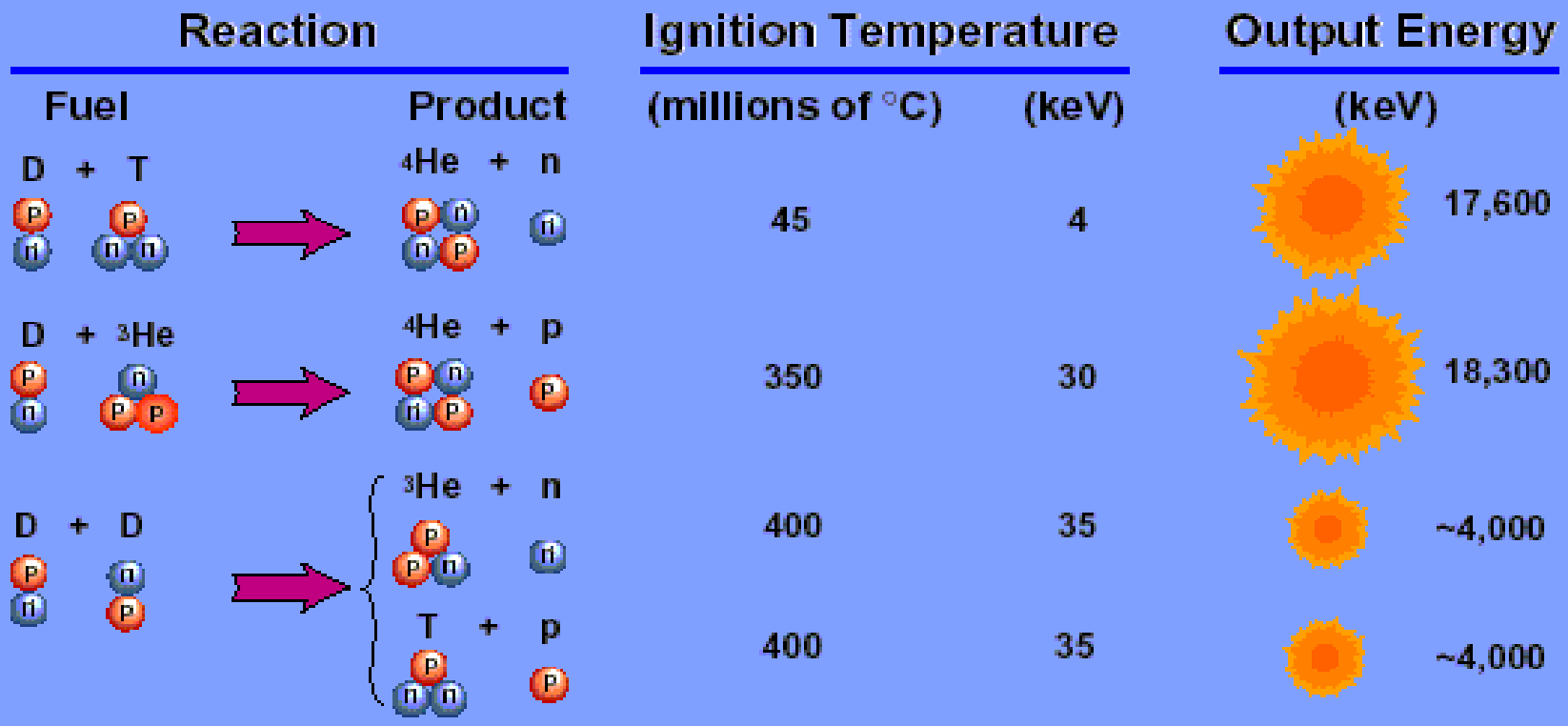
Princípio físico básico: $E = mc^2$



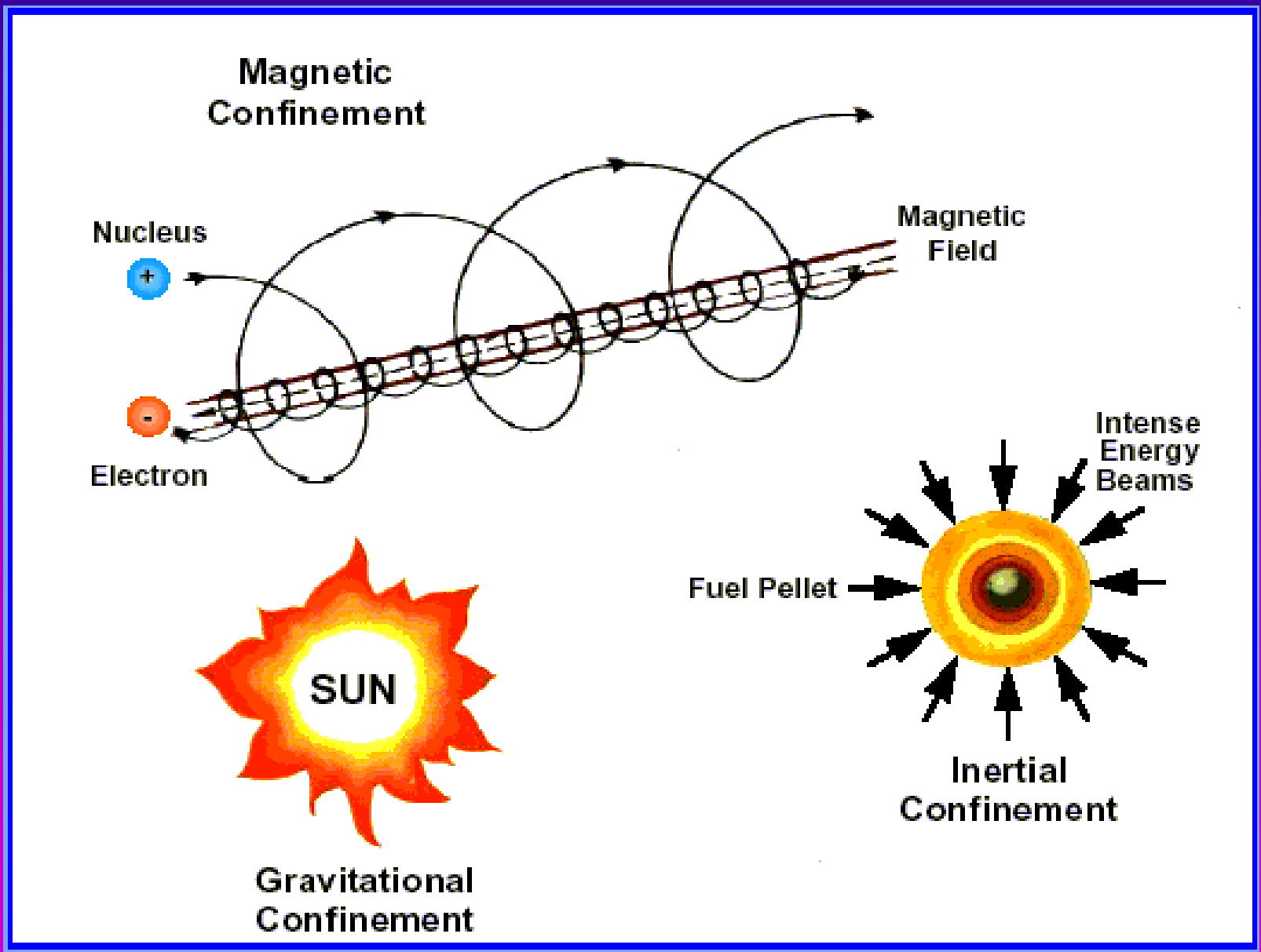


- **Energia liberada na fusão de um grama de DT equivale à obtida com a queima de 10.000 L de óleo**

Reações de fusão mais significativas



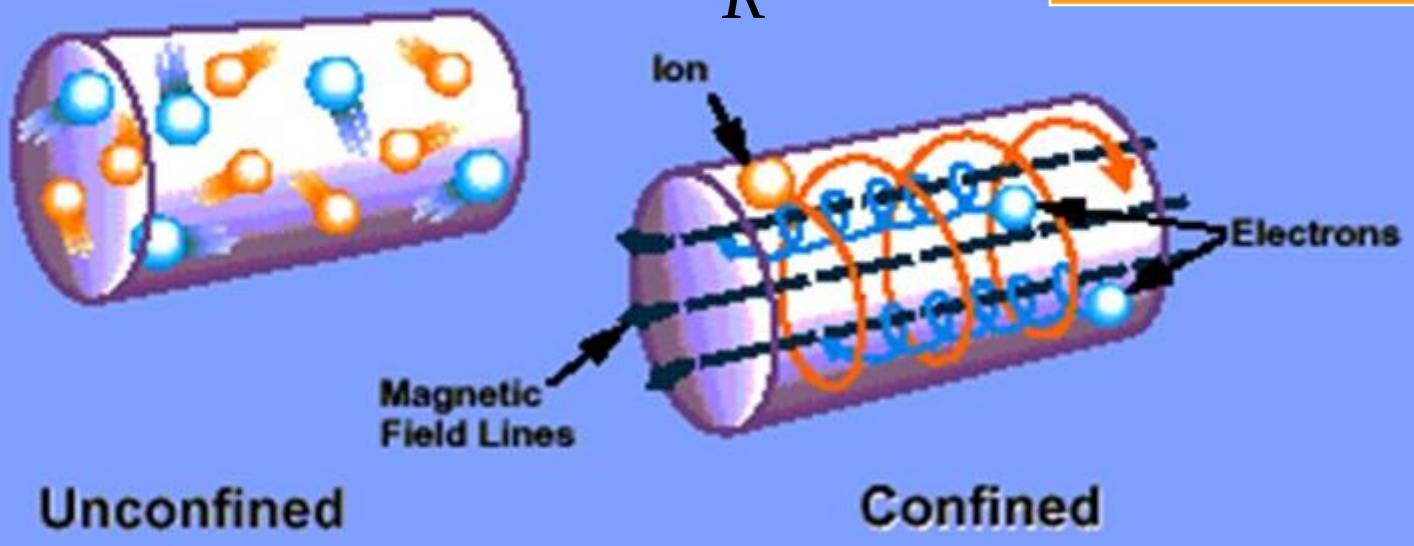
- **A fusão pode ser obtida de 3 maneiras diferentes**



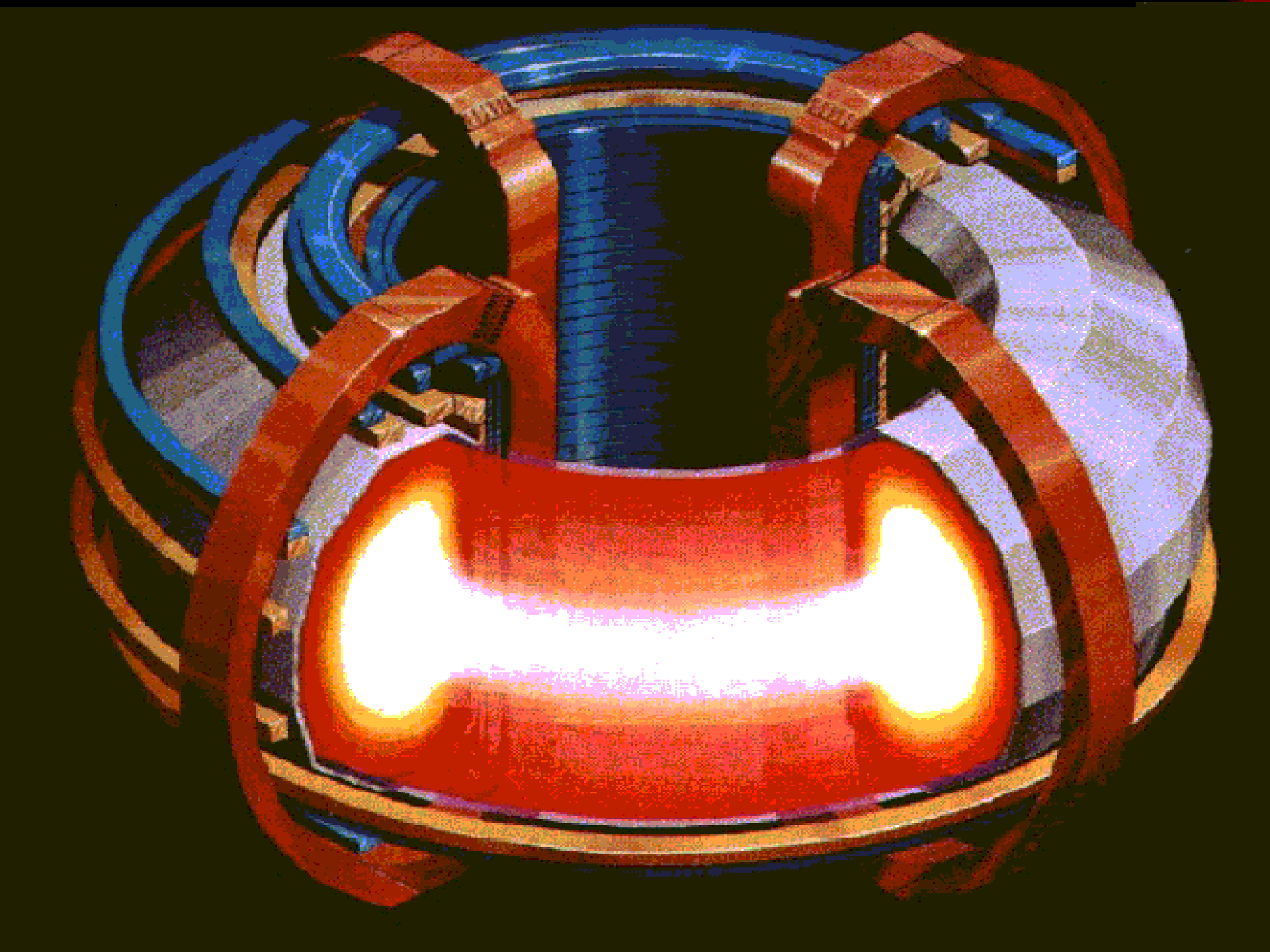
Confinamento Magnético

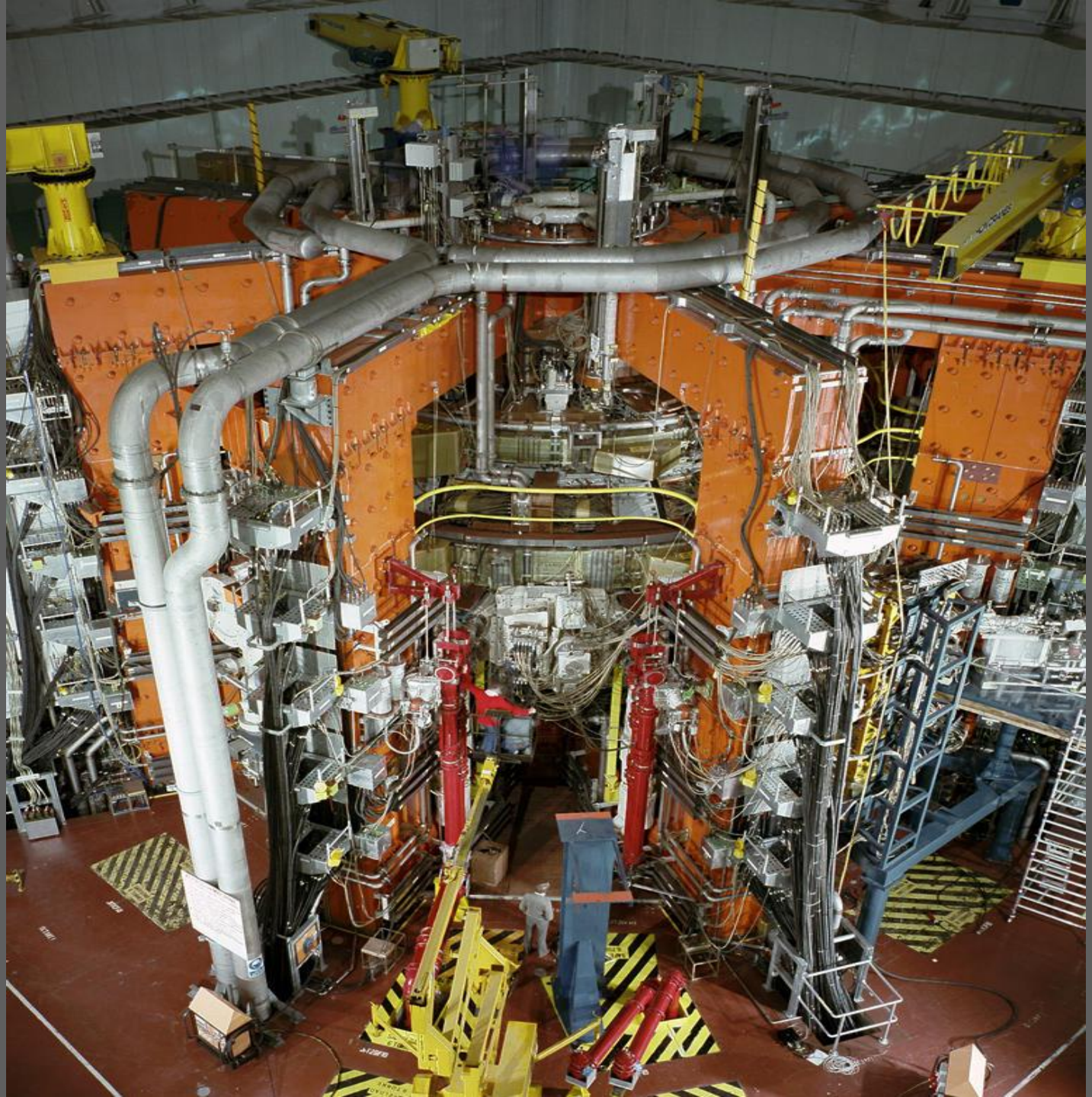
$$F = qvB$$

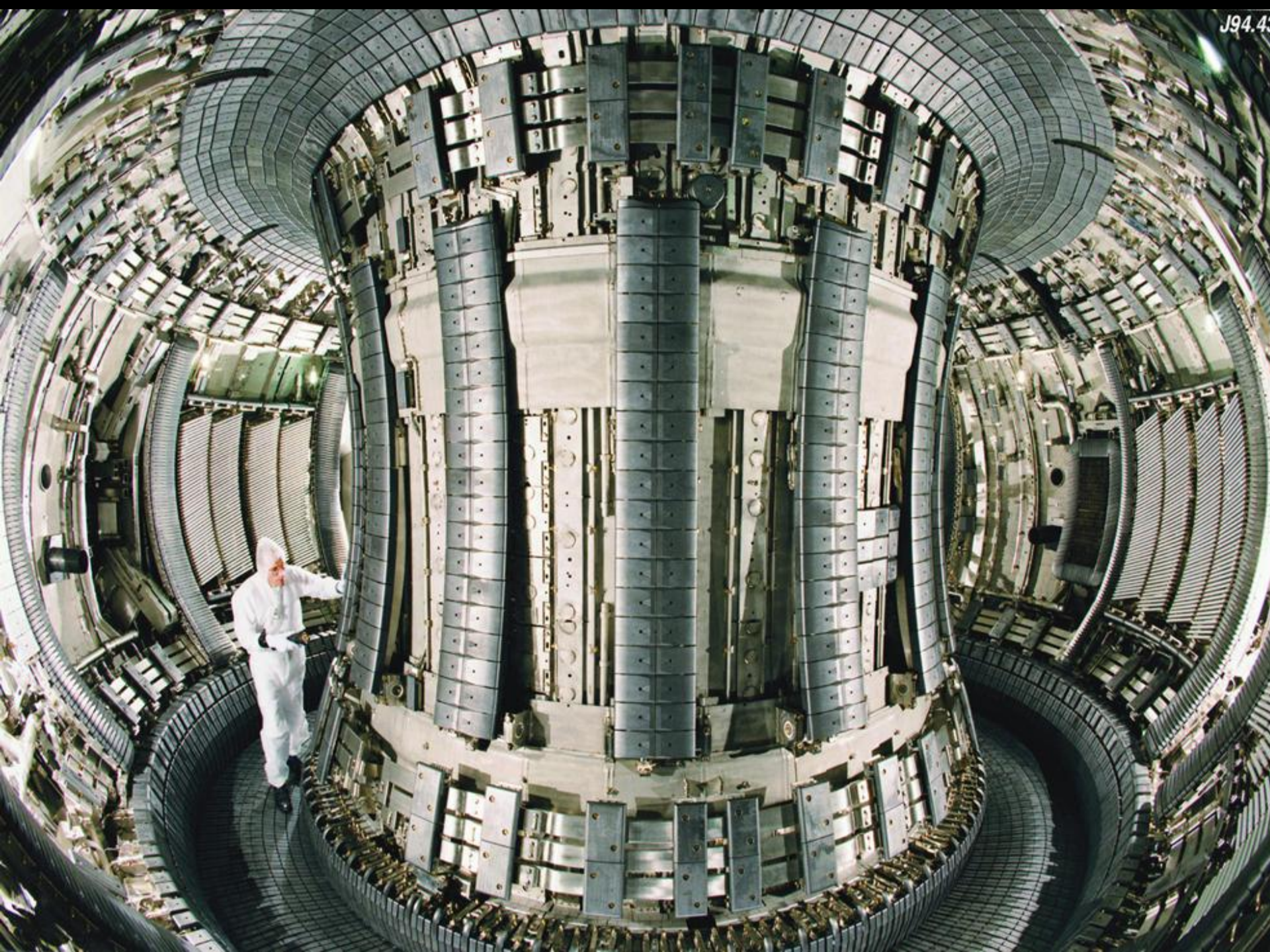
$$F = \frac{mv^2}{R} \quad \Rightarrow \quad R = \frac{mv}{qB}$$



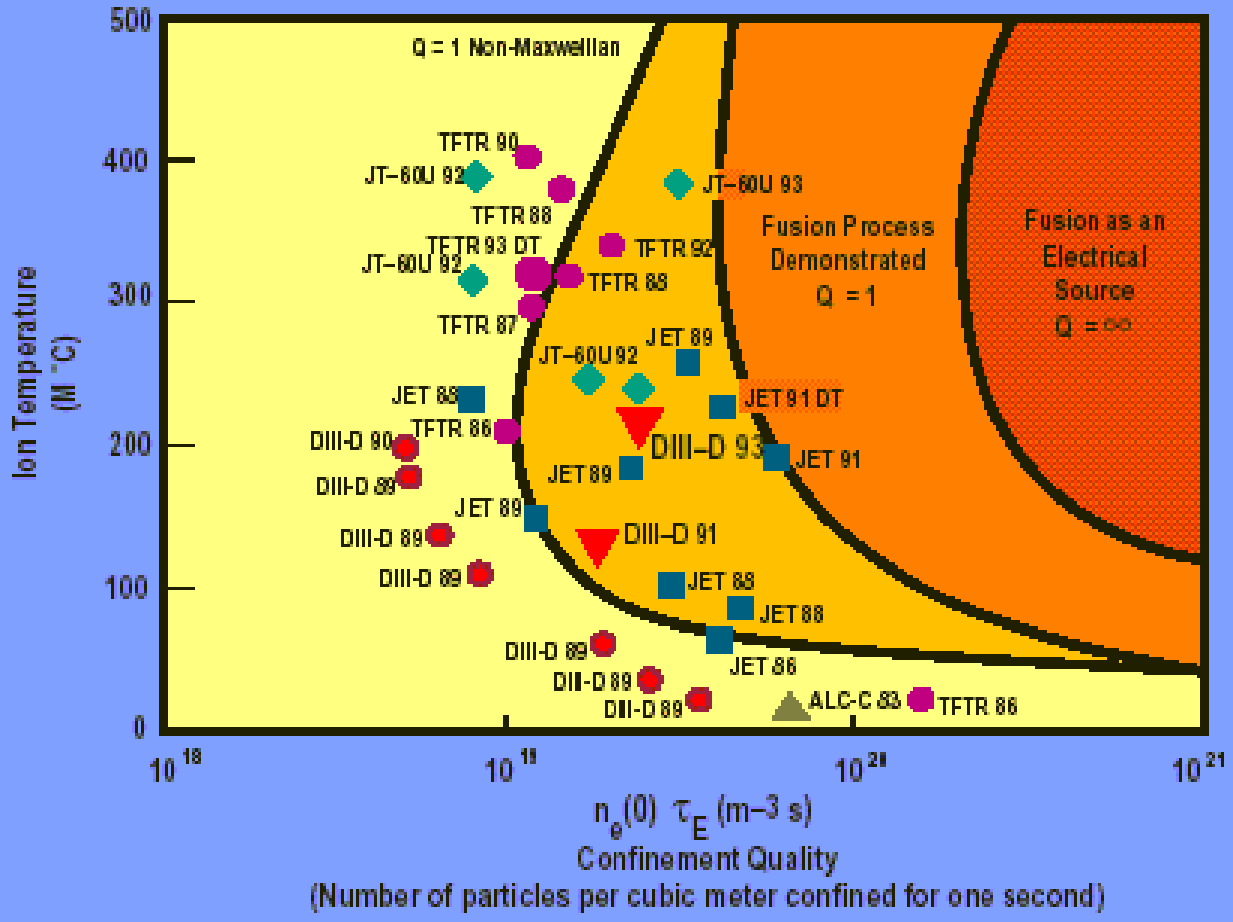
- O tokamak tem apresentado os melhores resultados

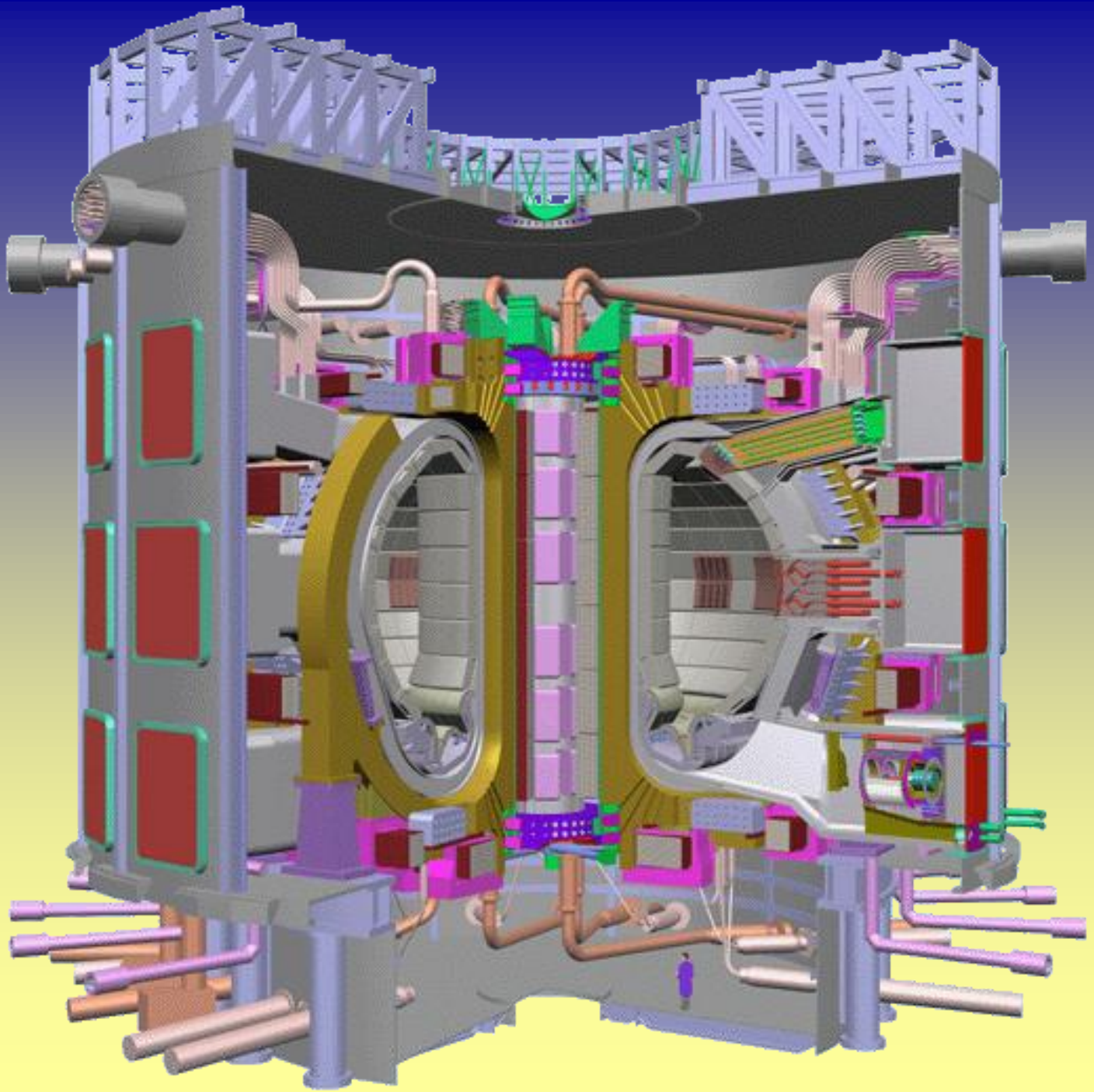






Fusion Experiments Now Approach Ignition Conditions





Main Plasma Parameters and Dimensions

Total fusion power	500 MW *(700MW)*
Q = fusion power/auxiliary heating power	≥ 10
Average neutron wall loading	0.57 MW/m^2 *(0.8 MW/m^2)*
Plasma inductive burn time	≥ 300 s
Plasma major radius	6.2 m
Plasma minor radius	2.0 m
Plasma current (I_p)	15 MA *(17.4 MA)*
Vertical elongation @95% flux surface/separatrix	1.70/1.85
Triangularity @95% flux surface/separatrix	0.33/0.49
Safety factor @95% flux surface	3.0
Toroidal field @6.2 m radius	5.3 T
Plasma volume	837 m^3
Plasma surface	678 m^2
Installed auxiliary heating/current drive power	73 MW *(100 MW)*

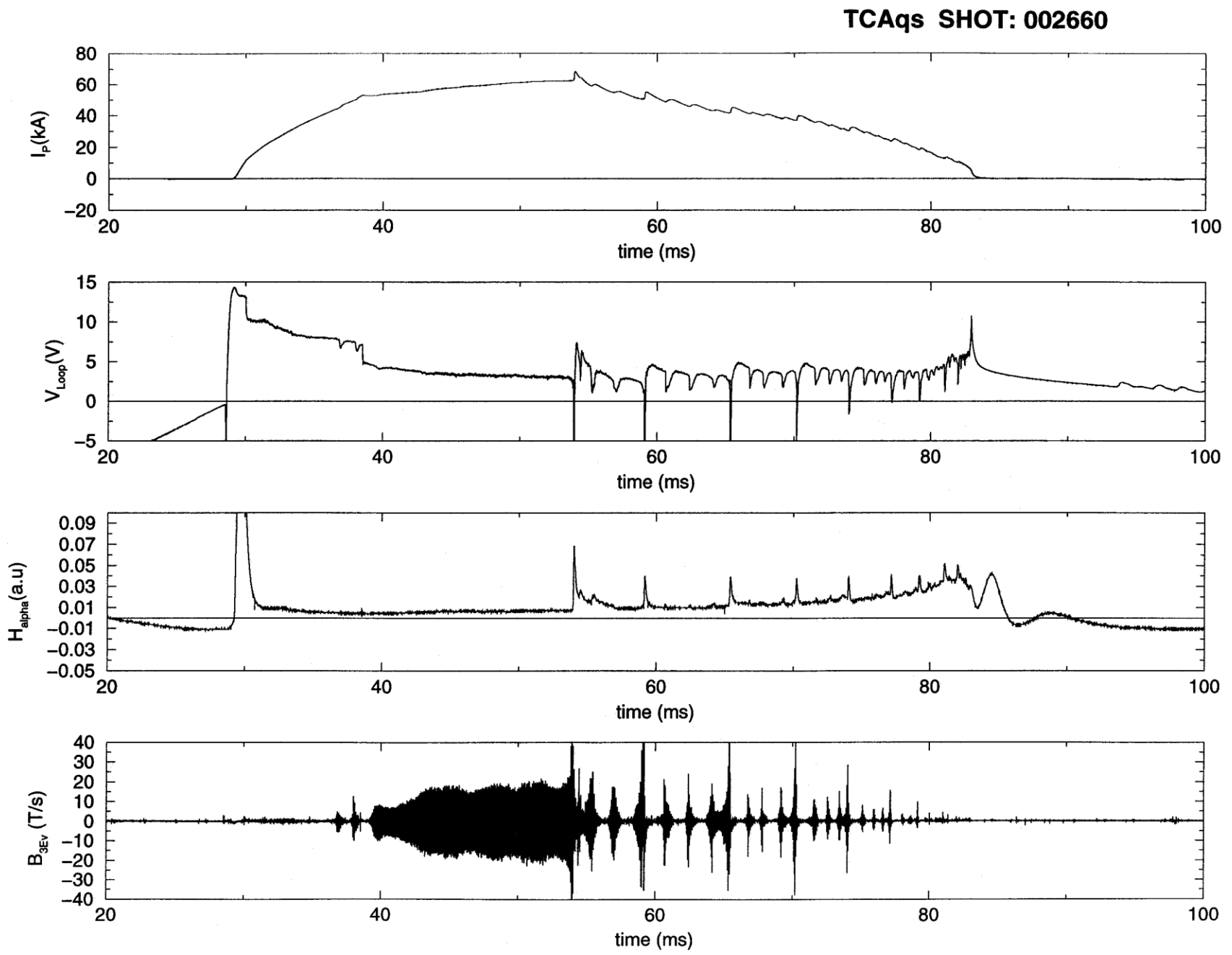
O Tokamak TCABR do IFUSP

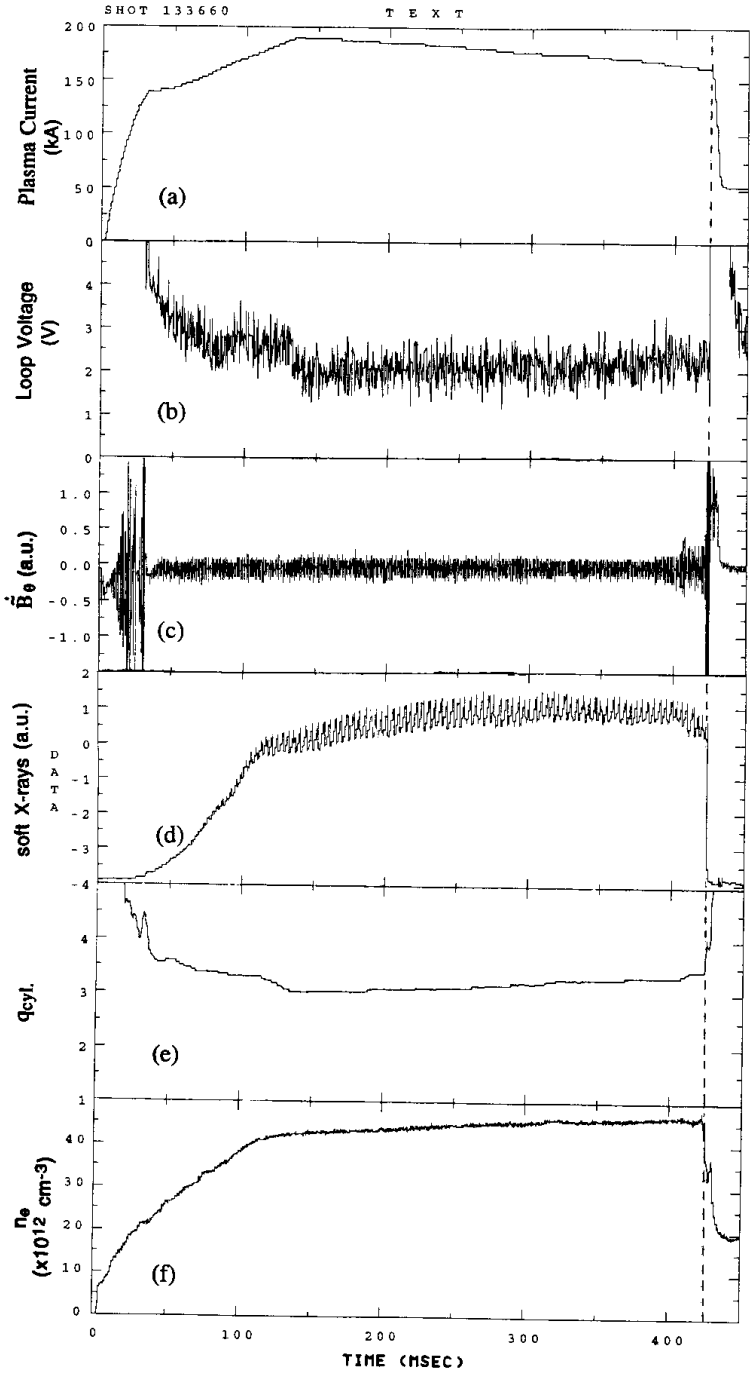
- **Máquina de pequeno-médio porte, trazido da Suiça**

- **Substituiu o pequeno tokamak TBR-1**

- **Principais parâmetros:**

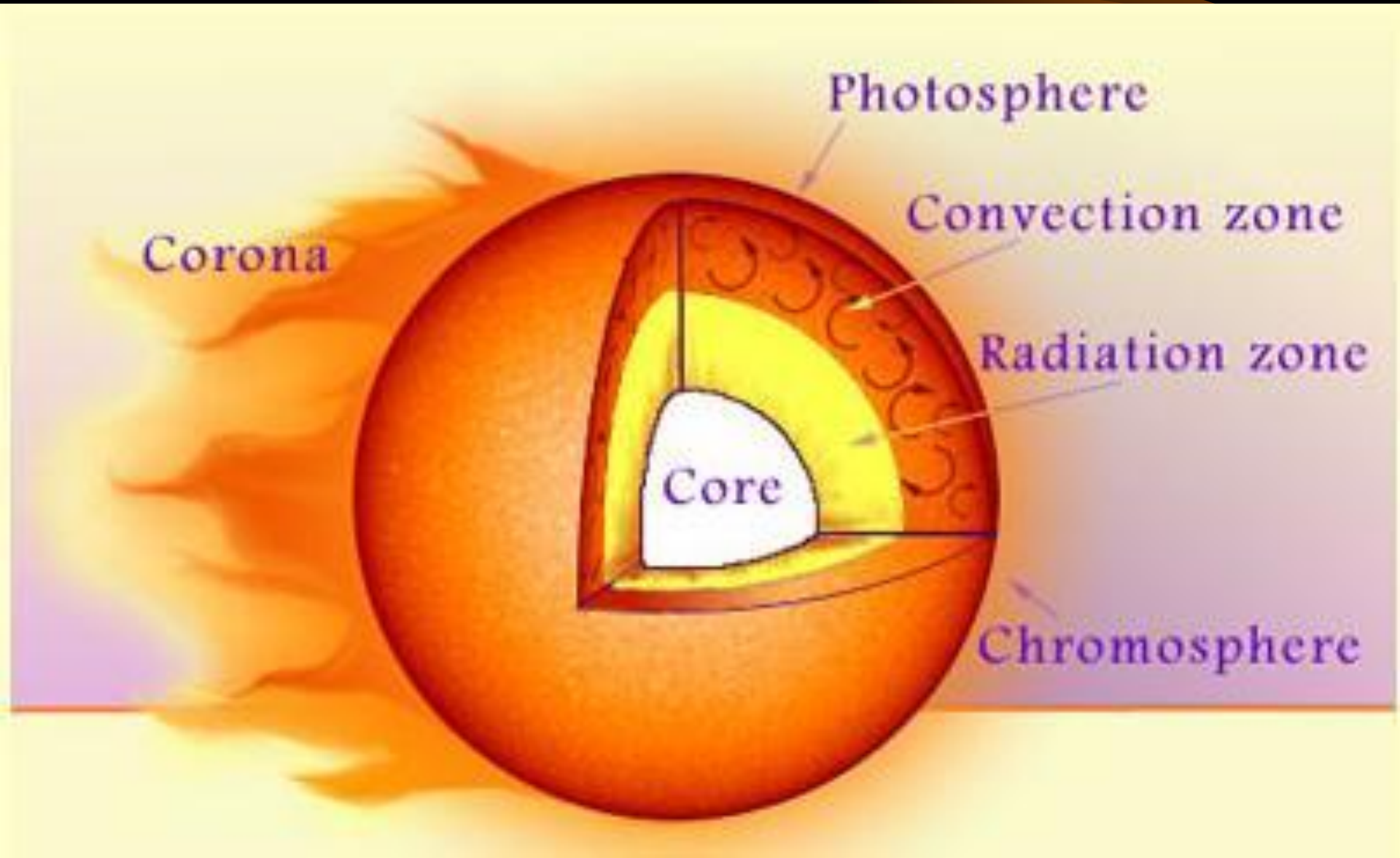
  - $I_p \sim 100$ kA
  - $\tau_p \sim 150$ ms
  - $B_t \sim 1{,}1$ T
  - $R_0 = 61$ cm
  - $a = 18$ cm

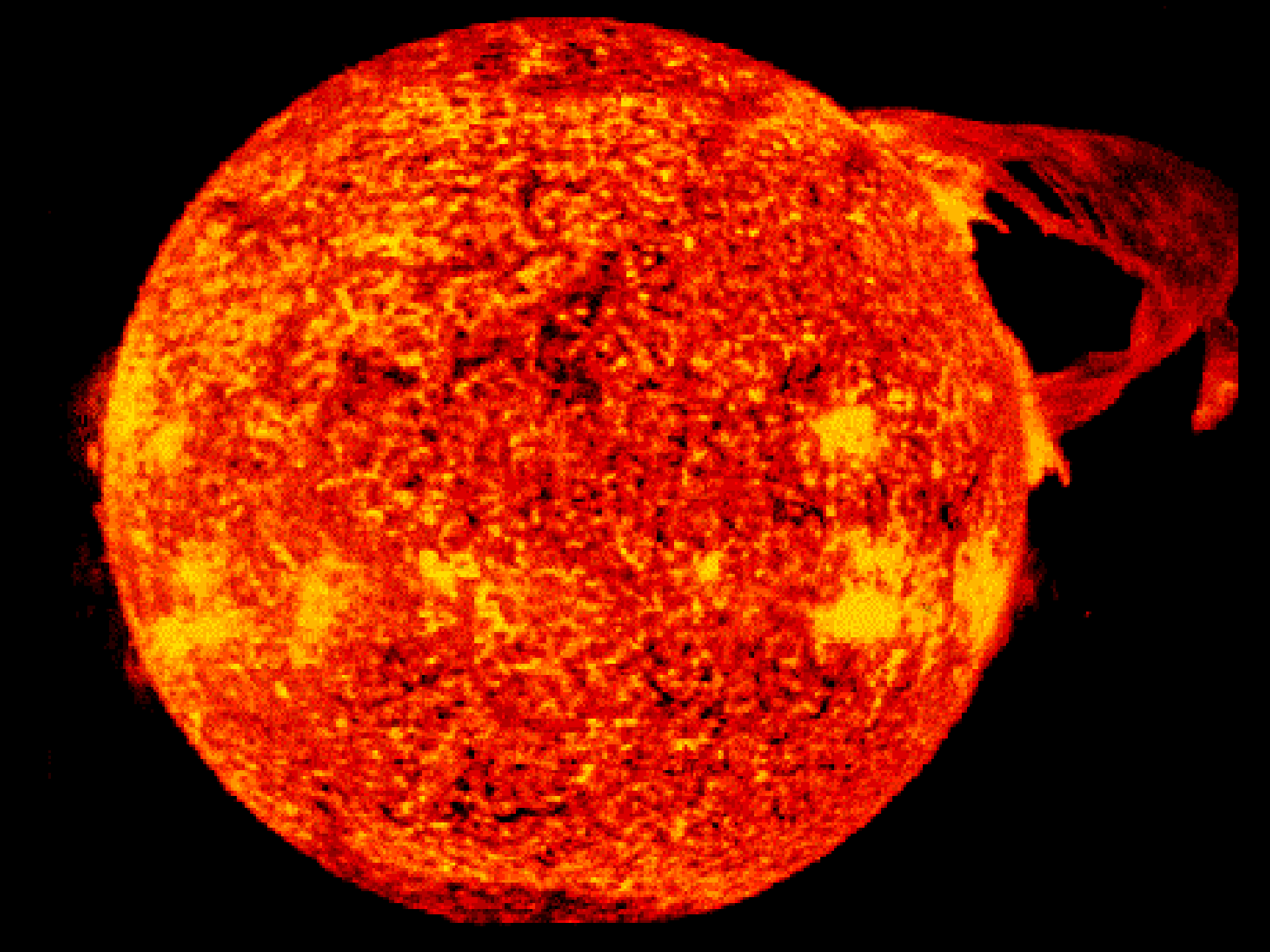

TCAqs SHOT: 002660
I_p(kA)
80
60
40
20
0
−20
20
40
60
80
100
time (ms)
V_{Loop}(V)
15
10
5
0
−5
20
40
60
80
100
time (ms)
H_{alpha}(a.u)
0.09
0.07
0.05
0.03
0.01
−0.01
−0.03
−0.05
20
40
60
80
100
time (ms)
B_{3Ev} (T/s)
40
30
20
10
0
−10
−20
−30
−40
20
40
60
80
100
time (ms)
TCABR

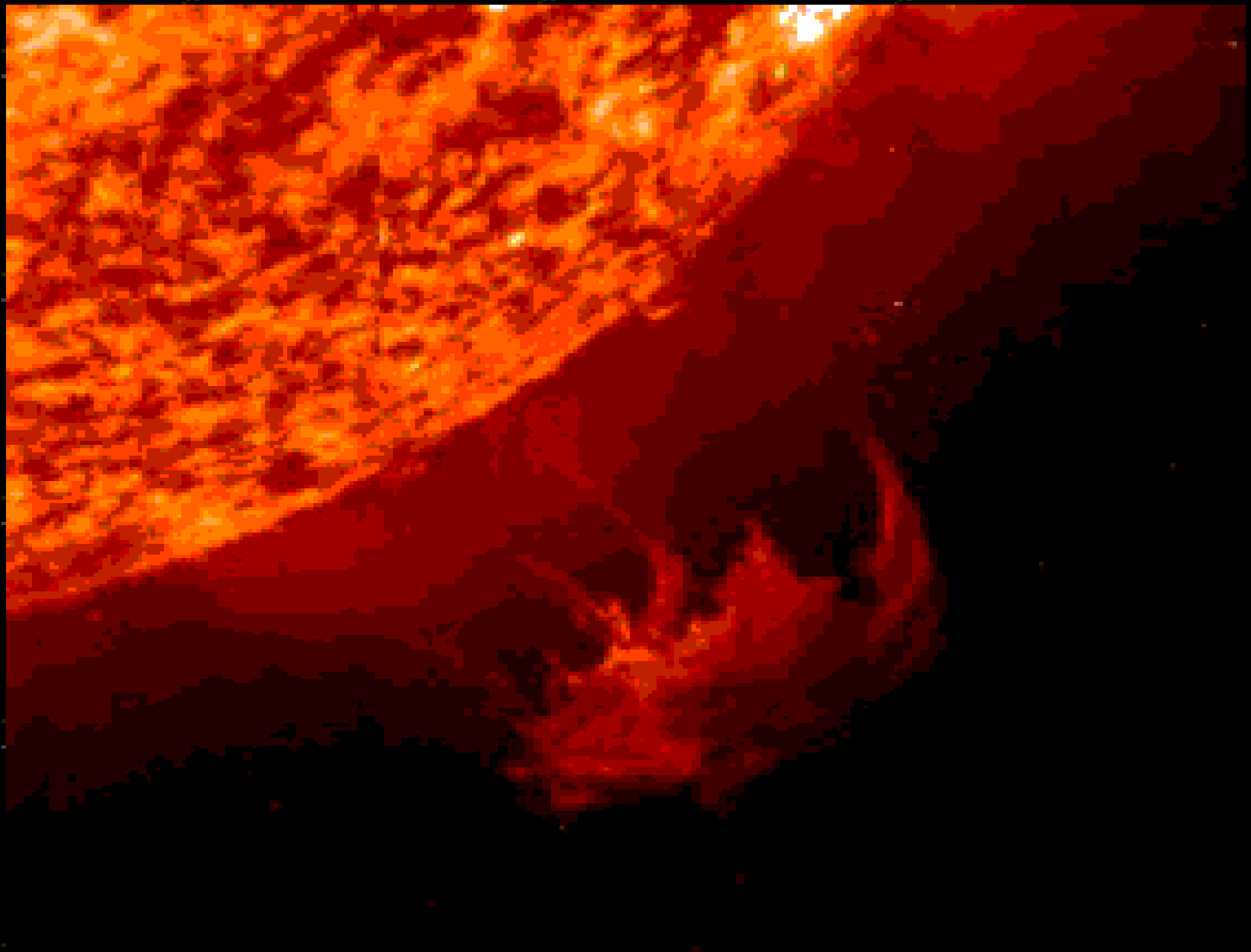


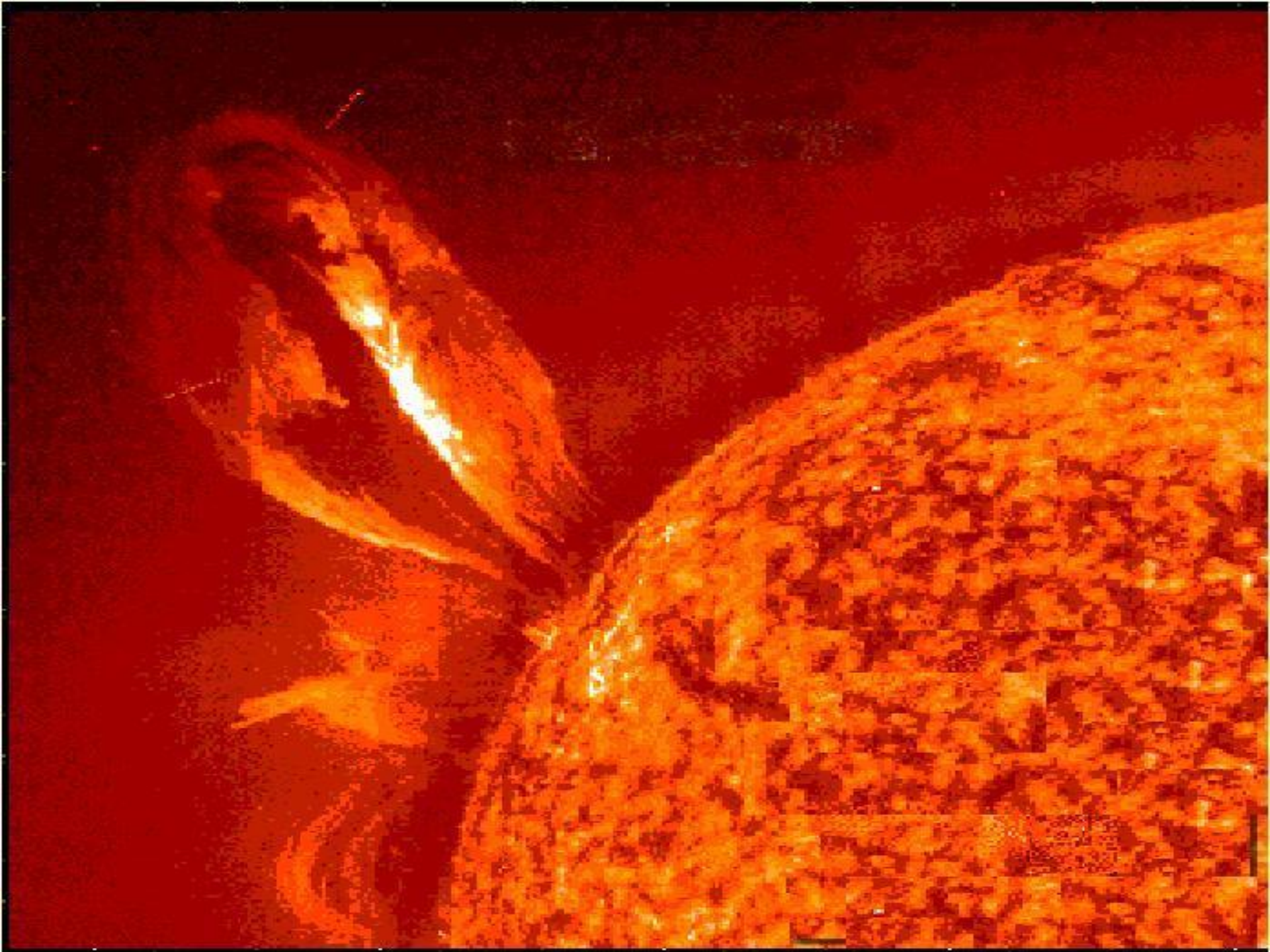
A. Vannucci and S.C. McCool - **Nucl. Fusion 37** (1997) 1229.

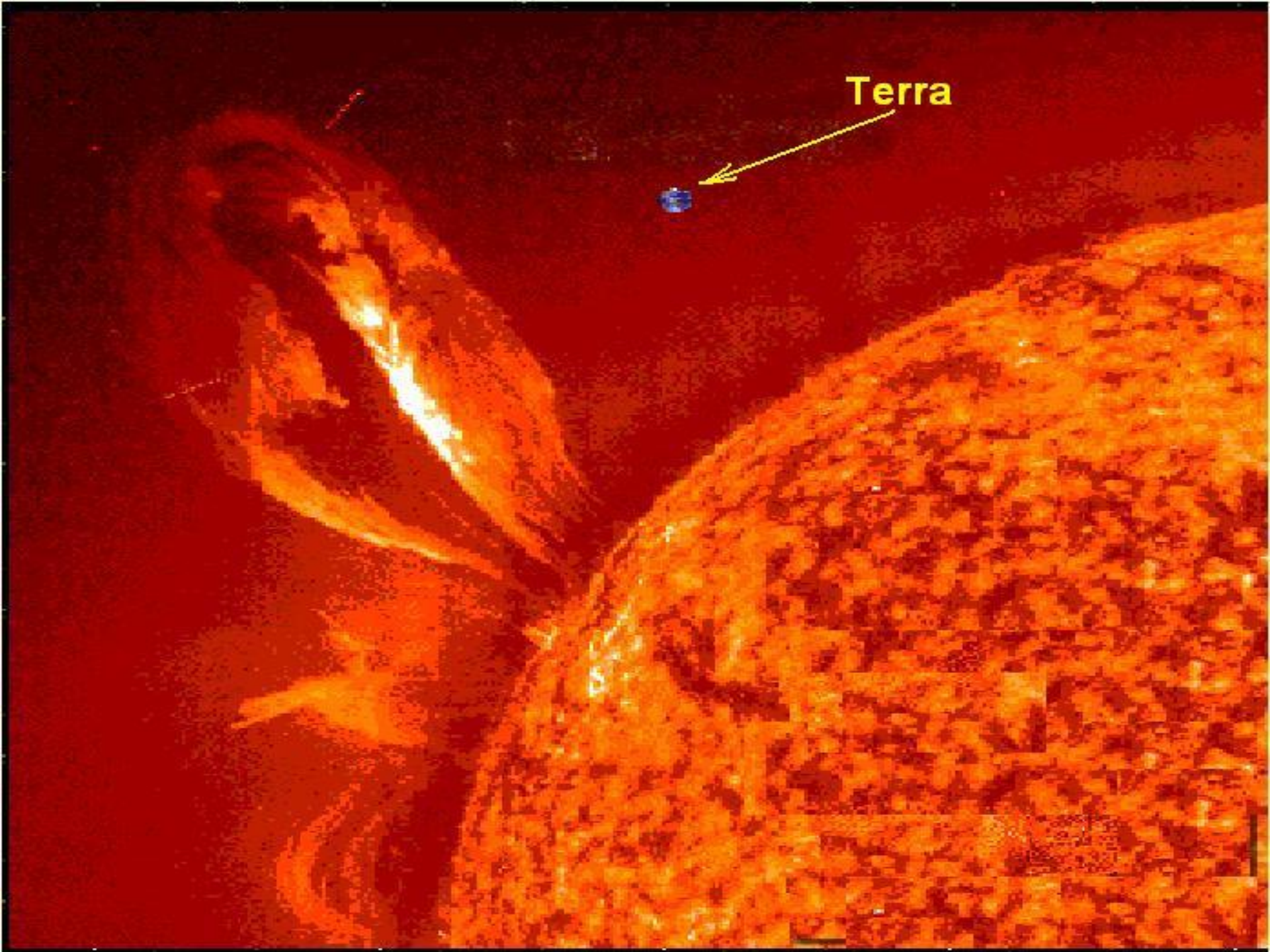
Confinamento Gravitacional

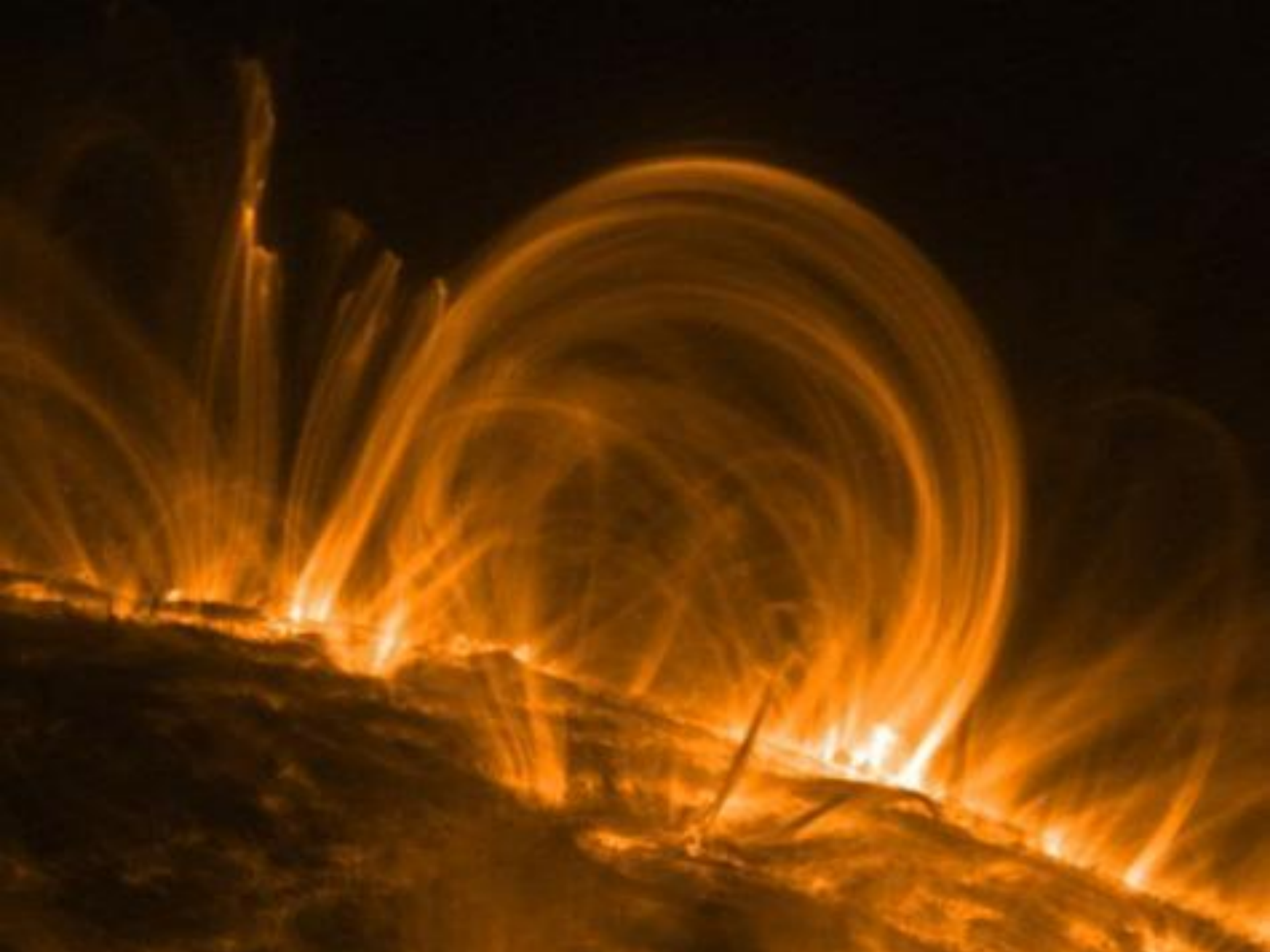


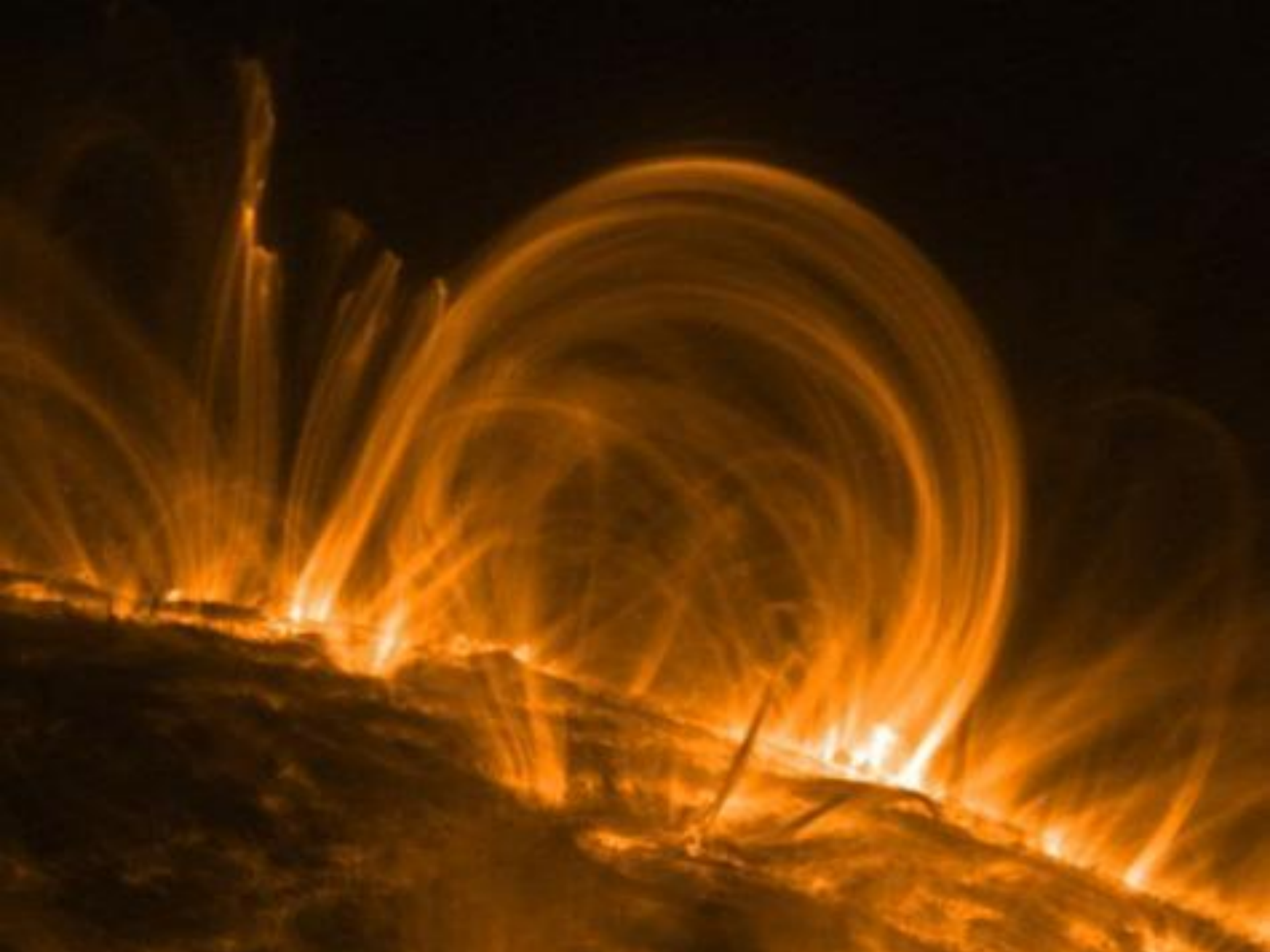




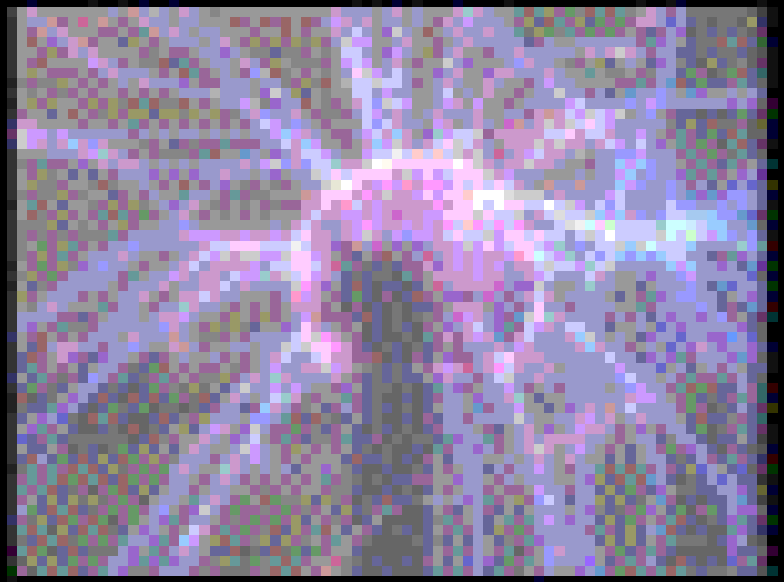



Terra

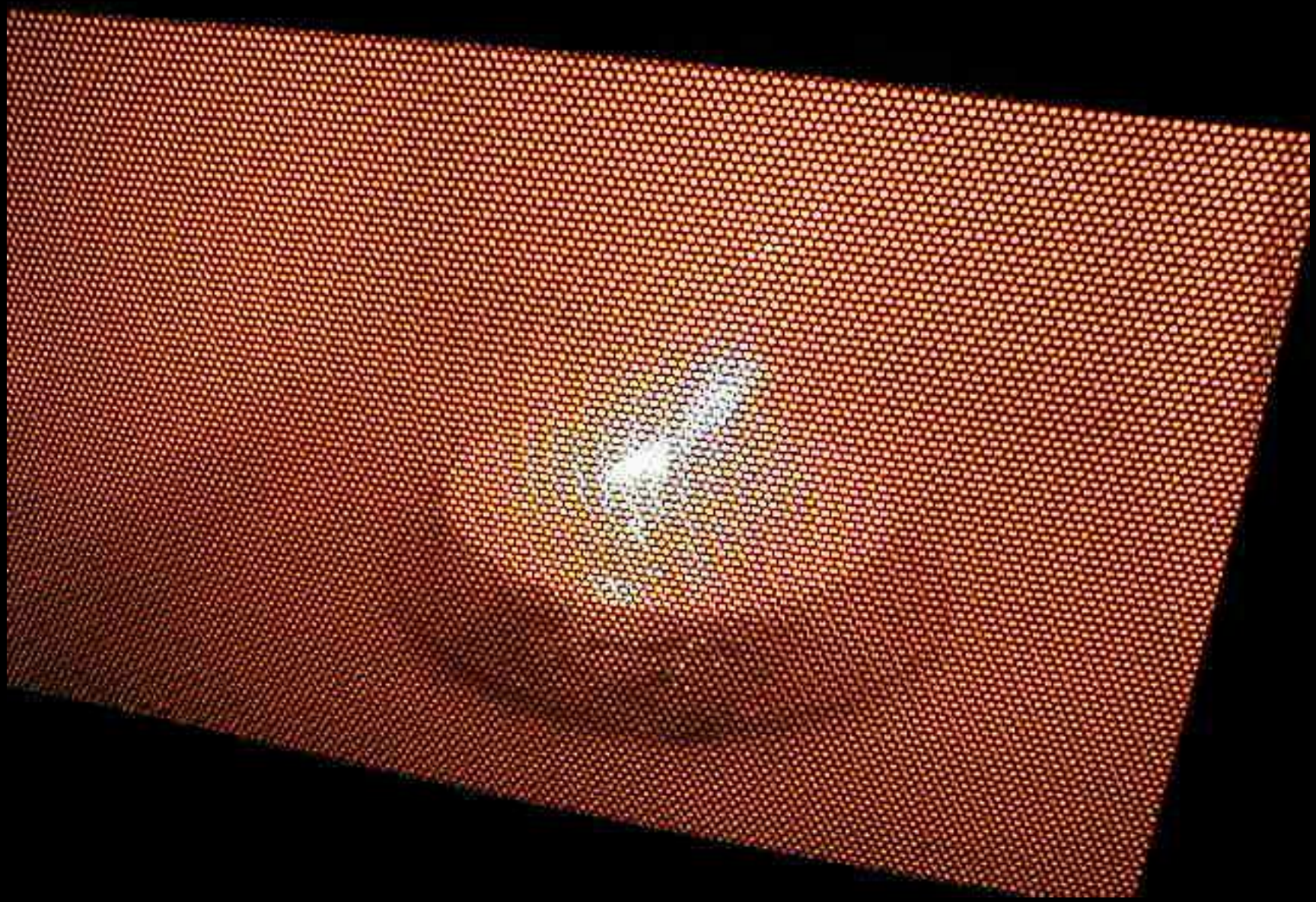


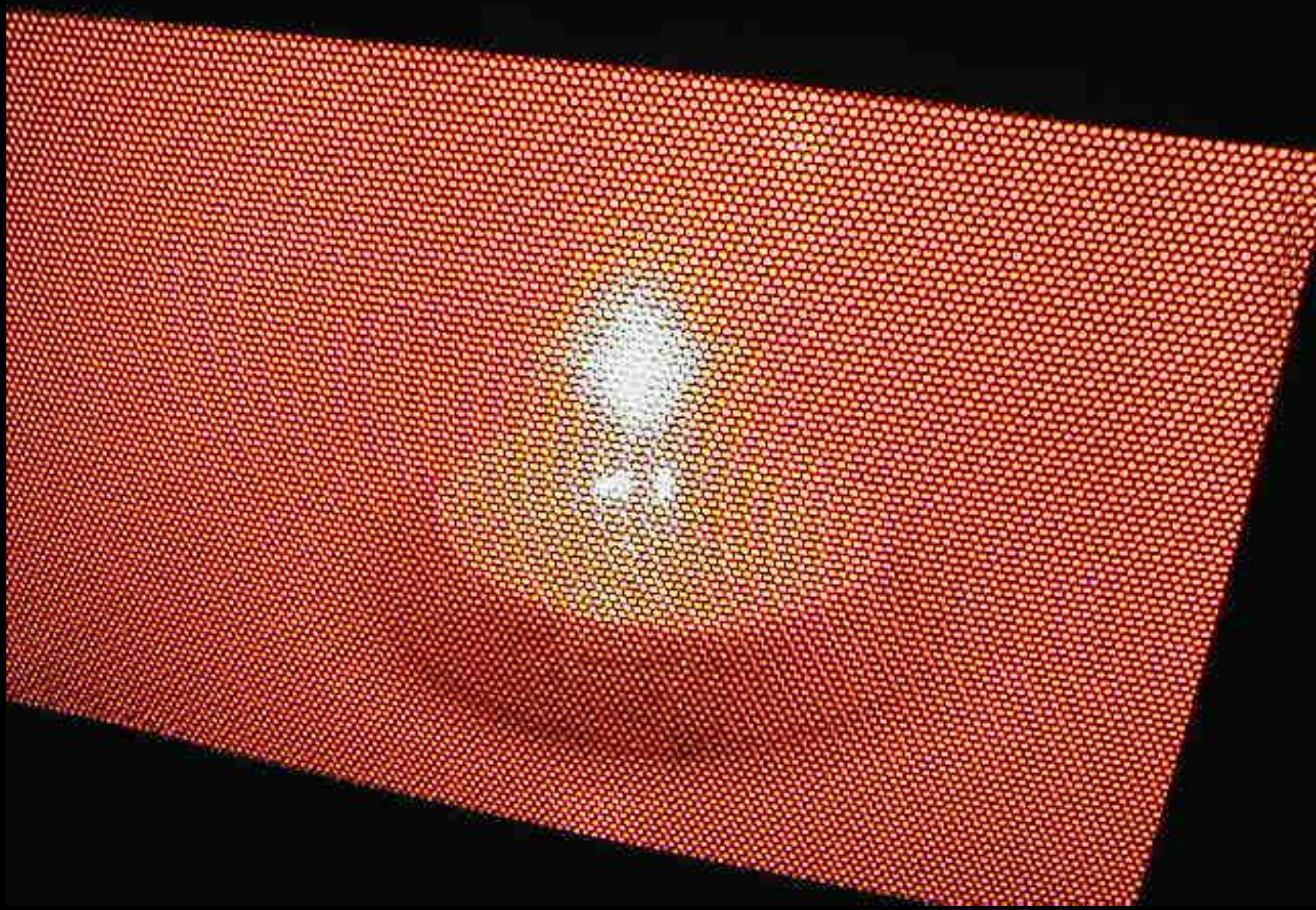


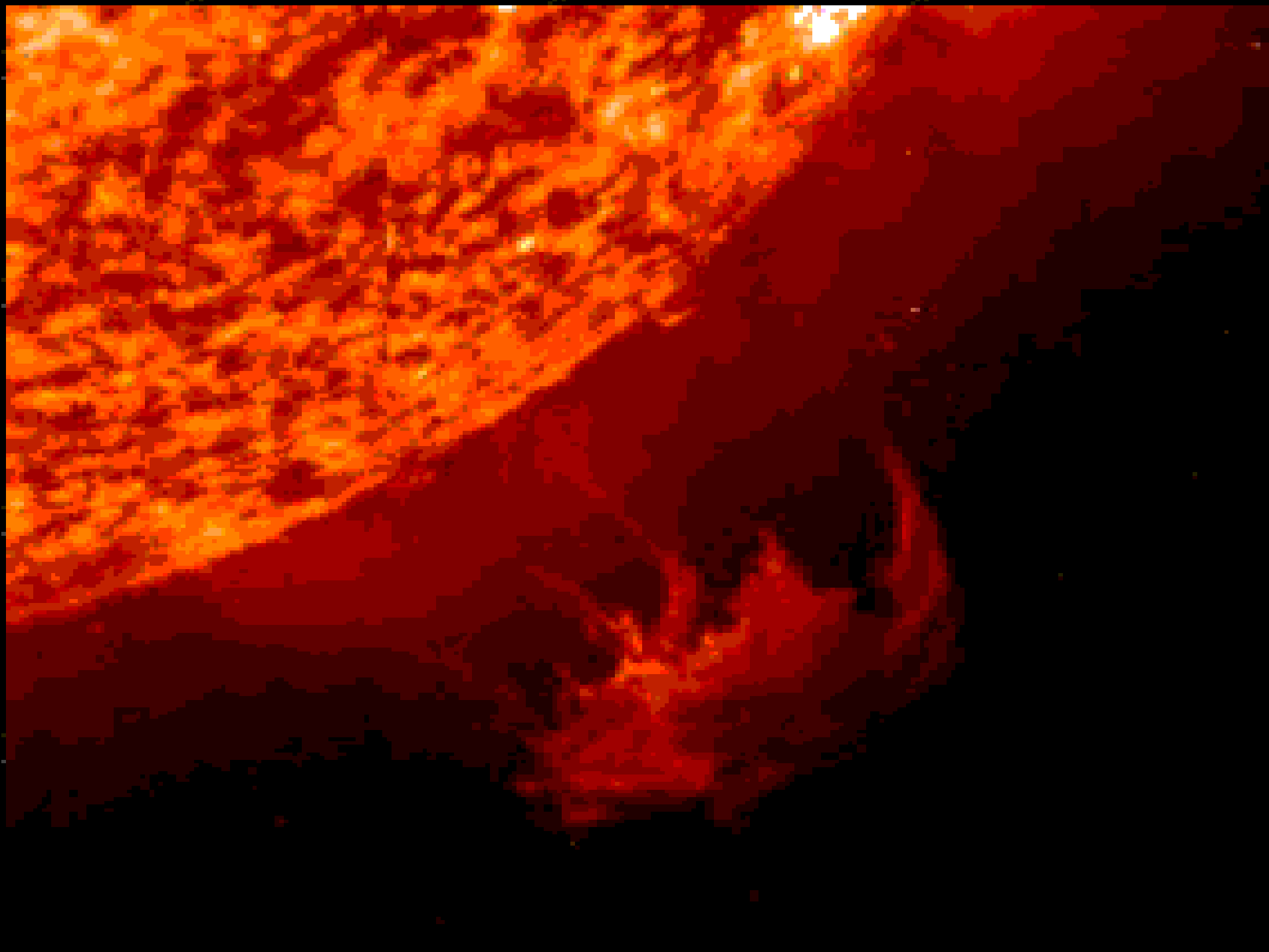
“Bola de Plasma”

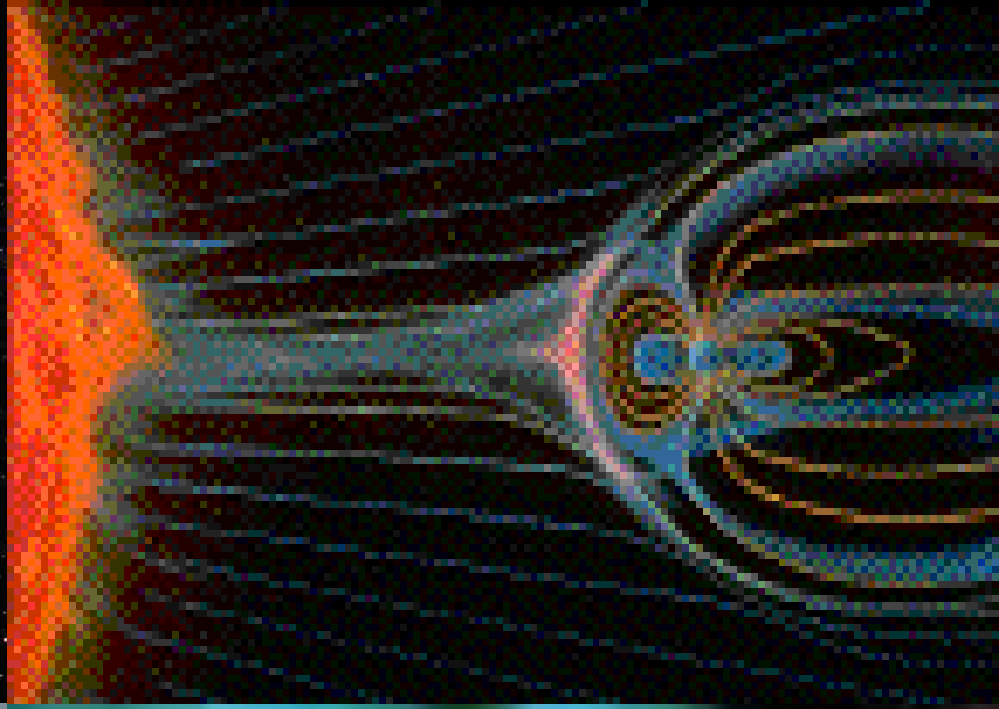


Plasma “feito em casa”









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