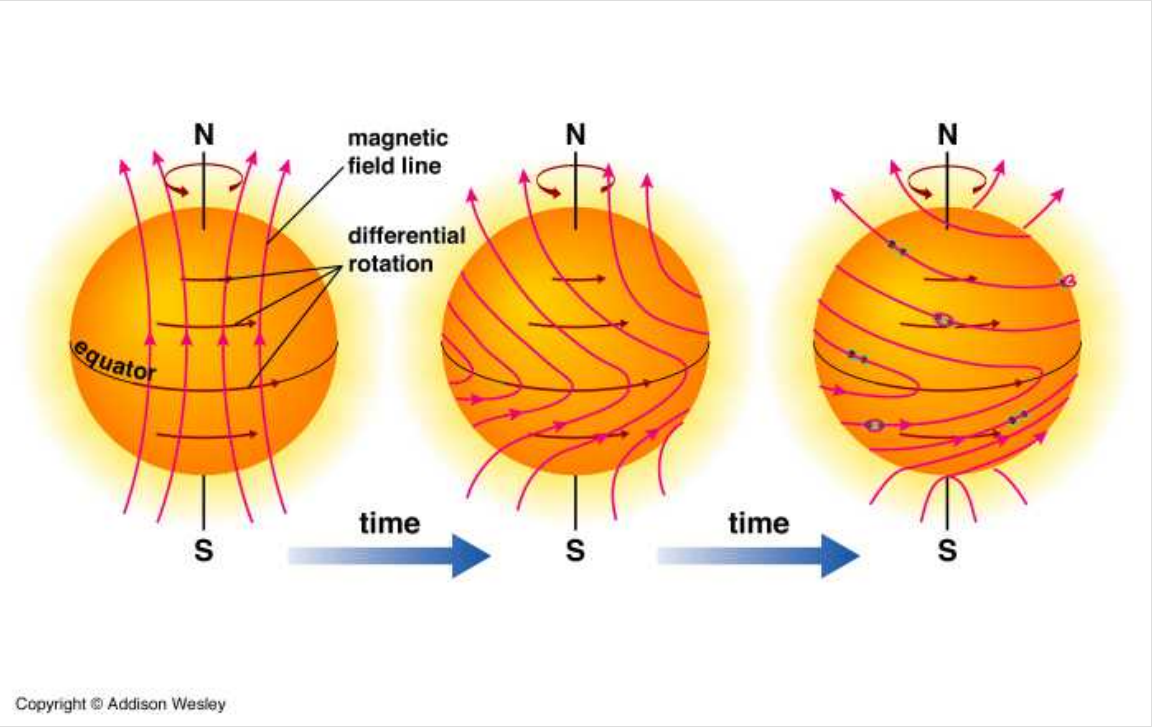
Differential Rotation

The Sun does not rotate as a solid body (like the Earth.) The equator rotates faster than the poles.

Period of Rotation:

25 days (equator)
30 days (poles)



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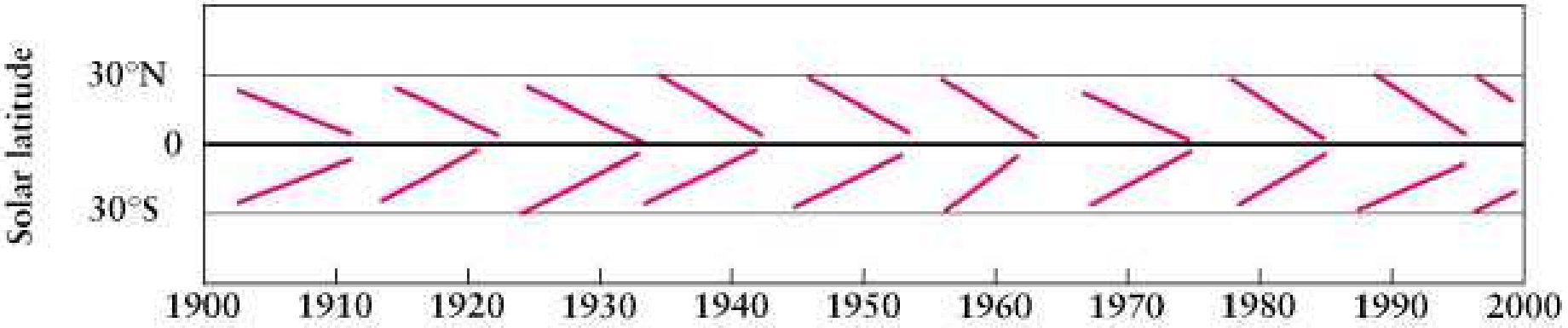
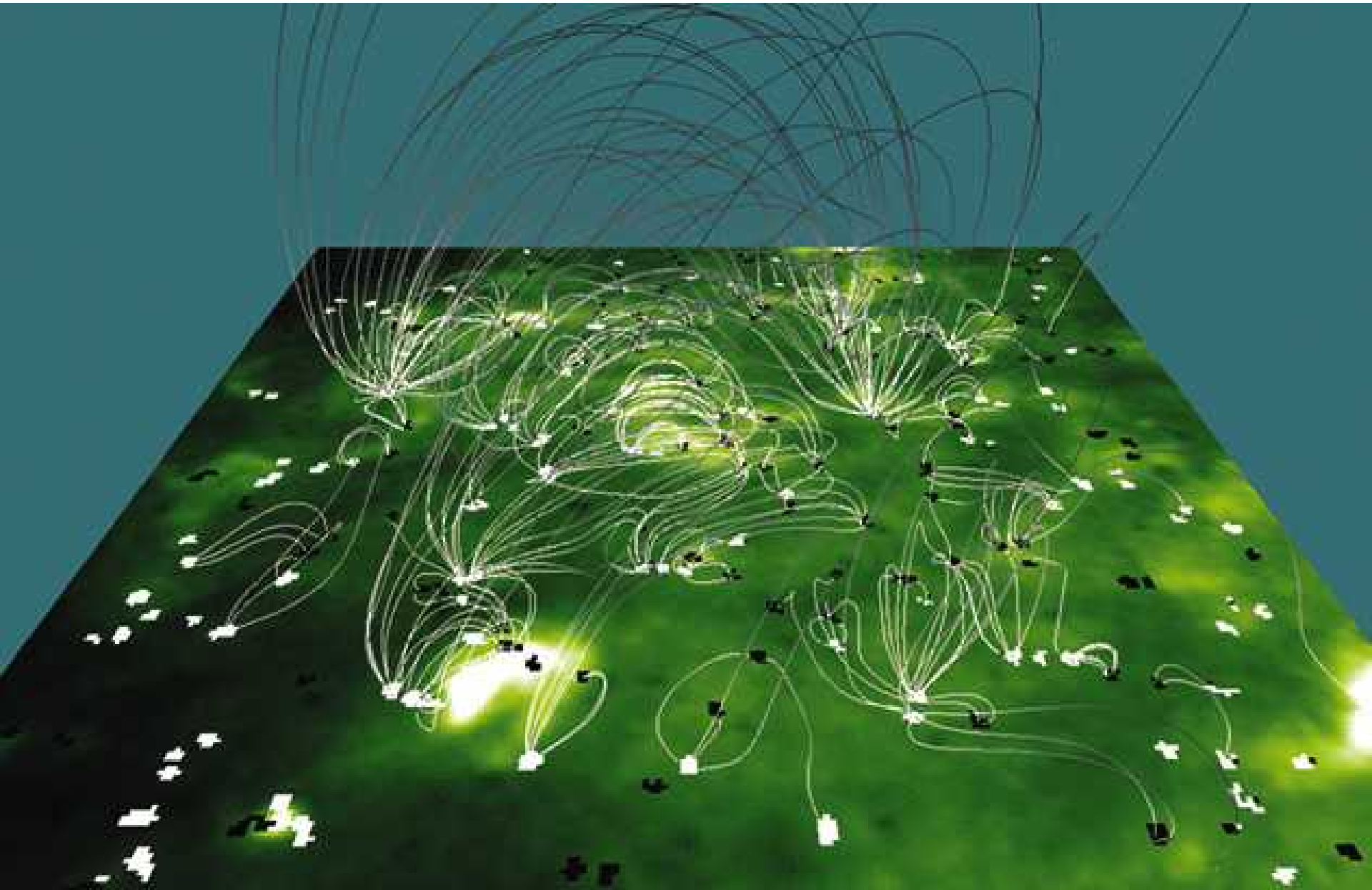
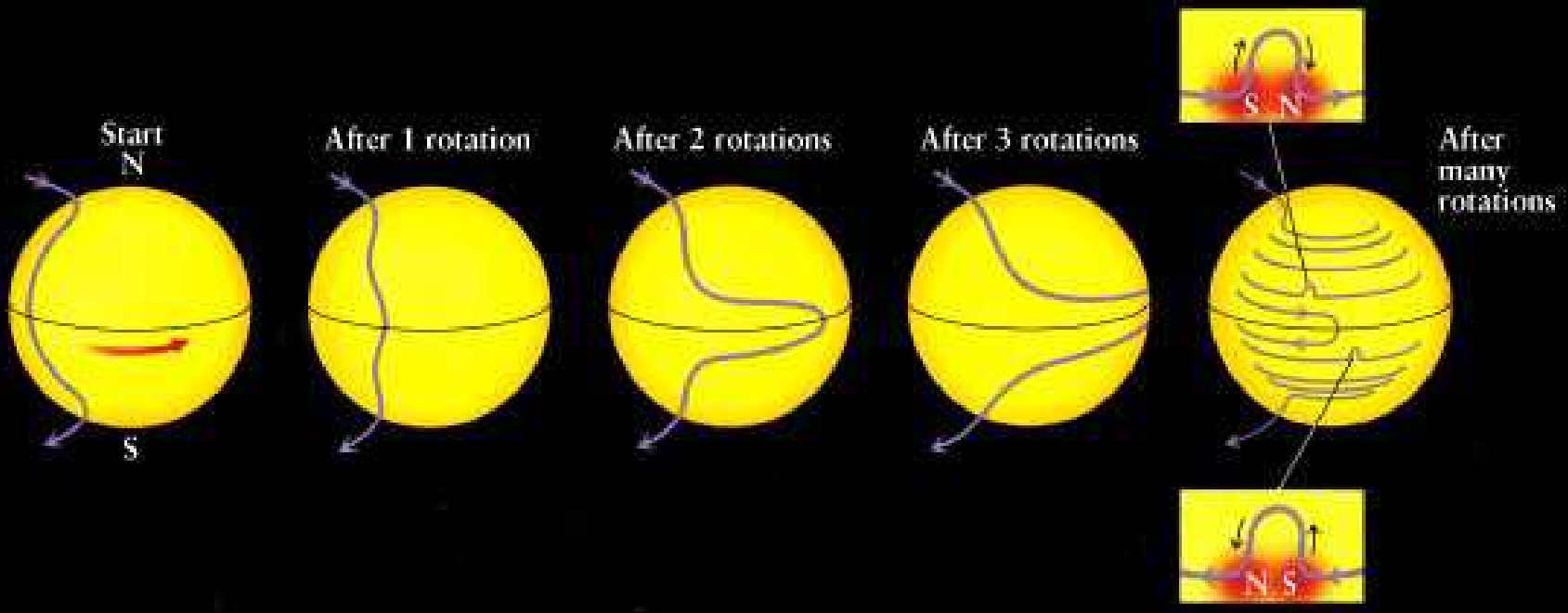
The cyclical change in the latitude of **sunspots** also reveals that the Sun experiences an 11-year solar cycle



Magnetic field lines connect sunspots on the Sun's photosphere



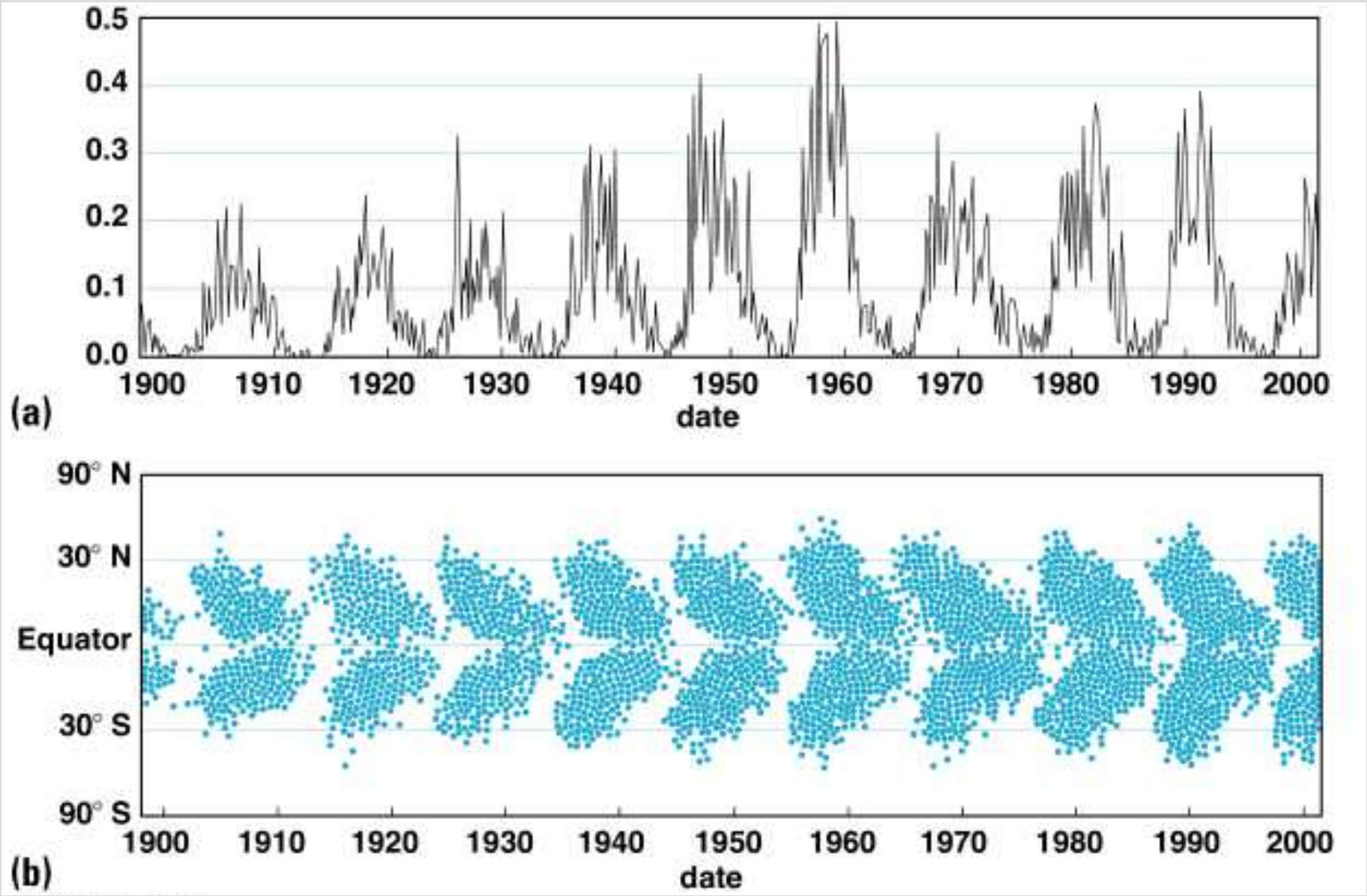
Babcock's magnetic dynamo is one possible explanation of the sunspot cycle where magnetic field lines become complexly entangled after many solar rotations



Solar Activity

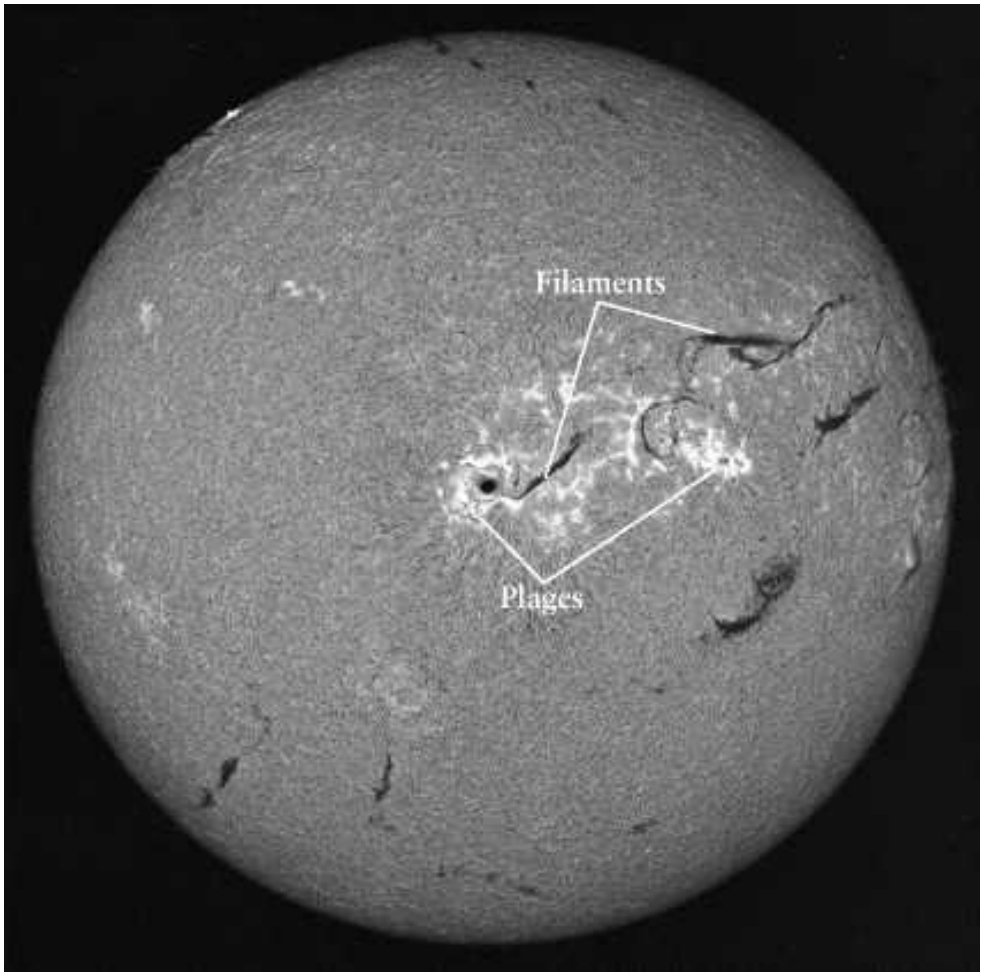
- The photosphere of the Sun is covered with sunspots.
- Sunspots are not constant; they appear & disappear.
- They do so in a cycle.
- It repeats every 11 yrs.
  - Sun's magnetic field switches polarity every 11 yrs
  - so the entire cycle repeats every 22 yrs

Sunspot Cycle



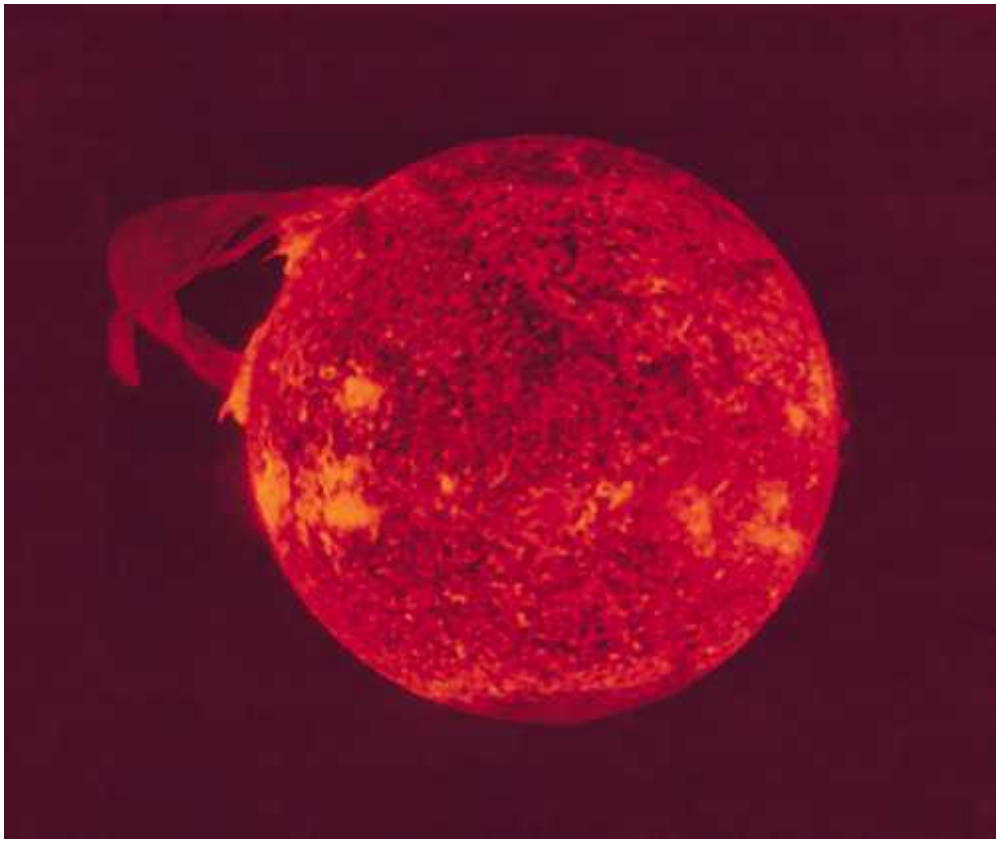
Solar magnetic fields also create other atmospheric phenomena

- plages
- filaments



Solar magnetic fields also create other atmospheric phenomena

- plages
- filaments
- prominences

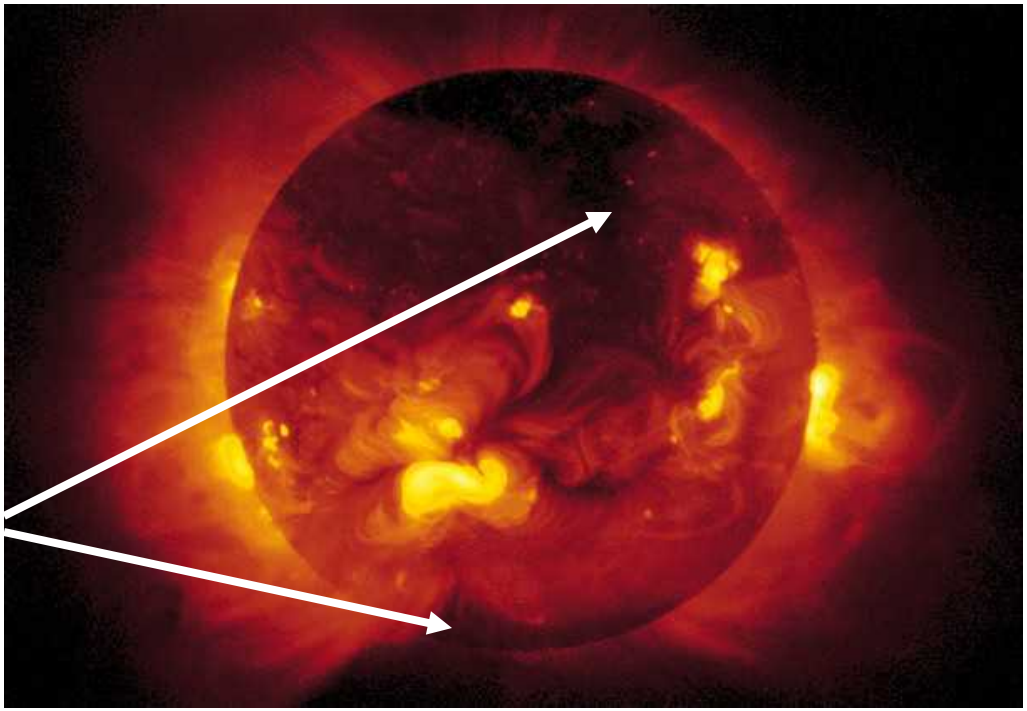


Solar magnetic fields also create other atmospheric phenomena

- plages
- filaments
- prominences
- solar flares

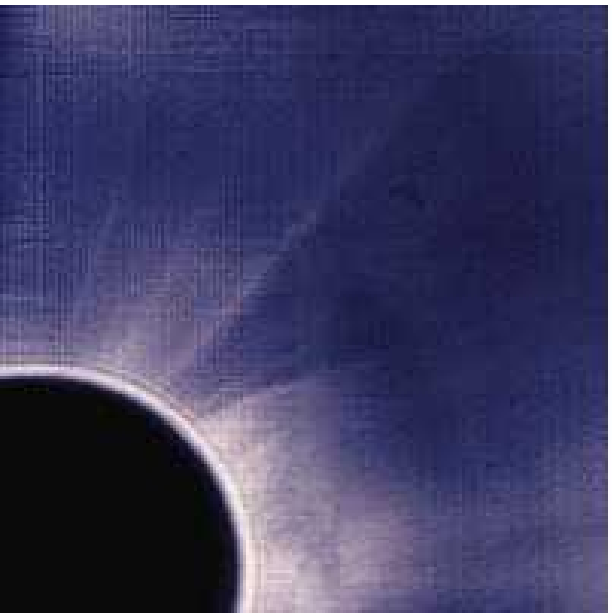
Solar magnetic fields also create other atmospheric phenomena

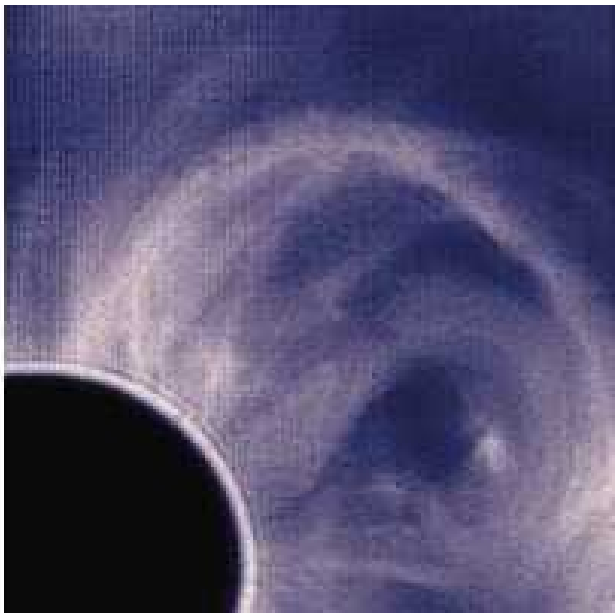
- plages
- filaments
- prominences
- solar flares
- coronal holes

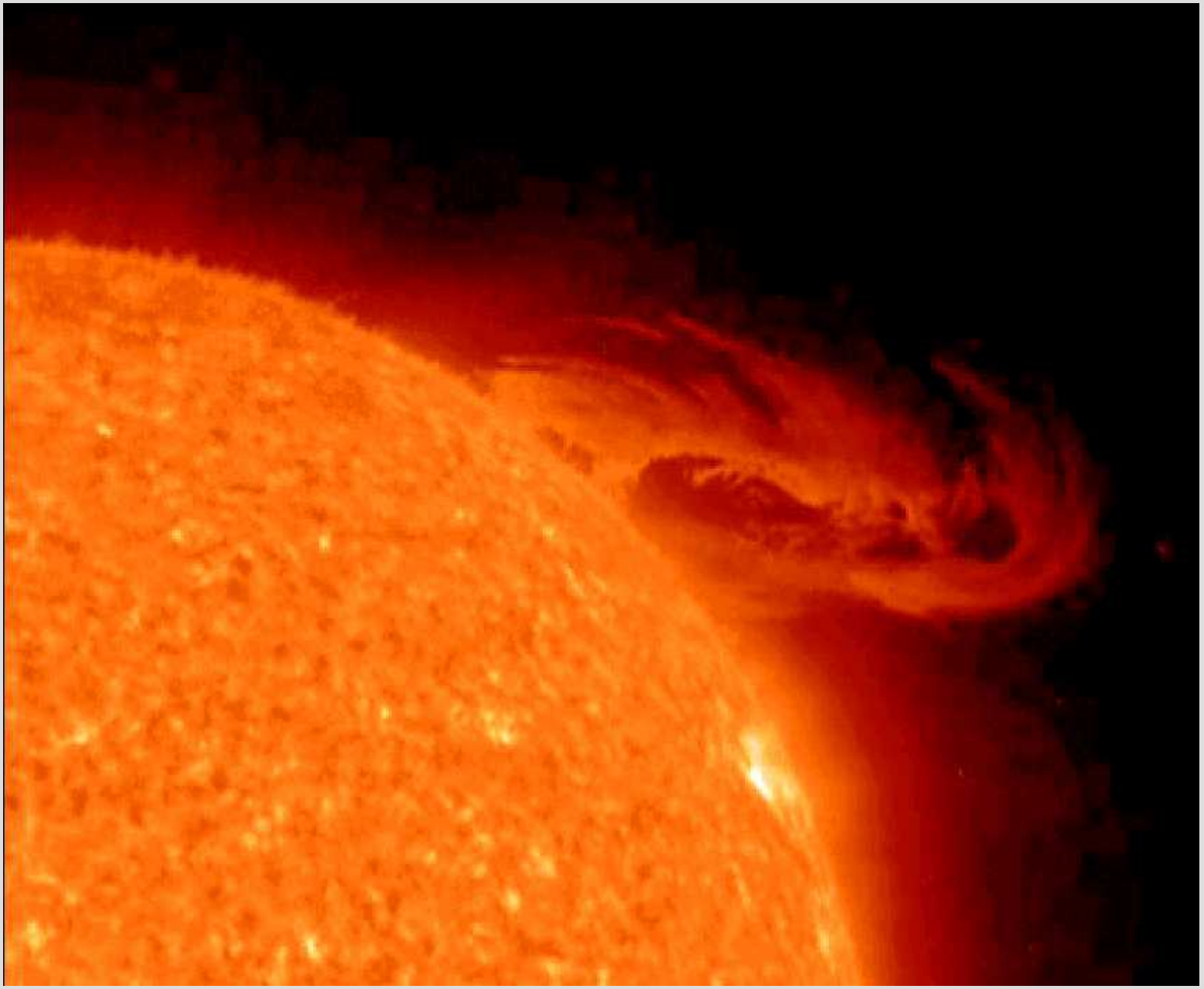


Solar magnetic fields also create other atmospheric phenomena

- plages
- filaments
- prominences
- solar flares
- coronal holes
- **coronal mass ejections (CMEs)**







Why does the Sun shine?

Is it on FIRE?

Is it on FIRE?

$$\frac{\text{Chemical Energy Content}}{\text{Luminosity}} \sim 10{,}000 \text{ years}$$

Is it on FIRE? … NO!

$$\frac{\text{Chemical Energy Content}}{\text{Luminosity}} \sim 10{,}000 \text{ years}$$

Is it CONTRACTING?

Is it CONTRACTING?

$$\frac{\text{Gravitational Potential Energy}}{\text{Luminosity}} \sim 25 \text{ million years}$$

Is it CONTRACTING? … NO!

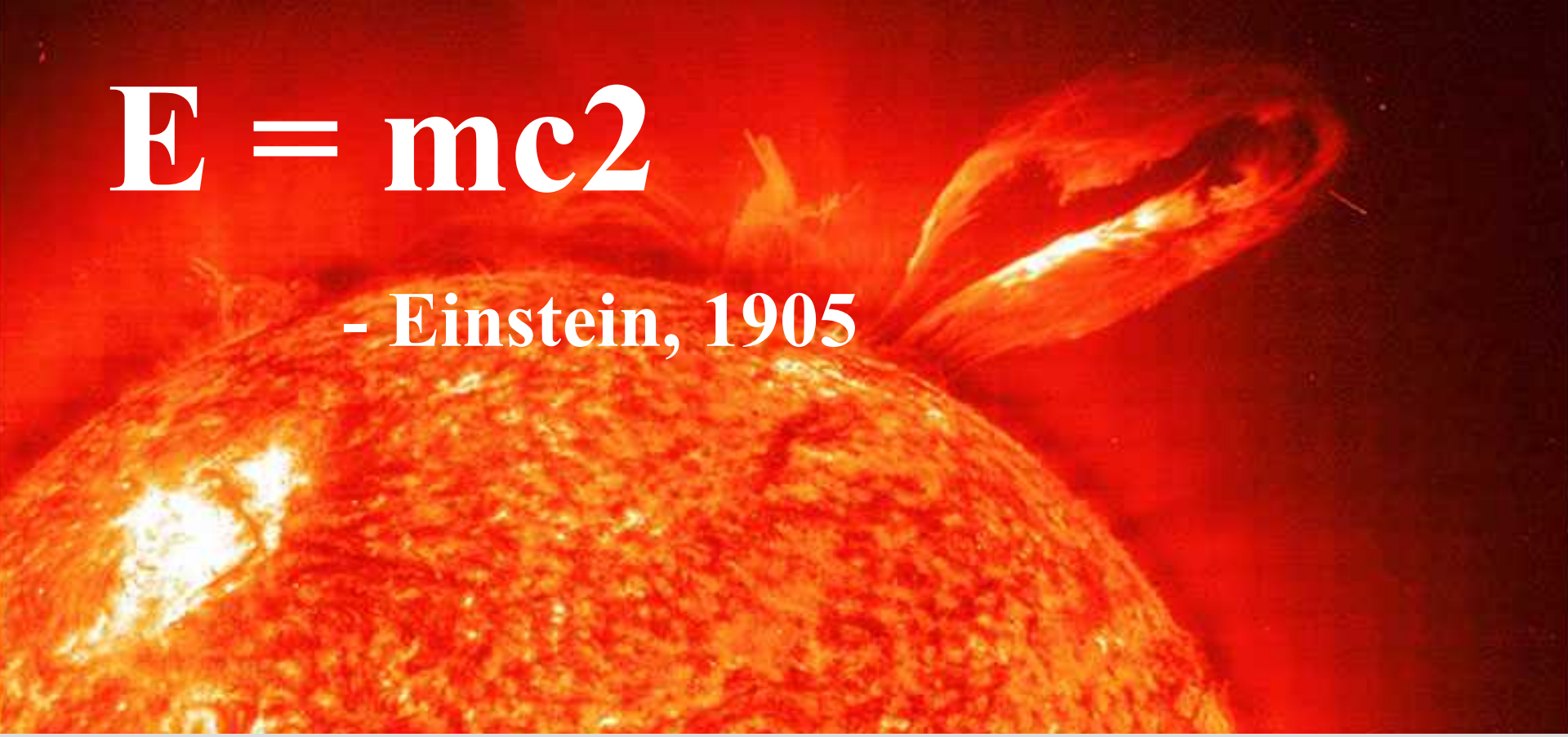
$$\frac{\text{Gravitational Potential Energy}}{\text{Luminosity}}$$

~ 25 million years

Is it CONTRACTING? … NO!

$$\frac{\text{Gravitational Potential Energy}}{\text{Luminosity}}$$

~ 25 million years



Is it powered by NUCLEAR ENERGY? … YES!

The Sun's Energy Source

- The first scientific theories involved chemical reactions or gravitational collapse.
  - chemical burning ruled out…it can not account for the Sun's luminosity
  - conversion of gravitational potential energy into heat as the Sun contracts would only keep the Sun shining for 25 million years
  - late 19th-century geological research indicated the Earth was older than that
- Development of nuclear physics led to the correct answer
  - the Sun generates energy via nuclear *fusion* reactions
  - Hydrogen is converted into Helium in the Sun's core
  - the mass lost in this conversion is transformed into energy
  - the amount of energy is given by Einstein's equation: $E = mc2$
  - given the Sun's mass, this will provide enough energy for the Sun to shine for 10 billion years

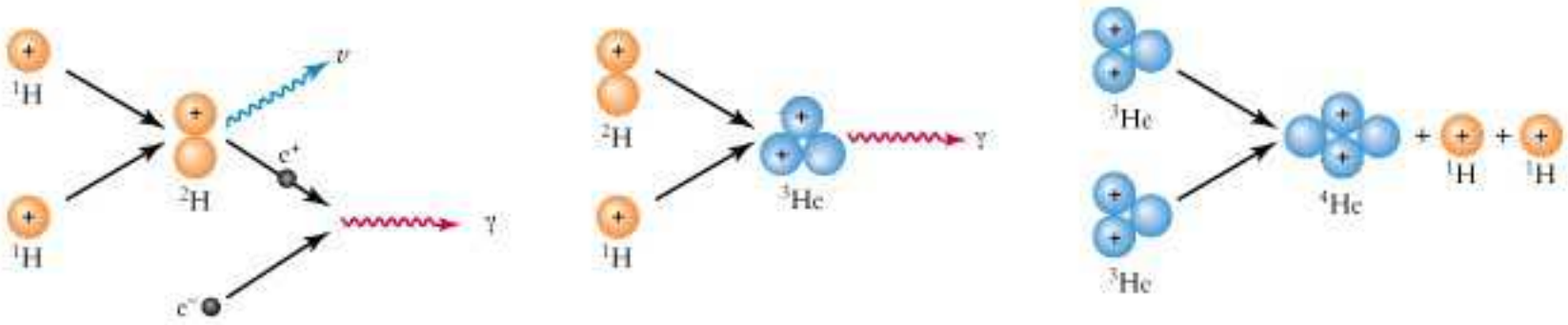
Homework #7

1. What is the mass difference between four Hydrogen nuclei and one Helium nucleus?

2. How much energy is released when 4 Hydrogen atoms fuse into 1 Helium atom?

3. If the Sun puts out the same amount of power during its whole lifetime, How long will the Sun fuse H into He?

Thermonuclear reactions in the core of the Sun produce its energy



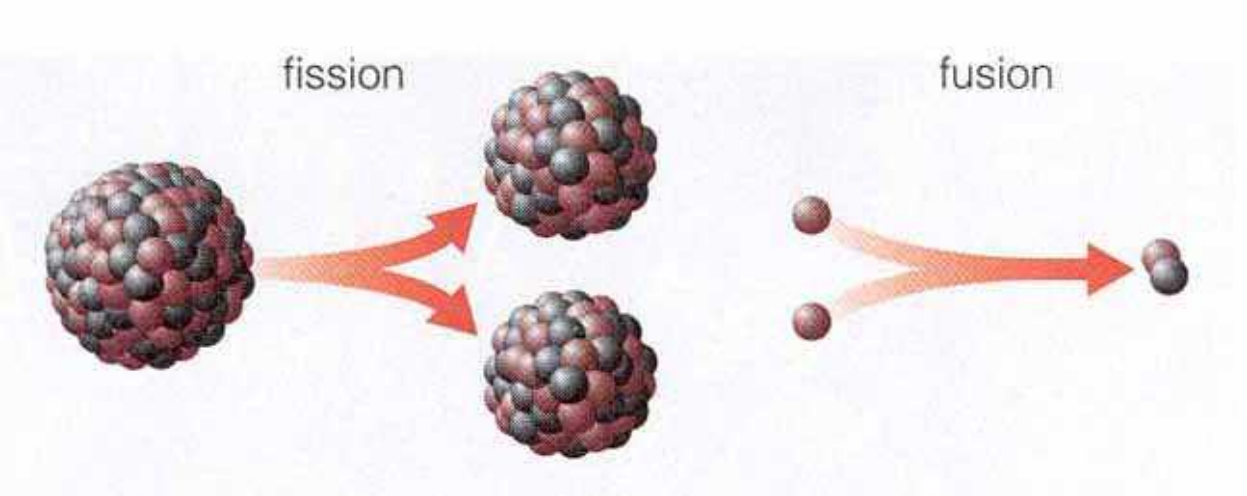
At extremely high temperatures and pressures, 4 Hydrogen atoms can combine to make 1 Helium atom and release energy in the process according to E = mc2

4H ⇨ He + energy

HYDROGEN FUSION

What is nuclear fission ?

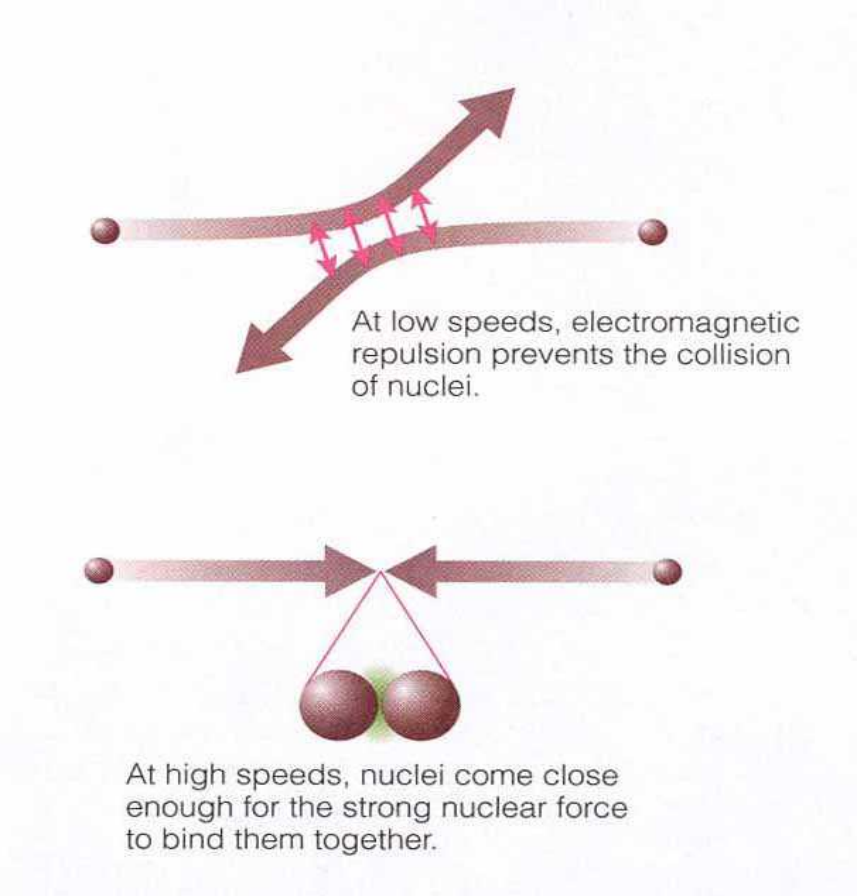
a reaction where lighter nuclei are created by splitting heavier nuclei.

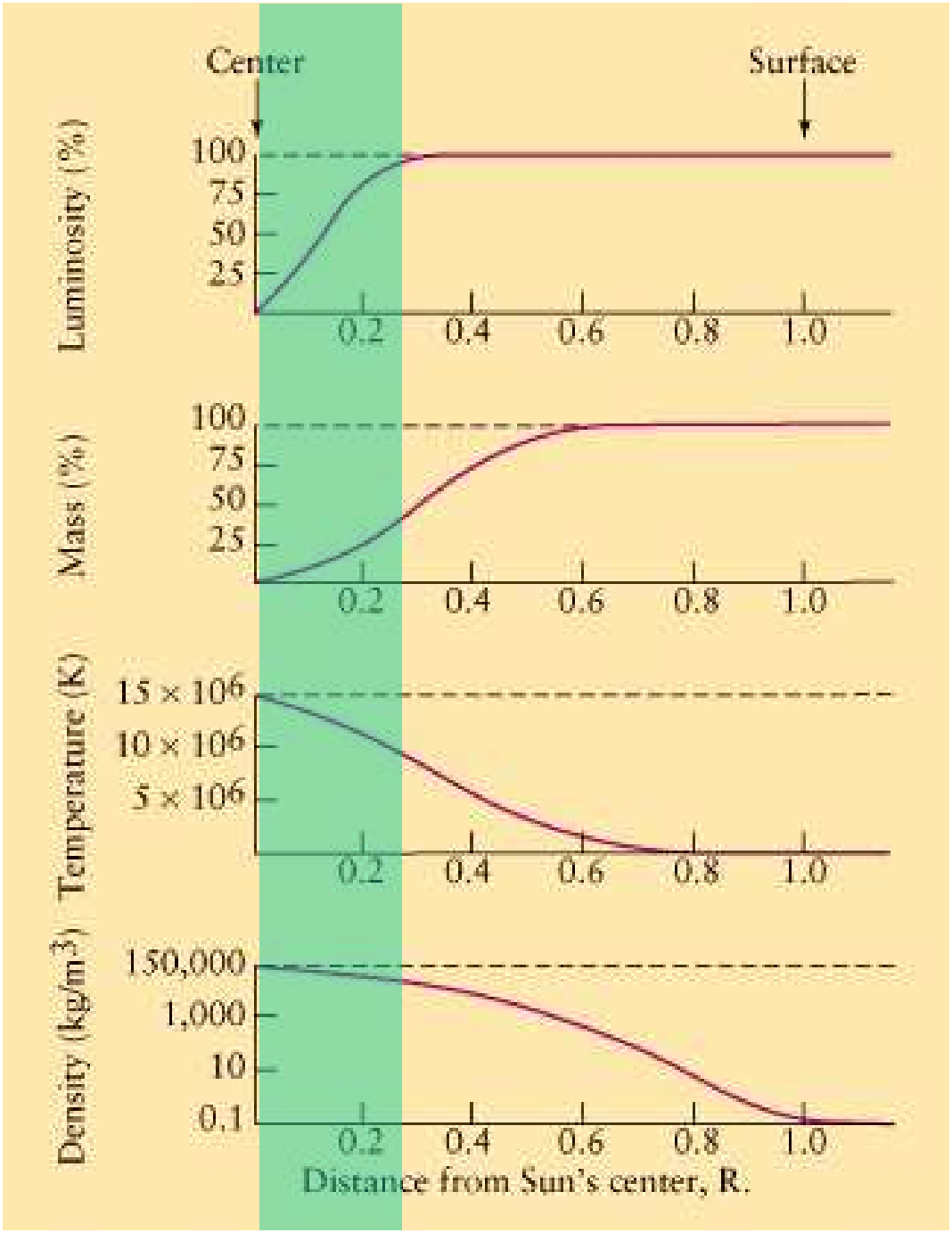


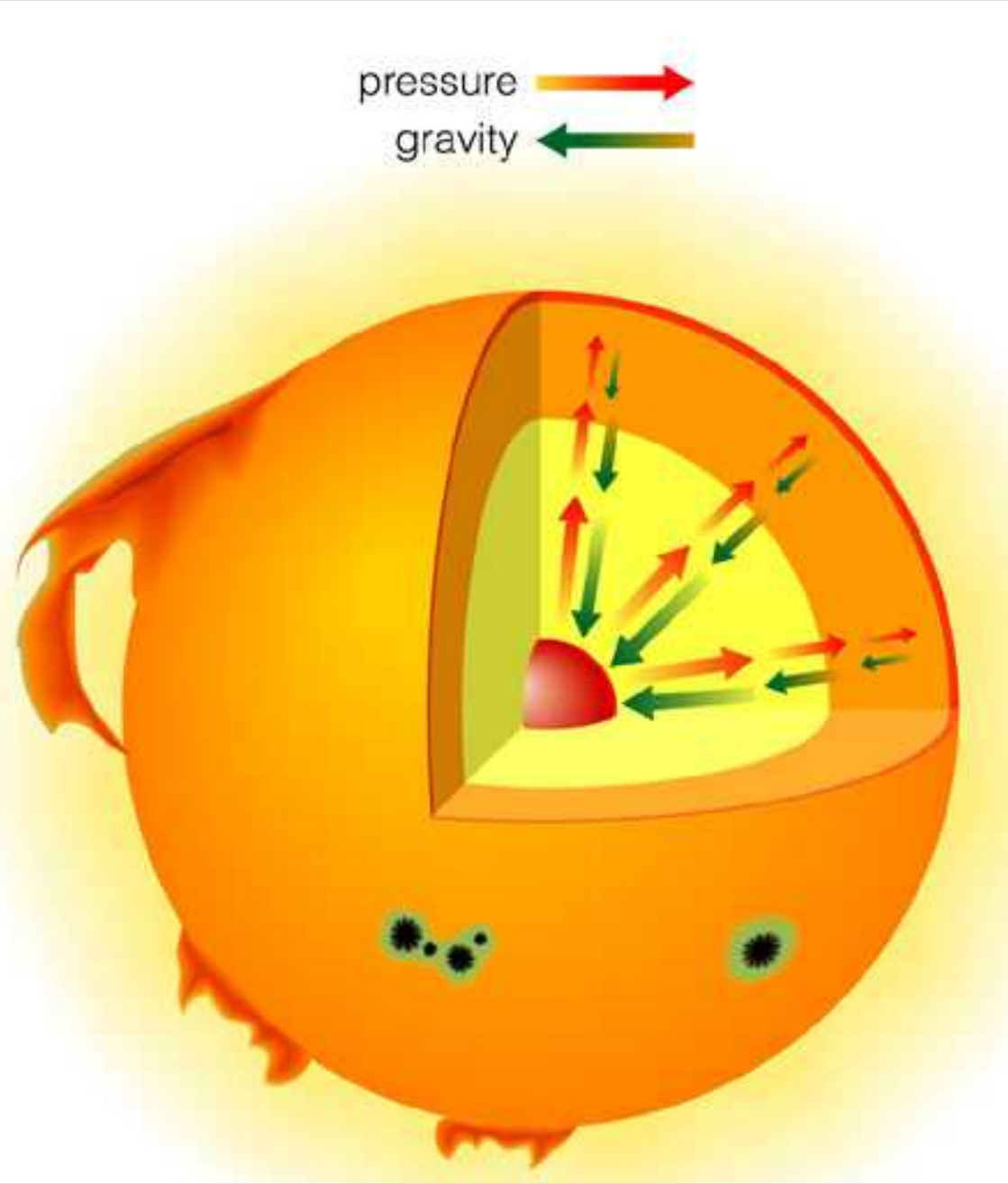
Both fission and fusion have been achieved by man – only fission has been controlled

Why does fusion occur in the Sun's core ?

- Nuclear fusion
  - a reaction where heavier nuclei are created by combining (*fusing*) lighter nuclei.
  - all nuclei are positively charged
- Electromagnetic force causes nuclei to repel each other.
  - for fusion to occur, nuclei must be moving fast enough to overcome E-M repulsion
  - this requires high temperatures & pressures
- When nuclei get very close, the nuclear force binds them together




Center
Surface
Luminosity (%)
100
75
50
25
0.2
0.4
0.6
0.8
1.0
Mass (%)
100
75
50
25
0.2
0.4
0.6
0.8
1.0
Temperature (K)
15 × 106
10 × 106
5 × 106
0.2
0.4
0.6
0.8
1.0
Density (kg/m3)
150,000
1,000
10
0.1
0.2
0.4
0.6
0.8
1.0
Distance from Sun's center, R.



Gravitational equilibrium:

The outward push of pressure balances the inward pull of gravity