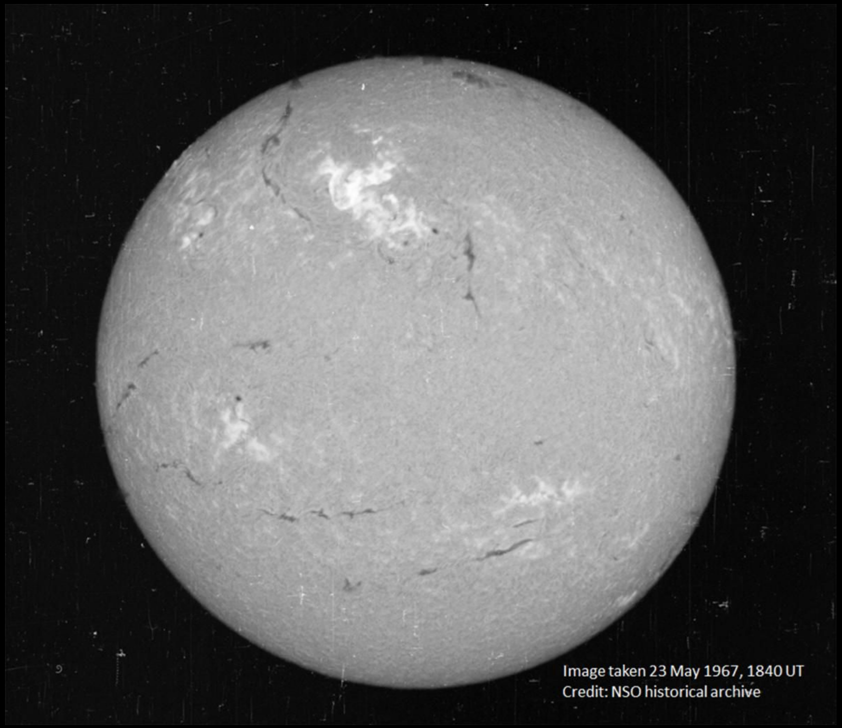

The Sun

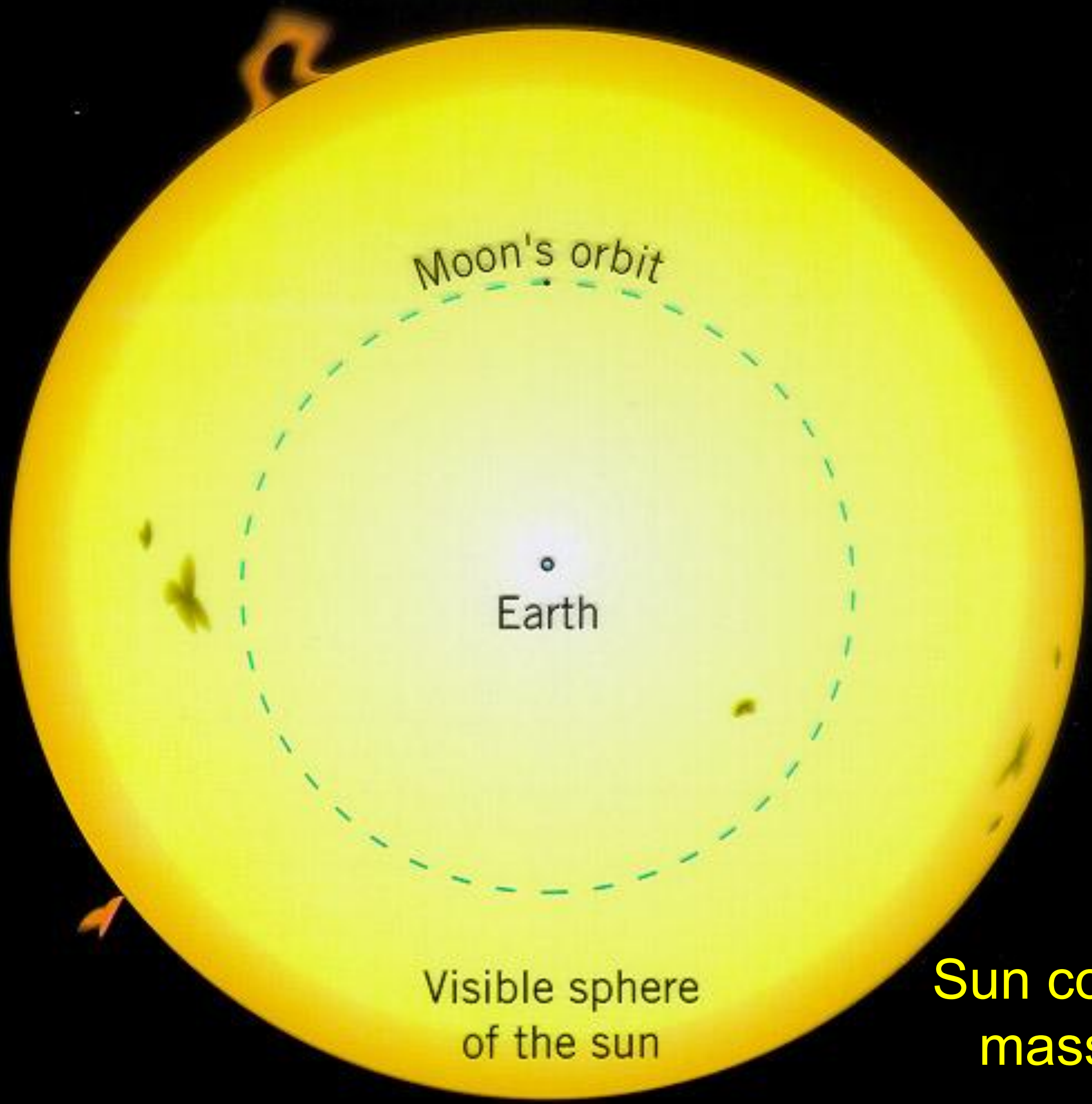
May 23, 1967

The day that World War III almost started.

May 23, 1967

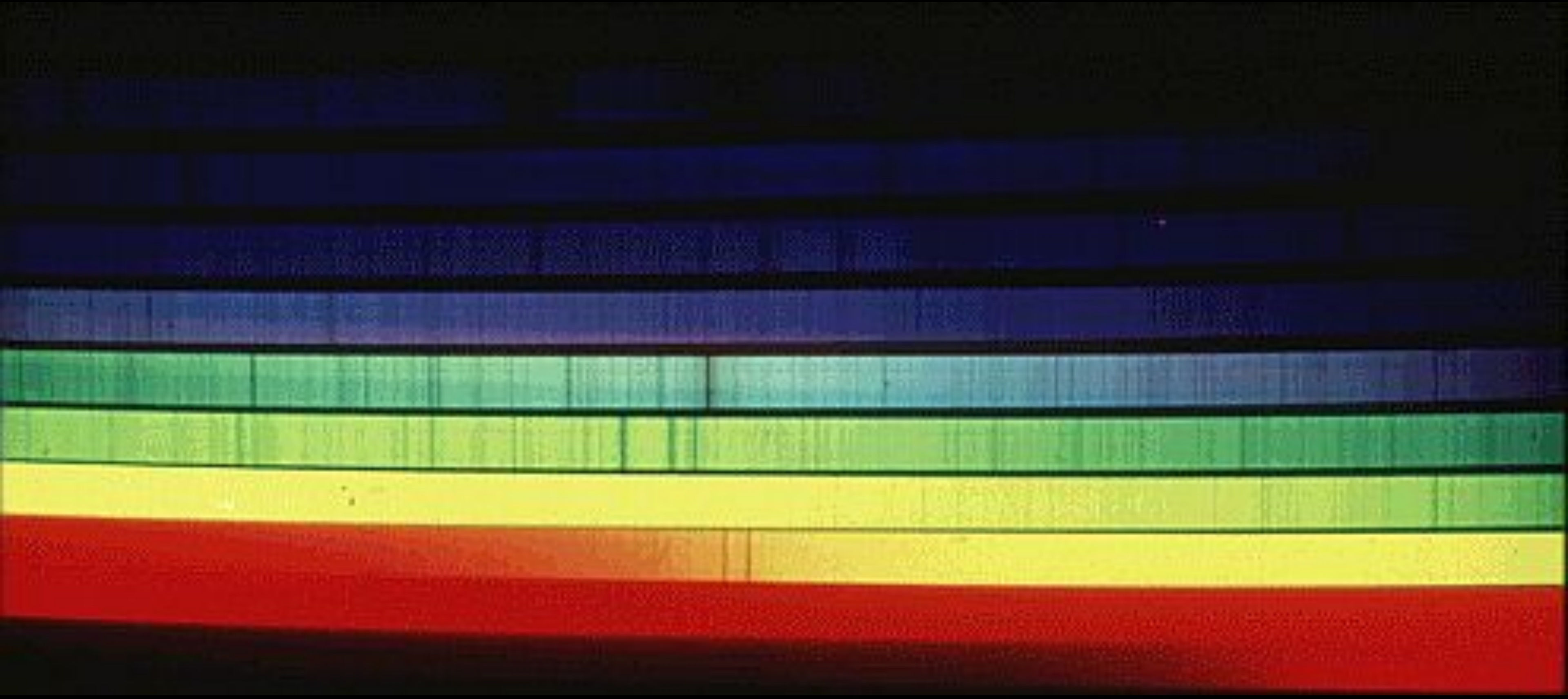
- Strategic Air Command (SAC) noticed a sudden burst of radio and radar interference that made watching ICBMs impossible.
- They had less than 30 minutes to determine if this was a natural event or Soviet subterfuge masking a nuclear attack.
- After about 10 minutes, the SAC staff realized that the interference was being caused by solar activity in an event now called the Great Storm of 1967.
- Knowledge of the sun’s effect on radar and communications prevent World War III.





Sun contains 99.86% of the mass of the entire Solar System.

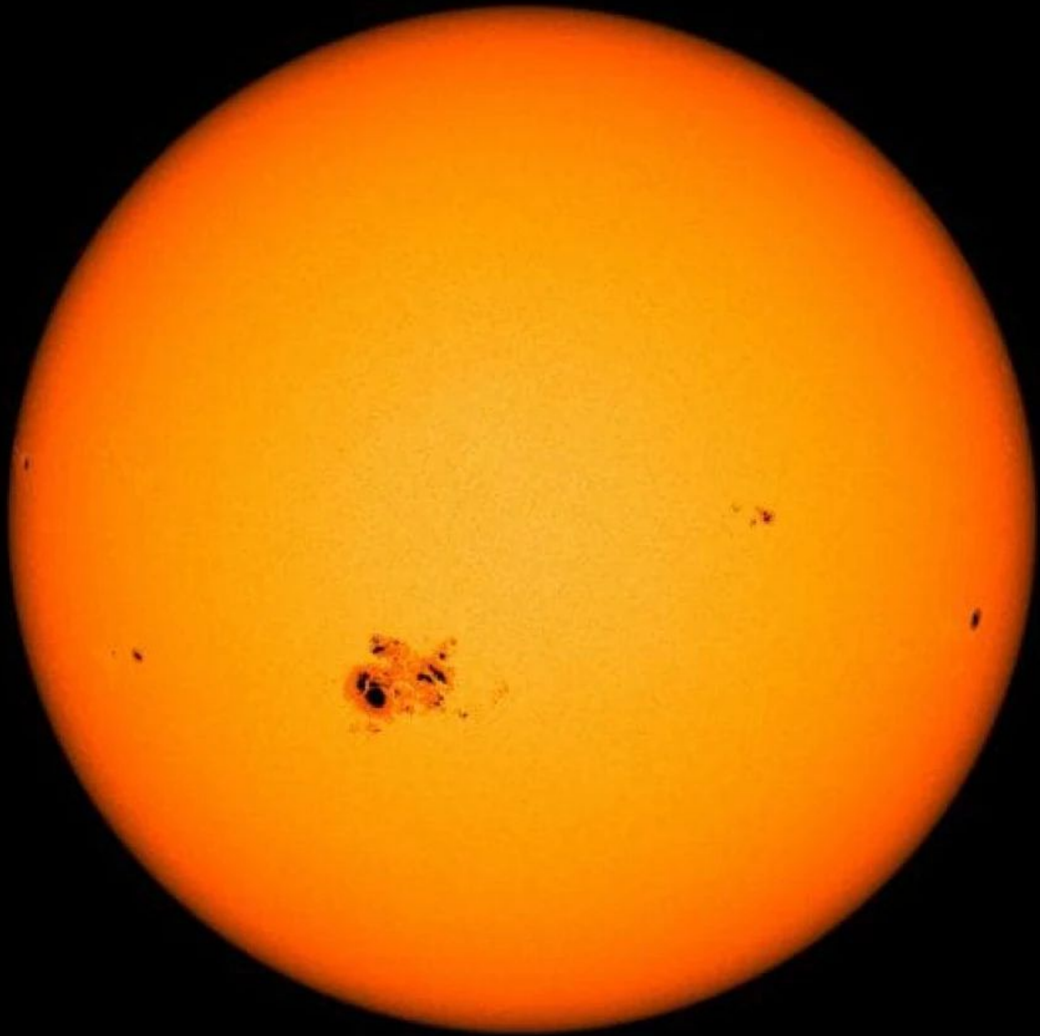
Solar Spectrum



Elements in the Sun

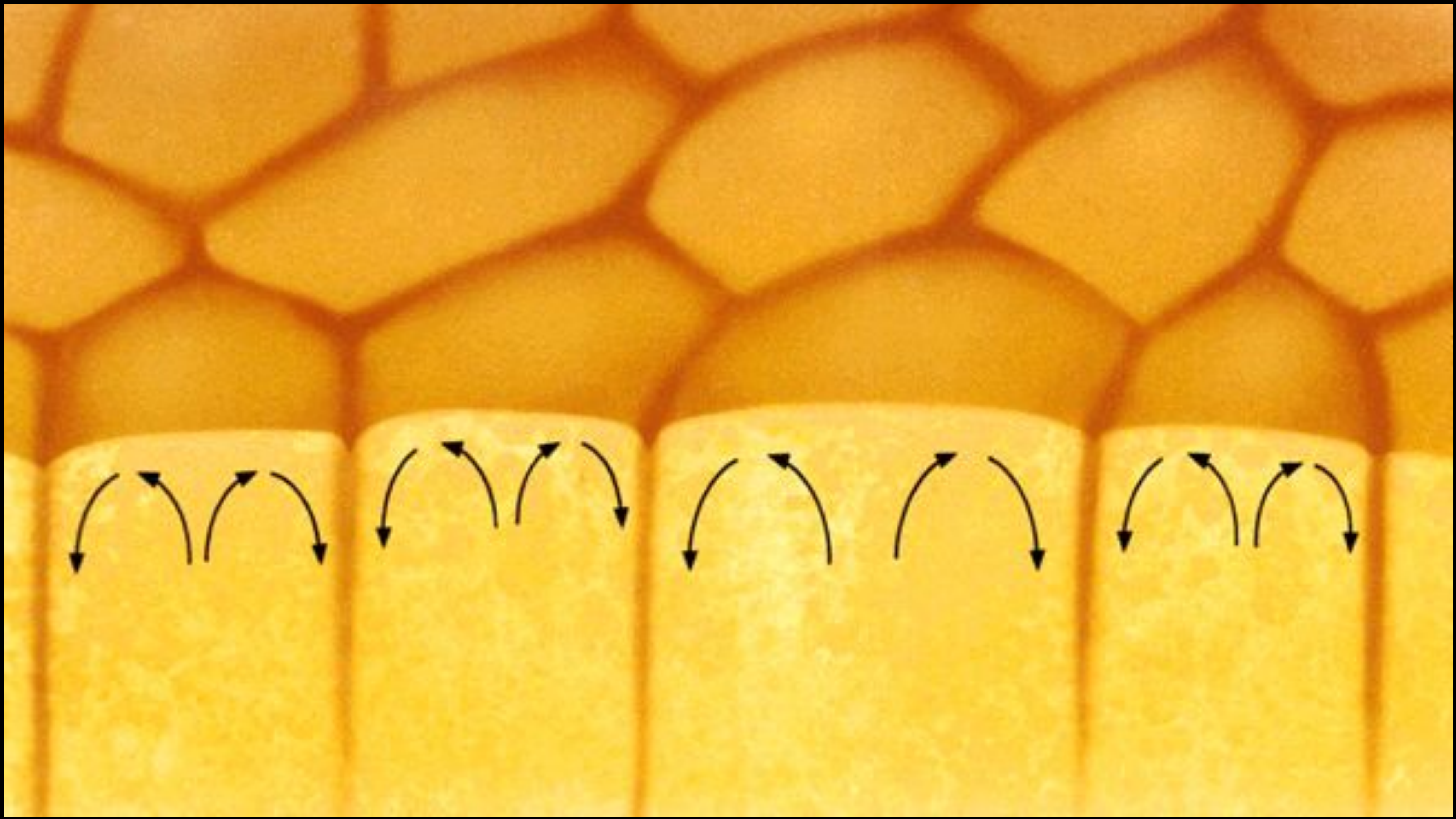
Element	% by Number	% by Mass
Hydrogen	92.0	73.4
Helium	7.8	25.0
Carbon	0.02	0.20
Nitrogen	0.008	0.09
Oxygen	0.06	0.8
Neon	0.01	0.16
Magnesium	0.003	0.06

THE PHOTOSPHERE

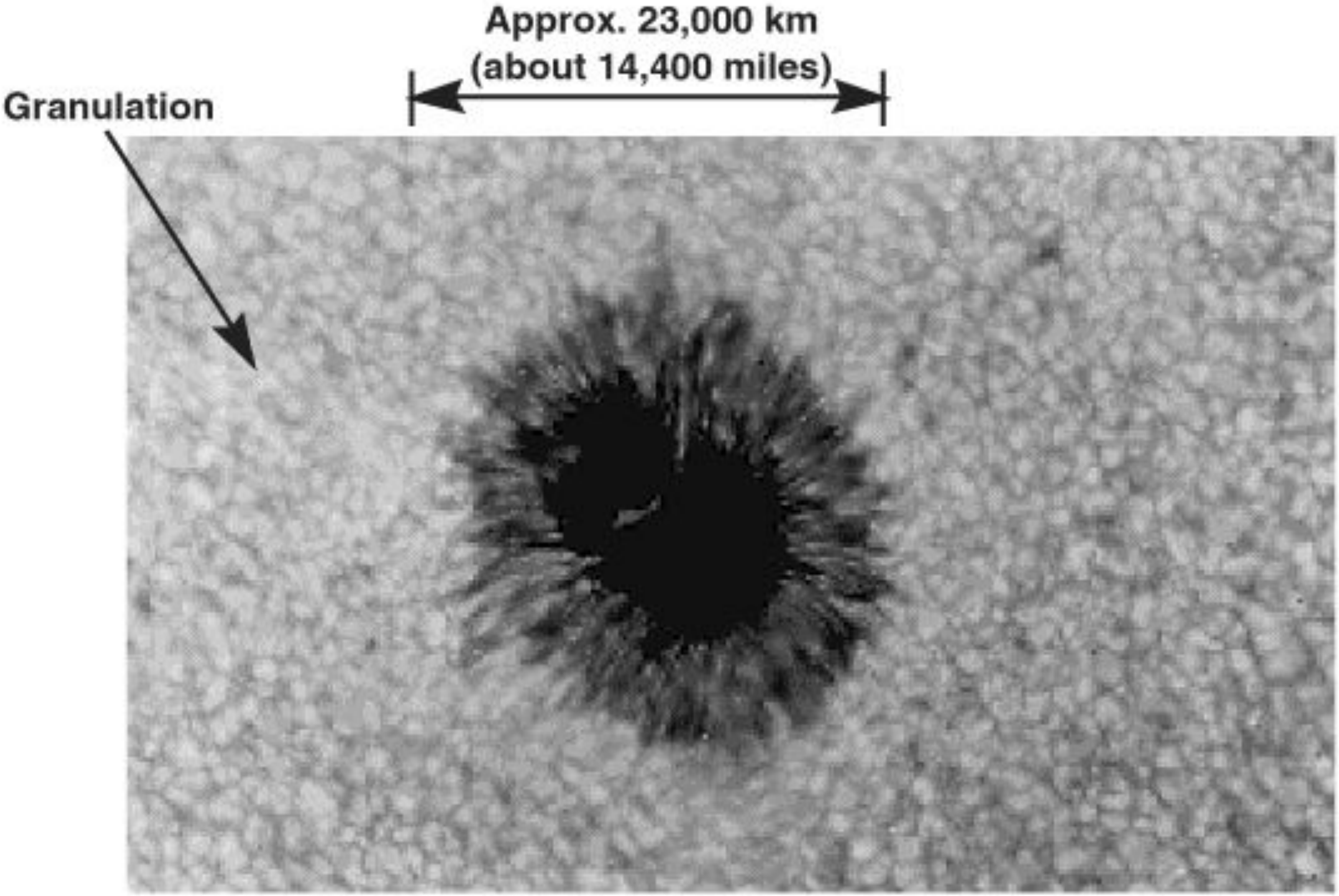


- Photosphere - "sphere of light", the visible surface of the Sun (~400 km (250 miles) thick)

Solar Granulation – Convection Features (hot gases rise to the surface, then cool and sink)



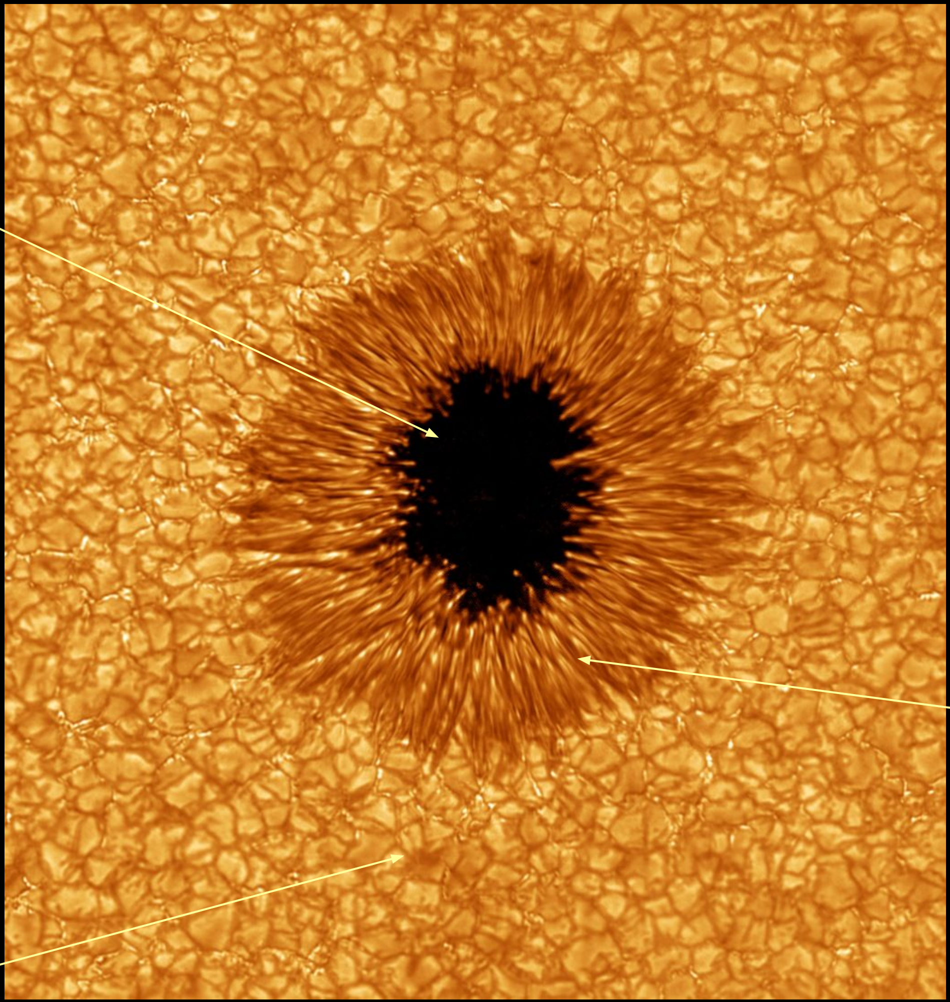
Sunspot



Sunspots

Umbra

4300K Red



Penumbra

5000 K
Orange

Granulation

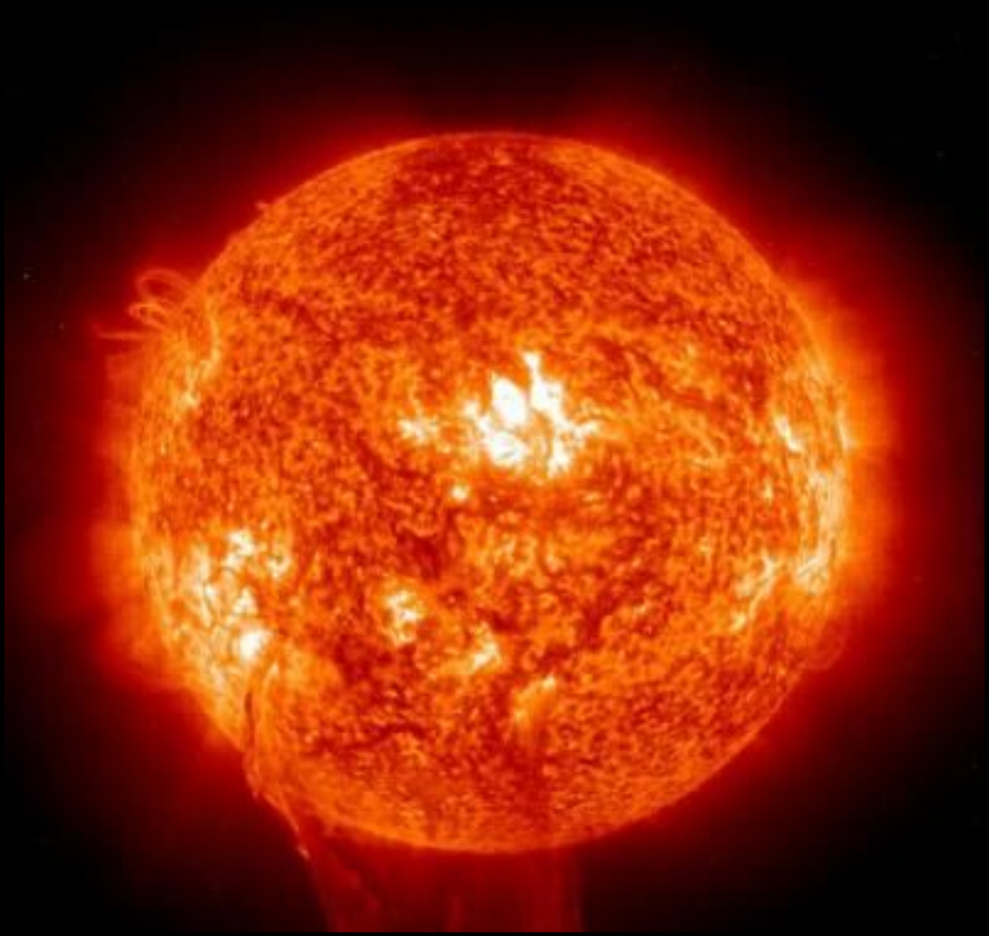
5800 K Yellow

Chromosphere

- Chromosphere - "sphere of color", visible during solar eclipses (~2000 km (1250 miles) thick)

The Chromosphere

Hydrogen-α



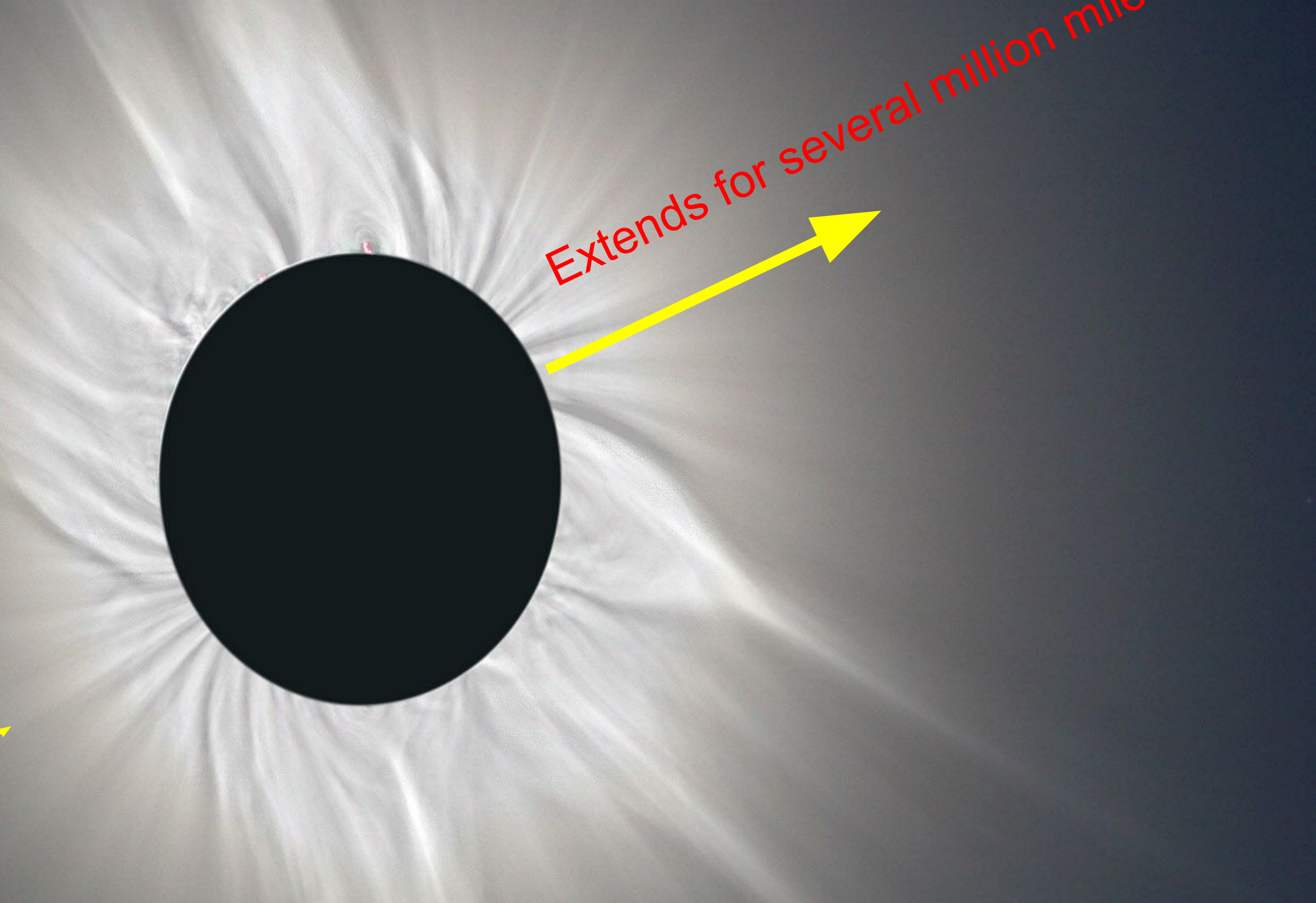
Spicules

(chromosphere)

Jets of gas emitted from the photosphere.

Solar Corona

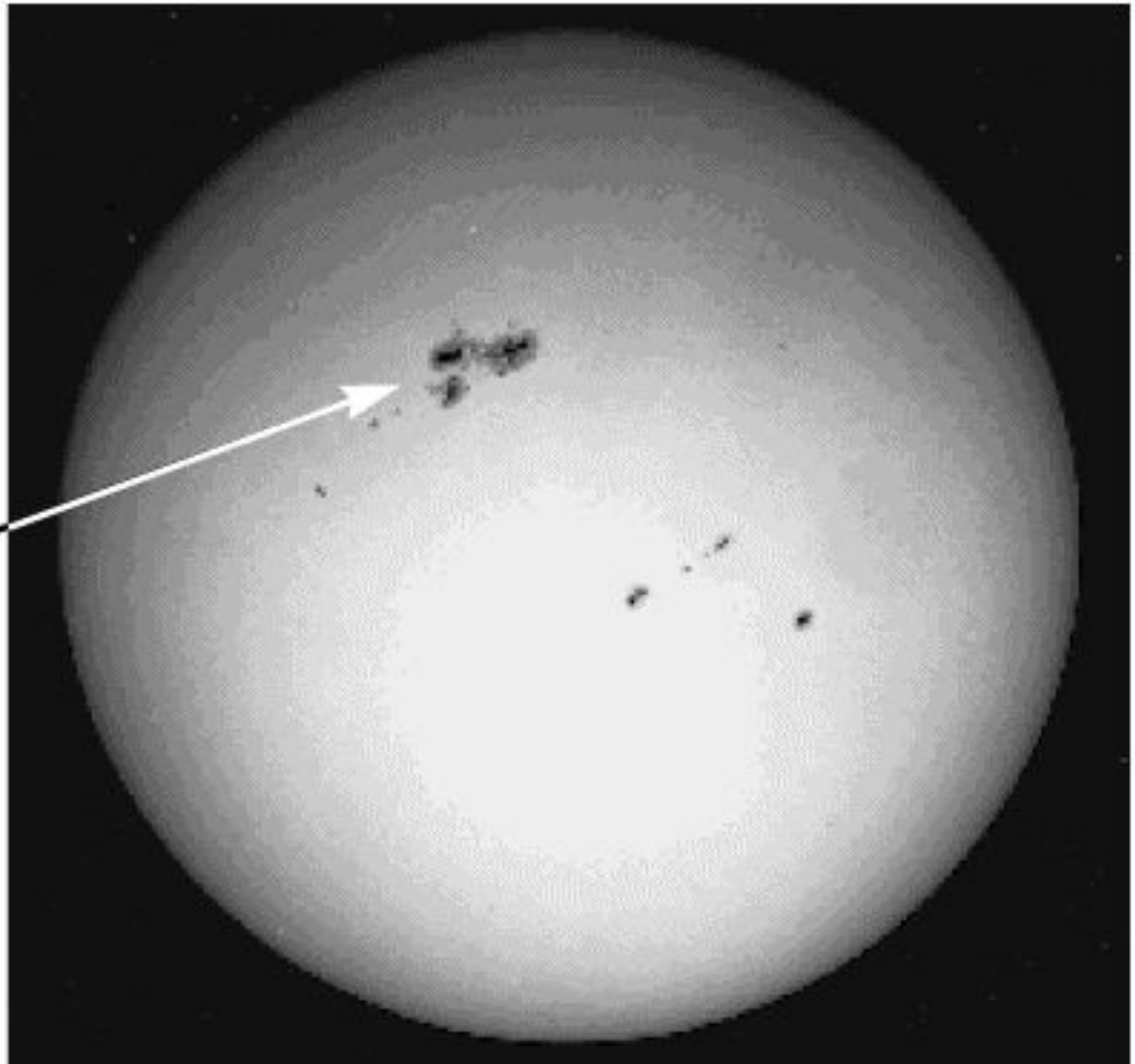
- Corona - the Sun's outermost atmosphere.
  - The outflow of gas in this region is called the solar wind, which are particles that have escaped the Sun's gravity.
  - 99.9% H, He ions; also Si, S, Ca, Cr, Ni, Ne, Ar



Temp actually increases in corona due to high Kinetic energy of solar particles.

Galileo watched sunspots and noticed that the sun rotates once every month.

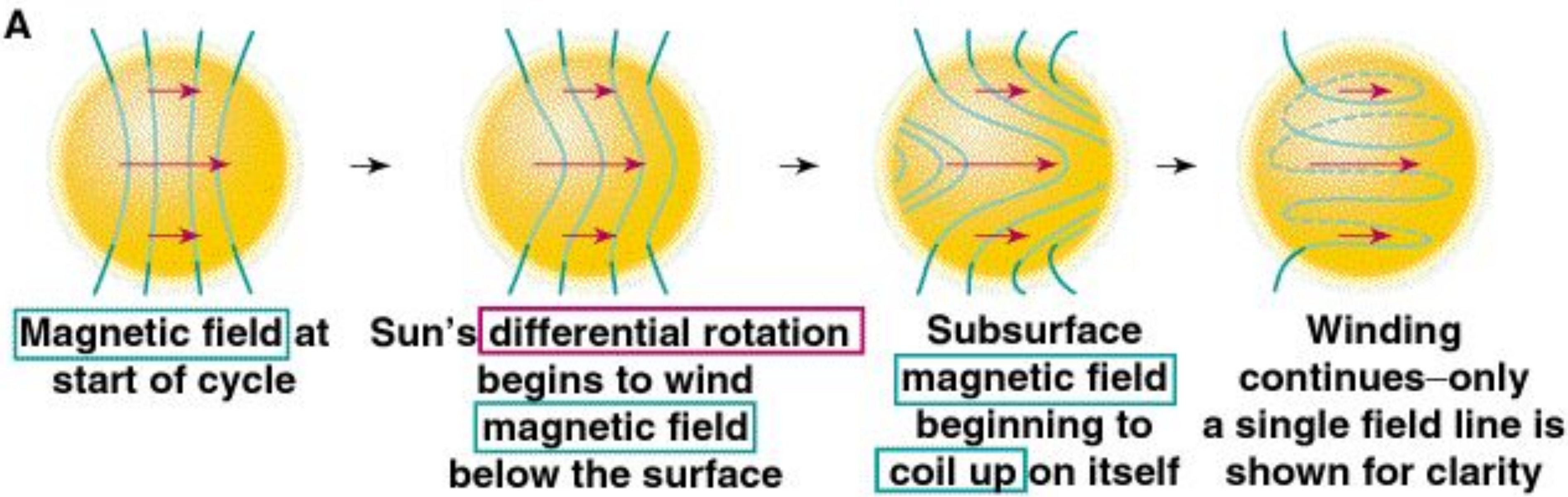
Sunspot Groups



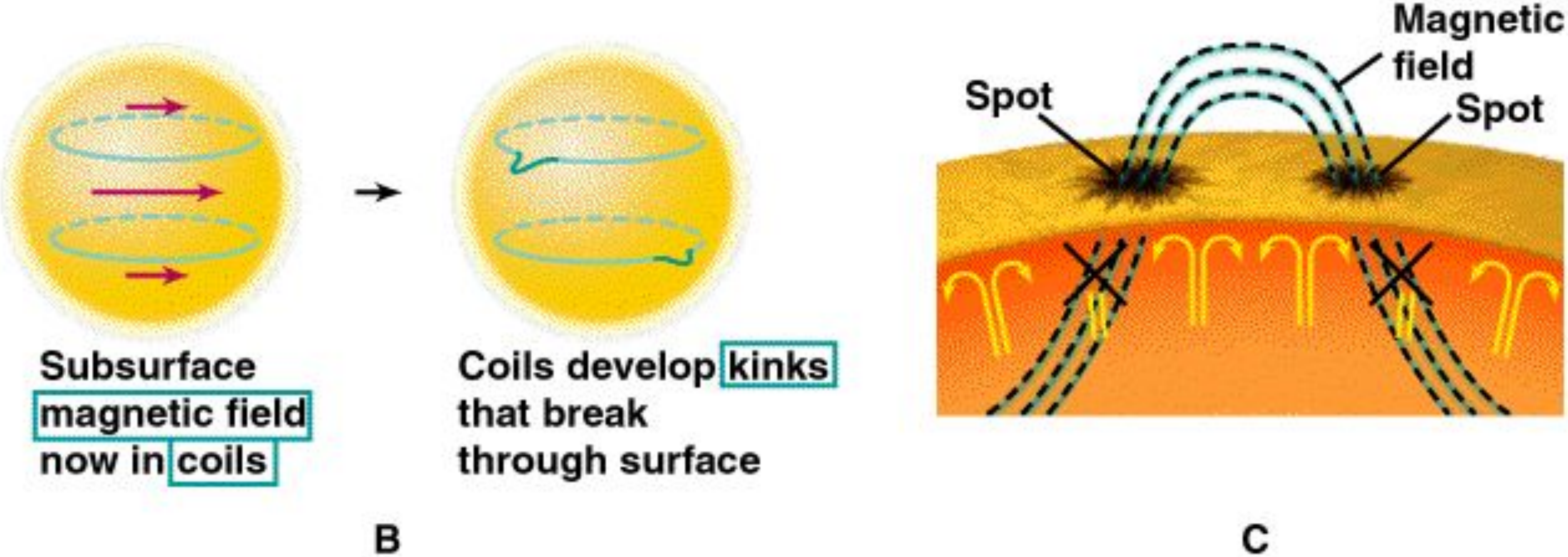
Solar Cycle

- The rotation rate varies from once every 25 days (equator) to once every 35 days (poles).
- This <u>differential rotation</u> twists the magnetic field lines.
- This causes the number of sunspots to vary over time.
  - *You will determine this time period in today's activity.*

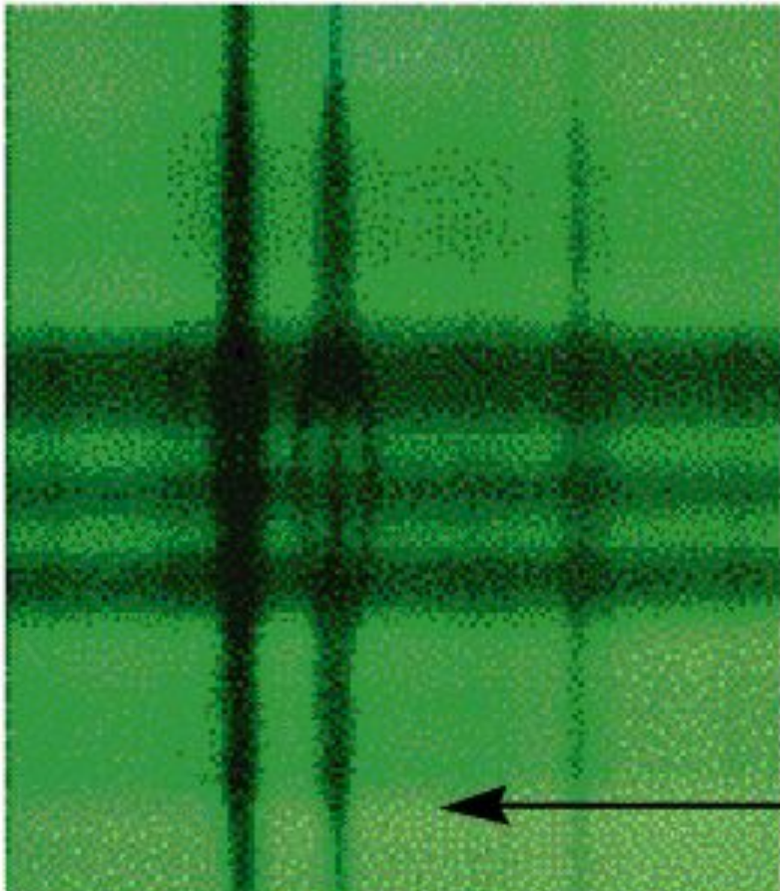
Winding of Sun’s Magnetic Field



Winding of Sun’s magnetic field



Zeeman Effect



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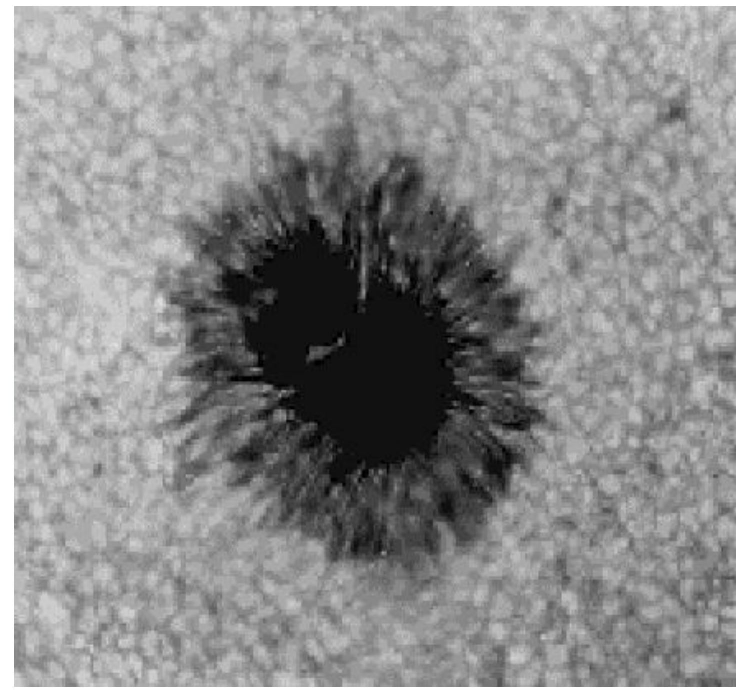
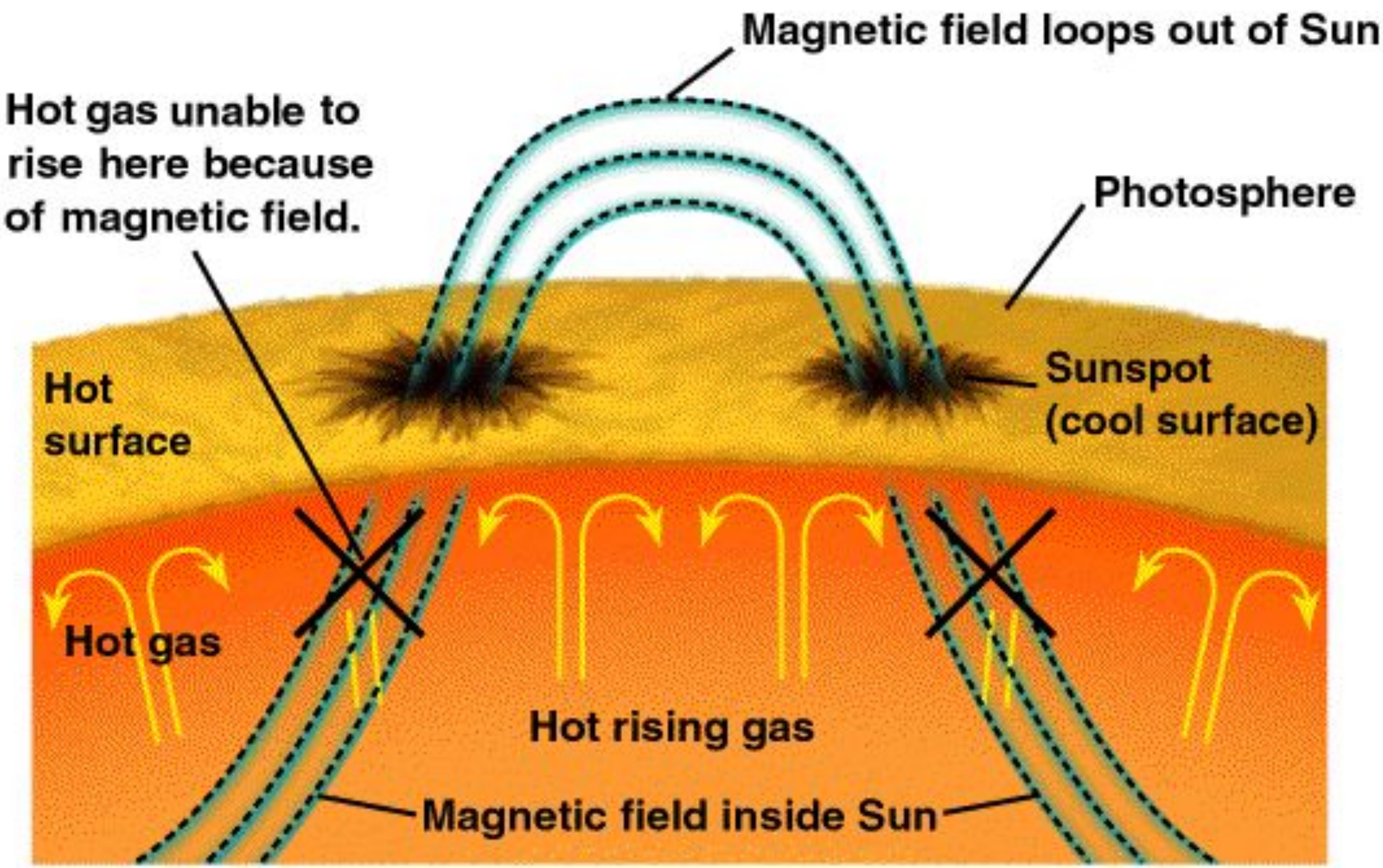
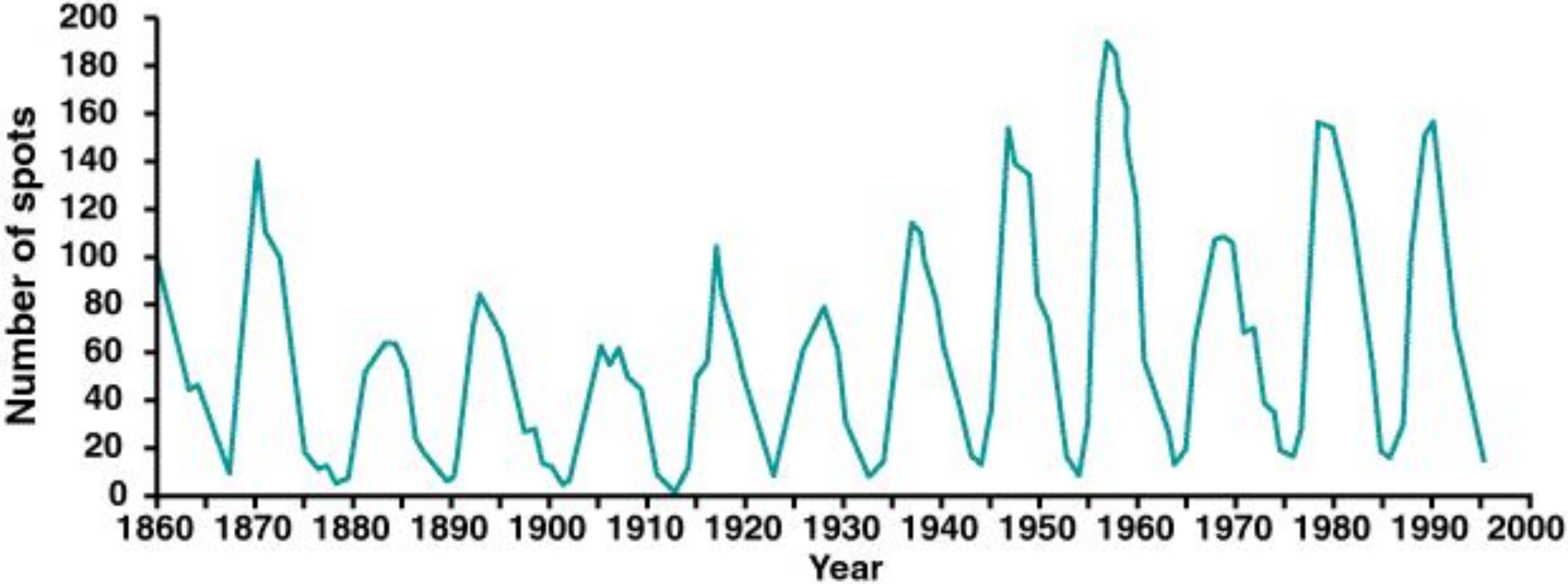


B

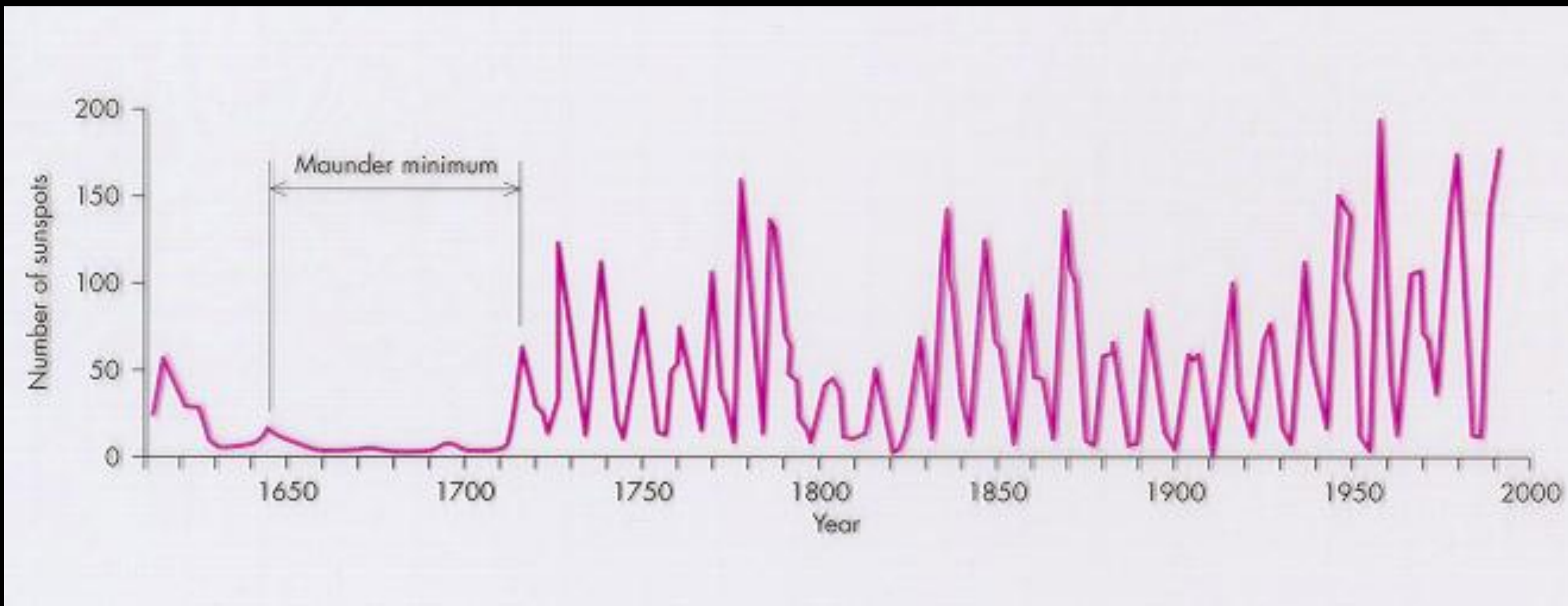
Why Sunspots are Dark



Sunspot Numbers



Maunder Minimum



"Little Ice Age" - From 1645-1715, severe winters in Europe and severe droughts in N. America.

We might be heading into one of these periods now!

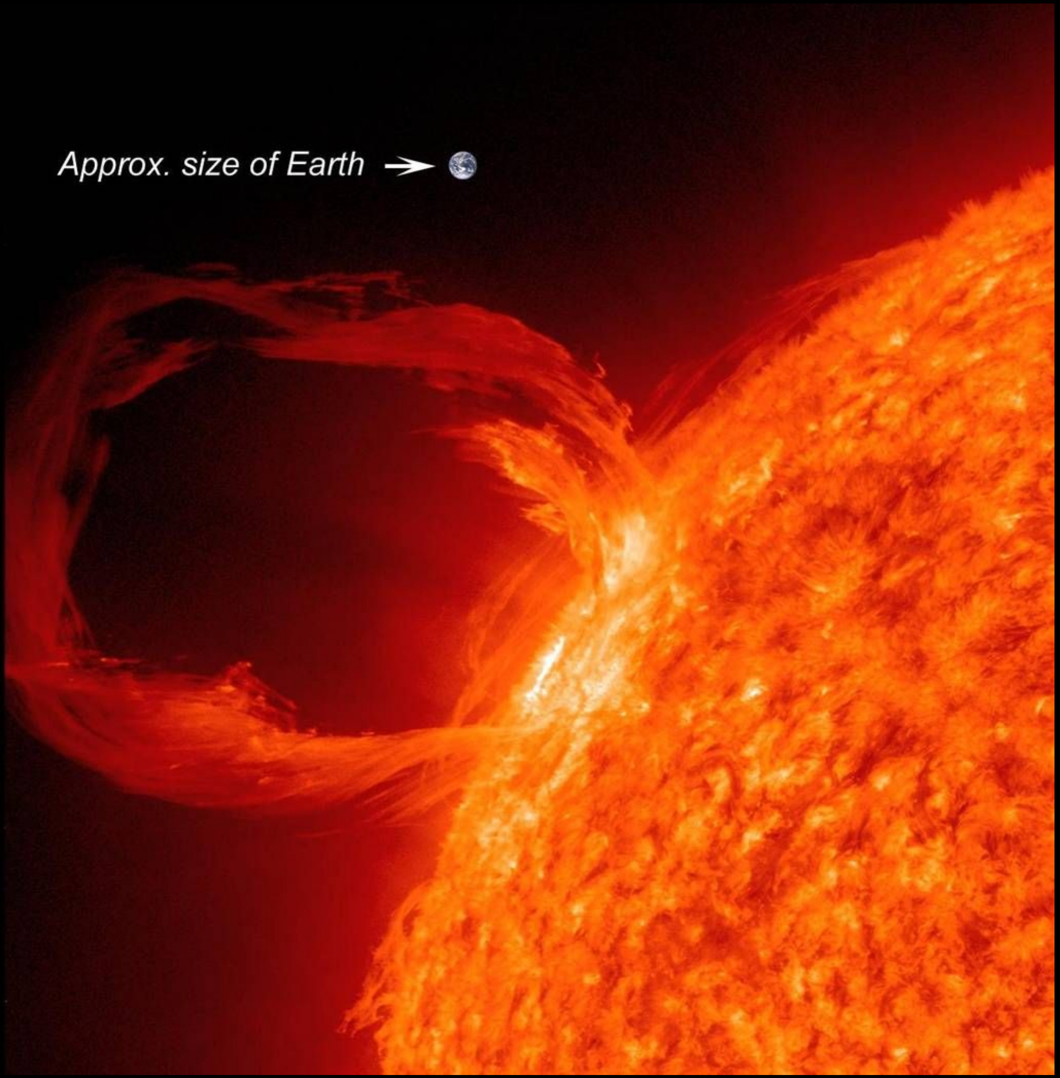
Typical Explosive Solar Phenomena

- <u>Flare </u>-eruptive event that sends out vast quantities of high energy particles, X-Rays, and UV radiation.

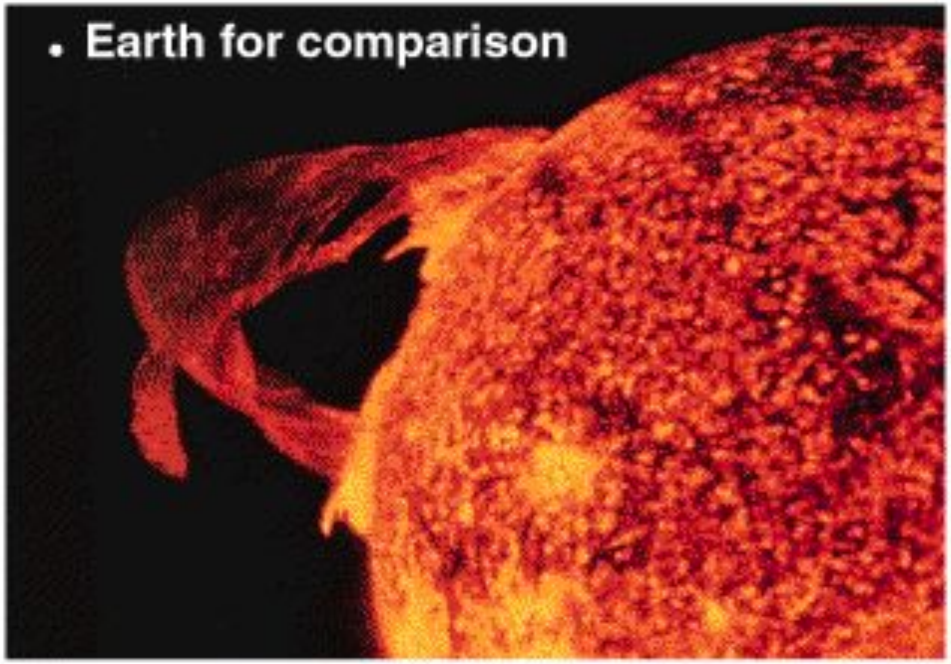
Typical Explosive Solar Phenomena

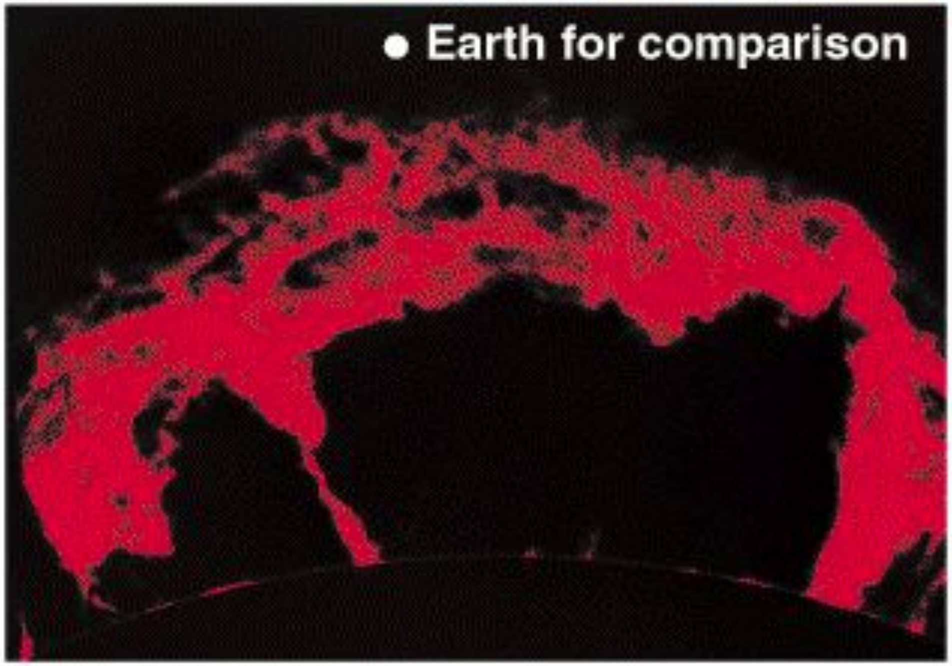
- Prominence - a flame-like protrusion seen near the limb of the Sun and extending into the solar corona.

- Associated with sunspots and follow magnetic field lines.



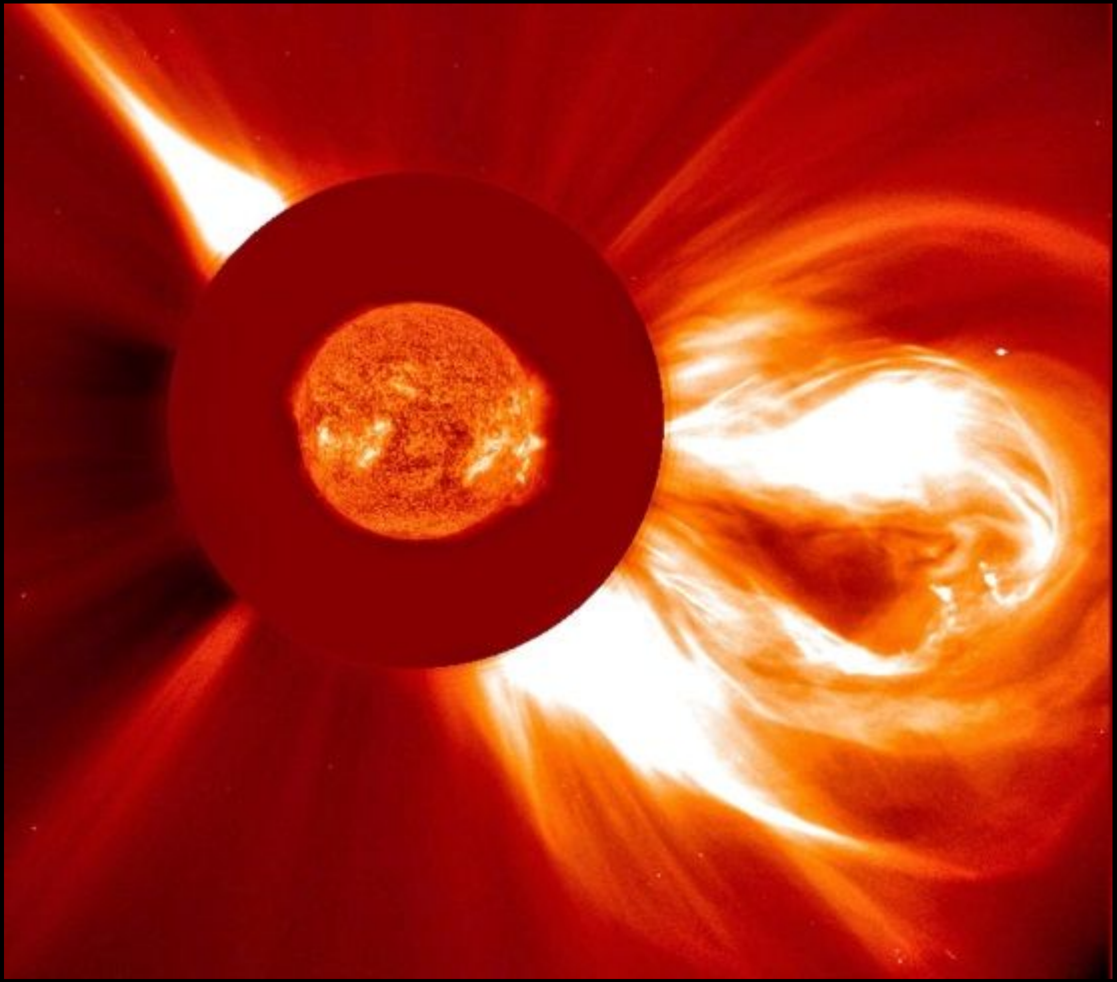
Solar Prominences





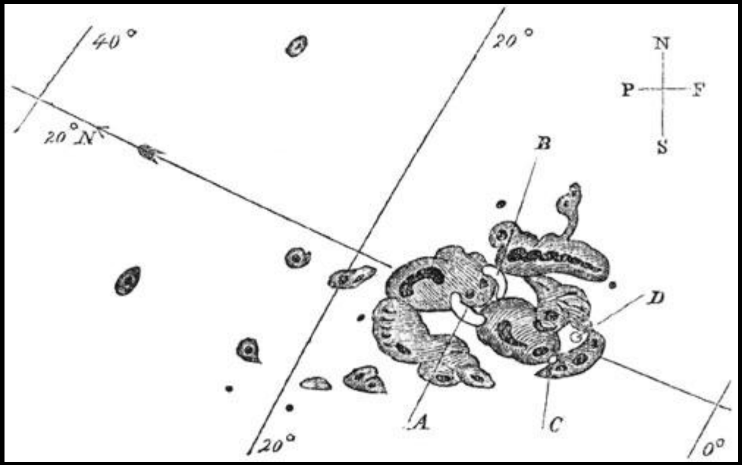
Typical Explosive Solar Phenomena

- Coronal Mass Ejections - explosions from the photosphere that expel approximately 2 trillion tons of matter at 400 km/s that last up to a few hours.
- Can temporarily alter the shape of the Sun's magnetic field.



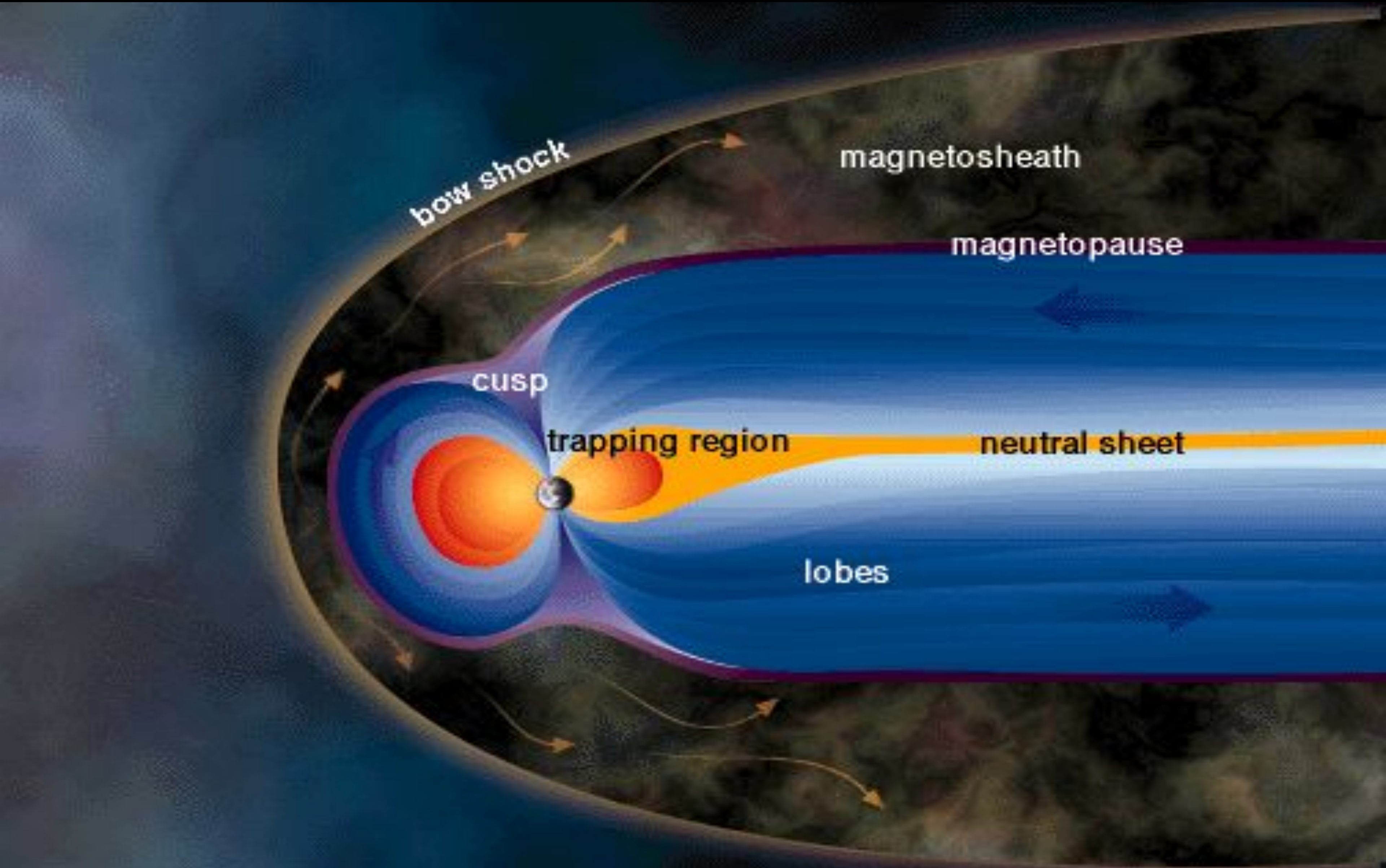
Perfect Solar Storms

- September 2, 1859
- Super storm!
    - Powerful CME direct hit on Earth.
    - Overloaded telegraph lines causing fires.
    - Auroras seen as far south as the Caribbean!

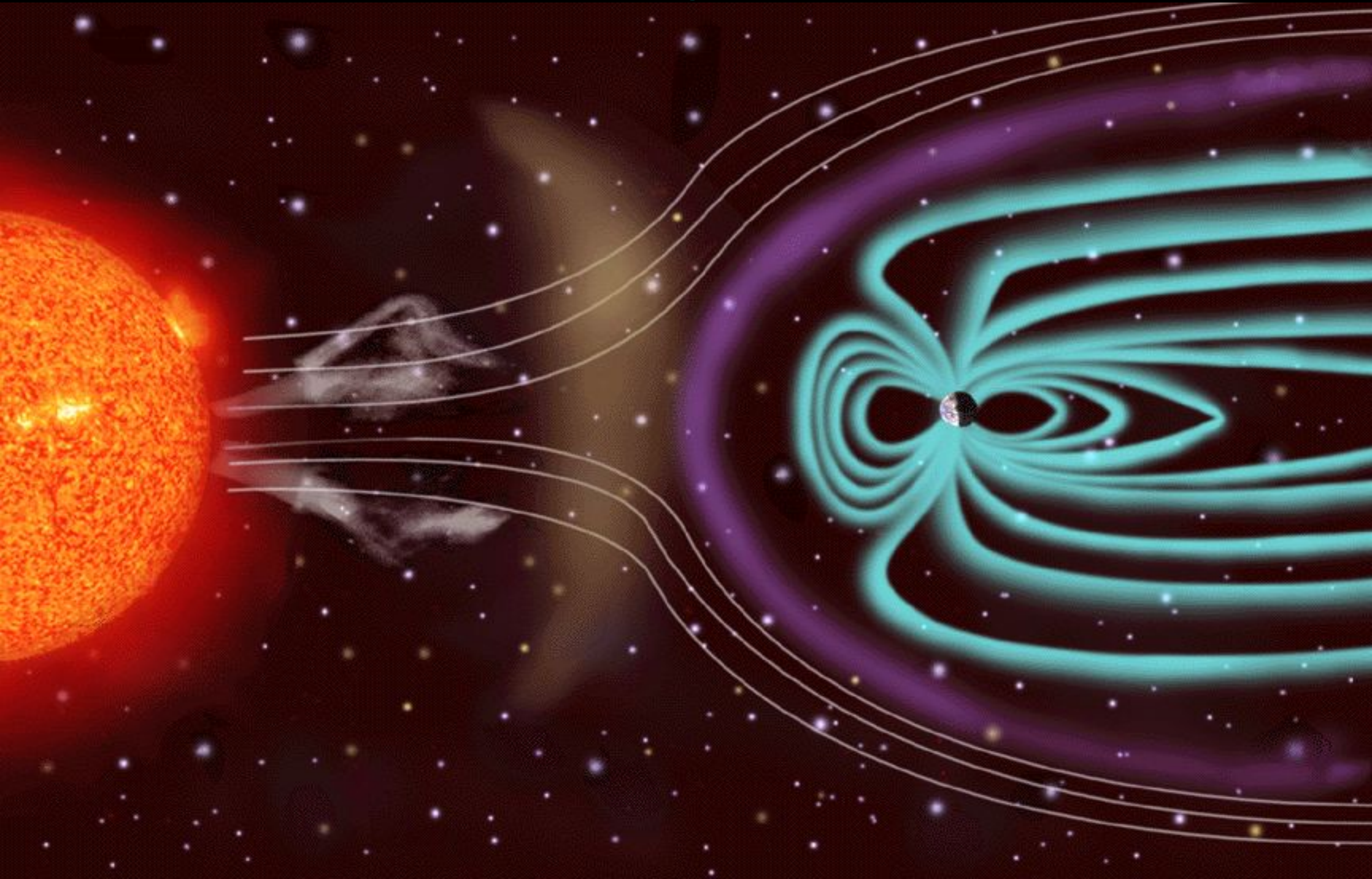


- March 9, 1998
    - CME hit Earth.
    - Knocked out power in Quebec due to increased ground electrical currents.
    - Satellites in polar orbit lost control for many hours.

Earth's Magnetic Field

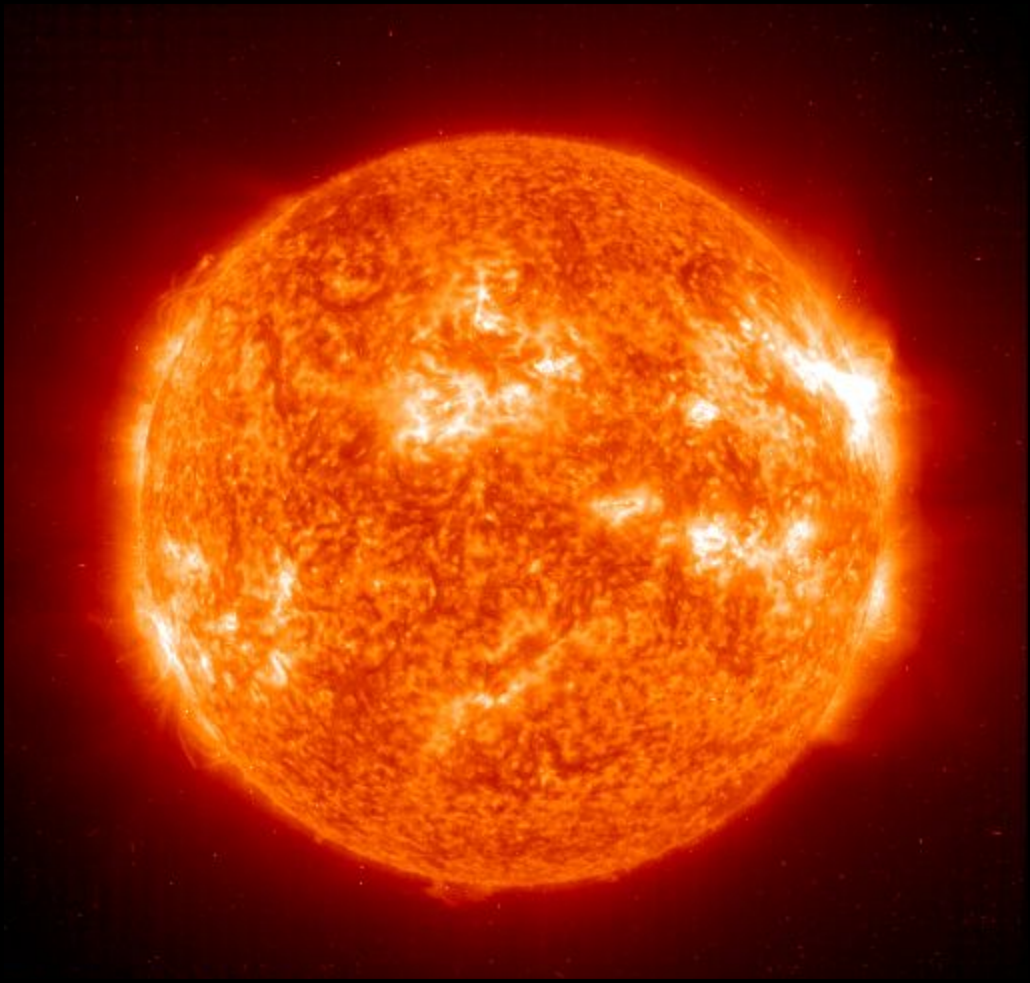


Earth’s Magnetic Field

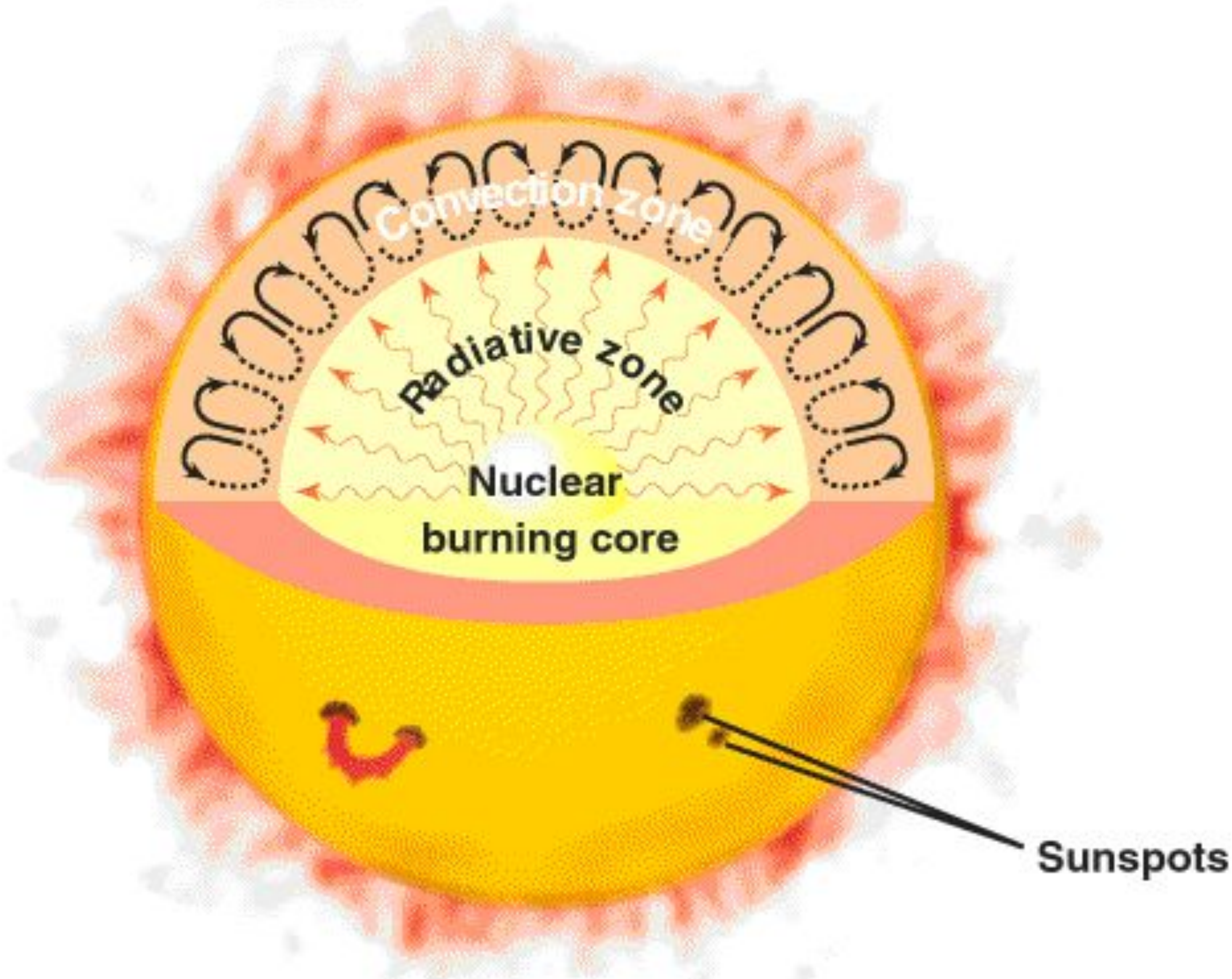


- <u>Auroras</u> are caused by the solar wind.

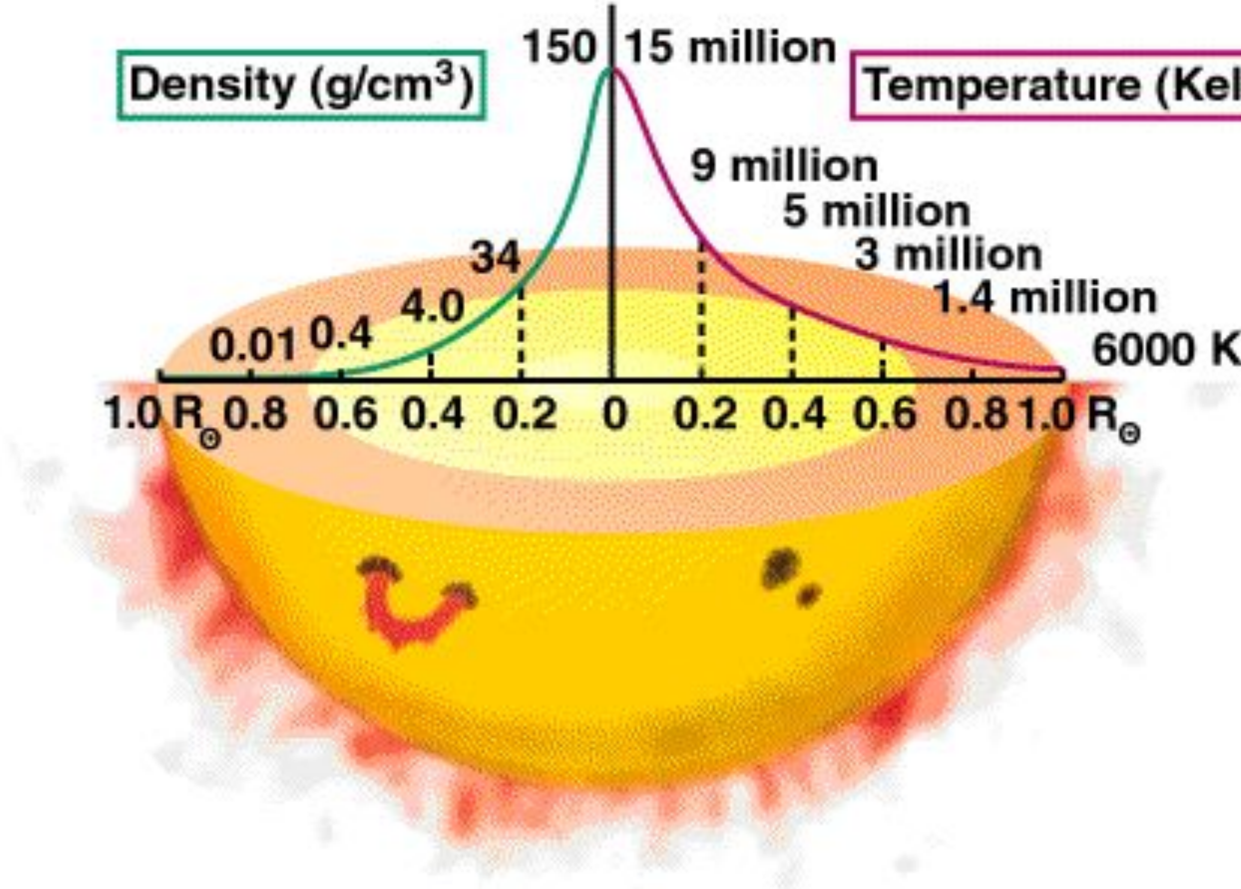
X-ray emission



Energy Flow in the Sun

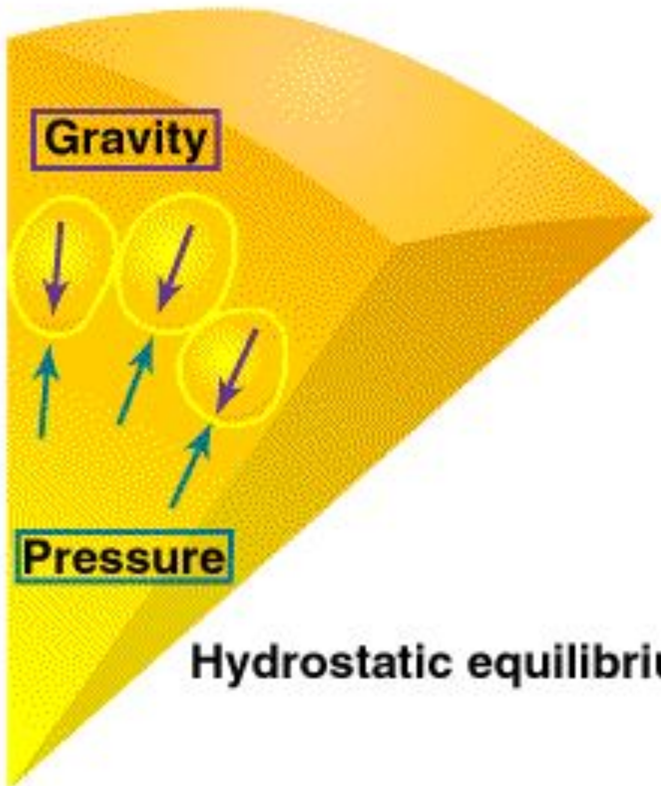


How Temperature and Density Vary Inside the Sun



Hydrostatic Equilibrium

The outward pressure force balances the inward gravitational force everywhere inside the Sun.



Hydrostatic equilibrium

What makes the Sun shine?

- Luminosity – the amount of energy emitted each second from a star.
- The Sun's luminosity is 3.9 x 10^{26} Watts (joules per second) or 1 solar luminosity.
- The symbol for the Sun's luminosity is ….

$$L_{\odot}$$

What makes the Sun shine?

- Thermonuclear fusion at the Sun's core is the source of the Sun's energy.

$$4\ \text{Hydrogen Atoms} \xrightarrow{\text{fusion}} 1\ \text{Helium Atom}$$

$$+\ 2\ \text{Positrons}$$

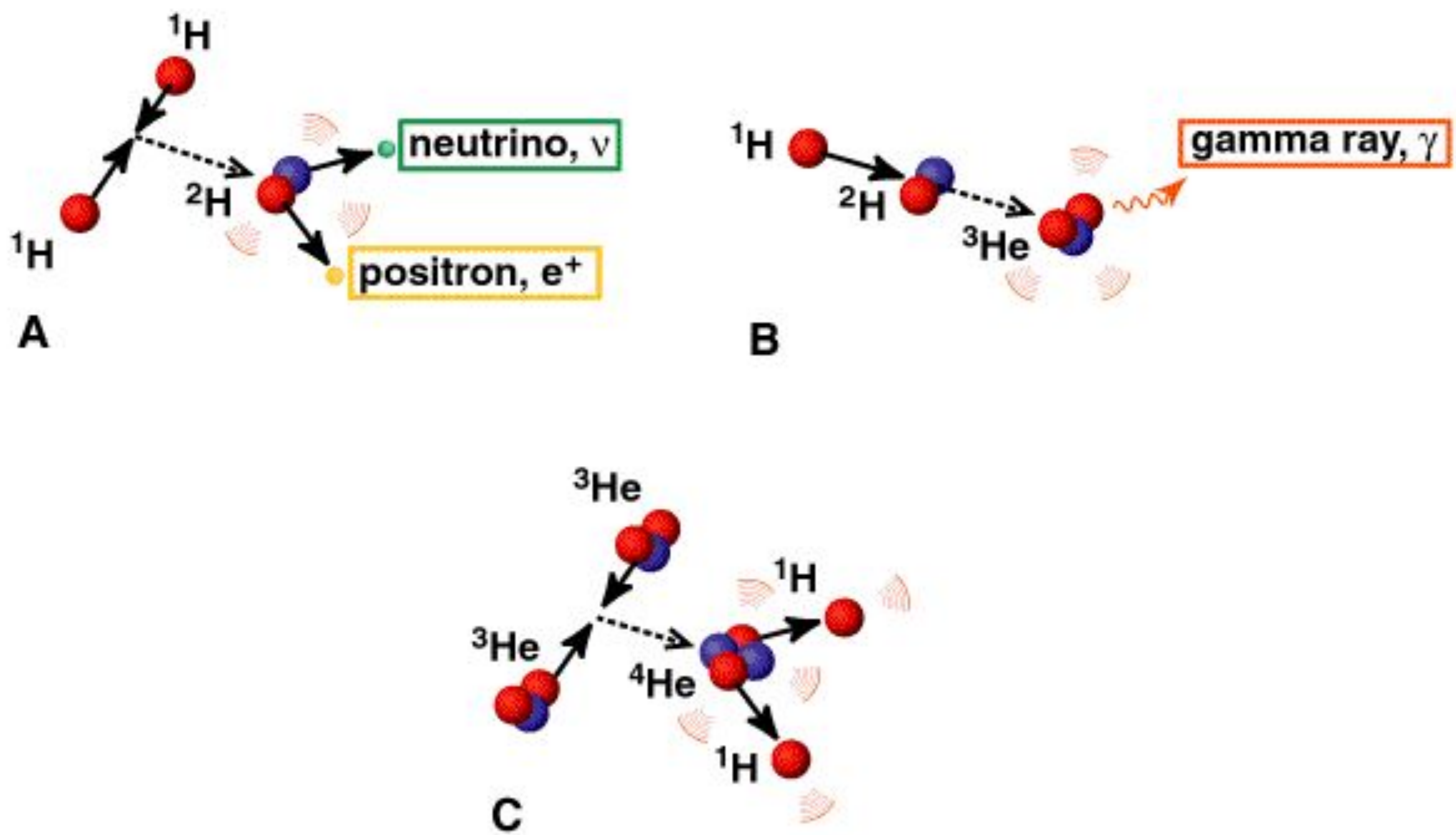
$$+\ 2\ \text{Neutrinos}$$

$$+\ \text{Light}$$

Fundamental Forces

- Gravity
  - Holds the large scale Universe together.
- Electromagnetic
  - Force involved with all forms of electricity and magnetism.
  - Holds atoms together – attractive force between electrons and protons in atomic nucleus
  - Responsible for all chemical reactions
- Weak Nuclear
  - Governs radioactive decay
- Strong Nuclear
  - Holds the nucleus (proton to proton) of the atom together
  - This force is involved in thermonuclear fusion.

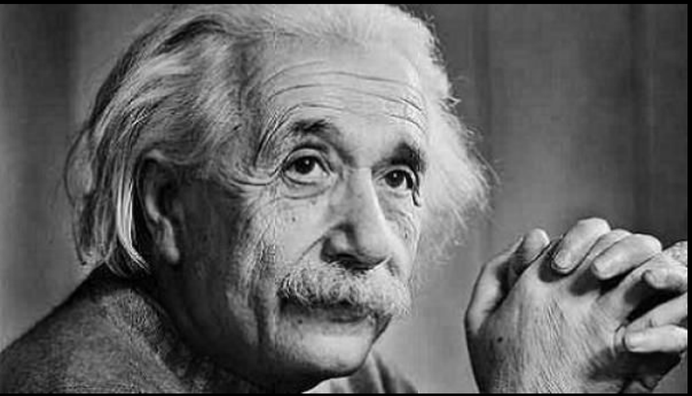
Proton–Proton Chain



Hydrogen Fusion

- Net result
  - 4H --> He + e^+ + ν + energy

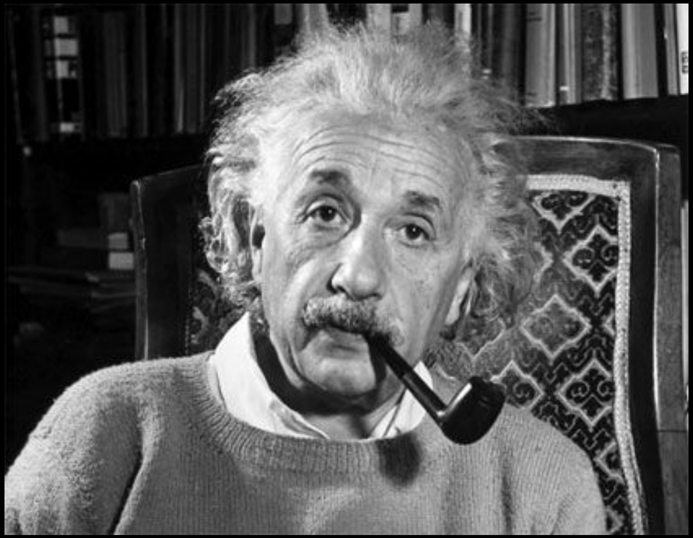
$$
\begin{aligned}
4 \times 1 \text{ hydrogen} &= 6.693 \times 10^{-27} \text{ kg} \\
- \; 1 \text{ helium} &= 6.645 \times 10^{-27} \text{ kg} \\
\hline
\text{Mass lost} &= 0.048 \times 10^{-27} \text{ kg}
\end{aligned}
$$



$$E = mc^2$$

Energy – Mass Equivalence

$$E = mc^2$$



- This equation tells us that a small amount of matter can be converted to a huge amount of energy.
- The only process in nature that can do this is the process of nuclear fusion.

Energy-Mass Equivalence Example

- How much energy could you produce if you could convert 1 kilogram (2.2 pounds) of matter 100% into energy?

$$E = mc^2 = (1kg)(3\times 10^8 \frac{m}{s})^2$$

$$= 9\times 10^{16} J$$

How much energy is this really?

- You are billed monthly based upon how many kilowatt-hours you use in electrical energy.
- 1kWh = 3,600,000 Joules
- Therefore, 1 kg of matter can produce…

$$9 \times 10^{16} J = 1.67 \times 10^{10} kWh$$

How much energy is this really?

- The average American household uses 1200 kWh per month.
- This means that if you could convert 1 kilogram (2.2 lbs) 100% into energy you would produce enough electrical power to run your home for **1.15 million years.**
- This would only be possible through the process of nuclear fusion.

The Neutrino Problem

Standard solar model is the generally accepted theory of solar energy production.

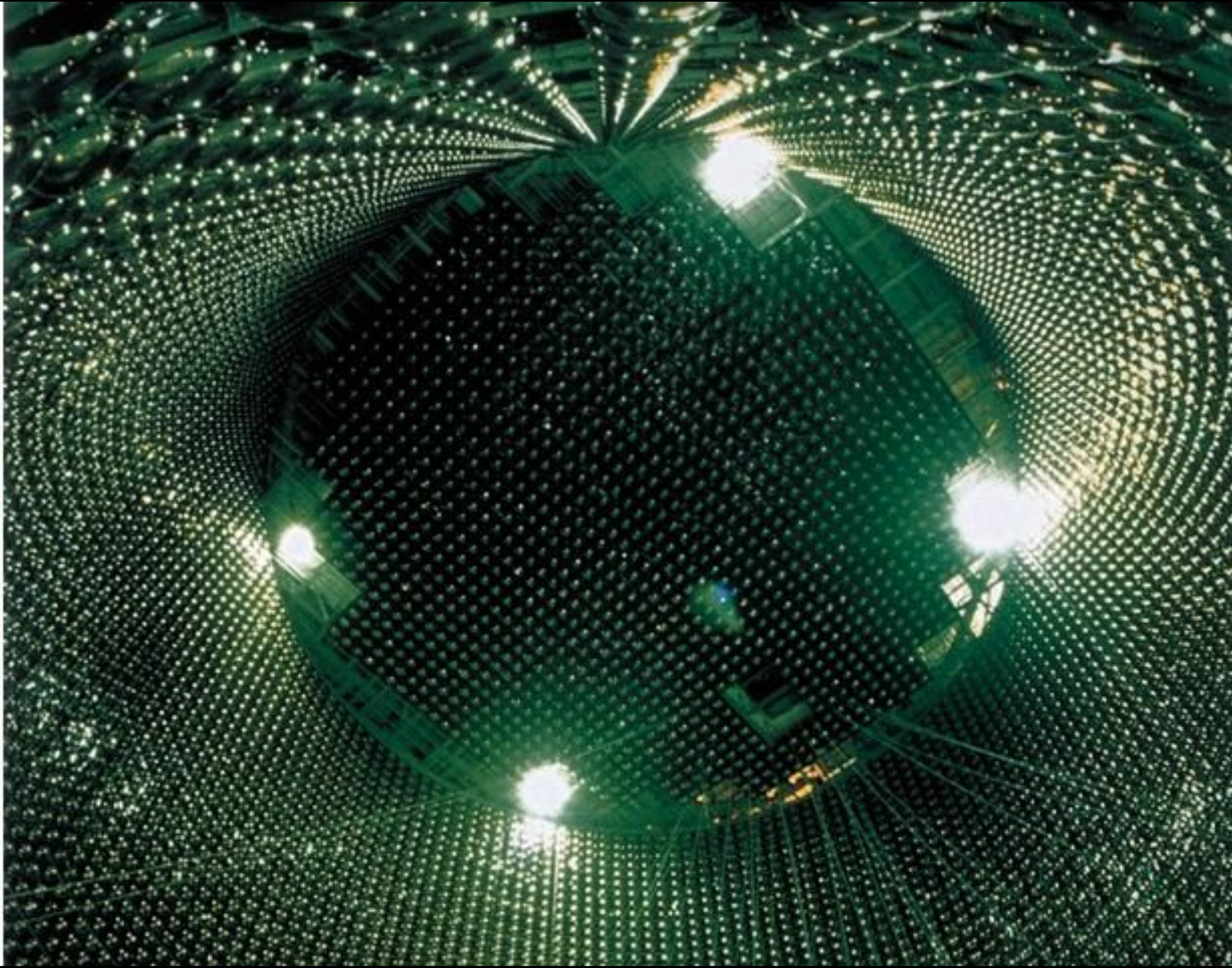
- The model predicts that billions of neutrinos (electron neutrinos) per second flow from the Sun.
- Neutrinos react very little with ordinary matter so detecting them is difficult.

- Neutrino ‘telescopes’ were constructed to find these elusive neutrinos.

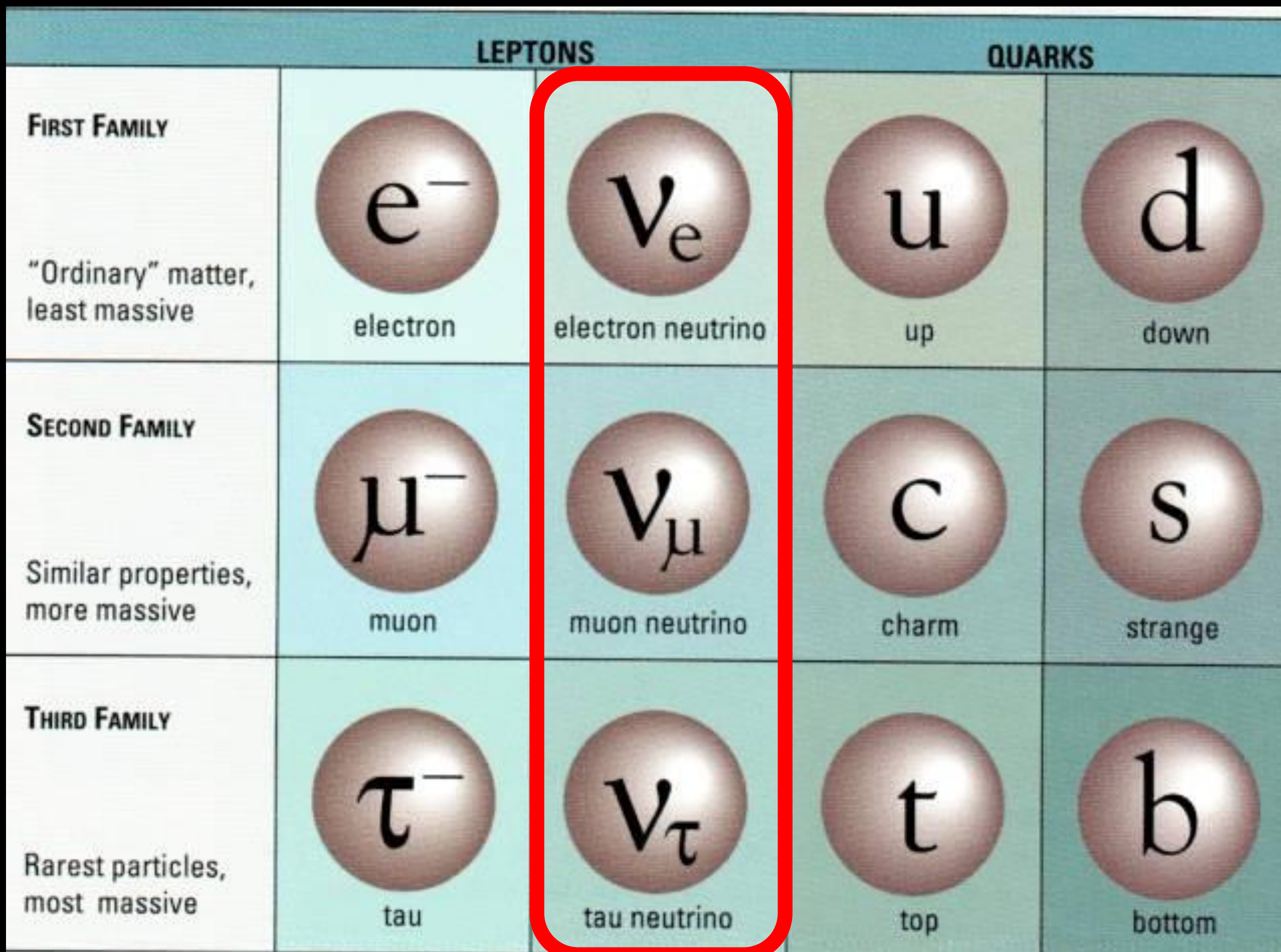
NEUTRINO TELESCOPE

- Detect the passage of neutrinos through the Earth, by observing reactions to an indicating fluid (heavy water, carbon tetrachloride).

- Sudbury Neutrino Telescope 1.4 miles underground in an old nickel mine in Sudbury, Ontario.



Types of Neutrinos



The Neutrino Problem – SOLVED!

- Before 2001, neutrino telescopes only detected 1/3 of the electron neutrinos predicted by theory.

  - In 2001, Sudbury Neutrino Telescope discovered that solar neutrinos can change “flavor” on their journey from the Sun (neutrino oscillation).

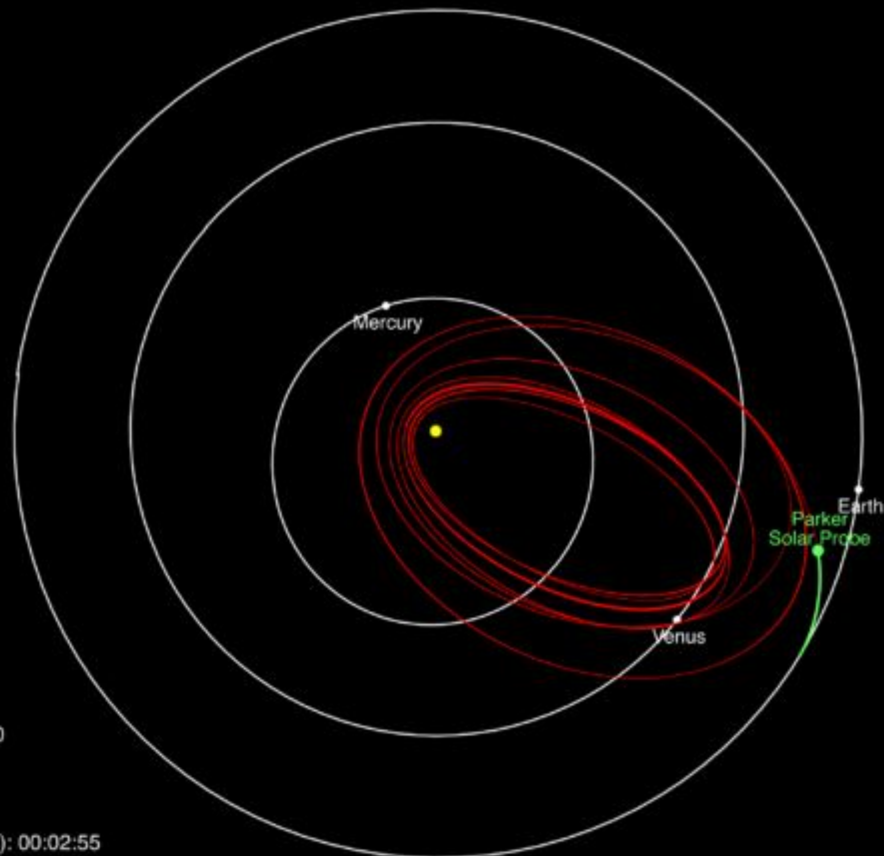
  - The other types of neutrinos are tau and muon neutrinos.

  - Astronomers are now able to account for the neutrinos that the Sun produces as predicted by theory (SNO 2004).

Robotic Explorers of the Sun

- Ulysses
  - October 1990 – today
  - Now in a polar orbit around the sun.
  - Mapping Sun’s magnetic field, solar particles, and interplanetary dust.
- SOHO
  - Solar and Heliospheric Observatory
  - December 1995 – today
  - Collects real time solar day for space weather predictions.
- Stereo Mission
  - Solar Terrestrial Relations Observatory
  - October 2006 - today
  - Twin spacecrafts
- Parker Solar Probe
  - Launch August 2018
  - Goal = 4 million mile *“close approach”* of photosphere
  - Mission to study the solar wind in best detail yet

Parker Solar Probe Mission Trajectory and Current Position



Heliocentric Velocity (km/s): 20.50
Distance from Sun (AU): 0.947
Distance from Sun (R_S): 203.5
Distance from Earth (AU): 0.175
Round-Trip Light Time (hh:mm:ss): 00:02:55
6 Sep 2018 15:00:00 UTC

PHYS 1403 LAB - THE SUN LAB

Name ______________________________ **Class Enrolled (circle one): Day Night**

PART ONE (optional): SOLAR OBSERVATIONS (ON CAMPUS)

Your instructor will demonstrate how to use a telescope to safely observe the Sun. Make a sketch of what you see (*in the circle*) and record your observation in the space below:

Description: ______________________________

____

____

____

____

____

PART TWO: SUNSPOT NUMBER AND THE SOLAR CYCLE

On the back, you will find a table containing data on the average number of sunspots as recorded every year for a period of just over 100 years.

1. From the table, what single year showed the greatest average number of sunspots? What was that sunspot number?

   ____

2. What single year showed the least relative number of sunspots? What was that number?

   ____

3. From the table, you should notice that the numbers of sunspots seem to periodically increase and decrease. What were the peak years for the average number of sunspots in your table?

   ____

   ____

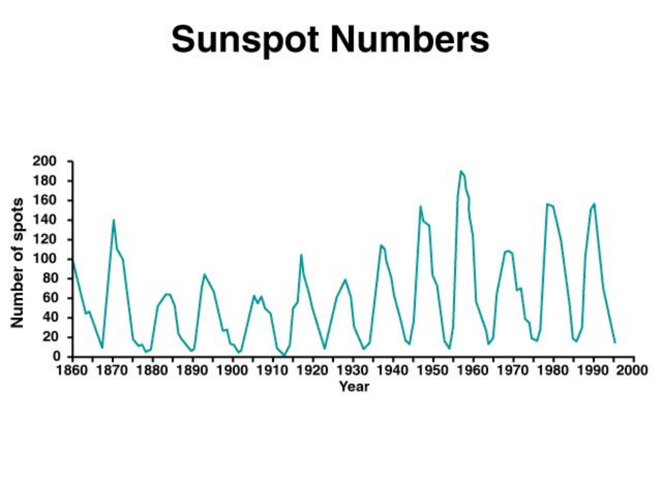
   ____

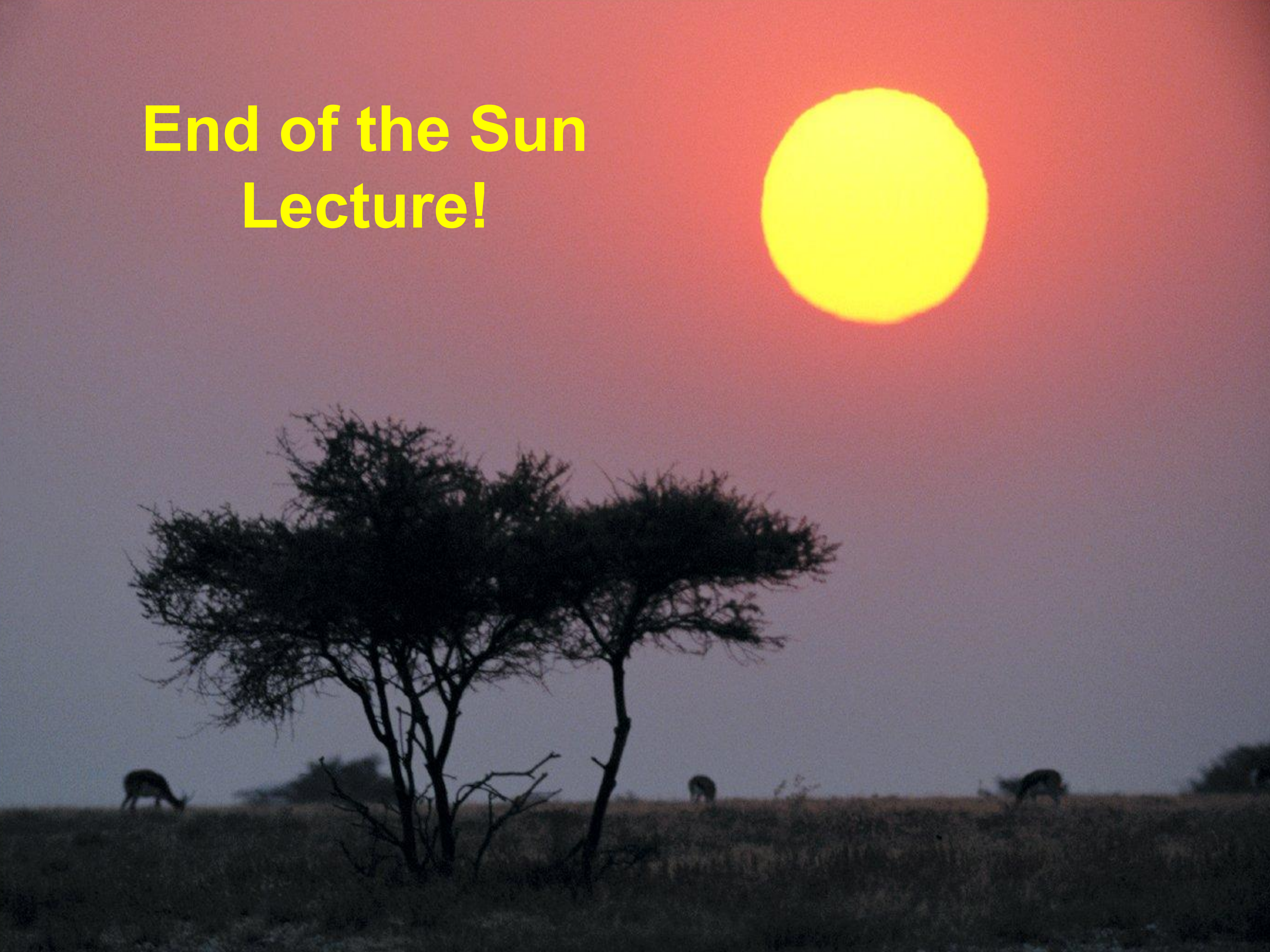
4. What is the average number of years between these peaks? This is known as the sunspot cycle.

11 years

9 years

YEAR	AVG. SUNSPOTS
1912	6
1913	2.4
1914	16.1
1915	79
1916	95
1917	173.6
1918	134.6
1919	105.7
1920	62.7
1921	43.5
1922	23.7
1923	9.7
1924	27.9
1925	74
1926	106.5
1927	114.7
1928	129.7
1929	108.2
1930	59.4
1931	35.1
1932	18.6
1933	9.2
1934	14.6
1935	60.2
1936	132.8
1937	190.6
1938	182.6
1939	148
1940	113
1941	79.2
1942	50.8
1943	27.1
1944	16.1




End of the Sun
Lecture!