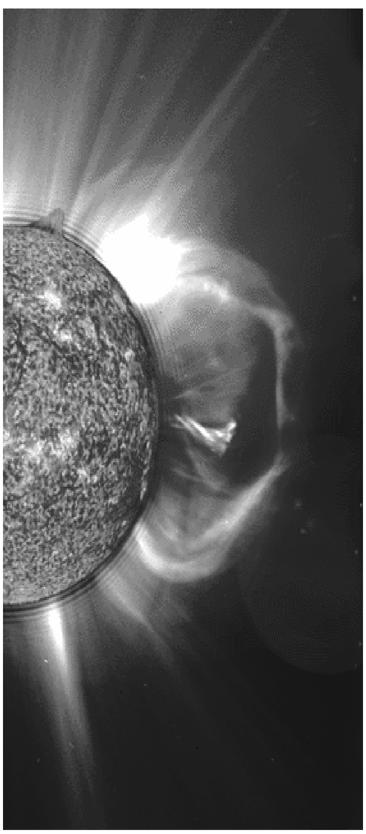
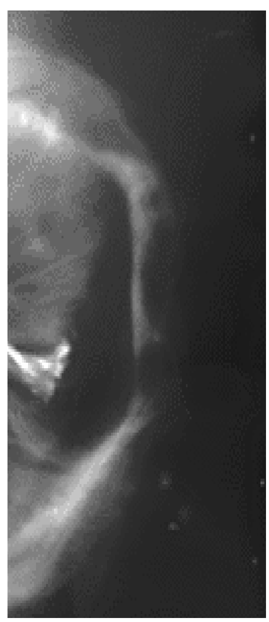
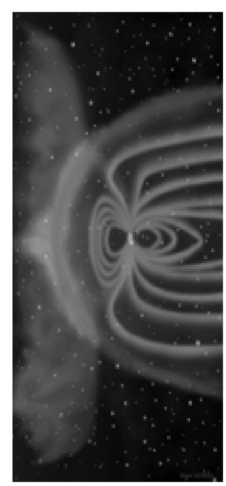
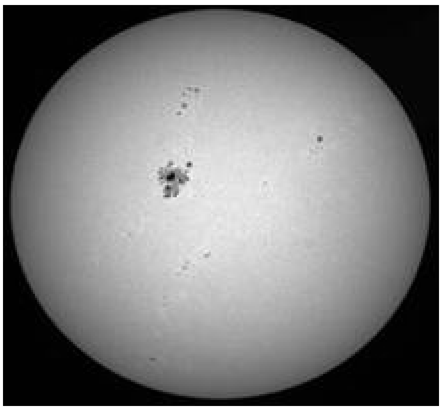
Space Weather:
Solar Storms to Auroral Substorms

What is the Sun?

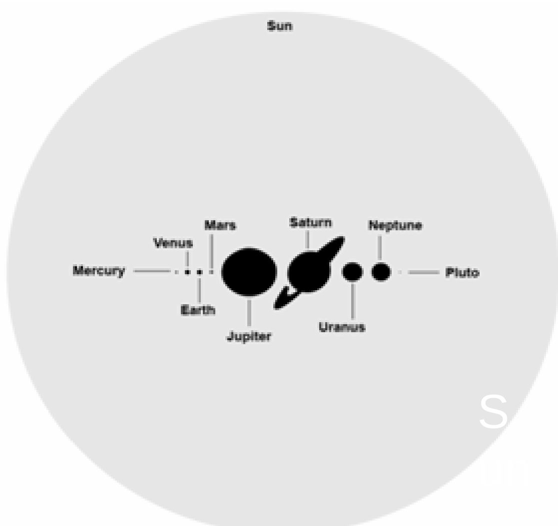


The Sun is a Star, but seen close-up.

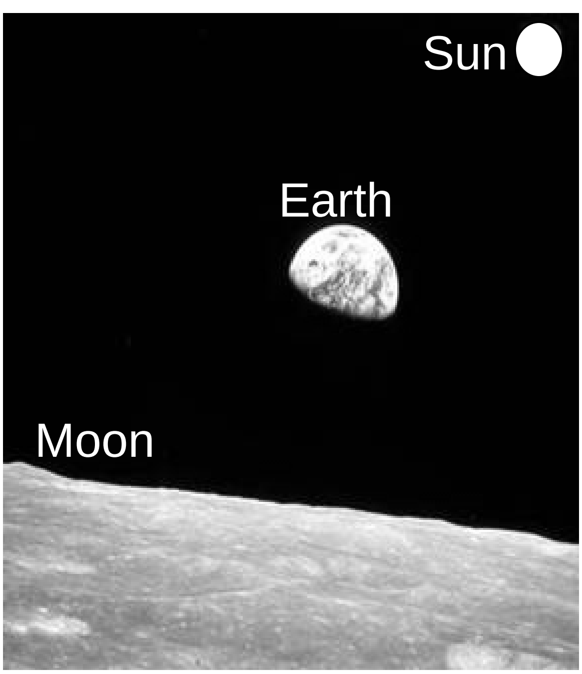
The Sun is giant ball of very hot, mostly ionized gas that shines under its own power.

Radius	696,000 km (109 times Earth's radius)
Rotation Rate	27 days (equator) to 31 days (poles)
Luminosity (Power Output)	3.8×10^{26} watts (10 trillion times the power consumption of all Earth's nations combined)
Surface Temperature	5,800 K (average)
Mass	2×10^{30} kg (300,000 times Earth's mass)
Composition	70% Hydrogen, 28% Helium, 2% heavier elements (by percentage of mass)
Age	5 billion years (expected to live another 5 billion)

Size and Distance of the Sun

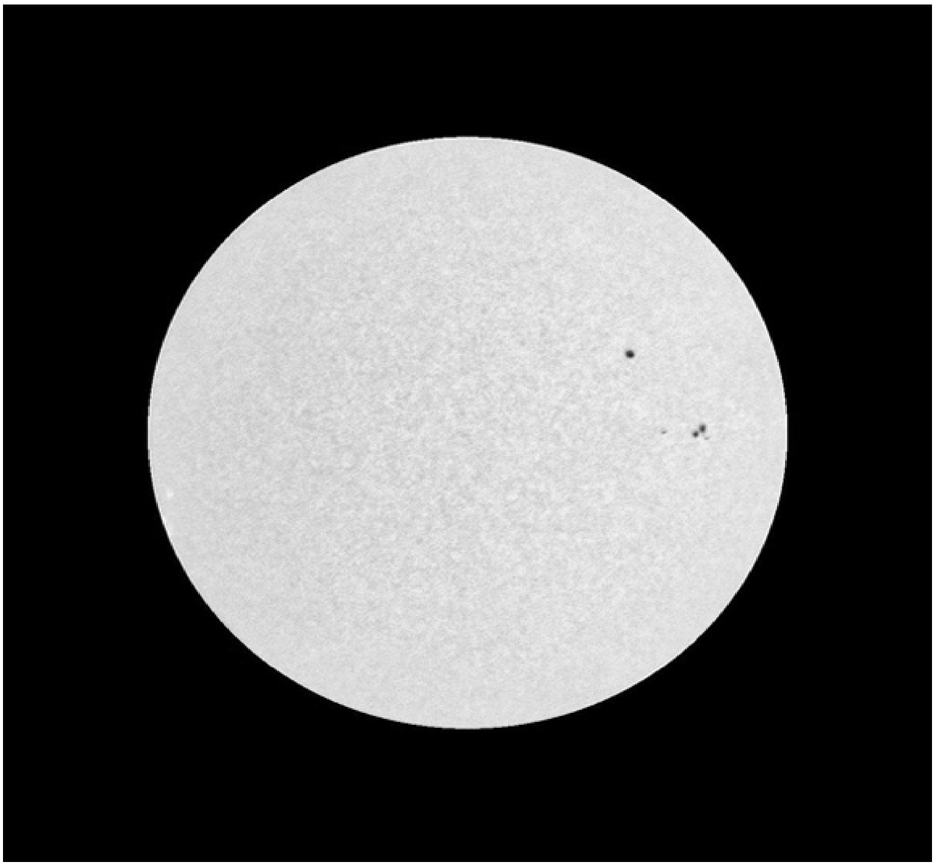


• The Sun is 109 times the diameter of Earth (10 times the diameter of Jupiter).
• Over 1,000,000 Earths could fit inside the Sun.



• The Sun is 150 million kilometers away from Earth, 390 times farther away than the Moon.
• It takes light 8 minutes to travel to Earth from the Sun.
• This distance is defined as 1 Astronomical Unit (AU)

The Sun’s Layers

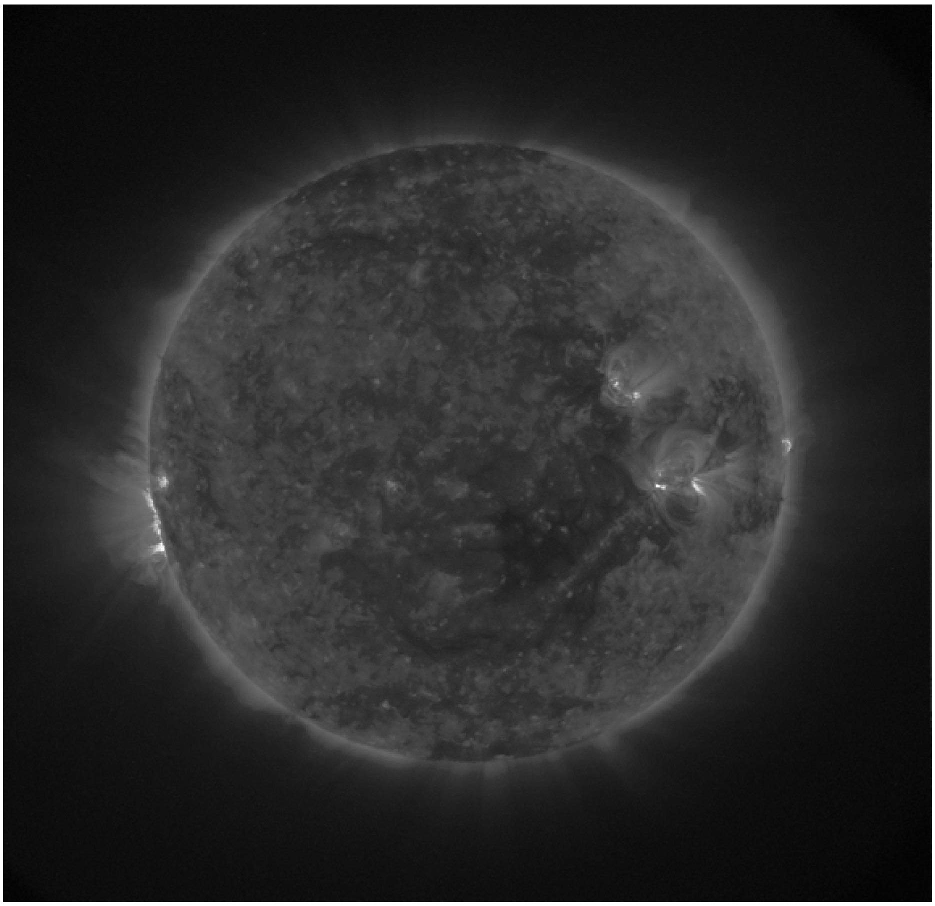


Looking at the Sun in different wavelengths of light reveals the different parts of the Sun.

Visible light (white light):
Wavelength = 400-700 nm

See radiation from Sun’s “surface,” or ***photosphere***

The Sun's Layers

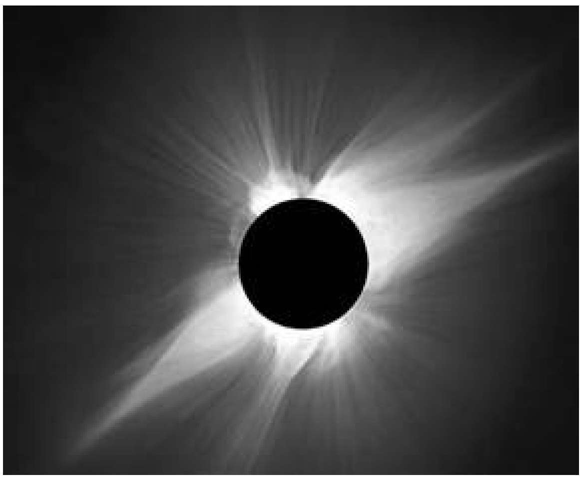


Looking at the Sun in different wavelengths of light reveals the different parts of the Sun.

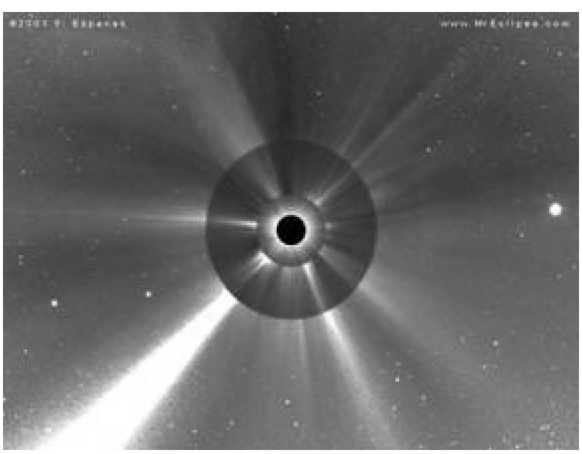
Extreme Ultraviolet (EUV) light:
Wavelength = 17.1 nm

See radiation from Sun's atmosphere, or ***corona***

The Sun’s Layers



During a total eclipse of the Sun, the very bright ***photosphere*** is blocked, and the Sun’s outer atmosphere becomes visible (in white light). We call it the ***corona.***

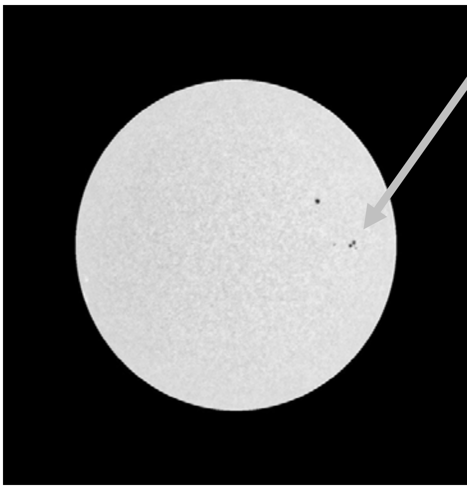


Spacecraft, like SOHO and STEREO, place a disk in front of their cameras to create an eclipse. Then they are able to take images with a larger view of the Sun’s corona.

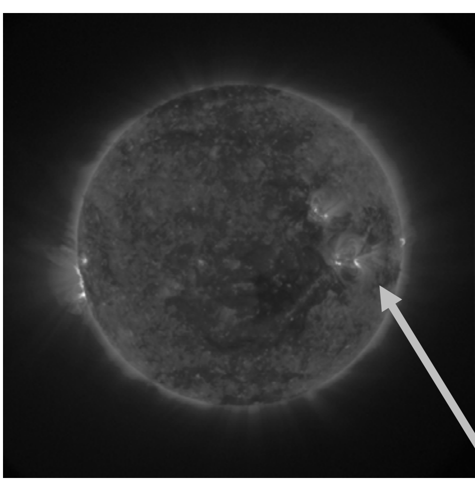
The Solar Wind

The solar wind is a stream of mostly charged particles that emanate from the Sun. It extends far out into and past the Solar System.

Sunspots

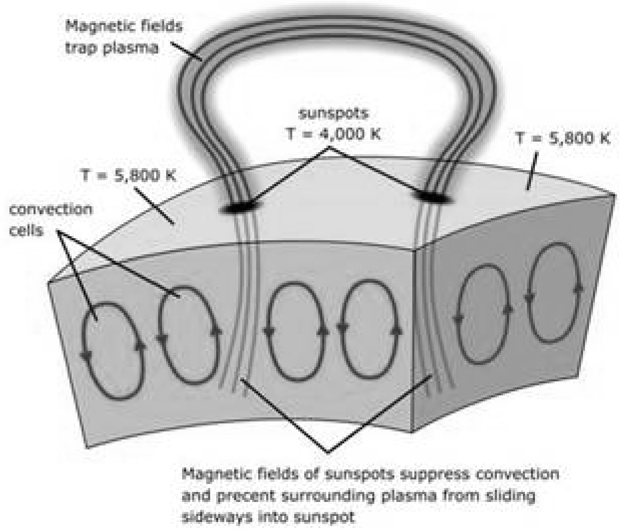


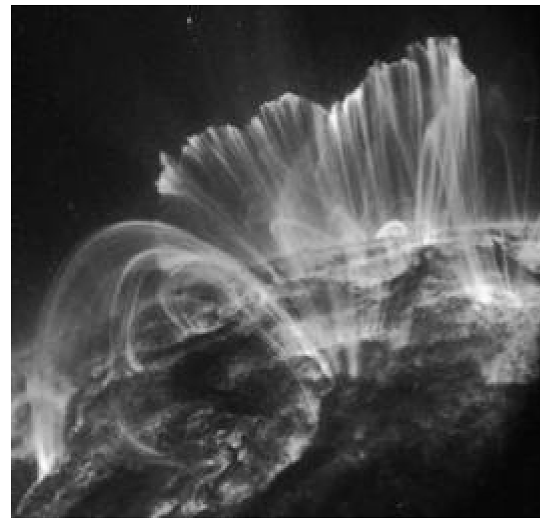
- ***Sunspots are dark splotches on the surface of the Sun (in the photosphere).***
- Sunspots are about 2,000 degrees Kelvin cooler than the average temperature on the photosphere.
- They appear to be dark only in comparison to their very bright surroundings.

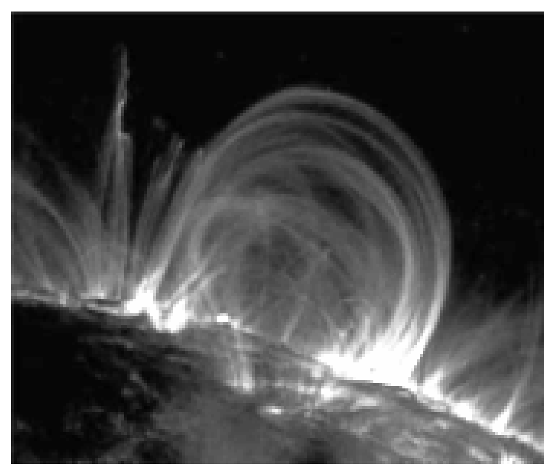


- The Italian astronomer Galileo was one of the first people to use Sunspots to track the Sun's rotation.
- Following long-lived sunspots through time allows one to determine the rotation rate of the Sun.
- ***The Sun spins faster at the equator than at the poles (once every 27 days versus every 31 days).***
- In the corona (above the photosphere) sunspots look brighter because they are hotter in the corona than the surrounding coronal gas.

The Magnetic Sun







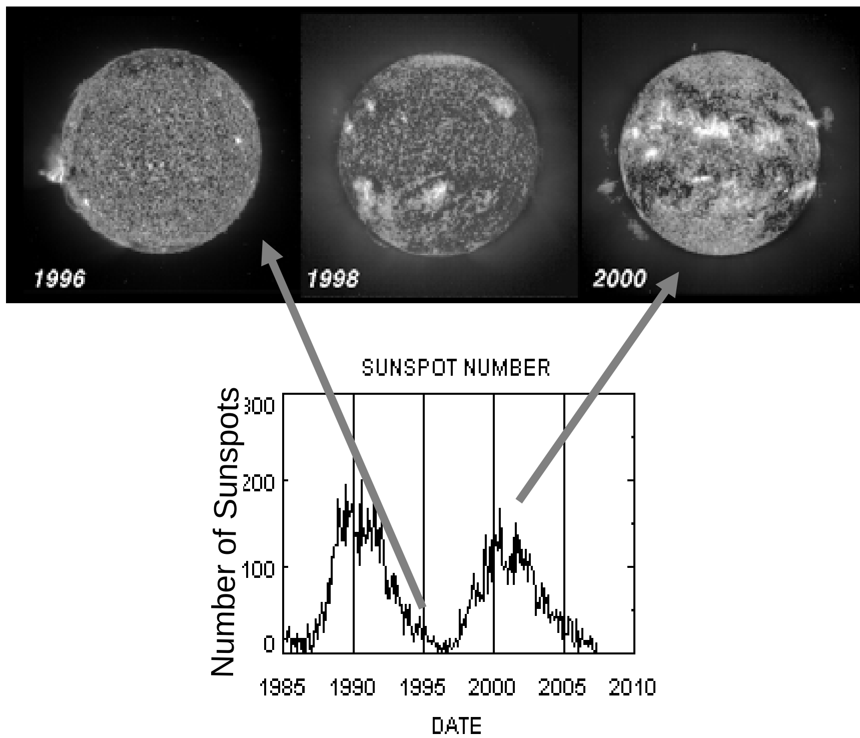
Images of the Sun in ultraviolet light reveal loops of hot ionized gas (plasma) trapped in magnetic fields above the locations of Sunspots in the corona.

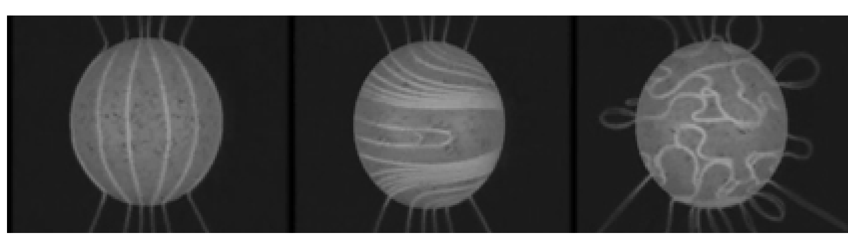
Sunspots (in the photosphere) are cooler because the magnetic fields do not allow plasma from the surrounding region to enter. The plasma pressure in the Sunspot drops and the temperature cools.

The Solar Cycle

The number of Sunspots
and solar flares increase and decrease on an 11-year cycle.

The Sun’s magnetic field becomes more and more twisted and complex from differential rotation. It finally breaks and flips every 11 years. So the total cycle is really 22 years from start to finish.



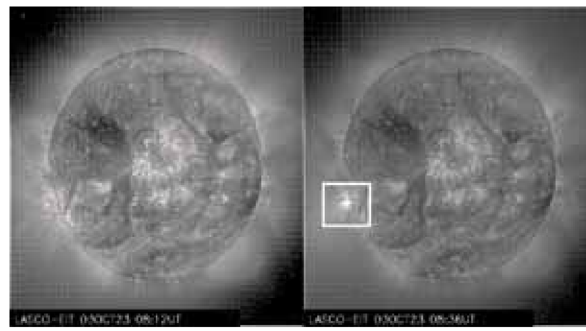


Movie (frames) courtesy of NASA/Goddard Space Flight Center Conceptual Image Lab.

Solar Storms

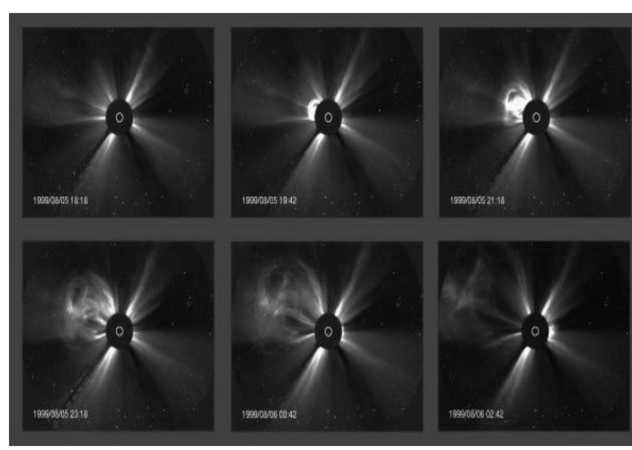
Solar flares are enormous explosions in the atmosphere of the Sun.

They release energy in the form of ***light, heat***, and the movement of large amounts of plasma near the Sun.



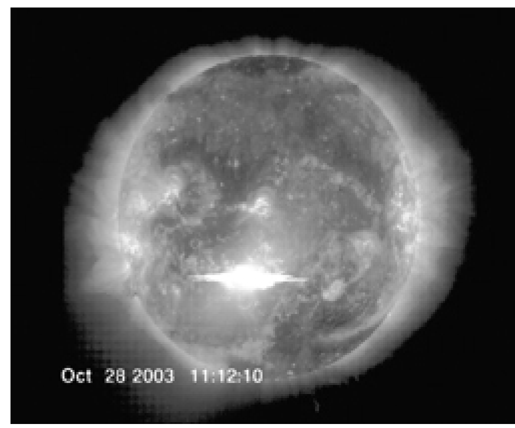
***Coronal Mass Ejections* (CMEs)** are literally ejections of mass from the Sun's corona.

They occur when large-scale magnetic fields "break" and release energy and ***enormous amounts of matter into space***.

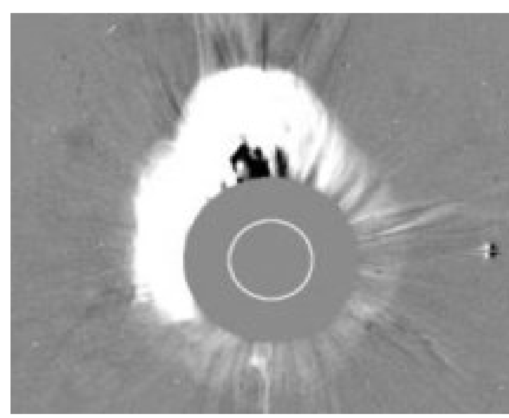


Solar Storms and Earth

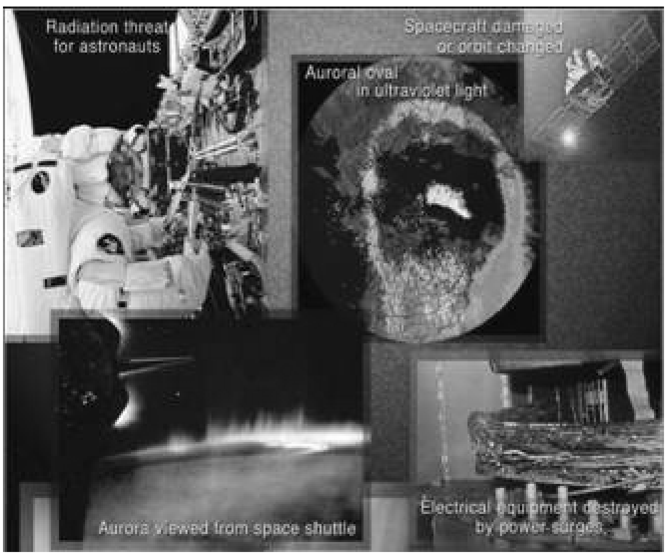
The (mostly x-ray) light from **solar flares** travels at the speed of light. It takes 8 minutes from the Sun to Earth when a flare is directed toward Earth.



The matter and magnetic fields from **Coronal Mass Ejections (CMEs)** travel faster than the solar wind, but slower than the speed of light. It takes anywhere from one to three days for a CME to reach Earth.

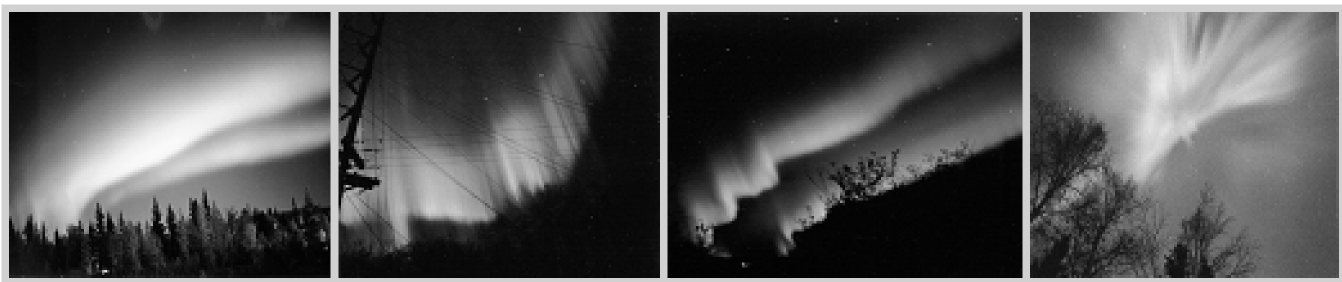


Space Weather Effects on Earth

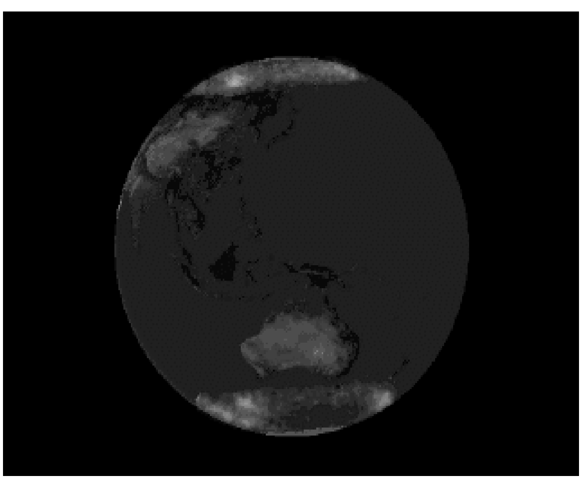


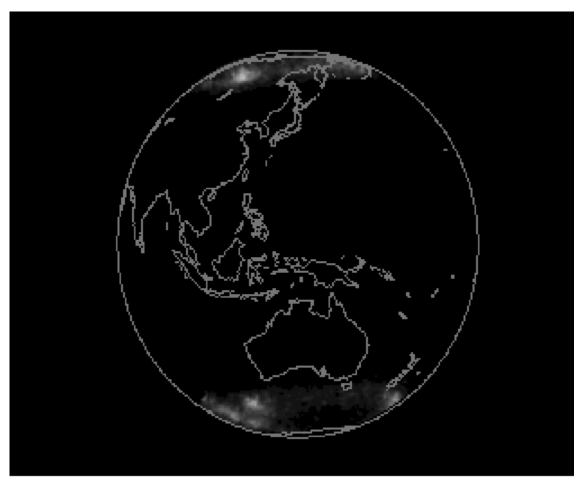
- **Energy from *solar flares* and *CMEs* can damage satellites and change orbits.**
- **Disrupt radio communications**
- **CME particles traveling near the speed of light threaten astronauts.**
- **CMEs can intensify *auroras* (Northern and Southern Lights)**
- **Electric currents from intense aurora can cause power surges and blackouts.**
- **Electric currents from intense aurora create interesting magnetic field variations detectable on Earth.**

Auroras: the Northern and Southern Lights



Auroras are lights in the upper atmosphere about 100 km - 300 km (60 miles- 180 miles) above Earth’s surface.

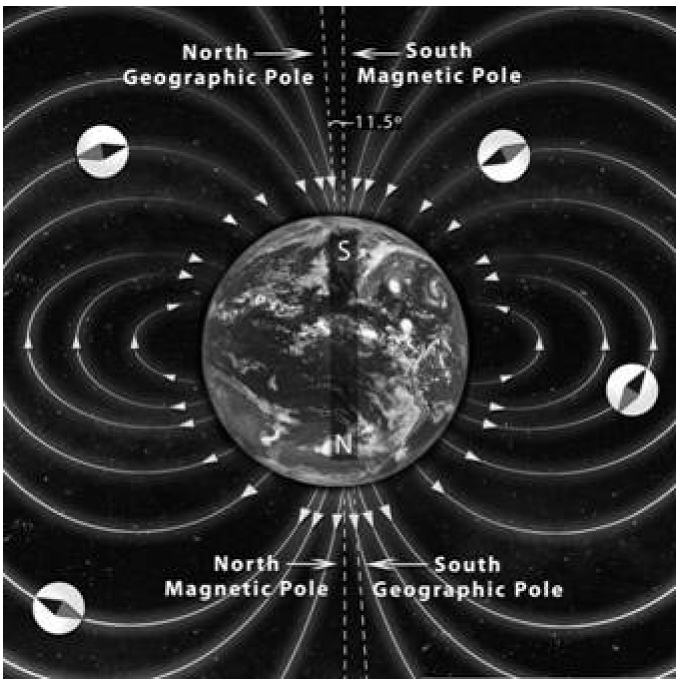


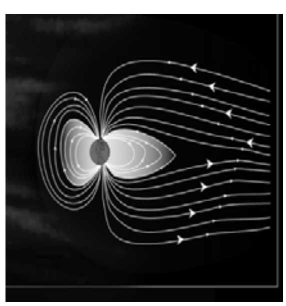


Misconception: Solar wind particles do not directly cause most aurorae, with exception of the rare “cusp aurora.” Actually, most aurora, like the ones shown here, are caused by particles coming from Earth’s Magnetosphere hitting Earth’s atmosphere.

Magnetosphere:

The magnetic field surrounding Earth

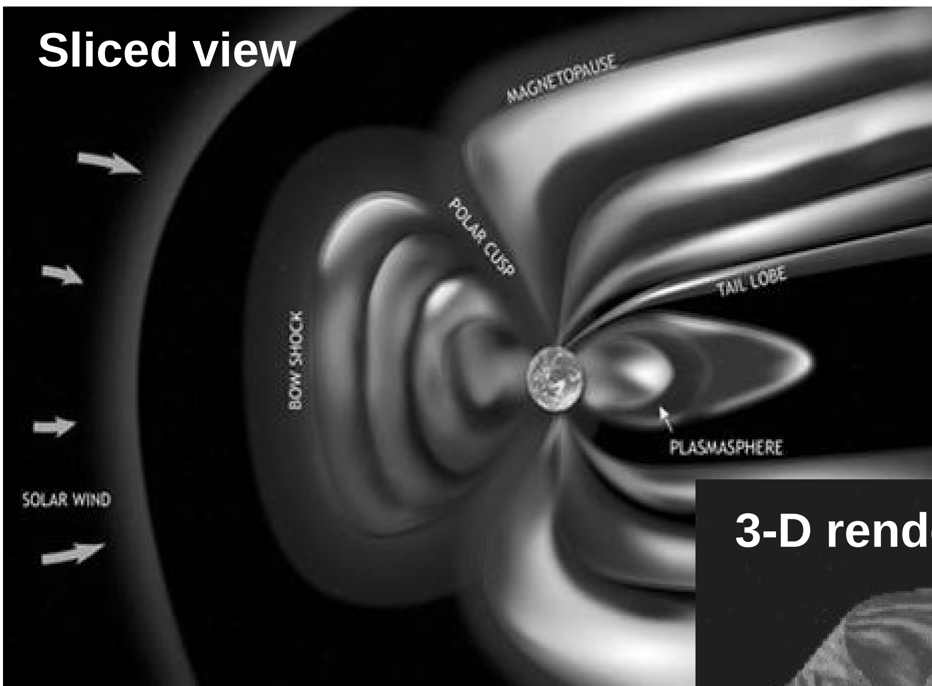


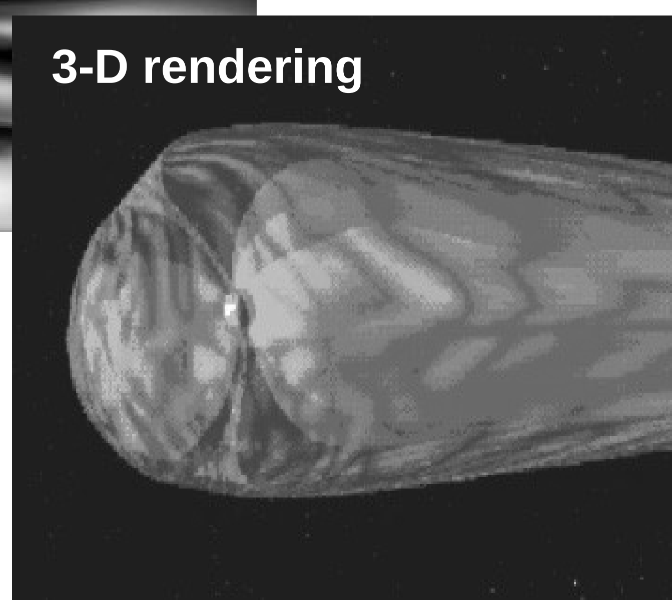


Electrical currents in Earth's molten iron outer core generate a large-scale magnetic field, similar to that of a bar magnet.

Interaction with the Solar Wind compresses Earth's magnetosphere on the dayside and elongates it on the night-side, forming a ***magnetotail***.

Magnetosphere:
The magnetic field surrounding Earth

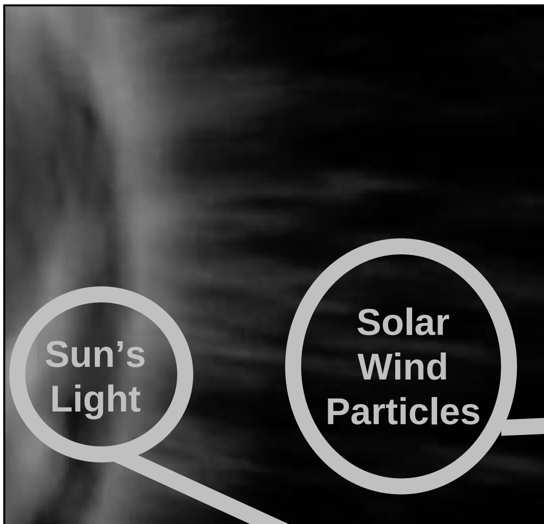




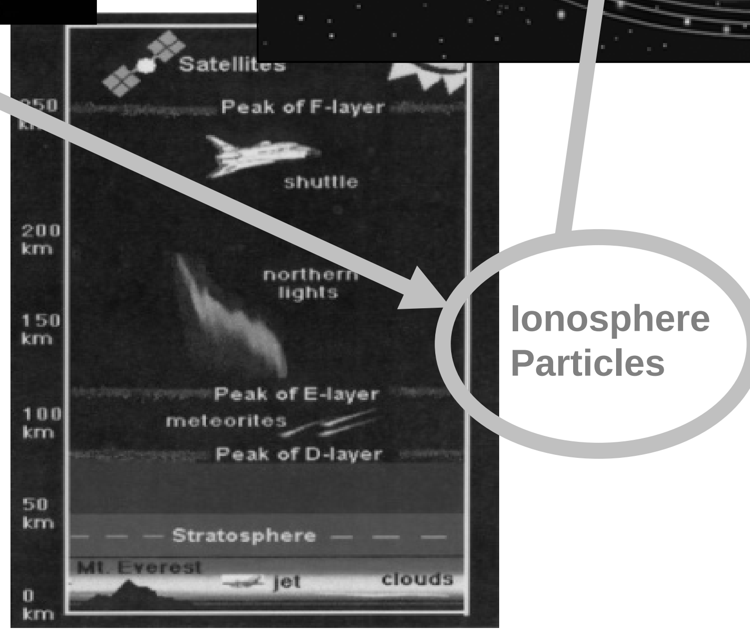
Most solar wind particles are deflected around Earth’s 3-dimensional magnetosphere.

Auroras:

Solar wind particles do not directly cause most auroras. Most are caused by particles in Earth’s magnetosphere.



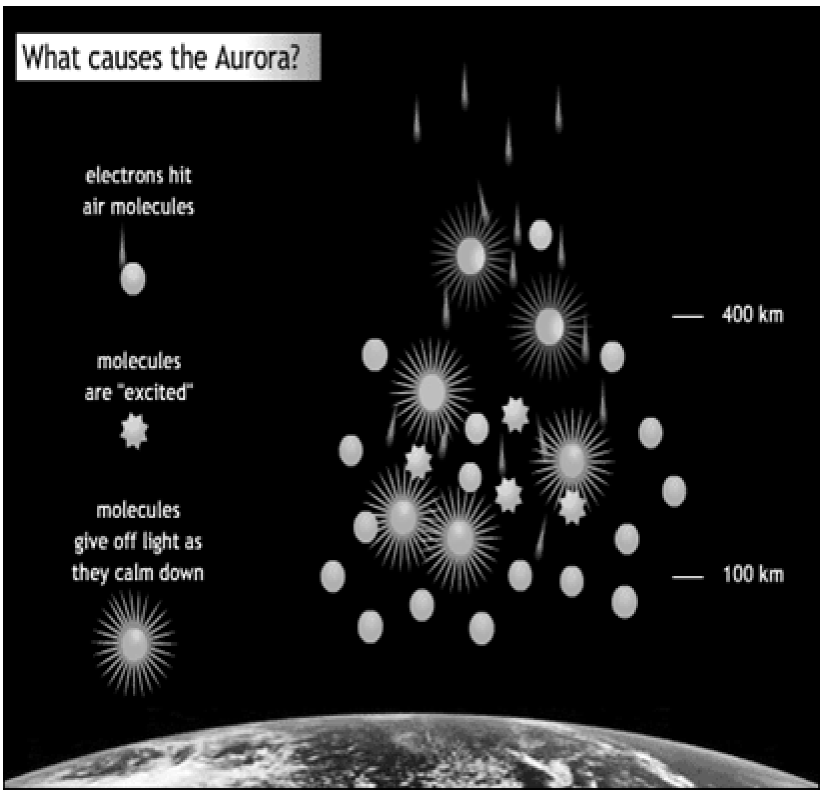
The ***ionosphere*** is created by sunlight stripping electrons off atoms in the atmosphere, making ions.



Particles in Earth’s Magnetosphere are made up of particles from the solar wind and Earth’s ionosphere.

Auroras:

caused by particles hitting the upper atmosphere.



Red & Green = Oxygen
Pink/white (Blue & Red) = Nitrogen

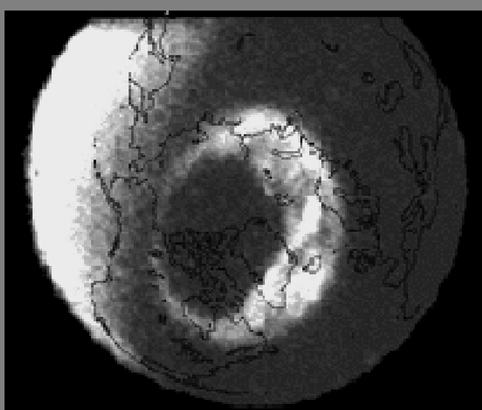
Electrons *collide* into the upper atmosphere, ionizing the gas, creating more electrons.

All the electrons cause the gas to glow like neon lights or a plasma ball.

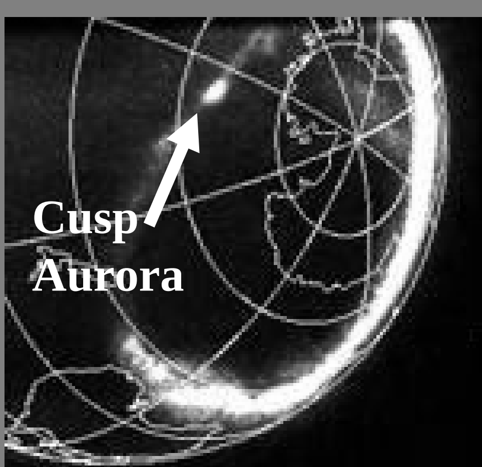
100 km (60 miles) above Earth’s surface.

Auroras: form an oval around the North and South Magnetic Poles

North Oval



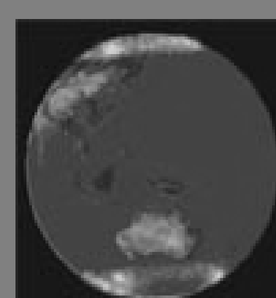
South Oval



***Auroral ovals* are always present.**

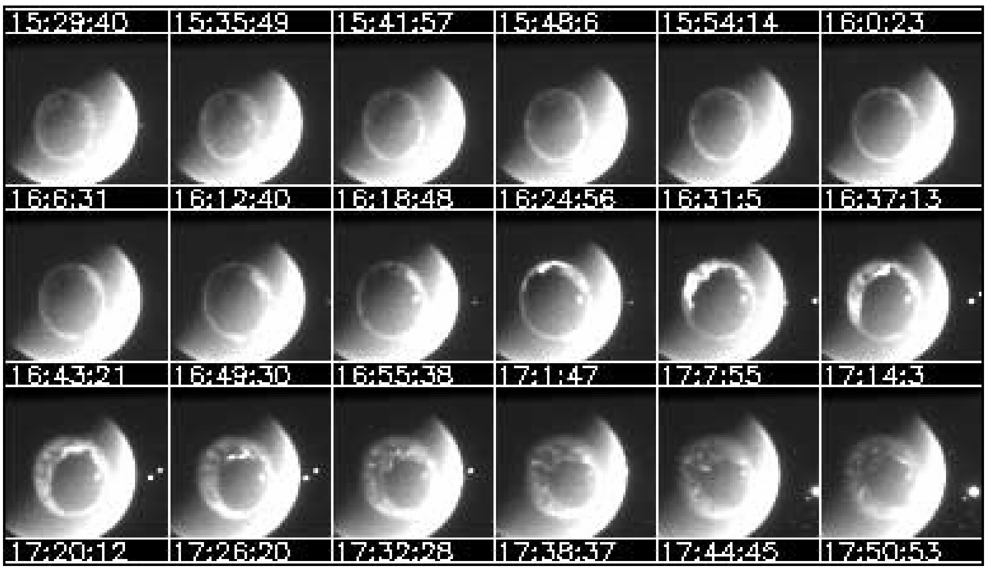
Images on the left are from the IMAGE satellite (in EUV light).

Im age on the right is from the Polar Satellite (in visible light).



Both Ovals

Auroral Substorms

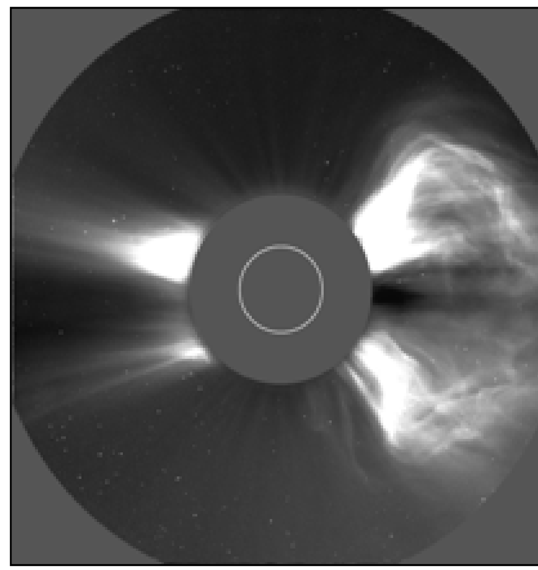


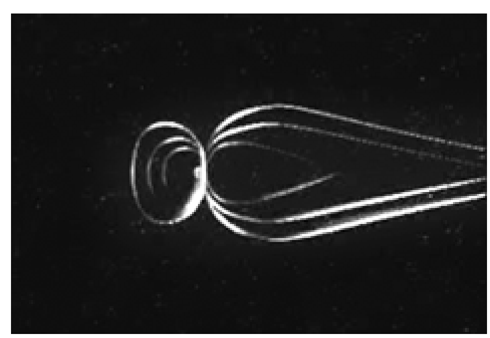
***Substorm*:** A pattern that the oval moves through in time, from a thin, quiet oval:

- to an expanding oval **(*growth phase*)**,
- to **(onset of)** a dynamic oval that expands/thickens ***(break-up*** **or** ***expansion phase)***,
- to a recovery back to the thin oval ***(recovery phase)***

CMEs can trigger Substorms

- When a CME passes Earth, it can “drag” the magnetic tail far out into space.
- One model suggests that stretched magnetic lines can break and then reconnect into a different shape.
- Electrons, guided by the magnetic field, speed up toward Earth and enhance auroras, sometimes displaying an auroral substorm.

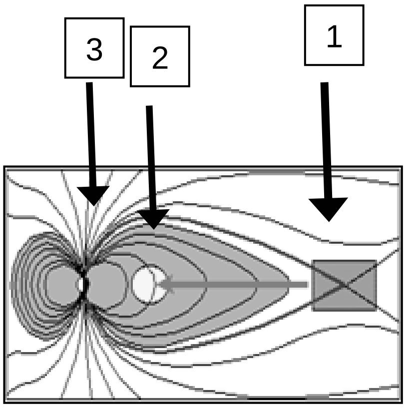




Movie (frames) courtesy of NASA/Goddard Space Flight Center Conceptual Image Lab

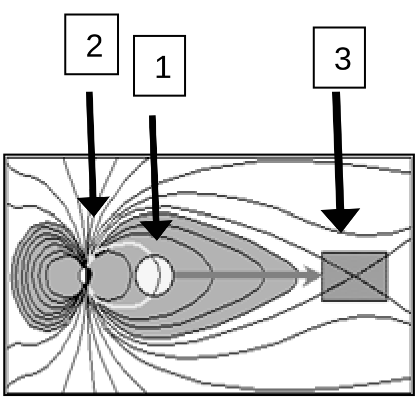
THEMIS:

with five satellites and many ground-based stations, learns more about dynamic aurora and the magnetosphere.



Magnetic Reconnection Model

1. Magnetic storm starts at 20 Earth Radii
2. Effects propagate to Current Disruption Region
3. Substorms and aurora are triggered



Current Disruption Model

1. Substorms start in the Current Disruption Region
2. Aurora are triggered on Earth
   Effects then propagate tailward
3. Reconnection is triggered