

The Sun-Earth Connection

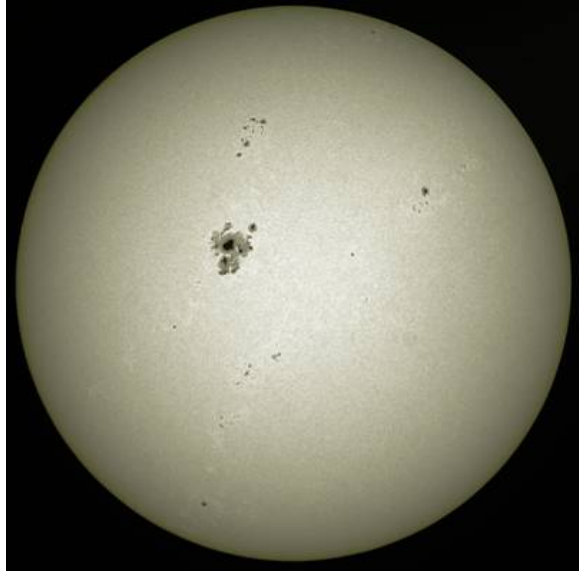


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Space Sciences Laboratory

University of California at Berkeley

What is the Sun?



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

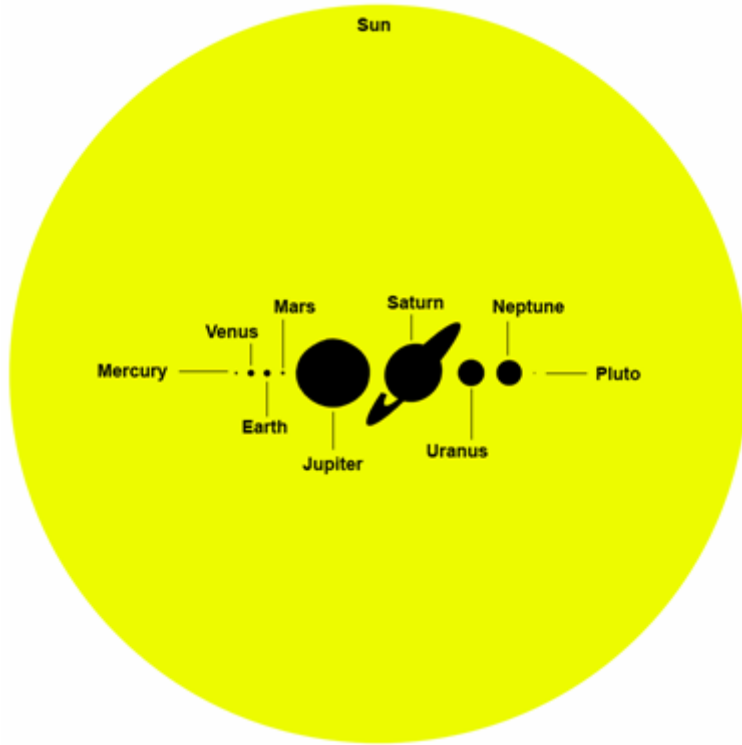
The Stars are other Suns but very far away.

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 Multiwavelength Sun



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

Radio light:
Wavelength = 17.6 cm

See radiation from Sun's atmosphere, **Corona**

The Multiwavelength Sun

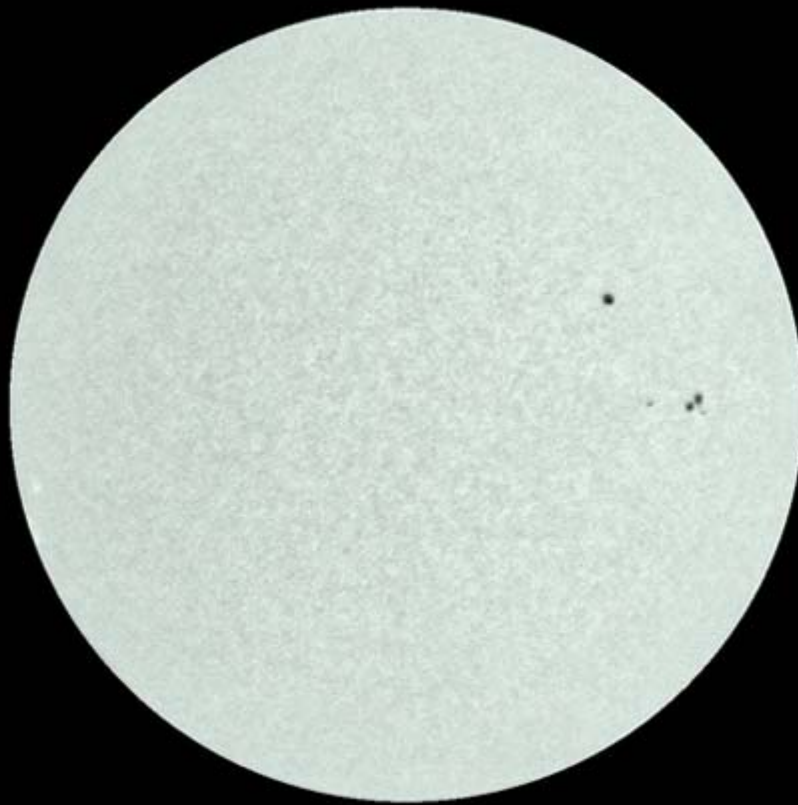


Looking at the Sun in different wavelengths of light reveals different parts of the Sun.

Visible light (H- α):
Wavelength = 656.3 nm

See radiation from layer just above Sun's surface,
Chromosphere

The Multiwavelength Sun

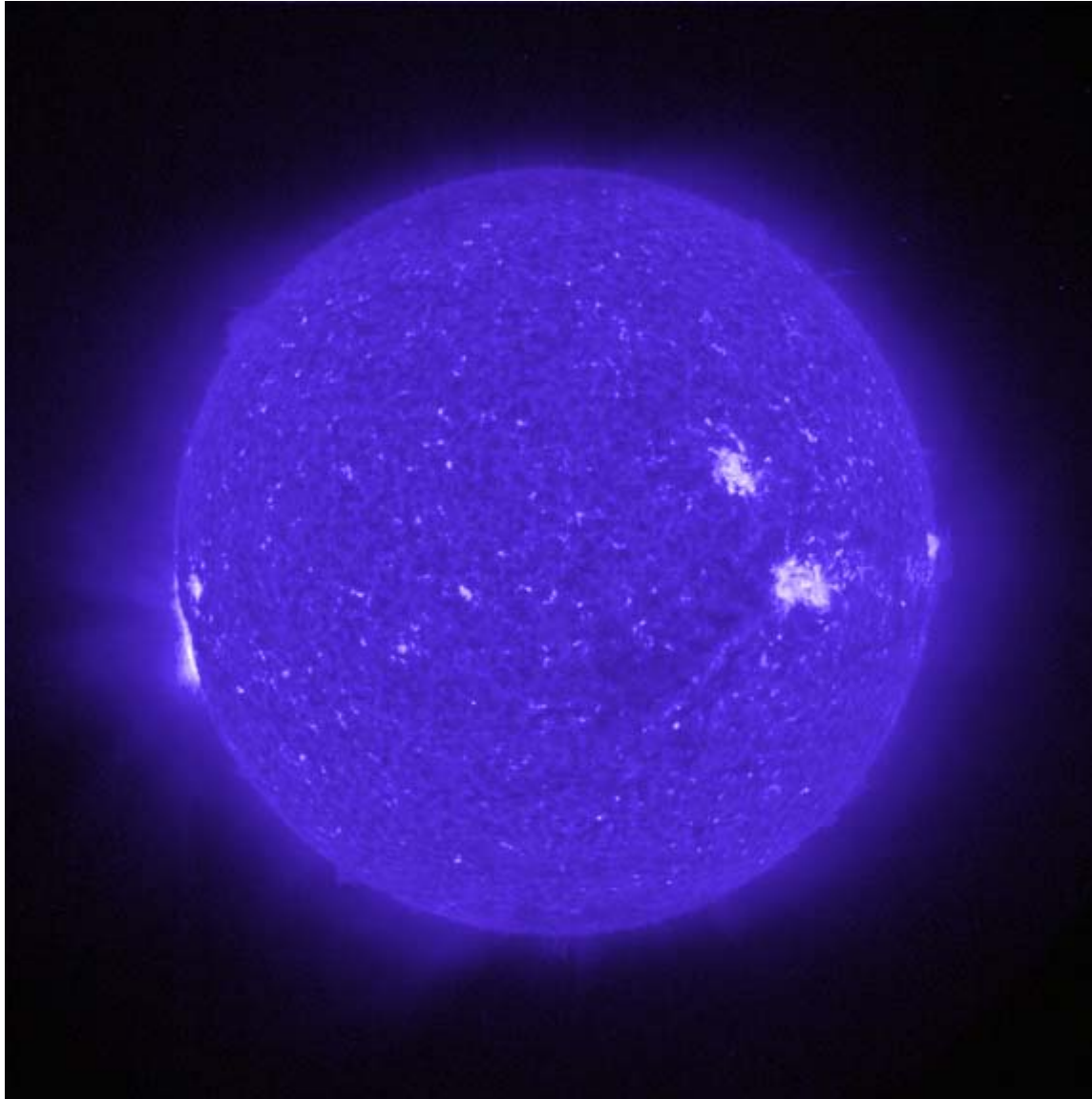


Looking at the Sun in different wavelengths of light reveals different parts of the Sun.

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

See radiation from Sun's
“surface”, **Photosphere**

The Multiwavelength Sun



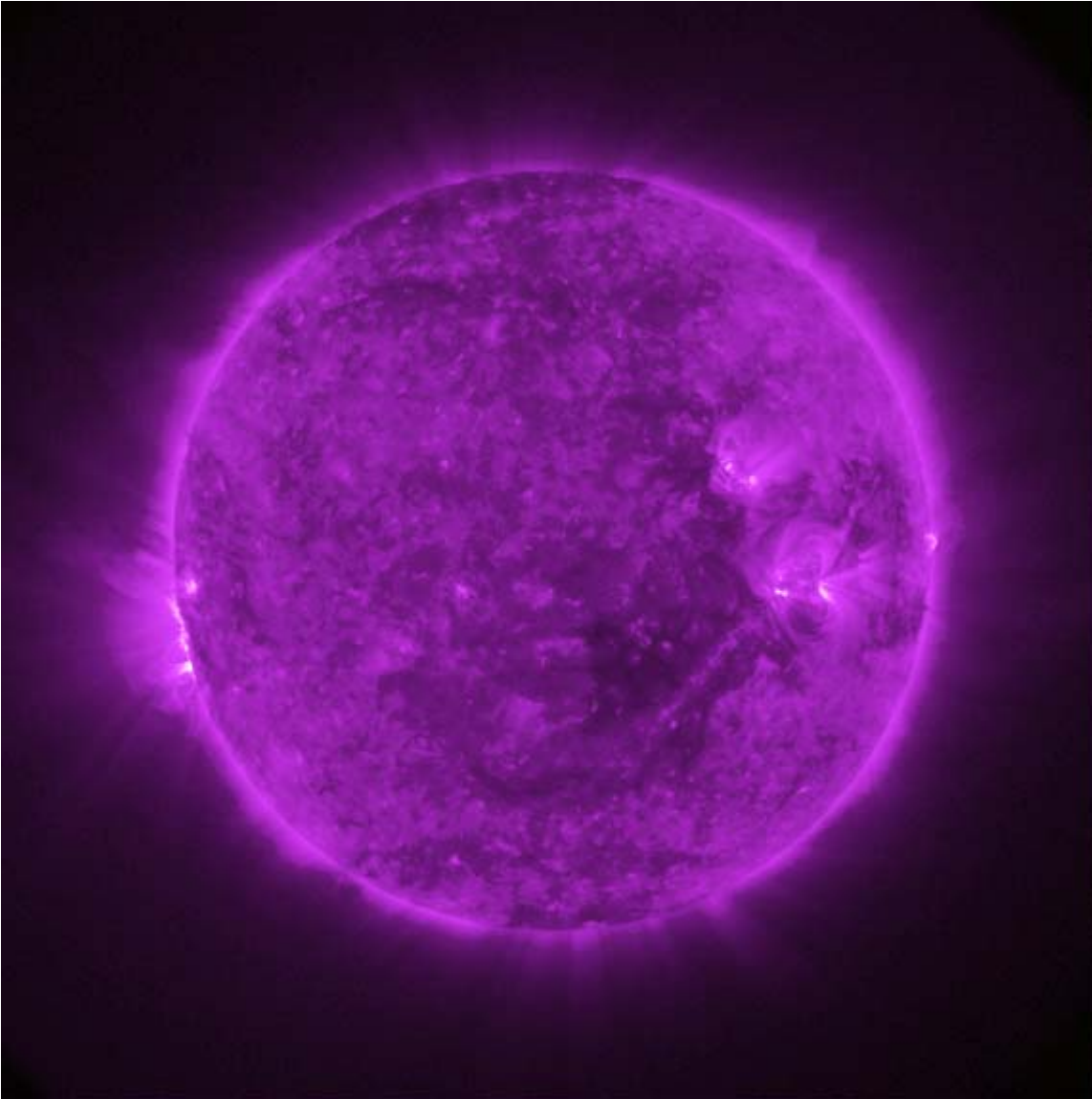
Looking at the Sun in different wavelengths of light reveals different parts of the Sun.

Extreme Ultraviolet light:
Wavelength = 30.4 nm

See radiation from Sun's atmosphere, **Corona**

Image from STEREO mission

The Multiwavelength Sun



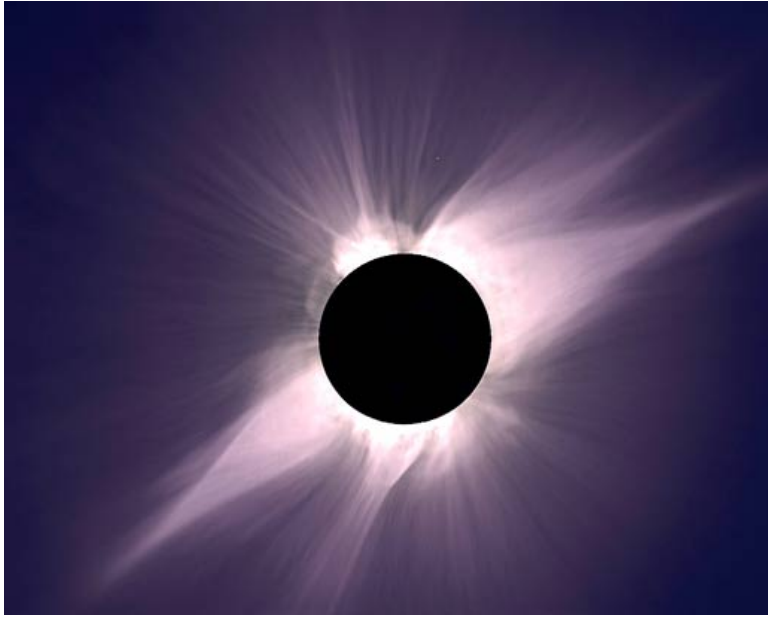
Looking at the Sun in different wavelengths of light reveals different parts of the Sun.

Extreme Ultraviolet light:
Wavelength = 17.1 nm

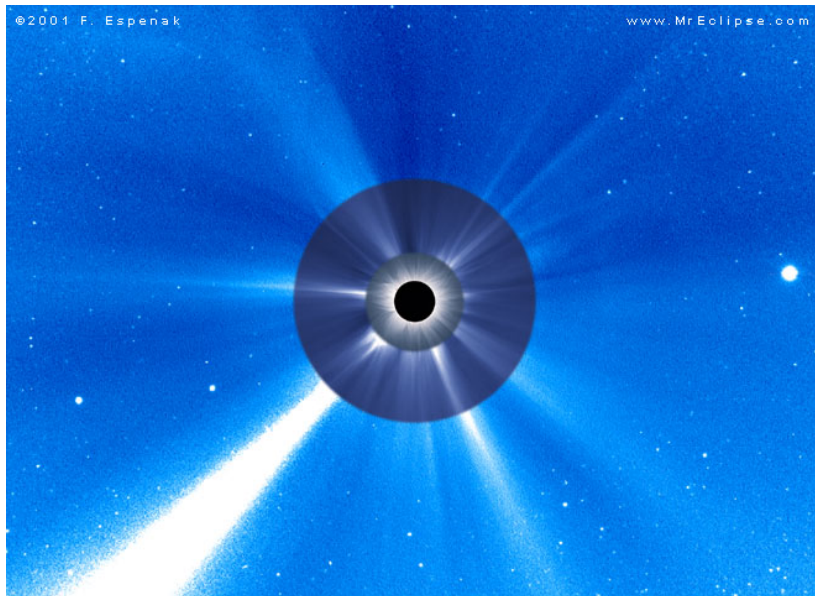
See radiation from Sun's atmosphere, **Corona**

Image from STEREO mission

The Different Parts of the Sun



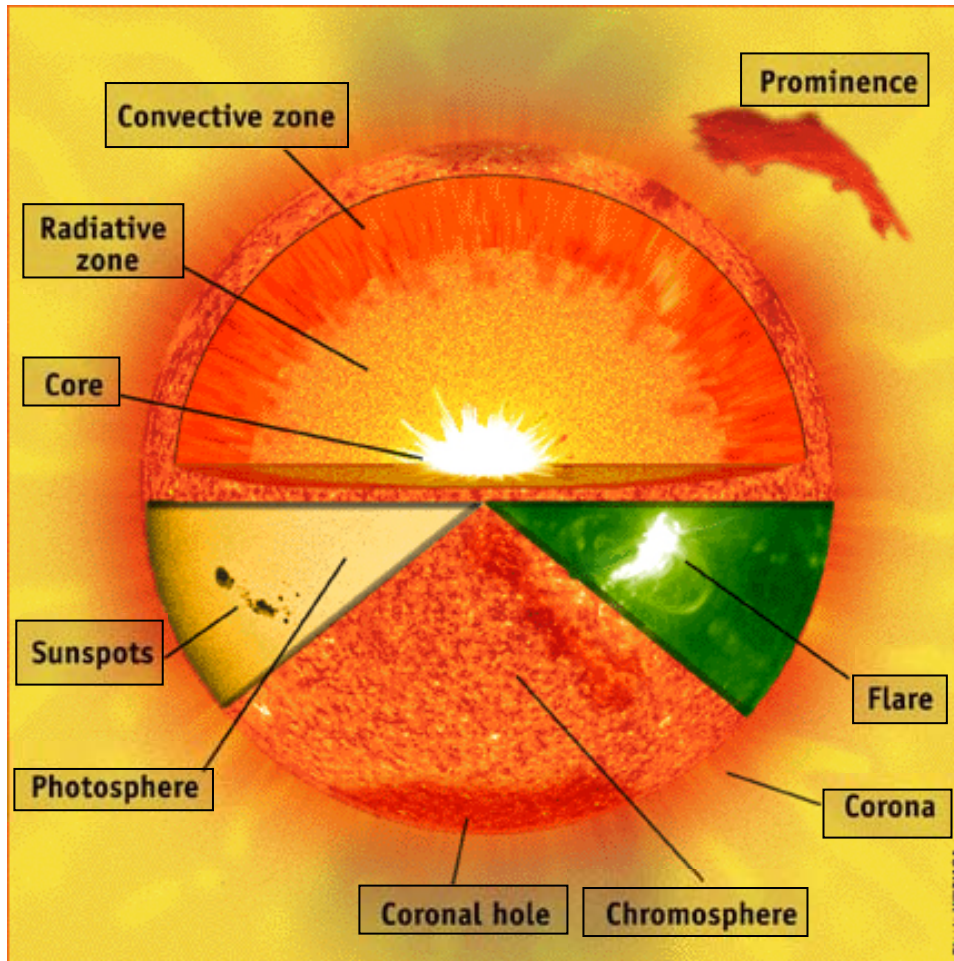
During a total eclipse of the Sun, the very bright **Photosphere** is blocked and the Sun's outer atmosphere becomes visible (in white light). We call it the **Corona**



Spacecraft, like SOHO and STEREO, place a disk in front of their cameras to create an eclipse. They are then able to take images with a larger view of the Sun's **Corona**

It extends far out into the Solar System, in fact we *live* in it!

The Different Parts of the Sun



Core

- Nuclear Fusion $H \rightarrow He$
- $T = 15,000,000\text{ K}$

Radiative Zone

- Energy transported by light
- $T = 10,000,000\text{ K}$

Convective Zone

- Energy transported by convection

Photosphere

- Visible surface
- Far less dense than Earth's atmosphere
- $T = 5,800\text{ K}$
- Sunspots: $T = 4,000\text{ K}$

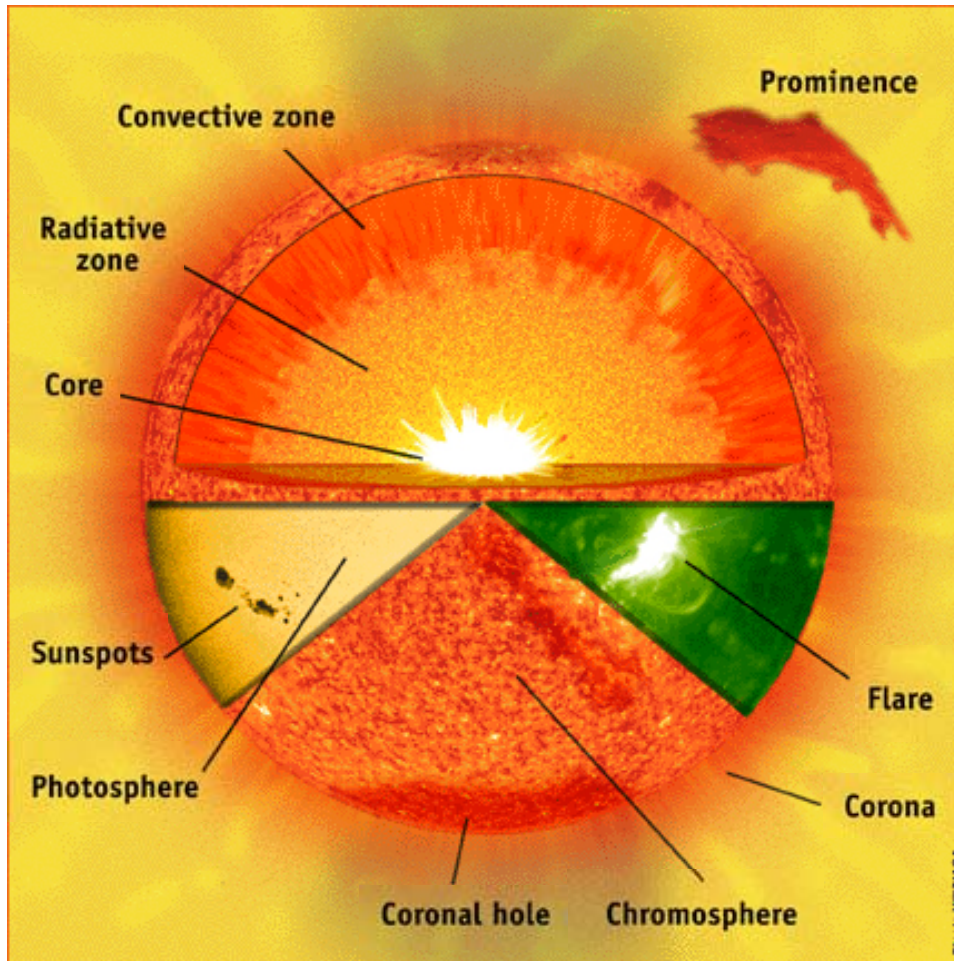
Chromosphere

- Thin layer above photosphere
- Produces most of Sun's UV light
- $T = 10,000\text{ K}$

Corona

- Tenuous, extends out millions of kilometers
- Emits X-rays
- $T = 1,000,000\text{ K}$

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The Solar Wind

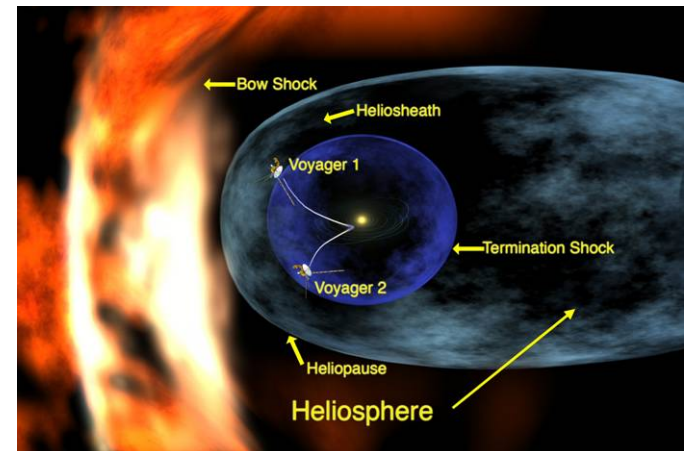


The solar wind is a stream of mostly charged particles that emanate from the Sun and blow throughout the Solar System.

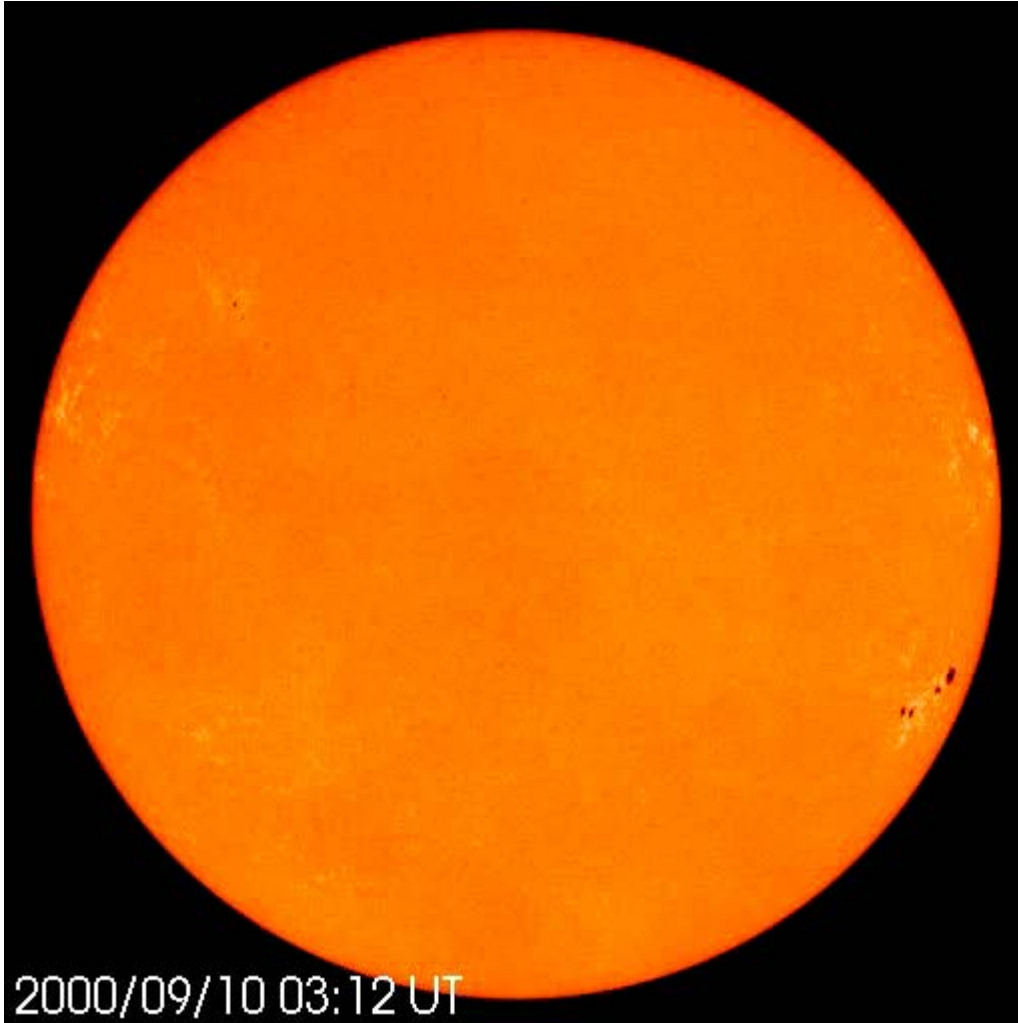
It blows a bubble in the interstellar medium about 200 AU in diameter. The space inside this bubble is called the **Heliosphere**.



The shape of Earth's magnetosphere is distorted by interactions with the solar wind.

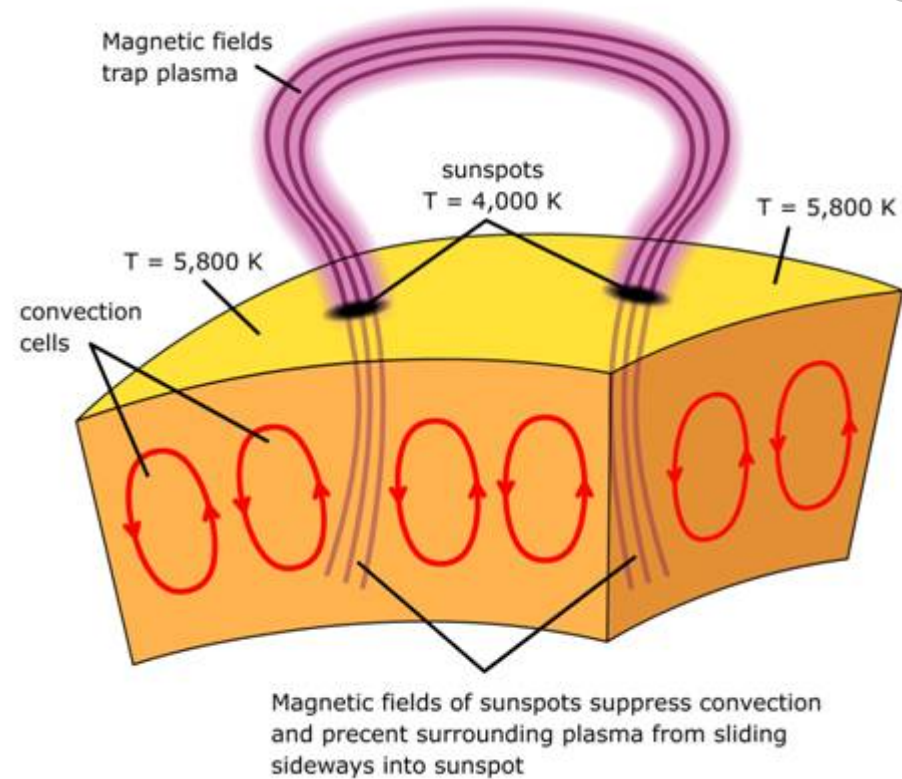


Sunspots



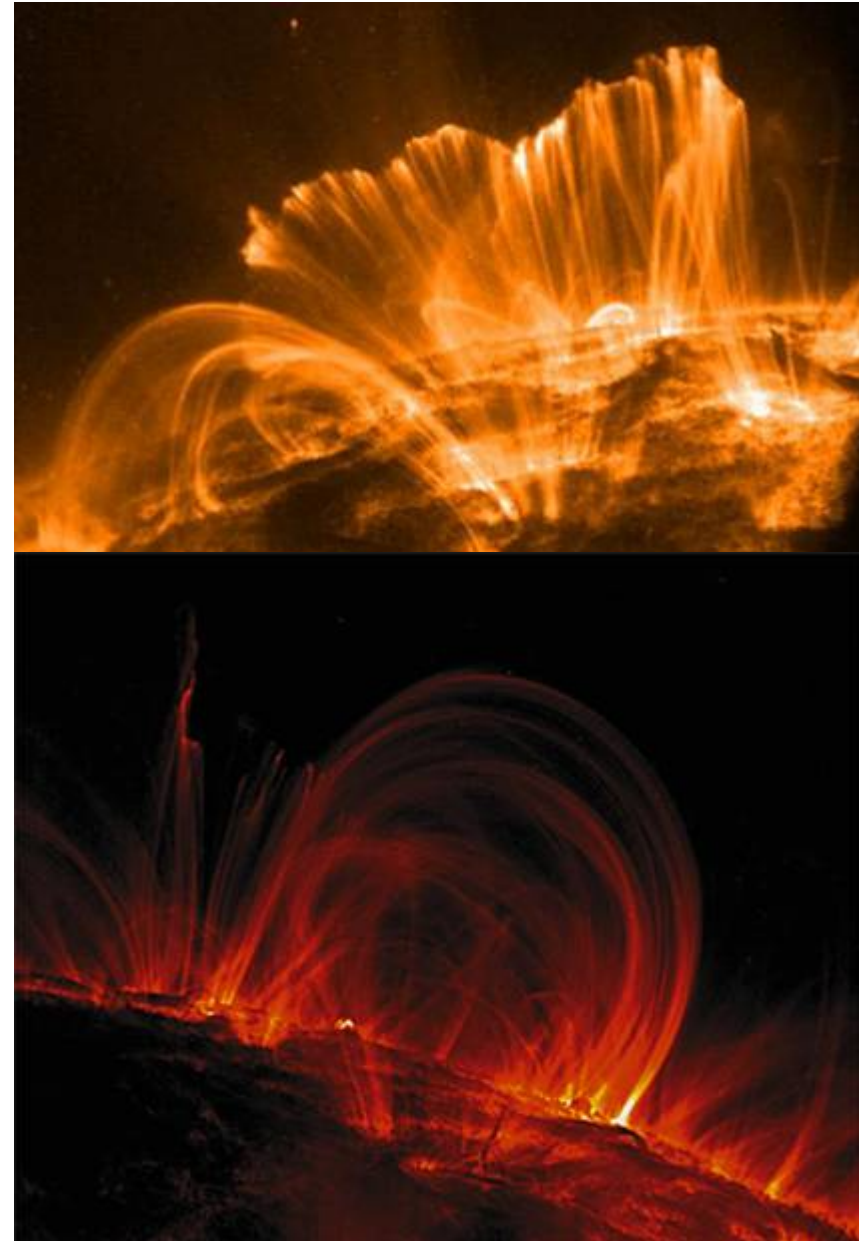
- Dark splotches on the face of the Sun.
- About 2,000 degrees Kelvin cooler than the average temperature on the photosphere.
- Appear to be dark only in comparison to their very bright surroundings.
- Following long-lived sunspots through time allows one to determine the rotation rate of the Sun.
- The Sun spins faster at the equator than at the poles.
- The Italian astronomer Galileo was one of the first people to use Sunspots to track the Sun's rotation.

The Magnetic Sun

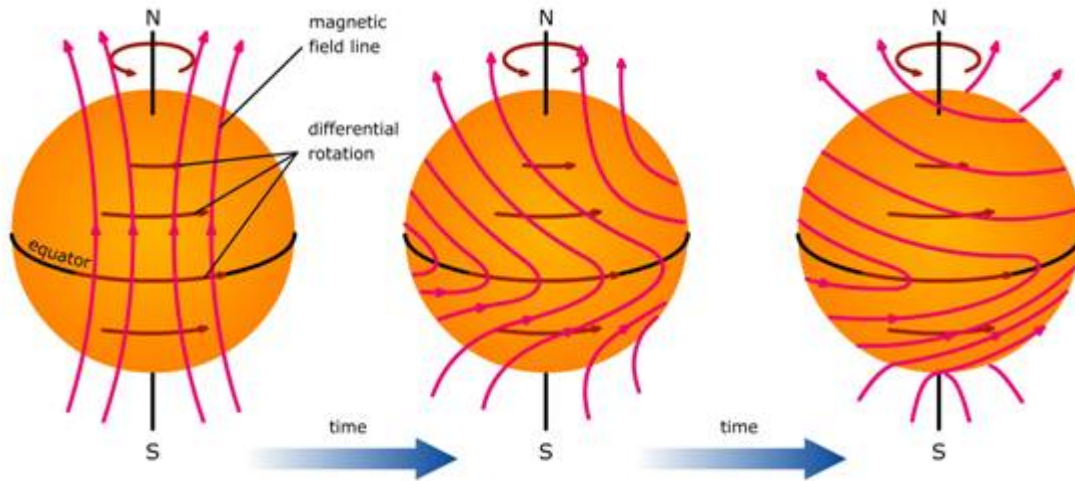
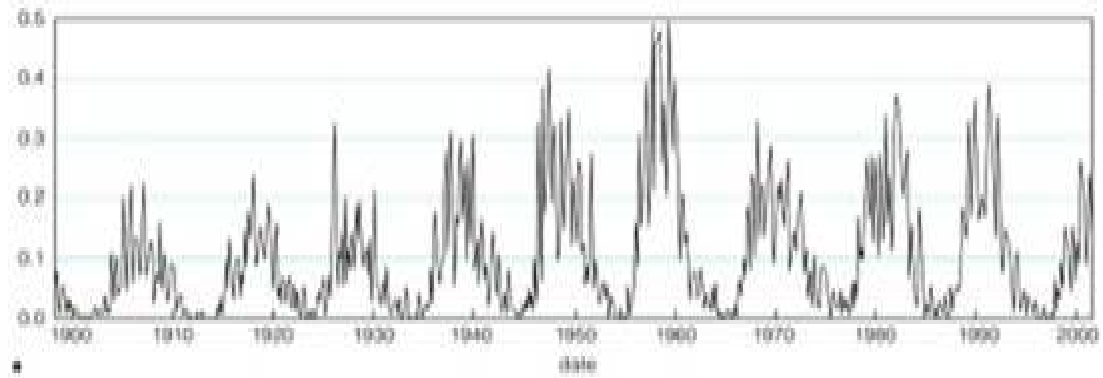


Images of the Sun in ultraviolet light reveal loops of hot ionized gas (plasma) trapped in magnetic fields above the locations of Sunspots.

Sunspots 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.

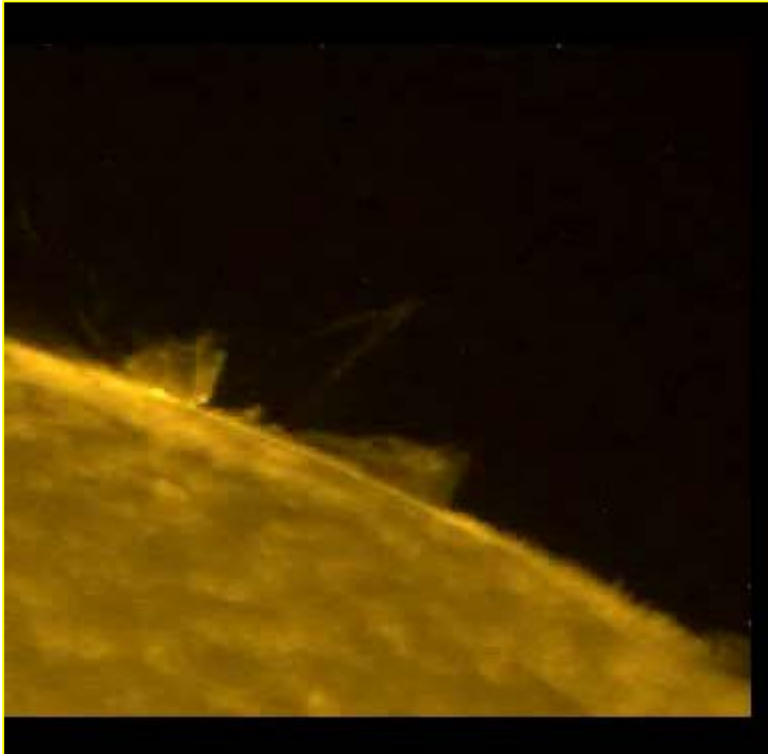
The Sun's magnetic field becomes more and more twisted and complex from differential rotation. It finally breaks and flips every 11 years. So the total cycle is really 22 years from start to finish.



Solar Flares & CMEs

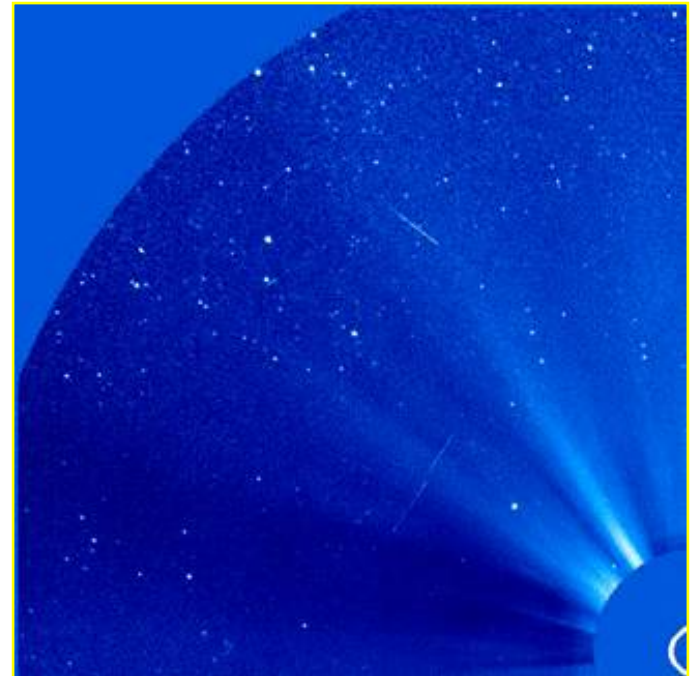
Solar flares are enormous explosions in the atmosphere of the Sun.

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



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

CMEs occur when large-scale magnetic fields “break” and release energy and enormous amounts of matter into space.



RHESSI Spies Solar Flares

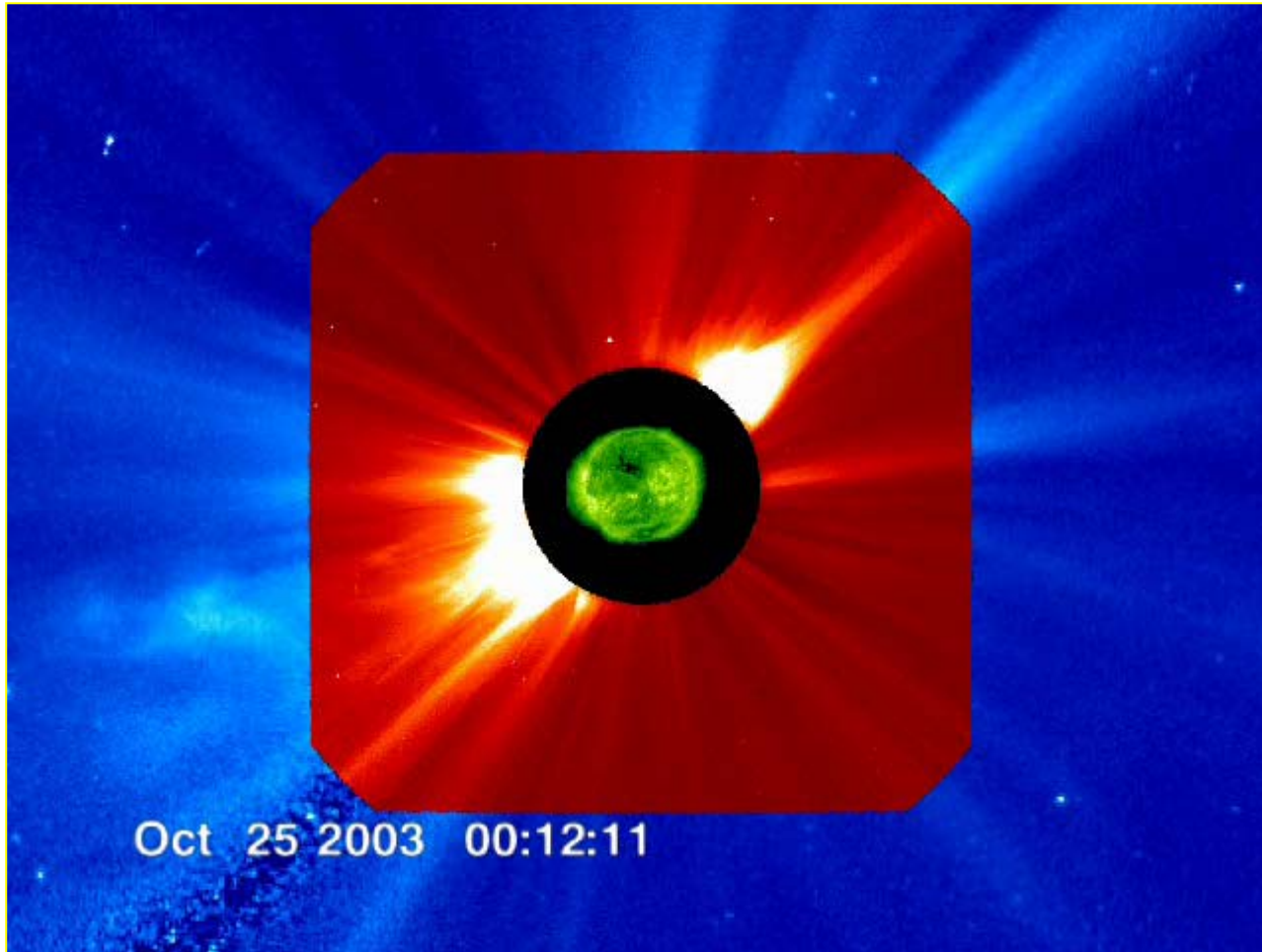
- Solar flare: rapid release of a large amount of magnetic energy in the Sun's atmosphere.
- Gas is heated to ~ 10 million degrees Kelvin (K)
- Radiates light across the entire EM spectrum
- RHESSI data has revealed electrons streaming along magnetic fields from high in the Sun's corona and then slamming into denser gas near the surface



Launched: 5-Feb-2002

Science Instruments: X-ray &
Gamma-Ray Imager and
Spectroscope

Earth is Affected by the Sun



CME's are sometimes directed at Earth.

It takes a few days for the material to arrive.

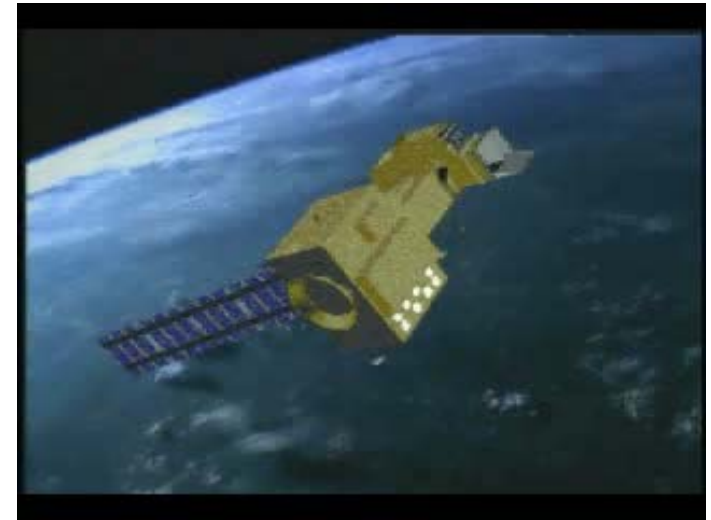
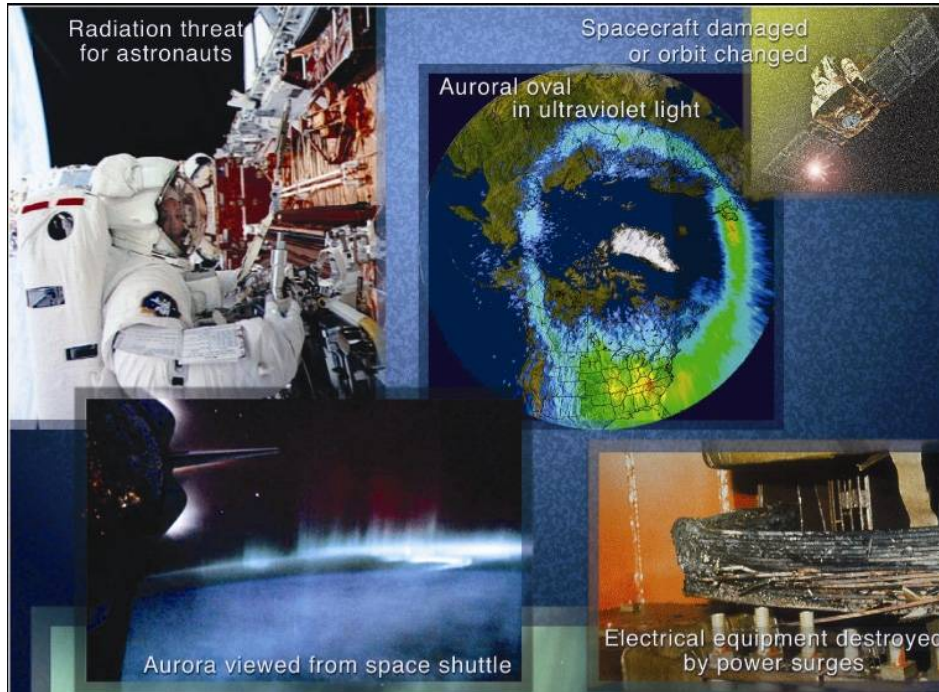
The CME can often travel faster than the Solar Wind material creating a Shock Wave.

Seeing the Sun in STEREO



NASA's STEREO mission has placed 2 satellites in orbit around the Sun on either side of Earth to study CME's and their possible effects on Earth

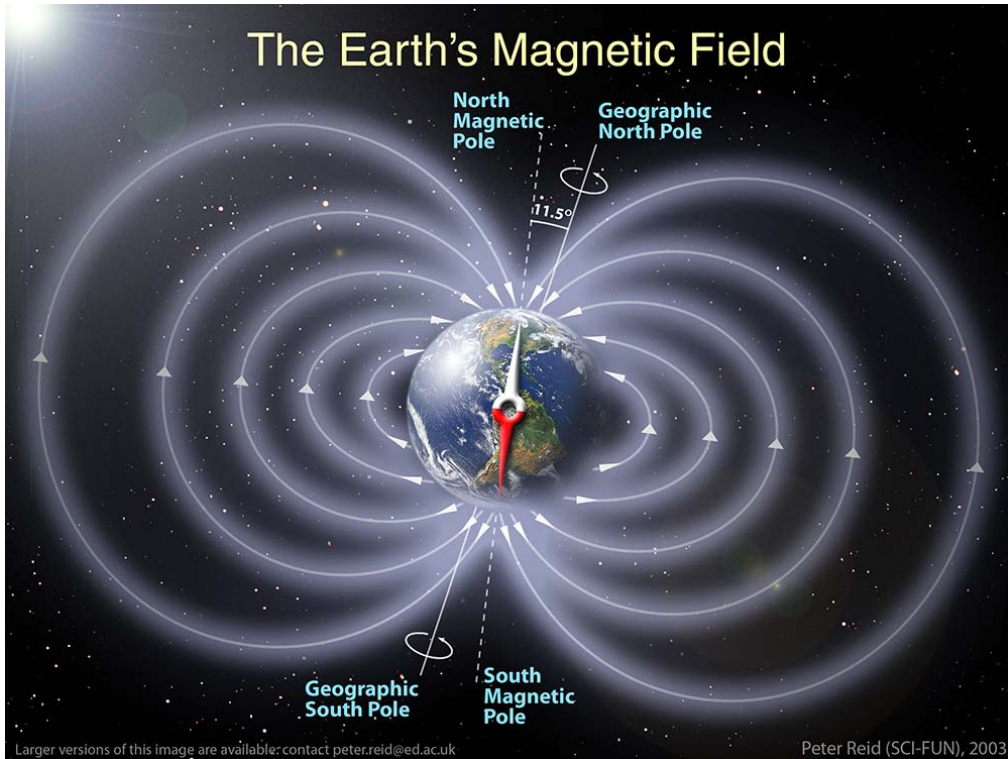
Space Weather Effects on Earth



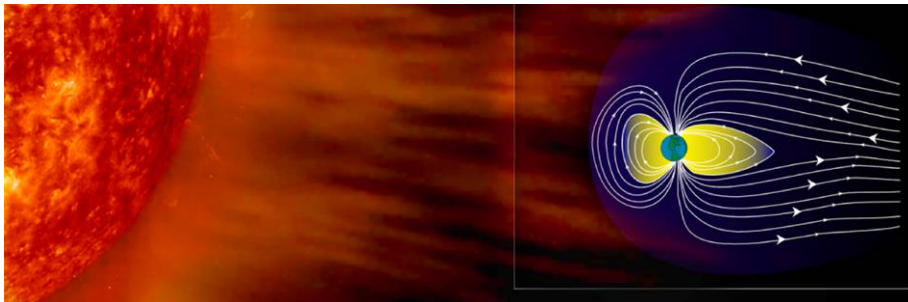
- Energy from Solar Flares and CMEs can damage satellites and change orbits.
- Disrupt radio communications
- CME particles traveling near the speed of light threaten Astronauts.
- CMEs can intensify auroras (Northern and Southern Lights)
- Electric currents from intense aurora can cause power surges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

Magnetosphere:

The magnetic field surrounding Earth



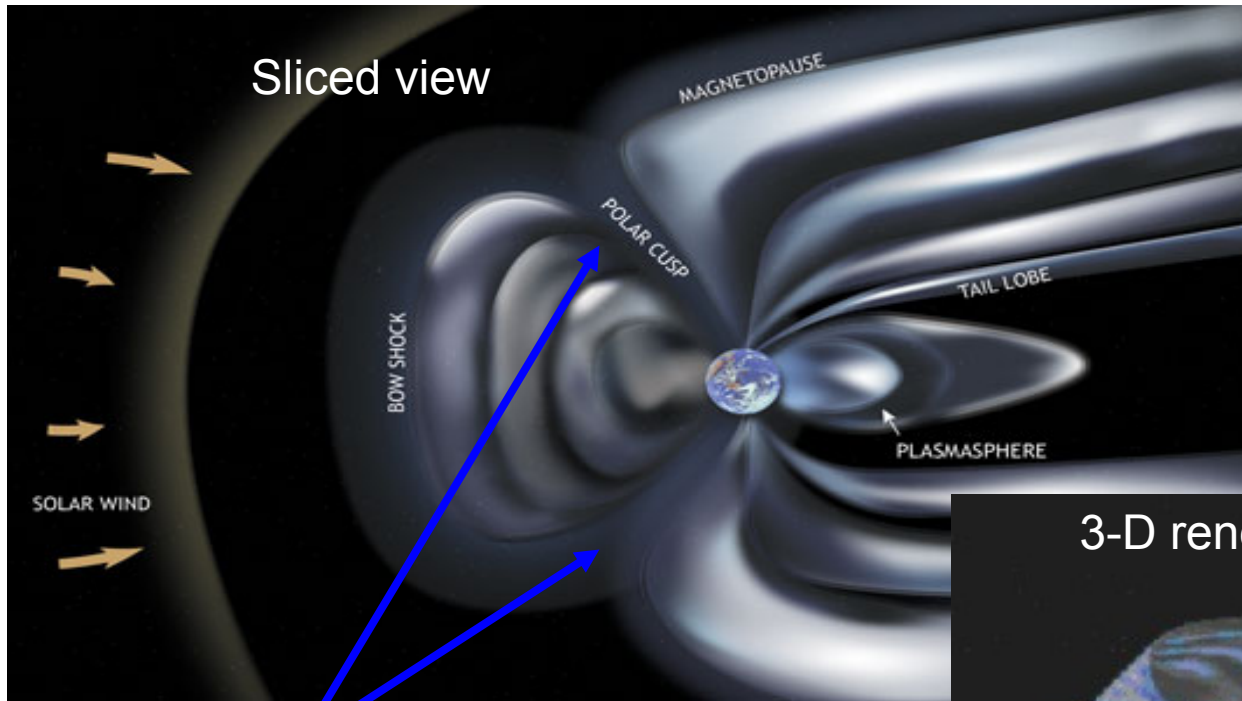
Electrical currents in Earth's molten iron outer core generate a large-scale magnetic field, similar to that of a bar magnet.



Interaction with the Solar Wind compresses Earth's magnetosphere on the dayside and elongates it on the night-side

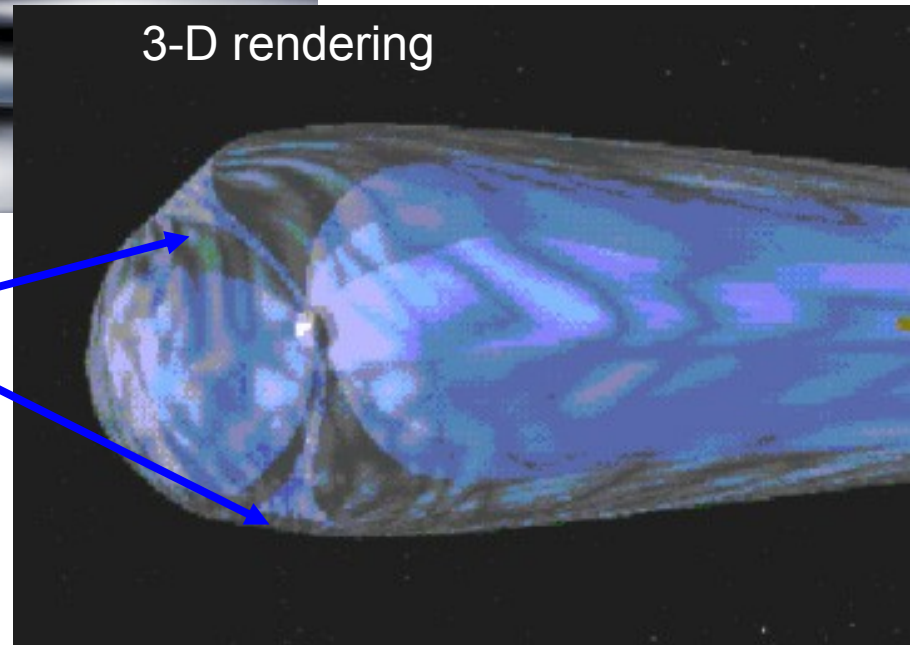
Magnetosphere:

The magnetic field surrounding Earth



Most solar wind particles are deflected around Earth's Magnetosphere.

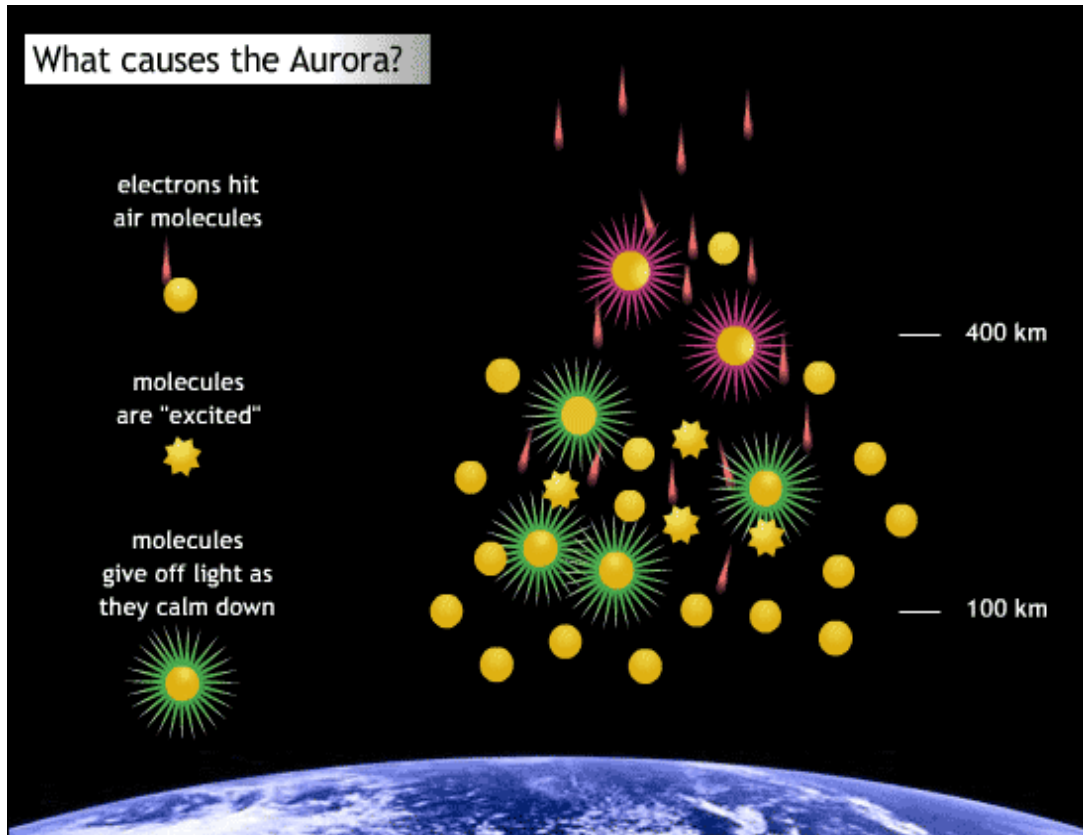
Two small magnetospheric funnels (cusps) are open to solar particles.



Auroras: the northern and southern lights



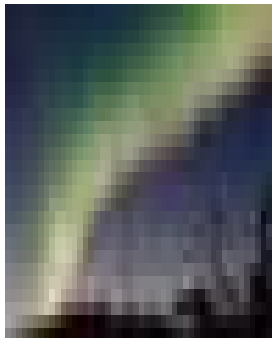
Auroras: caused by particles hitting the upper atmosphere.



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.

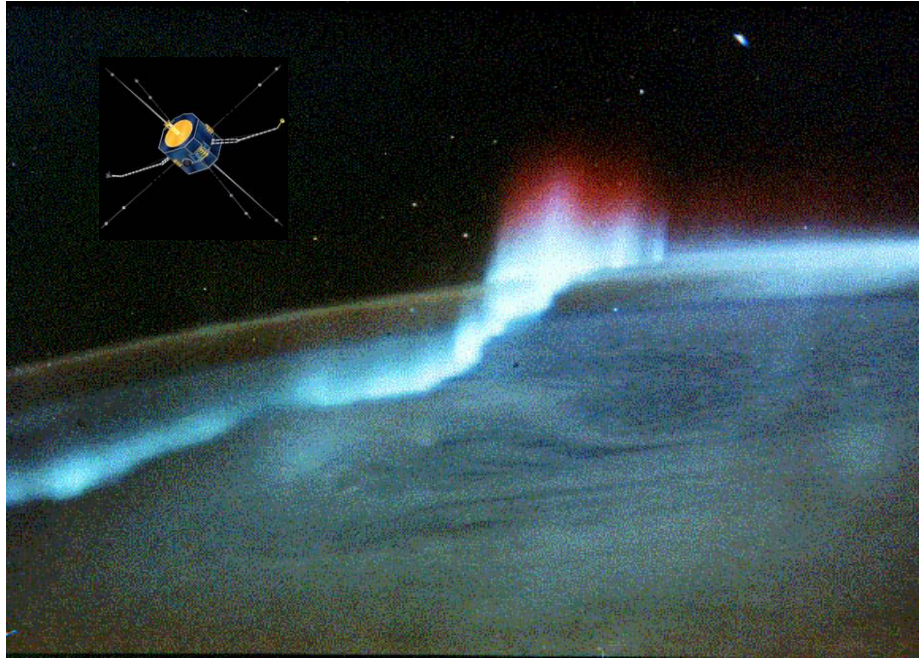
100 km (60 miles) above Earth's surface.



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



FAST Studies the Aurorae



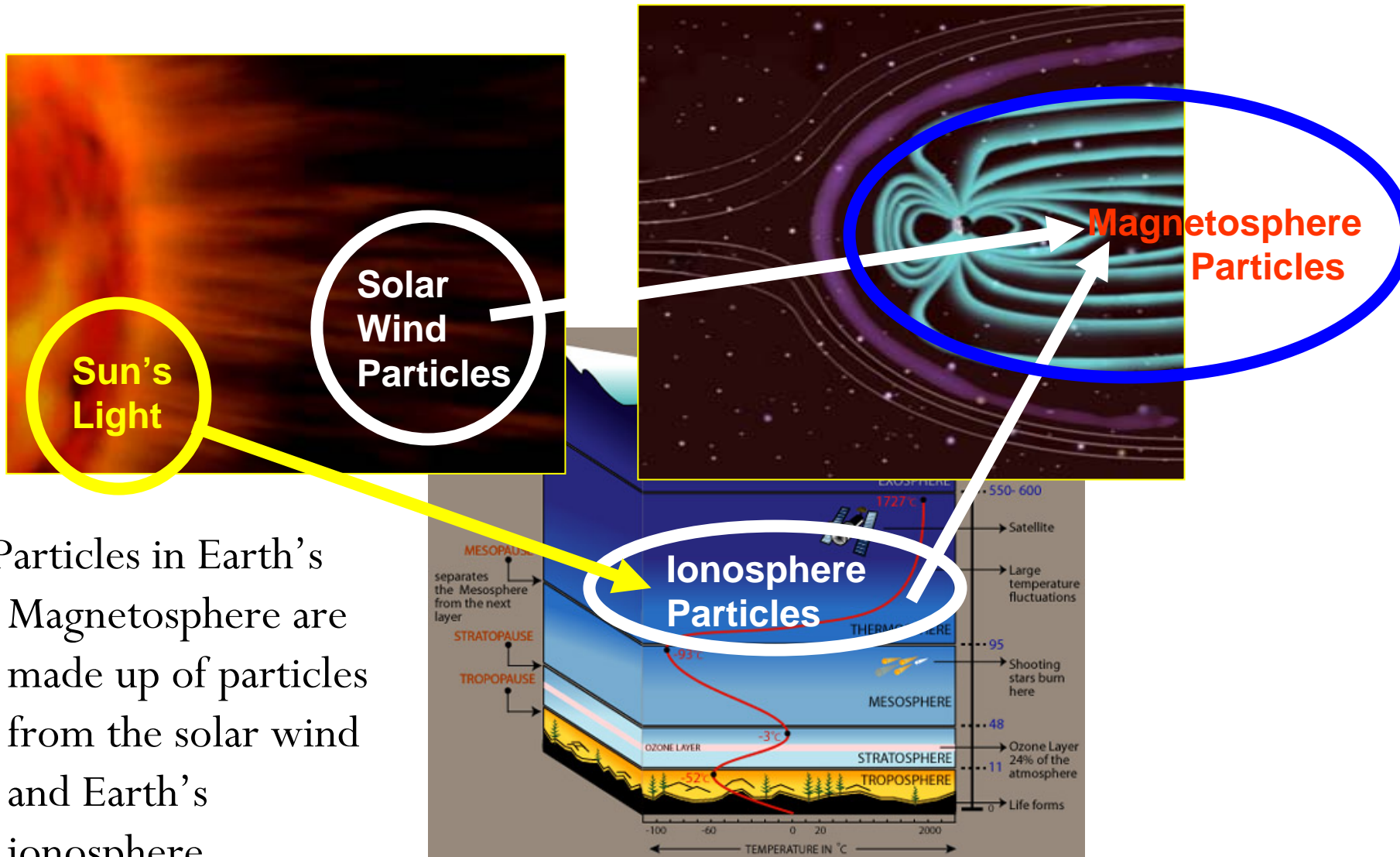
Particle detectors and magnetic and electric field sensors help FAST to study how auroral particles are accelerated before they crash into the atmosphere.

Launched in August, 1996

While spinning in its polar elliptical orbit around the Earth, FAST passes through the auroral regions located around Earth's northern and southern magnetic poles.

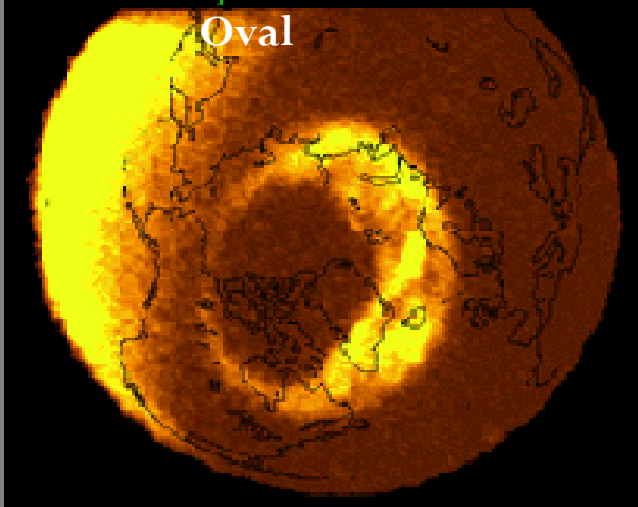
Auroras:

Solar Wind particles do not directly cause most aurorae.
Most are caused by Particles in Earth's Magnetosphere.



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

North
Oval



South Oval

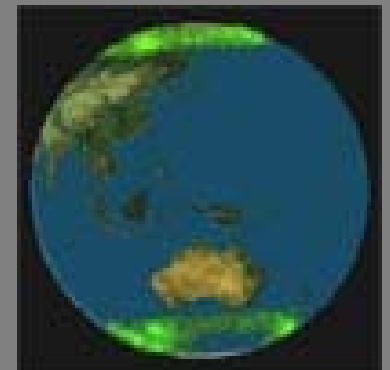
Cusp
Aurora



**Aurora ovals are
always present.**

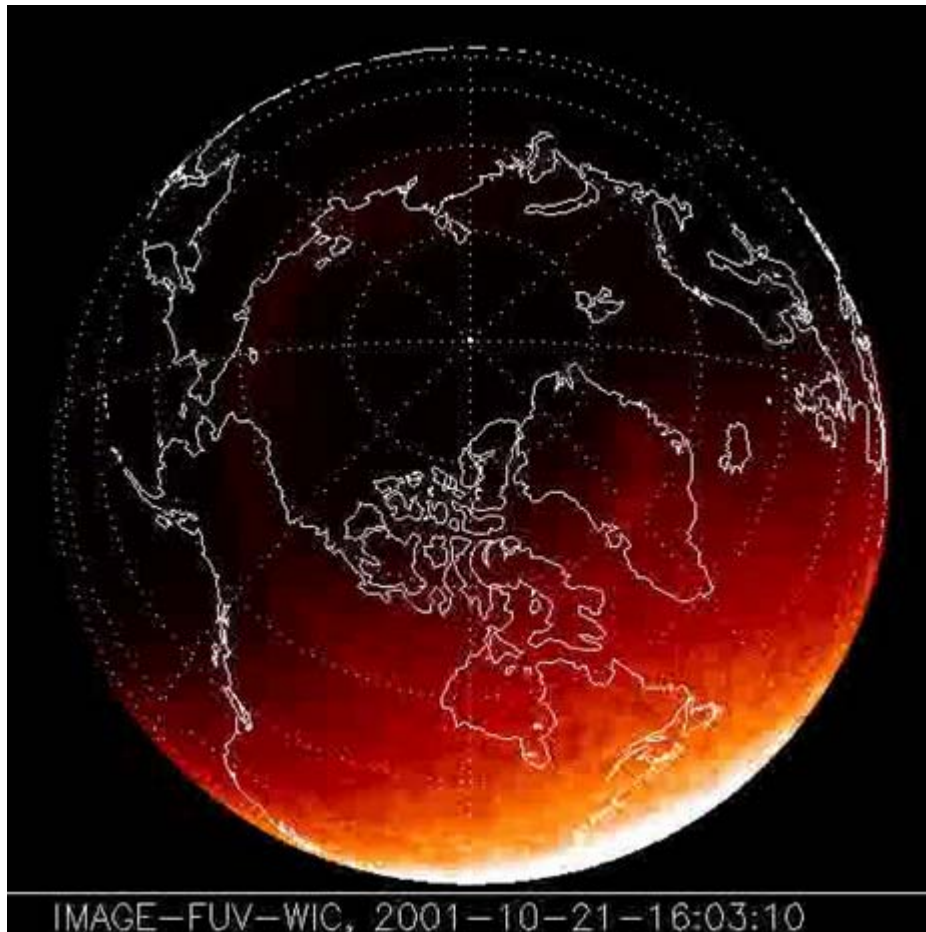
*Images on the left
are from the
IMAGE satellite.*

*Image on
the right is from the
Polar Satellite.*



Both Ovals

Auroral Substorms

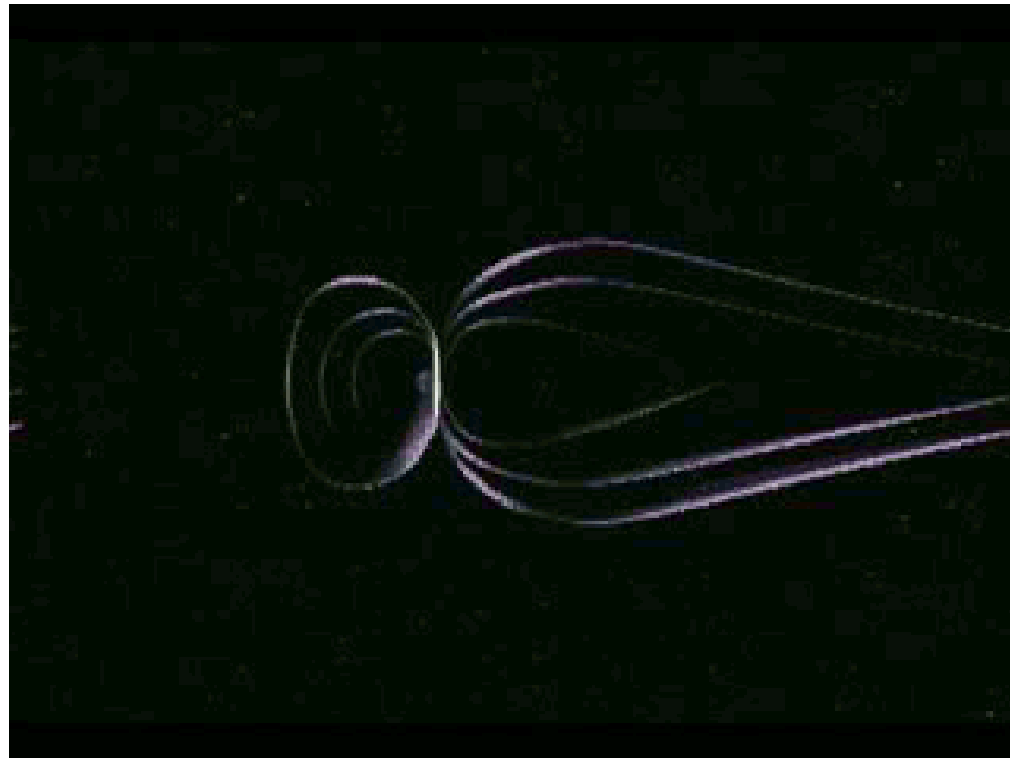
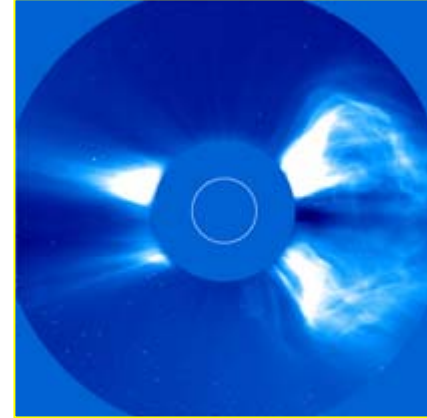


Substorm: A pattern that the oval moves through in time from a thin, quiet oval

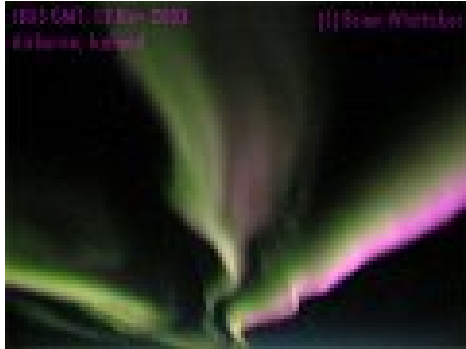
- to an expanding oval (**growth phase**),
- to (**onset of**) a dynamic oval that expands/thickens (**break-up or expansion phase**),
- to a recovery back to the thin oval (**recovery phase**)

CMEs can create Geomagnetic Substorms

- When a CME passes Earth, it can “drag” the magnetic tail far out into space.
- Stretched magnetic lines can break and then reconnect into a different shape.
- Electrons, guided by the magnetic field, speed up towards Earth and enhance auroras.



The Auroras of Nov. 2003



Brian Whittaker
36,000 feet above
Iceland from a airplane
Nov. 12th



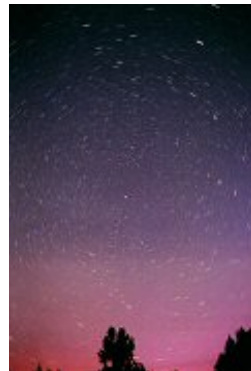
Ulrike Haug,
Alaska,
Nov. 15



Chris VenHaus,
Wisconsin
Nov. 20



Eric Honeycutt,
North Carolina,
Nov. 20

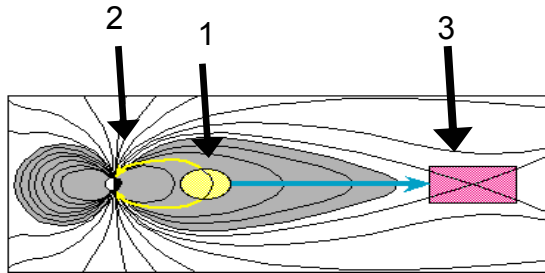


Chris Schur,
Arizona
Nov. 20



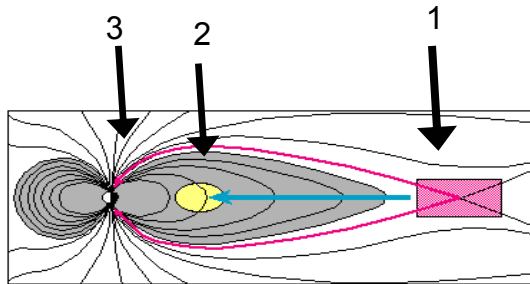
Connie Corbett,
Napa Valley,
California
Nov. 20

THEMIS: with 5 satellites and many ground-based stations, will learn more about dynamic aurora and the magnetosphere.



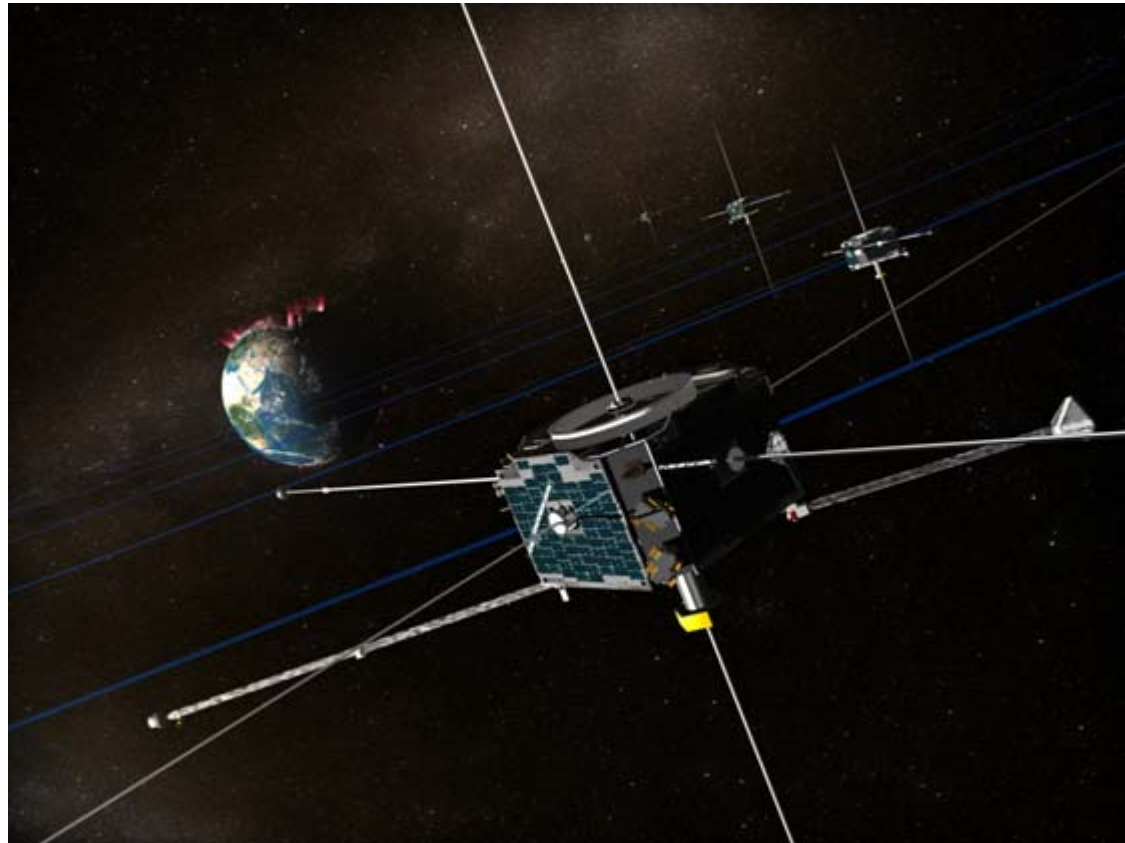
Current Disruption Model

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

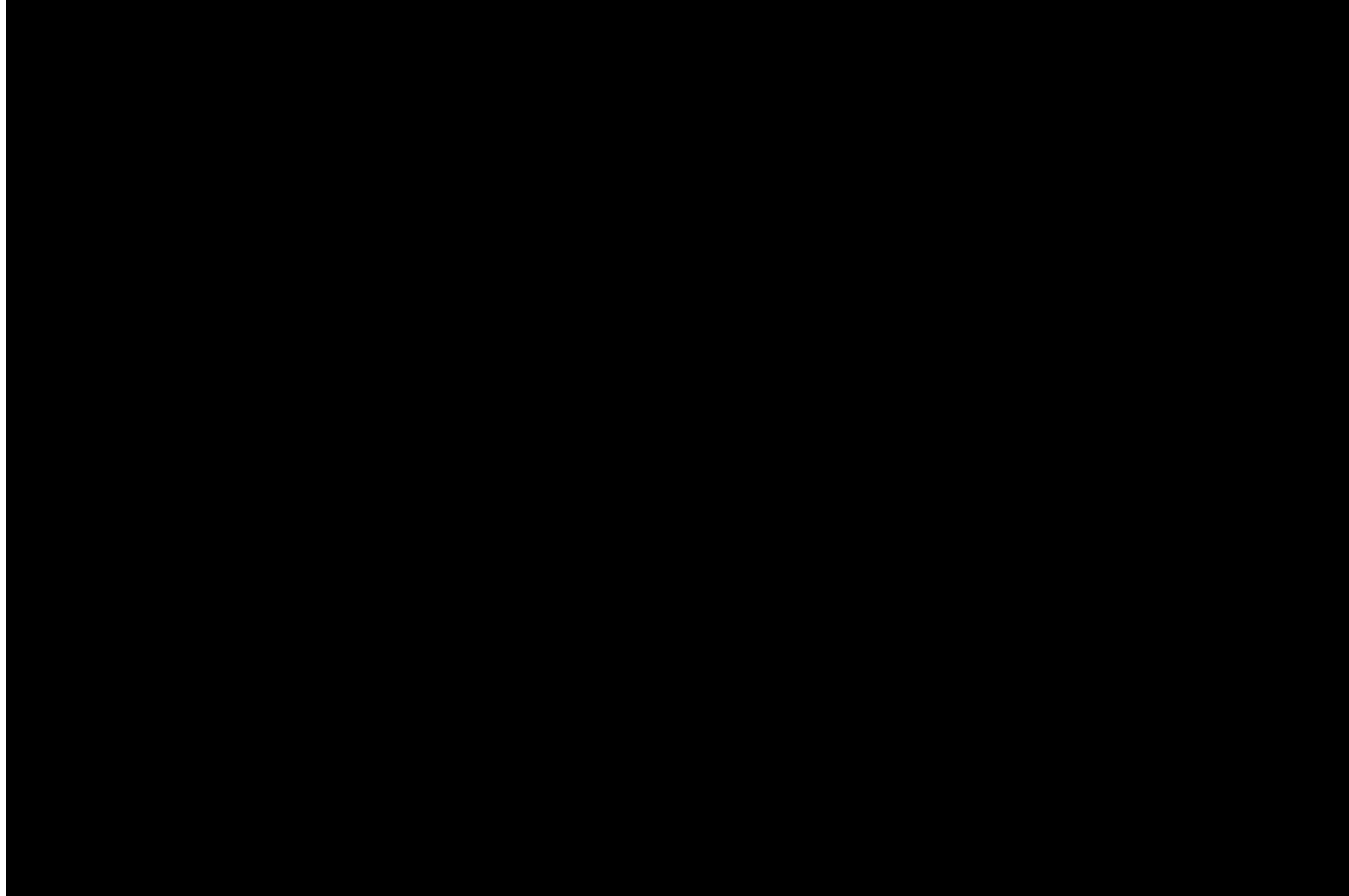


Magnetic Reconnection Model

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



THEMIS launches Feb. 15



Themis.mpeg