Our Sun

1. Basic Facts
2. Energy Generation
3. Internal Structure
4. Sunspots, Sunspot Cycle
5. Differential Rotation / Magnetic field
6. Space whether

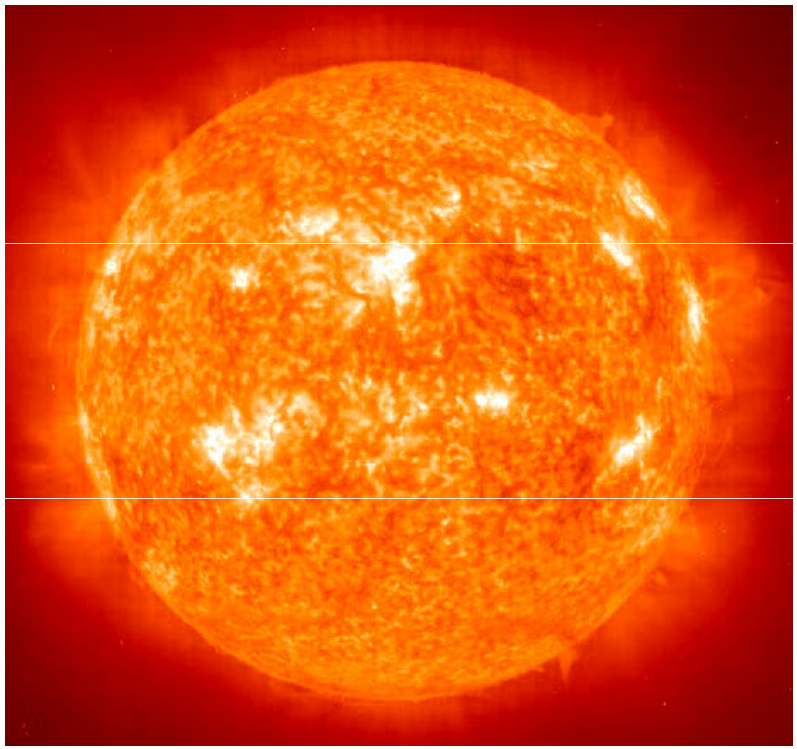
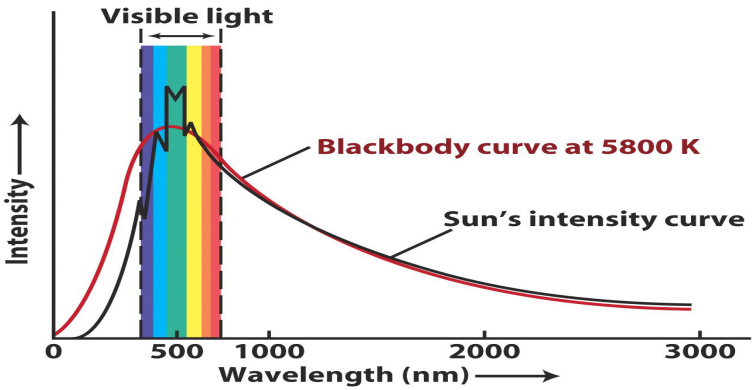


table 18-1 Sun Data

Distance from the Earth:	Mean: 1 AU = 149,598,000 km
	Maximum: 152,000,000 km
	Minimum: 147,000,000 km
Light travel time to the Earth:	8.32 min
Mean angular diameter:	32 arcmin
Radius:	696,000 km = 109 Earth radii
Mass:	1.9891×10^{30} kg = 3.33×10^5 Earth masses
Composition (by mass):	74% hydrogen, 25% helium,
	1% other elements
Composition (by number of atoms):	92.1% hydrogen, 7.8% helium,
	0.1% other elements
Mean density:	1410 kg/m^3
Mean temperatures:	Surface: 5800 K; Center: 1.55×10^7 K
Luminosity:	3.86×10^{26} W
Distance from center of Galaxy:	8000 pc = 26,000 ly
Orbital period around center of Galaxy:	220 million years
Orbital speed around center of Galaxy:	220 km/s

Basic Facts

- Radius: 700,000 Km
- Distance to Earth: 1 AU = 1.5 X 10^8 km
- Light travel time: 8 minutes
- Angular size: 30 arcmin
- Effective Surface Temperature: 5800 K



The Sun's energy is generated by thermonuclear reactions in its core

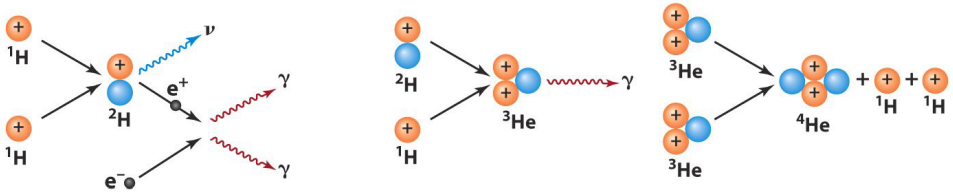
- Sun's total energy output: 10^{26} watts
- Hydrogen fusion occurs only at temperatures in excess of about 10^7 K
- In the Sun, hydrogen fusion occurs in the dense, hot core

Einstein's mass-energy equation

$$E = mc^2$$

Proton-Proton Chain Reaction

•The Sun's energy is produced by hydrogen fusion, a sequence of thermonuclear reactions in which **four hydrogen nuclei combine to produce a single helium** nucleus; called **proton-proton chain reaction**



(a) Step 1:

- Two protons (hydrogen nuclei, ^{1}H) collide.
- One of the protons changes into a neutron (shown in blue), a neutral, nearly massless neutrino (ν), and a positively charged electron, or positron (e^+).
- The proton and neutron form a hydrogen isotope (^{2}H).
- The positron encounters an ordinary electron (e^-), annihilating both particles and converting them into gamma-ray photons (γ).

(b) Step 2:

- The ^{2}H nucleus from the first step collides with a third proton.
- A helium isotope (^{3}He) is formed and another gamma-ray photon is released.

(c) Step 3:

- Two ^{3}He nuclei collide.
- A different helium isotope with two protons and two neutrons (^{4}He) is formed and two protons are released.

Proton-Proton Chain Reaction

4 H → He + energy + neutrinos

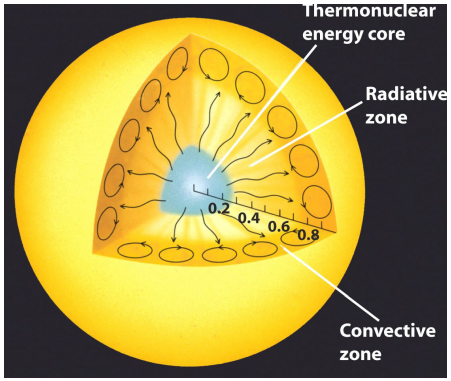
Mass of 4 H > Mass of 1 He

•In every second, 600 million tons of hydrogen converts into helium to power the Sun

•At this rate, the Sun can continue the hydrogen burning for more than 6 billion years.

Sun's Internal Structure: three layers

1. Energy Core: Hydrogen fusion takes place, extending from the Sun's center to about 0.25 solar radius
2. Radiative Zone: extending to about 0.71 solar radius
   - In this zone, energy travels outward through radiative diffusion
3. Convective Zone: an opaque zone at relatively low temperature and pressure
   - energy travels outward primarily through convection



The Sun's Atmosphere

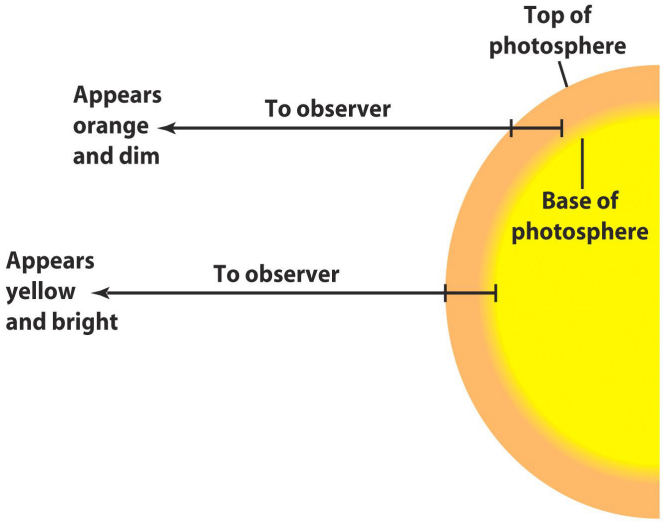
- The Sun atmosphere has three main layers:
  1. **Photosphere** (400 Km thick, innermost)
  2. **Chromosphere** (2000 Km thick, above photosphere)
  3. **Corona** (extended to millions of Kms)
- Everything below the solar atmosphere is called the solar interior

The photosphere is the lowest of three main layers in the Sun's atmosphere

- The photosphere (sphere of light) is the visible surface of the Sun
- It is only 400 km thick because of its opaqueness; Photons emitted below 400 km can not escape.
- Temperature decreases upward

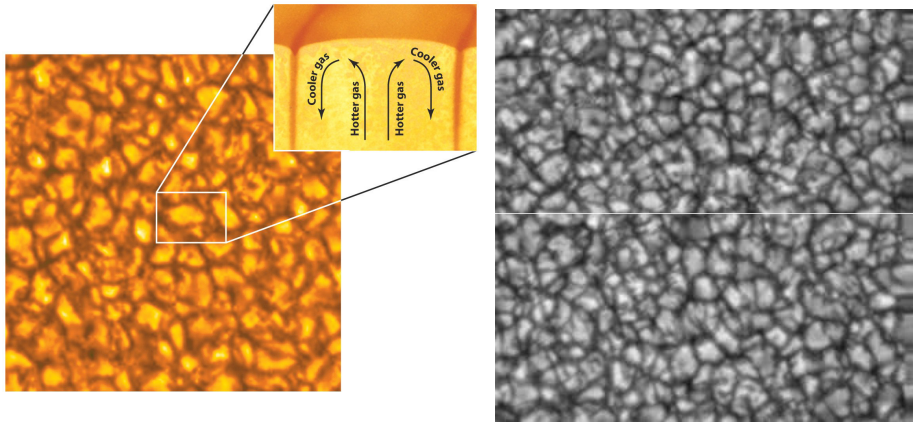
Photosphere: Limb Darkening Effect

At the limb, one can not see as deeply as at the center. The gas at higher altitude is less hot (or lower temperature), and thus emit less energy



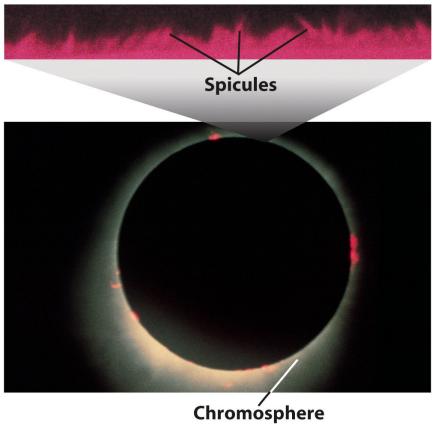
Convection in the photosphere produces granules

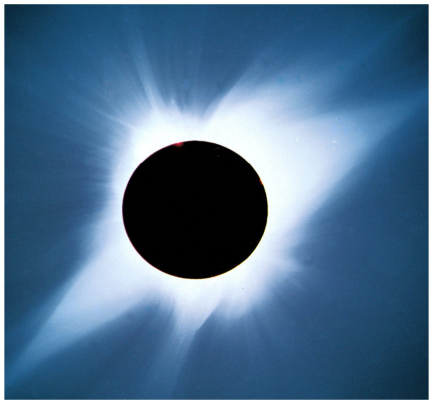
Granulation is the direct evidence of convection. Each granule is about 1000 km. Granules form, disappear and reform in cycles lasting a few minutes



The Chromosphere and Corona

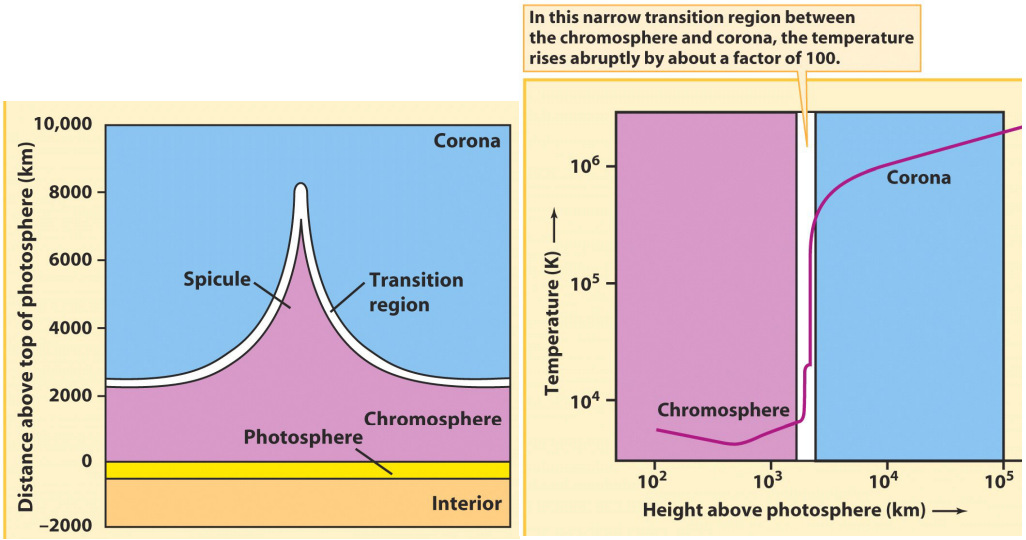
Above the photosphere is a layer of less dense but higher temperature gases called the chromosphere





The corona ejects mass into space to form the solar wind

The Sun's Atmosphere



The Sun's Magnetism

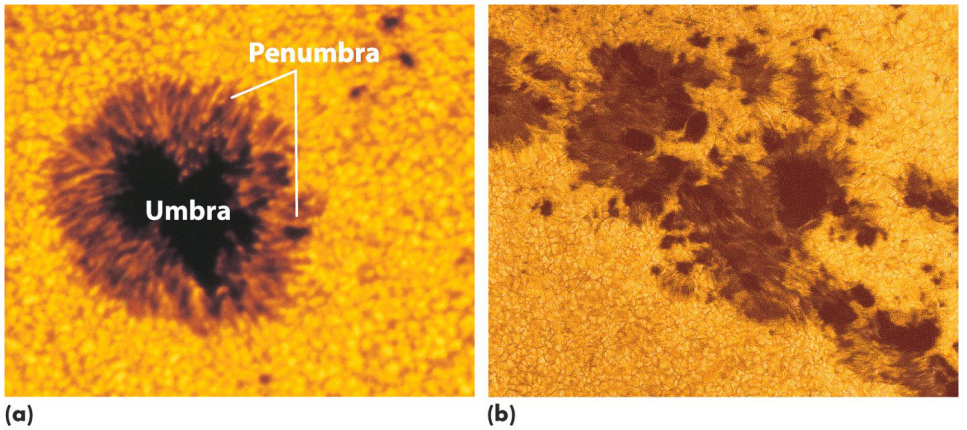
The outer corona is much hotter than the inner chromosphere and photosphere

The corona must be heated by a source other than the conduction or radiative diffusion from the underlying atmosphere, because the energy transfer of conduction and radiative diffusion is always from high temperature to low temperature

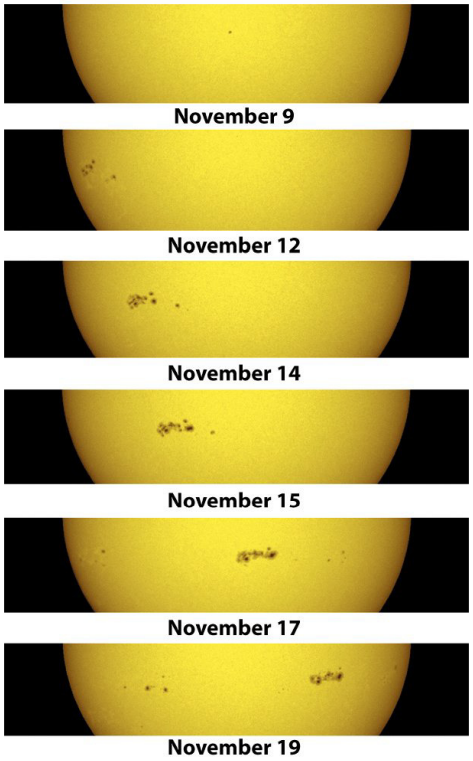
The corona heating is related to the ubiquitous presence of magnetic field in the Sun's atmosphere.

Sunspots

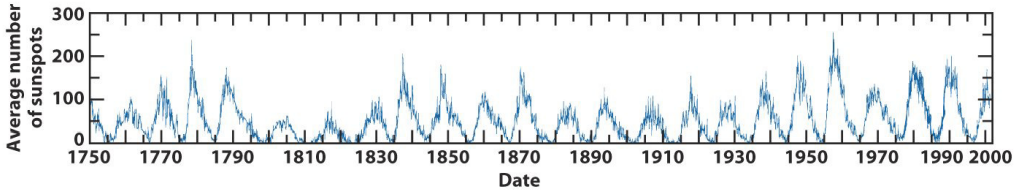
low-temperature regions in the photosphere
appears dark because it is cooler (radiate less energy)
Sunspot Umbra (core) and Penumbra (brighter border)



Tracking the Sun's Rotation with Sunspots



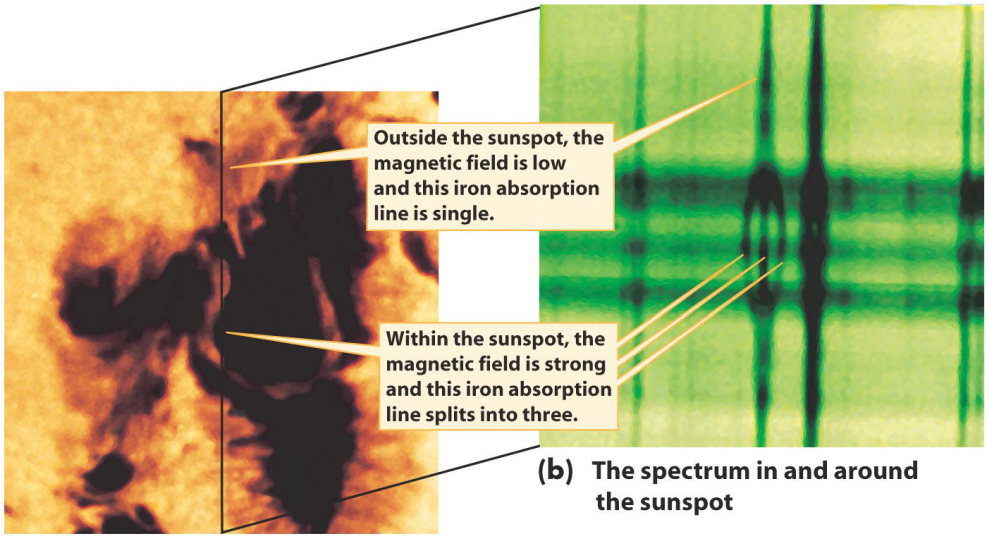
11-year sunspot cycle, or solar cycle



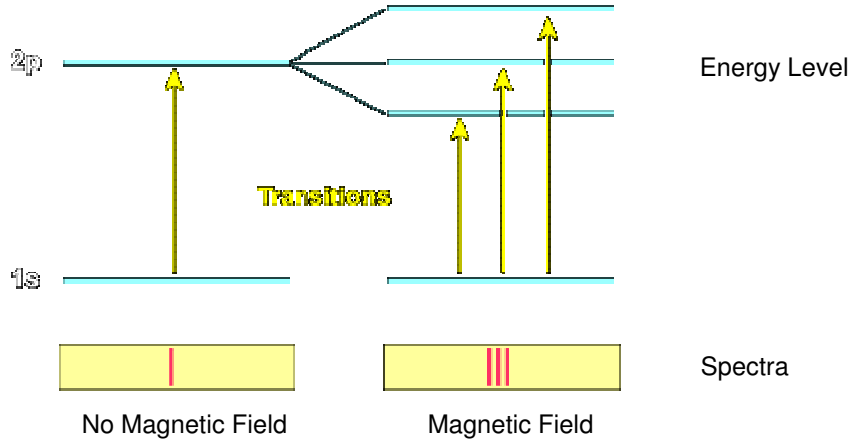
- The average number of sunspots increases and decreases in a regular cycle of approximately 11 years, with reversed magnetic polarities from one 11-year cycle to the next
- The last solar maximum was in 2011

Sunspots: Concentrated areas of magnetic field

- This is proved by direct measurement of magnetic field using Zeeman effect (spectral lines splits in magnetic fields)



Magnetic Field Measurement: Zeeman Effect



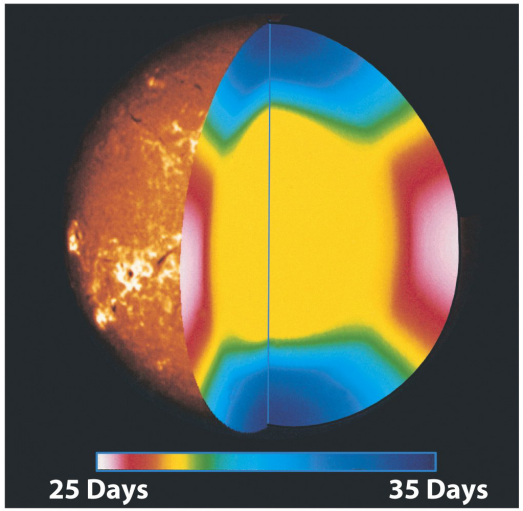
The splitting of a spectral line because of the presence of magnetic field

22-year of Solar Magnetic Cycle

- The Sun's polarity pattern completely reverse every 11 years
- In one 11-year sunspot cycle, the hemisphere that has preceding positive polarity will have preceding negative polarity in the next 11-year cycle, and vice versa
- The north and south magnetic poles of the Sun itself also reverses every 11 years
- The same magnetic pattern repeats after two sunspot cycle, or 22 years.

Differential Rotation of the Sun's Interior

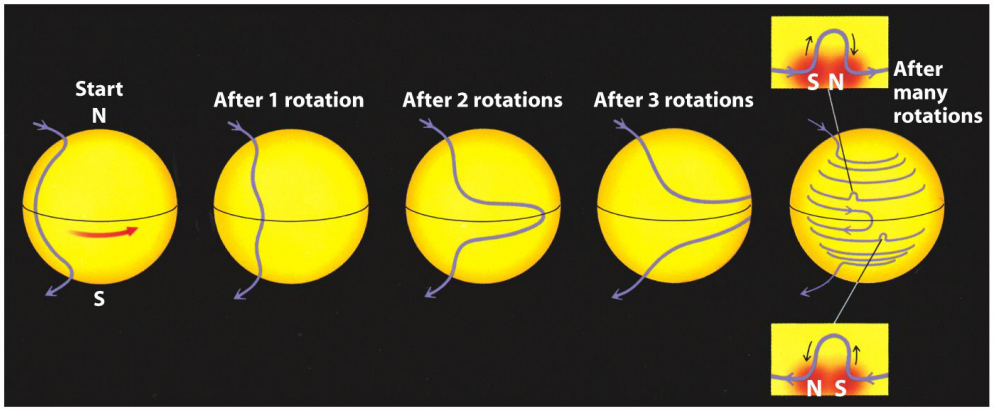
- The Sun's rotation varies with latitude and depth
- A short rotation period at the equator (25 days), and longer periods near the poles (35 days)



Differential rotation causes the magnetic fields

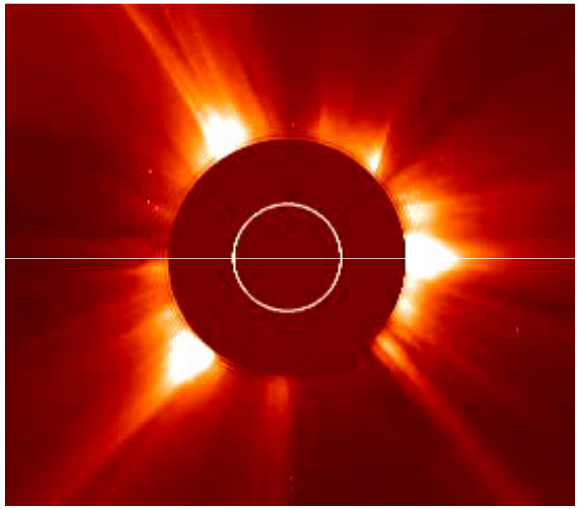
Solar Cycles are caused by the Sun's differential rotation and convection: Babcock's Magnetic Dynamo Model

Solar magnetic field is generated inside of the Sun by the mechanism called solar magnetic dynamo

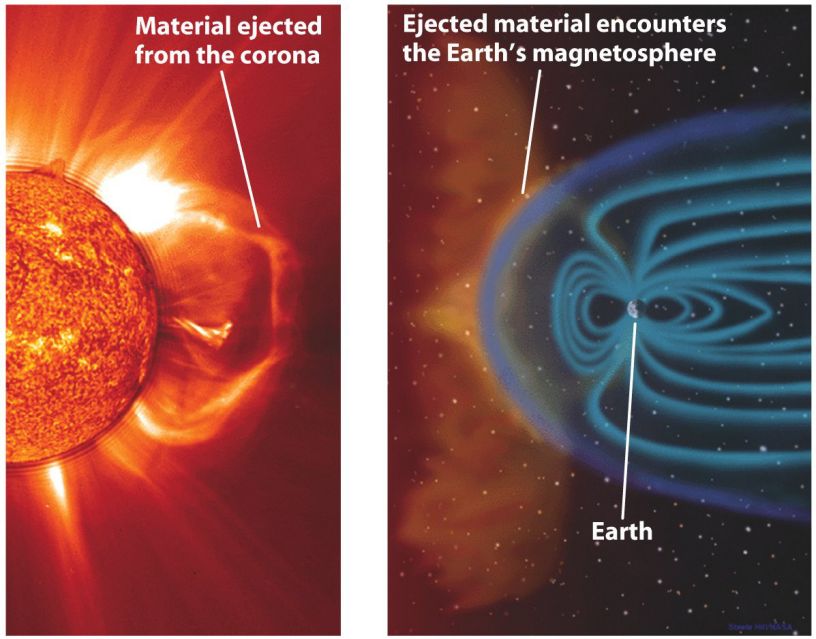


Active Sun: Coronal Mass Ejections

• A large scale eruption of coronal material and magnetic field. It is ejected into space at high speed. It impacts the Earth a few days later if at the right direction.



Space Weather Effect of Solar Activities



(a) A coronal mass ejection (b) Two to four days later