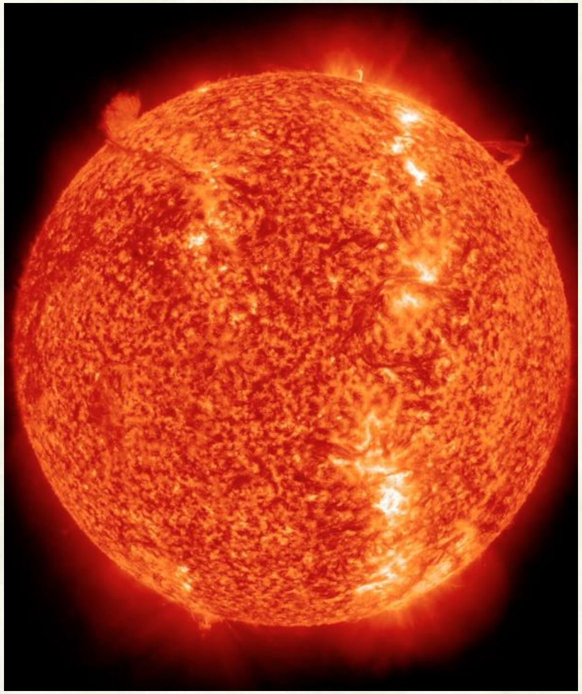
The Sun

ASTR 101

11/17/2014

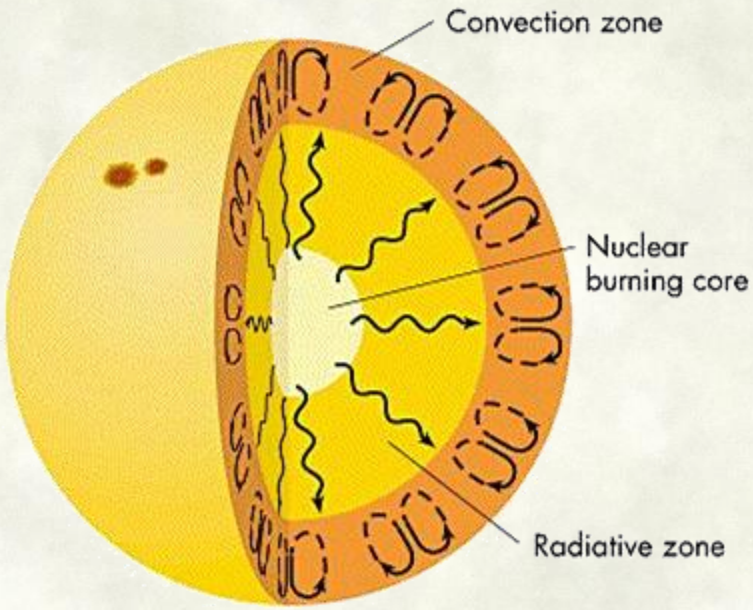
- Radius: 700,000 km (110 $R_{\oplus}$)
- Mass: 2.0×10^{30} kg (330,000 $M_{\oplus}$)
- Density: 1400 kg/m^3
- Rotation: Differential, about 25 days at equator, 30 days at poles.
- Surface temperature: 5800 K
- Total luminosity is about 4×10^{26} W
  - Solar constant—amount of Sun's energy reaching Earth—is 1400 W/m^2 (Solar constant).

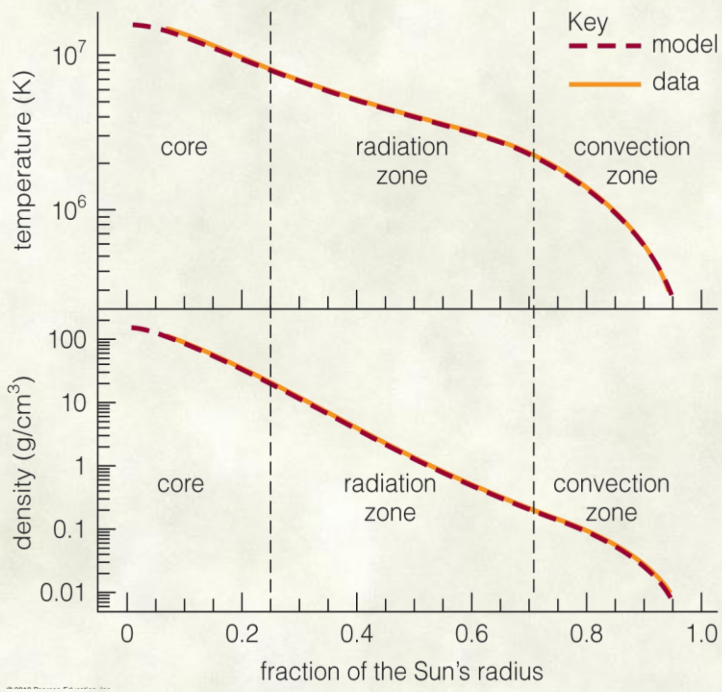


Sun is the nearest star, and is the only star whose surface we can study.

The sun is the source of almost all energy on the earth which life depends on. It been a subject of worship in most early societies.

Structure of the Sun

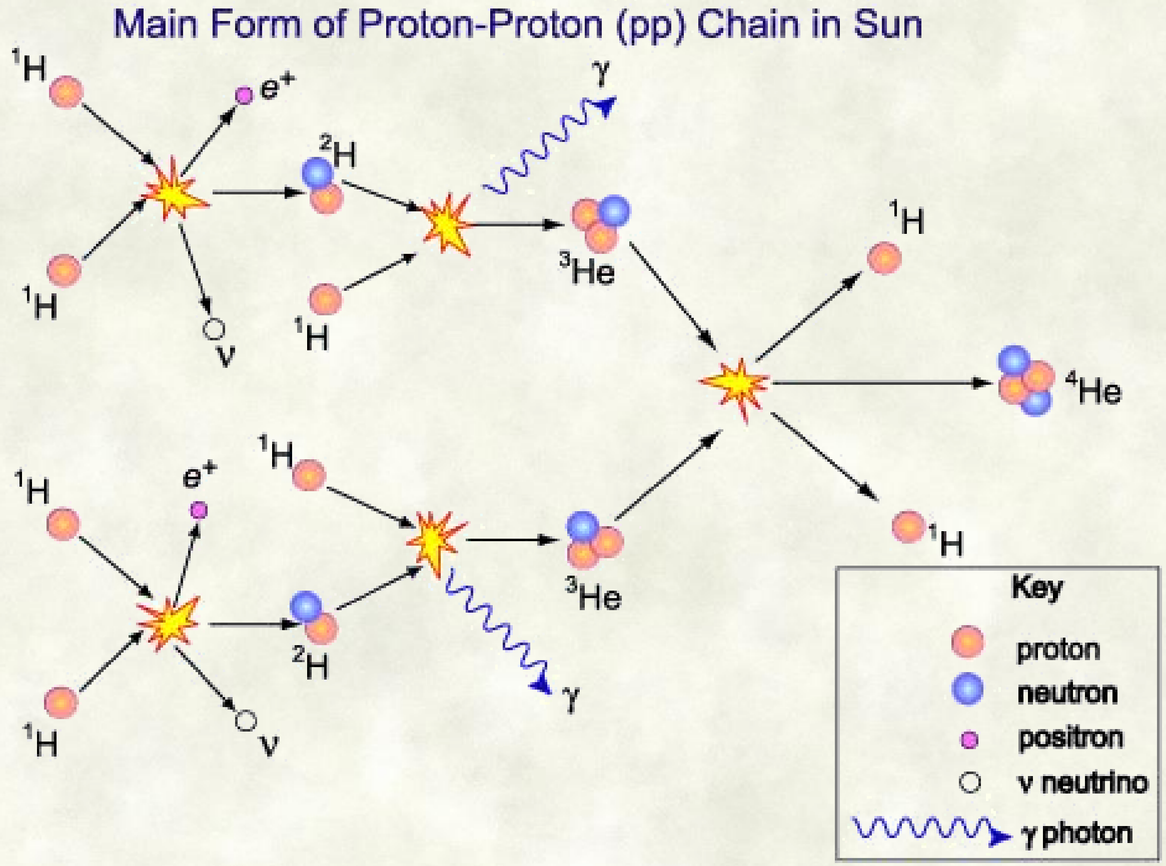




Interior of the Sun can be divided in to several layers:

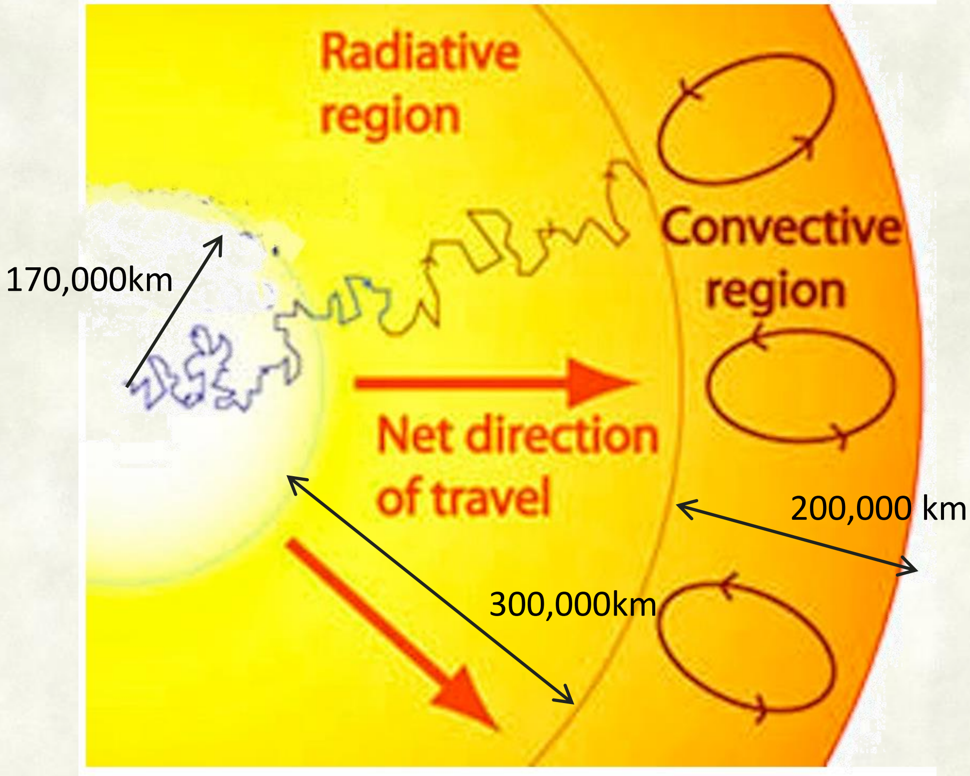
- **Core:** extending from the Sun's center to about 0.25 solar radius 170,000km.
- Temperature of the core is about 15 million K, well above the temperature needed for hydrogen fusion to take place.

The Proton-Proton Chain



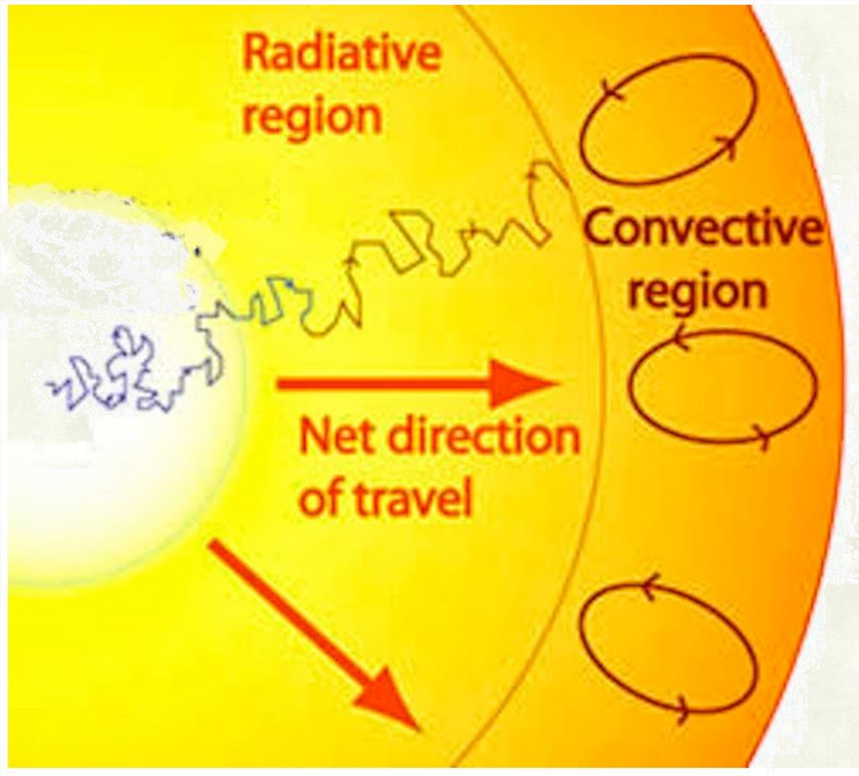
- 600 million tons of hydrogen turn into 596 million tons of helium in the sun's ore. 4 million tons/sec turned into energy, 4×10^{26} W. (.7% of mass becomes energy)

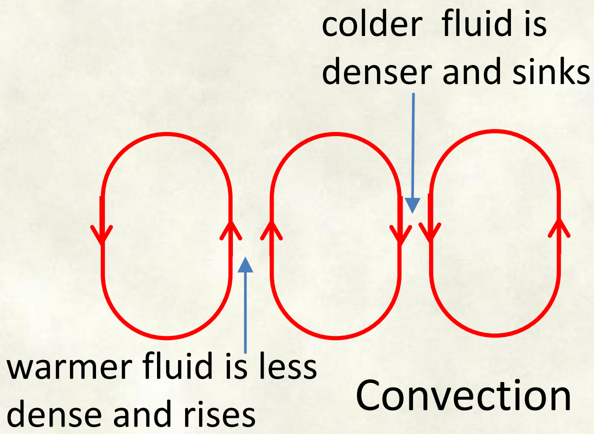
The Radiative Zone



- The core is surrounded by a radiative zone extending to about 0.7 solar radius. In this zone only mechanism energy can travel outward is through radiative diffusion.
  - In the deep interior, the stellar material is very opaque, so radiation travels only a small distance before it is absorbed. It is then re-emitted in a random direction, absorbed after a small distance, remitted, and so on until it reaches the surface, which takes about hundred thousand years.

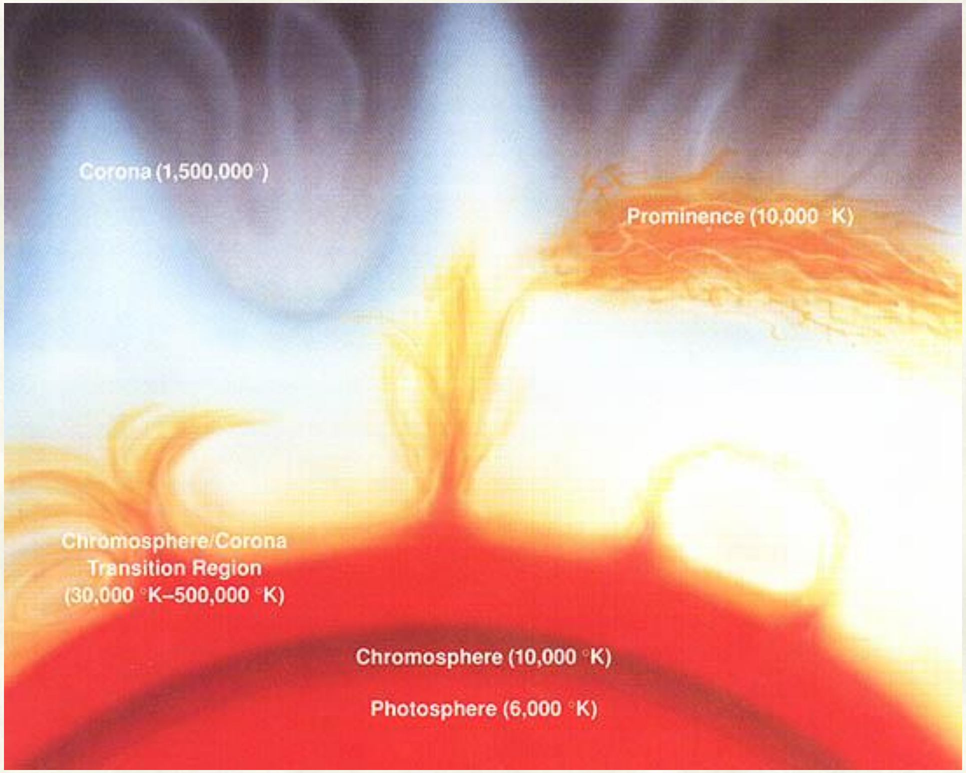
The Convection zone

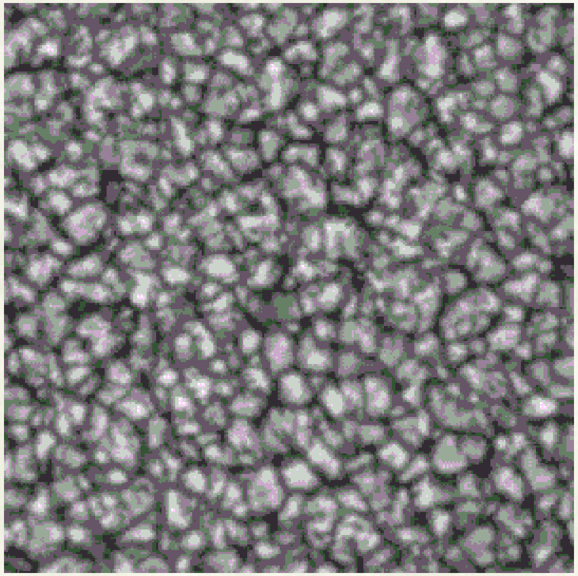




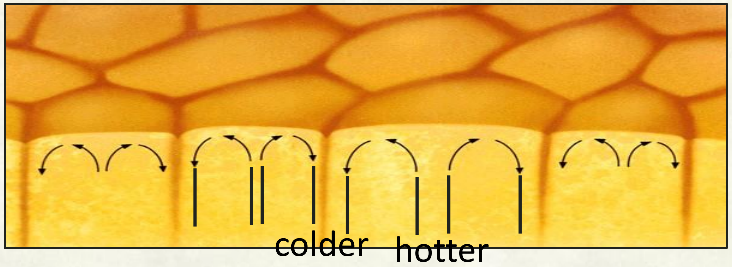
The radiative zone is surrounded by a rather opaque convective zone of gas at relatively low temperature and pressure. In this zone, conditions are favorable for convection, so energy travels outward primarily through convection.

Solar Atmosphere



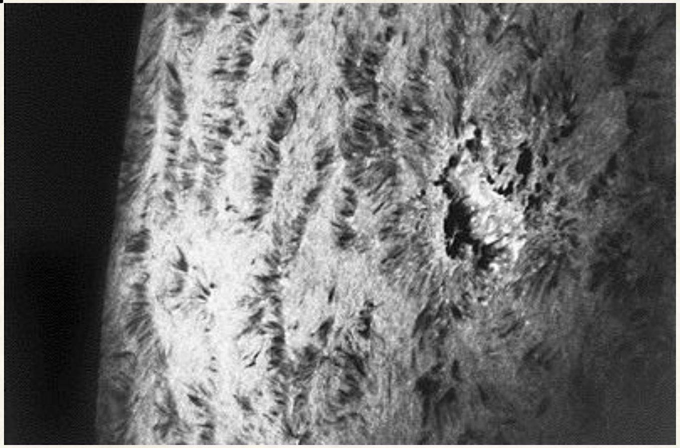


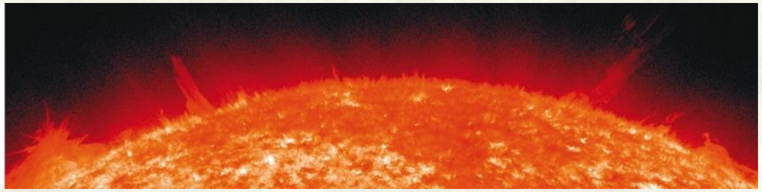
A fast motion image of the photosphere



- The Sun's atmosphere has three main layers: the photosphere, the chromosphere, and the corona.
- **Photosphere** is the lowest layer in the solar atmosphere, just above the convection zone. It is transparent, so light can escape without further absorption and scattering. So photosphere is the visible surface of the Sun.
- Photosphere appears granular, due to the convection cells in the photosphere(1000-2000 km in size). Areas of upwelling hot material looks brighter, they are surrounded by areas of sinking colder darker looking material.

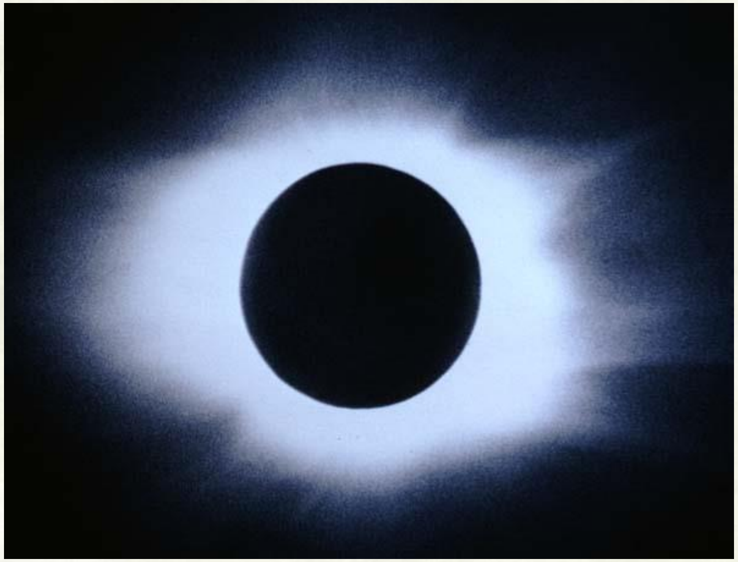
The Chromosphere

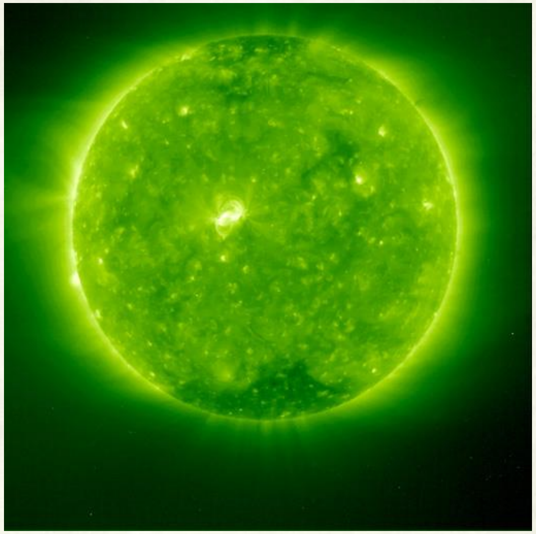




- Above the photosphere is a layer of less dense but higher temperature gases called the chromosphere. Spicules extend upward from the photosphere into the corona.
- The chromosphere is 2000-3000 km thick. It glows faintly relative to the photosphere, so difficult to see directly , unless Moon covers photosphere and not chromosphere during a solar eclipse.
- Small solar storms in the chromosphere emits spikes of gas called *spicules,* that rise through it.
- They short-lived (few minutes) narrow jets of gas rising out of the chromosphere at supersonic speeds up to tens of thousands of kilometers. Spicules are much denser than the surrounding gas, so they are seen dark (by absorption of light) against the bright chromosphere.

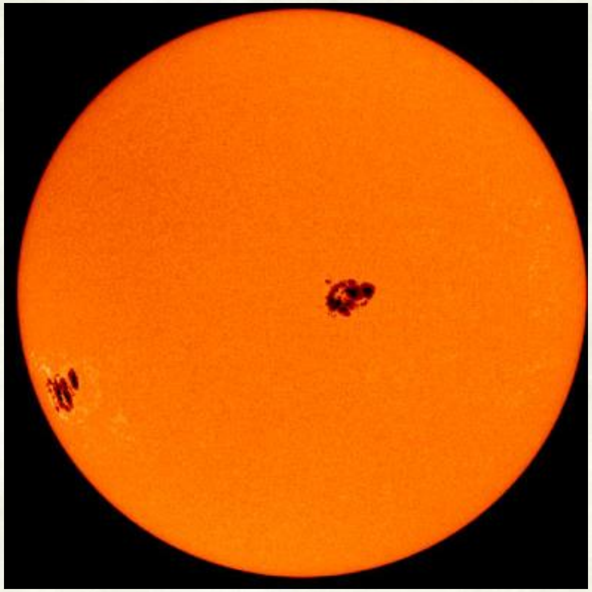
The Corona

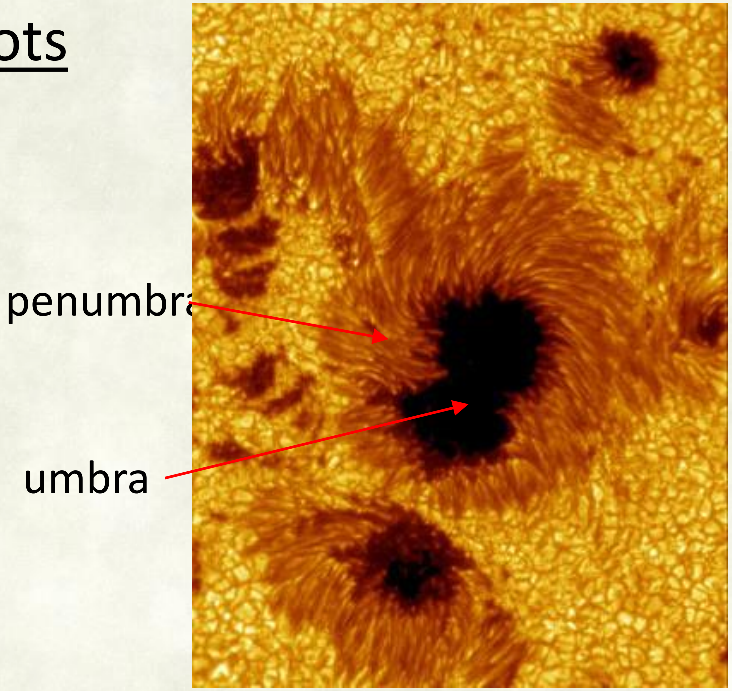


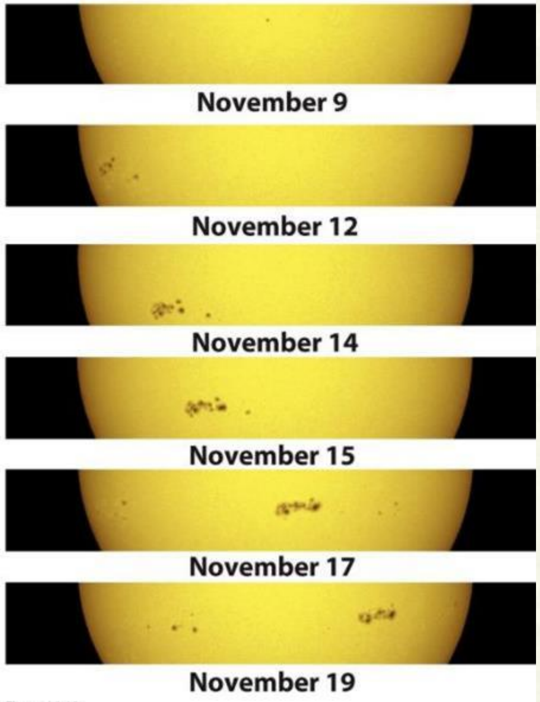


- The outermost layer of the solar atmosphere, the corona, is made of very high-temperature gases at extremely low density.
- It is faint, directly visible only during eclipses.
- Its temperature is very high 1- million K. So most of the elements in the corona is highly ionized.
- Fast-moving ions can escape the Sun's gravitational attraction. Moving outward at hundreds of kilometers/second, these positive and negative charges escaping the sun and travel outward are called the **solar wind**. Which travel to the farthest reaches of the solar system

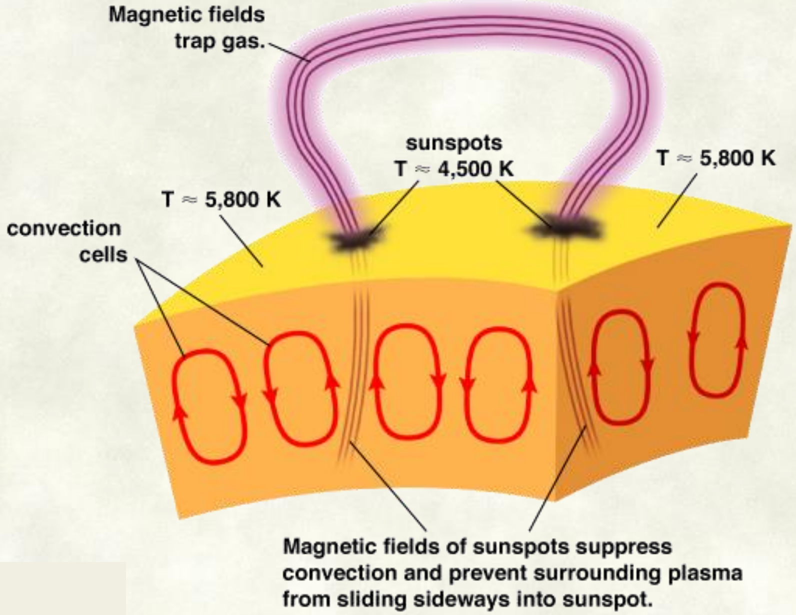
Sun Spots





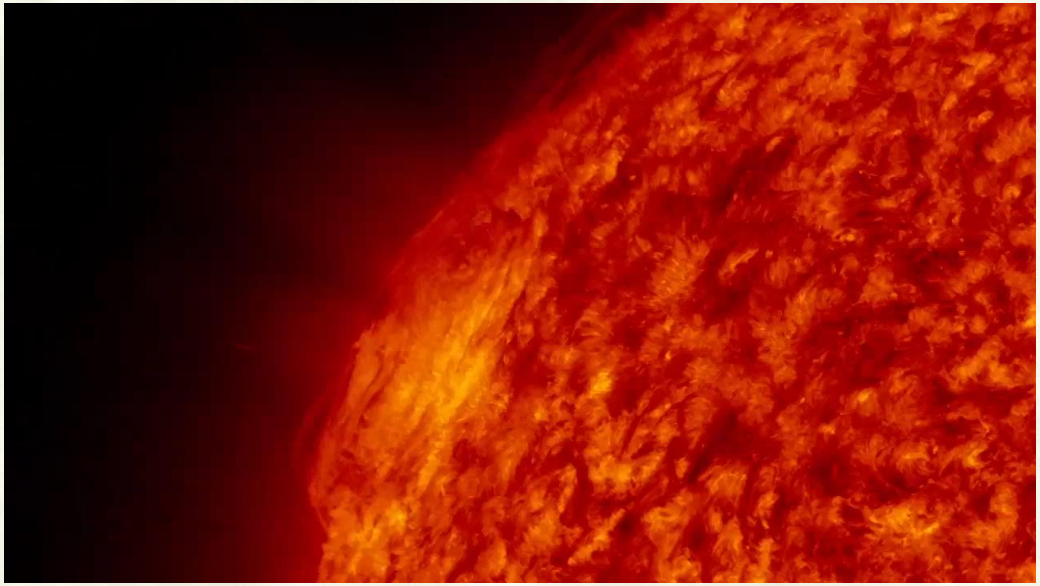


- Dark features on the sun’s photosphere. They appear dark because slightly cooler than the surroundings. (4000 K, compared with 5700 K for the surroundings).
- Sun spots can be as large as 50,000 km, and often appear as groups. Sunspots develop and persist for periods ranging from hours to months, and are carried around the surface of the Sun by its rotation .
- A typical sunspot consists of a dark central region called the *umbra* and somewhat lighter surrounding region called the *penumbra*



- Sunspots are produced by local concentrations of the Sun's magnetic field, in the form of loops.
- Since solar material is highly ionized plasma, the magnetic fields exert forces on them. This influence the convective motion beneath the photosphere.
- That hinder the convection of heat to the surface by making it harder for the hot gases to rise.
  - Thus, the region where there are strong magnetic fields tends to be cooler than the surrounding region and thus appears darker than the surrounding regions at higher temperature.
- Because sunspots are magnetic, they occur in pairs where one is a north pole while the other is a south pole.

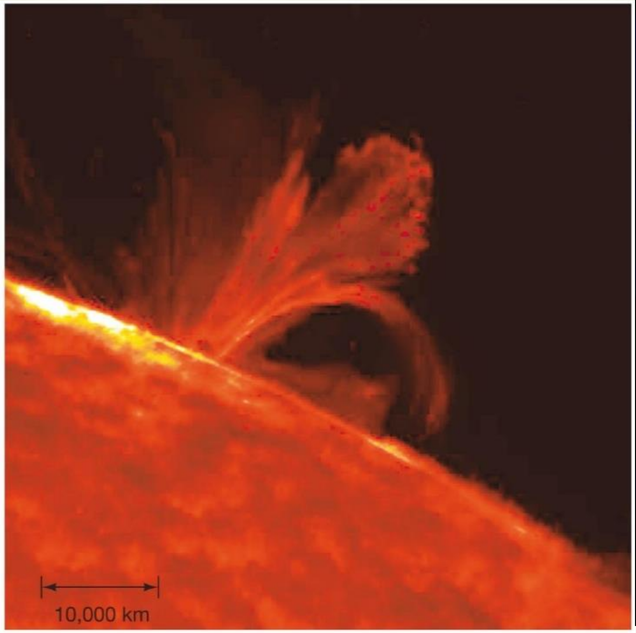
Solar prominences

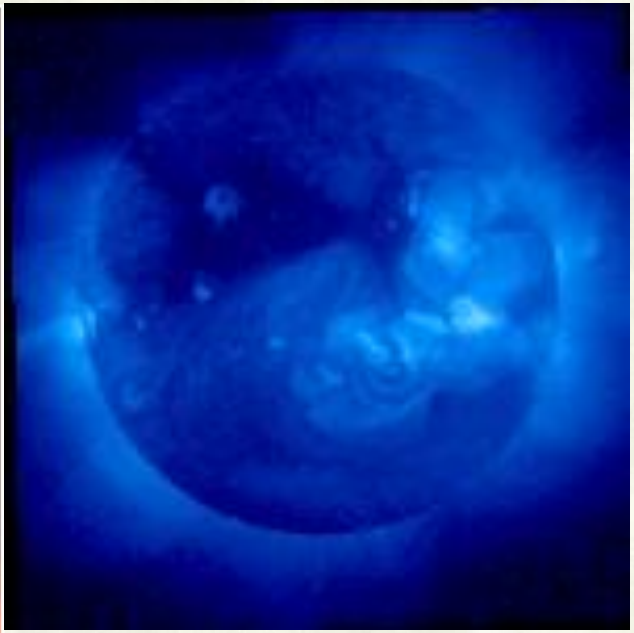



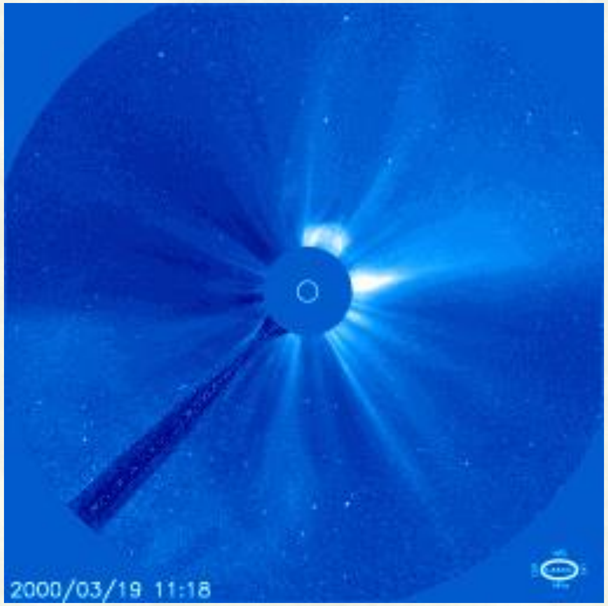
http://science.nasa.gov/science-news/science-at-nasa/2010/21apr_firstlight

- Areas around sunspots are active, large eruptions may occur in photosphere
- prominences are clouds of gas that erupt from disturbed regions near sunspots, extending outward from the Sun’s surface, often in a loop shape.
- The sun's magnetic field can hold them in place for days.

Solar Flares







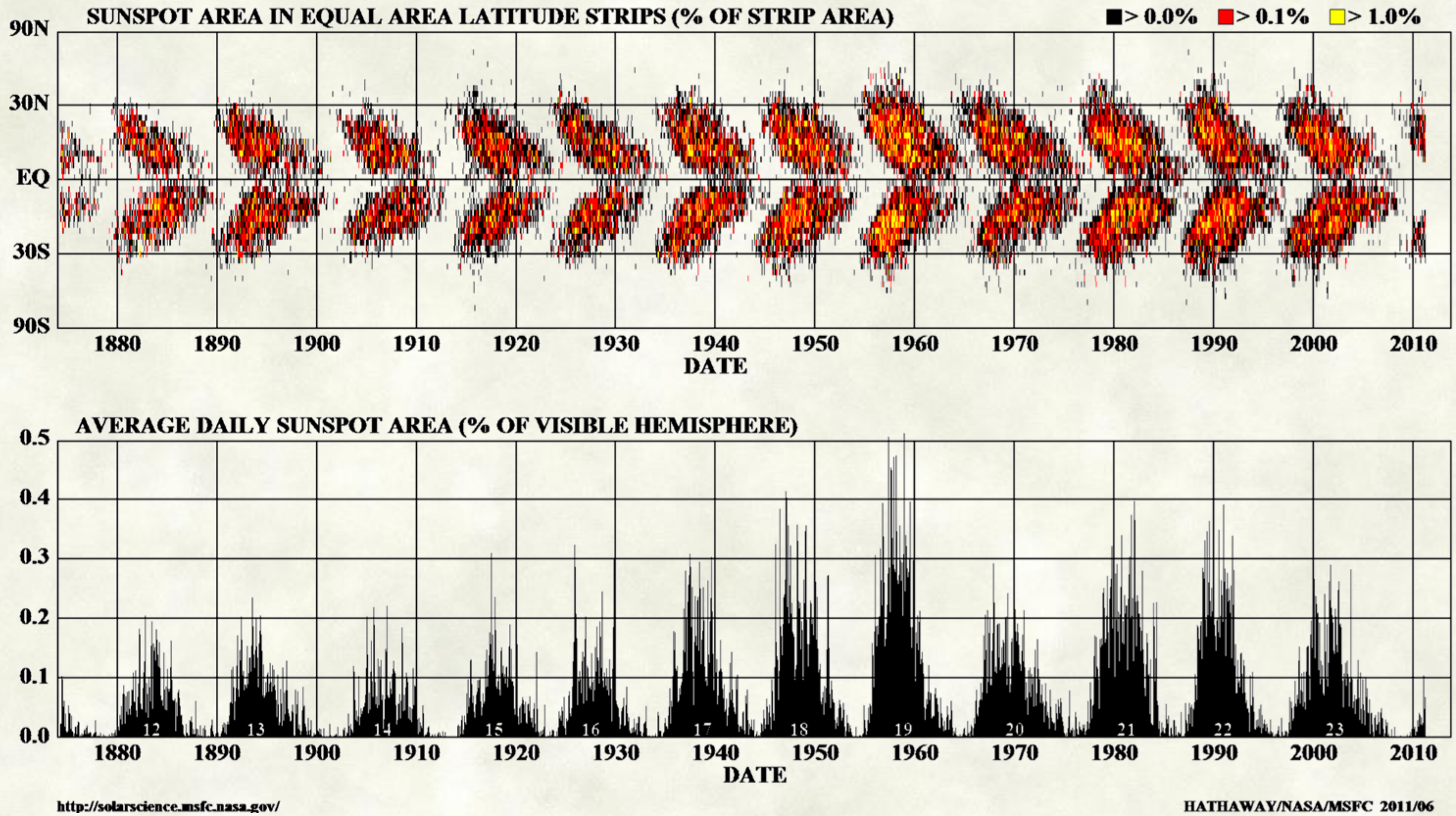
Sun in X-ray

- Solar flare is a large explosion on Sun’s surface, comparable in size to a prominence, but shorter in duration, seconds or minutes rather than days.
- A coronal mass ejection is a much larger eruption that involves immense amounts of gas from the corona.
- Solar flares and coronal mass ejections ionize the atmosphere, create geomagnetic storms, disrupting electronics, radio communication, and endangering satellites and astronauts, even electrical power plants.

The Solar Cycle

Latitude of sunspots

number of sunspots



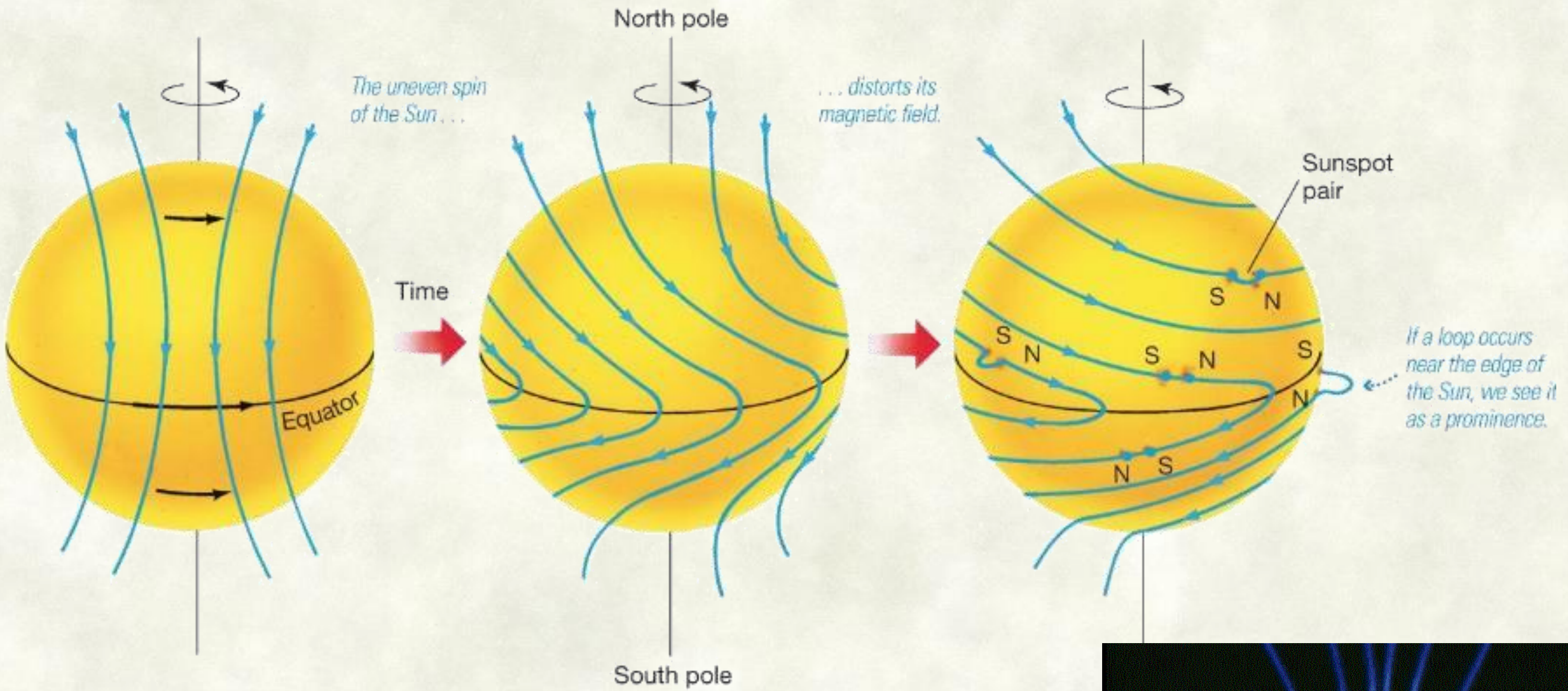
Butterfly diagram.

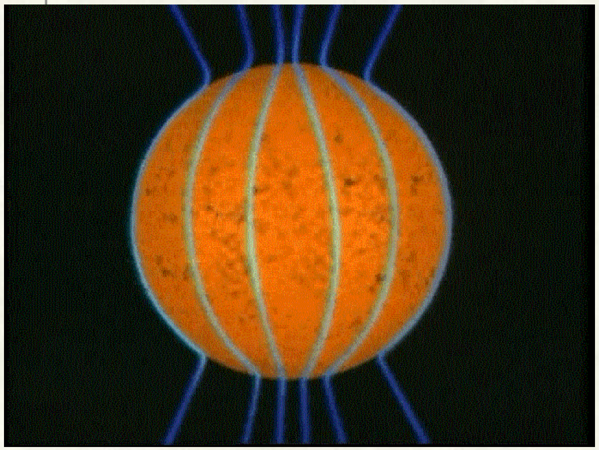
- The number of sunspots varies over an 11-year period.
  - Number of sunspots rises from ‘solar minimum’ to ‘solar maximum’, the numbers of flares and prominences also rise.
  - Sunspots tend to emerge over a range of higher latitudes after a solar minimum and later as the cycle progress, toward the solar equator.

Formation of magnetic loops and the solar cycle

slower

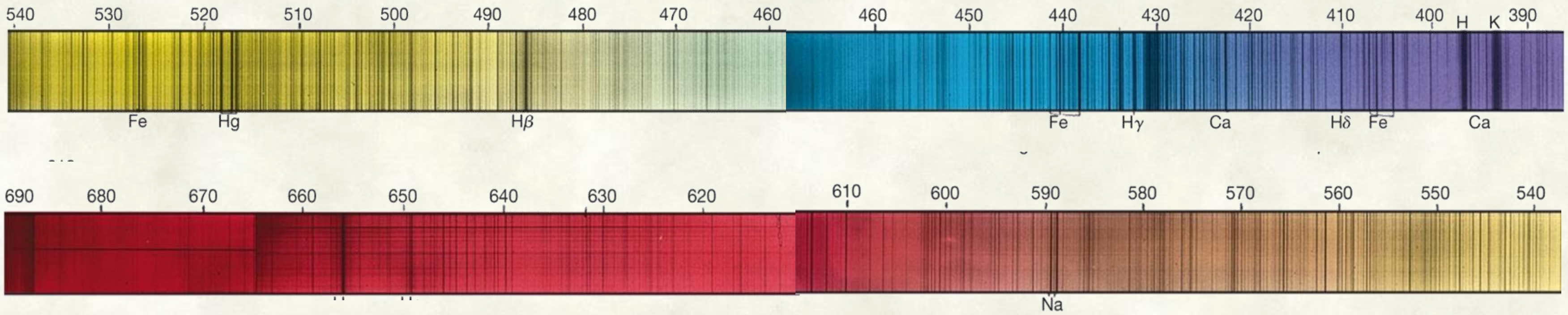
faster





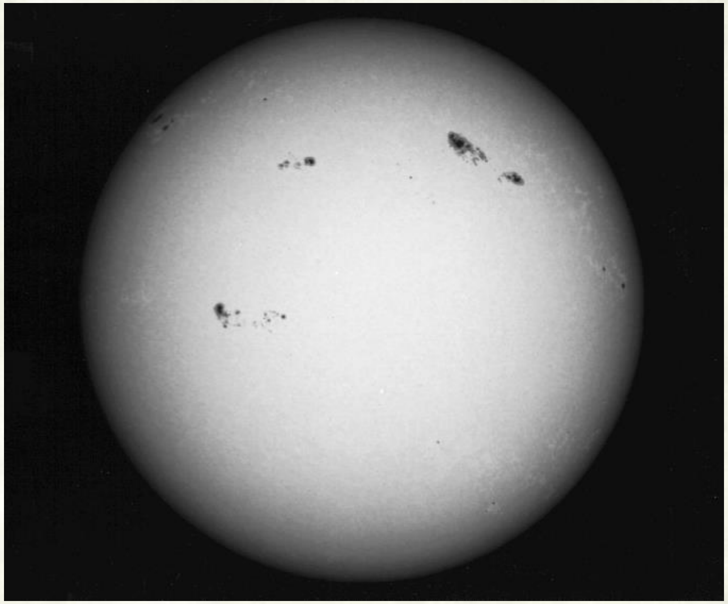
- Magnetic loops on the sun surface which create sunspots are formed when the Sun’s differential rotation wraps and distorts the solar magnetic field.
- Occasionally, the field lines burst out of the surface and loop through the lower atmosphere, and loop through the lower atmosphere, thereby creating a sunspot pair.

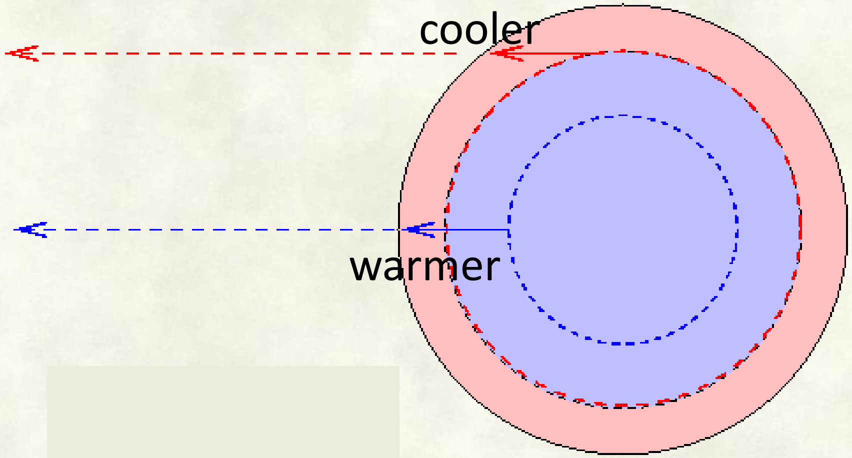
The Solar spectrum



- The solar spectrum consists of a continuum with thousands of dark absorption lines superposed.
- The lines are called the Frauenhofer lines after Joseph Frauenhofer who discovered them in 1814. Solar spectrum is sometimes called the Frauenhofer spectrum.
- Spectral classification of the Sun is G2
- These lines are produced primarily in the photosphere, by hydrogen and other elements.

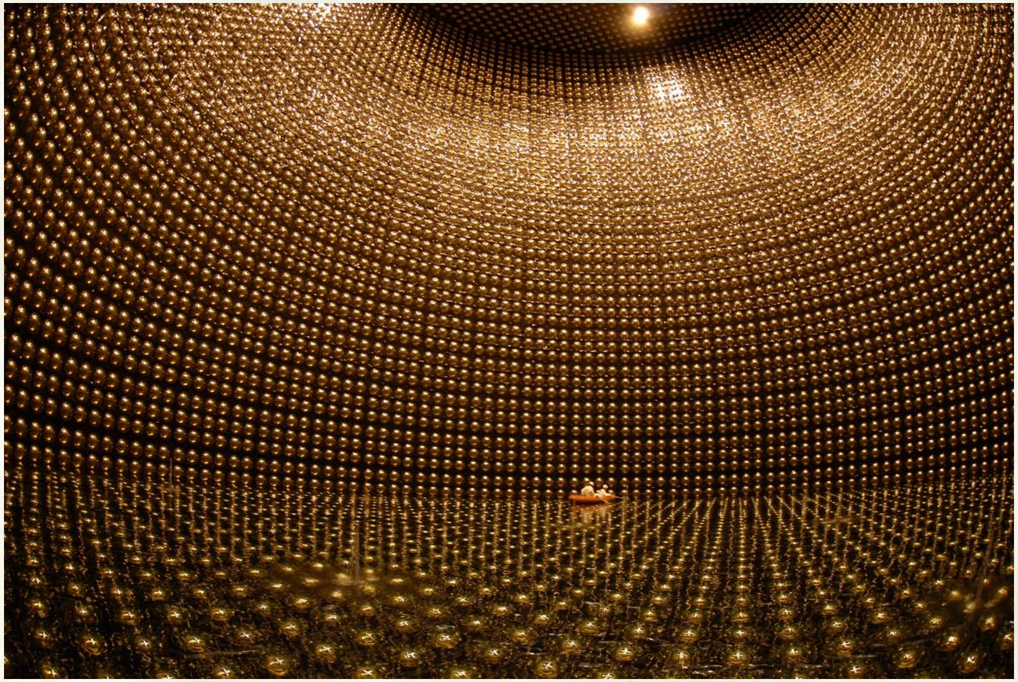
Limb darkening



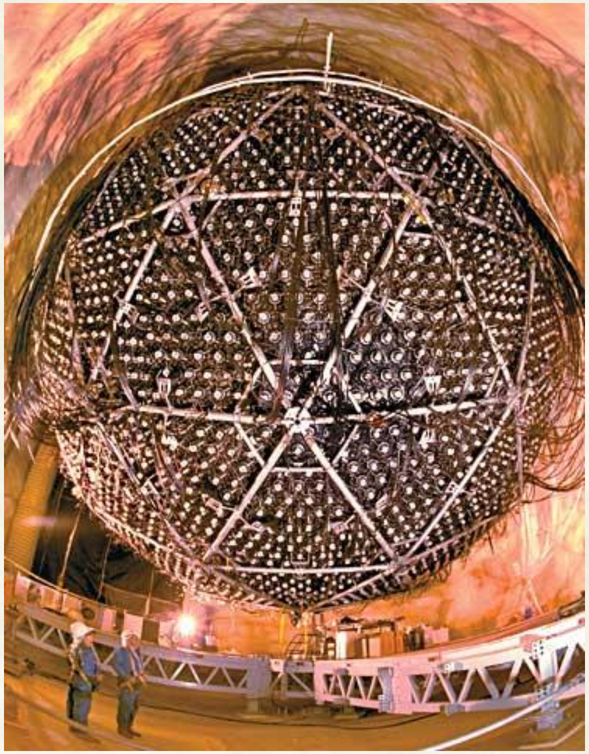


- Limb darkening is the gradual decrease in brightness of the disk of the Sun as observed from its center to its edge (called limb, it also becomes redder).
- Two factors contribute to the limb darkening.
  - The density of the solar photosphere decreases as the distance from the center increases
  - The temperature of the photosphere decreases as the distance from the center increases.
- At the center of the solar disk, an observer sees the deepest and warmest layers that emit the most light.
- At the limb, only the upper, cooler layers that produce less light can be sen.
- Observations of solar limb darkening are used to determine the temperateure structure of the Sun's atmosphere.

Solar Neutrinos



Inside the Super-Kamiokande Neutrino Detector- Japan



Sudbury Neutrino Detector Canada

- Since large number of neutrinos are produced in the hydrogen fusion process, working of the sun can also be studied observing those neutrinos.
- Neutrinos interact only very weakly interact with matter, so large detectors are used to record few neutrinos a day.
- Neutrinos going through a medium (water) interact with matter and produce particles, they generate tiny speck of light, which is detected by photomultiplier tubes (extremely sensitive light detectors)