Sunspots and Solar Spectrum

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Goals

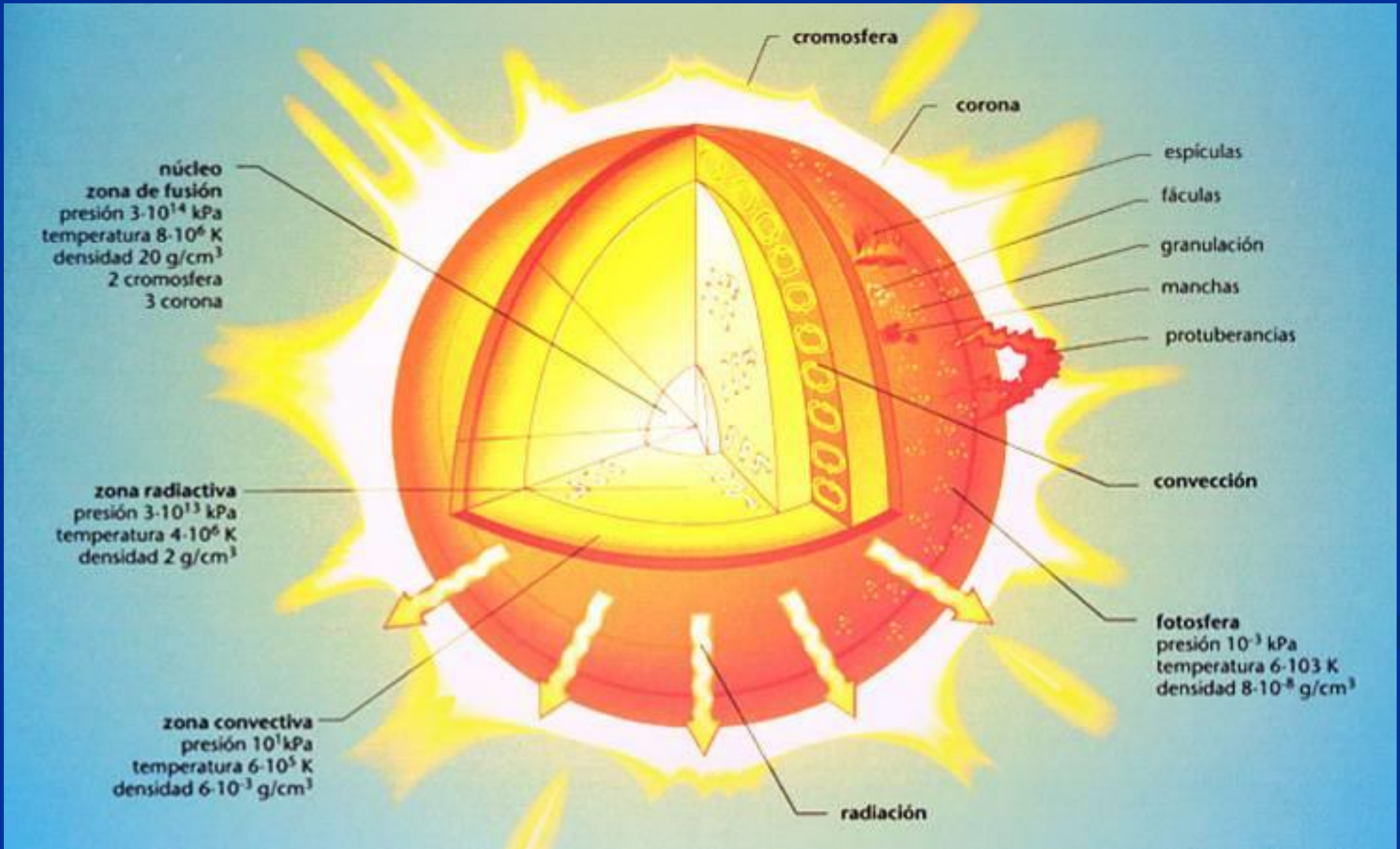
- Understand the nature of the solar spectrum
- Understand the generation of the solar spectrum
- Understand the nature of sunspots
- Understand the historical significance of Galileo's work on sunspots

Solar Radiation

Almost all the energy (heat and light) that we use on Earth comes or has come from the Sun

Solar Radiation

The radiation is created in the core of the Sun, at a very high pressure and at a temperature of 15 million degrees. It is produced through nuclear fusion reactions.



$4\,{}^{1}_{1}H \rightarrow {}^{4}_{2}He + 2e^{+} + 2\nu + 2\gamma$

Solar Radiation

- 4 protons (hydrogen nuclei) come together to form a helium atom (fusion).

$$4\,{}^{1}_{1}H \rightarrow {}^{4}_{2}He + 2\,e^{+} + 2\,\nu + 2\,\gamma$$

- The resulting mass is less than the mass of initial 4 protons since the "left-over" mass is transformed into energy:

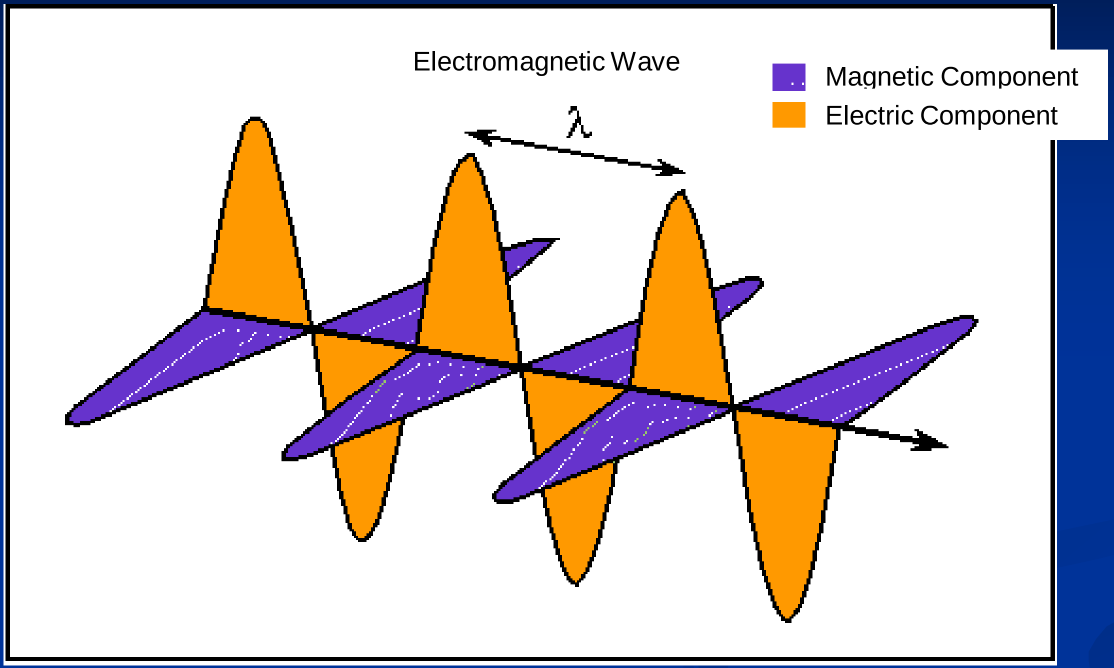
$$E = mc^{2}$$

- Every second, 600 million tons of hydrogen are converted into 595.5 million tons of helium. The rest of the mass is converted into energy.
- The Sun is so massive that, even losing at this rate, it will last billions of years.

Solar Radiation

The energy travels from the surface of the Sun at a speed of 299,793 km/s. It takes 8 minutes to reach the Earth.

Solar Spectrum: Radiation

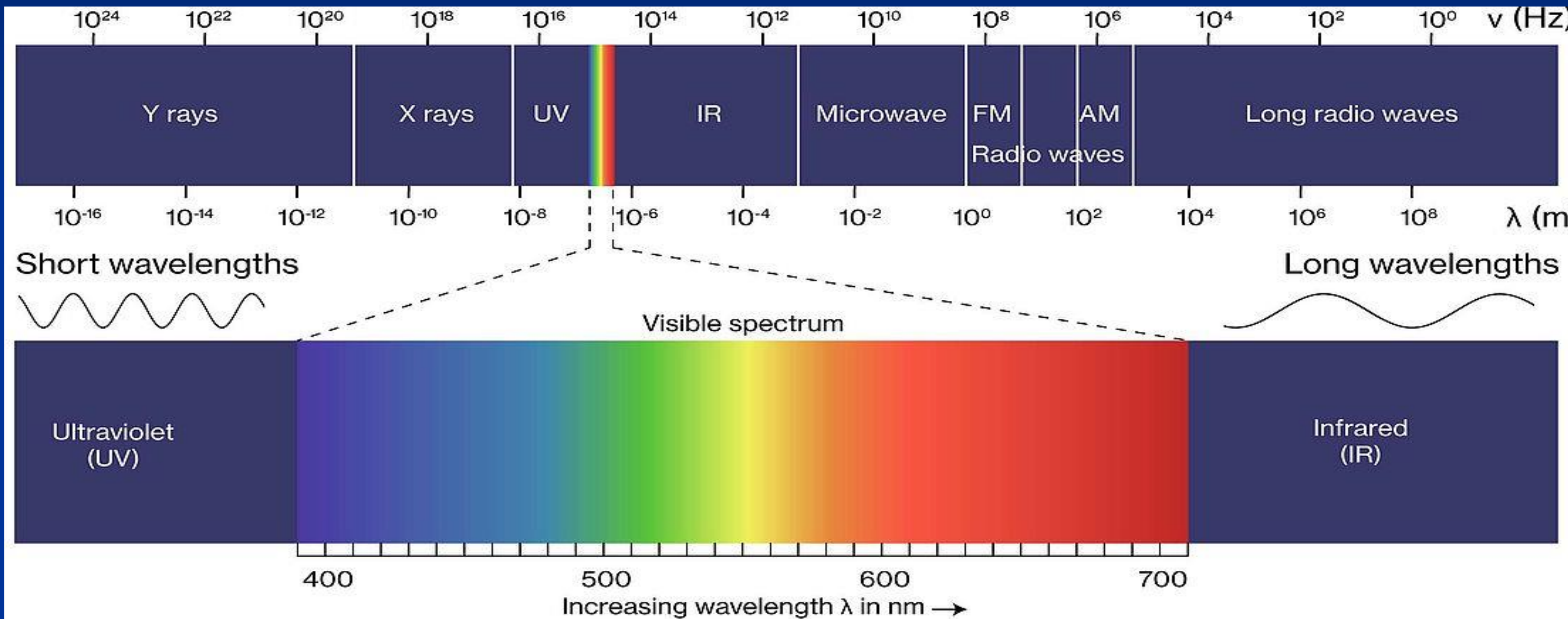


Wavelength λ, frequency ν and the propagation speed c of electromagnetic waves are related by the equation:

$$c = \lambda \cdot \nu$$

Solar Spectrum: Radiation

The Electromagnetic Spectrum



Gamma

X-ray

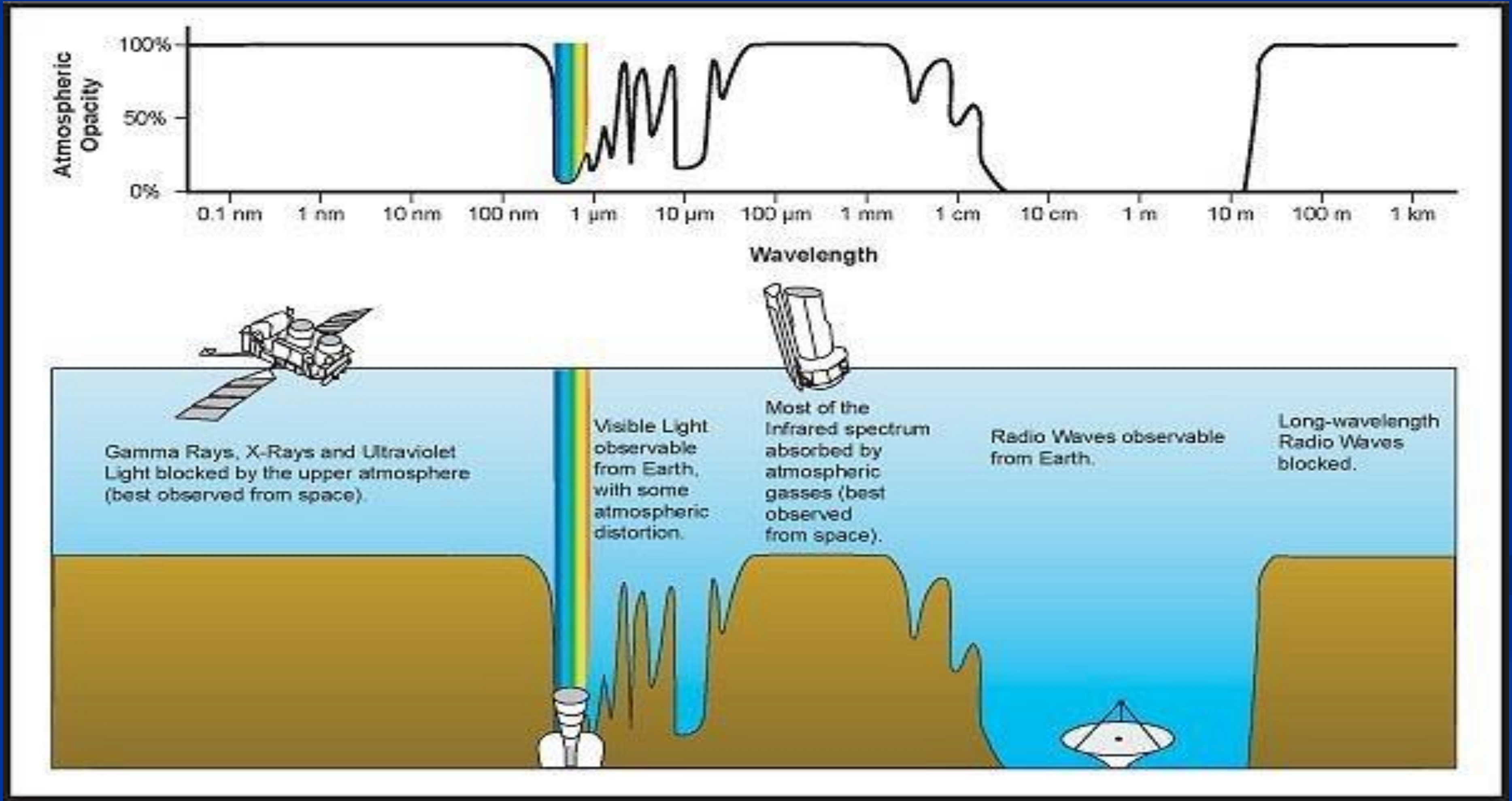
Visible

Infrared

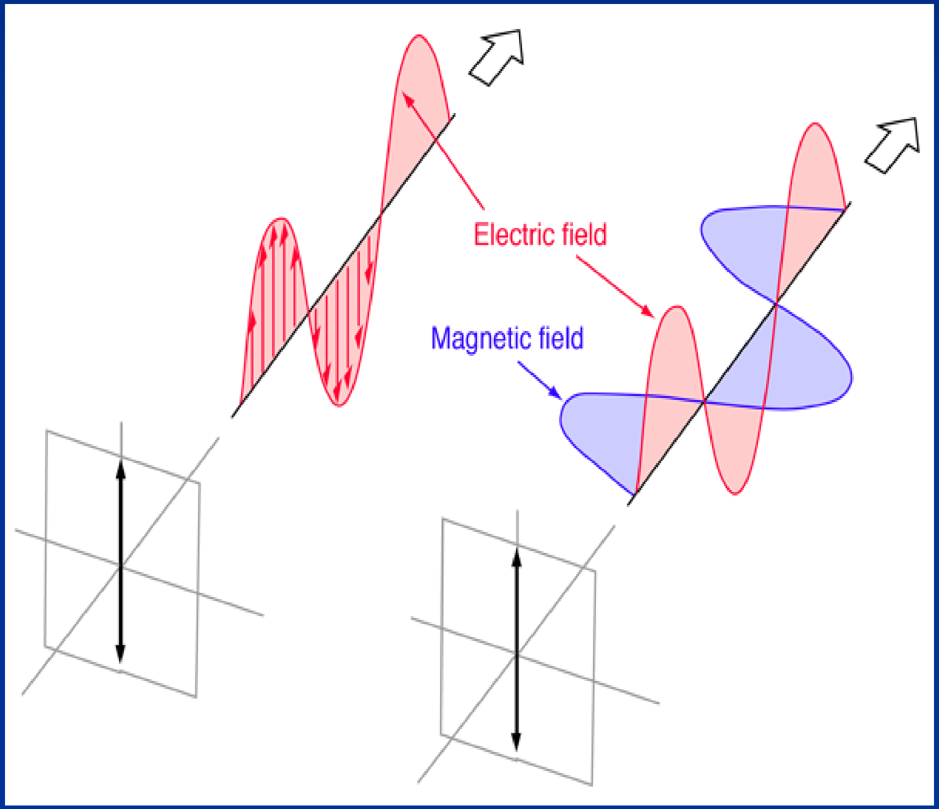
Radio

Solar spectrum: Radiation

The Earth's atmosphere is opaque to most wavelengths of radiation.



Solar Radiation: Polarisation

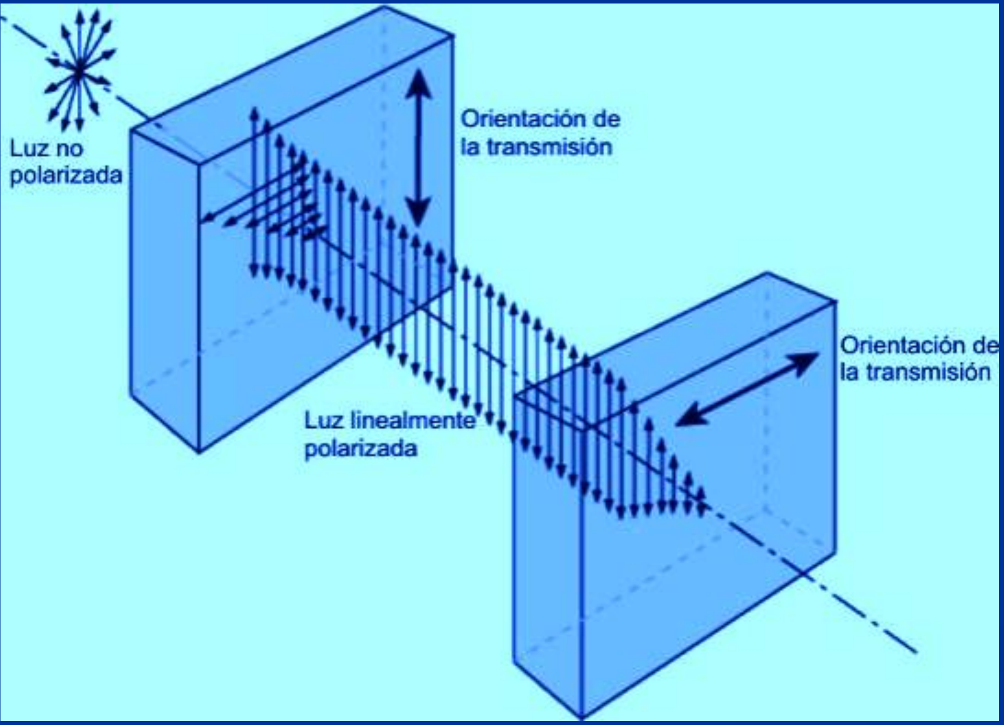


- Simple electromagnetic radiation has a profile as seen in the figure.
- There is a vibration direction for the electric field and another for the magnetic field.
- This wave is linearly polarized. In this case vertically polarised.
- Sunlight does not have any privileged direction of vibration.

Solar Spectrum: Polarisation

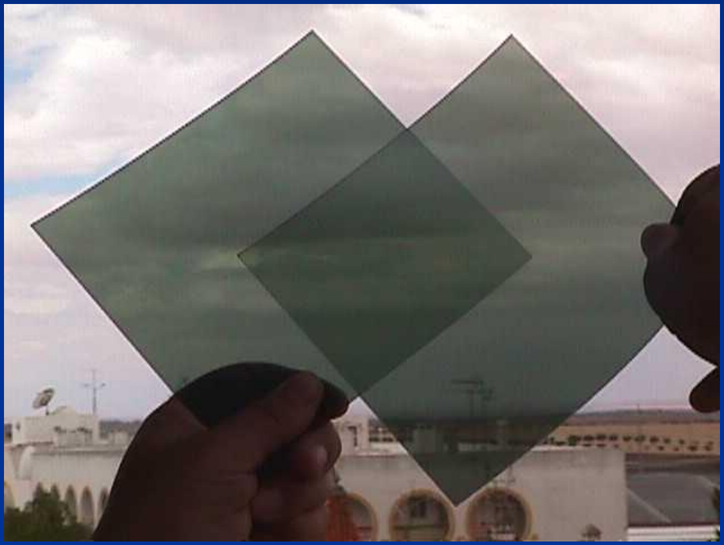
Sunlight can be polarised:

- By reflection
- By passing it through a polarising filter

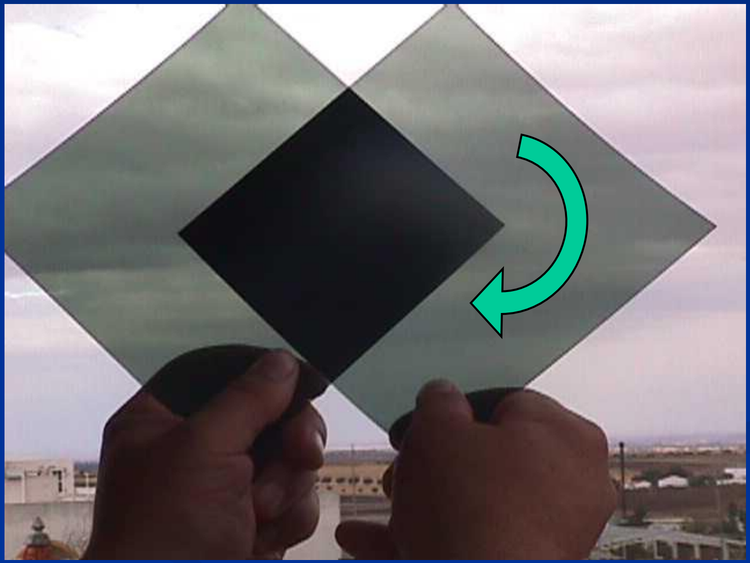


When the two polarising filters have parallel directions of polarisation, light passes through. If their directions are perpendicular, the light that passes through the first filter is blocked by the second and no light passes through.

Activity 1: Solar Spectrum Polarization



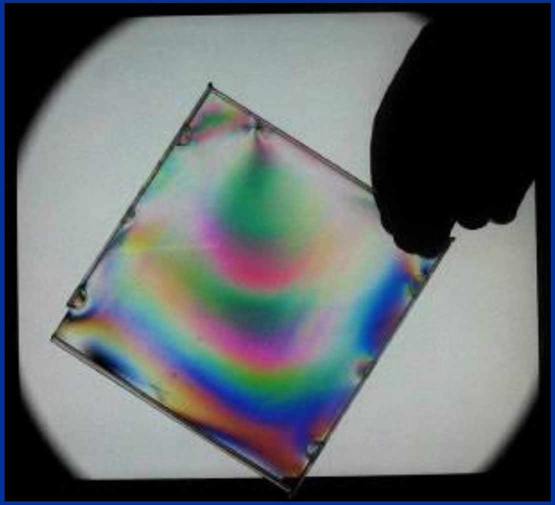
If the filters have the same orientation, light passes through.



If one of the filters is turned 90º, light is blocked.

Activity 1: Solar Spectrum Polarisation

- Light can be polarised by reflection.
- Polaroid sunglasses help you avoid reflections.
- Polarisation is used in photography and in engineering to view internal stresses in materials.



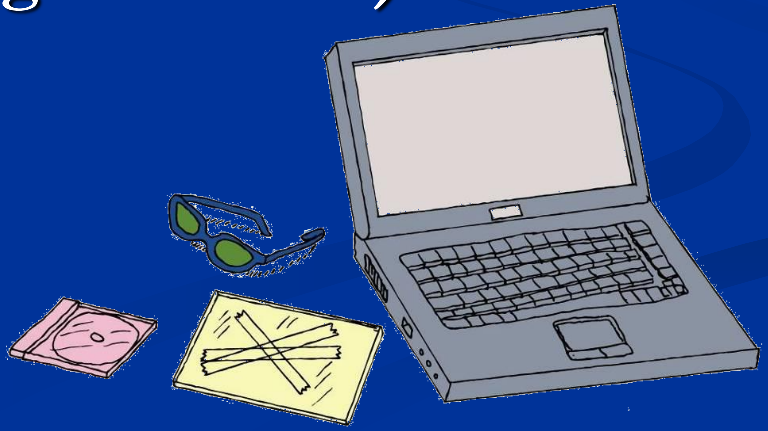
Activity 2: Light polarization

• A laptop or mobile phone screen emits polarized light.

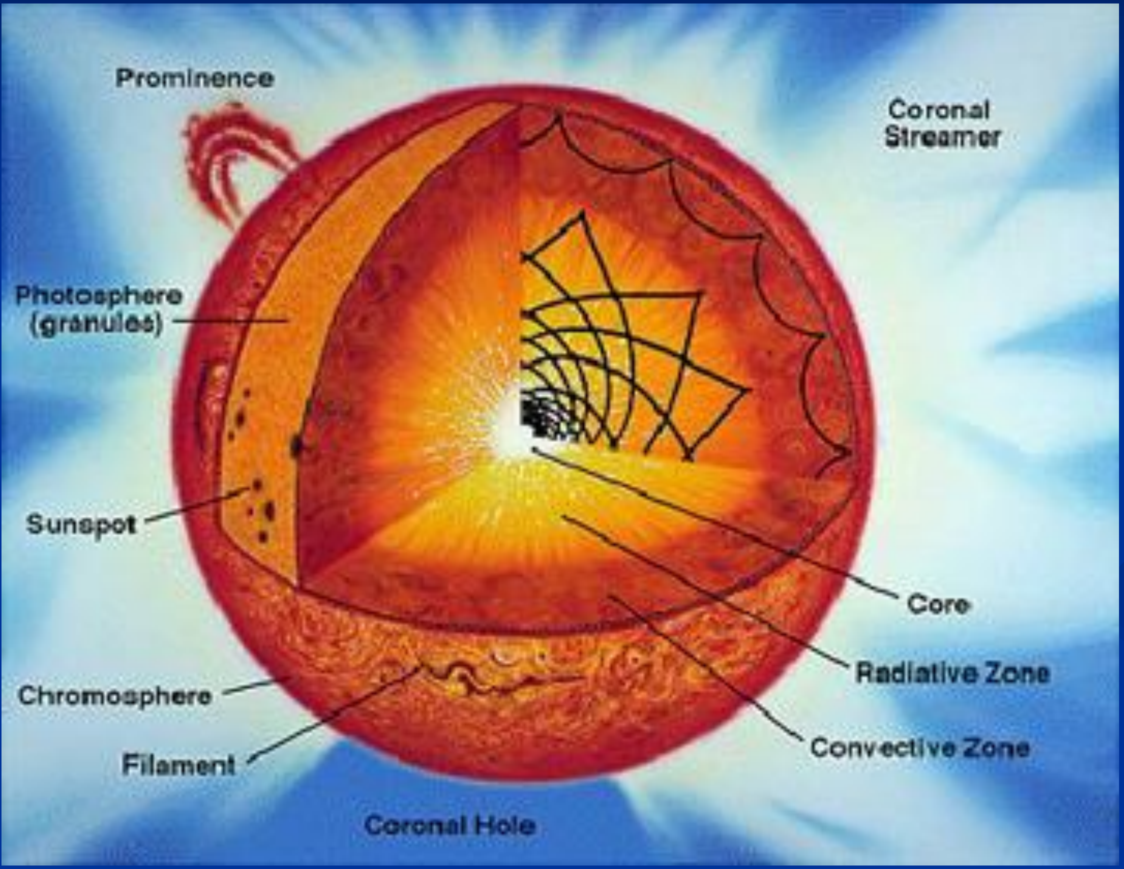
• Observe the plane of polarisation with polarised sunglasses.

• Some objects rotate the plane of polarisation: tape over plastic.

• Observe the internal stresses in a piece of transparent plastic (e.g. a CD box)



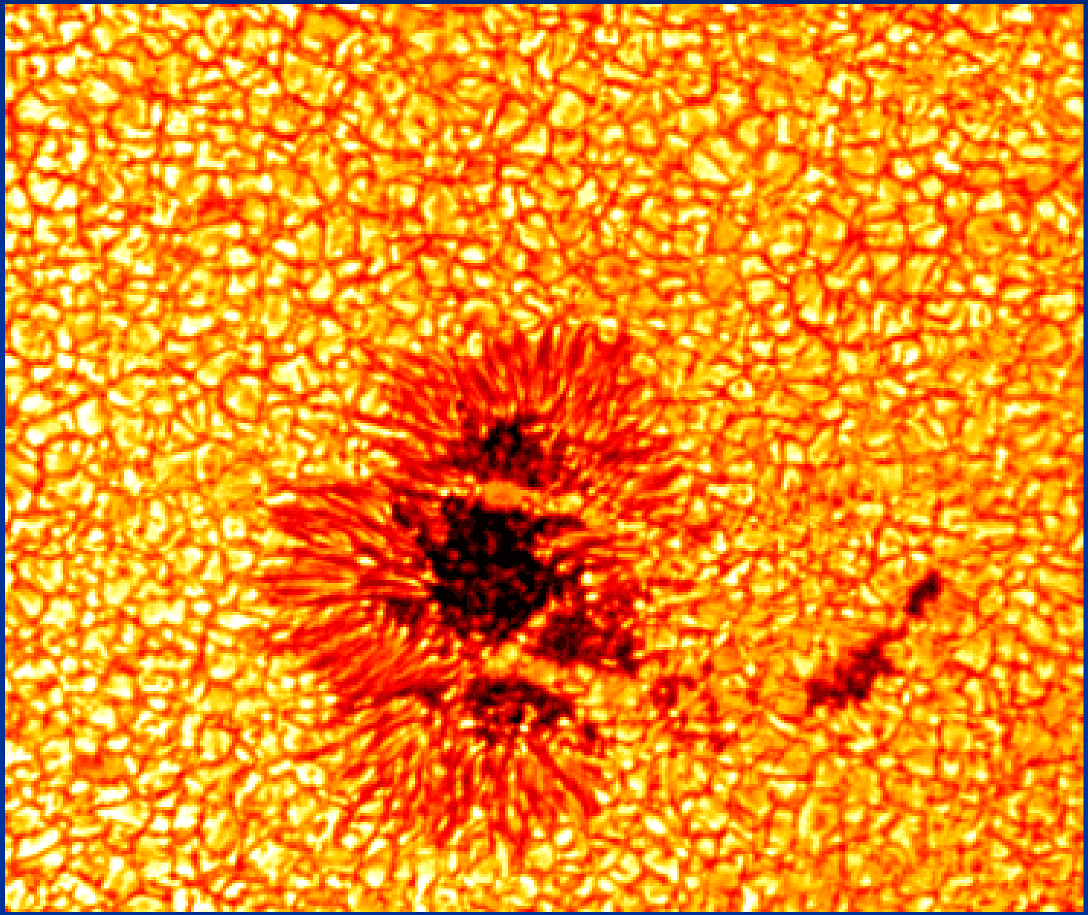
Structure of the Sun



- Core:
  15 million K
- Radiative zone:
  8 million K
- Convective zone:
  500 000 K

There is convection (movement of matter) in the outer layers of the Sun.

Structure of the Sun



- Photosphere:

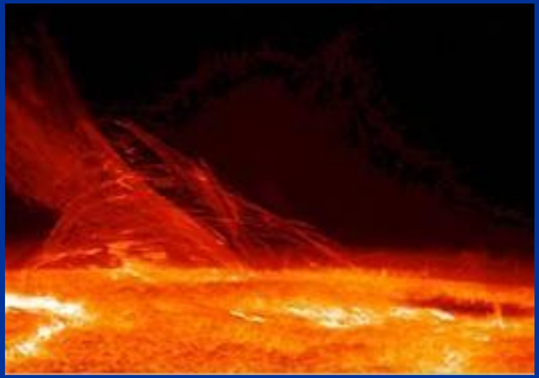
  6 400 – 4 200 K

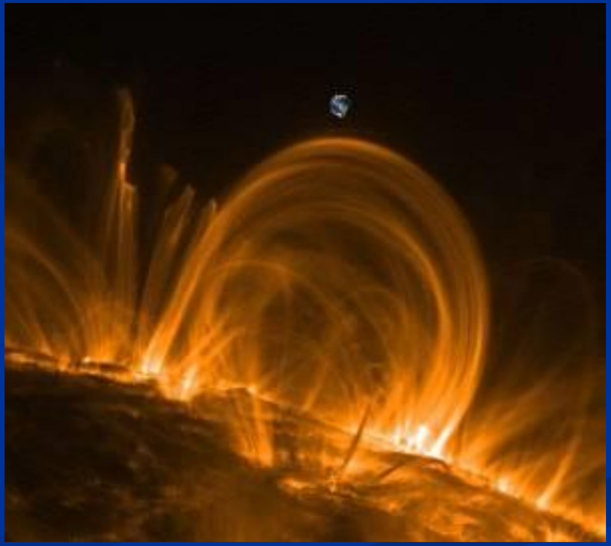
It is the "surface" of the Sun.

Contains granules of ~1 000 km size

Structure of the Sun

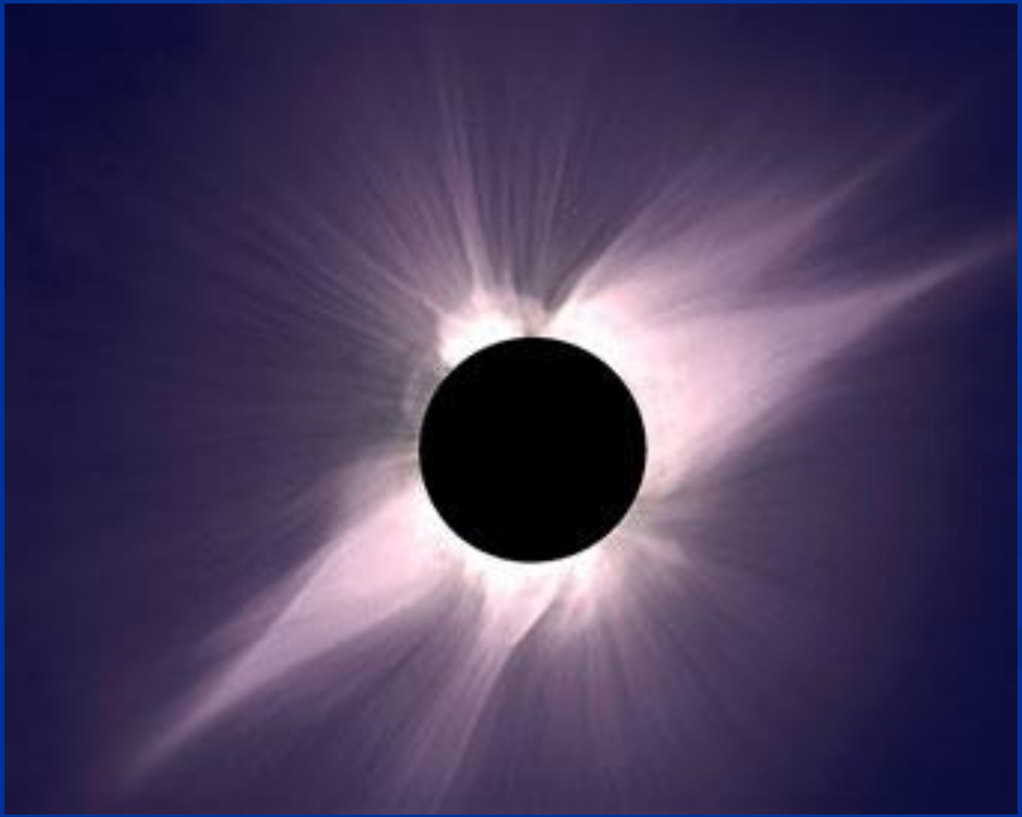
- Chromosphere: "burning prairie" of 4 200 to 1 000 000 K. There are prominences and flares.



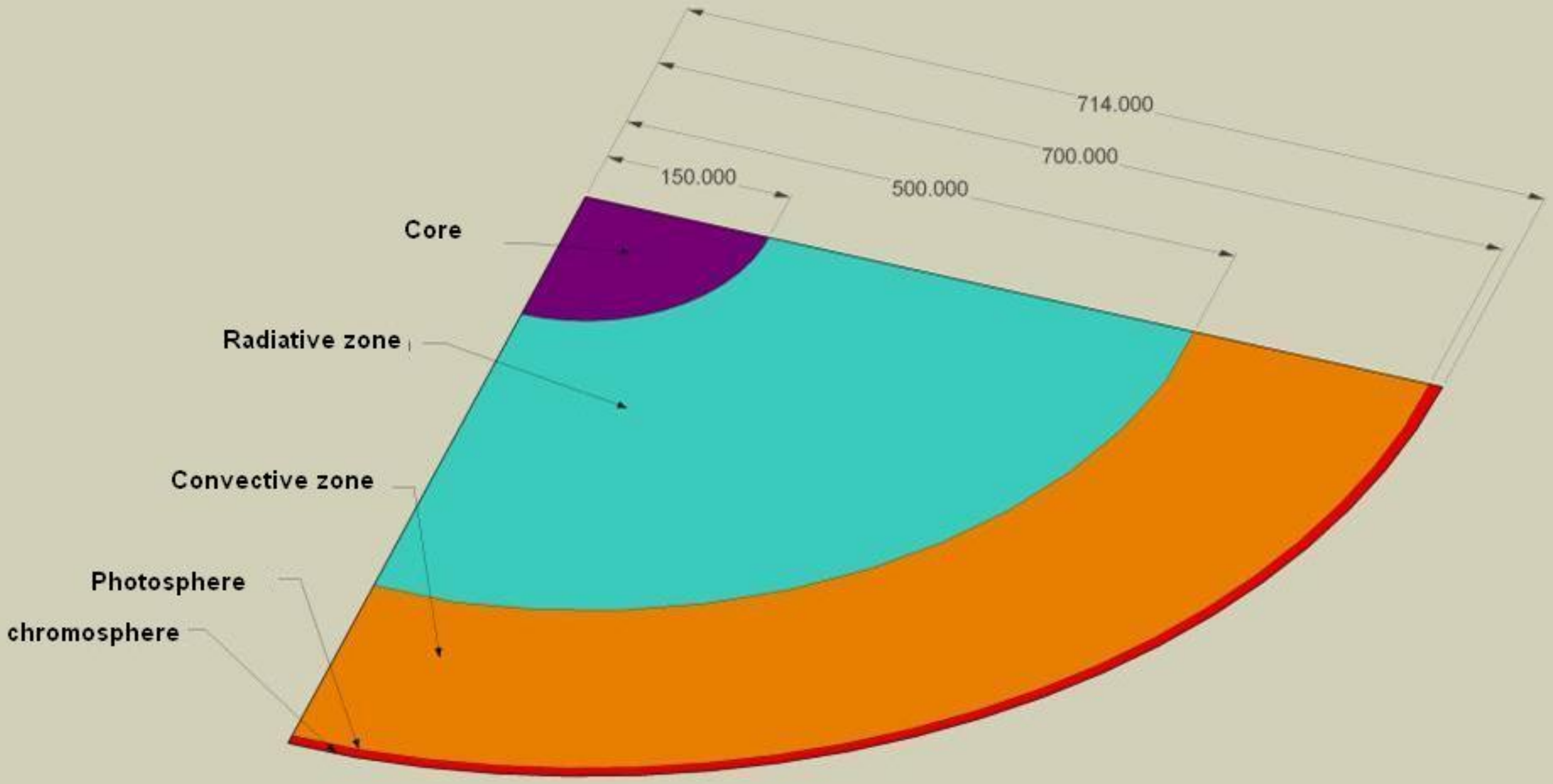


The Structure of the Sun

- Corona: the solar wind, 1 to 2 000 000 K.
- Only seen in eclipses or with a special instrument (a coronagraph).



Structure of the Sun

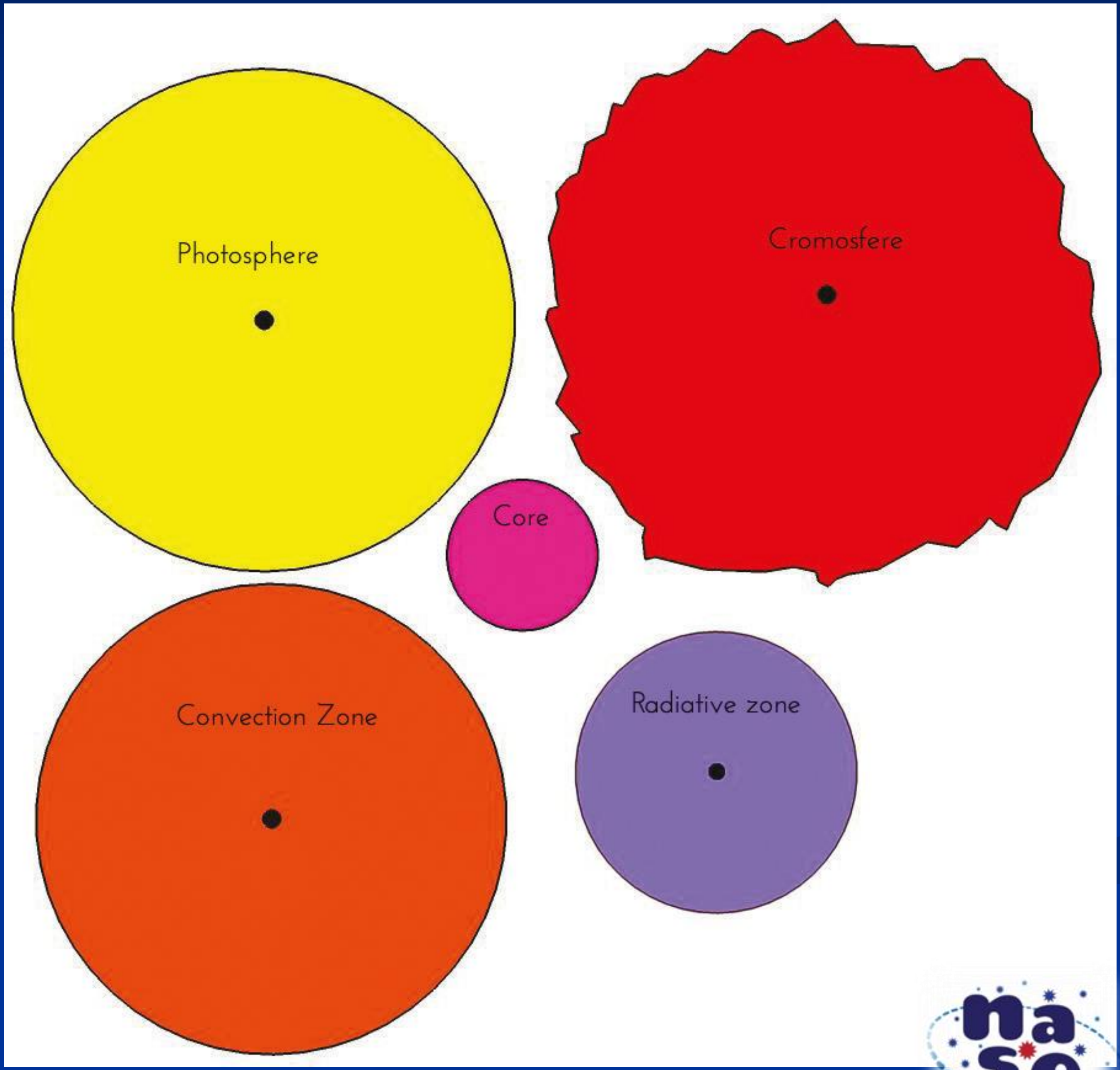


Activity 3: Solar Structure

Make a simple model of the layers of the Sun.

The goal is to cut out the different shapes.

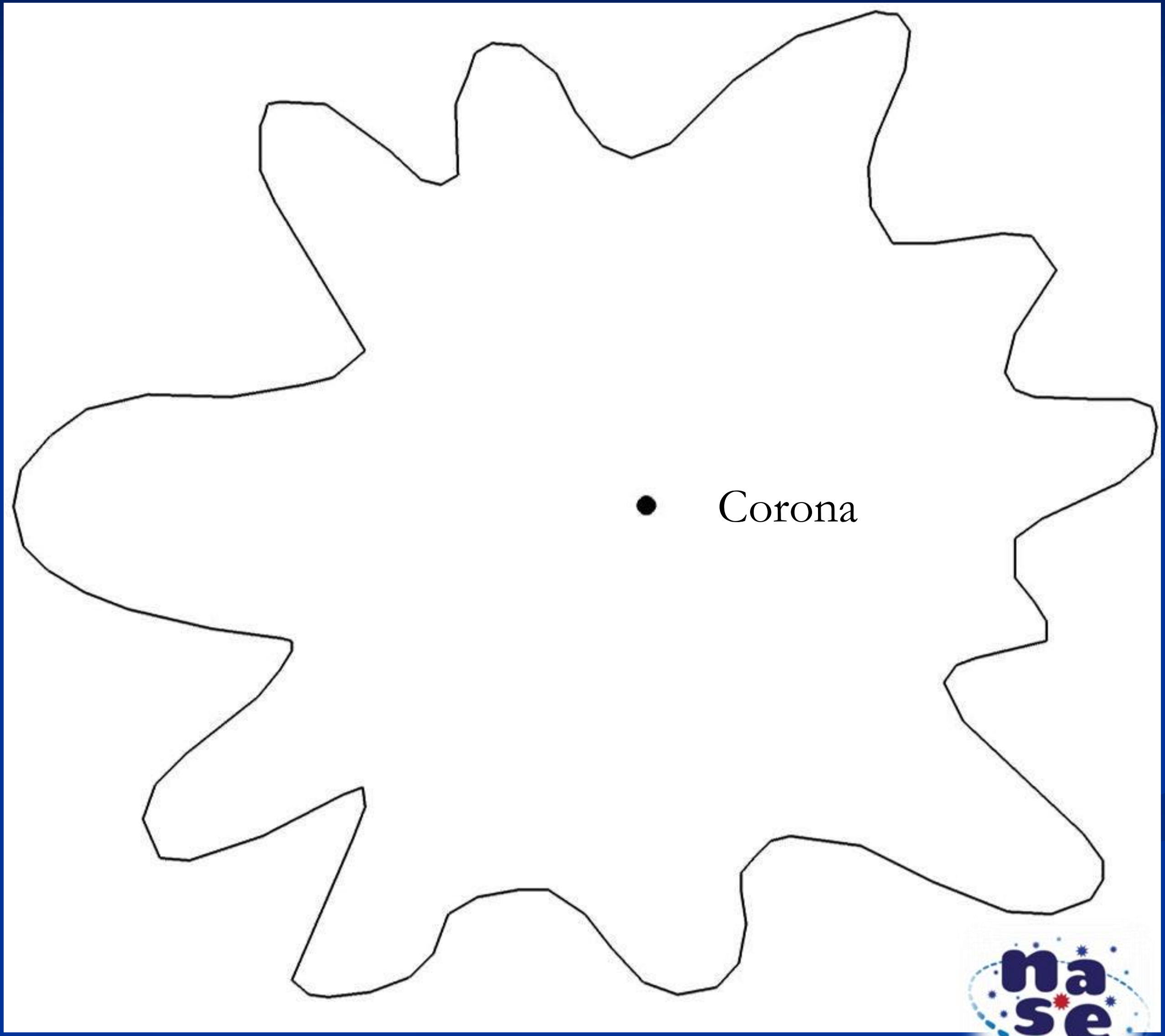
They can be cut from different coloured pieces of paper or be painted.



Activity 3: Solar Structure

The Corona can made of OHP film.

Finally you can paste one above each other in the correct order.



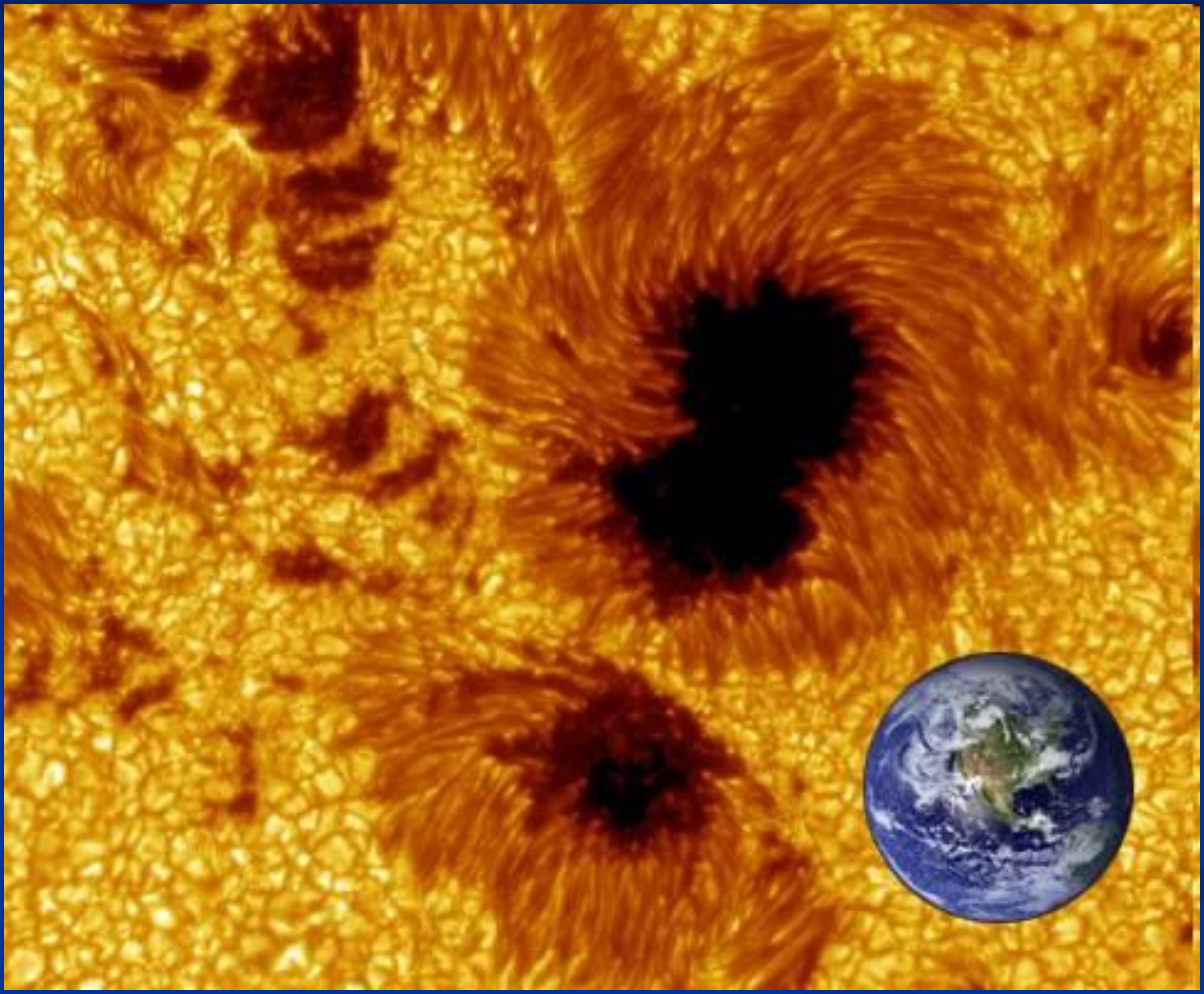
Activity 3: Solar Structure

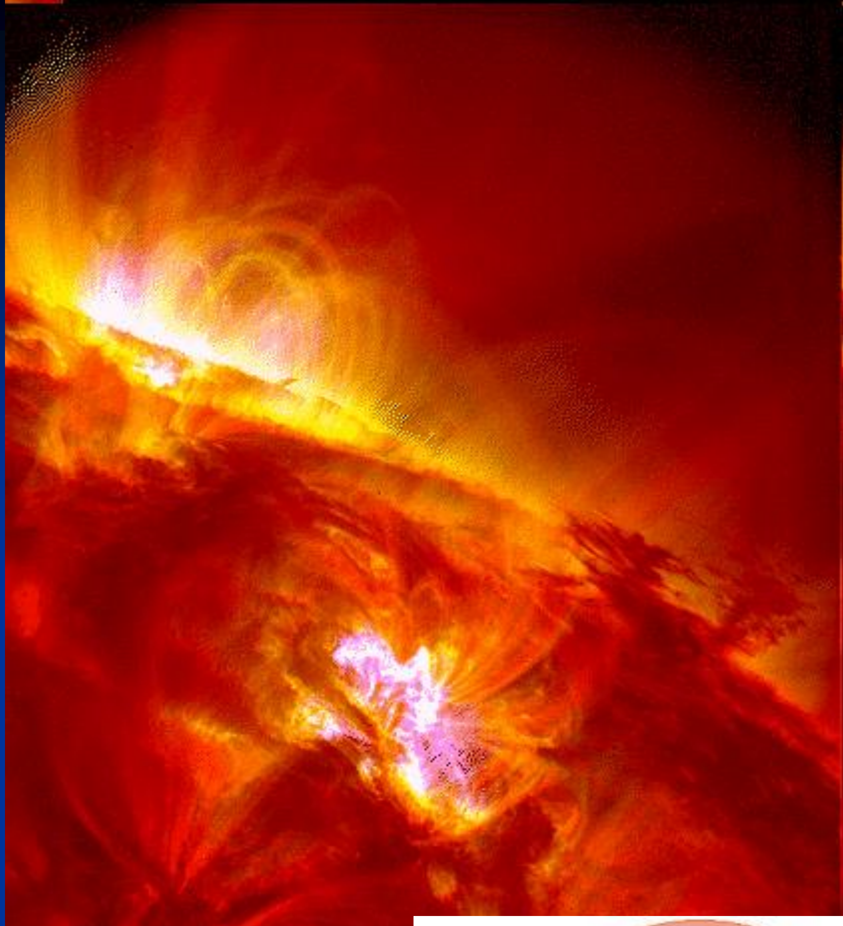
Sunspots

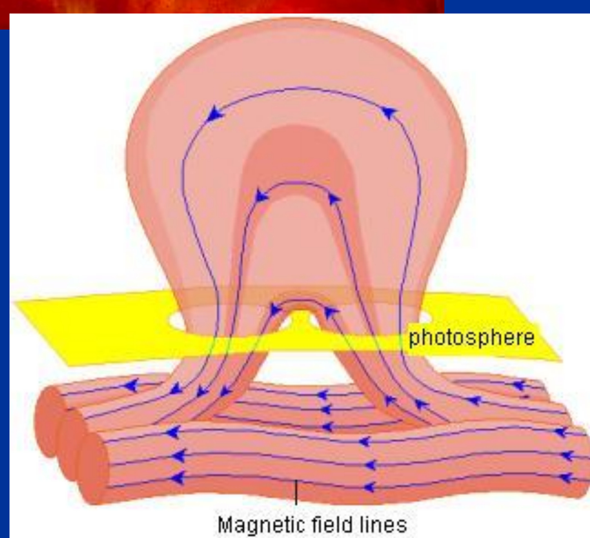
- Dark spots on the photosphere that are ~4 200 K instead of 6 000 K.

- Each sunspot has two regions: Umbra (central area) and Penumbra (outer area).

Sunspots



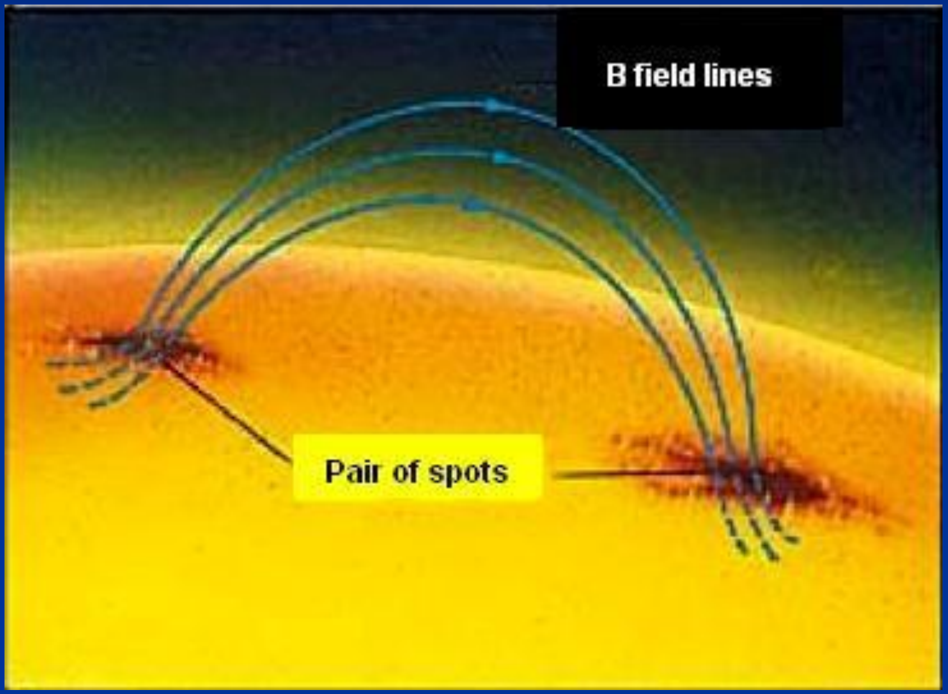


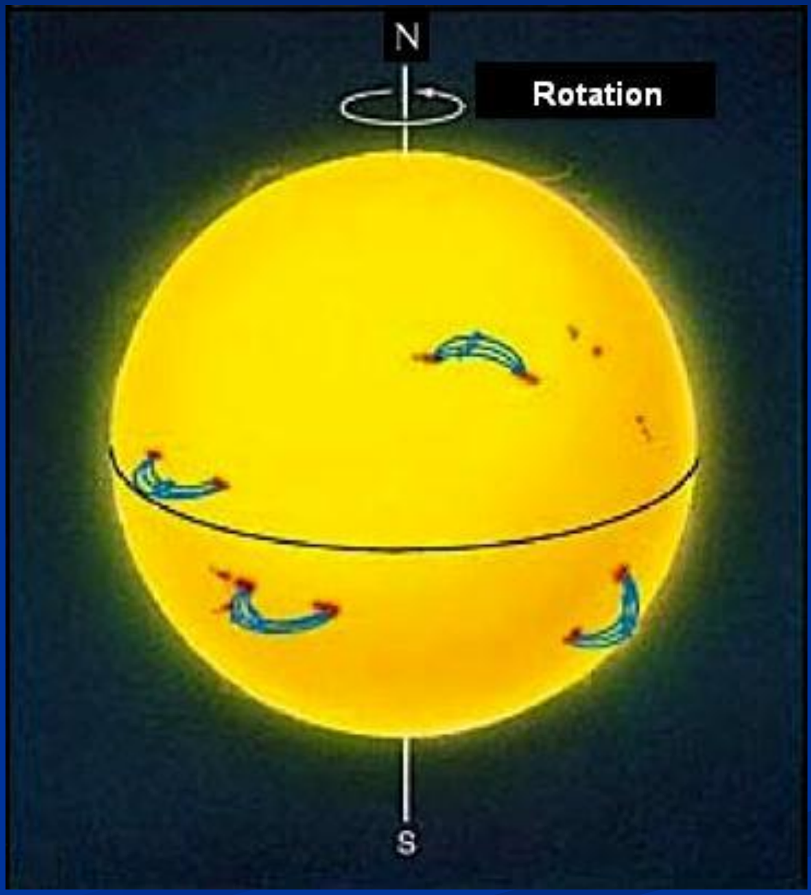


Sunspots

- There are strong magnetic fields in them.
- They are caused by the outburst of lines of magnetic field. Here is a loop rising from the interior.

Sunspots

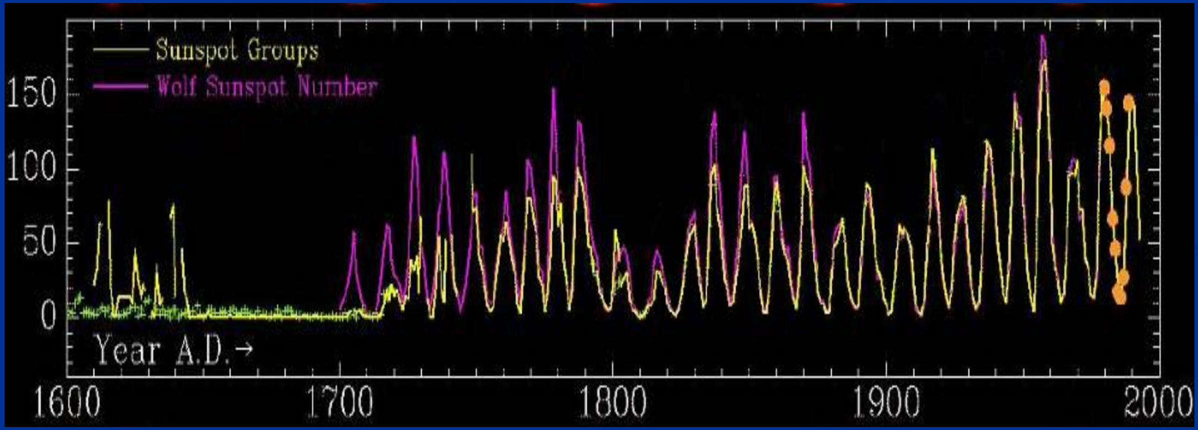


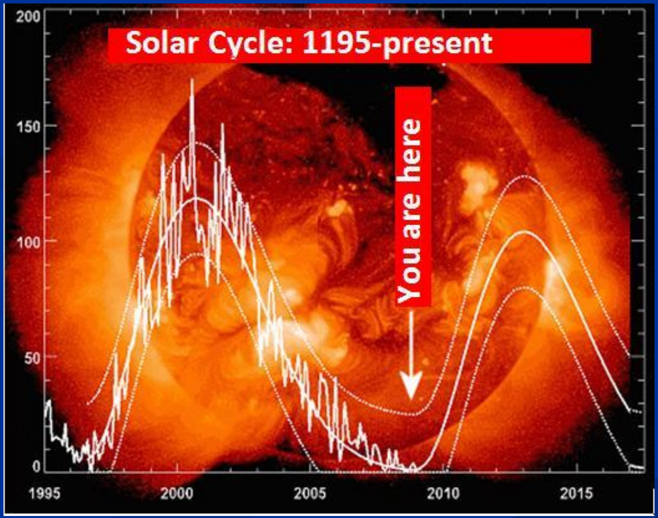


Sunspots

- The number of sunspots indicates the “solar activity”
- The Wolf Number = 10G + F

  (G = groups; F = total number of sunspots)
- There is an 11-year sunspot cycle.

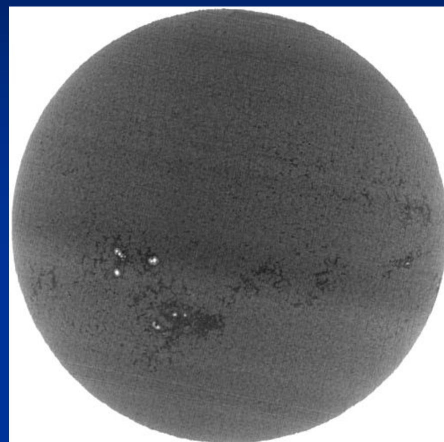




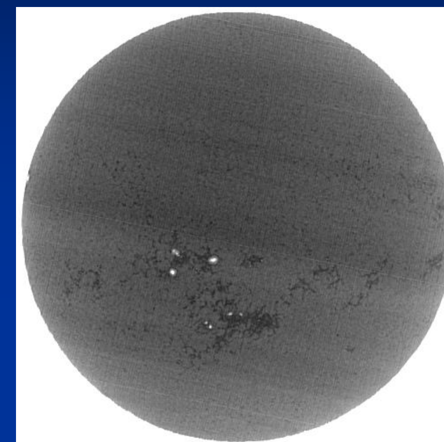
In 2008 there was a minimum of Sun’s activity that lasted longer than usual.

Sunspots: Solar Rotation

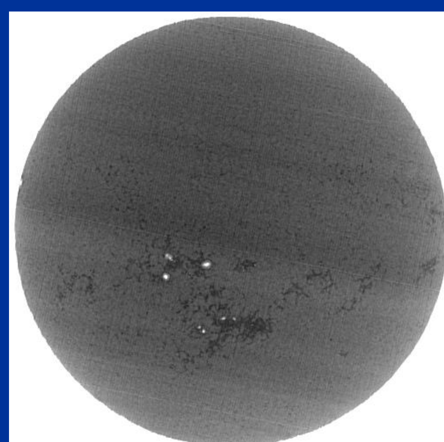
November 21 1992



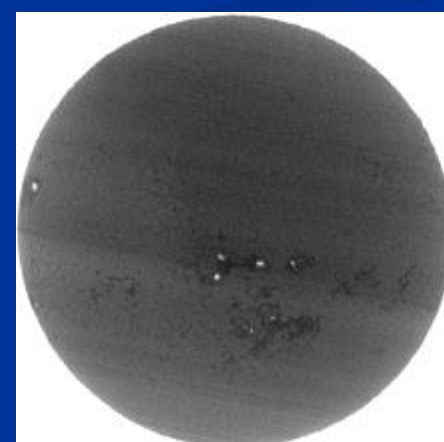
November 22 1992



November 23 1992

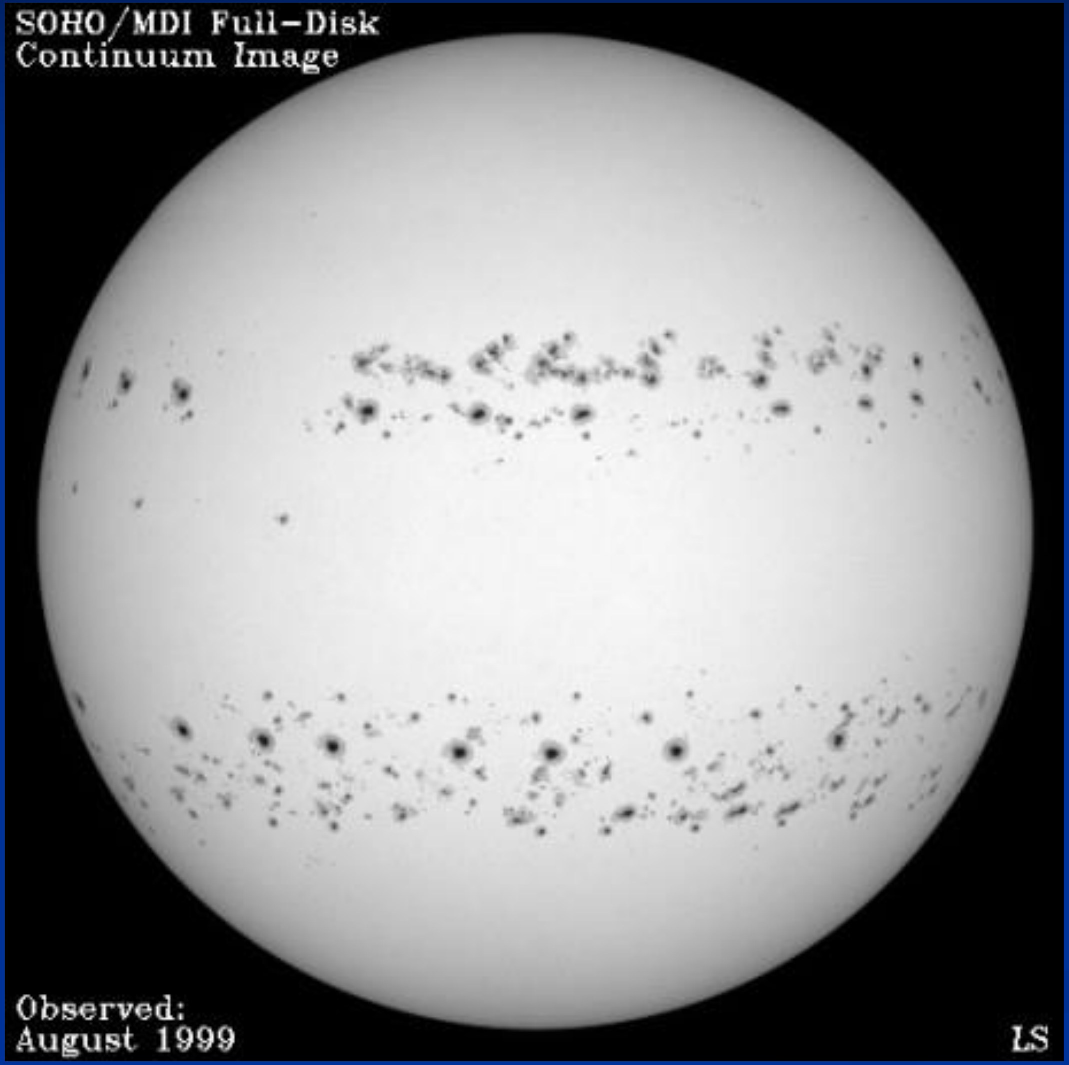


November 24 1992



Credit for images: Astronomical Observatory of the University of Coimbra

Sunspots and Solar Rotation



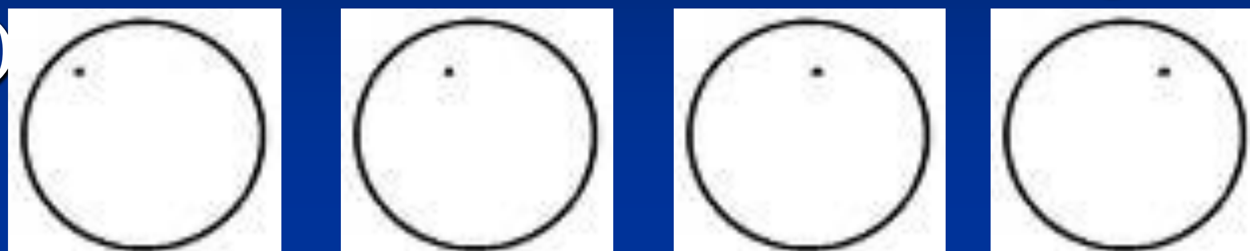
- Sunspots can be used to measure the solar rotation.
- Galileo was one of the first who saw Sunspots using a telescope. He used them to measure the period of solar rotation.
- Different rotation periods: from 25 days at equator to 38 days at the poles.

Activity 4: Determining the Sun's rotation period

- Observations of the Sun should always be done by projection with a telescope or binoculars. Never directly.

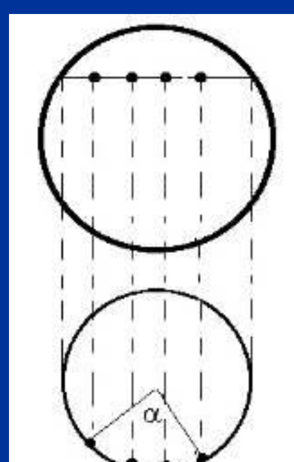
Activity 4: Determining the Sun's rotation period

• Sunspots are drawn for several days during the time t (in days)

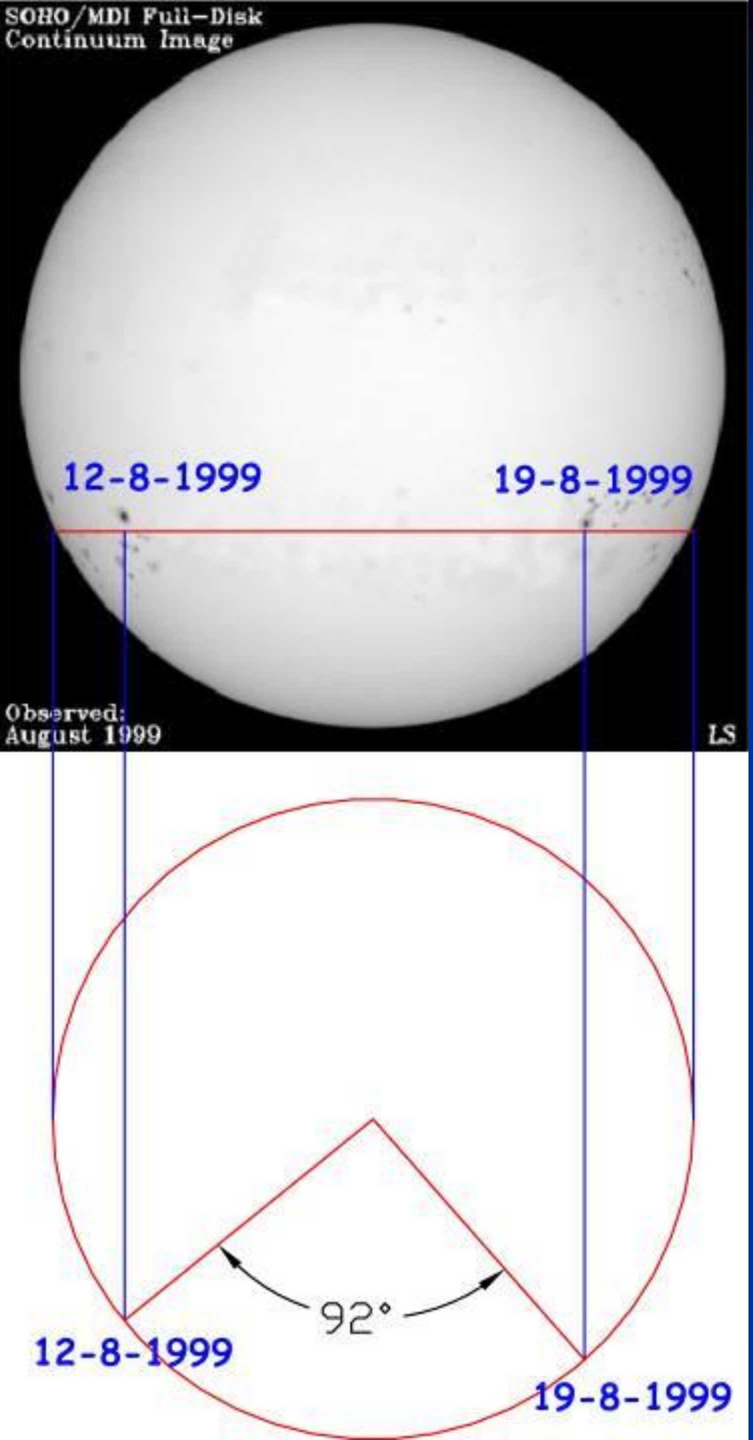


Day 1 Day 4 Day 6 Day 8

• Draw the path, the circumference and the angle α. Then the period T can be calculated in days.



$$\frac{360^o}{\alpha^o} = \frac{T}{t}$$



Activity 4: Determining the Sun's rotational period

$$T = \frac{360^{o} \times 7 days}{92^{o}} = 27{,}3 days$$

Solar Radiation

• The Sun is a large nuclear reactor producing photons, each with a frequency (colour) and an energy of $E = h\nu$

• The brightness (power in watts) of the Sun is enormous: every second it emits the equivalent of trillions of atomic bombs.

• That energy is transmitted through space like a bubble getting bigger and bigger with time.

• The surface area of the bubble is $4\pi R^2$.

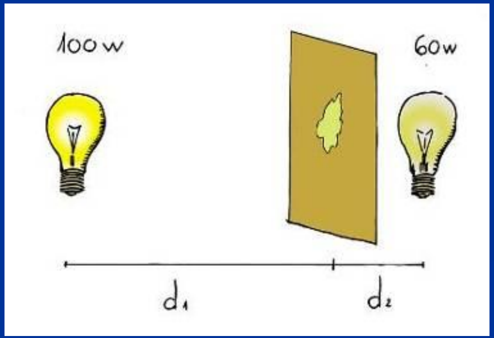
• At a distance R from the Sun, the energy that arrives every second in an area of 1 m^2 is:
(where P is the total power of the Sun)

$$\frac{P}{4\pi R^2}$$

Activity 5: Measure Sun's luminosity

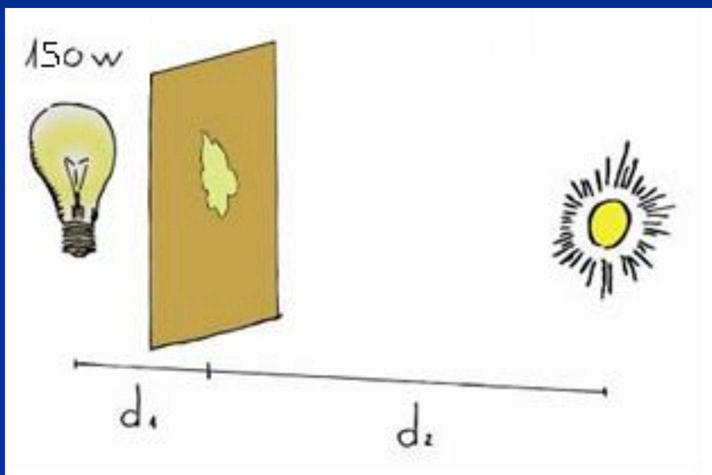
- The transmitted energy depends on the inverse of the square distance. If we know the distance from the Sun, we can calculate its power.
- We make an oil-spot photometer. When the light from both sides of the paper is equal, the spot is not visible; that is, the same energy arrives from each side. Then:

$$\frac{P_1}{4 \cdot \pi \cdot d_1^{\ 2}} = \frac{P_2}{4 \cdot \pi \cdot d_2^{\ 2}}$$



Activity 5: Measure Sun's luminosity

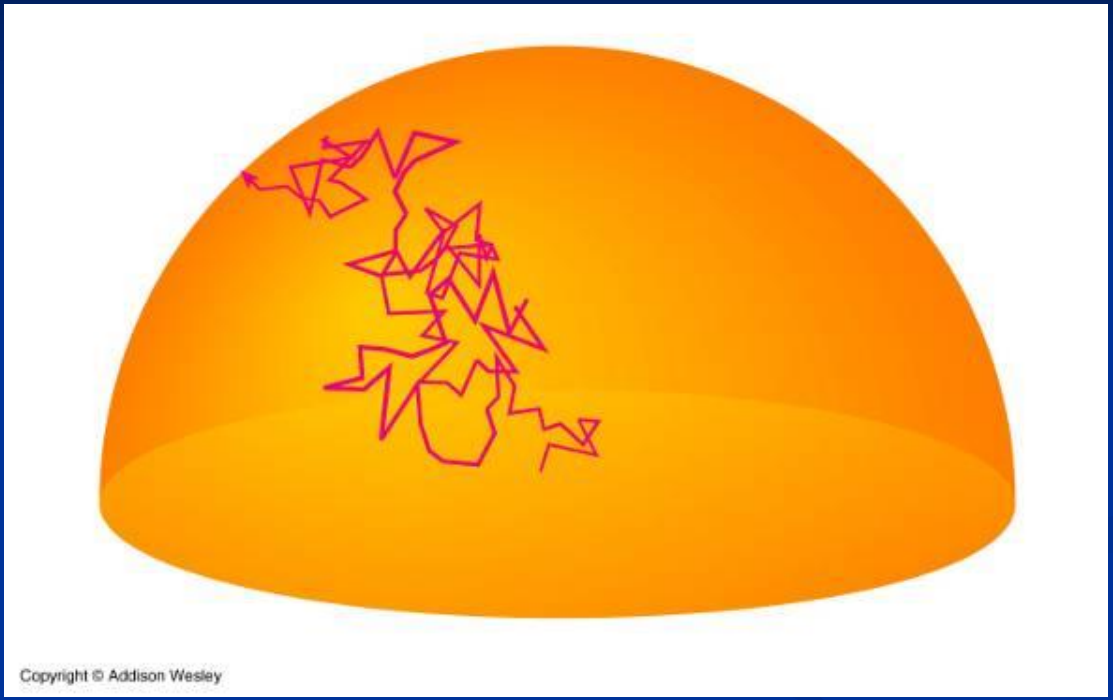
We compare a bulb of 150 W with the Sun, which is at 150 million km (1.5×10^{11} m), and we measure P.



$$\frac{150W}{d_1^{\ 2}} = \frac{P}{d_2^{\ 2}}$$

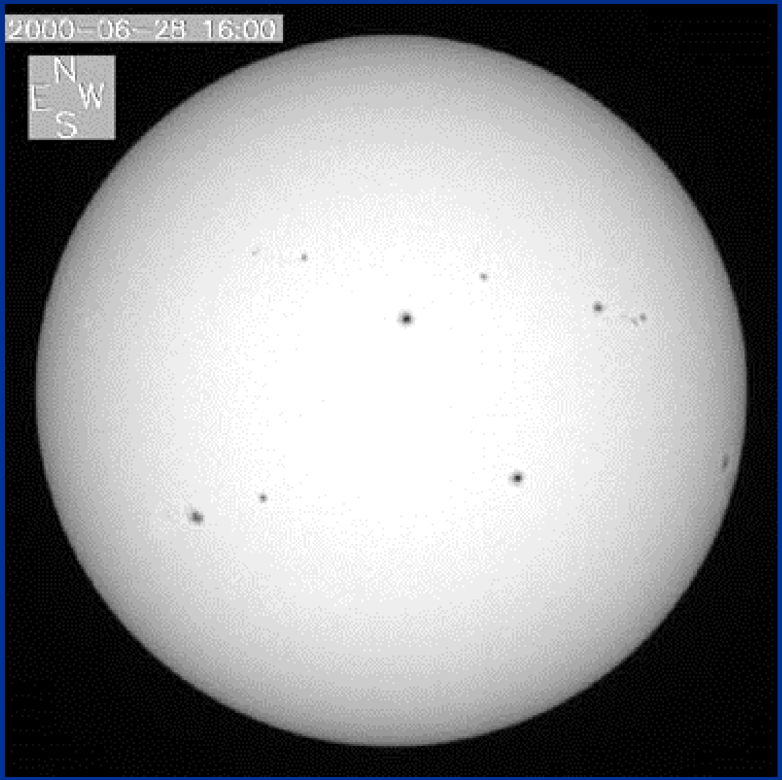
- The result should be approximately 3.8×10^{26} W

Solar Spectrum: Opacity



Photons are produced in the innermost part of the Sun and interact with the very dense material in that area. A photon produced in the Sun's core takes up to 1 million years to reach the photosphere.

Solar Spectrum: Opacity



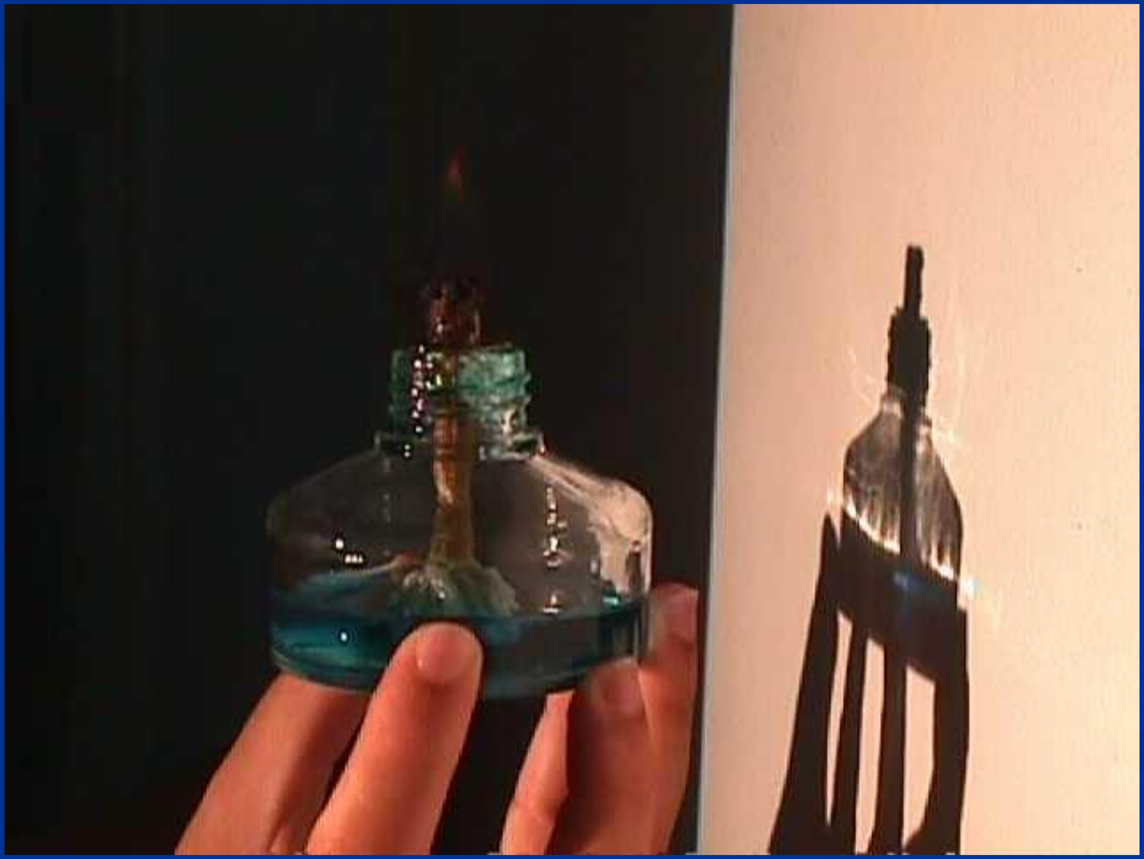
The inner parts of the Sun are opaque (many interactions, as in a solid).

The outer parts are transparent.

Evidence: limb darkening - at its edge, the Sun is less bright because it is more transparent.

Activity 6: Transparency and opacity

Transparent is not the same as invisible!



Spectrum

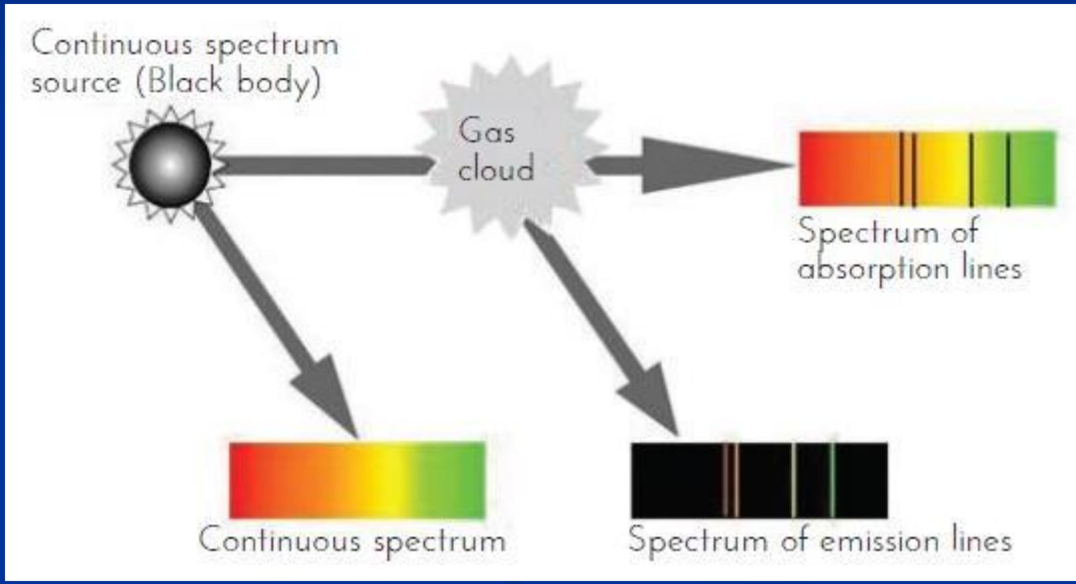
Fuente: Deutsche Bundespost 1993

In 1701, Newton used a prism and decomposed Sunlight into its colours.
Any light can be decomposed with a prism or a diffraction grating. The results is a spectrum.

Kirchhoff's and Bunsen's Laws

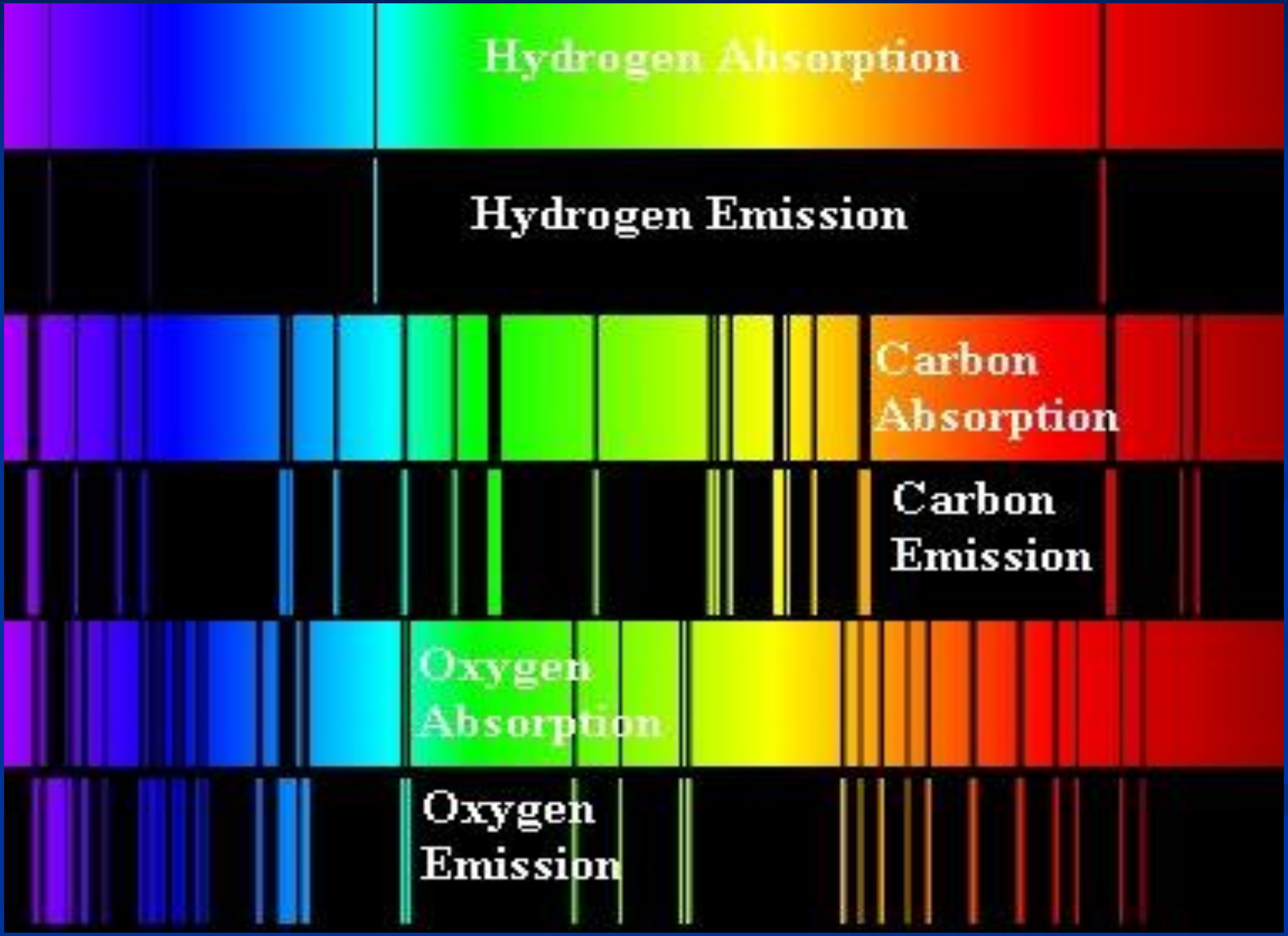
1st Law - An incandescent solid object produces light with a continuous spectrum.

2nd Law - A hot tenuous gas produces light only at certain wavelengths, which depend on that gas's chemical composition.

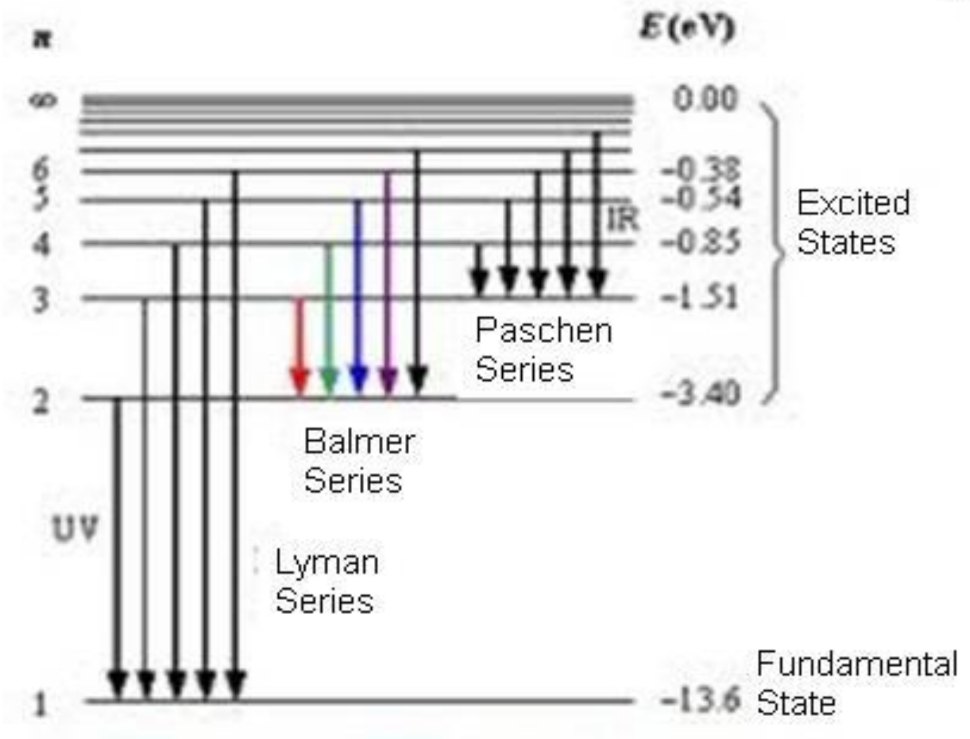


3rd Law - A incandescent solid object surrounded by a low-pressure gas produces a continuous spectrum with gaps at wavelengths whose positions corresponds to those of 2nd law.

Spectrum


Hydrogen Absorption
Hydrogen Emission
Carbon Absorption
Carbon Emission
Oxygen Absorption
Oxygen Emission

Spectrum



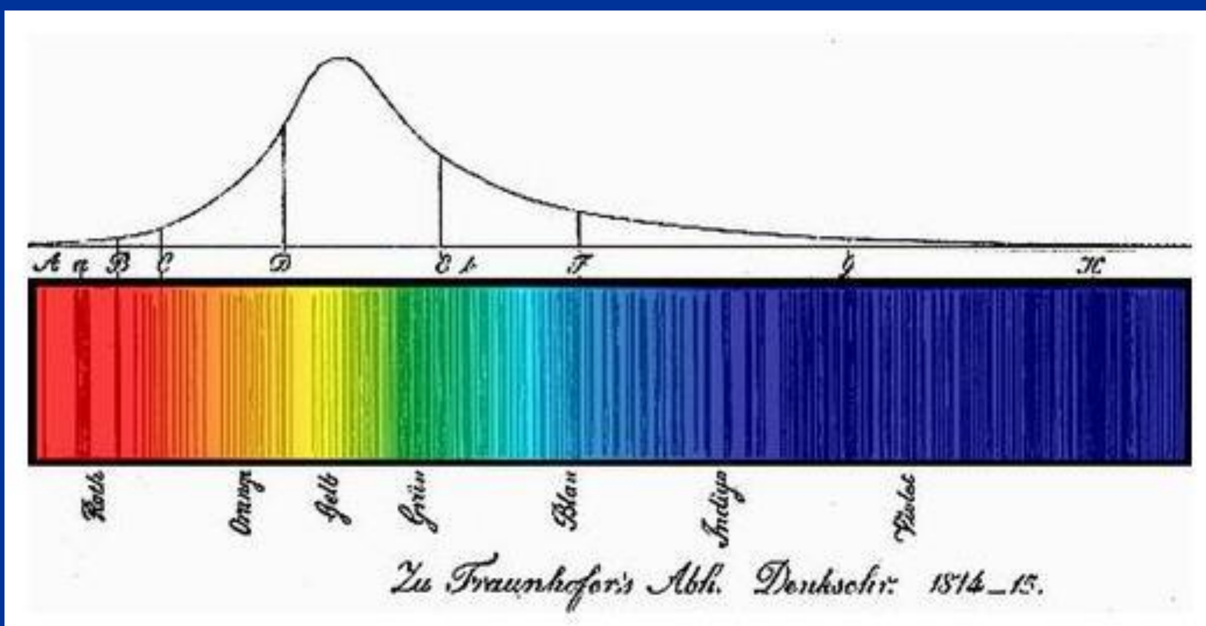
Energy levels of the hydrogen atom, with some of the transitions which produce the spectral lines indicated

Emission and absorption lines form due to electron jumps between two quantized energy levels.

Solar spectrum: Absorption Spectrum

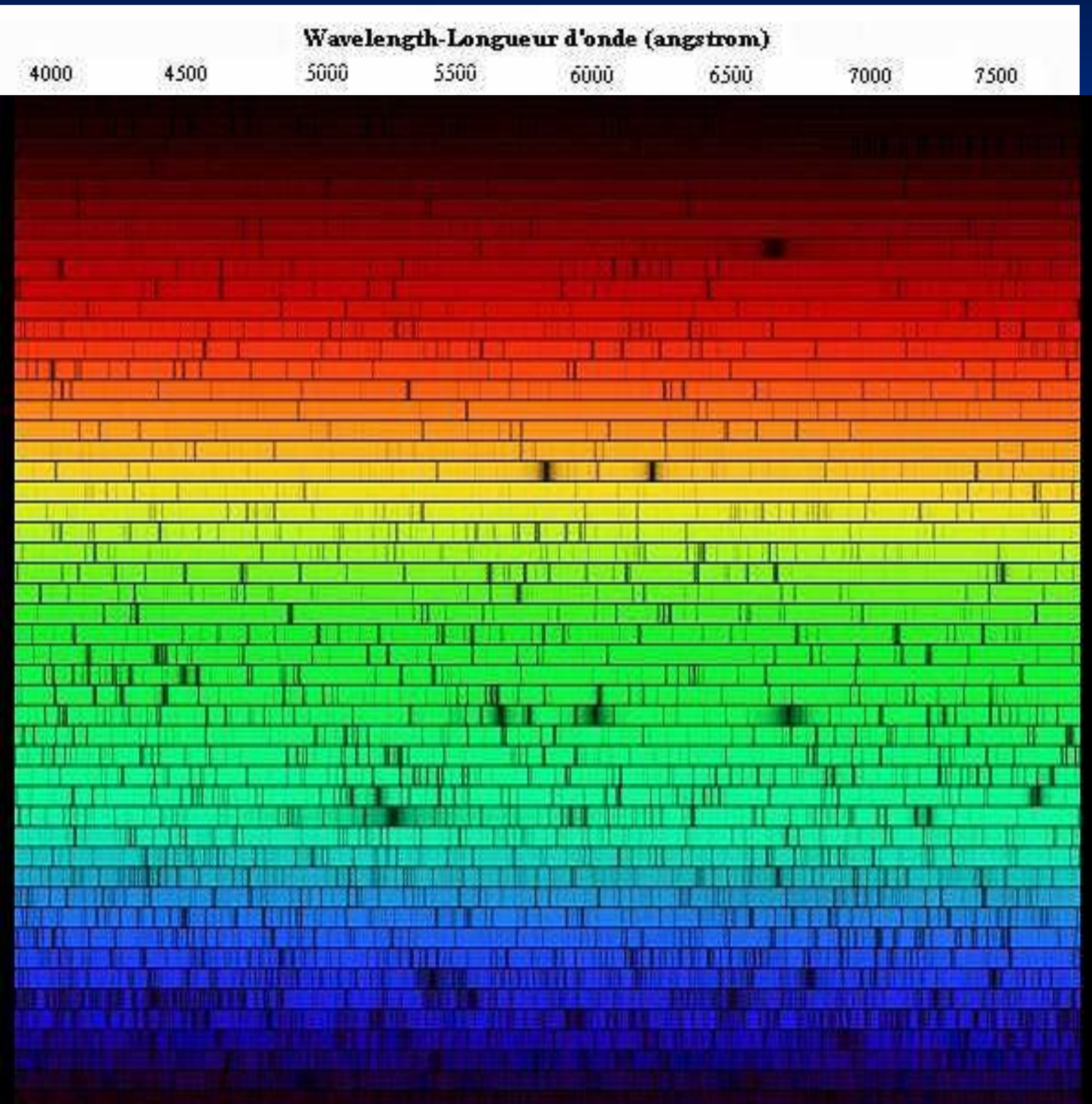
In 1802, William Wollaston observed black lines in the solar spectrum.

In 1814, Joseph Fraunhofer systematically studied the spectrum of the Sun and detected about 700 dark lines.



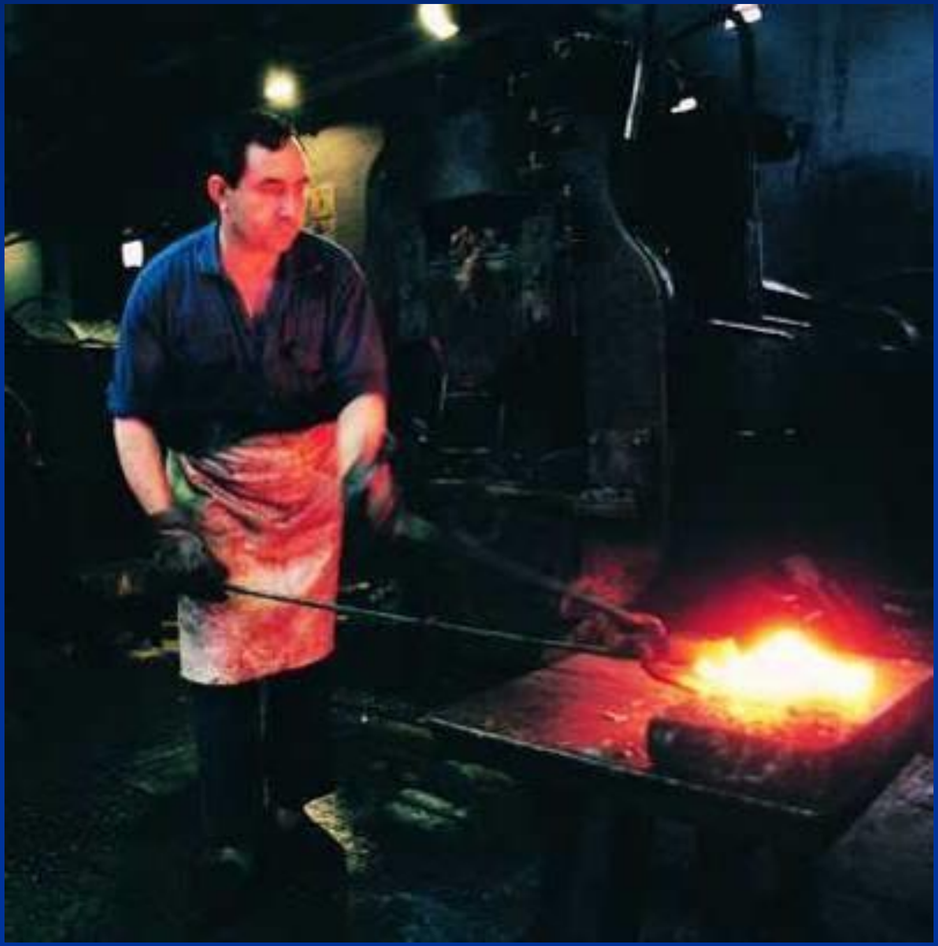
Joseph Fraunhofer
1787-1826

Solar spectrum: Absorption Spectrum



- The dark lines appear due to the presence of cooler gases just above the surface of the Sun.
- We can know of what the Sun is made of without probing inside.
- Today, high definition spectra show many more lines.

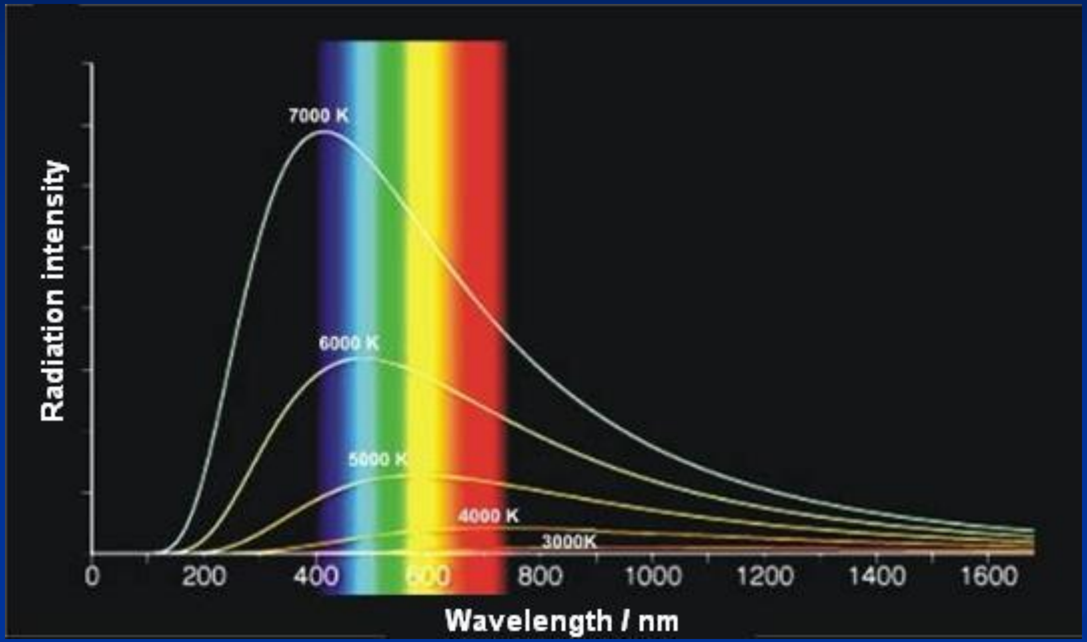
Black body radiation



As the iron warms up in the furnace, the light it emits changes colour as follows:

- Red
- Yellow
- White
- Bluish

Blackbody Radiation



Any "black body" when heated emits light at many wavelengths.

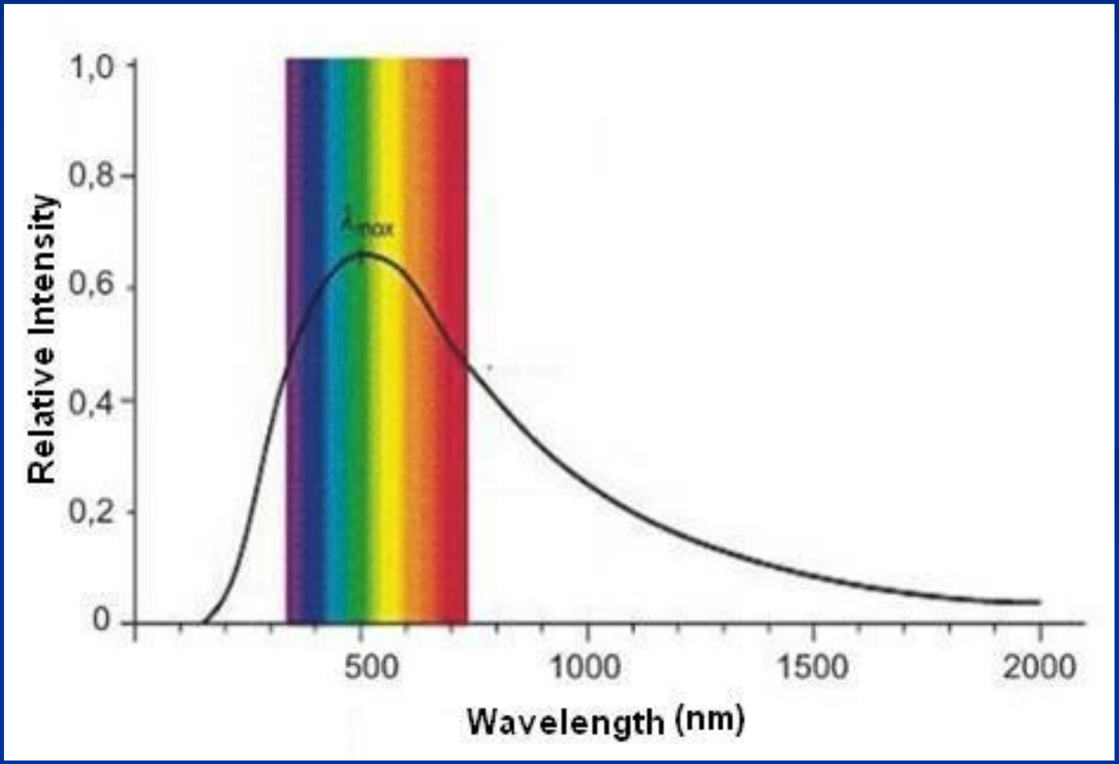
There is λ_{max} at which the energy is maximum. This λ_{max} depends on the temperature T:

$$\lambda_{max} = \frac{2.898 \times 10^{-3}}{T} \quad (m)$$

Wien's Law

By studying the radiation of a distant object, we can measure its temperature without having to go there.

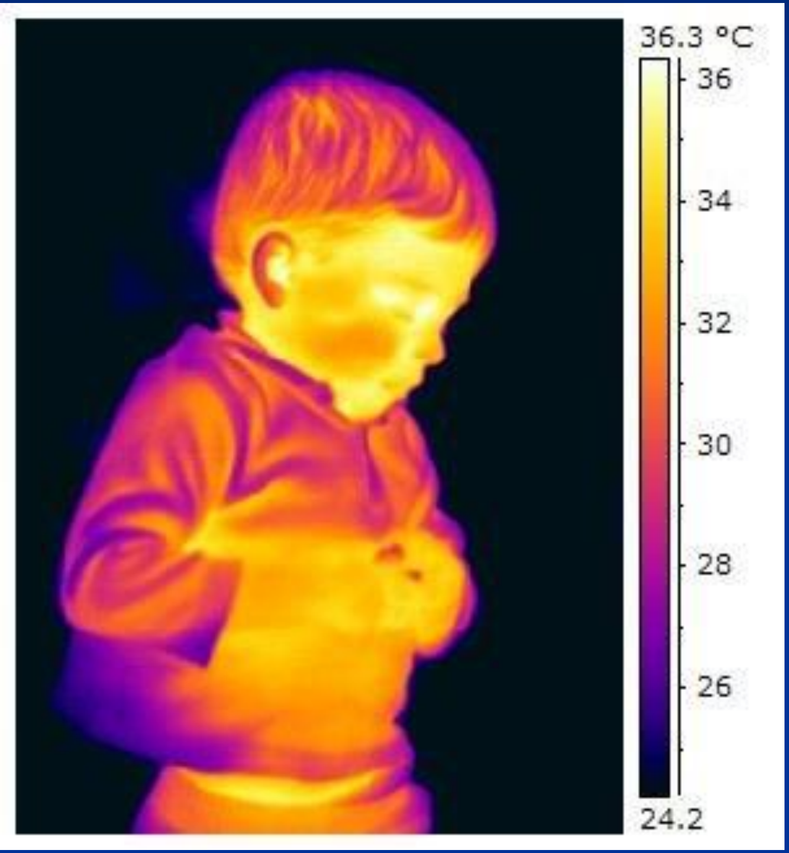
Blakbody Radiation



The Sun has a λ_{max} of 500 nm.

This means that its surface temperature is 5,800 K.

Blackbody Radiation



The human body has a temperature of

$$T = 273 + 37 = 310 \text{ K}.$$

A human body emits most energy at λ_{max} = 9300 nm. This is in the far infrared.

Night vision devices use this wavelength.

Light Scattering

•If the white light passes through a gas with large particles, all colours will be equally scattered (white cloud).

•If the sizes of particles are much smaller than the wavelength of incident photons, shorter-wavelength photons are scattered more than the ones with longer wavelenght (Rayleigh scattering).

•In our atmosphere, the blue photons are scattered more than red, and they come from all directions:

Therefore, we see a blue sky.

At sunset, the light passes through more atmosphere, and so it is more yellow-red.

Activity 7: Dispersion of light

- You need some water in a glass with a few drops of milk, a projector and a piece of black cardboard with a hole of the size of the glass.

- First you see the light without water
- Then with some milky water
- Finally with a full glass
- The transmitted light becomes redder. At the sides of the glass you can see the bluish scattering.

Thank you very much
for your attention!