Sunspots and Solar Spectrum

Alexandre Costa, Beatriz García, Ricardo Moreno
International Astronomical Union Comm 46,
Escola Secundária de Loulé, Portugal
Universida Tecnológica Nacional, Argentina
Colegio Retamar de Madrid, España

Goals

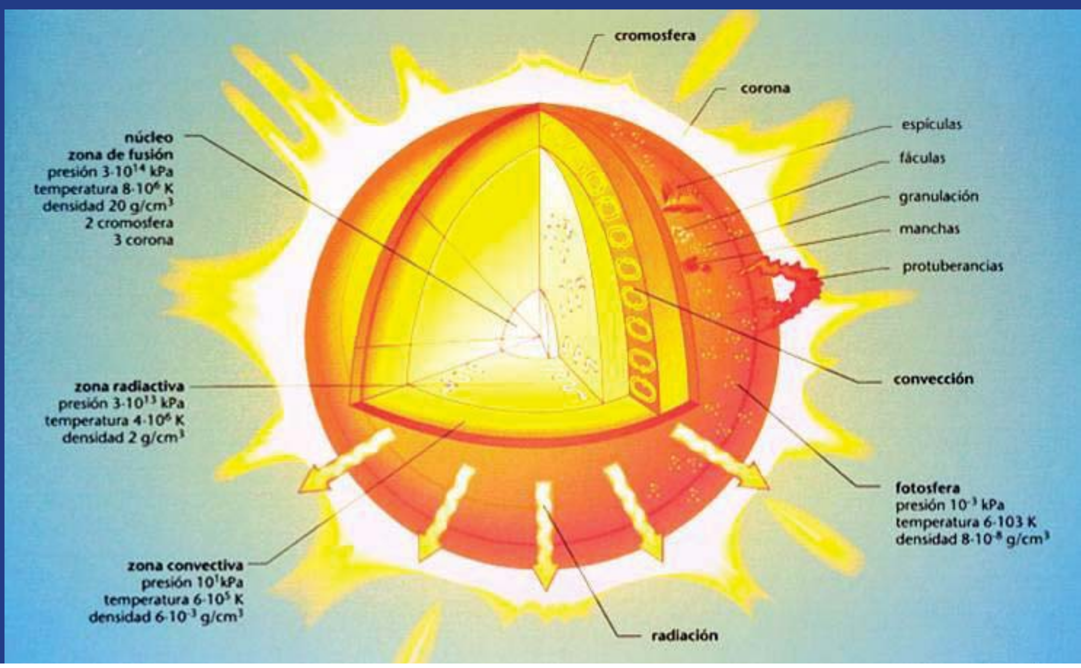
- Understand what is the solar spectrum
- Understand the "why" of the solar spectrum
- Understand what are sunspots.
- Understand the historical significance of Galileo's work on sunspots.

Solar Radiation

All energy (light, heat) that
we use comes from the Sun

Solar Radiation

That radiation is created inside the core, at very high pressure and at 15 million degrees. It is produced through nuclear fusion reactions



Solar Radiation

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

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

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

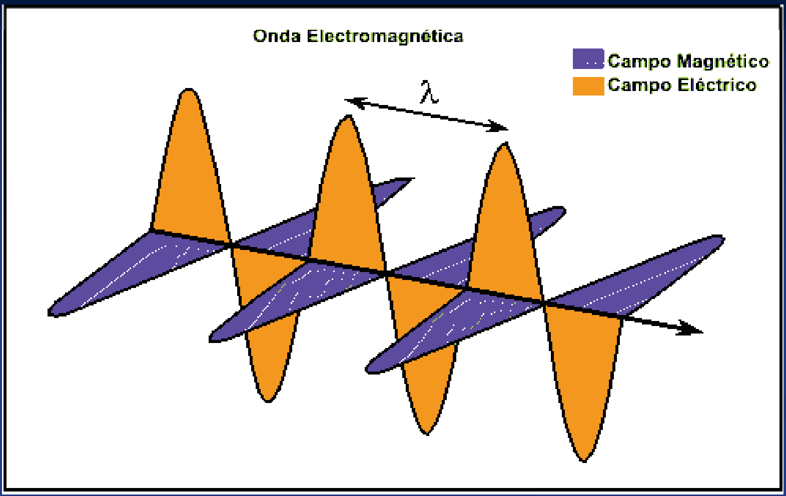
$$E=mc^2$$

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

Solar Radiation

That energy is transported at a speed of 299,793 km /s.
Takes 8 minutes to reach the Earth

Solar Spectrum: Radiation

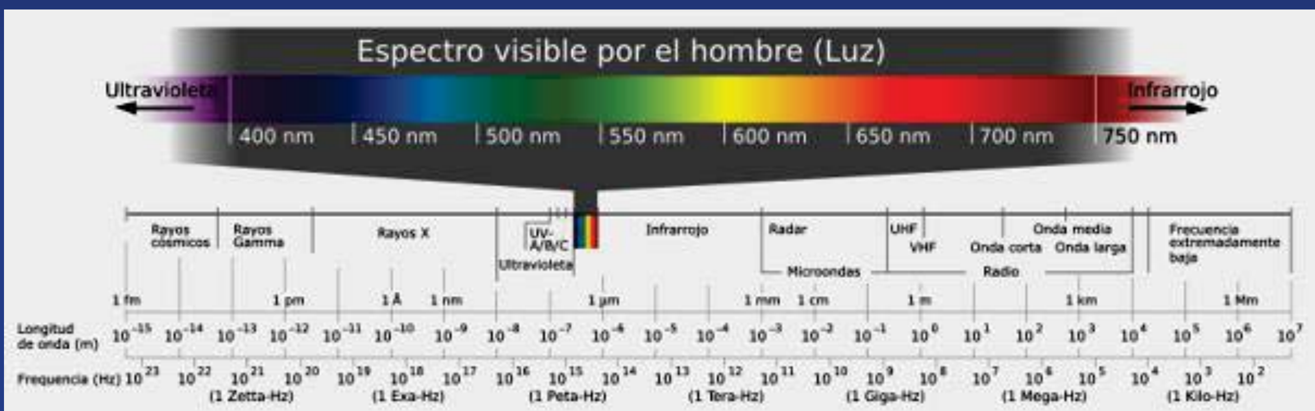


Wavelength λ, frequency ν and the propagation speed c of electromagnetic waves are related by the equation:

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

Solar Spectrum: Radiation

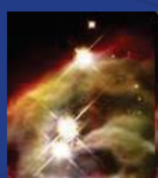
Electromagnetic spectrum



Gamma

X-ray

Visible

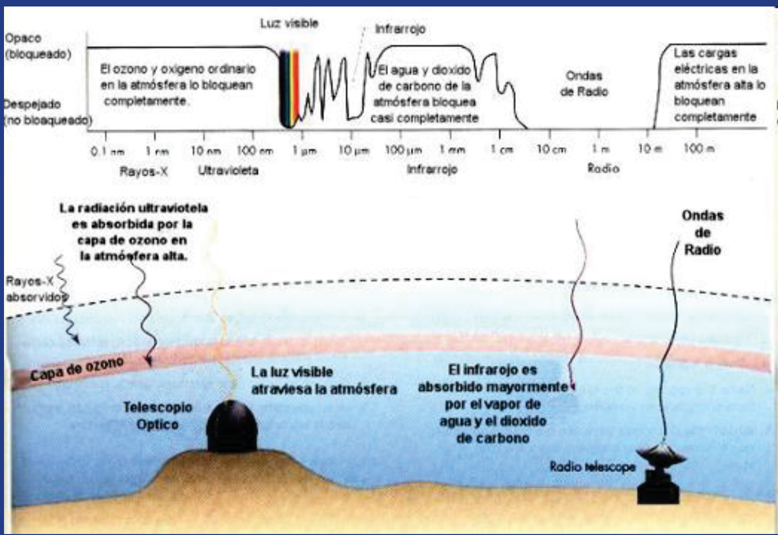


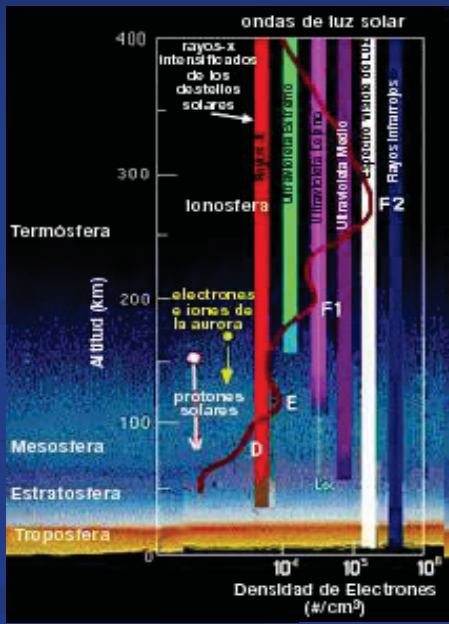
Infrared

Radio

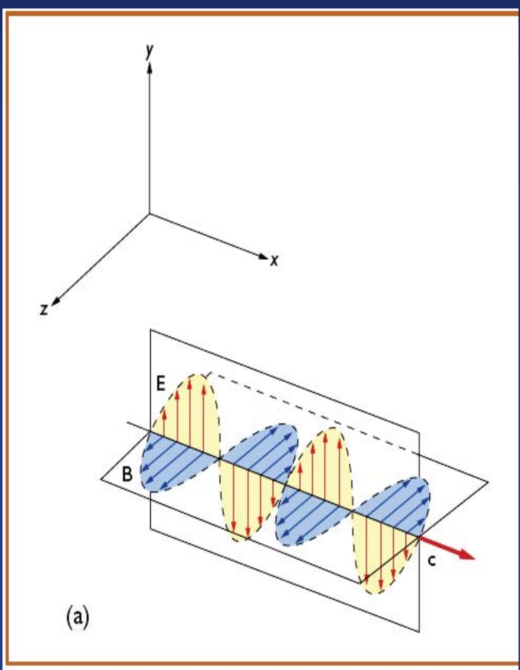
Solar spectrum : Radiation

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





Solar Radiation: Polarization



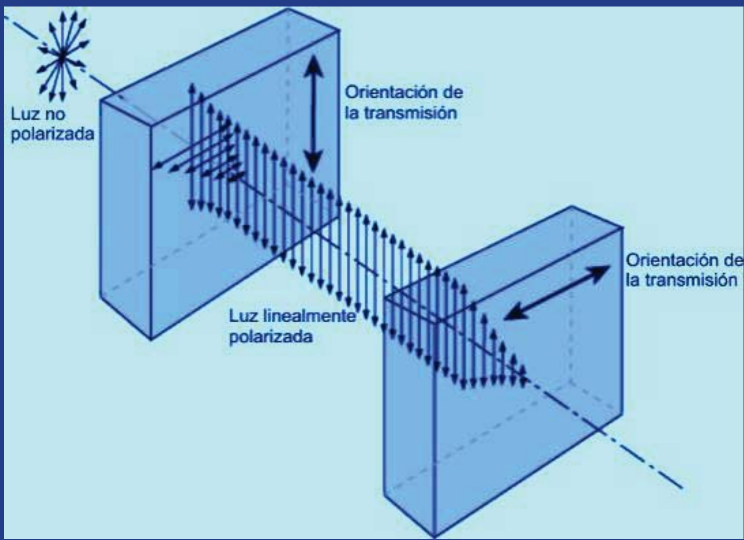
- Perfect electromagnetic radiation has a profile as seen in the figure.
- There is a vibration direction for each of the electric and magnetic fields.
- It is said to be linearly polarized.
- Sunlight does not have any privileged direction of vibration.

Solar Spectrum: Polarization

Sunlight can be polarized:

•By reflection

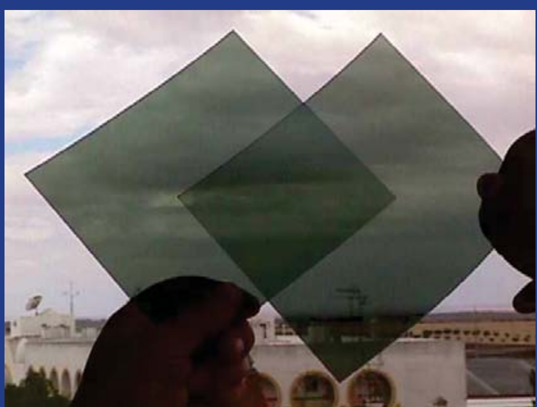
•By passing it through a polarizing filter

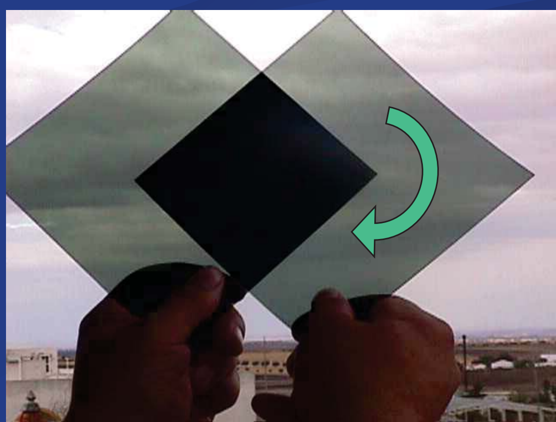


When the two polarizing filters have parallel polarization orientations, light passes through them. If they are perpendicular, the light that passes through the first filter is blocked by the second and the no light comes through.

Solar Spectrum: Polarization

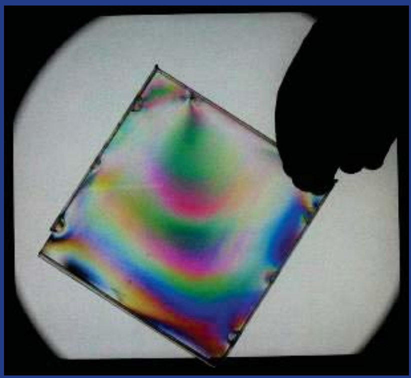
DEMONSTRATION





Solar Spectrum: Polarization

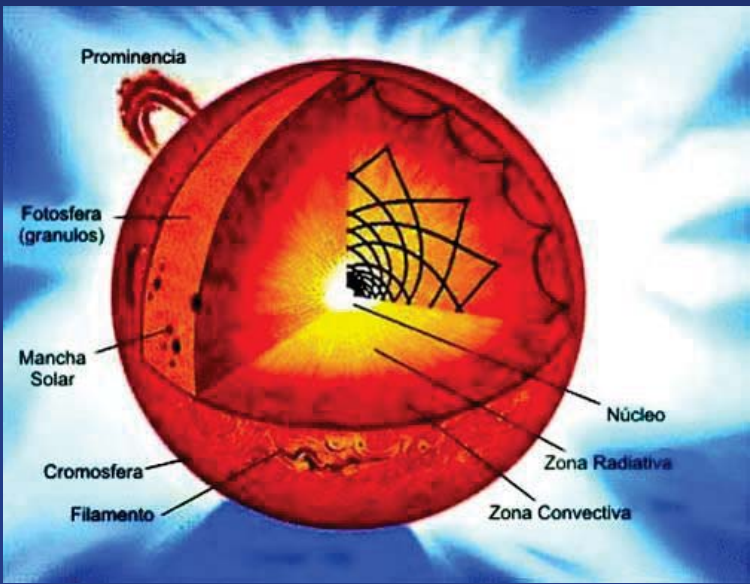
•Light can be also polarized by reflection.
•Polarized sunglasses help you avoid reflections.
•Polarization is used in photography and engineering to view internal tensions in materials.



Activity 1: Light polarization

•The liquid crystal display of laptop emits polarized light.
•Observe the plane of polarization with polarized sunglasses.
•Some objects rotate the plane of polarization: tape over crystal
•Observe the internal stresses in a piece of transparent plastic (e.g., a CD box)

Structure of the Sun

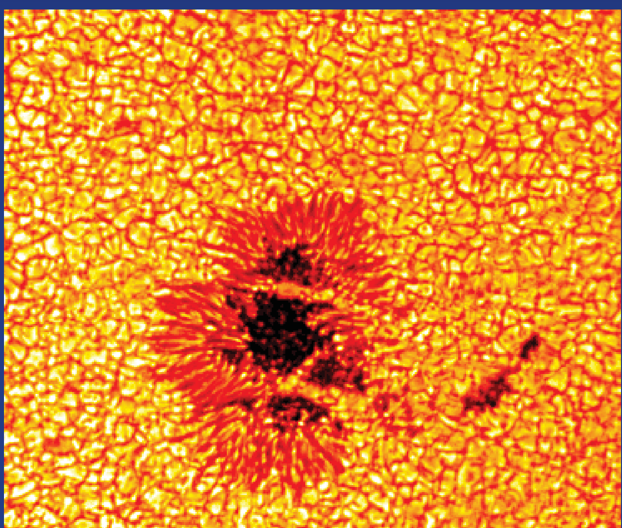


•Core:
15 million K

•Radiative zone:
8 million K

•Convective zone:
500 000 K.
There is convection (movement of matter) in the sun.

Structure of the Sun



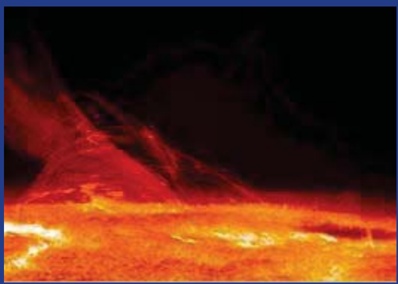
•photosphere:

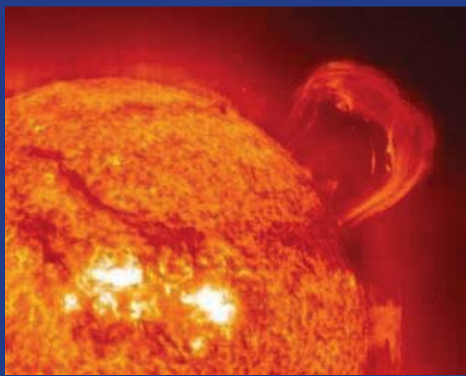
6.400 - 4.200 K,
is the "surface" of the Sun

Contains granules of ~1000 km

Structure of the Sun

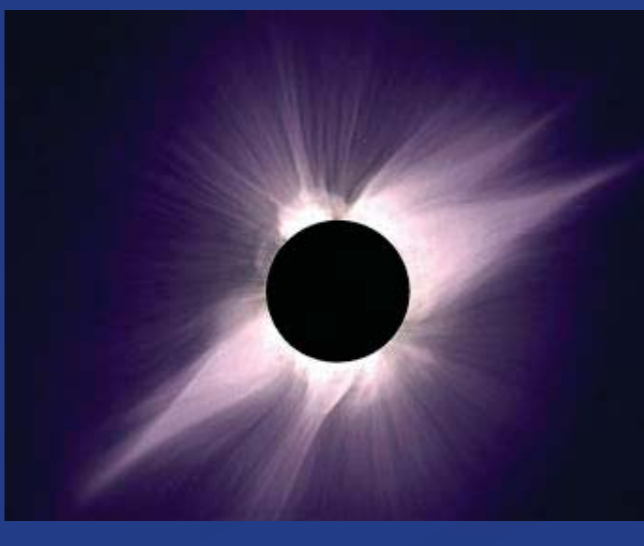
•Chromosphere: "burning prairie“ of 4.200-1·10^6 K. There are prominences (protuberances) and flares



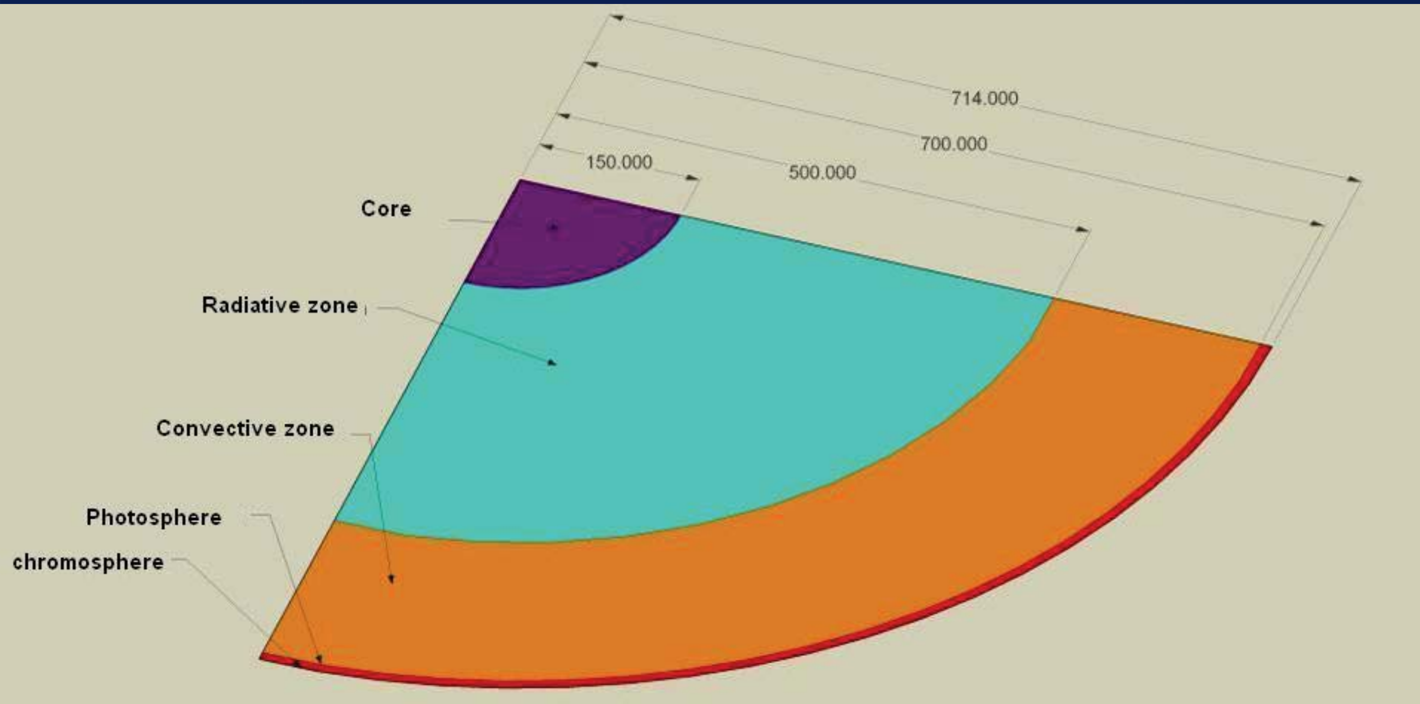


The Structure of the Sun

•Corona: solar wind, 1-2·10^6 K.
•Only seen in eclipses or with special instrument (the coronograph).



Structure of the Sun

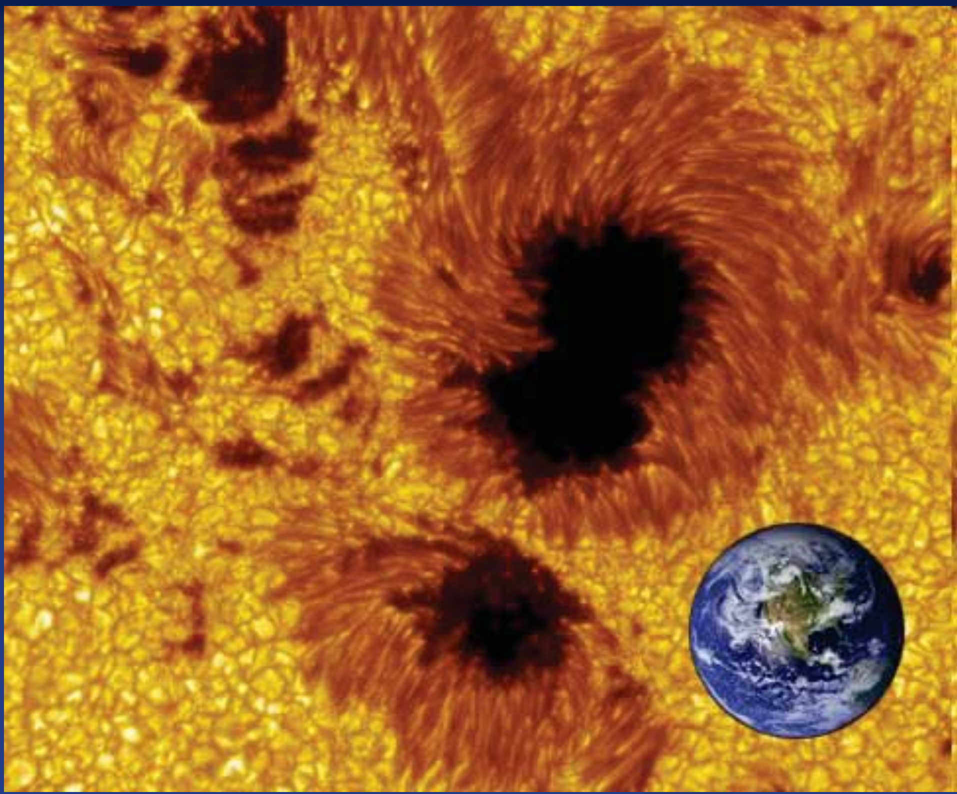


Sunspots

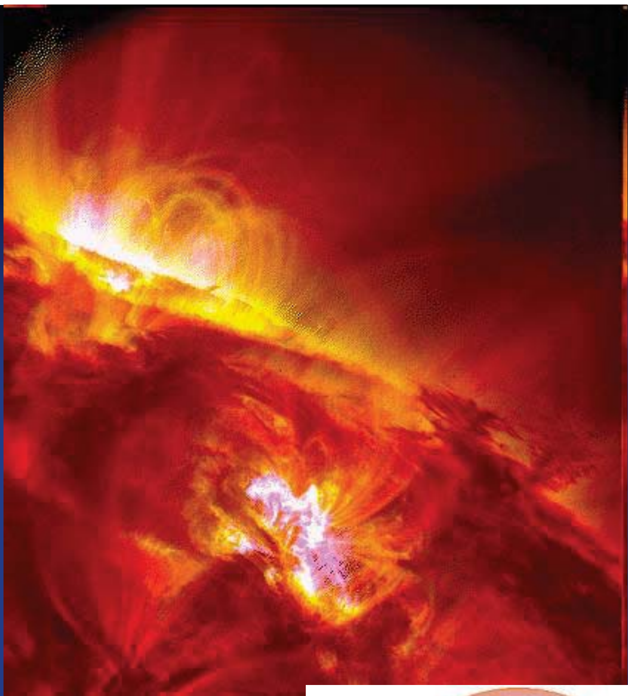
•Dark spots on the photosphere that are ~4200 K instead of 6000 K.

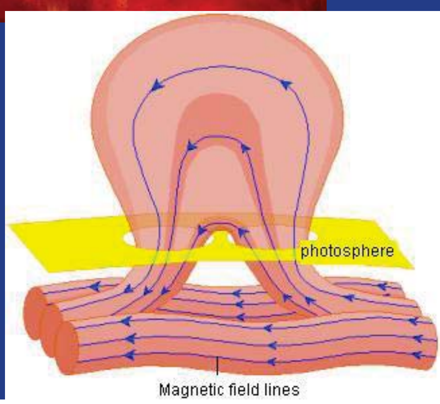
•Each sunspot has two regions: Umbra (central) and Penumbra.

Sunspots



Sunspots

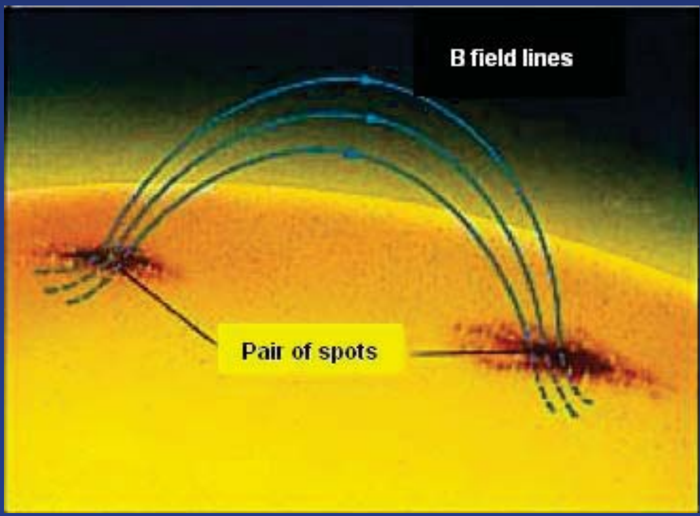


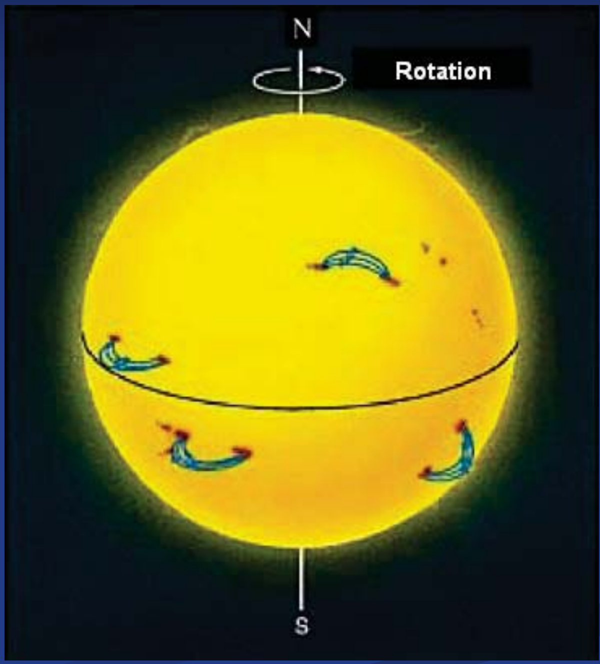


- There are strong magnetic fields in them.

- They are caused by the outcrop of magnetic lines in the loop rising from the inside.

Sunspots

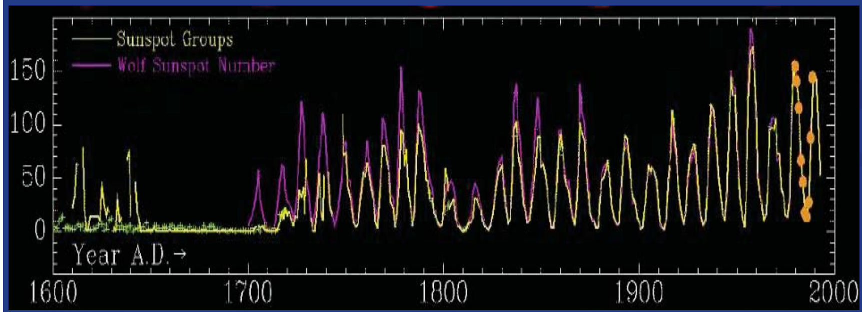


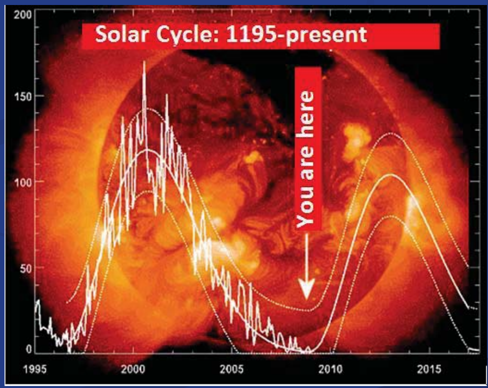


Sunspots

- The number of sunspots indicates the "solar activity"
- Nº of Wolf = 10·G+F

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

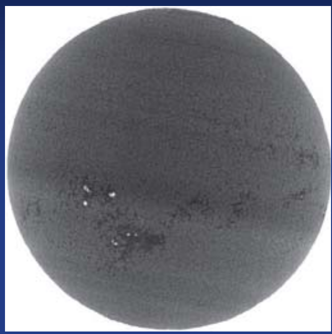




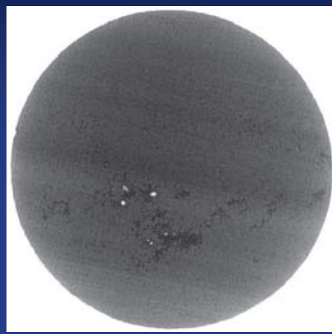
In 2008 there was a minimum of Sun's activity that lasted longer than usual.

Sunspots: Solar Rotation

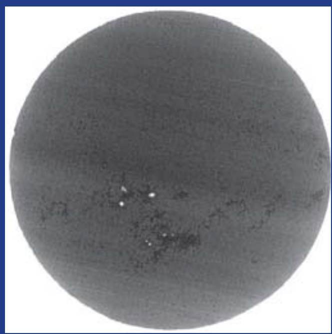
November 21 1992



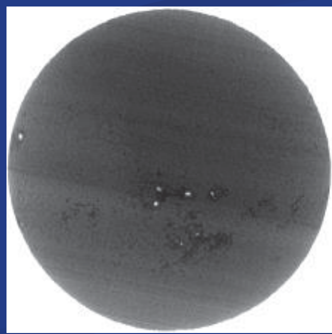
November 221992



November 23 1992

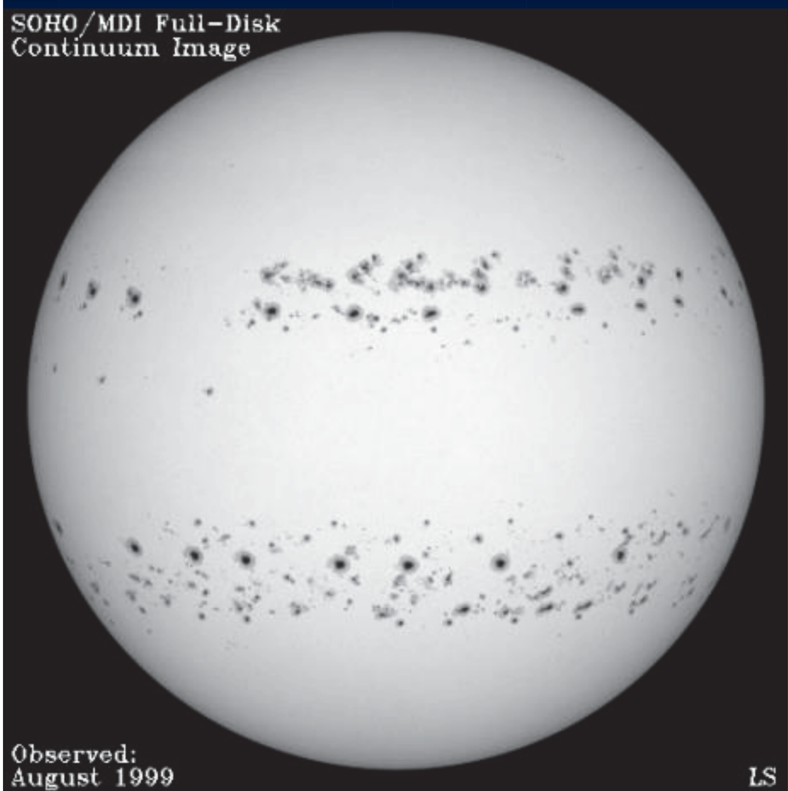


November 24 1992



Credit for images: Astronomical Observatory of the University of Coimbra

Sunspots and Solar Rotation

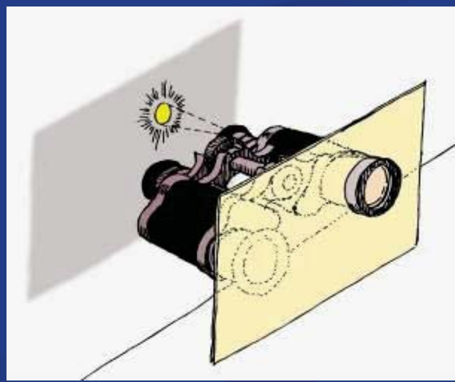


- They can be used to measure the solar rotation.
- Galileo was one of the first who saw sunspots using a telescope; he used them to measure the period of solar rotation.

- Differential Rotation: 25 days in equator / 34 days at the poles.

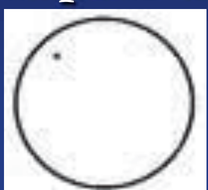
Activity 2: Determining the Sun's rotation period

•The observations of the Sun should always be done by projection with a telescope or binoculars. Never directly.



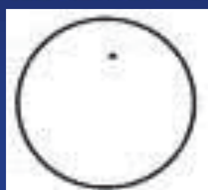
Activity 2: Determining the Sun's rotation period

•Sunspots are drawn for several days.

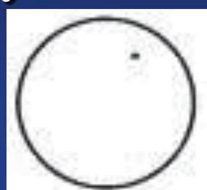


Day 1

Day 4

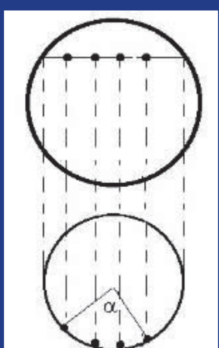


Day 6

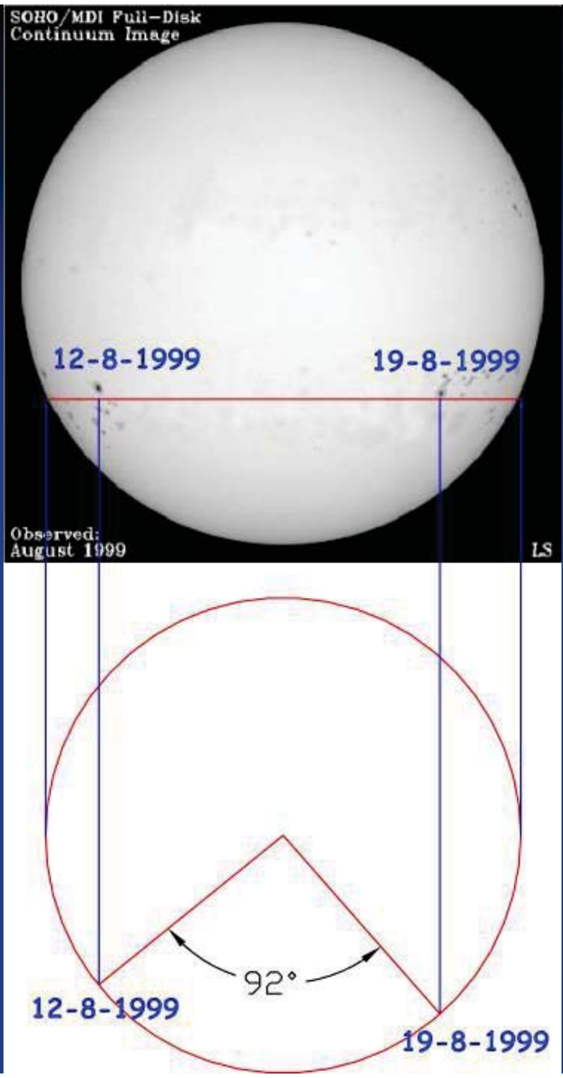


Day 8

•Draw the route, the circumference and angle α. Then the period P can be measured in days



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



Activity 2: Determining the Sun's rotation period

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

Solar Radiation

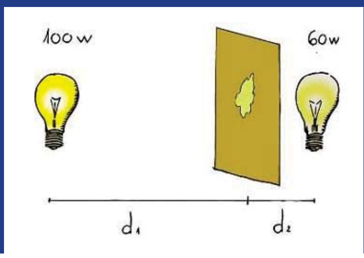
- The Sun is a large nuclear reactor producing photons, each with a frequency (color) and an energy of $E = h \cdot \nu$
- The brightness (power in watts) of the Sun is enormous: every second it emits the equivalent of trillions of atomic bombs.
- That energy is transmitted through space like a bubble getting bigger and bigger in time.
- The area of the bubble is $4 \cdot \pi \cdot R^2$.
- At distance R from the Sun, the energy that arrives in every second at 1 m^2 is:

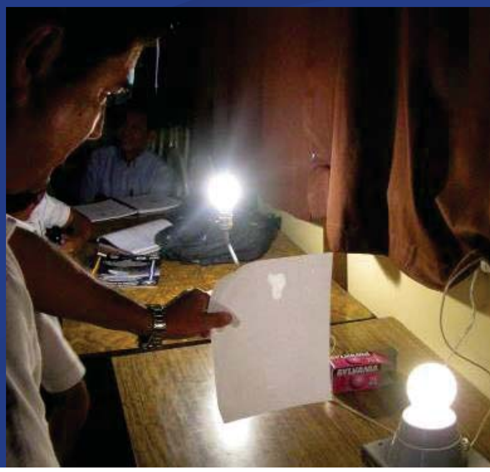
$$\frac{P}{4\pi R^2}$$

Activity 3: Measure Sun's luminosity

- The energy is transmitted as the inverse square of the 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 the same, the spot is not seen anymore; that is, the same energy arrived from both sides, and then:

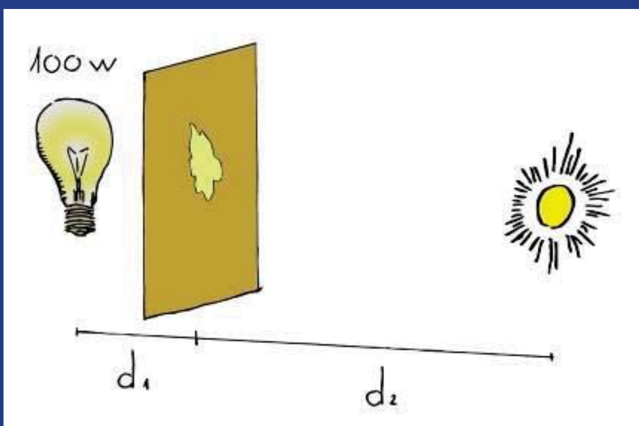
$$\frac{P_1}{4\cdot\pi\cdot d_1^{\,2}} = \frac{P_2}{4\cdot\pi\cdot d_2^{\,2}}$$





Activity 3: Measure Sun's luminosity

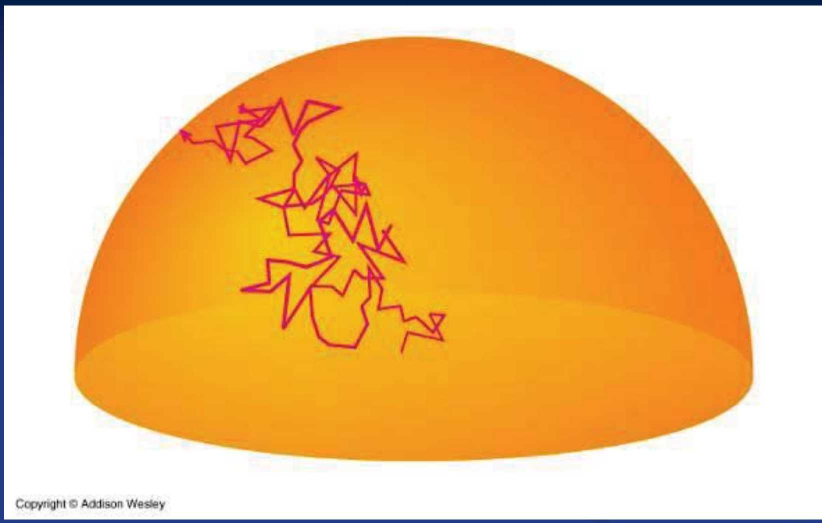
We compare a bulb of 100 W with the Sun, which is at 150 million km ($1.5 \cdot 10^{11}$ m), and we measure P.



$$\frac{100\,W}{d_1^{\,2}} = \frac{P}{d_2^{\,2}}$$

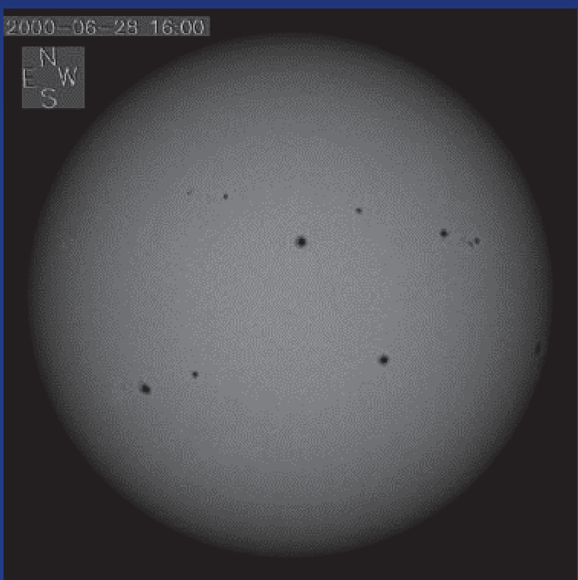
- The result should be approximately $3.8\cdot 10^{26}$ W

Solar Spectrum: Opacity



Photons are produced in the innermost parts 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 the edge the Sun is less bright because it is more transparent.

Activity 4: Transparency and opacity

Transparent is not the same as invisible

Spectrum

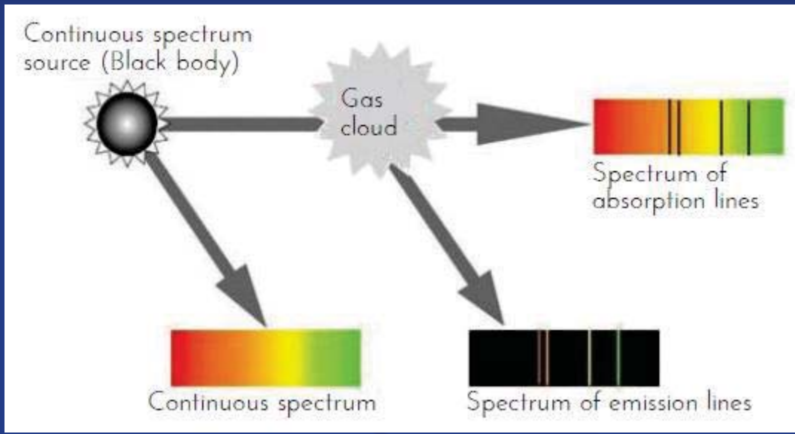
Fuente: Deutsche Bundespost 1993

In 1701, Newton used a prism and decomposed the sunlight into colors.
Any light can be decomposed with a prism or a diffraction grating. What you get is the spectrum.

Kirchoff and Bunsen Laws

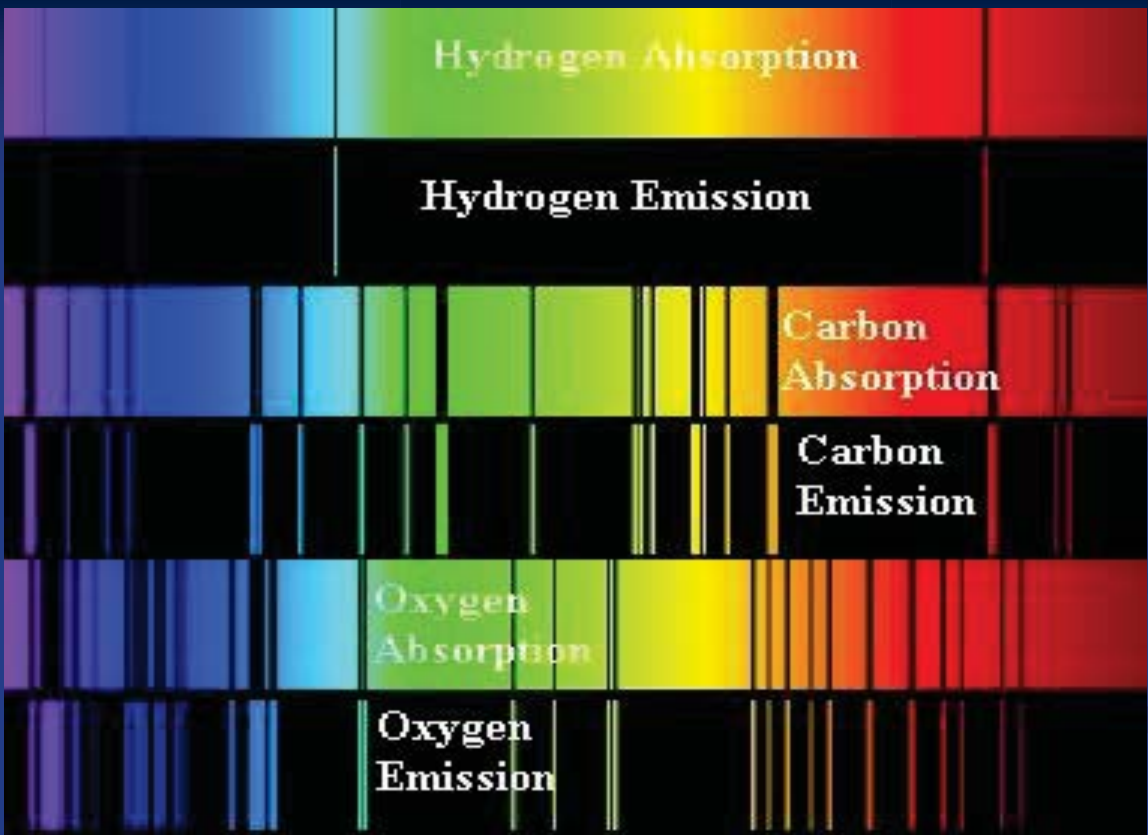
1st Law - An incandescent solid object produces light with continuous spectrum.

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

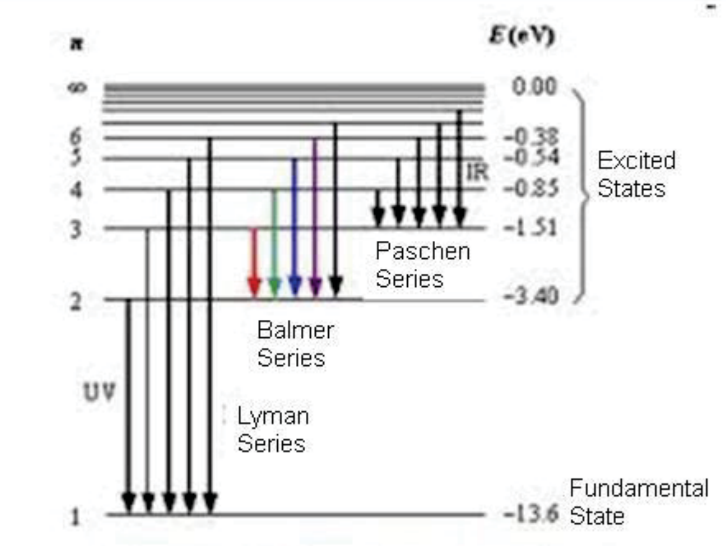


3rd Law - A incandescent solid object surrounded by a low pressure gas produces a continuous spectrum with voids in wavelengths whose positions corresponds to those of 2nd Law

Spectrum



Spectrum



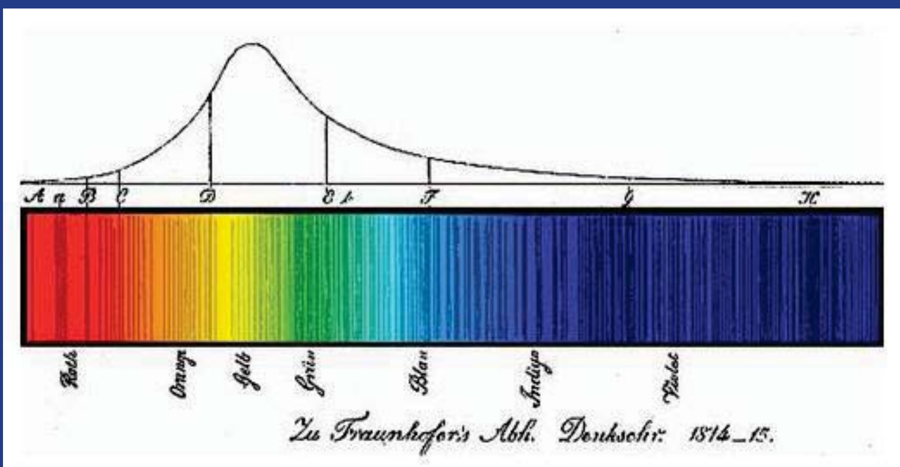
Energy levels of the hydrogen atom, with some of the transitions which produce the spectral lines indicated

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

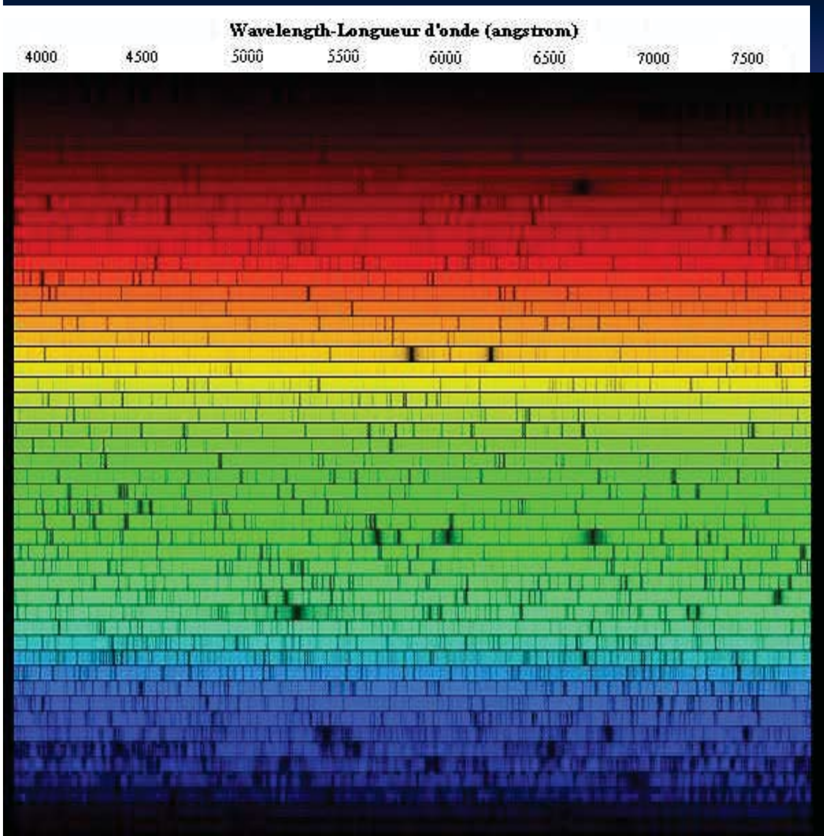
Solar spectrum: ABSORPTION SPECTRUM

In 1802, William Wollaston observed black lines on the solar spectrum.
In 1814, Joseph Fraunhofer systematically studied the spectrum of the Sun and detected about 700 dark lines.

Joseph Fraunhofer
1787-1826

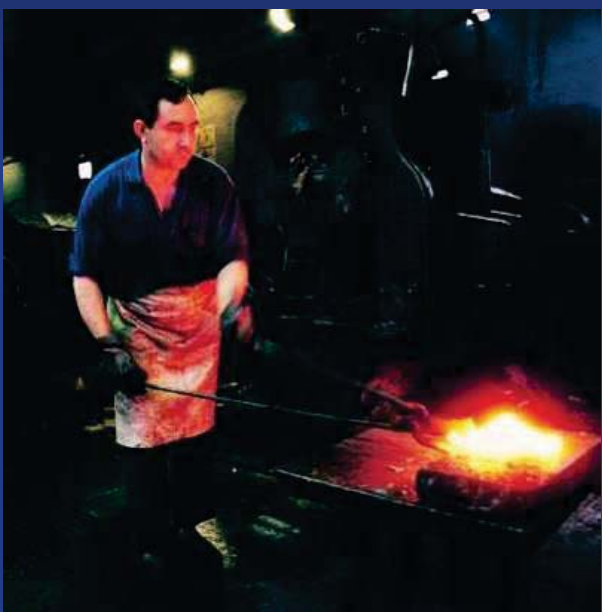


Solar spectrum: ABSORPTION SPECTRUM



- The dark lines appear due to the presence of gases in the solar atmosphere.
- We can know of what the Sun is made without entering inside
- Today high definition spectra show many more lines.

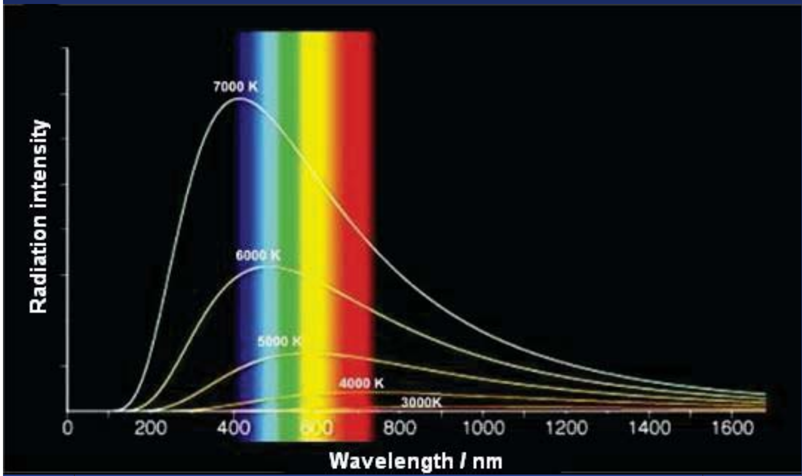
Black body radiation



When an iron warms up, it emits light :

- Red
- Yellow
- White
- Bluish.

Black body radiation



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

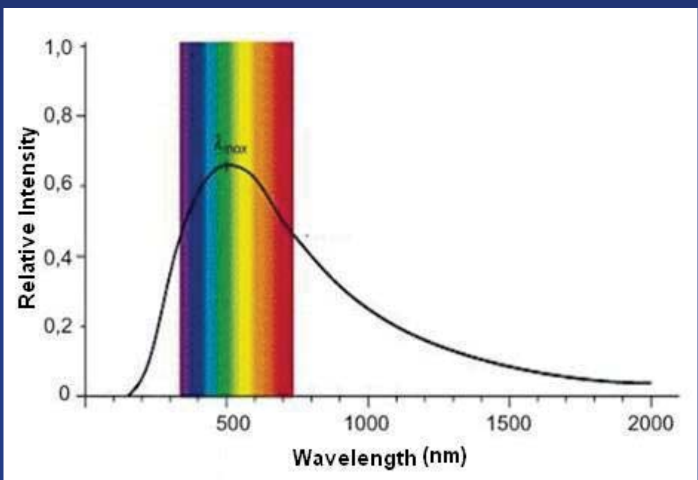
There is $\lambda_{máx}$ at which the energy is maximum. This $\lambda_{máx}$ depends on the temperature T:

$$\lambda_{máx} = \frac{2{,}898 \times 10^{-3}}{T} \quad (\mathrm{m})$$

Wien Law

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

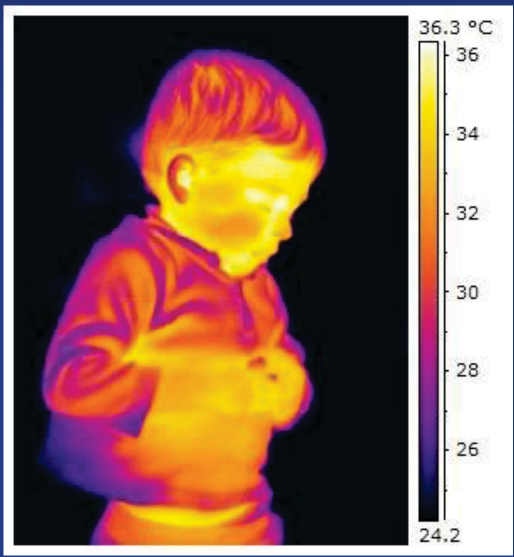
Black body radiation



The Sun has a $\lambda_{máx}$ of 500 nm.

This means that its surface temperature is 5800 K.

Black body radiation



The human body has a temperature of

$T = 273+37 = 310$ K.

A body emits most energy at $\lambda_{máx} = 9300$ nm.

Night vision devices use those λ.

Light scattering

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

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

•Those particles that have similar size to λ of photons will be scattered, and the others not (Rayleigh scattering).

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

Therefore, we see blue sky.

Activity 5: Dispersion of light

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

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

Thank you very much for your attention!