Sunspots and Solar Spectrum
太阳黑子和光谱

Alexandre Costa, Beatriz García, Ricardo Moreno

International Astronomical Union
Escola Secundária de Loulé, Portugal
ITeDA and Universidad Tecnológica Nacional, Argentina
Colegio Retamar de Madrid, Spain

Goals
教学目标

- Understand the nature of the solar spectrum
- 理解太阳光谱的本质
- Understand the generation of the solar spectrum
- 理解太阳光谱是如何生成的
- Understand the nature of sunspots
- 理解太阳黑子的本质
- Understand the historical significance of Galileo's work on sunspots
- 理解伽利略的太阳黑子观测工作在历史上的重要意义。

Solar Radiation
太阳辐射

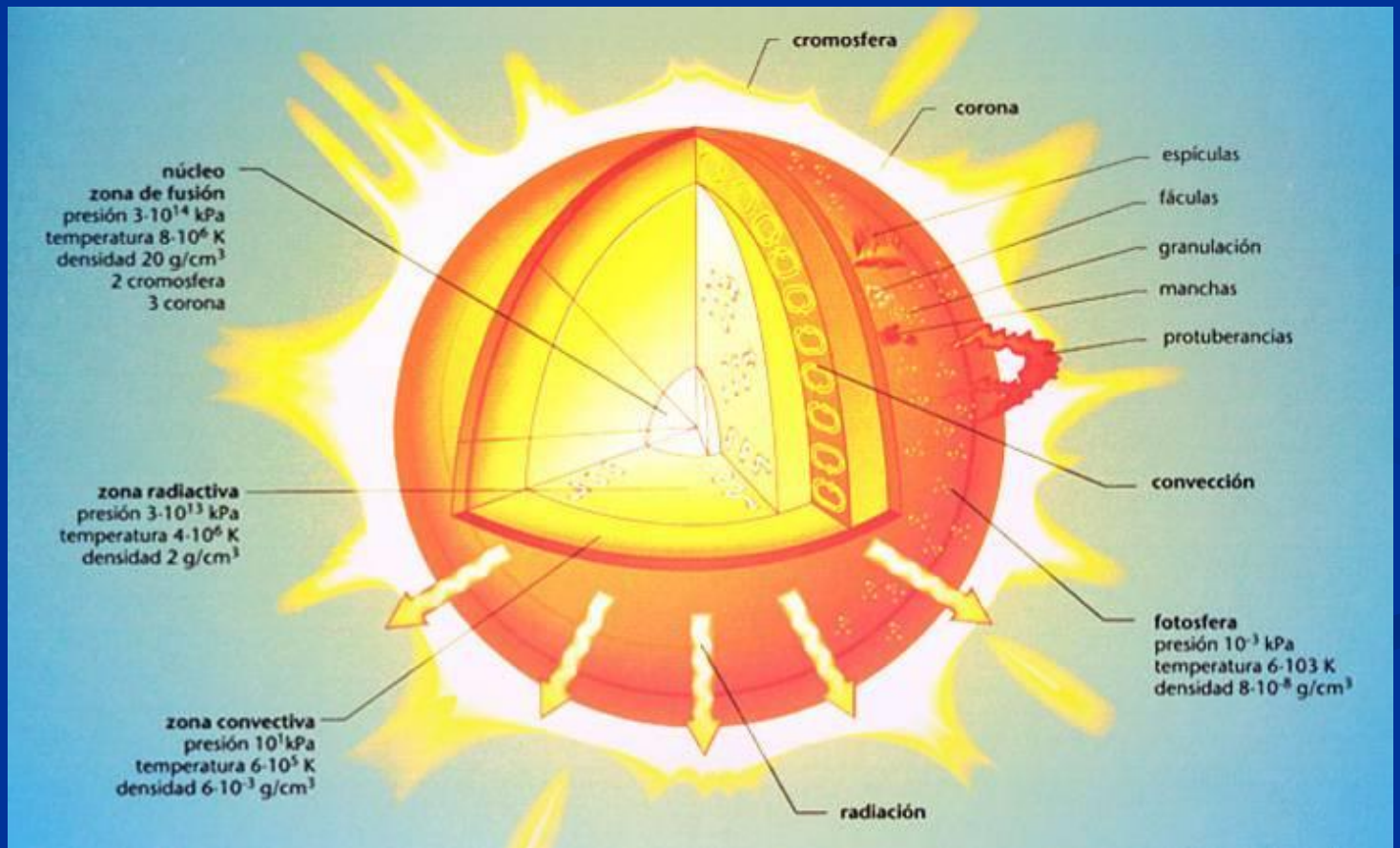
Almost all the energy (heat and light) that we use on Earth comes or has come from the Sun

地球上几乎所有的能量(光和热)都源自于太阳

Solar Radiation 太阳辐射

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.

辐射来自于日核的核聚变反应，那里有极高的压力，温度高达1500万度。



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

Solar Radiation 太阳辐射

- 4 protons (hydrogen nuclei) come together to form a helium atom (fusion).
- 4个质子（氢核）聚变为1个氦原子（核聚变）

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

- The resulting mass is less than the mass of initial 4 protons since the “left-over” mass is transformed into energy:
- 转化后的质量要比之前少一点，这些损失的质量转化为能量：

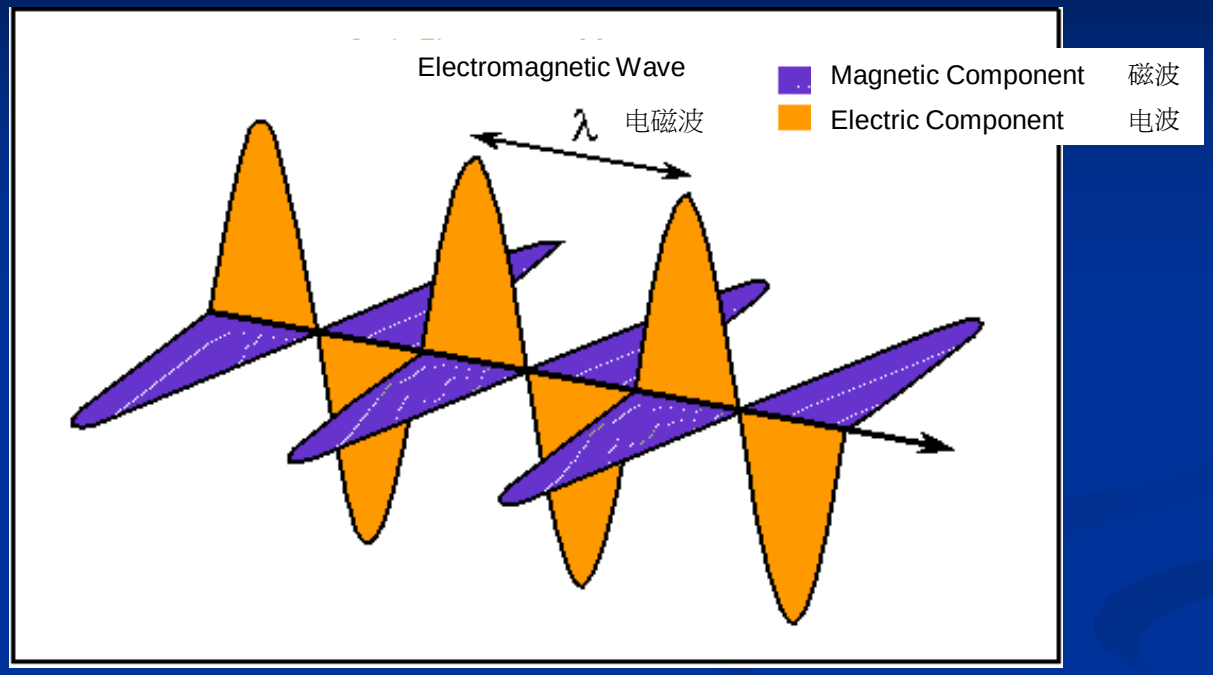
$$E = mc^2$$

- 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.
- 每秒有6亿吨氢聚变为5.955亿吨氦，其余质量转化为能量。
- The Sun is so massive that, even losing at this rate, it will last billions of years.
- 太阳能以这样的方式反应持续数十亿年。

Solar Radiation 太阳辐射

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.
从太阳表面辐射出的能量以299,793 km /s的速度传播，8分钟后到达地球。

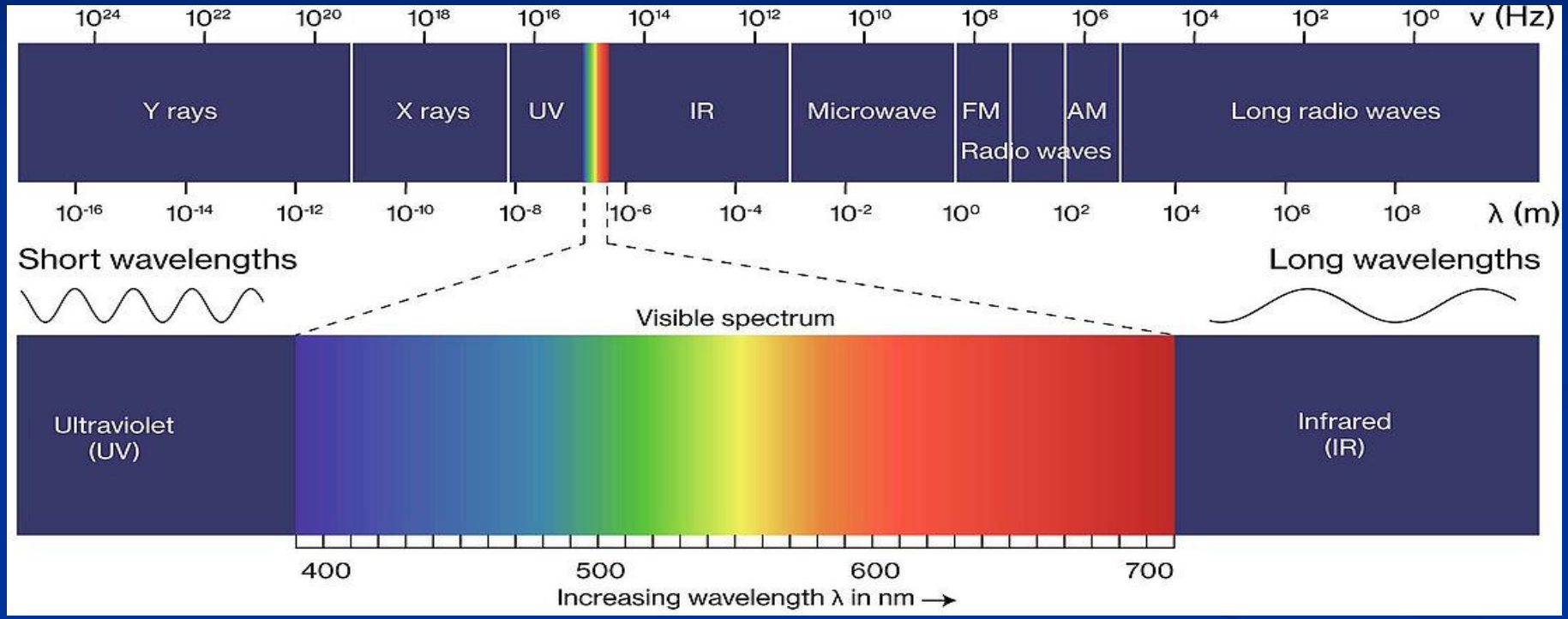
Solar Spectrum: Radiation
太阳光谱：辐射



Wavelength λ, frequency ν and the propagation speed c of electromagnetic waves are related by the equation:
波长λ、频率ν和传播速度c的关系：

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

Solar Spectrum: Radiation
太阳光谱：辐射
The Electromagnetic Spectrum 电磁波谱



Gamma
伽马射线

X-ray
X射线

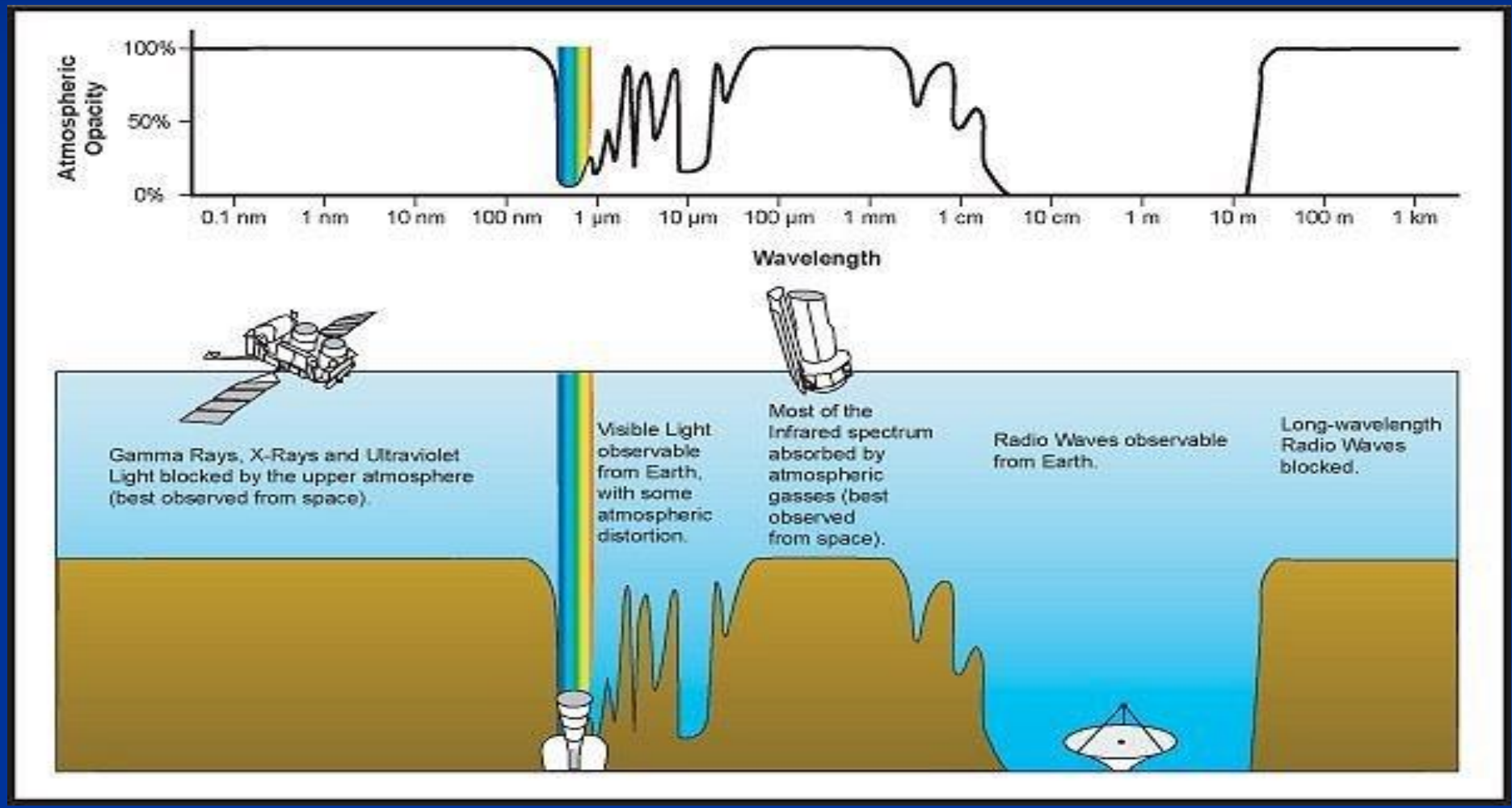
Visible
可见光

Infrared
红外线

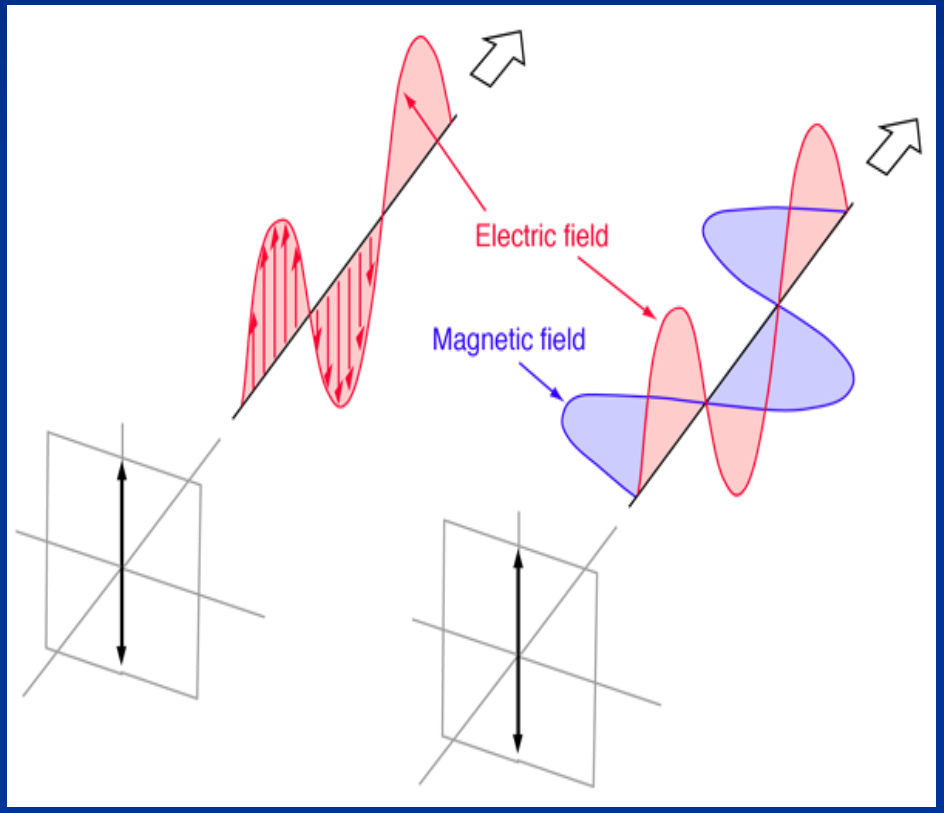
Radio
无线电波

Solar spectrum: Radiation
太阳光谱：辐射

The Earth's atmosphere is opaque to most wavelengths of radiation.
地球大气阻挡了多数波长的辐射



Solar Radiation: Polarisation
太阳辐射：偏振



- Simple electromagnetic radiation has a profile as seen in the figure.
- 简单的电磁辐射如左图所示。

- There is a vibration direction for the electric field and another for the magnetic field.
- 电波和磁波有各自的偏振方向。

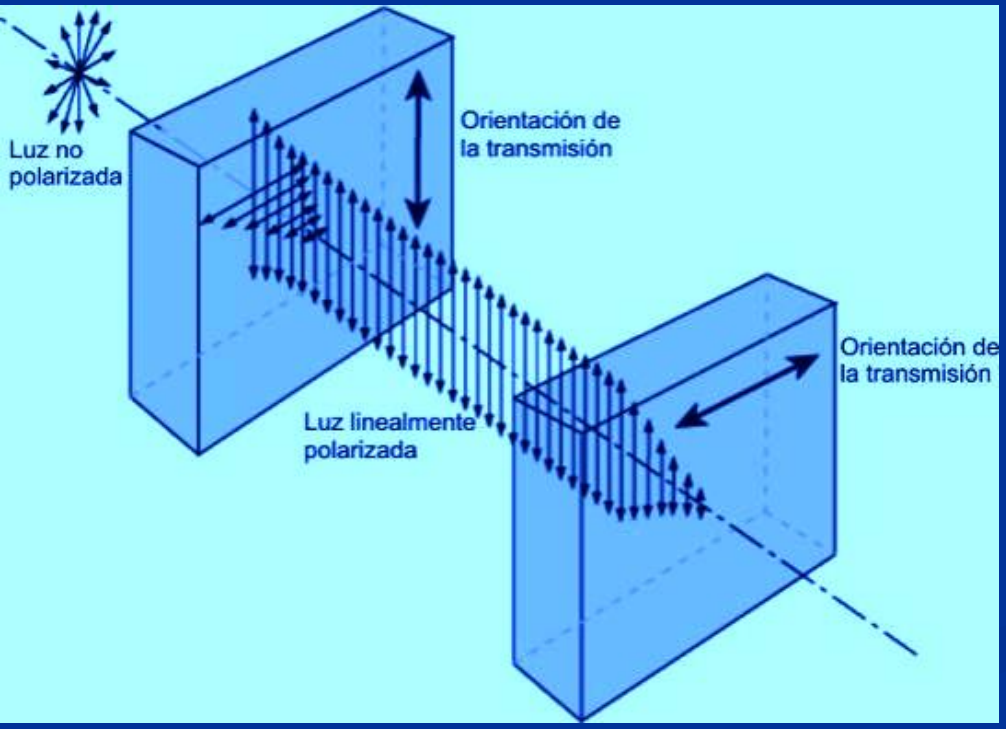
- This wave is linearly polarized. In this case vertically polarised.
- 这种电磁波是线偏振，它的电波和磁波互相垂直。

- Sunlight does not have any privileged direction of vibration.
- 太阳光没有特定的偏振方向。

Solar Spectrum: Polarisation 太阳光谱：偏振

Sunlight can be polarised: 太阳光可以变成偏振光：

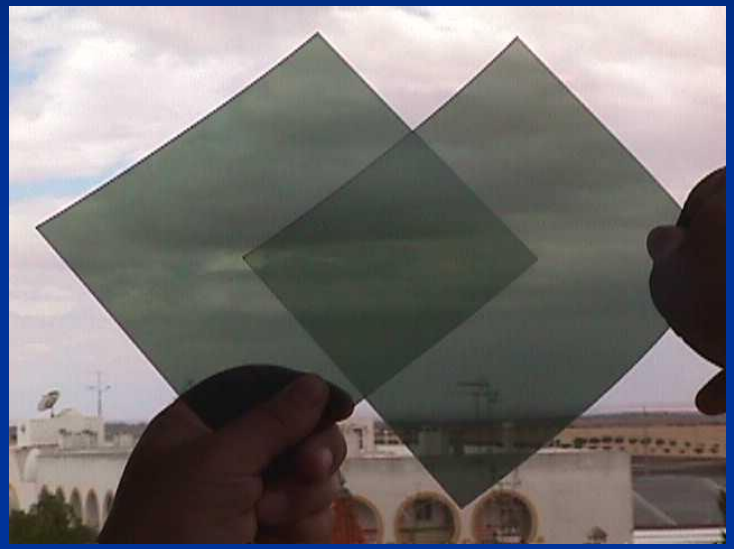
- By reflection 通过反射
- By passing it through a polarising filter 通过偏振片



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.

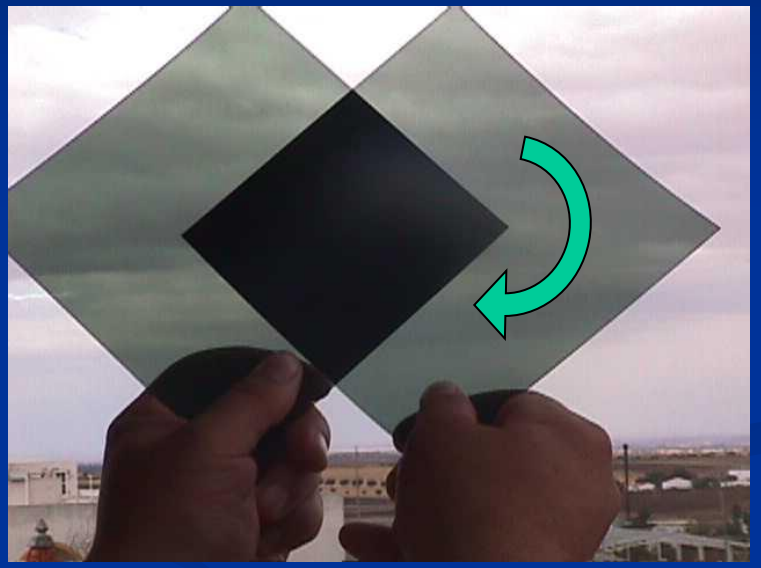
两个偏振片方向相同重叠放置时，光可以穿过它们，将其中一个转90度后，穿过第一个偏振片的光会被第二个偏振片挡住，就没有光穿过了。

Activity 1: Solar Spectrum Polarization
活动1：太阳光谱偏振



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

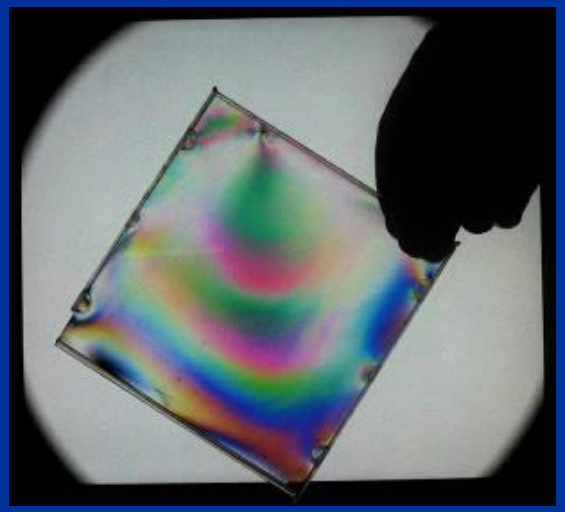
两个偏振片方向相同重叠放置时，光可以穿过它们。



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

将其中一个转90度后，穿过第一个偏振片的光会被第二个偏振片挡住，就没有光穿过了。

Activity 1: Solar Spectrum Polarisation
活动1：太阳光谱偏振

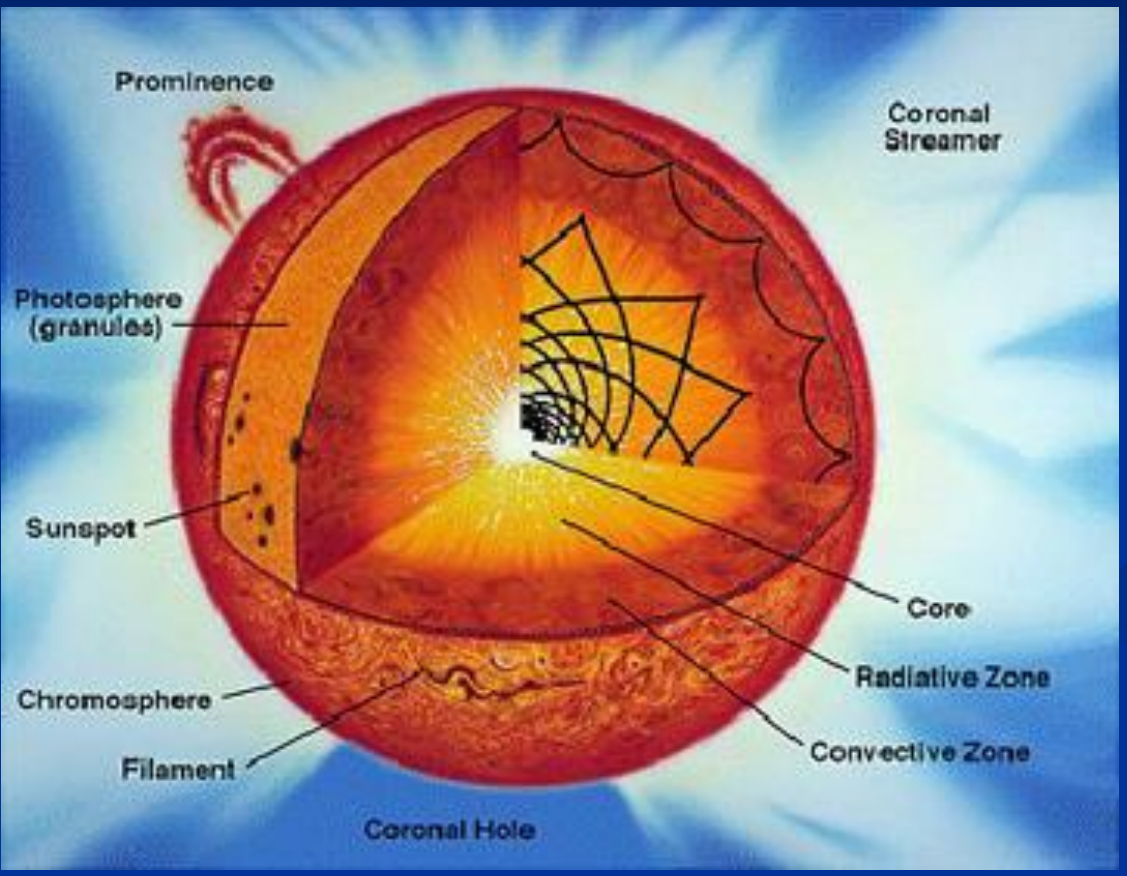


- Light can be polarised by reflection.
- 光可以通过反射变成偏振光
- Polaroid sunglasses help you avoid reflections.
- 偏振太阳镜帮助我们避开这样的反射
- Polarisation is used in photography and in engineering to view internal stresses in materials.
- 偏振通常被应用在摄影和工程材料的内应力检测上

Activity 2: Light polarization
活动2：光的偏振

- The liquid crystal display of laptop or phone emits polarised light.
- 笔记本电脑或手机的液晶显示屏发出的是偏振光。
- Observe the plane of polarisation with polarised sunglasses.
- 通过偏振太阳镜来观察偏振面。
- Some objects rotate the plane of polarisation: tape over plastic.
- 有些物体会让偏振面发生旋转：贴在塑料上的胶带。
- Observe the internal stresses in a piece of transparent plastic (e.g. a CD box)
- 观察一片透明塑料（例如CD盒）的内应力。

Structure of the Sun
太阳的结构



- Core:
  15 million K

日核：1500万K

- Radiative zone:
  8 million K

辐射层：800万K

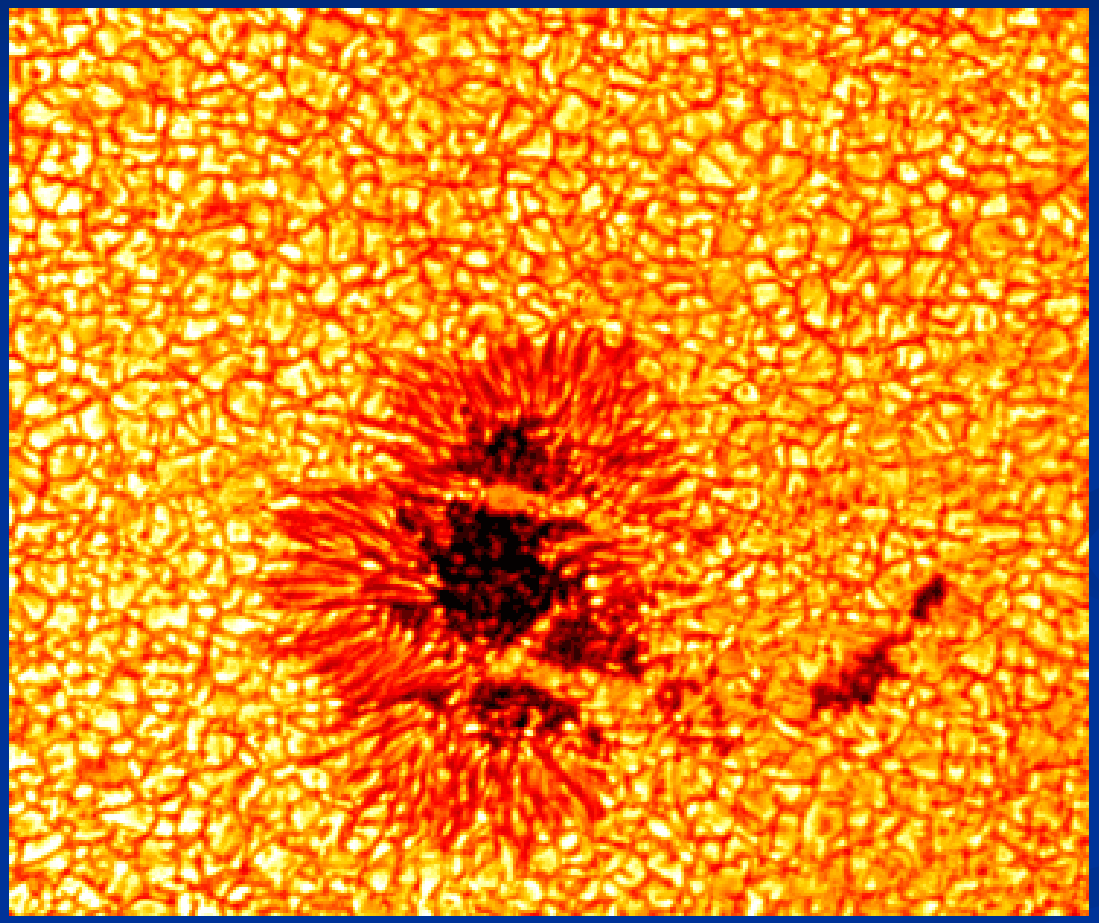
- Convective zone:
  500 000 K

对流层：500 000K

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

太阳的外层结构中存在对流现象（物质运动）

Structure of the Sun
太阳的结构



- Photosphere:
  6 400 – 4 200 K

光球层： 6 400 – 4 200 K

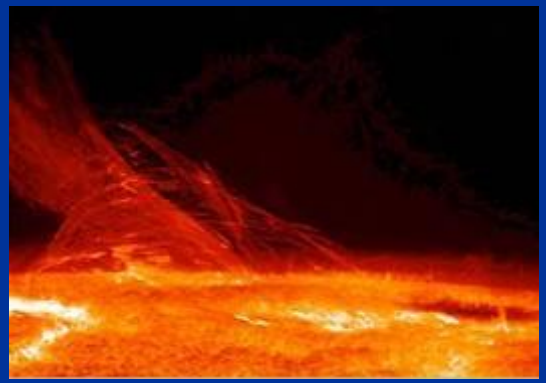
It is the “surface” of the Sun.
它是太阳表面。

Contains granules of ~1 000 km size
米粒组织的尺度大约是1000千米

Structure of the Sun 太阳的结构

• Chromosphere: “burning prairie” of 4 200 to 1 000 000 K. There are prominences and flares.

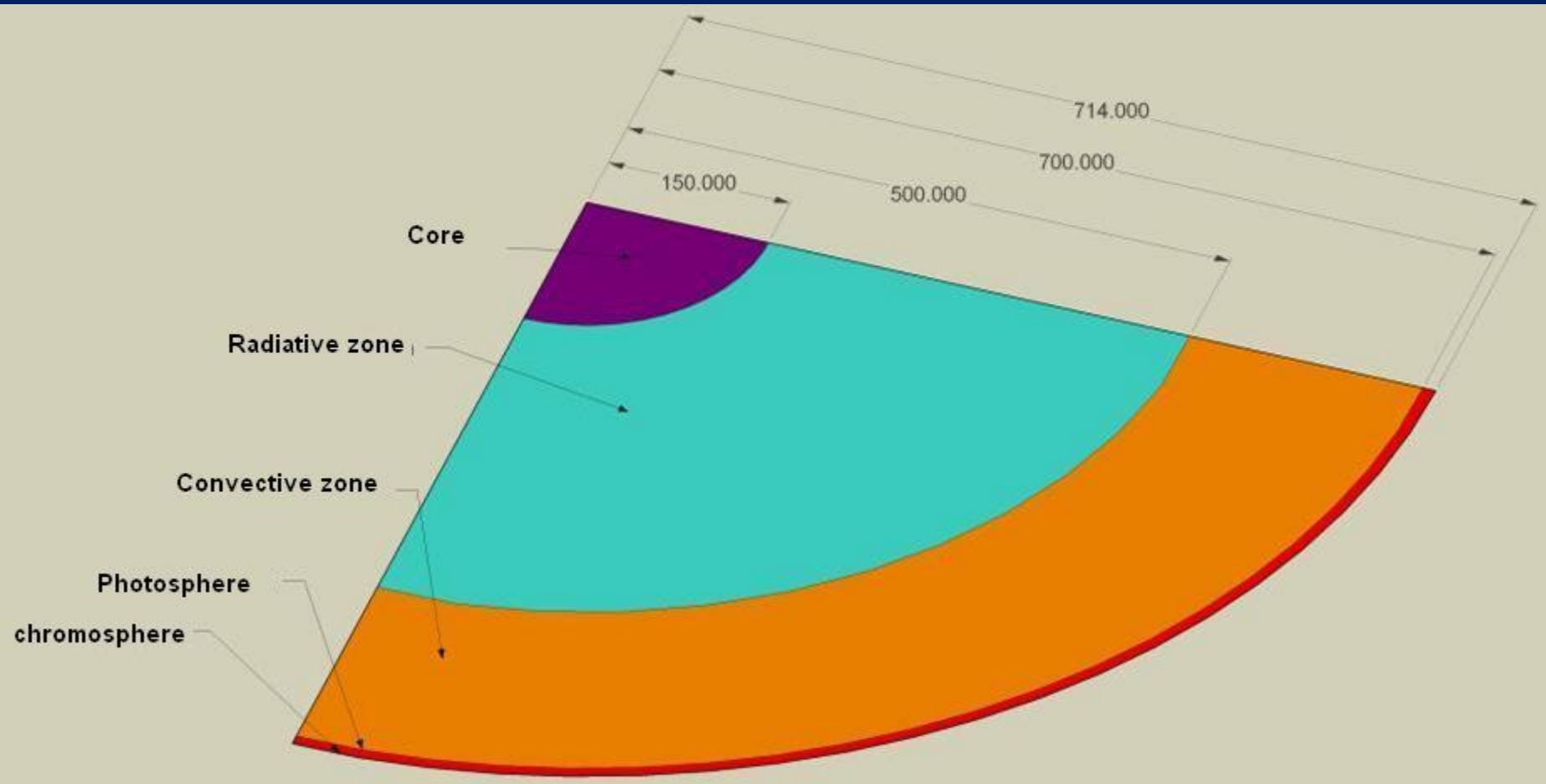
•色球层：一片温度达4200K至1 000 000K的“燃烧的草原”，这里有日珥和耀斑。



The Structure of the Sun
太阳的结构

- Corona: the solar wind, 1 to 2 000 000 K.
- Only seen in eclipses or with a special instrument (a coronagraph).
- 日冕：太阳风，1 000 000至2 000 000K。
- 只有通过日冕仪或日全食期间才能看到日冕。

Structure of the Sun 太阳的结构



Activity 3: Solar Structure
活动3：太阳的结构

Make a simple model of the layers of the Sun.

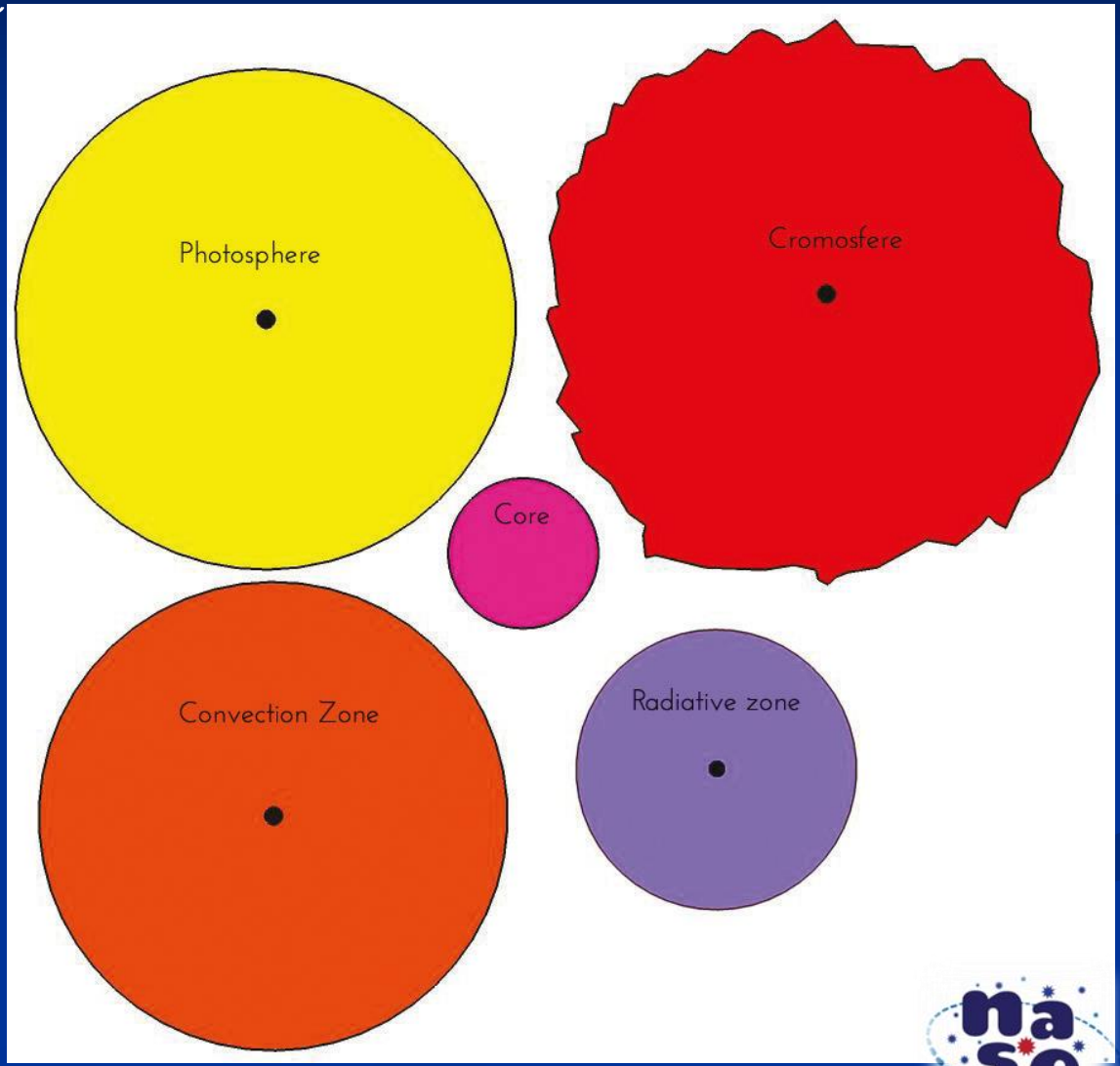
The goal is to cut out the different shapes.

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

制作一个简单的太阳分层模型。

剪出不同的形状。

它们可以从不同颜色的纸上剪下来，也可以涂不同色。



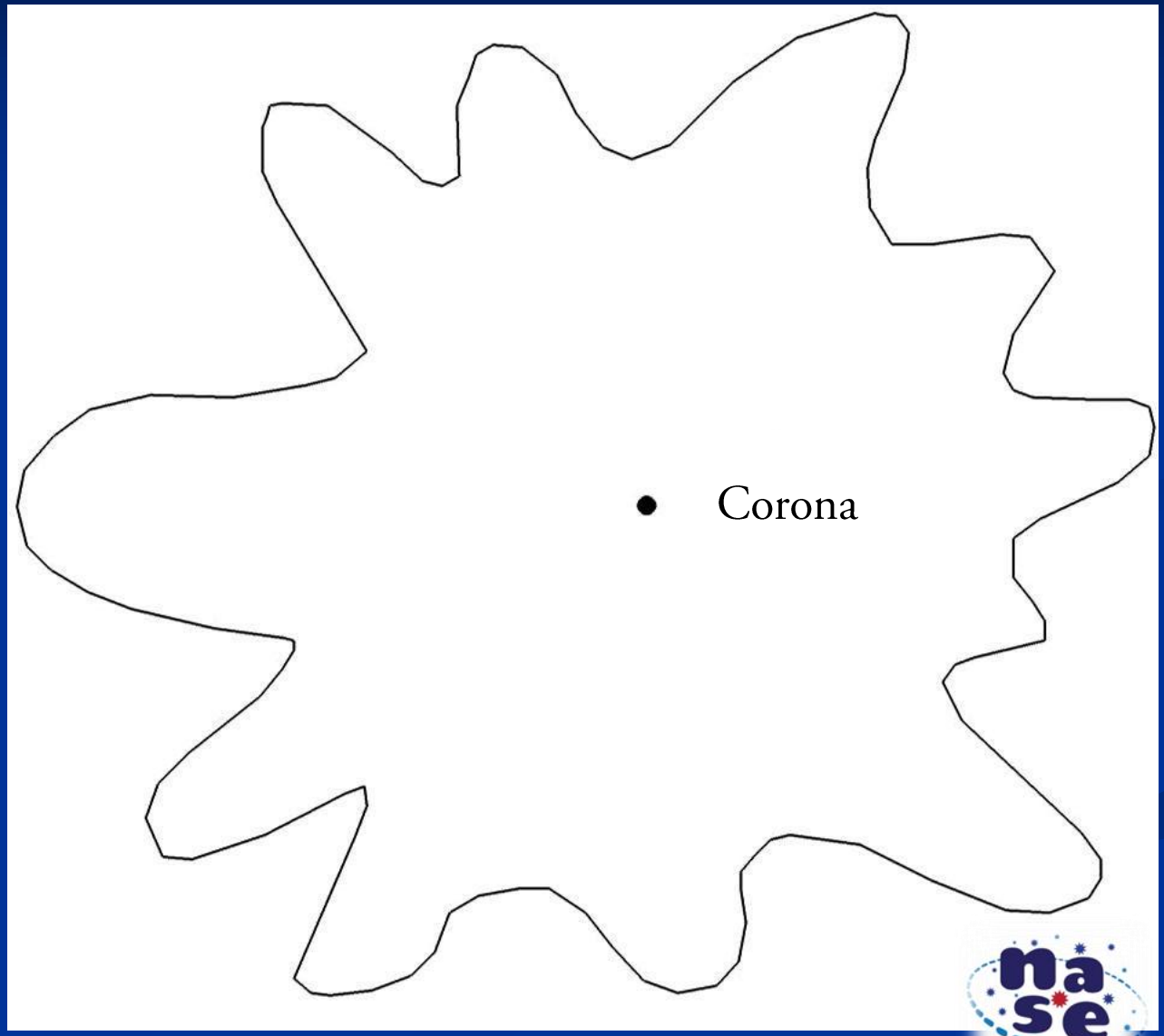
Activity 3: Solar Structure
活动3：太阳的结构

The Corona can made of OHP film.

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

日冕可以用投影胶片来制作。

将不同的层按照正确的顺序，一层层粘起来。



Activity 3: Solar Structure
活动3：太阳的结构

Sunspots 太阳黑子

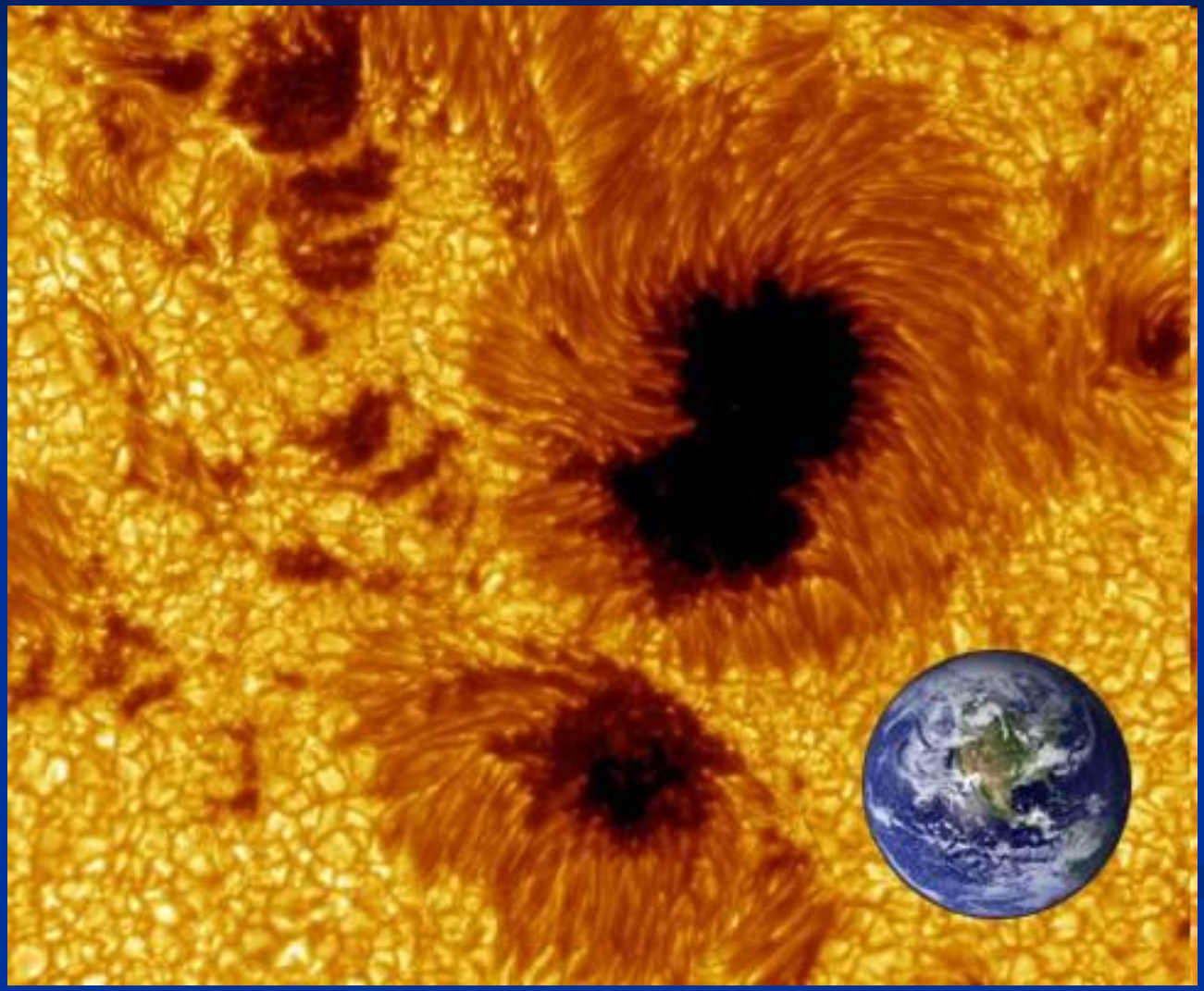
• Dark spots on the photosphere that are ~4 200 K instead of 6 000 K.

•黑子位于光球层(6 000K)，温度约为4200K。

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

•黑子由本影(内部)和半影组成(外部)。

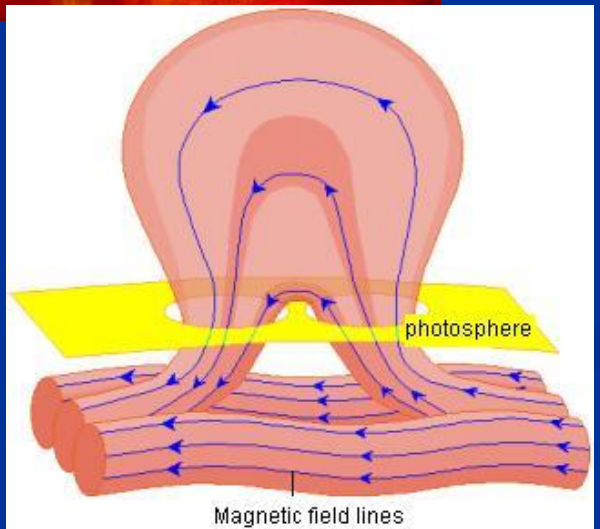
Sunspots 太阳黑子



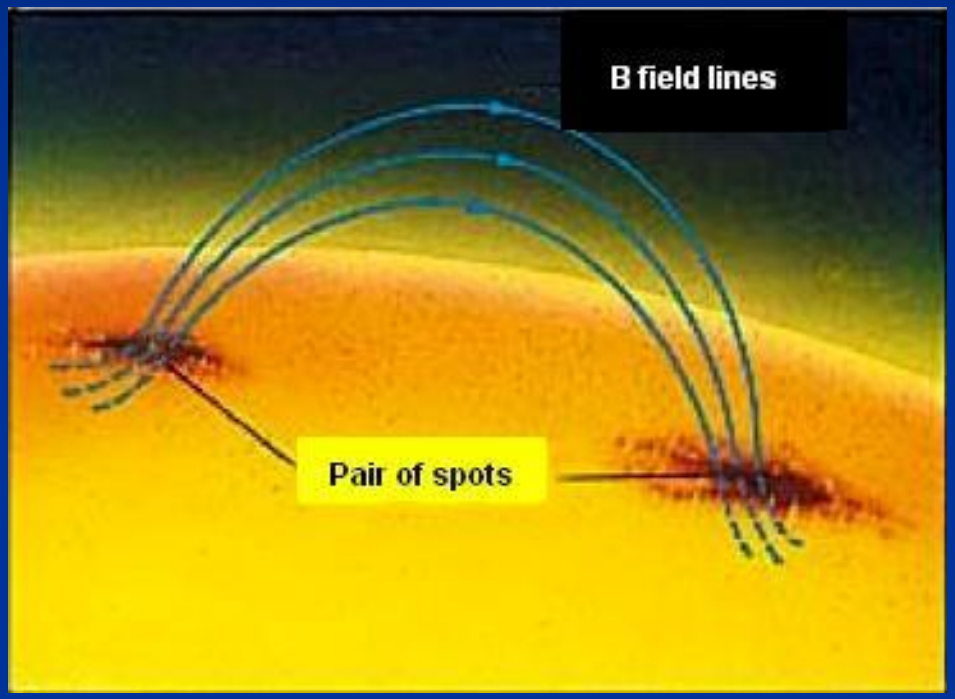
Sunspots
太阳黑子

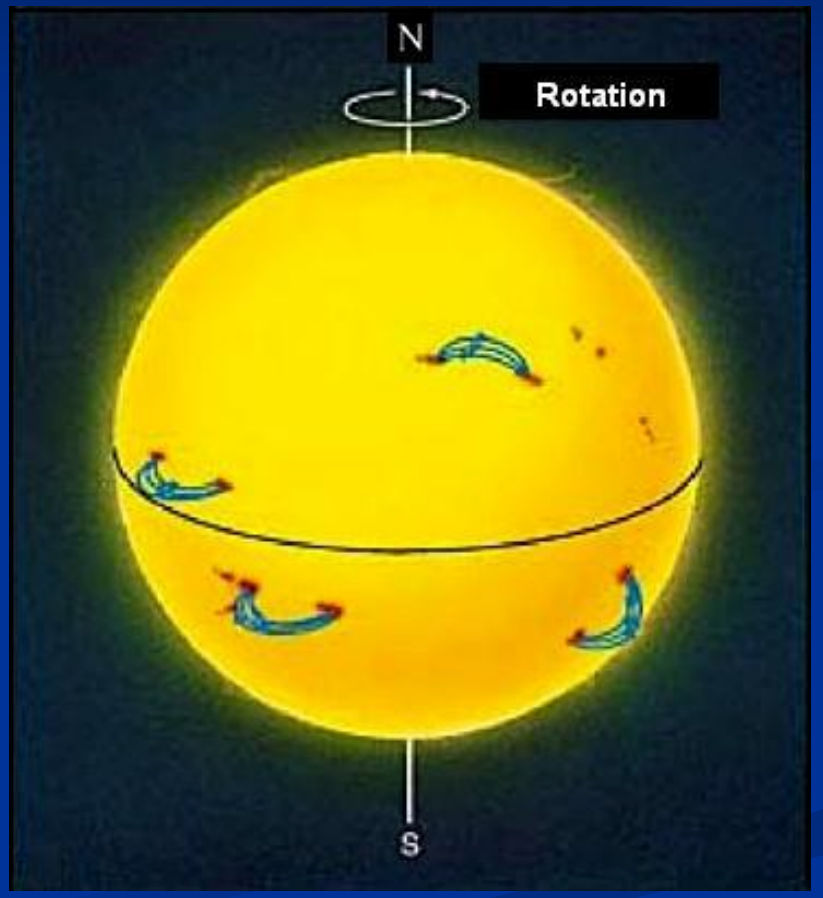
- There are strong magnetic fields in them.
- 黑子有很强的磁场

- They are caused by the outburst of lines of magnetic field. Here is a loop rising from the interior.
- 它们是由磁力线爆发并穿出太阳表面产生的。这是磁力线从太阳内部穿出表面的示意图。



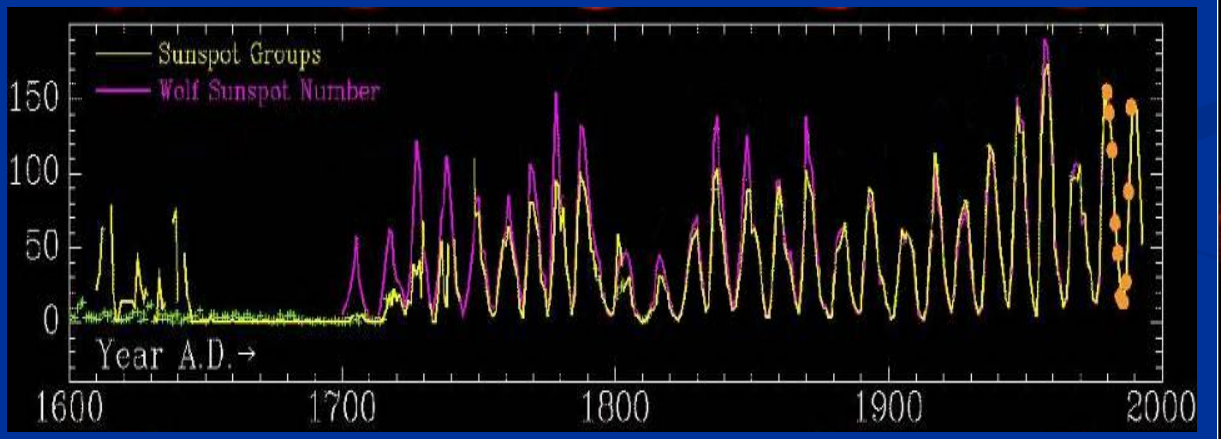
Sunspots 太阳黑子

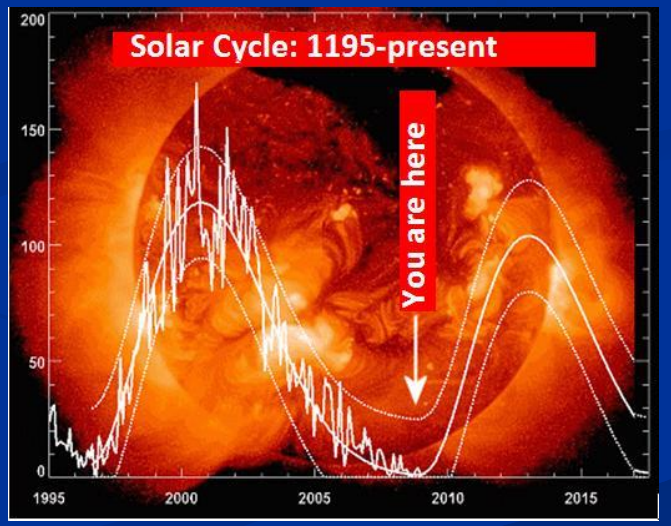




Sunspots 太阳黑子

- The number of sunspots indicates the “solar activity”
- 太阳黑子数反映太阳的活动程度。
- The Wolf Number **黑子相对数**= 10G + F
  (G = groups **群**; F = total number of sunspots **黑子总数**)
- There is an 11-year sunspot cycle.
- 周期为11年。



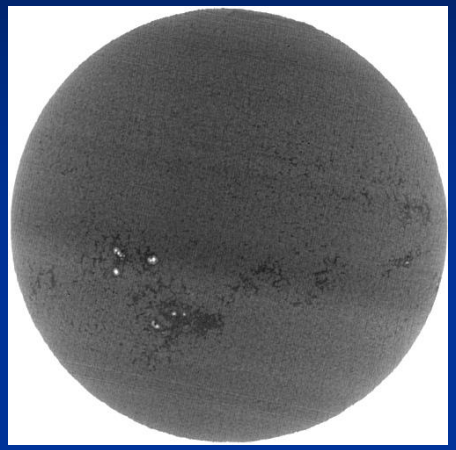


In 2008 there was a minimum of Sun’s activity that lasted longer than usual.

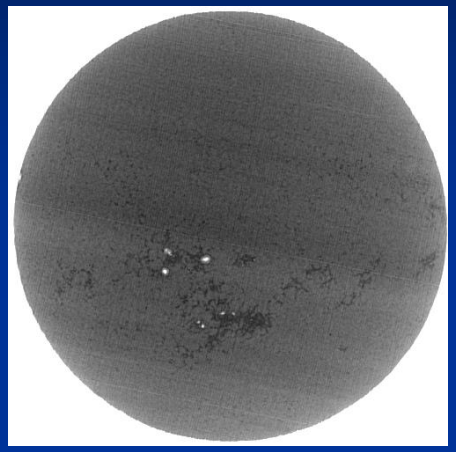
2008年是太阳活动的极小期，而且比通常的极小期要长。

Sunspots: Solar Rotation 太阳黑子：太阳自转

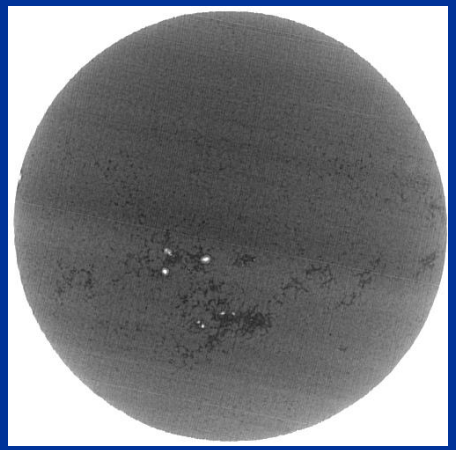
November 21 1992



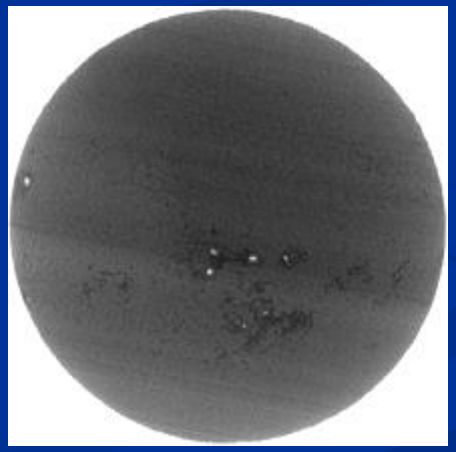
November 22 1992



November 23 1992

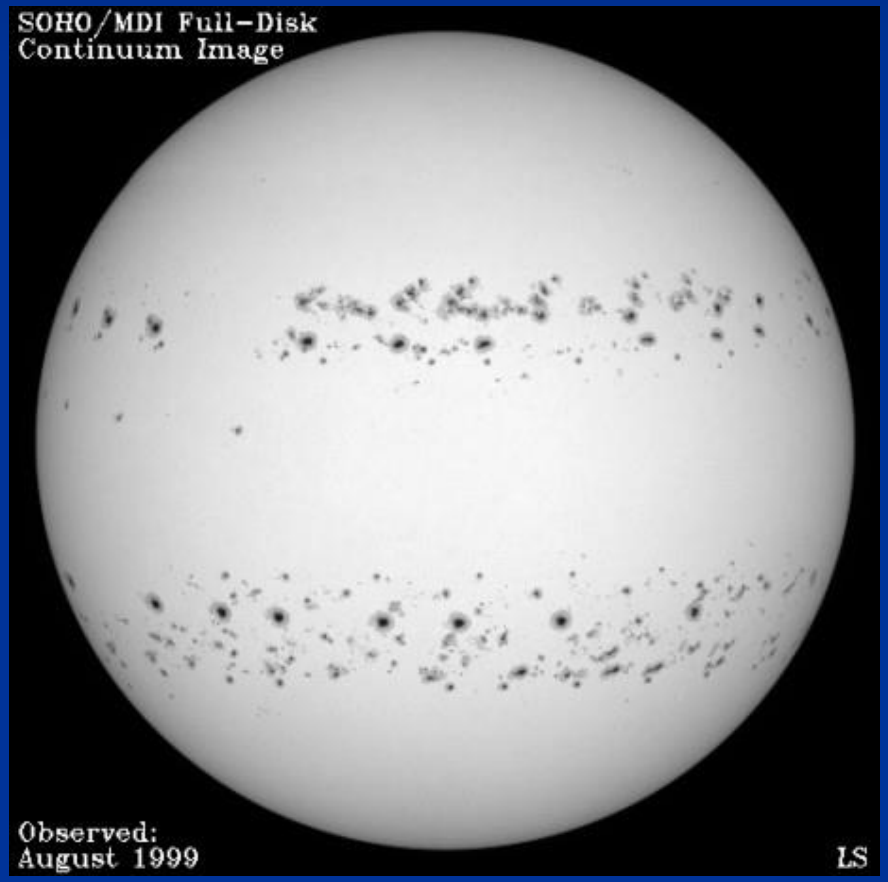


November 24 1992



Credit for images: Astronomical Observatory of the University of Coimbra

Sunspots and Solar Rotation 太阳黑子与太阳自转



- Sunspots can be used to measure the solar rotation.
- 太阳黑子可以用来测量太阳自转。

- Galileo was one of the first who saw Sunspots using a telescope. He used them to measure the period of solar rotation.
- 伽利略是第一批使用望远镜观测太阳黑子的人，并利用太阳黑子测量了太阳自转的周期。

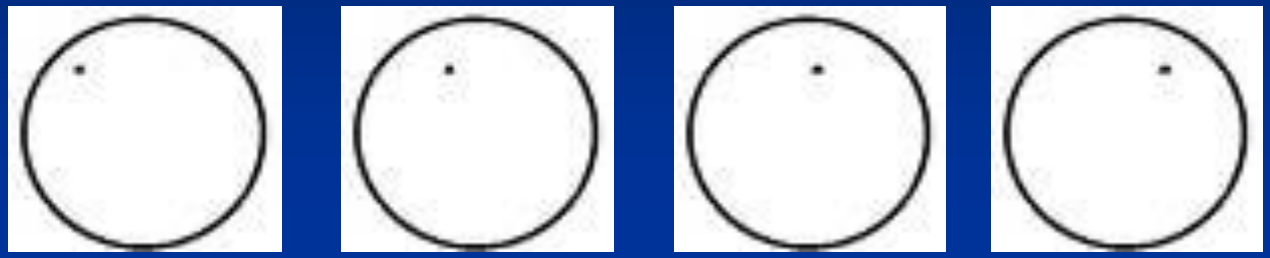
- Differential Rotation: 25 days in equator to 38 days at the poles.
- 较差自转：赤道25天，极区38天

Activity 4: Determining the Sun's rotation period
活动4：测算太阳的自转周期

- Observations of the Sun should always be done by projection with a telescope or binoculars. Never directly.
- 通过望远镜投影来观测太阳，绝对不能用望远镜直接观测太阳！

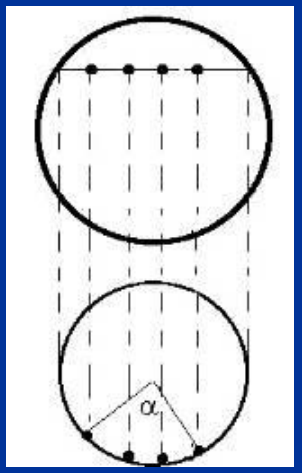
Activity 4: Determining the Sun's rotation period
活动4：测算太阳的自转周期

- Sunspots are drawn for several days. Time t days.
- **数天内黑子位置记录图。**

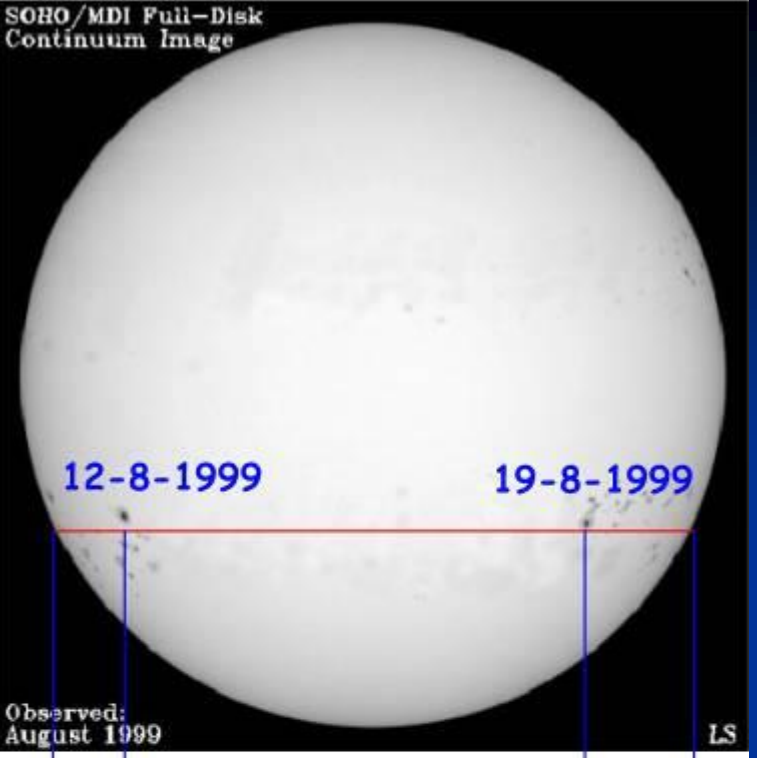


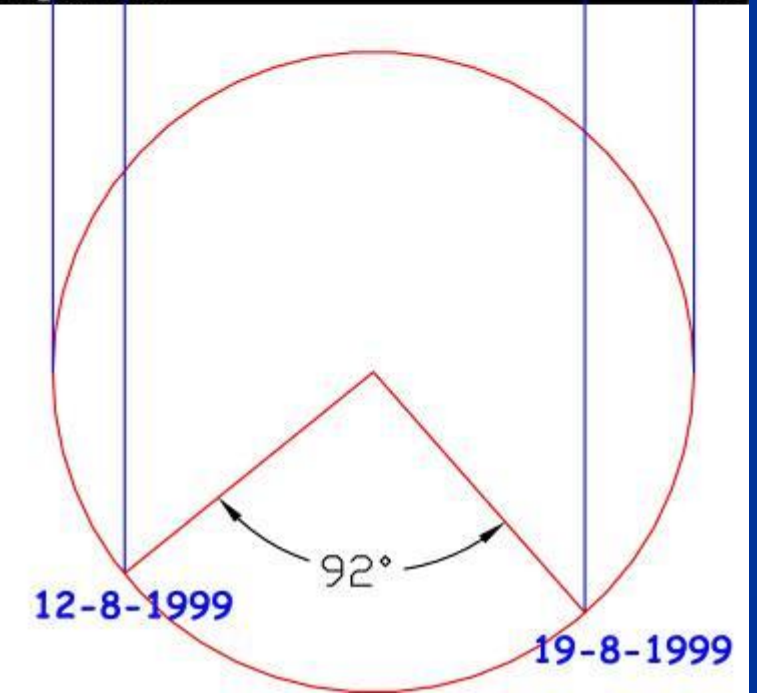
Day 1　Day 4　Day 6　Day 8

- Draw the path, the circumference and angle α. Then the period T can be measured in days.
- 画出下图，测量角α，计算以天为单位的周期



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





Activity 4: Determining the Sun's rotational period

活动4：测算太阳的自转周期

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

Solar Radiation 太阳辐射

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

•太阳剧烈的核反应产生光子，光子的能量和频率的满足$E = h\nu$

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

•太阳的亮度(以瓦特为单位的功率)是巨大的:每秒钟它释放出相当于数万亿颗原子弹的能量。

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

•辐射出的能量像个不断扩大的球一样向周围传播。

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

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

•球的表面积是$4\pi R^2$ 。

• 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)

•R是到太阳的距离，此处每秒每平方米接收的能量是：（ P是太阳的总功率）

Activity 5: Measure Sun's luminosity

活动5：测量太阳的光度

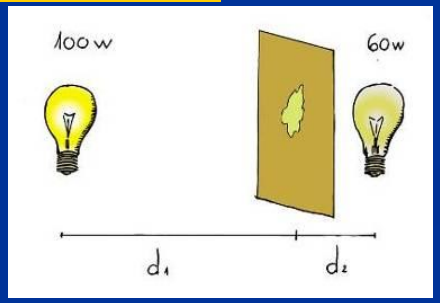
- The energy is transmitted as the inverse square of the distance. If we know the distance from the Sun, we can calculate its power.

•能量以距离的平方反比传递。如果我们知道离太阳的距离，就能计算出它的能量。

- 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:

•我们做了一个油斑光度计。当纸张两边的光度相等时，斑点是看不见的，也就是说，来自两边的能量是相同的。然后：

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

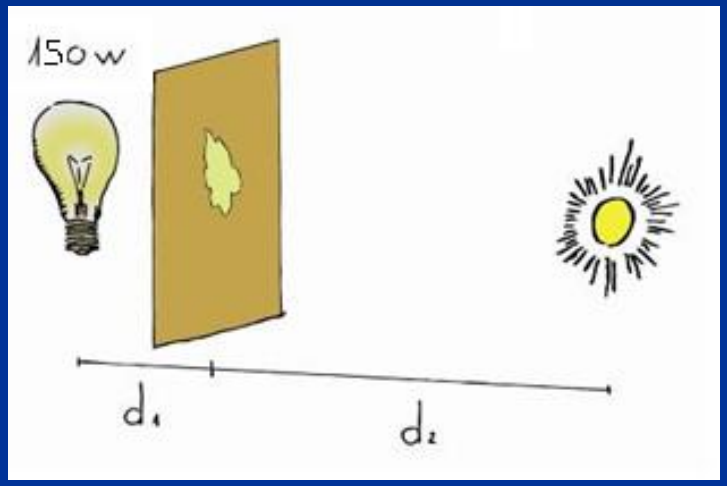


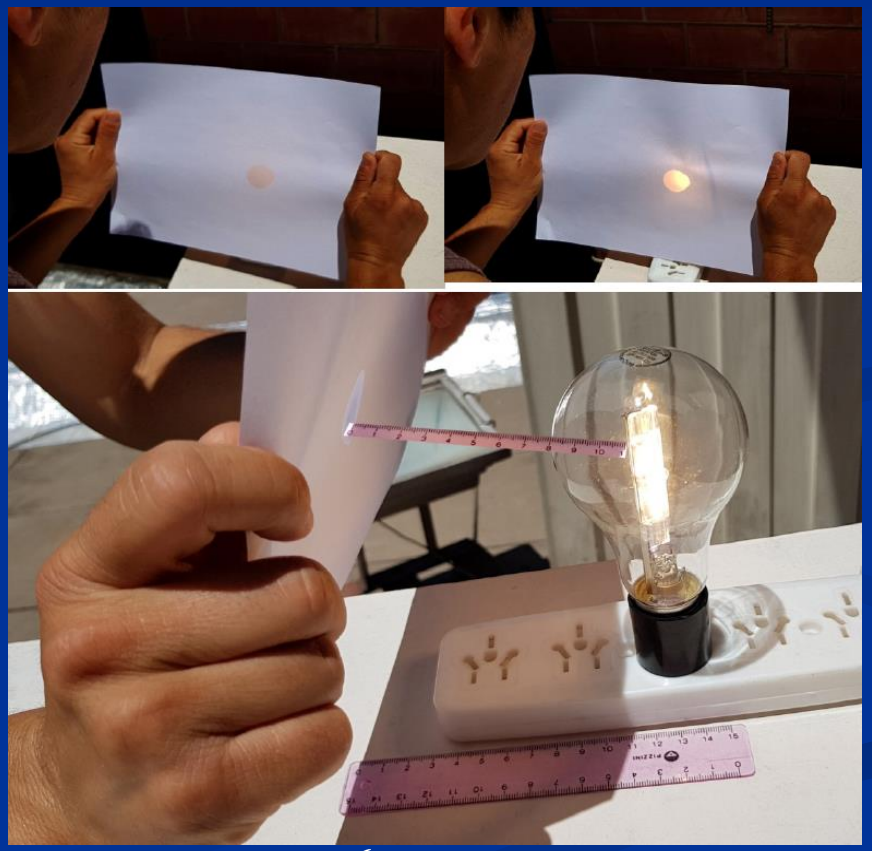
Activity 5: Measure Sun's luminosity

活动5：测量太阳的光度

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.

使用150W的灯泡和太阳（日地距离为1.5×10^{11} m）进行比较，测量太阳总功率P。

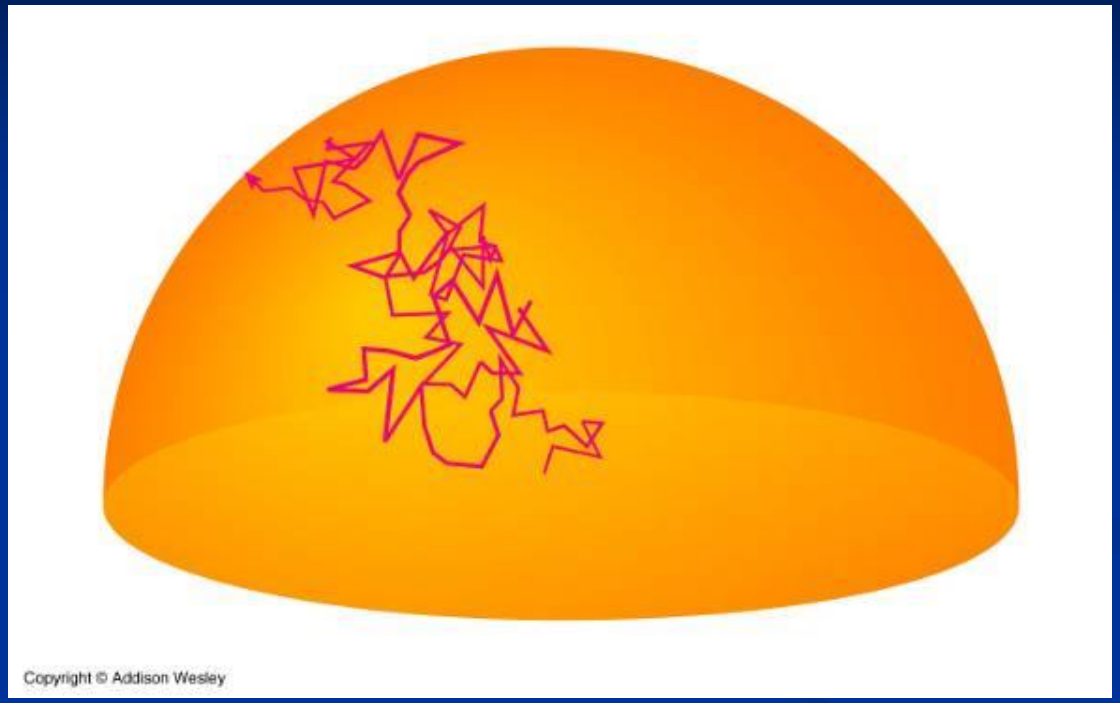




$$\frac{150W}{d_1^2} = \frac{P}{d_2^2}$$

- The result should be approximately 3.8×10^{26} W
- 结果应该约为3.8×10^{26} W

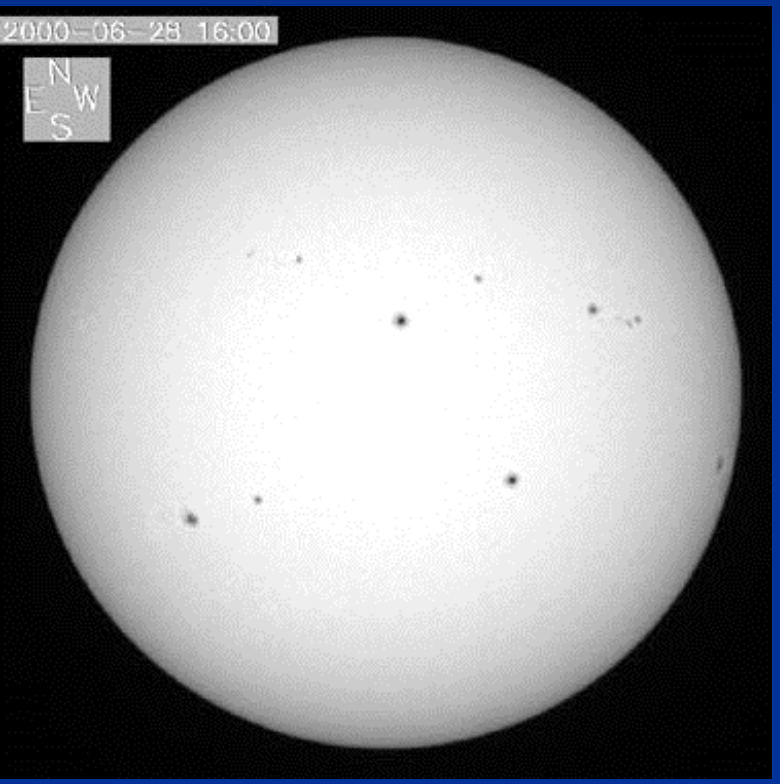
Solar Spectrum: Opacity
太阳光谱：不透明



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.

光子产生于太阳核心，并与该区域的高密度物质相互作用。太阳核心产生的光子需要100万年才能到达光球层。

Solar Spectrum: Opacity
太阳光谱：不透明



The inner parts of the Sun are opaque (many interactions, as in a solid).
太阳的内部是不透明的(许多相互作用，如同在固体中)。

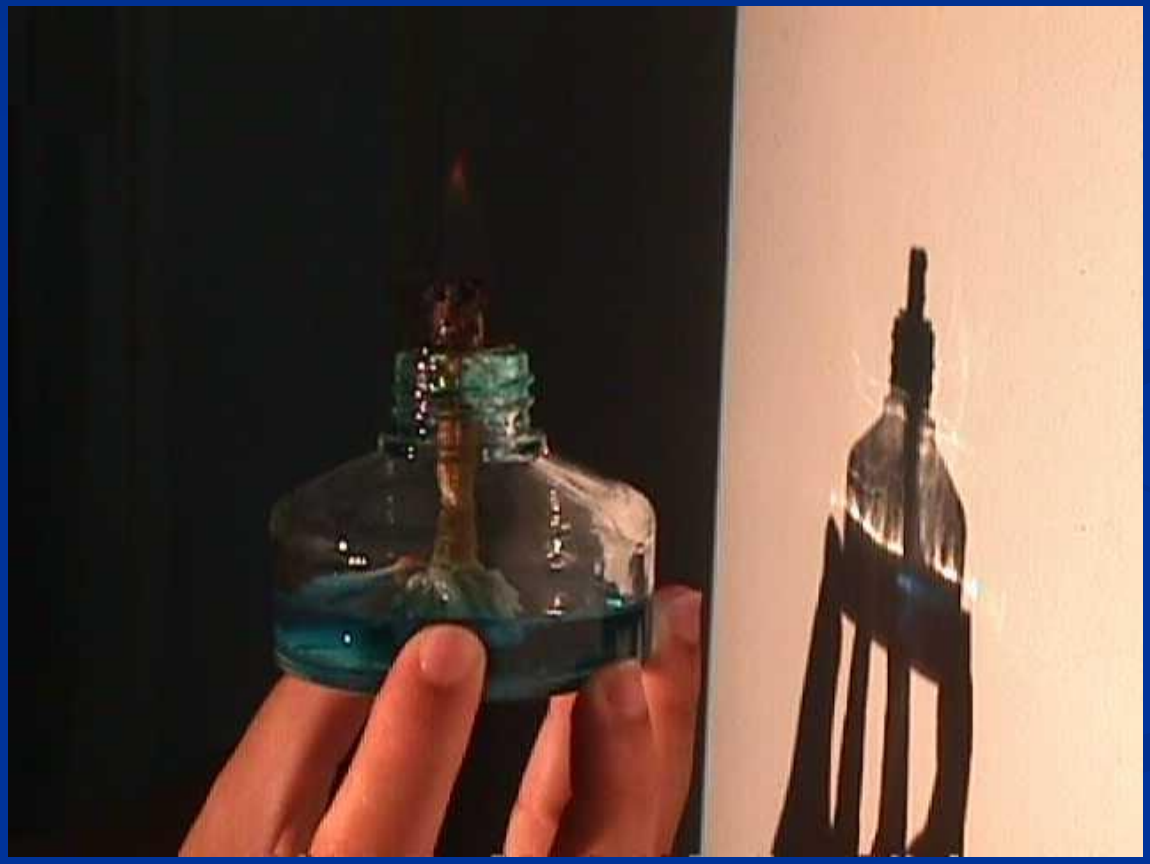
The outer parts are transparent.
外部是透明的。
Evidence: limb darkening - at its edge, the Sun is less bright because it is more transparent.
证据:临边昏暗现象——在它的边缘，太阳不那么明亮，因为它更透明。

Activity 6: Transparency and opacity

活动6：透明和不透明

Transparent is not the same as invisible!

透明不等于不可见！



Spectrum 光谱

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 in a spectrum.

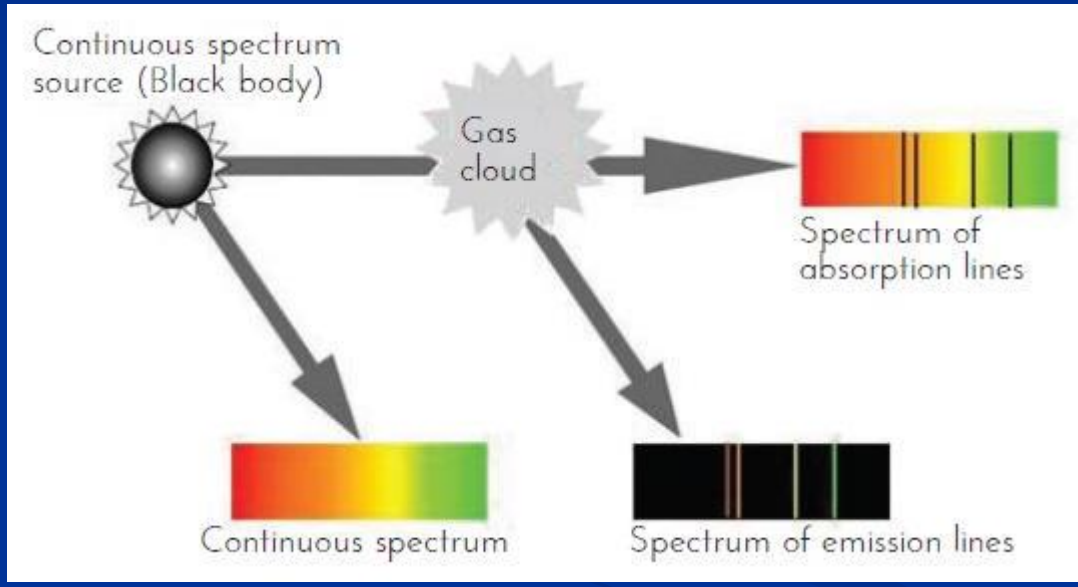
1701年，牛顿用棱镜把太阳光分解成彩色光谱。

任何光都可以用棱镜或衍射光栅分解成光谱。

Kirchhoff's and Bunsen's Laws基尔霍夫和本森定律

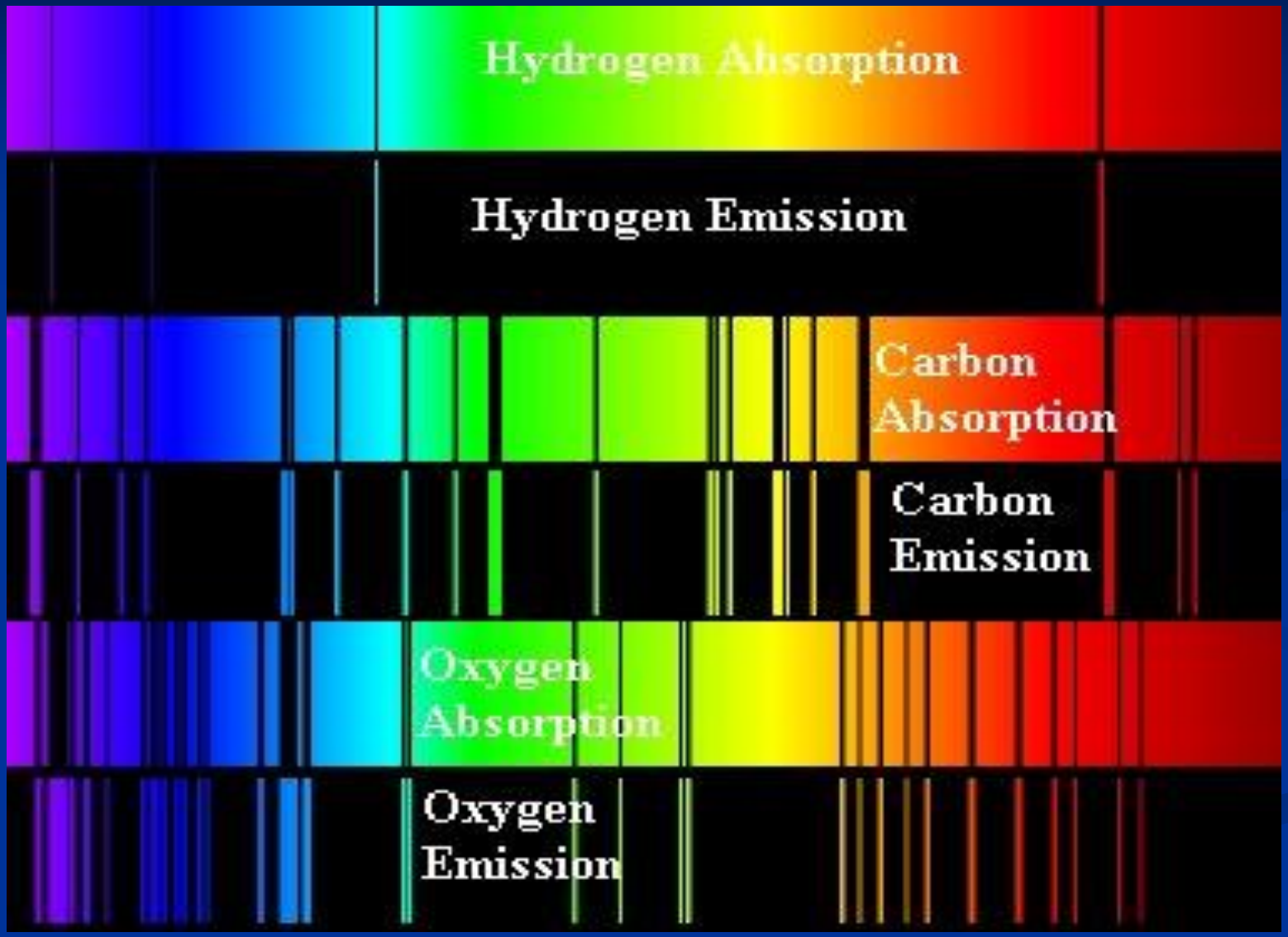
1st Law - An incandescent solid object produces light with a continuous spectrum.
第一定律：炙热的固体产生连续谱。

2nd Law - A hot tenuous gas produces light only at certain wavelengths, which depend on that gas's chemical composition.
第二定律：炙热的气体产生发射线，取决于气体的化学组成。



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.
第三定律，炙热固体发出的光穿过低压气体产生吸收光谱。

Spectrum 光谱



氢吸收光谱

氢发射线

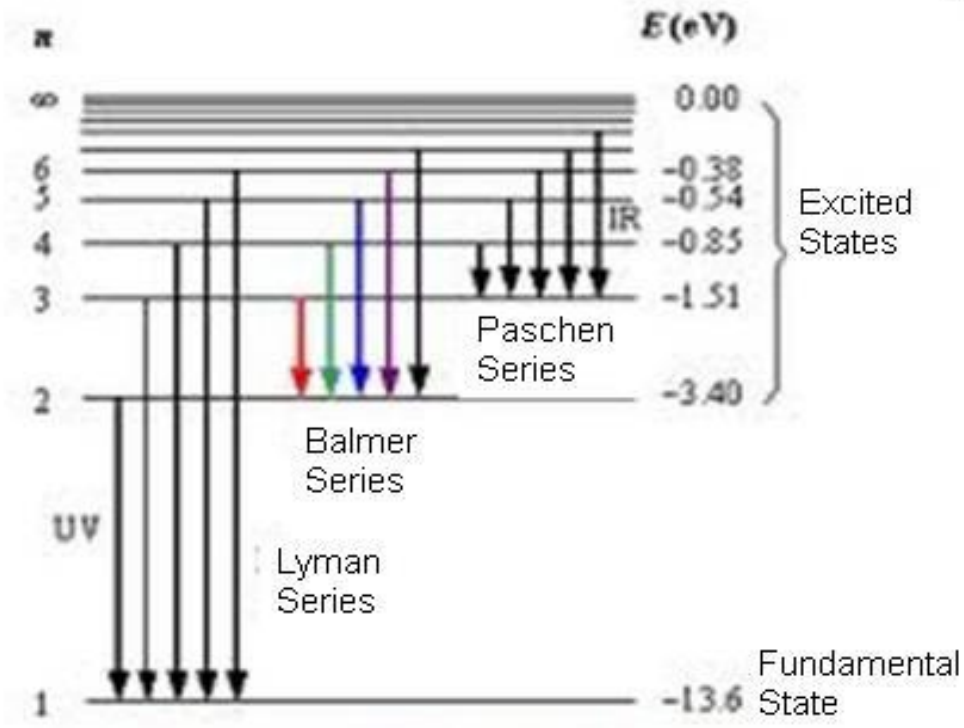
碳吸收光谱

碳发射线

氧吸收光谱

氧发射线

Spectrum 光谱



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.

发射线和吸收线是由于电子在两个不同能级之间跃迁产生的。

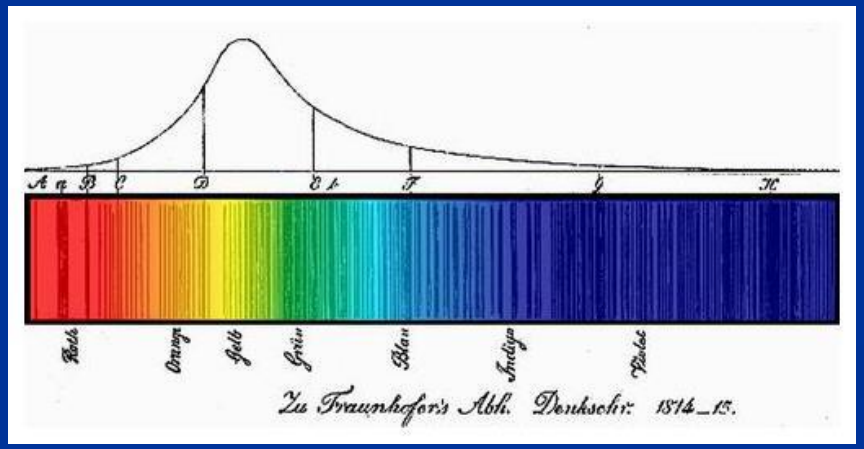
Solar spectrum: Absorption Spectrum
太阳光谱是吸收线谱

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

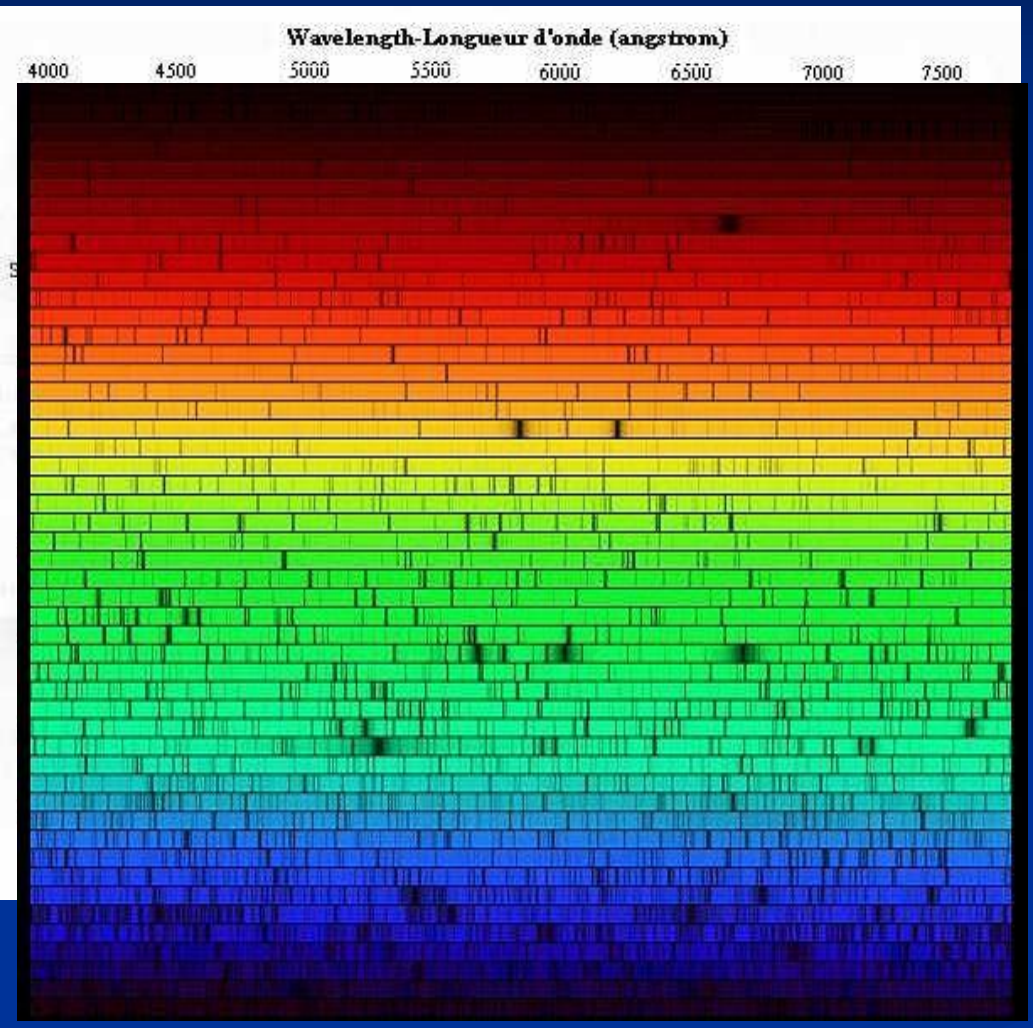
In 1814, Joseph Fraunhofer systematically studied the spectrum of the Sun and detected about 700 dark lines.

1802年，威廉·沃拉斯顿观察到了太阳光谱中的黑线。

1814年，约瑟夫·夫琅禾费系统地研究了太阳光谱，并发现大约700条黑线。



Solar spectrum: Absorption Spectrum
太阳光谱是吸收线谱



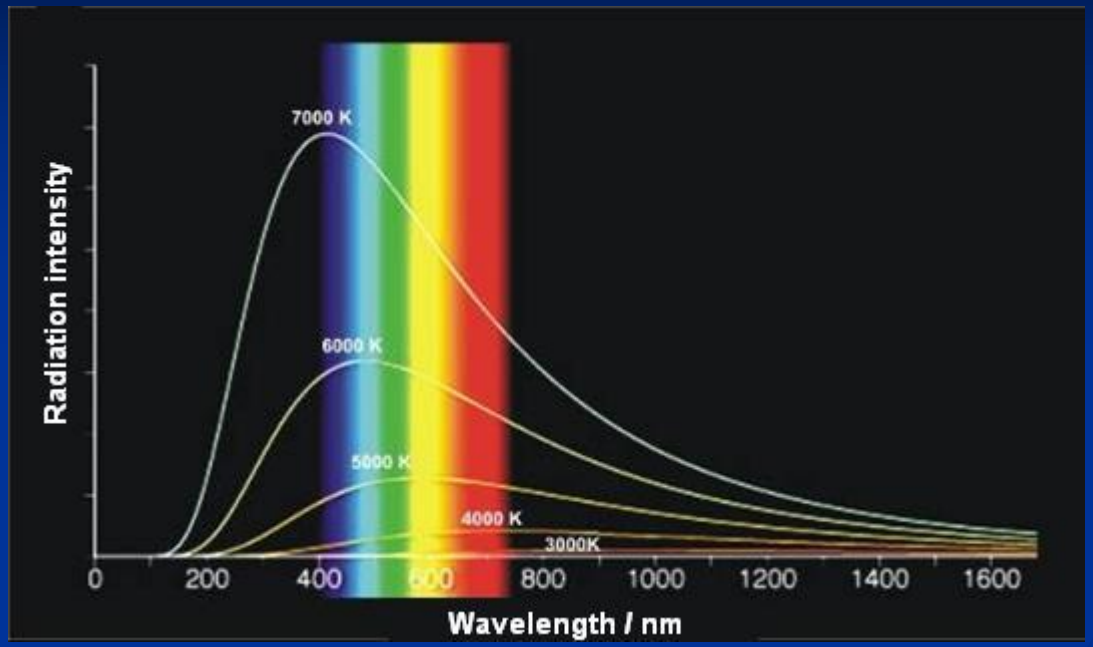
- The dark lines appear due to the presence of cooler gases just above the surface of the Sun.
- 吸收线代表着太阳大气中的元素。
- We can know of what the Sun is made of without probing inside.
- 我们不需要做内部探查，就可以知道太阳由什么组成。
- Today, high definition spectra show many more lines.
- 今天高分辨率的光谱揭示了更多吸收线

Black body radiation
黑体辐射

As the iron warms up in the furnace, the light it emits changes colour as follows:
当铁在炉中被逐渐加热时，它发出光的颜色会发生改变：

- Red 红色
- Yellow 黄色
- White 白色
- Bluish 蓝色

Blackbody Radiation
黑体辐射



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

通过测量远处物体的辐射，我们就可以知道它的温度，而不需要接近它。

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

黑体被加热时会发出不同波长的光。

There is λ_{max} at which the energy is maximum.

λ_{max}表示能量最强的辐射对应的波长。

This λ_{max} depends on the temperature T:

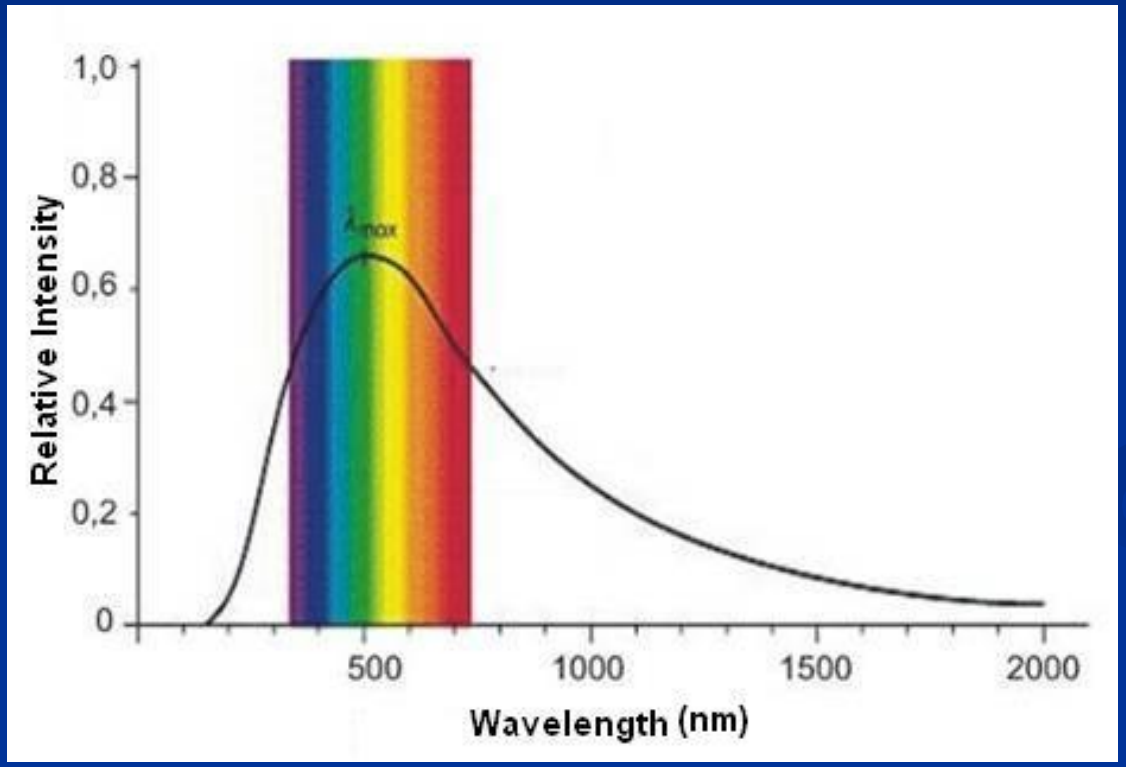
λ_{max}与温度有关

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

Wien's Law

维恩位移定律

Blakbody Radiation
黑体辐射



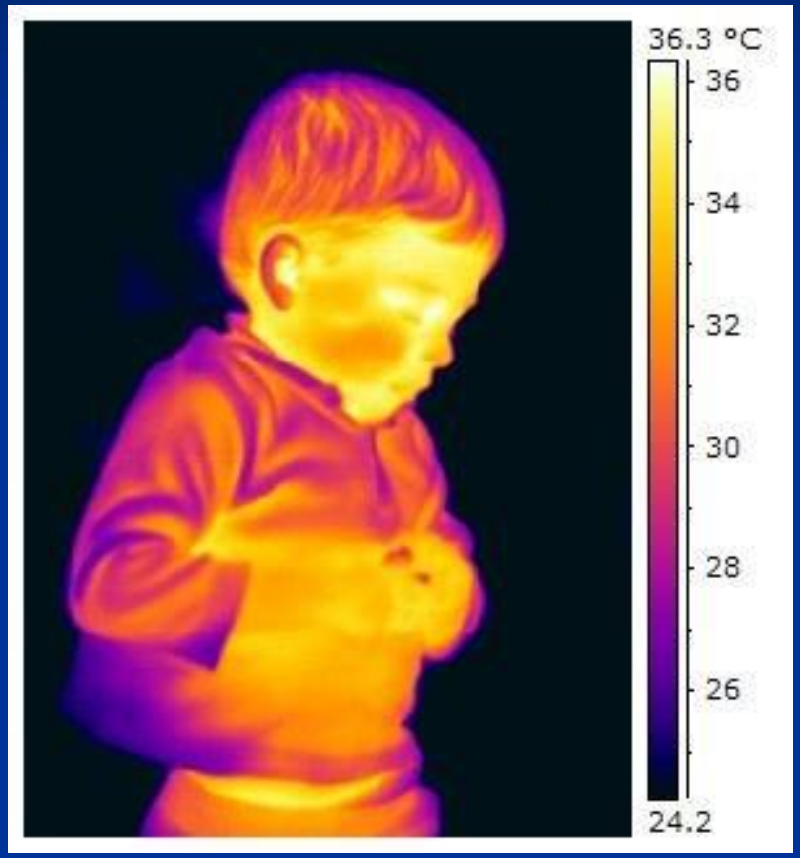
The Sun has a λ_{max} of 500 nm.

太阳发出的最强辐射波长是500nm

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

因此它的表面温度是5800K

Blackbody Radiation
黑体辐射



The human body has a temperature of
T = 273 + 37 = 310 K.
人体的温度是310K

A human body emits most energy at λ_{max} = 9300 nm. This is in the far infrared.
人体辐射的波长是9300nm

Night vision devices use those wavelengths.
夜视仪可以观测到这个波长

Light Scattering 光的散射

- If the white light passes through a gas with large particles, all colours will be equally scattered (white cloud).
- 当光穿过大颗粒气体时，所有的光都被散射掉了（白云）。
- If the sizes of particles are much smaller than the wavelength of incident photons, shorter-wavelength photons are scattered more than longer ones (Rayleigh scattering).
- 当颗粒比光的波长小得多时，波长越短的光散射越强（瑞利散射）。
- In our atmosphere, the blue photons are scattered more than red, and they come from all directions:

Therefore, we see a blue sky.

在地球大气中，蓝光比红光散射强烈。

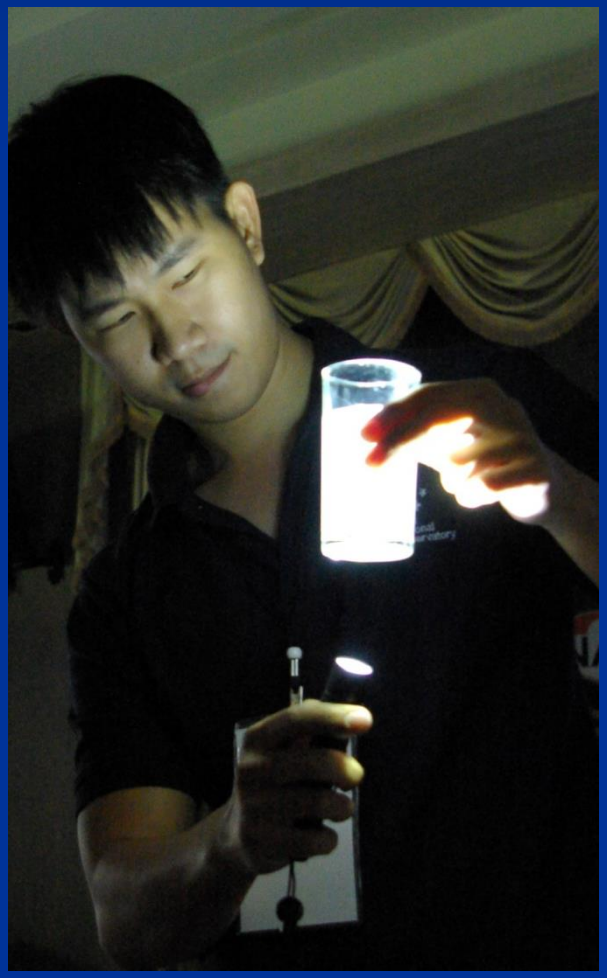
因此天空是蓝色的。

Light Scattering 光的散射

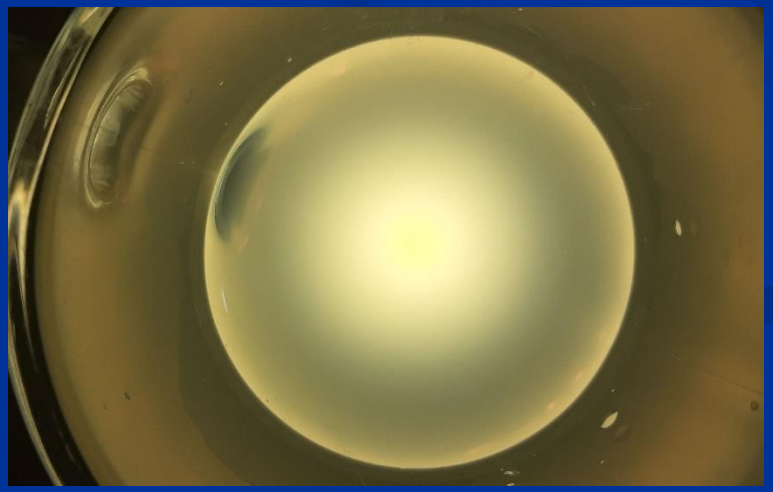
At sunset, the light passes through more atmosphere, and so it is more yellow-red.
在日落时，阳光穿过更多的大气层，所以它更黄更红。

Activity 7: Dispersion of light 活动7：光的色散

•Water in a tall glass with a few drops of milk and a flashlight. When the light passes through the milky water:
在有几滴牛奶的高玻璃杯里加水，一个手电筒。当手电筒的光穿过混有牛奶的水时：



•If the light passes through the glass laterally, it appears bluish.
•如果光从旁边穿过玻璃杯，那么看起来是蓝色的
•But if the light goes through the entire glass, if we look from the top of the glass, the light becomes red.
•但如果光穿过整个玻璃杯，假如我们从玻璃杯上端俯视的话，那么光看起来是红色的



Activity 7: Dispersion of light 活动7：光的色散

- Hot melt silicone stick to use for payment
- The flashlight of a mobile
- 热熔硅胶棒
- 手机的手电筒

- The bar near the mobile light is bluish in color.
- 靠近手机手电筒的硅胶棒看起来是蓝色的
- The bar in the area furthest from the light of the mobile looks yellowish and reddish.
- 距手机手电筒最远端的硅胶棒看起来是黄色和红色的

Thank you very much
for your attention!
谢谢