Cosmic Lights

INTERNATIONAL
YEAR OF LIGHT
2015

Cosmic Lights

Over 1,000 years in the physical study of light

NASE
Network for Astronomy Education in School
Working Group of the Commission on Education and
Development of the IAU

Editors: Rosa M. Ros and Mary Kay Hemenway

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Introduction

Learning is experience; everything else is information, Albert Einstein.

Throughout the history of mankind light has been a fascinating subject of study. The basis of Astronomy is the scientific study of electromagnetic energy, either from the radiation coming from celestial objects (produced or reflected by them) or from the physical study of it. The applications of this energy in technology have meant a fundamental change in the lives of human beings.

A remarkable series of milestones in the history of the science of light allow us to ensure that their study intersects with science and technology. In 1815, in France Fresnel exhibited the theory of the wave nature of light; in 1865 in England. Maxwell described the electromagnetic theory of light, the precursor of relativity; in 1915, in Germany Einstein developed general relativity which confirmed the central role of light in space and time, and in 1965, in the United States Penzias and Wilson discovered the cosmic microwave background, fossil remnant of the creation of universe. Moreover, 2015 will mark 1000 years since the great works of Ibn al-Haytham on optics, published during the Islamic Golden Age.

The electromagnetic energy in general, necessary and sufficient condition for life, has marked the evolution on the planet, has modified our lives and constitutes a powerful tool that we need to know to use it properly.

The Network for Astronomy School Education, NASE, has as main objective to develop quality training courses in all countries concerned to strengthen astronomy at different levels of education. It proposes to incorporate issues related to the discipline in different curriculum areas that introduce young people to science through the approach of the study of the universe. The presence of astronomy in schools is essential and goes hand in hand with teacher training.

NASE proposes two monographic texts **Geometry of Light and Shadows** and **Cosmic Lights**, to show the possibilities offered by the light in teaching concepts in different areas of the natural sciences, from mathematics to biology, and to create awareness of the great achievements and discoveries of mankind related to light and the need for responsible use of this energy on Earth.

Although the texts can be worked independently, both cover many aspects of astronomy and astrophysics found in the programs of education around the globe.

To learn more about the courses developed in different countries, activities and new courses that have arisen after the initial course, we invite the reader to go to the NASE website (http://www.naseprogram.org). The program is not limited to provide basic training, but tends to form working groups with local teachers, which is what keeps the flame of this project alive, creating new materials and new activities which are made available to the international network on the Internet. The supplementary material from NASE offers a universe of possibilities to the professor who has followed the basic courses, allowing them to expand their knowledge and select new activities to develop at their own courses and institutions.

The primary objective of NASE is to bring Astronomy for all to understand and enjoy the process of assimilating new knowledge.

Finally, we thanks all the authors for their help in preparation of materials. Also, we emphasize the great support received for translations and help with the two versions of this book (Spanish / English) including those who prepared and revised figures and graphs: Ligia Arias, Barbara Castanheira, Lara Eakins, Jaime Fabregat, Keely Finkelstein, Irina Marinova, Néstor Marinozzi, Mentuch Erin Cooper, Isa Oliveira, Cristina Padilla, Silvina Pérez, Claudia Romagnolli, Colette Salyk, Viviana Sebben, Oriol Serrano, Ruben Trillo and Sarah Tuttle.

The Evolution of the Stars

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Summary

This article contains useful information about stars and stellar evolution for teachers of Physical Science at the secondary school level. It also includes links to the typical school science curriculum, and suggests some relevant activities for students.

Goals

- Understand stellar evolution and the processes that determine it.
- Understand the Hertzsprung-Russel Diagram
- Understand the system of absolute and apparent magnitudes.

Introduction

Stellar evolution means the changes that occur in stars, from their birth, through their long lives, to their deaths. Gravity “forces” stars to radiate energy. To balance this loss of energy, stars produce energy by nuclear fusion of lighter elements into heavier ones. This slowly changes their chemical composition, and therefore their other properties. Eventually they have no more nuclear fuel, and die. Understanding the nature and evolution of the stars helps us to understand and appreciate the nature and evolution of our own Sun -the star that makes life on Earth possible. It helps us to understand the origin of our solar system, and of the atoms and molecules of which everything, including life, is made. It helps us to answer such fundamental questions as “do other stars produce enough energy, and live long enough, and remain stable enough, so that life could develop and evolve on planets around them?” For these and other reasons, stellar evolution is an interesting topic for students.

The Properties of the Sun and Stars

The first step to understand the origin and evolution of the Sun and stars is to understand their properties. Students should understand how these properties are determined. The Sun is the nearest star. The Sun has been discussed in other lectures in this series. In this article, we consider the Sun as it relates to stellar evolution. Students should understand the properties and structure and energy source of the Sun, because the same principles enable astronomers to determine the structure and evolution of all stars.

The Sun

The basic properties of the Sun are relatively easy to determine, compared with those of other stars. Its average distance is 1.495978715 x 10^{11} m; we call this *one Astronomical Unit*. From this, its observed angular radius (959.63 arc sec) can be converted, by geometry, into a linear radius: 6.96265 x 10^{8} m or 696,265 km. Its observed flux (1,370 W/m^{2}) at the earth's distance can be converted into a total power: 3.85 x 10^{26} W.

Its mass can be determined from its gravitational pull on the planets, using Newton's laws of motion and of gravitation: 1.9891 x 10^{30} kg. The temperature of its radiating surface - the layer from which its light comes - is 5780 K. Its rotation period is about 25 days, but varies with latitude on the Sun, and it is almost exactly round. It consists primarily of hydrogen and helium. In activity 2, students can observe the Sun, our nearest star, to see what a star looks like.

The Stars

The most obvious observable property of a star is its apparent brightness. This is measured as a *magnitude*, which is a logarithmic measure of the flux of energy that we receive.

The magnitude scale was developed by the Greek astronomer Hipparchus (c.190-120 BCE). He classified the stars as magnitude 1, 2, 3, 4, and 5. This is why fainter stars have more positive magnitudes. Later, it was found that, because our senses react logarithmically to stimuli, there was a fixed *ratio* of brightness (2.512) corresponding to a *difference* of 1.0 in magnitude. The brightest star in the night sky has a magnitude of -1.44. The faintest star visible with the largest telescope has a magnitude of about 30.

The apparent brightness, B, of a star depends on its power, P, and on its distance, D. According to the *inverse-square law of brightness*: the brightness is directly proportional to the power, and inversely proportional to the square of the distance: $B \cong P/D^{2}$. For nearby stars, the distance can be measured by *parallax*. In Activity 1, students can do a demonstration to illustrate parallax, and to show that the parallax is inversely proportional to the distance of the observed object. The power of the stars can then be calculated from the measured brightness and the inverse-square law of brightness.

Different stars have slightly different *colour*; you can see this most easily by looking at the stars Rigel (Beta Orionis) and Betelgeuse (Alpha Orionis) in the constellation Orion (figure 1). In Activity 3, students can observe stars at night, and experience the wonder and beauty of the real sky. The colours of stars are due to the different temperatures of the radiating layers of the stars. Cool stars appear slightly red; hot stars appear slightly blue. (This is opposite to the colours that you see on the hot and cold water taps in your bathroom!) Because of the way in which our eyes respond to colour, a red star appears reddish-white, and a blue star appears bluish-white. The colour can be precisely measured with a photometer with colour filters, and the temperature can then be determined from the colour.

Fig. 1: The Constellation Orion. Betelgeuse, the upper left star, is cool and therefore appears reddish. Deneb, the lower right star, is hot and therefore appears bluish. The Orion Nebula appears below the three stars in the middle of the constellation.

The star's temperature can also be determined from its spectrum - the distribution of colours or wavelengths in the light of the star (figure 2). This figure illustrates the beauty of the colours of light from stars. This light has passed through the outer atmosphere of the star, and the ions, atoms, and molecules in the atmosphere remove specific wavelengths from the spectrum. This produces dark lines, or missing colours in the spectrum (figure 2). Depending on the temperature of the atmosphere, the atoms may be ionized, excited, or combined into molecules. The observed state of the atoms, in the spectrum, therefore provides information about the temperature.

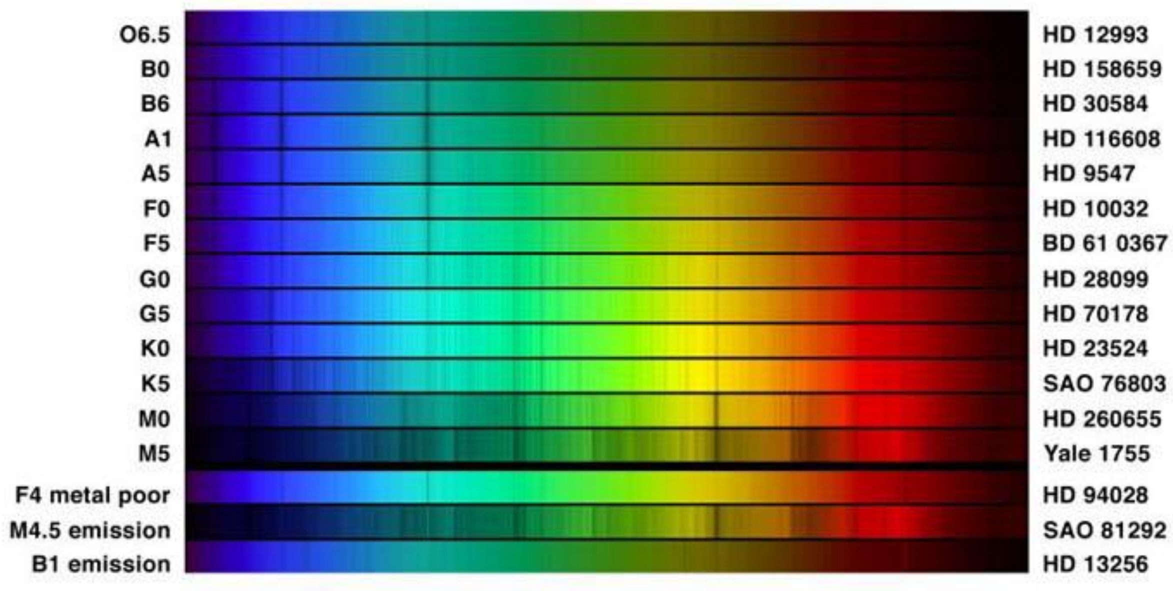

Fig. 2: The spectra of many stars, from the hottest (O6.5: top) to the coolest (M5: fourth from bottom). The different appearances of the spectra are due to the different temperatures of the stars. The three bottom spectra are of stars that are peculiar in some way. Source: National Optical Astronomy Observatory.

A century ago, astronomers discovered an important relation between the power of a star, and its temperature: for most (but not all) stars, the power is greater for stars of greater temperature. It was later realized that the controlling factor was the mass of the star: more massive stars are more powerful, and hotter. A power-temperature graph is called a Hertzsprung-Russell diagram (figure 3). It is very important for students to learn to construct graphs (Activity 8) and to interpret them (figure 3).

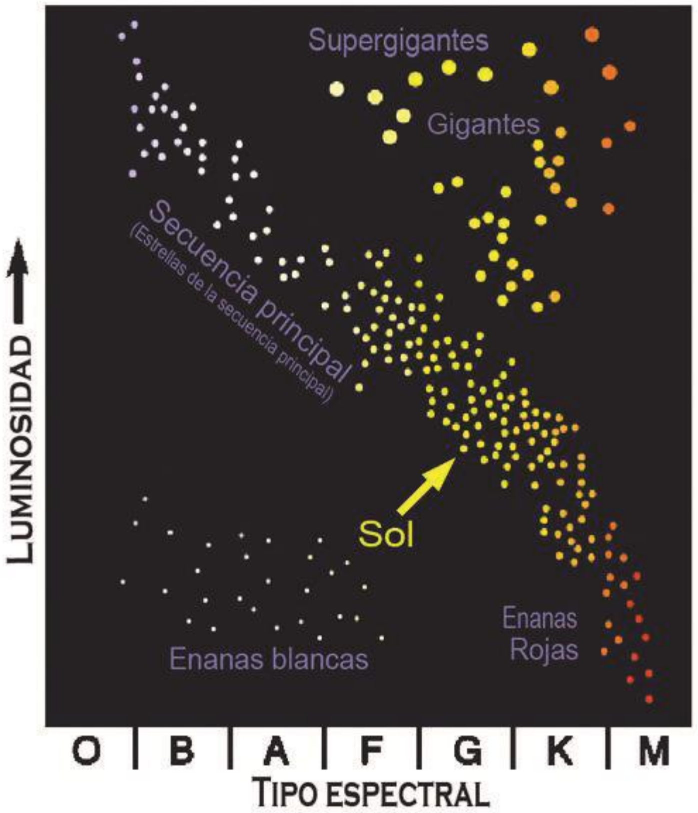

Fig. 3: The Hertzsprung-Russell Diagram, a graph of stellar power or luminosity versus stellar temperature. For historical reasons, the temperature increases to the left. The letters OBAFGKM are descriptive spectral types which are related to temperature. The diagonal lines show the radius of the stars; larger stars (giants and supergiants) are in the upper right, smaller ones (dwarfs) are in the lower left. Note the main sequence from lower right to upper left. Most stars are found here. The masses of main-sequence stars are shown. The locations of some well-known stars are also shown. Source: University of California Berkeley.

A major goal of astronomy is to determine the powers of stars of different kinds. Then, if that kind of star is observed elsewhere in the universe, astronomers can use its measured brightness B and its assumed power P to determine its distance D from the inverse-square law of brightness: $B \cong P/D^2$.

The spectra of stars (and of nebulae) also reveal what stars are made of: the cosmic abundance curve (figure 4). They consist of about 3/4 hydrogen, 1/4 helium, and 2 % heavier elements, mostly carbon, nitrogen, and oxygen.

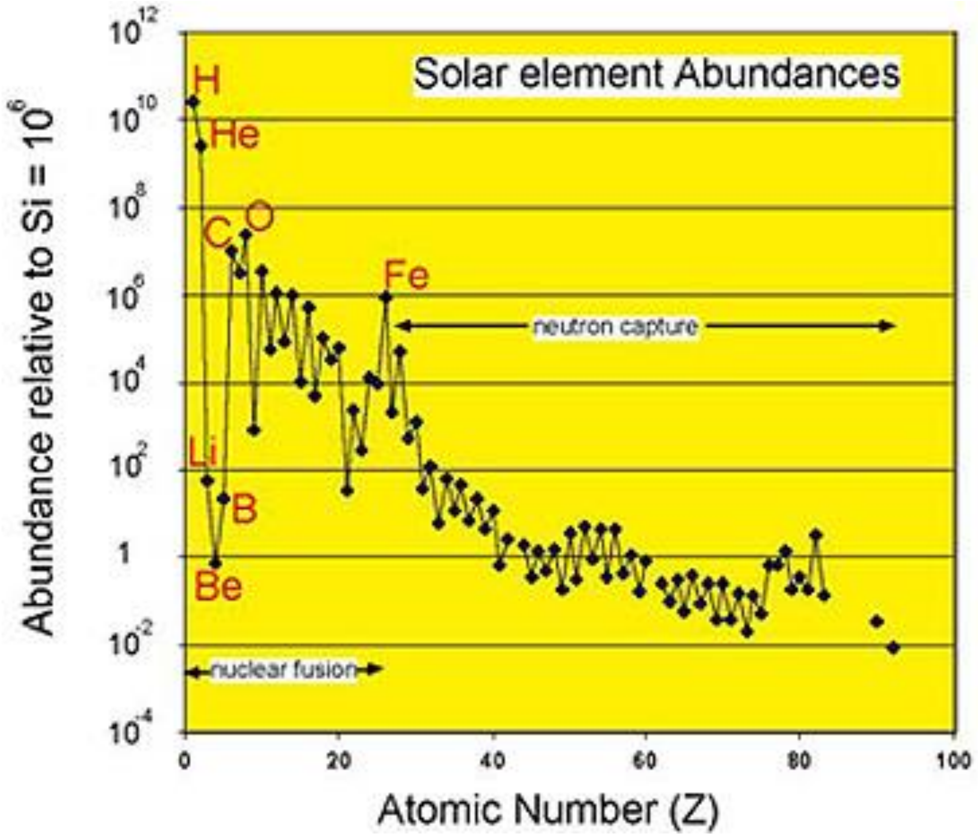

Fig. 4: The abundances of the elements in the Sun and stars. Hydrogen and helium are most abundant. Lithium, beryllium, and boron have very low abundances. Carbon, nitrogen, and oxygen are abundant. The abundances of the other elements decreases greatly with increasing atomic number. Hydrogen is 10^{12} times more abundant than uranium. Elements with even numbers of protons have higher abundances than elements with odd numbers of protons. The elements lighter than iron are produced by nuclear fusion in stars. The elements heavier than iron are produced by neutron capture in supernova explosions. Source: NASA.

About half of the stars in the Sun's neighbourhood are *binary* or *double stars* - two stars in orbit about each other. Double stars are important because they enable astronomers to measure the masses of stars. The mass of one star can be measured by observing the motion of the second star, and vice versa. Sirius, Procyon, and Capella are examples of double stars. There are also *multiple stars*: three or more stars in orbit around each other. Alpha Centauri, the nearest star to the Sun, is a triple star. Epsilon Lyrae is a quadruple star.

As mentioned above, there is an important relationship between the power of a star, and its mass: the power is proportional to approximately the cube of the mass. This is called *the mass-luminosity relation.*

The masses of stars range from about 0.1 to 100 times that of the Sun. The powers range from about 0.0001 to 1,000,000 times that of the Sun. The hottest normal stars are about 50,000 K; the coolest, about 2,000 K. When astronomers survey the stars, they find that the Sun is more massive and powerful than 95 % of all the stars in its neighbourhood. Massive, powerful stars are extremely rare. The Sun is not an average star. It is above average!

The Structure of the Sun and Stars

The structure of the Sun and stars is determined primarily by gravity. Gravity causes the fluid Sun to be almost perfectly spherical. Deep in the Sun, the pressure will increase, because of the weight of the layers of gas above. According to the gas laws, which apply to a perfect gas, the density and temperature will also be greater if the pressure is greater. If the deeper layers are hotter, heat will flow outward, because heat always flows from hot to less hot. This may occur by either radiation or convection. These three principles result in the mass-luminosity law.

If heat flows out of the Sun, then the deeper layers will cool, and gravity will cause the Sun to contract – unless energy is produced in the centre of the Sun. It turns out it is, as the Sun is not contracting but is being held up by radiation pressure created from the process of thermonuclear fusion, described below.

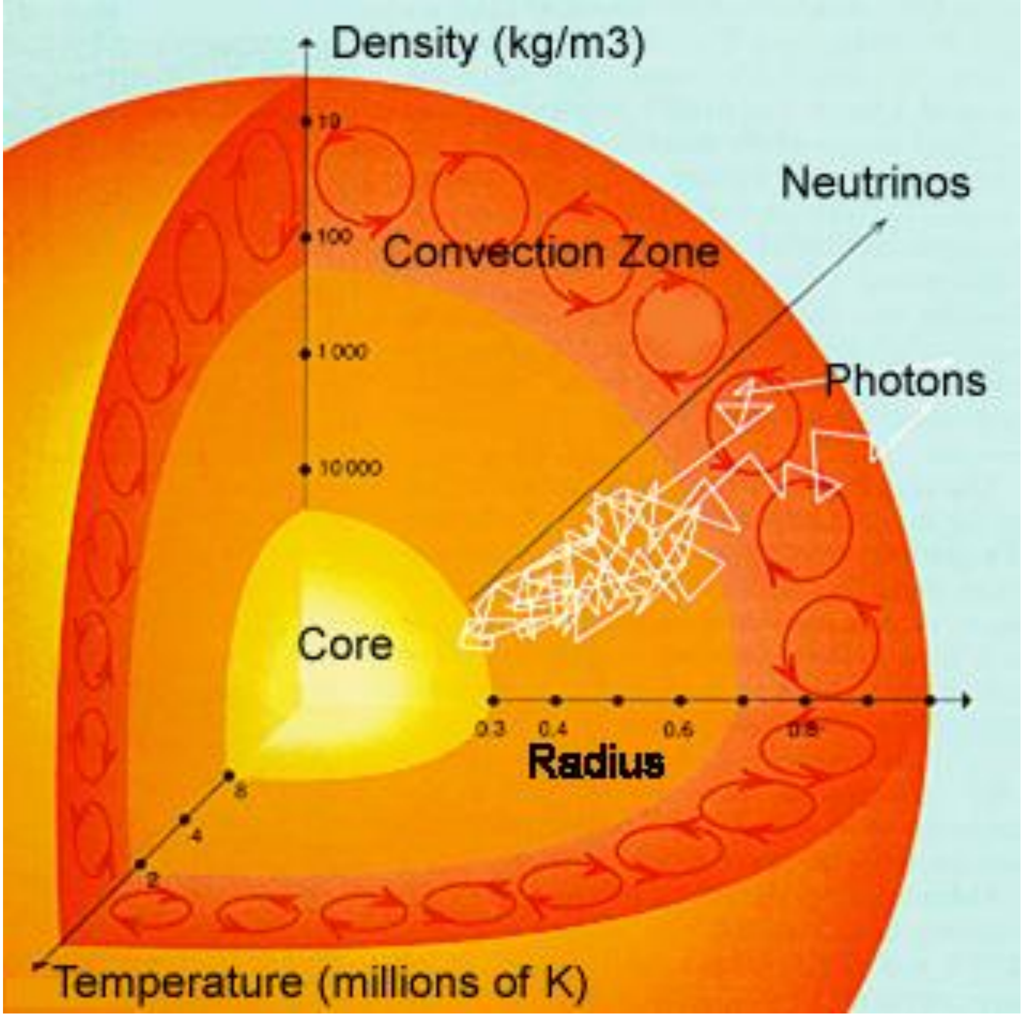

Fig. 5: A cross-section of the Sun, as determined from physical models. In the outer convection zone, energy is transported by convection; below that, it is transported by radiation. Energy is produced in the core.
Source: Institute of Theoretical Physics, University of Oslo.

These four simple principles apply to all stars. They can be expressed as equations, and solved on a computer. This gives a *model* of the Sun or any star: the pressure, density, pressure, and energy flow at each distance from the centre of the star. This is the basic method by which astronomers learn about the structure and evolution of the stars. The model is constructed for a specific assumed mass and composition of the star; and from it astronomers are able to predict the star's radius, power and other observed properties. (figure 5).

Astronomers have recently developed a very powerful method of testing their models of the structure of the Sun and stars - *helioseismology* or, for other stars, *asteroseismology*. The Sun and stars are gently vibrating in thousands of different patterns or modes. These can be observed with sensitive instruments, and compared with the properties of the vibrations that would be predicted by the models.

The Energy source of the Sun and Stars

Scientists wondered, for many centuries, about the energy source of the Sun and stars. The most obvious source is the chemical burning of fuel such as oil or natural gas but, because of the very high power of the Sun (4×10^{26} W), this source would last for only a few thousand years. But until a few centuries ago, people thought that the ages of the Earth and Universe were only a few thousand years, because that was what the Bible seemed to say!

After the work of Isaac Newton, who developed the Law of Universal Gravitation, scientists realized that the Sun and stars might generate energy by slowly contracting. Gravitational (potential) energy would be converted into heat and radiation. This source of energy would last for a few tens of millions of years. Geological evidence, however, suggested that the Earth, and therefore the Sun, was much older than this.

In the late 19th century, scientists discovered radioactivity, or nuclear fission. Radioactive elements, however, are very rare in the Sun and stars, and could not provide power for them for billions of years.

Finally, scientists realized in the 20th century that light elements could fuse into heavier elements, a process called nuclear fusion. If the temperature and density were high enough, these would produce large amounts of energy - more than enough to power the Sun and stars. The element with the most potential fusion energy was hydrogen, and hydrogen is the most abundant element in the Sun and stars.

In low-mass stars like the Sun, hydrogen fusion occurs in a series of steps called the pp chain. Protons fuse to form deuterium. Another proton fuses with deuterium to form helium-3. Helium-3 nuclei fuse to produce helium-4, the normal isotope of helium (figure 6).

In massive stars, hydrogen fuses into helium through a different series of steps called the *CNO cycle*, in which carbon-12 is used as a catalyst (figure 7). The net result, in each case, is that four hydrogen nuclei fuse to form one helium nucleus. A small fraction of the mass of the hydrogen nuclei is converted into energy; see Activity 9. Since nuclei normally repel each other, because of their positive charges, fusion occurs only if the nuclei collide energetically (high temperature) and often (high density).

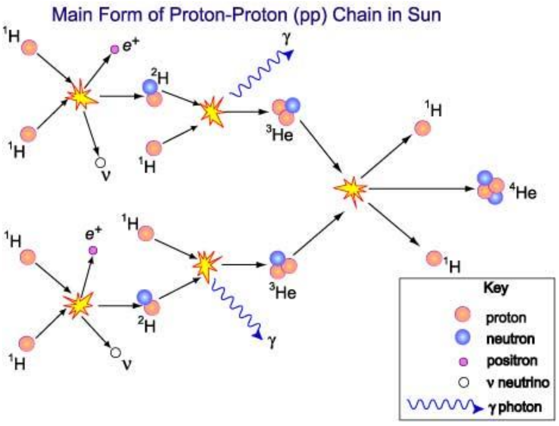

Fig. 6: The proton-proton chain of reactions by which hydrogen is fused into helium in the Sun and other low-mass stars. In this and the next figure, note that neutrinos (ν) are emitted in some of the reactions. Energy is emitted in the form of gamma rays (γ-rays) and the kinetic energy of the nuclei. Source: Australia National Telescope Facility.

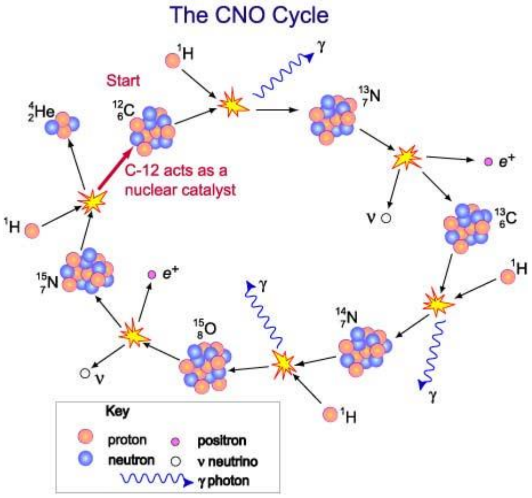

Fig. 7: The CNO cycle by which hydrogen is fused into helium in stars more massive than the Sun. Carbon-12 (marked ``start") acts as a catalyst; it participates in the process without being used up itself. Source: Australia National Telescope Facility.

If nuclear fusion powers the Sun, then the fusion reactions should produce large numbers of subatomic particles called neutrinos. These normally pass through matter without interacting with it. There are billions of neutrinos passing through our bodies each second. Special "neutrino observatories" can detect a few of these neutrinos. The first neutrino observatories detected only a third of the predicted number of neutrinos. This "solar neutrino problem" lasted for over 20 years, but was eventually solved by the Sudbury Neutrino Observatory (SNO) in Canada (figure 8). The heart of the observatory was a large tank of heavy water - water in which some of the hydrogen nuclei are deuterium. These nuclei occasionally absorb a neutrino and emit a flash of light. There are three types of neutrino. Two-thirds of the neutrinos from the Sun were changing into other types. SNO is sensitive to all three types of neutrinos, and detected the full number of neutrinos predicted by theory.

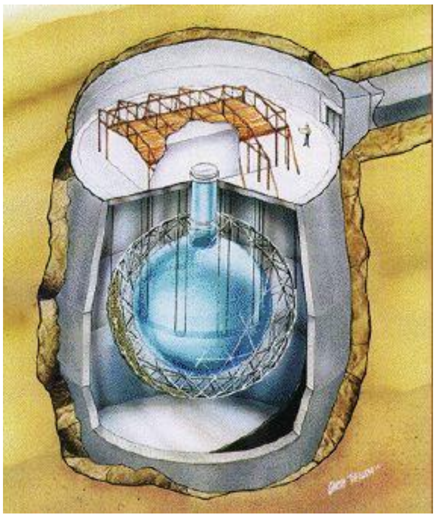

Fig. 8: The Sudbury Neutrino Observatory, where scientists confirmed the models of nuclear fusion in the Sun by observing the predicted flux of neutrinos. The heart of the observatory is a large tank of heavy water. The deuterium nuclei (see text) occasionally interact with a neutrino to produce an observable flash of light. Source: Sudbury Neutrino Observatory.

The Lives of the Sun and Stars

Because "the scientific method" is such a fundamental concept in the teaching of science, we should start by explaining how astronomers understand the evolution of the stars:

- by using computer simulations, based on the laws of physics, as described above;
- by observing the stars in the sky, which are at various stages of evolution, and putting them into a logical "evolutionary sequence";
- by observing star clusters: groups of stars which formed out of the same cloud of gas and dust, at the same time, but with different masses. There are thousands of star clusters in our galaxy, including about 150 *globular clusters* which are among the oldest objects in our galaxy. The Hyades, Pleiades, and most of the stars in Ursa Major, are clusters that can be seen with the unaided eye. Clusters are "nature's experiments": groups of stars formed from the same material in the same place at the same time. Their stars differ only in mass. Since different clusters have different ages, we can see how a collection of stars of different masses would appear at different ages after their birth.
- by observing, directly, rapid stages of evolution; these will be very rare, because they last for only a very small fraction of the stars' lives;
- by studying the changes in the periods of pulsating variable stars. These changes are small, but observable. The periods of these stars depend on the radius of the star. As the radius changes due to evolution, the period will, also. The period change can be measured through systematic, long-term observations of the stars.

The first method, the use of computer simulations, was the same method that was used to determine the *structure* of the star. Once the structure of the star is known, we know the temperature and density at each point in the star, and we can calculate how the chemical composition will be changed by the thermonuclear processes that occur. These changes in composition can then be incorporated in the next model in the evolutionary sequence.

The most famous pulsating variable stars are called Cepheids, after the star Delta Cephei that is a bright example. There is a relation between the period of variation of a Cepheid, and its power. By measuring the period, astronomers can determine the power, and hence the distance, using the inverse-square law of brightness. Cepheids are an important tool for determining the size and age scale of the universe.

In Activity 5, students can observe variable stars, through projects such as Citizen Sky. This enables them to develop a variety of science and math skills, while doing real science and perhaps even contributing to astronomical knowledge.

The Lives and Deaths of the Sun and Stars

Hydrogen fusion is a very efficient process. It provides luminosity for stars throughout their long lives. The fusion reactions go fastest at the centre of the star, where the temperature and density are highest. The star therefore develops a core of helium which gradually expands outward from the centre. As this happens, the star's core must become hotter, by shrinking, so that the hydrogen around the helium core will be hot enough to fuse. This causes the outer layers of the star to expand -slowly at first, but then more rapidly. It becomes a red giant star, up to a hundred times bigger than the Sun. Finally the centre of the helium core becomes hot enough so that the helium will fuse into carbon. This fusion balances the inward pull of gravity, but not for long, because helium fusion is not as efficient as hydrogen fusion. Now the carbon core shrinks, to become hotter, and the outer layers of the star expand to become an even bigger red giant. The most massive stars expand to an even larger size; they become *red supergiant stars*.

A star dies when it runs out of fuel. There is no further source of energy to keep the inside of the star hot, and to produce enough gas pressure to stop gravity from contracting the star. The type of death depends on the mass of the star.

The length of the star's life also depends on its mass: low-mass stars have low luminosities and very long lifetimes- tens of billions of years. High-mass stars have very high luminosities, and very short lifetimes -millions of years. Most stars are very low-mass stars, and their lifetimes exceed the present age of the universe.

Before a star dies, it loses mass. As it uses the last of its hydrogen fuel, and then its helium fuel, it swells up into a red giant star, more than a hundred times bigger in radius, and more than a billion times bigger in volume than the Sun. In Activity 4, students can make a scale model, to visualize the immense changes in the size of the star as it evolves. The gravity in the outer layers of a red giant is very low. Also it becomes unstable to pulsation, a rhythmic expansion and contraction. Because of the large size of a red giant, it takes months to years for every pulsation cycle. This drives off the outer layers of the star into space, forming a beautiful, slowly-expanding *planetary nebula* around the dying star (figure 9). The gases in the planetary nebula are excited to fluorescence by ultraviolet light from the hot core of the star. Eventually, they will drift away from the star, and join with other gas and dust to form new nebulae from which new stars will be born.

Fig. 9: The Helix Nebula, a planetary nebula. The gases in the nebula were ejected from the star during its red giant phase of evolution. The core of the star is a hot white dwarf. It can be seen, faintly, at the centre of the nebula. Source: NASA.

The lives of massive stars are slightly different from those of low-mass stars. In low-mass stars, energy is transported outward from the core by radiation. In the core of massive stars, energy is transported by convection, so the core of the star is completely mixed. As the last bit of hydrogen is used up in the core, the star very rapidly changes into a red giant. In the case of low-mass stars, the transition is more gradual.

Stars must have a mass of more than 0.08 times that of the Sun. Otherwise, they will not be hot and dense enough, at their centres, for hydrogen to fuse. The most massive stars have masses of about a hundred times that of the Sun. More massive stars would be so powerful that their own radiation would stop them from forming, and from remaining stable.

Common, Low-Mass Stars

In stars with an initial mass less than about eight times that of the Sun, the mass loss leaves a core less than 1.4 times the mass of the Sun. This core has no thermonuclear fuel. The inward pull of gravity is balanced by the outward pressure of electrons. They resist any further contraction because of the Pauli Exclusion Principle – a law of quantum theory that states that there is a limit to the number of electrons that can exist in a given volume. This core is called a *white dwarf*. White dwarfs have masses less than 1.44 times that of the Sun. This is called the *Chandrasekhar limit*, because the Indian-American astronomer and Nobel Laureate Subrahmanyan Chandrasekhar showed that a white dwarf more massive than this would collapse under its own weight.

White dwarfs are the normal end-points of stellar evolution. They are very common in our galaxy. But they are hard to see: they are no bigger than the earth so, although they are hot, they have very little radiating area. Their powers are thousands of times less than that of the Sun. They radiate only because they are hot objects, slowly cooling as they radiate their energy. The bright stars Sirius and Procyon both have white dwarfs orbiting around them. These white dwarfs have no source of energy, other than their stored heat. They are like embers of coal, cooling in a fireplace. After billions of years, they will cool completely, and become cold and dark.

Rare, Massive Stars

Massive stars are hot and powerful, but very rare. They have short lifetimes of a few million years. Their cores are hot and dense enough to fuse elements up to iron. The iron nucleus has no available energy, either for fusion or for fission. There is no source of energy to keep the core hot, and to resist the force of gravity. Gravity collapses the core of the star within a second, converting it into a ball of neutrons (or even stranger matter), and liberating huge amounts of gravitational energy. This causes the outer layers of the star to explode as a s*upernova* (figure 10). These outer layers are ejected with speeds of up to 10,000 km/sec.

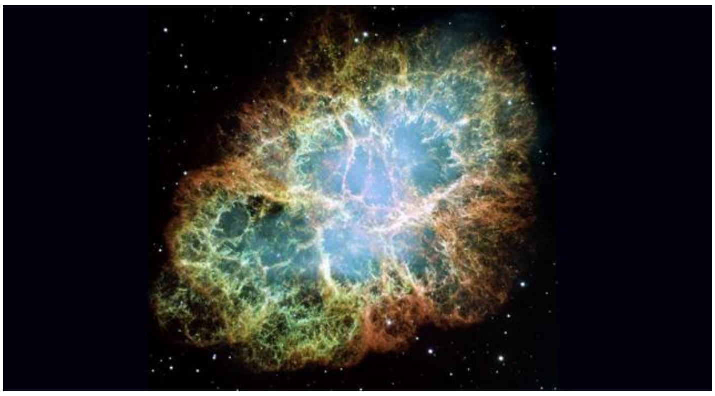

Fig. 10: The Crab Nebula, the remnant of a supernova explosion that was recorded by astronomers in Asia in 1054 AD. The core of the exploded star is a rapidly-rotating neutron star, or pulsar, within the nebula. A small fraction of its rotational energy is being transmitted to the nebula, making it glow. Source: NASA.

A supernova, at maximum brightness, can be as bright as a whole galaxy of hundreds of billions of stars. Both Tycho Brahe and Johannes Kepler observed and studied bright supernovas, in 1572 and 1604 respectively. According to Aristotle, stars were perfect and didn't change; Brahe and Kepler proved otherwise. No supernova has been observed in our Milky Way galaxy for 400 years. A supernova, visible with the unaided eye, was observed in 1987 in the Large Magellanic Cloud, a small satellite galaxy of the Milky Way.

The mass of the core of the supernova star is greater than the Chandrasekhar limit. The protons and electrons in the collapsing core fuse to produce neutrons, and neutrinos. The burst of neutrinos could be detected by a neutrino observatory. As long as the mass of the core is less than about three times the mass of the Sun, it will be stable. The inward force of gravity is balanced by the outward quantum pressure of the neutrons. The object is called a *neutron star*. Its diameter is about 10 km. Its density is more that 10^{14} times that of water. It may be visible with an X-ray telescope if it is still very hot, but neutron stars were discovered in a very unexpected way -- as sources of pulses of radio waves called *pulsars*. Their pulse periods are about a second, sometimes much less. The pulses are produced by the neutron star's strong magnetic field, being flung around at almost the speed of light by the star's rapid rotation.

There is a second kind of supernova that occurs in binary star systems in which one star has died and become a white dwarf. When the second star starts to expand, it may spill gas onto its white dwarf companion. If the mass of the white dwarf becomes greater than the Chandrasekhar limit, the white dwarf "deflagrates"; its material fuses, almost instantly, into carbon, releasing enough energy to destroy the star.

In a supernova explosion, all of the chemical elements that have been produced by fusion reactions are ejected into space. Elements heavier than iron are produced in the explosion, though in small amounts, as neutrons irradiate the lighter nuclei that are being ejected.

Very rare, Very Massive Stars

Very massive stars are very rare - one star in a billion. They have powers of up to a million times that of the Sun and lives which are very short. They are so massive that, when they run out of energy and their core collapses, its mass is more than three times the mass of the Sun. Gravity overcomes even the quantum pressure of the neutrons. The core continues to collapse until it is so dense that its gravitational force prevents anything from escaping from it, even light. It becomes a *black hole*. Black holes emit no radiation but, if they have a normal-star companion, they cause that companion to move in an orbit. The observed motion of the companion enables astronomers to detect the black hole, and measure its mass. Furthermore: a small amount of gas from the normal star may be pulled toward the black hole, and heated until it glows in X-rays before it falls into the black hole (figure 11). Black holes are therefore strong sources of X-rays, and are discovered with X-ray telescopes.

At the very centre of many galaxies, including our Milky Way galaxy, astronomers have discovered *supermassive black holes*, millions or billions of times more massive than the Sun. Their mass is measured from their effect on visible stars near the centres of galaxies. Supermassive black holes seem to have formed as part of the birth process of the galaxy, but it is not clear how this happened. One of the goals of 21st-century astronomy is to understand how the first stars and galaxies and super-massive black holes formed, soon after the birth of the universe.

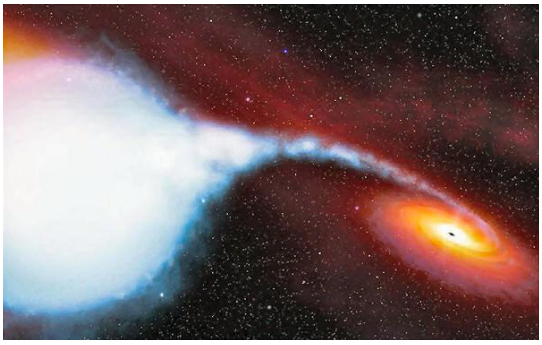

Fig. 11: An artist's conception of the binary-star X-ray source Cygnus X-1. It consists of a massive normal star (left), and a black hole (right), about 15 times the mass of the Sun, in mutual orbit. Some of the gases from the normal star are pulled into an *accretion disc* around the black hole, and eventually into the black hole itself. The gases are heated to very high temperatures, causing them to emit X-rays. Source: NASA.

Cataclysmic Variable Stars

About half of all stars are binary stars, two or more stars in mutual orbit. Often, the orbits are very large, and the two stars do not interfere with each other's evolution. But if the orbit is small, the two stars may interact, especially when one swells into a red giant. And if one star dies to become a white dwarf, neutron star, or black hole, the evolution of the normal star may spill material onto the dead star, and many interesting things can happen (figure 12). The binary star system varies in brightness, for various reasons, and is called a *cataclysmic variable star*. As noted above, a white dwarf companion could explode as a supernova if enough mass was transferred to it. If the normal star spilled hydrogen-rich material onto the white dwarf, that material could explode, through hydrogen fusion, as a *nova*. The material falling toward the white dwarf, neutron star, or black hole could simply become very hot, as its gravitational potential energy was converted into heat, and produce high-energy radiation such as X-rays.

In the artist's conception of a black hole (figure 11), you can see the *accretion disc* of gas around the black hole, and the stream of gas from the normal star, flowing towards it.

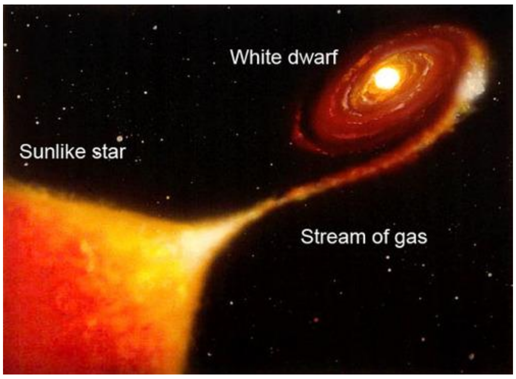

Fig. 12: A cataclysmic variable star. Matter is being pulled from the normal star (left) towards the white dwarf (right). It strikes the accretion disc around the white dwarf, which causes a flickering in brightness. The matter eventually lands on the white dwarf, where it may flare up or explode. Source: NASA.

The Births of the Sun and Stars

Stars are being born now! Because the most massive stars have lifetimes of only a few million years, and because the age of the universe is over ten billion years, it follows that these massive stars must have been born quite recently. Their location provides a clue: they are found in and near large clouds of gas and dust called nebulae. The gas consists of ions, atoms, and molecules, mostly of hydrogen, with some helium, and a very small amount of the heavier elements. The dust consists of grains of silicate and graphite, with sizes of less than a micrometer. There is much less dust than gas, but the dust plays important roles in the nebula. It enables molecules to form by protecting them from the intense radiation from nearby stars. Its surface can provide a catalyst for molecule formation. The nearest large, bright nebula is the Orion Nebula (figure 13). Hot stars in the nebula make the gas atoms glow by fluorescence. The dust is warm, and emits infrared radiation. It also blocks out light from stars and gas behind it, causing dark patches in the nebula.

Gravity is an attracting force, so it is not surprising that some parts of a nebula would slowly contract. This will happen if the gravitational force is greater than the pressure of the turbulence of that part of the cloud. The first stages of contraction may be helped by a shock wave from a nearby supernova or by the radiation pressure from a nearby massive star. Once gravitational contraction begins, it continues. About half of the energy released, from gravitational contraction, heats the star. The other half is radiated away. When the temperature of the centre of the star reaches about 1,000,000K, thermonuclear fusion of deuterium begins; when the temperature is a bit hotter, thermonuclear fusion of normal hydrogen begins. When the energy being produced is equal to the energy being radiated, the star is "officially" born.

Fig. 13: The Orion Nebula, a large cloud of gas and dust in which stars (and their planets) are forming. The gas glows by fluorescence. The dust produces dark patches of absorption that you can see, especially in the upper left. Source: NASA.

When the gravitational contraction first begins, the material has a very small rotation (angular momentum), due to turbulence in the cloud. As the contraction continues, "conservation of angular momentum" causes the rotation to increase. This effect is commonly seen in figure skating; when the skater wants to go into a fast spin, they pull their arms as close to their axis of rotation (their body) as possible, and their spin increases. As the rotation of the contracting star continues, "centrifugal force" (as it is familiarly but incorrectly called) causes the material around the star to flatten into a disc. The star forms in the dense centre of the disc. Planets form in the disc itself -rocky planets close to the star, and gassy and icy planets in the cold outer disc.

In nebulae such as the Orion Nebula, astronomers have observed stars in all stages of formation. They have observed proplyds - protoplanetary discs in which planets like ours are forming. And starting in 1995, astronomers have discovered *exoplanets* mor *extra-solar planets* -planets around other Sun-like stars. This is dramatic proof that planets really do form as a normal by-product of star formation. There may be many planets, like earth, in the universe!

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Cosmology

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Summary

Although each individual celestial object has its particular charms, understanding the evolution of the universe is a fascinating subject in its own right. Even though we are anchored in Earth's neighborhood, understanding that we know so much about the universe is captivating.

Astronomy in the 19th century was focused on cataloguing the properties of individual celestial objects: planets, stars, nebulae, and galaxies. By the end of the 20th century the focus changed tounderstanding the properties of categories of objects: clusters of stars, formation of galaxies, and structure of the Universe. We now know the age and the history of the Universe, and that its expansion is accelerating, we do not yet know the nature of dark mater. And new discoveries continue to be made.

We will first describe some properties of galaxies that are part of large structures in the universe. Later we will address what is known as the standard model of the Big Bang and the evidence that supports the model.

Goals

- Understand how the Universe has evolved since the Big Bang to today.
- Know how matter and energy are organized in the Universe.
- Analyze how astronomers learn about the history of the Universe.

The Galaxies

Galaxies are composed of stars, gas, dust, and dark matter, and they can be very large, more than 300 000 light years in diameter. The galaxy to which the Sun belongs, has a hundred billion (100 000 000 000) stars. In the Universe there are billions of such galaxies.

Our galaxy is a large spiral galaxy, similar to the Andromeda galaxy (figure 1a). The Sun takes 200 million years to orbit its center, traveling at 250 kilometers per second. Because our solar system is immersed in the disk of the galaxy, we cannot see the whole galaxy, much like trying to picture a forest when you are in the middle of it. Our galaxy is called the Milky Way. With the unaided eye from Earth, we can see many single stars and a wide belt composed of an enormous number of stars and interstellar clouds of gas and dust. Our galaxy's structure was discovered through observations with visible and radio telescopes, and by observing other galaxies. (If there were no mirrors, we could imagine what our own face is like by looking at other faces.) We use radio waves since they can pass through clouds that are opaque to visible light, similar to the way we can receive calls on mobile phones inside a building.

Fig. 1a: Galaxy of Andromeda. Spiral galaxy very similar to our own Milky Way. The Sun is at the outer edge of one arm of our galaxy. (Photo: Bill Schoening, Vanessa Harvey / REU program / NOAO / AURA / NSF).Fig.1b: Large Magellanic Cloud. Irregular satellite galaxy of the Milky Way that can be seen with the unaided eye from the southern hemisphere. (Photo: ESA and Eckhard Slawik)

We classify galaxies into three types. Irregular galaxies are smaller and abundant and are usually rich in gas, and form new stars. Many of these galaxies are satellites of other galaxies. The Milky Way has 30 satellite galaxies, and the first of these discovered were the Magellanic Clouds, which are seen from the southern hemisphere.

Spiral galaxies, like our own, in general have two arms tightly or loosely twisted in spirals emanating from the central part called the bulge. The cores of galaxies like ours tend to have a black hole millions of times the mass of the Sun. New stars are born mainly in the arms, because of the greater density of interstellar matter whose contraction gives birth to stars.

When black holes in galactic nuclei attract clouds of gas or stars, matter is heated and before falling into the black hole, part of it emerges in jets of incandescent gas that move through space and heat the intergalactic medium. They are known as active galactic nuclei and a large number of spiral galaxies have them.

The largest galaxies are the ellipticals (although there are also small ellipticals). It is thought that these, as well as the giant spirals, are formed when smaller galaxies merge together. Some evidence for this comes from the diversity of ages and chemical composition of the various groups of stars in the merged galaxy.

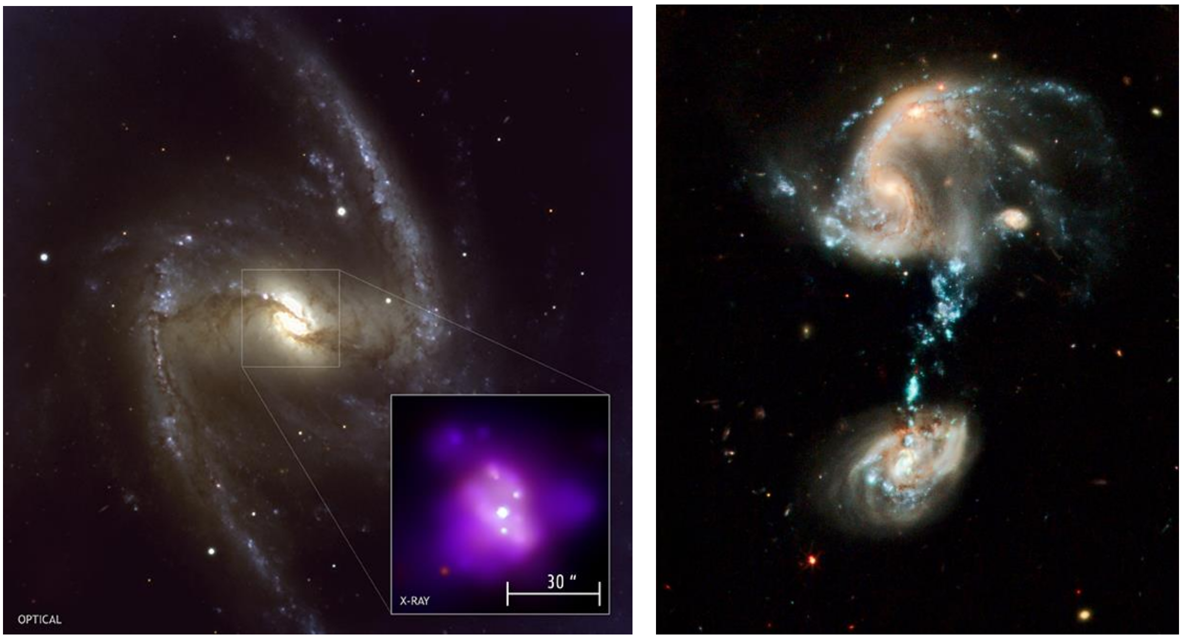


Fig. 2a: Optical image of the galaxy NGC 1365 taken with the ESO VLT and Chandra image of X-ray material close to the central black hole. (Photo: NASA, ESA, the Hubble Heritage (STScI / AURA) -ESA/Hubble Collaboration, and A. Evans). Fig. 2b: Arp 194 – a system of two galaxies interact in a very spectacular process. The cores are merging, and a blue tail is released (credit: NASE,ESA and the hubble Heritage Team (STScl))

Galaxies form clusters of galaxies, with thousands of components. Giant ellipticals are usually found in the cluster centers, and, some of them have two cores as a result of a recent merger of two galaxies.

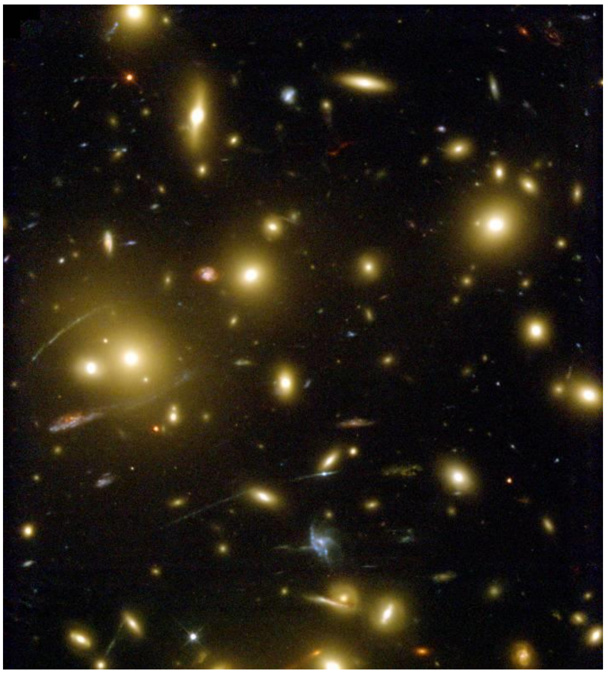


Fig. 3: Abell 2218 cluster of galaxies. Arcs can be seen, caused by a gravitational lensing effect. (Photo: NASA, ESA, Richard Ellis (Caltech) and Jean-Paul Kneib (Observatoire Midi-Pyrenees, France)).

Clusters and superclusters of galaxies are distributed in the universe in filamentary structures surrounding immense regions devoid of galaxies. It is as if the universe on a large scale was a bubble bath where galaxies are on the bubble surface.

Cosmology

We will describe some properties of the universe in which we live. The universe consists of matter, energy and space and evolves with time. Its temporal and spatial dimensions are much larger than we use in our daily lives.

Cosmology tries to answer to fundamental questions about the universe: Where did we come from? What is the future of the Universe? Where are we? How old is the Universe?

It is worth mentioning that science evolves. The more we know, the more we realize how much we do not know. A map is useful even if it is only is a representation of a site, just as science allows us to have a representation of nature , see some of its aspects and predict events, all based on reason able assumptions that necessarily have to be supported with measurements and data.

The dimensions of the universe

The distances between stars are vast. The Earth is 150 000 000 km from the Sun, Pluto is 40 times farther away. The nearest star is 280 000 times more distant, and the nearest galaxy is ten billion (10 000 000 000) times more. The filament structure of galaxies is ten trillion (a one followed by 12 zeros) times greater than the distance from the Earth to the Sun.

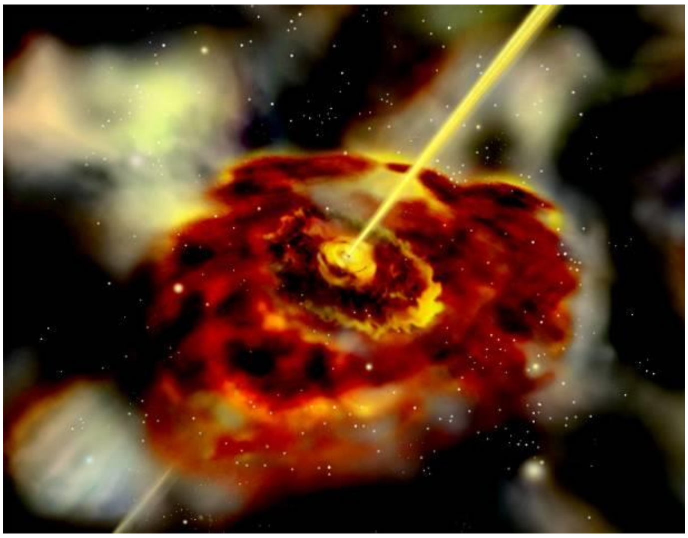
The age of the universe

Our universe began 13.7 billion (13 700 000 000) years ago. The solar system formed much later at 4.6 billion (4 600 000 000) years ago. Life on Earth emerged 3.8 billion (3 800 000 000) years ago and the dinosaurs became extinct 6 5 million years ago. Modern humans have only been around a mer e 150,000 years.

We reason that our universe had an origin in time because we observe that it is expanding rapidly. This means that all clusters of galaxies are moving away from each other and the more distant they are the faster they recede. If we measure the expansion rate we can estimate when all of space was together. This calculation gives an age of 13.7 billion years. This age does not contradict stellar evolution since we do not observe stars and galaxies older than 13.5 billion years. The event that started the expansion of the universe is known as Big Bang.

Measuring Speed

You can measure the velocity of a star or galaxy using the Doppler effect. In everyday life we experience the Doppler effect when we hear the change in tone of an ambulance or police siren as it approaches and then passes by. A simple experiment is to place a ringing alarm clock in a bag with a long handle. If someone else spins the bag by the handle with their arm extended above their head, we can detect that the tone changes when the clock's moves toward or away from us. We could calculate the clock's speed by listening to the change of the tone, which is higher if the speed is greater.



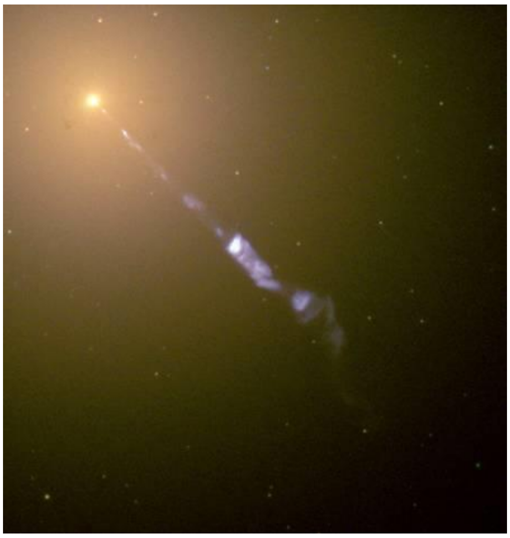


Fig. 4a: Artistic illustration of a black hole in the center with of a galaxy. (Photo: NASA E / PO - Sonoma State Univ.). Fig 4b: Galaxy M87, an example of real galaxy a jet. (Photo: NASA and Hubble Heritage Team).

Light emitted by celestial objects also goes through a frequency change or color change that can be measured depending on the speed with which they approach or depart. The wavelength becomes longer (redder) when moving away from us and shorter (blue) when they move toward us.

When the universe was more compact, sound waves passing through it produced regions of higher and lower density. Superclusters of galaxies formed where the matter density was highest. As the universe expanded, the space between the regions of high density increased in size and volume. The filament structure of the universe is the result of the expanding universe.

Sound waves

Sound travels through a medium such as air, water or wood. When we produce a sound we generate a wave that compresses the material around it. This compression wave travels through the material to our ear and compresses the eardrum, which sends the sound to our sensitive nerve cells. We do not hear the explosions from the sun or the storms of Jupiter because the space between the celestial objects is almost empty and therefore sound compression cannot propagate.

It is noteworthy that there is no center of the universe's expansion. Using a two-dimensional analogy, imagine we were in Paris at the offices of UNESCO and the Earth is expanding. We would observe that all cities would move away from each other, and us but we would have no reason to say that we are in the center of the expansion because all the inhabitants of other cities would observe the expansions the same way.

Fig. 5: To date, over 300 dark and dense clouds of dust and gas have been located, where star formation processes are occurring. Super Cluster Abell 90/902. (Photo: Hubble Space Telescope, NASA, ESA, C. Heymans (University of British Columbia) and M. Gray (University of Nottingham)).

Although from our point of view, the speed of light of 300 000 kilometers per second is extremely fast, it is not infinitely fast. Starlight takes hundreds of years to reach Earth and the light from galaxies takes millions of years. All information from cosmos takes a very long time to arrive so that we always see the stars as they were in the past, not as they are now.

There are objects so distant that their light has not had time to reach us yet so we cannot see them. It is not that they are not there, simply that they were formed after the radiation from that region of the sky has caught up to us.

The finite speed of light has several implications for astronomy. Distortions in space affect the trajectory of light, so if we see a galaxy at a given place it may not actually be there now, because the curvature of space changes its position. In addition, a star is no longer at the spot you observe it to be because the stars are moving. Nor are they like we see them now. We always see celestial objects as they were, and the more distant they are the further back in their past we see them. So analyzing similar objects at different distances is equivalent to seeing the same object at different times in its evolution. In other words we can see the history of the stars if we look at those we assume are similar types, but at different distances.

We cannot see the edge of the universe because its light has not had time to reach Earth. Our universe is infinite in size, so we only see a section, 13.7 billion light years in radius, i.e., where the light has had time to reach us since the Big Bang. A source emits light in all directions, so different parts of the universe become are of its existence at different times.

We see all the celestial objects as they were at the time they emitted the light we now observe, because it takes a finite time for the light to reach us. This does not mean we have some privileged position in the universe, any observer in any other galaxy would observe something equivalent to what we detect.

Just like all the sciences, in astronomy and astrophysics the more we learn about our universe, the more questions we uncover. Now we will discuss dark matter and dark energy, to give an idea of how much we still do not know about the universe.

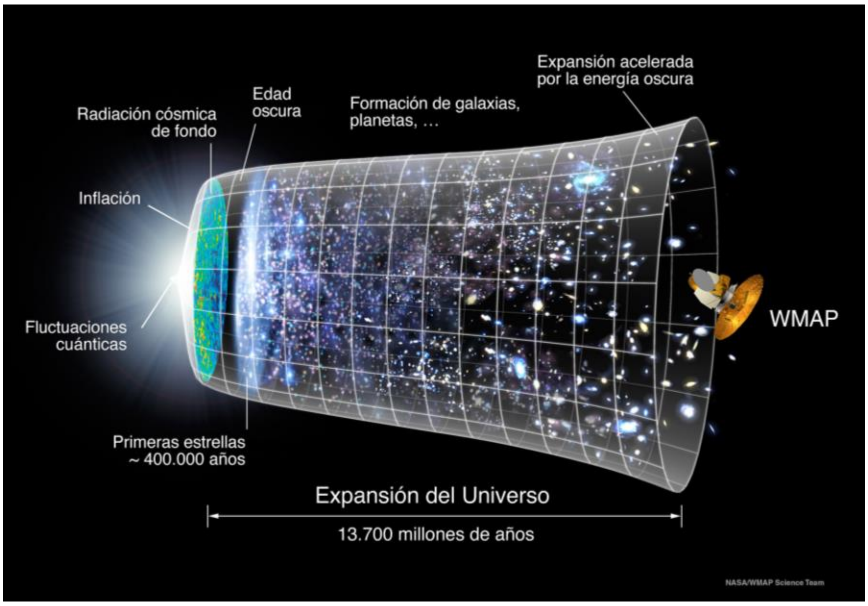


Fig. 6: Expansion of the Universe. (Photo: NASA).

Dark matter does not interact with electromagnetic radiation, so it does not absorb or emit light. Ordinary matter, like that in a star, can produce light, or absorb it, as does a cloud of interstellar dust. Dark matter is insensitive to any radiation, has mass, and therefore has gravitational attraction. It was discovered through its effects on the motion of visible matter. For example, if a galaxy moves in an orbit around apparently empty space, we are certain that something is attracting it. Just as the solar system is held together by the Sun’s gravitational force, which keeps the planets in their orbits, the galaxy in question has an orbit because something attracts it. We now know that dark matter is present in individual galaxies, it is present in clusters of galaxies, and it appears to be the foundation of the filamentary structure of the universe. Dark matter is the most common type of matter in the universe.

We also now know that the expansion of the universe is accelerating. This means that there is a force that counteracts the effect of gravity. Dark energy is the name given by astronomers to this recently discovered phenomenon. In the absence of dark energy, the expansion of the universe would be slowing down.

Our current knowledge of the matter-energy content of the universe is that 74 percent is dark energy, 22 percent is dark matter and only 4 percent is normal, luminous matter (all the galaxies, stars, planets, gas, dust) Basically, the nature and properties of 96 percent of the universe remain to be discovered.

The future of our universe depends on the amounts of visible matter, dark matter and dark energy. Before the discovery of dark matter and dark energy, it was thought that the expansion would cease, and gravity would reverse the expansion resulting in Big Crunch, where everything would return to a single point. But once the existence of dark matter was established, the theory was modified. Now, the expansion would reach a constant value at an infinite time in the future. But now that we know of dark energy, the expected future is that the expansion accelerates, as does the volume of the universe. The end of the universe is very cold and very dark at an infinite time.

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Stellar, solar, and lunar demonstrators

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Summary

This worksheet presents a simple method to explain how the apparent motions of stars, the Sun, and the Moon are observed from different places on Earth. The procedure consists of building simple models that allows us to demonstrate how these movements are observed from different latitudes.

Goals

- Understand the apparent motions of stars as seen from different latitudes.
- Understand the apparent motions of the Sun as seen from different latitudes.
- Understand the Moon's movement and shapes as seen from different latitudes.

The idea behind the demonstrator

It is not simple to explain how the apparent motions of the Sun, the Moon, or stars are observed from the Earth. Students know that the Sun rises and sets every day, but they are surprised to learn that the Sun rises and sets at a different point every day or that solar trajectories can vary according to the local latitude. The demonstrators simplify and explain the phenomenon of the midnight sun and the solar zenith passage. In particular, the demonstrators can be very useful for understanding the movement of translation and justify some latitude differences.

It is easy to remember the shape and appearance of each constellation by learning the mythological stories and memorizing the geometric rules for finding the constellation in the sky. However, this only works at a fixed location on Earth. Because of the motion of the Celestial Sphere, an observer that lives at the North Pole can see all the stars in the Northern Hemisphere and one who lives at the South Pole can see all the stars in the Southern Hemisphere. But what do observers see that live at different latitudes?

The stellar demonstrator: why are there invisible stars?

Everything gets complicated when the observer lives in a zone that is not one of the two poles. In fact, this is true for most observers. In this case, stars fall into three different categories depending on their observed motions (for each latitude): circumpolar stars, stars that rise and set, and invisible stars (figure 1). We all have experienced the surprise of discovering that one can see some stars of the Southern Hemisphere while living in the Northern Hemisphere. Of course it is similar to the surprise that it is felt when the phenomenon of the midnight sun is discovered.

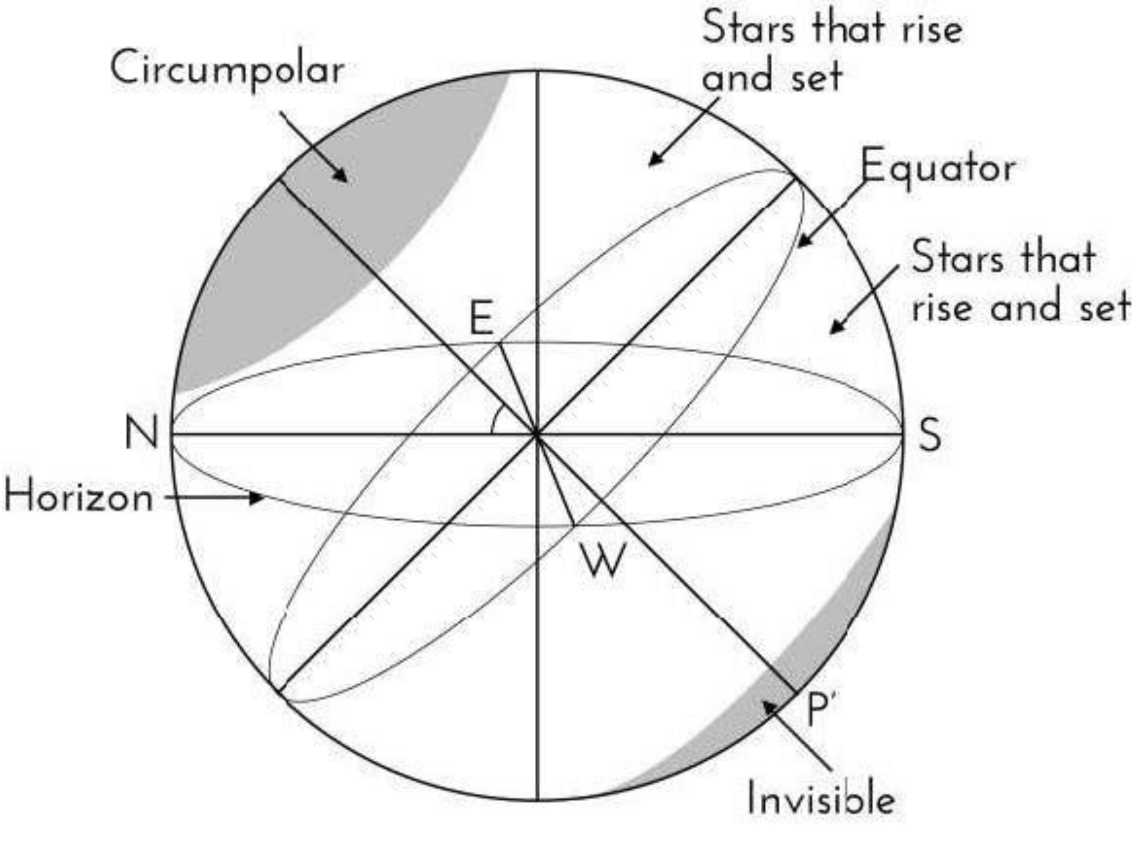

Fig 1: Three different types of stars (as seen from a specific latitude): circumpolar, stars that rise and set, and invisible stars.

Depending on their age, most students can understand fairly easily why some stars appear circumpolar from the city where they live. However, it is much more difficult for them to imagine which ones would appear circumpolar as seen from other places in the world. If we ask whether one specific star (e.g., Sirius) appears to rise and set as seen from Buenos Aires, it is difficult for students to figure out the answer. Therefore, we will use the stellar demonstrator to study the observed motions of different stars depending on the latitude of the place of observation.

The main goal of the demonstrator

The main objective is to discover which constellations are circumpolar, which rise and set, and which are invisible at specific latitudes. If we observe the stars from latitude of around 45º N, it is clear that we can see quite a lot of stars visible from the Southern Hemisphere that rise and set every night (figure 1).

In our case, the demonstrator should include constellations with varying declinations (right ascensions are not as important at this stage). It is a very good idea to use constellations that are familiar to the students. These can have varying right ascensions so they are visible during different months of the year (figure 2).

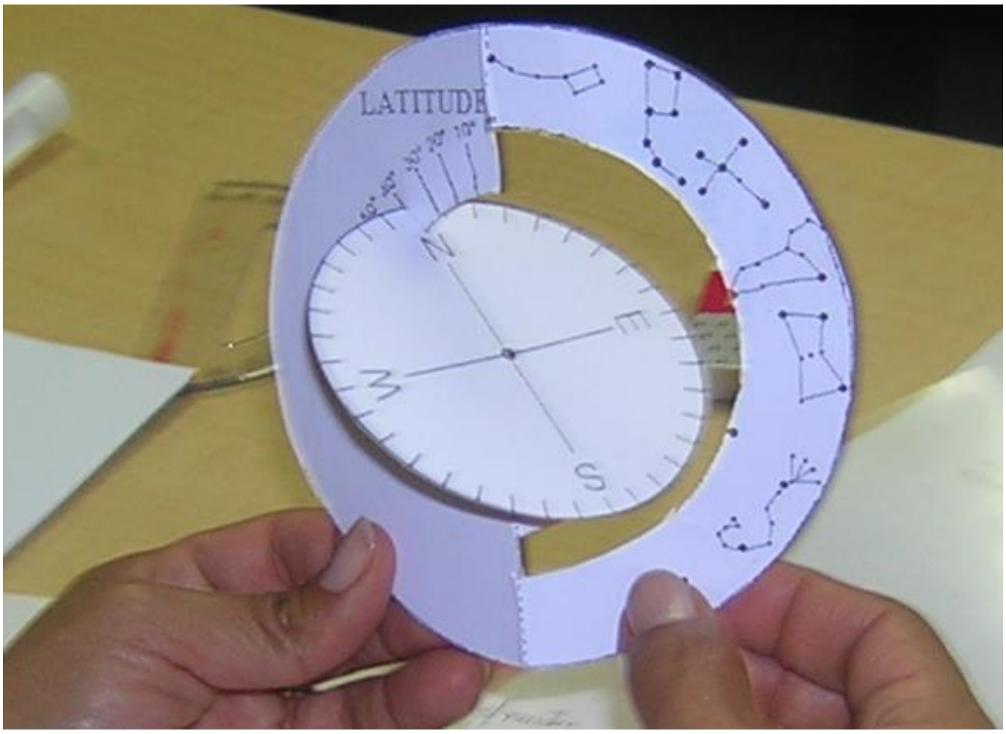

Fig 2: Using the demonstrator: this is an example of a demonstrator for the Northern Hemisphere using constellations from Table 1.

When selecting the constellation to be drawn, only the bright stars should be used so that its shape is easily identified. It is preferable not to use constellations that are on the same meridian, but rather to focus on choosing ones that would be well known to the students (Table 1). If you are interested in making a model for each season, you can make four different demonstrators, one for each season for your hemisphere. You should use constellations that have different declinations, but that have right ascension between 21h and 3h for the autumn (spring), between 3h and 9h for the winter (summer), between 9h and 14h for spring (autumn), and between 14h and 21h for the summer (winter) in the Northern (Southern) hemisphere for the evening sky.

Constellation	*Maximum declination*	*Minimum declination*
Ursa Minor	+90º	+70º
Ursa Major	+60º	+50º
Cygnus	+50º	+30º
Leo	+30º	+10º
Orion and Sirius	+10º	-10º
Scorpius	-20º	-50º
South Cross	-50º	-70º

Table 1: Constellations appearing in the demonstrator shown in figure 1.

If we decide to select constellations for only one season, it may be difficult to select a constellation between, for example, 90ºN and 60ºN, another between 60ºN and 40ºN, another between 40ºN and 20ºN, and another between 20ºN and 20ºS, and so on, without overlapping and reaching 90ºS. If we also want to select constellations that are well known to students, with a small number of bright stars that are big enough to cover the entire meridian, it may be difficult to achieve our objective. Because big, well-known, bright constellations do not cover the whole sky throughout the year, it may be easier to make only one demonstrator for the entire year.

There is also another argument for making a unique demonstrator. Any dispute regarding the seasons take place only at certain latitudes of both hemispheres.

Making the demonstrator

To obtain a sturdy demonstrator (figure 3), it is a good idea to glue together the two pieces of cardboard before cutting (figures 4 and 5). It is also a good idea to construct another one, twice as big, for use by the teacher.

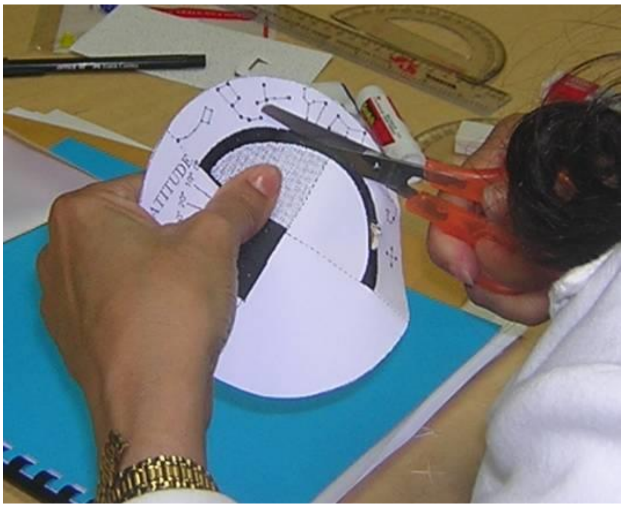

Fig. 3: Making the stellar demonstrator.

The instructions to make the stellar demonstrator are given below.

Demonstrator for Northern Hemisphere

a) Make a photocopy of figures 4 and 5 on cardboard.
b) Cut both pieces along the continuous line (figures 4 and 5).
c) Remove the black areas from the main piece (figure 4).
d) Fold the main piece (figure 4) along the straight dotted line. Doing this a few times will make the demonstrator easier to use.
e) Cut a small notch above the "N" on the horizon disk (figure 5). The notch should be large enough for the cardboard to pass through it.
f) Glue the North-East quadrant of the horizon disk (figure 5) onto the grey quadrant of the main piece (figure 4). It is very important to have the straight north-south line following the double line of the main piece. Also, the "W" on the horizon disk must match up with latitude 90º.
g) When you place the horizon disk into the main piece, make sure that the two stay perpendicular.
h) It is very important to glue the different parts carefully to obtain the maximum precision.

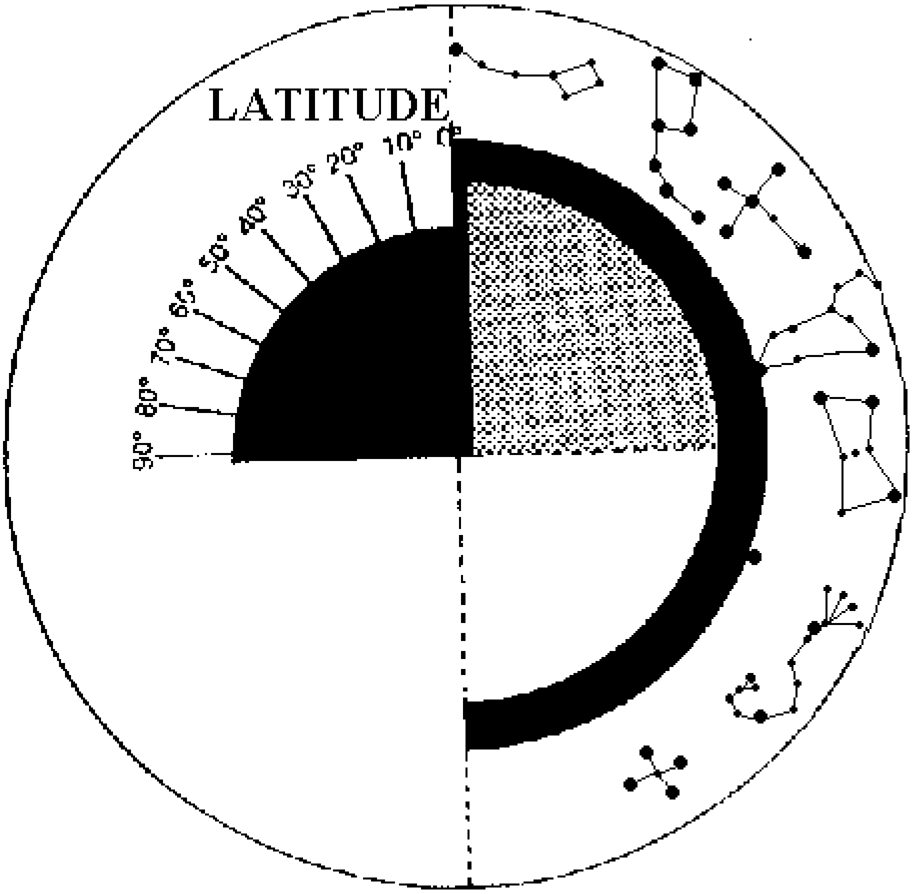

Fig. 4: The main part of the stellar demonstrator for the Northern Hemisphere.

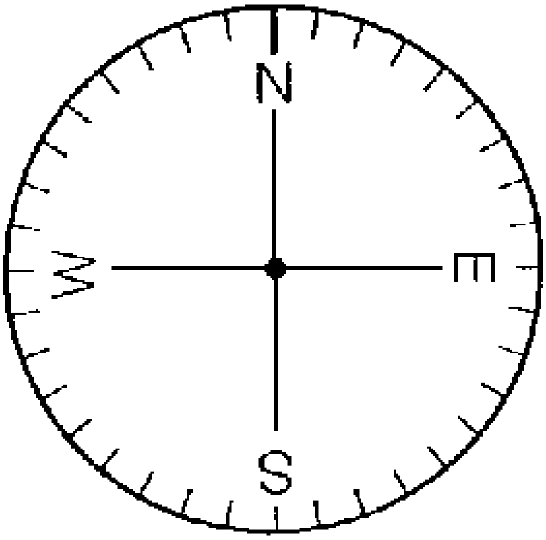

Fig. 5: The horizon disc.

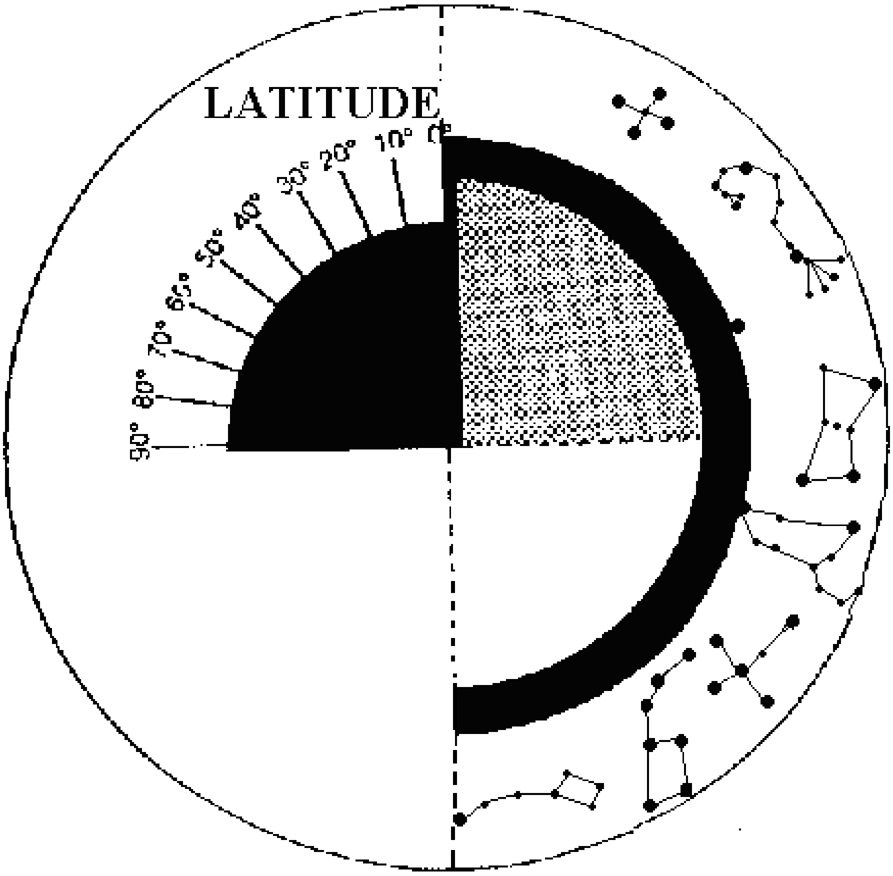

Fig. 6: The main part of the stellar demonstrator for the Southern Hemisphere.

Demonstrator for Southern Hemisphere

a) Make a photocopy of figures 5 and 6 on cardboard.
b) Cut both pieces along the continuous line (figures 5 and 6).
c) Remove the black areas from the main piece (figure 6).
d) Fold the main piece (figure 6) along the straight dotted line. Doing this a few times will make the demonstrator easier to use.
e) Cut a small notch on the "S" of the horizon disk (figure 5). It should be large enough for the cardboard to pass through it.
f) Glue the South-West quadrant of the horizon disk (figure 5) onto the grey quadrant of the main piece (figure 6). It is very important to have the straight north-south line following the double line of the main piece. Also the "E" on the horizon disk must match up with latitude 90º.
g) When you place the horizon disk into the main piece, make sure that the two stay perpendicular.
h) It is very important to glue the different parts carefully to obtain the maximum precision.

Choose which stellar demonstrator you want to make depending on where you live. You can also make a demonstrator by selecting your own constellations following different criteria.

For instance, you can include constellations visible only for one season, constellations visible only for one month, etc. For this, you must consider only constellations with right ascensions between two specific values. Then draw the constellations with their declination values on figure 7. Notice that each sector corresponds to 10º.

Demonstrator applications

To begin using the demonstrator you have to select the latitude of your place of observation. We can travel over the Earth's surface on an imaginary trip using the demonstrator.

Use your left hand to hold the main piece of the demonstrator (figure 4 or 6) by the blank area (below the latitude quadrant). Select the latitude and move the horizon disk until it shows the latitude chosen. With your right hand, move the disk with the constellations from right to left several times.

You can observe which constellations are always on the horizon (circumpolar), which constellations rise and set, and which of them are always below the horizon (invisible).

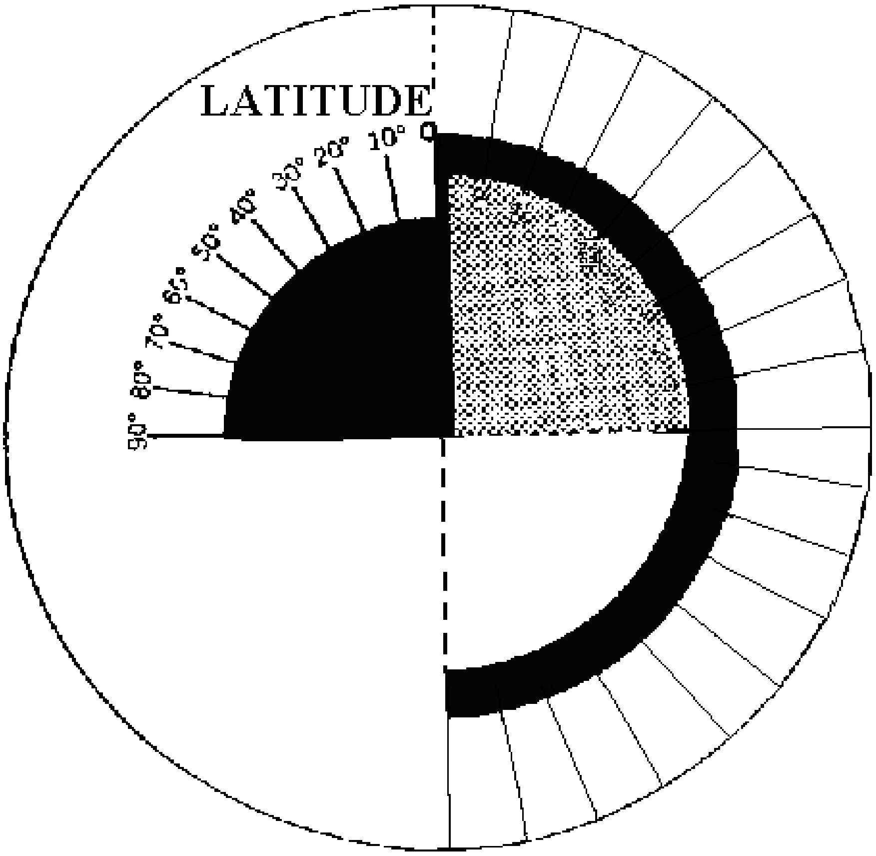

Fig. 7: The main part of the stellar demonstrator for the Northern or Southern Hemispheres.

- ***Star path inclination relative to the horizon***

With the demonstrator, it is very easy to observe how the angle of the star path relative to the horizon changes depending on the latitude (figures 8 and 9).

If the observer lives on the equator (latitude 0º) this angle is 90º. On the other hand, if the observer is living at the North or South Pole, (latitude 90º N or 90º S) the star path is parallel to the horizon. In general, if the observer lives in a city at latitude L, the star path inclination on the horizon is 90º minus L every day.

We can verify this by looking at figures 8 and 9. The photo in figure 9 was taken in Lapland (Finland) and the one in figure 8 in Montseny (near Barcelona, Spain). Lapland is at a higher latitude than Barcelona so the star path inclination is smaller.

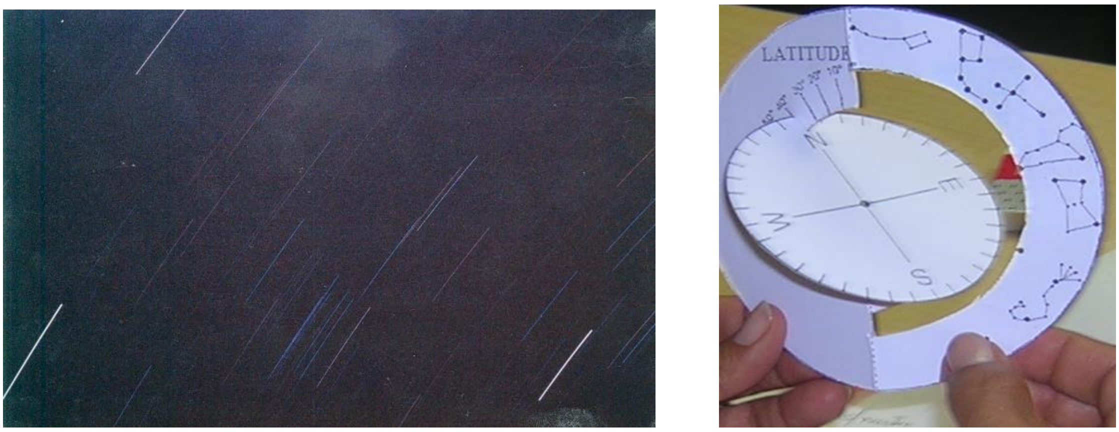

Fig. 8a and 8b: Stars rising in Montseny (near Barcelona, Spain). The angle of the star path relative to the horizon is 90º minus the latitude (Photo: Rosa M. Ros).

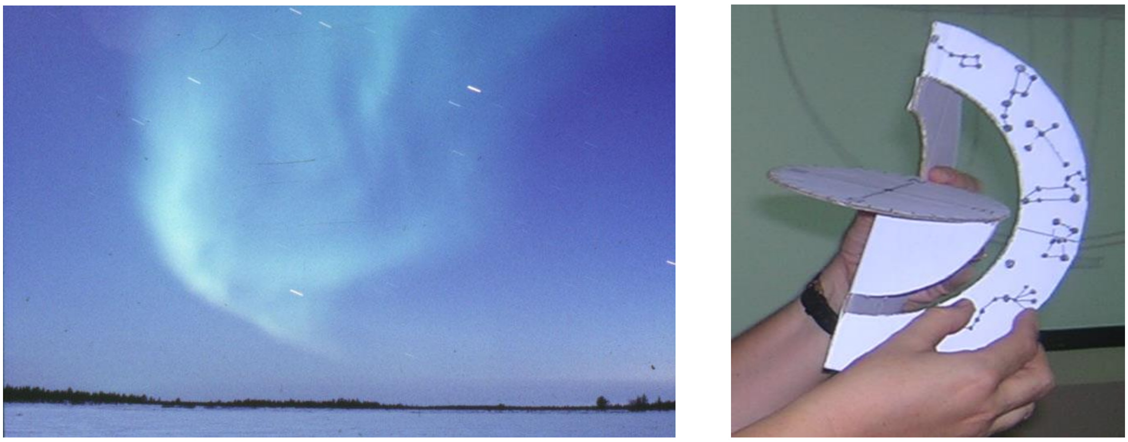

Fig. 9a and 9b: Stars setting in Enontekiö in Lapland (Finland). The angle of the star path relative to the horizon is 90º minus the latitude. Note that the star paths are shorter than in the previous photo because the aurora borealis forces a smaller exposure time (Photo: Irma Hannula).

Using the demonstrator in this way, the students can complete the different activities below.

1) If we choose the latitude to be 90ºN, the observer is at the North Pole. We can see that all the constellations in the Northern Hemisphere are circumpolar. All the ones in the Southern Hemisphere are invisible and there are no constellations which rise and set.
2) If the latitude is 0º, the observer is on the equator, and we can see that all the constellations rise and set (perpendicular to the horizon). None are circumpolar or invisible.
3) If the latitude is 20º (N or S), there are less circumpolar constellations than if the latitude is 40º (N or S, respectively). But there are a lot more stars that rise and set if the latitude is 20º instead of 40º.
4) If the latitude is 60º (N or S), there are a lot of circumpolar and invisible constellations, but the number of constellations that rise and set is reduced compared to latitude 40º (N or S respectively).

The solar demonstrator: why the Sun does not rise at the same point every day

It is simple to explain the observed movements of the sun from the Earth. Students know that the sun rises and sets daily, but feel surprised when they discover that it rises and sets at different locations each day. It is also interesting to consider the various solar trajectories according to the local latitude. And it can be difficult trying to explain the phenomenon of the midnight sun or the solar zenith passage. Especially the simulator can be very useful for understanding the movement of translation and justify some latitude differences.

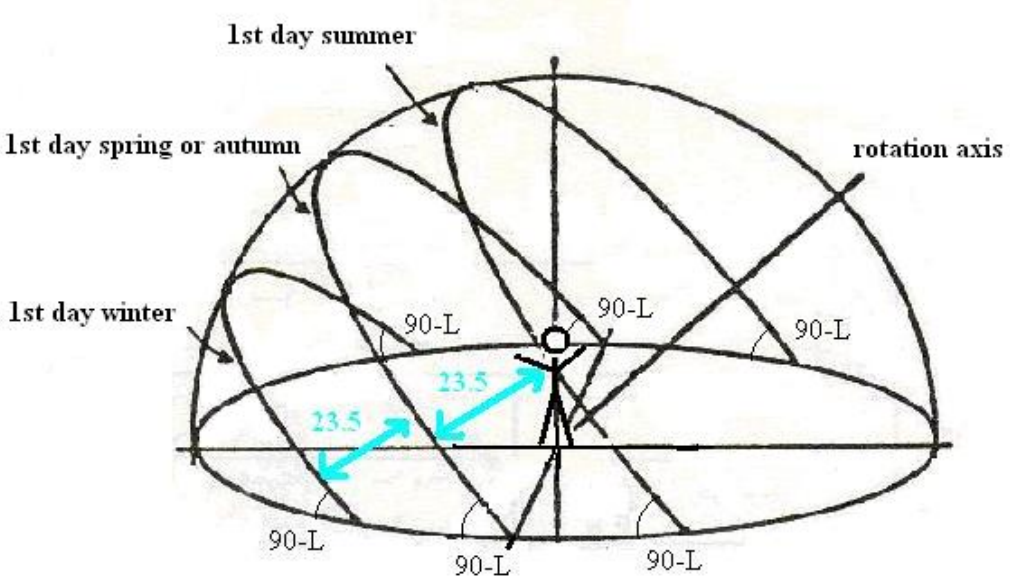

Fig. 10: Three different solar paths (1st day of spring or autumn, 1st day of summer, and 1st day of winter).

Making the demonstrator

To make the solar demonstrator, we have to consider the solar declination, which changes daily. Then we have to include the capability of changing the Sun's position according to the seasons. For the first day of spring and autumn, its declination is 0º and the Sun is moving along the equator. On the first day of summer (winter in the Southern Hemispheres), the Sun's declination is +23.5 º and on the first day of winter (summer in the Southern Hemisphere) it is -23.5º (figure 10). We must be able to change these values in the model if we want to study the Sun's trajectory.

To obtain a sturdy demonstrator (figures 11a y 11b), it is a good idea to glue two pieces of cardboard together before cutting them. Also you can make one of the demonstrators twice as large, for use by the teacher.

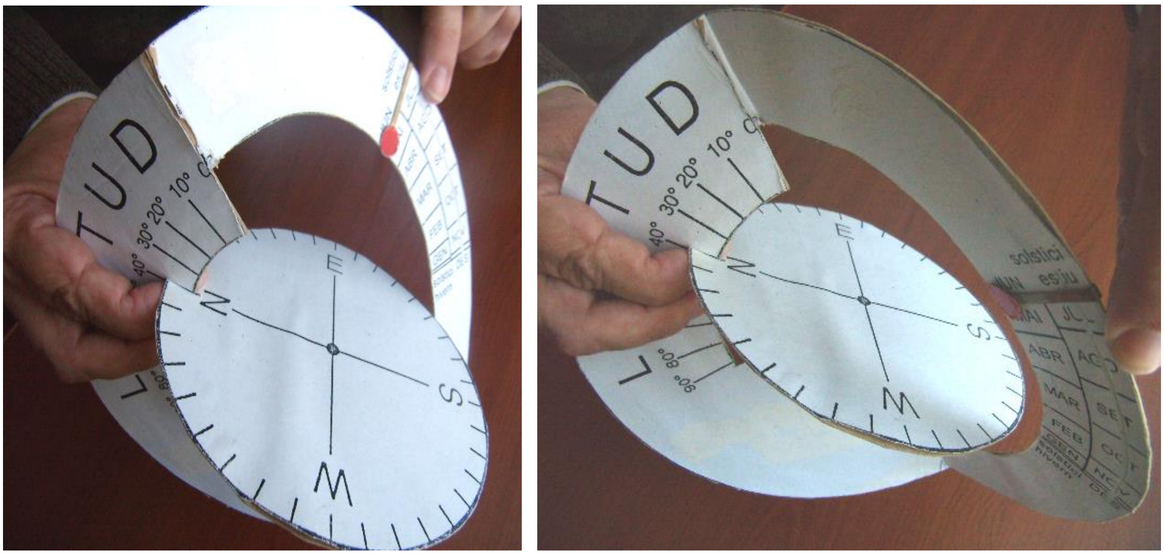

Fig. 11a and 11b: Preparing the solar demonstrator for the Northern Hemisphere at latitude +40º.

The build instructions listed below.

Demonstrator for Northern Hemisphere

a) Make a photocopy of figures 12 and 13 on cardboard.
b) Cut both pieces along the continuous line (figures 12 and 13).
c) Remove the black areas from the main piece (figure 13).
d) Fold the main piece (figure 13) along the straight dotted line. Doing this a few times will make the demonstrator easier to use.
e) Cut a small notch above the “N” on the horizon disk (figure 13). The notch should be large enough for the cardboard to pass through it.
f) Glue the North-East quadrant of the horizon disk (figure 13) onto the grey quadrant of the main piece (figure 12). It is very important to have the straight north-south line following the double line of the main piece. Also, the “W” on the horizon disk must match up with latitude 90º.
g) When you place the horizon disk into the main piece, make sure that the two stay perpendicular.
h) It is very important to glue the different parts carefully to obtain the maximum precision.
i) In order to put the Sun in the demonstrator, paint a circle in red on a piece of paper. Cut it out and put it between two strips of sticky tape. Place this transparent strip of tape with the red circle over the declination area in figure 12. The idea is that it should be easy to move this strip up and down in order to situate the red point on the month of choice.

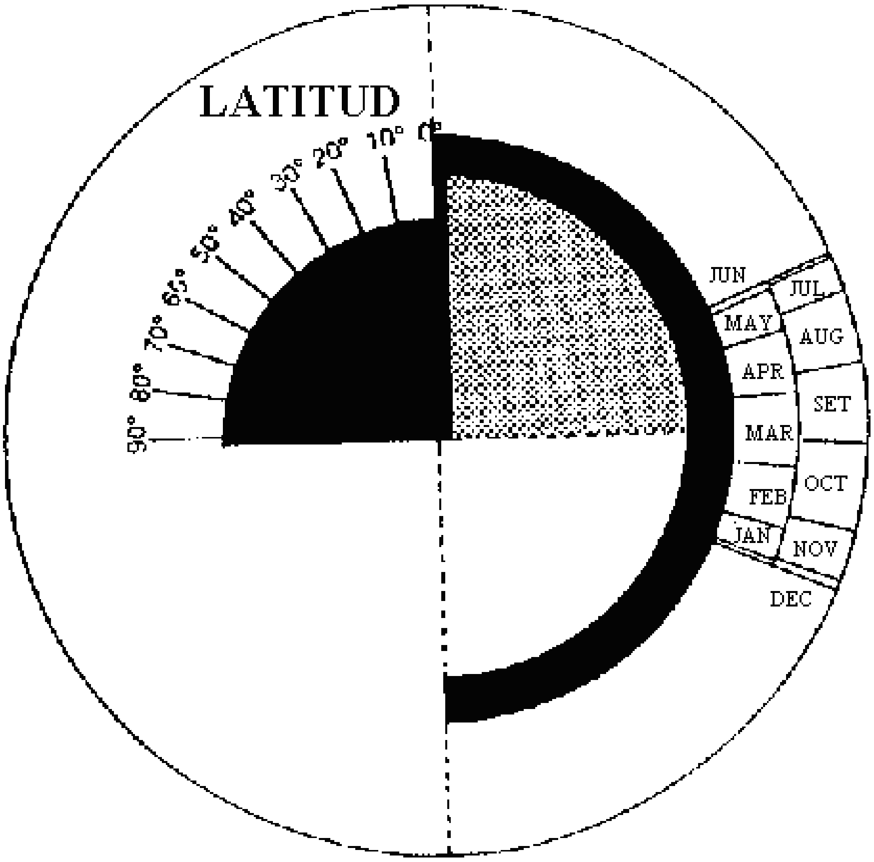

Fig. 12: The main part of the solar demonstrator for the Northern Hemisphere.

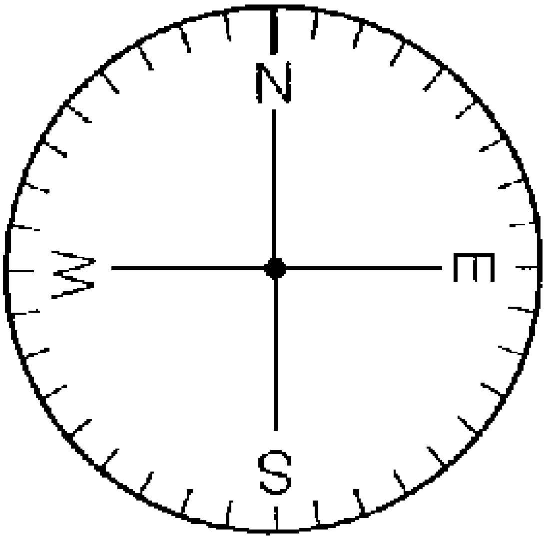

Fig. 13: The horizon disk.

To build the solar demonstrator in the Southern Hemisphere you can follow similar steps, but replace figure 12 with figure 14.

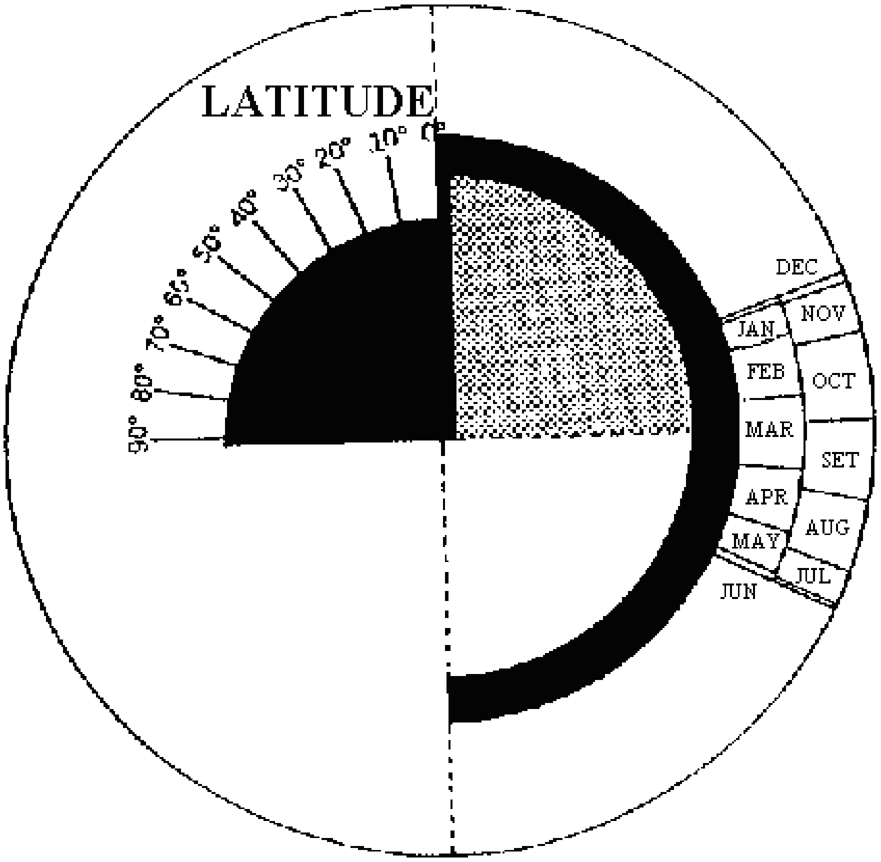

Fig. 14: The main part of the solar demonstrator for the Southern Hemisphere.

Demonstrator for Southern Hemisphere

a) Make a photocopy of figures 13 and 14 on cardboard.
b) Cut both pieces along the continuous line (figures 13 and 14).
c) Remove the black areas from the main piece (figure 14).
d) Fold the main piece (figure 14) along the straight dotted line. Doing this a few times will make the demonstrator easier to use.
e) Cut a small notch above the “S” on the horizon disk (figure 13). The notch should be large enough for the cardboard to pass through it.
f) Glue the South-West quadrant of the horizon disk (figure 13) onto the grey quadrant of the main piece (figure 14). It is very important to have the straight north-south line following the double line of the main piece. Also, the “E” on the horizon disk must match up with latitude 90º.
g) When you place the horizon disk into the main piece, make sure that the two stay perpendicular.
h) It is very important to glue the different parts carefully to obtain the maximum precision.
i) In order to put the Sun in the demonstrator, paint a circle in red on a piece of paper. Cut it out and put it between two strips of sticky tape. Place this transparent strip of tape with the red circle over the declination area in figure 14. The idea is that it should be easy to move this strip up and down in order to situate the red point on the month of choice.

j) Using the solar demonstrator

To use the demonstrator you have to select your latitude. Again, we can travel over the Earth's surface on an imaginary trip using the demonstrator.

We will consider three areas:

1. Places in an intermediate area in the Northern or Southern Hemispheres
2. Places in polar areas
3. Places in equatorial areas

1. - Places in intermediate areas in the Northern or Southern Hemispheres: SEASONS

- ***Angle of the Sun's path relative to the horizon***

Using the demonstrator it is very easy to observe that the angle of the Sun's path relative to the horizon depends on the latitude. If the observer lives on the equator (latitude 0º) this angle is 90º. If the observer lives at the North or South Pole (latitude 90º N or 90º S), the Sun's path is parallel to the horizon. In general, if the observer lives in a city at latitude L, the inclination of the Sun's path relative to the horizon is 90 minus L every day. We can verify this by looking at figures 15 and 16. The picture in figure 15 was taken in Lapland (Finland), and the one in figure 16 in Gandia (Spain). Lapland is at higher latitude than Gandia, so the inclination of the Sun's path is smaller.

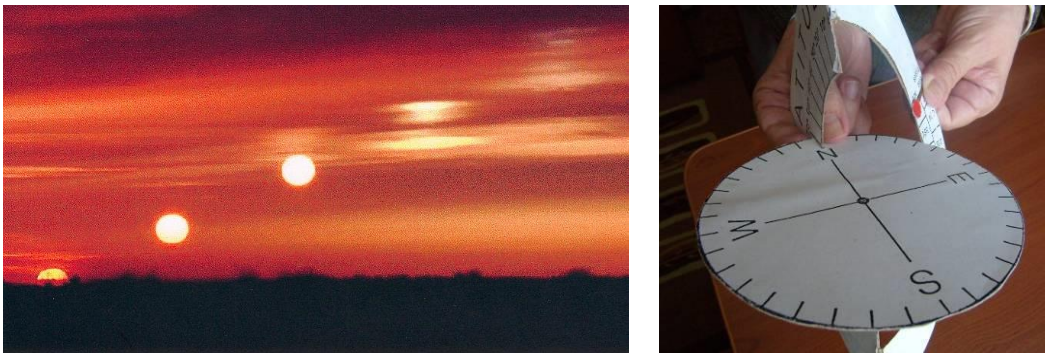

Fig. 15a y 15b: Sun rising in Enontekiö in Lapland (Finland). The angle of the Sun's path relative to the horizon is the co-latitude (90º minus the latitude) (Photo: Sakari Ekko).

Fig. 16a y 16b: Sun rising in Gandia (Spain). The angle of the Sun's path relative to the horizon is 90 minus the latitude (Photo: Rosa M. Ros).

- ***The height of the Sun's path depending on the season***

1a) the Northern Hemisphere

Using the demonstrator for your city (select the latitude of your city), it is easy to verify that the altitude (height) of the Sun above the horizon changes according to the season. For instance, on the first day of spring the declination of the Sun is 0º. We can put the Sun on March 21st. Then we can move the Sun exactly along the equator from the East towards the West. We can see that the Sun's path is at a certain height over the horizon.

At the same latitude we repeat the experiment for different days. When we move the Sun along the equator on the 1st day of summer, the 21st of June, (solar declination +23º.5), we observe that the Sun's path is higher than on the 1st day of spring. Finally, we repeat the experiment for the 1st day of winter, the 21st of December (solar declination -23º.5). We can see that in this case the Sun's path is lower. On the 1st day of autumn the declination is 0º and the Sun's path follows the equator in a similar way as it did on the 1st day of spring.

Fig. 17a y 17b: The Sun's path in summer and winter in Norway. It is clear that the Sun is much higher in summer than in winter. This is why there are many more hours of sunlight during summer.

1b) the Southern Hemisphere

Using the demonstrator for your city (select the latitude of your city), it is easy to verify that the altitude of the Sun above the horizon changes according to the season. For instance, on the first day of spring the declination of the Sun is 0º. We can put the Sun on September 23rd. Then we can move the Sun along the equator from the East towards the West. We can see that the Sun's path is at a certain height over the horizon.

At the same latitude we can repeat the experiment for different days. On the 1st day of summer, the 21st of December (solar declination -23º.5), when we move the Sun along the equator, we observe that the Sun's path is higher than on the 1st day of spring.

Finally, we can repeat the experiment at the same latitude for the 1st day of winter, the 21st of June (solar declination +23º.5). We can see that in this case the Sun's path is lower. On the 1st day of autumn the declination is 0º and the Sun's path follows the equator in a similar way as on the 1st day of spring.

Of course if we change the latitude, the height of the Sun's path changes, but even then the highest path is still always on the 1st day of summer and the lowest on the 1st day of winter.

Remarks:
In the summer, when the Sun is higher, the Sun's light hits the Earth at an angle that is more perpendicular to the horizon. Because of this, the radiation is concentrated in a smaller area and the weather is hotter. Also in summertime, the number of hours of sunlight is larger than in winter. This also increases temperatures during the summer.

- ***The Sun rises and sets in a different place every day***

In the preceding experiments, if we had focused our attention on where the Sun rises and sets, we would have observed that it is not the same place every day. In particular, the distance on the horizon between the sunrise (or sunset) on the 1st day of two consecutive seasons increases with the increasing latitude (figure 18a y 18b).

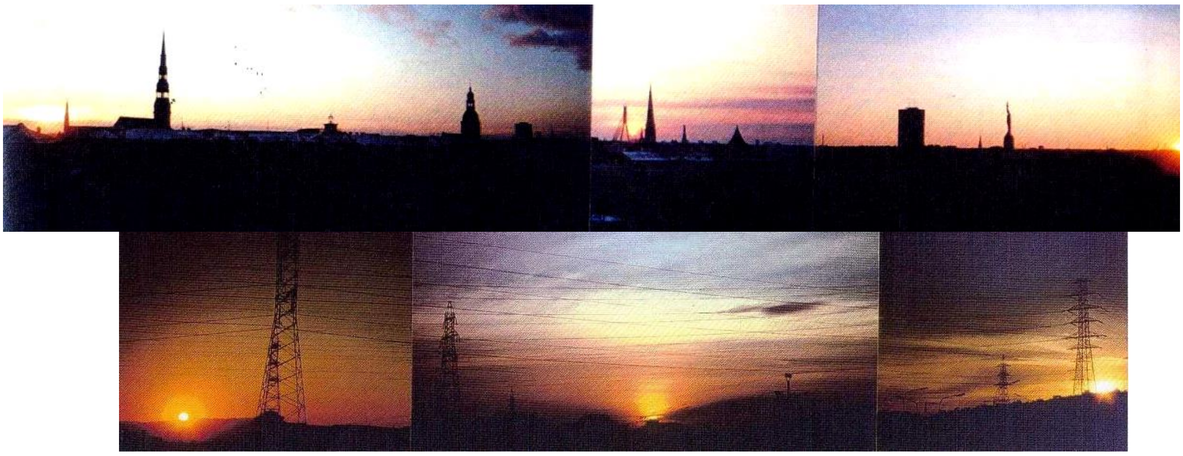

Fig. 18a y 18b: Sunsets in Riga (Latvia) and Barcelona (Spain) the first day of each season (left/winter, center/spring or autumn, right/summer). The central sunsets in both photos are on the same line. It is easy to observe that the summer and winter sunsets in Riga (higher latitude) are much more separated than in Barcelona (Photos: Ilgonis Vilks, Latvia and Rosa M. Ros, Spain).

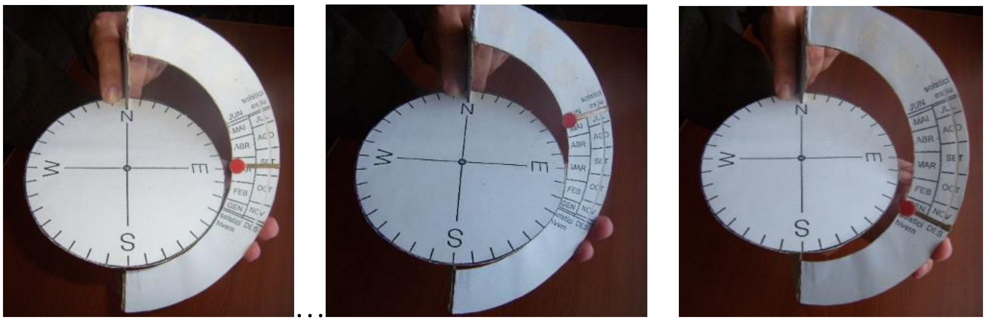

Fig. 19a: Sunrises on the first day of 1st day of spring or autumn, Fig. 19b: Sunrises on the first day 1st day of summer, Fig. 19c: Sunrises on the first day of 1st day of winter

This is very simple to simulate using the demonstrator. Just mark the position of the Sun in each season for two different latitudes, for instance 60º and 40º (figure 19a, 19b y 19c).

The illustrations in figures 18 and 19 are for the Northern Hemisphere, but the same concepts hold for the Southern Hemisphere (figure 20a y 20b). The only difference is the timing of the seasons.

Fig. 20a and 20b: Sunsets in La Paz (Bolivia) and Esquel (Argentina) the first day of each season (left/summer, centre/spring and autumn, right/winter). The central sunsets in both photos are on the same line, it is easy to observe that the summer and winter sunsets in Esquel (higher latitude) are much more separate than in La Paz (Photos: Juan Carlos Martínez, Colombia and Nestor Camino, Argentina).

Remarks:
The Sun does not rise exactly in the East and does not set exactly in the West. Although this is a generally accepted idea, it is not really true. It only occurs on two days every year: the 1st day of spring and the 1st day of autumn at all latitudes.

Another interesting fact is that the Sun crosses the meridian (the imaginary line that goes from the North Pole to the zenith to the South Pole) at midday at all latitudes (in solar time). This can be used for orientation.

2. - Polar regions: MIDNIGHT SUN

- ***Polar summer and polar winter***

If we introduce the polar latitude in the demonstrator (90º N or 90º S depending on the pole under consideration) there are three possibilities. If the Sun declination is 0º, the Sun is moving along the horizon, which is also the equator.

If the declination coincides with the 1st day of summer, the Sun moves parallel to the horizon. In fact the Sun always moves parallel to the horizon from the second day of spring until the last day of summer. That means half a year of sunlight.

On the 1st day of autumn the Sun again moves along the horizon. But beginning on the second day of the autumn until the last day of winter, the Sun moves parallel to the horizon but below it. That means half a year of night.

Of course the above example is the most extreme situation. There are some northern latitudes where the Sun's path is not parallel to the horizon. At these latitudes there are still no sunrises or sunsets because the local latitude is too high. In these cases we can observe what is known as "the midnight Sun".

- ***Midnight Sun***

If we select on the demonstrator the latitude 70º N (or 70º S depending on the hemisphere under consideration), we can simulate the concept of the midnight sun. If we put the Sun on the 1st day of summer, the 21st of June, in the Northern Hemisphere (or the 21st of December in the Southern Hemisphere), we can see that the Sun does not rise and set on this day. The Sun's path is tangential to the horizon, but never below it. This phenomenon is known as the midnight Sun, because the Sun is up at midnight (figure 21a and 21b).

Fig. 21a and 22b: Path of the midnight Sun in Lapland (Finland). The Sun approaches the horizon but does not set. Rather, it begins to climb again (Photo: Sakari Ekko).

At the poles (90º N or 90º S) the Sun appears on the horizon for half a year and below the horizon for another half a year. It is very easy to illustrate this situation using the demonstrator (figure 22a and 22b).

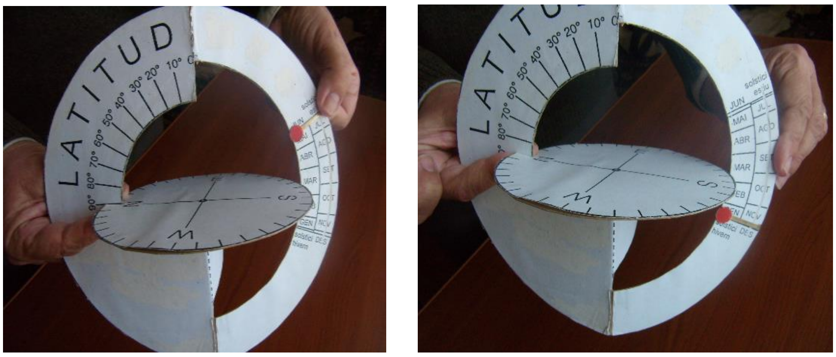

Fig. 22a and 22b: The demonstrator showing the Sun over the horizon for half a year and below the horizon for a half a year.

3. - Equatorial areas: THE SUN AT THE ZENITH

- ***The Sun at the zenith***

In equatorial areas, the four seasons are not very distinct. The Sun’s path is practically perpendicular to the horizon and the solar height is practically the same during the whole year. The length of the days is also very similar (figures 23a, 23b and 23c).

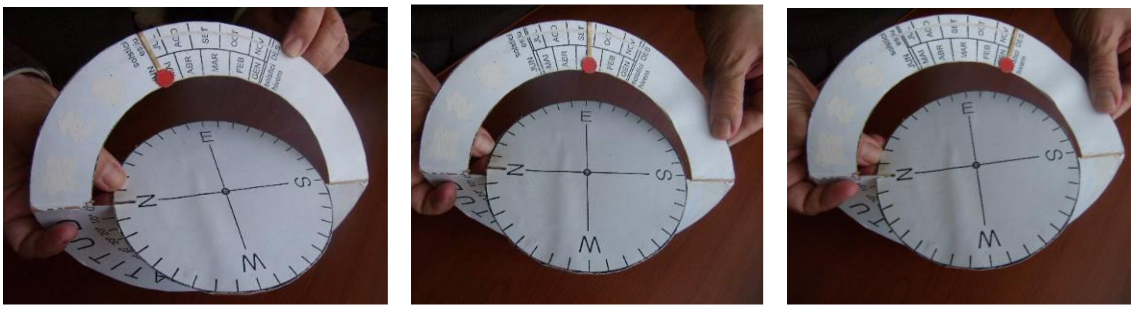

Fig. 23a, 23b and 23c: The Sun rises on the first day of each season: left - 1st day of summer, center - 1st day of spring or autumn, and right - 1st day of winter (in the Northern Hemisphere). On the equator the Sun’s path is perpendicular to the horizon. The Sun rises at almost the same point every season. The angular distances between sunrises are only 23.5º (the ecliptic obliquity). In more extreme latitudes the Sun’s path is more inclined and the distances between the three sunrise points increase (figures 17 and 19).

Moreover, in tropical countries there are some special days: the days when the Sun passes at the zenith. On these days, sunlight hits the Earth’s surface at the equator perpendicularly. Because of this, the temperature is hotter and people’s shadows disappear under their shoes (figure 24a). In some ancient cultures these days were considered to be very special because the phenomenon was very easy to observe. This is still the case now. In fact, there are two days per year when the Sun is at the zenith for those living between the Tropic of Cancer and the Tropic of Capricorn. We can illustrate this phenomenon using the demonstrator. It is also possible to approximately calculate the dates, which depend on the latitude (figure 24b).

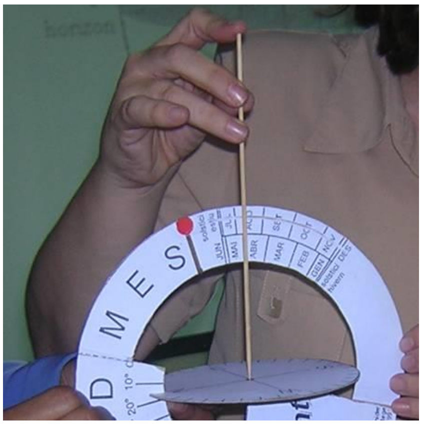

Fig. 24a: Small shadow (the Sun is almost at the zenith in a place near the equator). Fig. 24b: Simulating the Sun at the Zenith in Honduras (latitude 15º N).

For example (figure 24b), if we select a latitude of 15º N, using the demonstrator we can calculate approximately on what days the Sun is at the zenith at midday. It is only necessary to hold a stick perpendicular to the horizon disc and we see that these days are at the end of April and in the middle of August.

XXL demonstrators

Naturally, the demonstrator can be made with other materials, for instance wood (figure 25a). In this case a light source can be introduced to show the Sun's position. With a camera, using a long exposure time, it is possible to visualize the Sun's path (figure 25b).

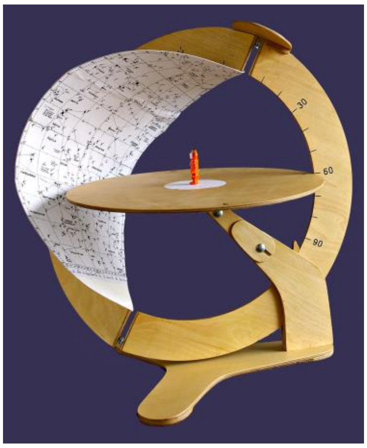

Fig. 25a: XXL wooden demonstrator. Fig. 25b: Stellar wooden demonstrator. Fig. 25c: With a camera it is possible to photograph the solar path using a large exposure time. (Photos: Sakari Ekko).

Lunar demonstrator: why the Moon smiles in some places?

When teaching students about the Moon, we would like them to understand why the moon has phases. Also, students should understand how and why eclipses happen. Moon phases are very spectacular and it is easy to explain them by means of a ball and a light source.

Models such as those in figure 26 provide an image of the crescent Moon and sequential changes. There is a rule of thumb that says the crescent Moon is a "C" and waning as a "D". This is true for the inhabitants of the Southern Hemisphere, but it is useless in the northern hemisphere where they say that Luna is a "liar".

Our model will simulate the Moon's phases (figure 26), and will show why the moon looks like a "C" or a "D" depending on the phase. Many times, the Moon is observed at the horizon as shown in figure 27. However, depending on the country, it is possible to observe the Moon as an inclined "C", an inclined "D" (figure 28a) or in other cases as a "U" (called a "smiling Moon"; figure 28b). How can we explain this? We will use the lunar demonstrator to understand the varying appearance of the Moon's quarter at different latitudes.

Fig. 26: Moon phases.

Fig. 27: Moon phases observed at the horizon.

If we study the movements of the Moon, we must also consider its position relative to the Sun (which is the cause of its phases) and its declination (since it also changes every day, and more rapidly than the Sun.) We must therefore build a demonstrator that gives students the ability to easily change the position of the moon relative to the Sun and at a declination that varies considerably over a month. Indeed, as seen from Earth against the background stars, the Moon describes a trajectory in a month rather close to that of the Sun in one year, in line with the "ecliptic" (but titled about 5 ° due to the inclination of its orbit).

The Moon is in the direction of the Sun when there is a “New Moon”. When there is a “Full Moon”, it is at a point opposite of the ecliptic, and its declination is opposite to that of the Sun (within 5 degrees north or south). For example, at the June solstice, the “Full Moon” is at the position where the Sun is during the December solstice; its declination is negative (between -18º and -29º). The diurnal motion of the full moon in June is similar to that of the Sun in December.

If we consider the crescent-shaped "D" in the northern hemisphere (and "C" in the Southern), we know that the Moon is 90° relative to the Sun. However, it is “far” from the sun on the ecliptic path (about three months’ difference). In June, the crescent moon will have a declination close to the declination of the Sun in September (0°). In the month of September, it will have a declination close to that of the Sun in December (-23.5°), etc...

Fig. 28a: Slanting crescent Moon, Fig. 28b: Smiling Moon.

Making the demonstrator

The lunar demonstrator is made the same way as the solar demonstrator. As before, we need a model to simulate the observations from the Northern Hemisphere, and one for the Southern Hemisphere (figures 12 and 13 for the Northern Hemisphere and 12 and 14 for the Southern Hemisphere). It is also a good idea to build one that is two times larger for use by the teacher.

Facilities such as solar simulator on a waning moon (in the form of "C" for the northern hemisphere, or in the form of "D" for the southern hemisphere) in place of the sun and get a lunar simulator. According to the instructions below.

In order to put the Moon in the demonstrator, cut out figure 29b (quarter Moon) and glue two pieces of sticky tape on and under the cut-out of the Moon (blue half-dot). Place this transparent strip on the area of the demonstrator where the months are specified (figures 12 or 14 depending on the hemisphere). The idea is that it will be easy to move this strip up and down in this area in order to situate it on the month of choice.

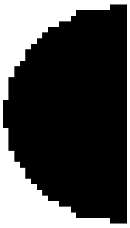

Fig. 29a: Using the demonstrator, Fig.29b: the Moon in the transparent strip Moon quarter.

Uses of the lunar demonstrator

To use the demonstrator you have to select latitude. We will travel over the Earth's surface on an imaginary trip using the demonstrator.

Using your left hand, hold the main piece of the demonstrator (figure 30) by the blank area (below the latitude quadrant). Select the latitude and move the horizon disc until it shows the chosen latitude. Choose the day for which you want to simulate the movement of a waning moon. Add three months to that value and put the moon in the fourth phase (figure 29b). The month that the moon is facing is where the sun will be in three months. Use your right hand to move the disk that holds the moon from east to west.

With the simulator for the Northern Hemisphere, you can see that the appearance of the fourth quarter of the moon changes with the latitude and time of year. From the doll's perspective, the waning fourth quarter moon can appear as a "C" or a "U" on the horizon.

- If we select latitude around 70º N or 70º S we can see the quarter Moon as a "C" moving from East to West. The time of year does not matter. For all seasons the Moon looks like a "C" (figure 30a).
- If the latitude is 20º N or 20º S, the observer is close to the tropics, and we can see the quarter Moon smiling like a "U". The Moon moves following a line more perpendicular to the horizon than in the previous example (figure 30b). The "U" shape does not change with the month. It looks like this all year round.
- If the latitude is 90º N or 90º S, the observer is at the Poles, and depending on the day considered:
    -We can see the quarter Moon as a "C" moving on a path parallel to the horizon.
    -We can't see it, because its trajectory is below the horizon.

- If the latitude is 0º, the observer is on the equator, and we can see the quarter Moon smiling as a “U”. The Moon rises and sets perpendicularly to the horizon. It will hide (at midday) in “U” shape, and will return like this: “∩”

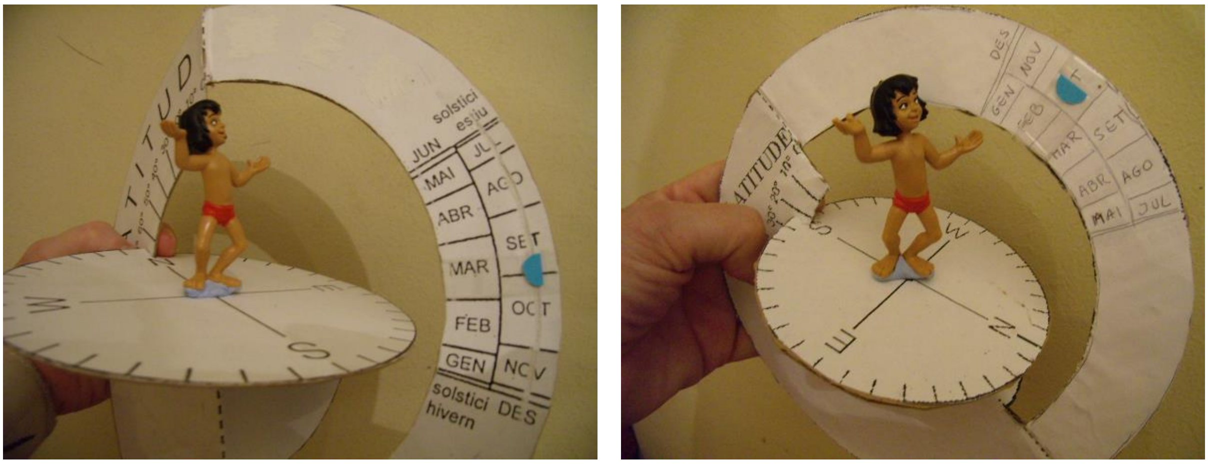

Fig. 30a: Demonstrator for latitude 70º N, Fig. 30b: latitude 20º S.

For other observers who live at intermediate latitudes, the quarter Moon rises and sets more or less at an angle, and has an intermediate shape between a “C” and a “U”.

The above comments apply similarly for the moon in a "D" shape. Again, we have to remember to correct the day (in this case we will have to take off three months) when we put in the position of the Sun.

- If we introduce a -70° latitude (or 70° south) we can see the waning moon as a "D" that moves from east to west. This does not depend on the time of year. In all seasons the Moon appears as a "D" (figure 30a).

- If the latitude is -20° (figure 30b) the observer is in the tropics and sees the Moon smiling like a "U", possibly slightly tilted. The Moon moves in a trajectory perpendicular to the horizon unlike in the previous example (figure 30b). The shape of "U" does not change depending on the month.

- If the latitude is - 90°, the observer is at the South Pole and, according to the date, will be able to:
  - -View the Moon as a "D" that moves in a path parallel to horizon.
  - - Not see the Moon, because its path is below the horizon.

- At latitude 0°, as in the simulator of the Northern Hemisphere, the observer is at the Equator, and we can see the smile of the moon as a "U". The moon rises perpendicular to the horizon and it will hide (around noon) in a "U" and reappear as “∩”.

For other observers who live in middle latitudes, the phase of the Moon rises and sets in an intermediate position between a "D" and a "U", and is more or less inclined to match the latitude of observation.

These comments can be applied in a similar way to when the Moon appears as a "C", again subtracting three months from the Sun's position.

“Acknowledgement: The authors wish to thank Joseph Snider for his solar device produced in 1992 which inspired her to produce other demonstrators.”

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Solar Spectrum and Sunspots

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Summary

This workshop includes a theoretical approach to the spectrum of sunlight that can be used in high school. The activities are appropriate for primary and secondary levels.

The Sun is the main source of almost all wavelengths of radiation. However, our atmosphere has high absorption of several non-visible wavelengths so we will only consider experiments related to the visible spectrum, which is the part of the spectrum that is present in the daily lives of students. For the activities in non-visible wavelengths, see the corresponding workshop.

First we will present the theoretical background followed by experimental demonstrations of all the concepts developed. These activities are simple experiments that teachers can reproduce in the classroom, introducing topics such as polarization, extinction, blackbody radiation, the continuous spectrum, the emission spectrum, the absorption spectrum (e.g. sunlight) and Fraunhofer lines.

We also discuss differences between the areas of regular solar output and the emission of sunspots. Additionally, we mention the evidence of solar rotation and how this concept can be used for school projects.

Goals

- To understand what the Sun's spectrum is.
- Understand the spectrum of sunlight.
- Understand what sunspots are.
- Understand the historical significance of sunspots and of Galileo's work on the rotation of the Sun.
- Understand some characteristics of the light such as polarization, dispersion, etc

Solar Radiation

Solar energy is created inside the Sun in a region called the core where the temperature reaches 15 million degrees and the pressure is very high. The conditions of pressure and temperature in the core usually allow nuclear reactions to occur. In the main nuclear reaction that occurs in the core of the Sun, four protons (hydrogen nuclei) are transformed into alpha particles (helium nuclei) and generate two positrons, two neutrinos and two gamma photons according to the equation:

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

The resulting mass is less than that of the four protons added together. The mass that is lost, according to the following equation discovered by Einstein, is transformed into energy:

$$E = mc^2$$

Every second 600 million tons of hydrogen are transformed into helium, but there is a loss of 4 to 5 million tons which is converted into energy. While this may seem a very large loss, the Sun's mass is such that it can work like this for billions of years. The energy produced in the core will follow a long journey to reach the surface of the Sun.

The energy produced in the interior of the Sun will follow a long route to reach the Sun's surface.

After being emitted by the Sun, energy propagates through space at a speed of 299,793 km / s in the form of electromagnetic radiation.

Electromagnetic radiation has wavelengths or frequencies which are usually grouped in different regions as shown in figure 1.

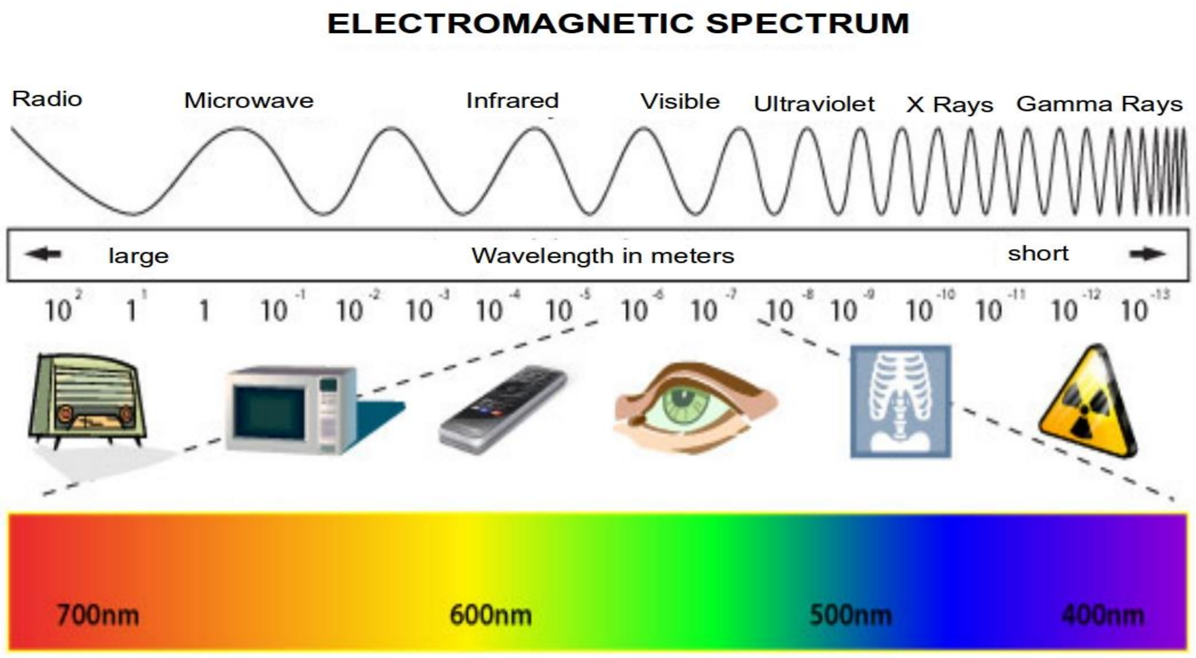


Fig. 1: Solar Spectrum

The frequency ν, wavelength λ and the speed of light are related by the expression

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

Although the Sun is a major source of many wavelengths of light, we'll make most of our approach to solar radiation using the visible spectrum. Except for radio frequencies and small bands in the infrared or ultraviolet, wavelengths of visible light are those to which our atmosphere is transparent (figure 3) and we do not need sophisticated equipment to view them. Therefore, they are the best for experimentation in the classroom.

Polarization of Light

Perfect electromagnetic radiation, linearly polarized, has a profile like that shown in figure 2.

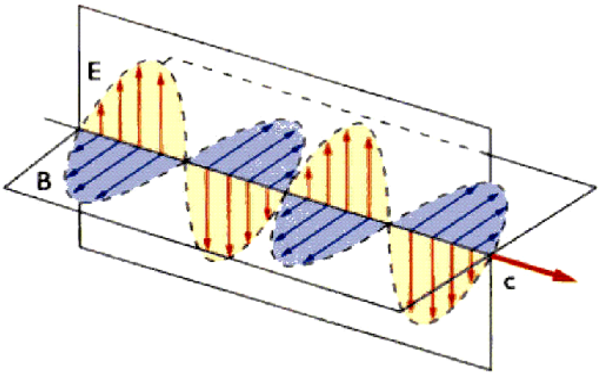


Fig. 2: Polarized light.

Sunlight has no privileged direction of vibration, but can be polarized when reflected under a determined angle, or if it passes through certain filters called polarizers.

The light passing through one of these filters (figure 3), vibrates only in one plane. If you add a second filter, two things can happen: when the two filters have parallel polarization orientation, light passes through both of them (figure 4a), but if they have perpendicular polarization, light passing through the first filter is blocked by second one (figure 3) and the filters become opaque (figure 4b).

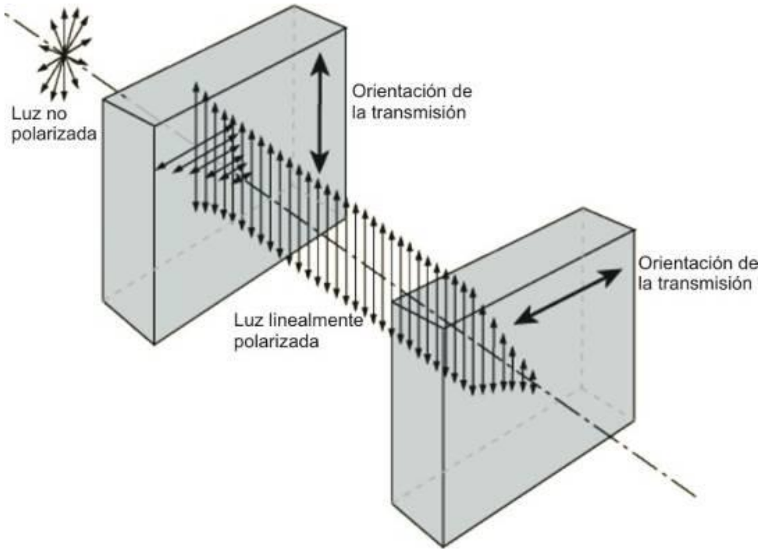
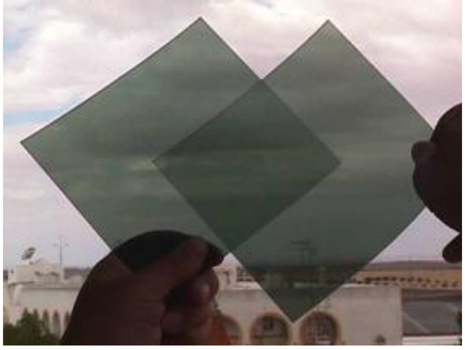


Fig. 3: When two filters have a perpendicular transmition orientation, the light which passes through the first is blocked by the second.



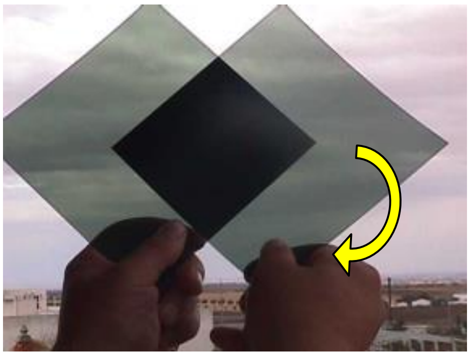


Fig. 4a: If the filters have the same orientation, light passes through, Fig. 4b: If one of the filters is turned 90º, light is blocked.

Many sunglasses are polarized to filter reflected light, abundant in the snow or on the sea, which is usually polarized (figures 5a and 5b). Polarizing filters are also used in photography, and with them reflections are eliminated and the sky appears darker.

Fig. 5a and 5b: Reflected light, photographed with and without a polarizing filter.

Most 3D cinema systems record the film with two cameras, separated by the distance between human eyes. Then, in cinemas, they are shown with two projectors using polarized light in perpendicular directions. Viewers wear special glasses that have various polarizing filters with perpendicular directions. This means that each eye sees only one of the two images, and the viewer sees the images in 3D.

Activity 1: Polarization of Light

In order to make polarizing filters, cut the bridge of the nose of colorless 3D glasses to create two pieces (green / red glasses cannot be used in this activity) so you can do the activity in figures 4a and 4b. You can also take two pairs of sunglasses or 3D glasses and orient them to show the polarization so that you don't have to break them into two pieces.

Many sunglasses have polarization to filter the light and LCD computer screens and televisions (not plasma) emit light that is polarized. You can check both by looking at the screen of a laptop with sunglasses on and turning your head: if they are polarized, viewing at a specific angle will make the screen black.

There are some plastics and glasses that will affect polarized light passed through it, according to their thickness and composition. If you look at them with polarized sunglasses, you will see different colored light.

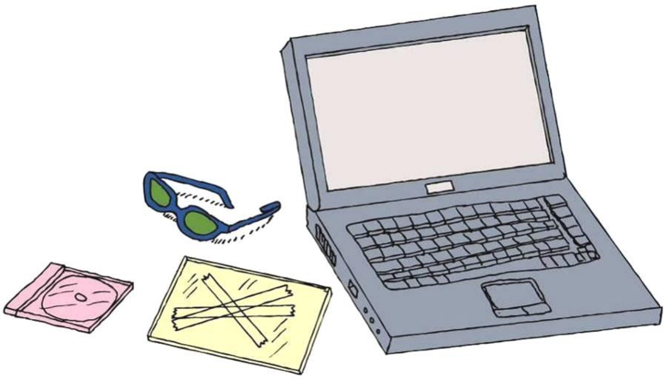


Fig. 6: The light from the TFT screen of a computer is polarized, and the tape rotates the polarization angle. Colors are seen when viewed with polarized sunglasses.

Stick several strips of tape on a piece of glass (such as from a photo frame) so that in some areas three layers of tape overlap each other, in other areas two pieces overlap and in other areas there is only one piece (figure 6). On a television or computer with LCD screen, display an image that has white as the main color, for example, a blank document in a word processor. Place the glass in front of the screen and look with polarized sunglasses. If you turn the glass, you will see the tape appear different colors. Instead of glass you can use a clear plastic CD case. You will see the points where more tension concentrated in the plastic. If you bend the plastic, you will see color changes in the plastic when viewed with the polarized light and filters.

The Structure of the Sun at a Glance

The Sun has a structure that can be divided into five main parts:

1) The core and the radiative zone are the areas where the thermonuclear fusion reactions are produced. Temperatures inside the core are 15 million Kelvin (K) and a bit lower in the radiative zone, which are about 8,000,000 K. Energy is transferred by radiation through the region closest to the core. They could be considered two distinct regions (the core and radiative zone) but it is very difficult to tell where one ends and where another begins because their functions are mixed.
2) The convection zone is where energy is transported by convection and has temperatures below 500 000 K. It lies between 0.3 solar radius and just below the photosphere.
3) The photosphere, which we can somehow consider as the "surface" of the Sun, is the source of the absorption and continuous spectra. It has temperatures ranging from 6400 to 4200 K. It is fragmented into cells of about 1000 km in size, which last only a few hours. In addition, it normally has some colder areas ("only" 4,200 K), which look like dark spots.

4) The chromosphere, which lays outside the photosphere and has a temperature between 4,200 to 1 million K. It looks like vertical filaments that resemble a "burning prairie", with prominences (bumps) and flares.
5) The corona, which is the source of the solar wind, has temperatures between one and two million K.

Activity 2: Simple model of Sun layers

This activity can be done with young children. The goal is to cut out the different figures below (figures 7 and 8). They can be cut from different colored pieces of paper or be painted with the following colors: corona in white, chromosphere in red, photosphere in yellow, convection zone in orange, radiative zone in blue and the core in maroon.

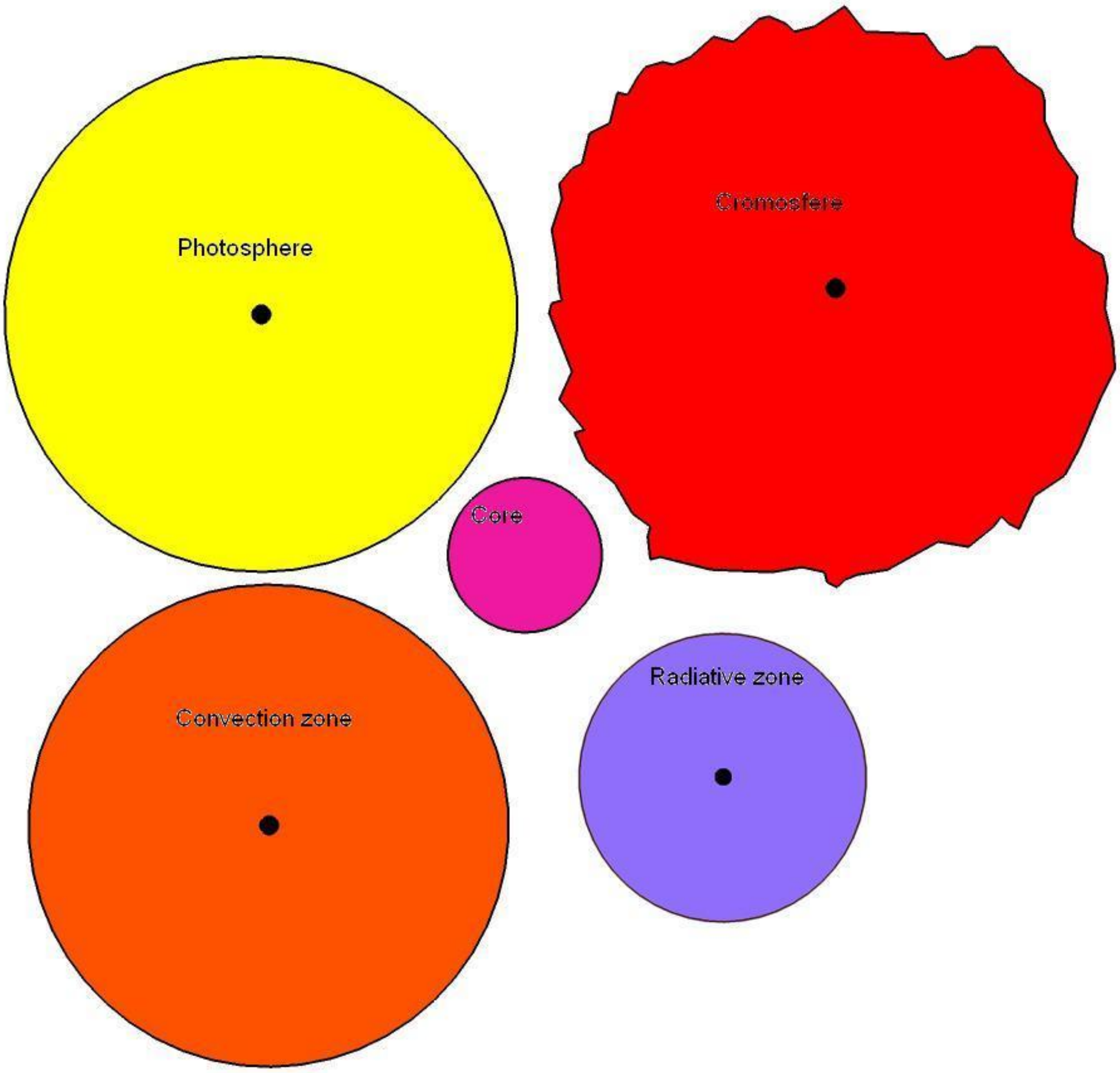


Fig. 7: Sun's parts to cut out.

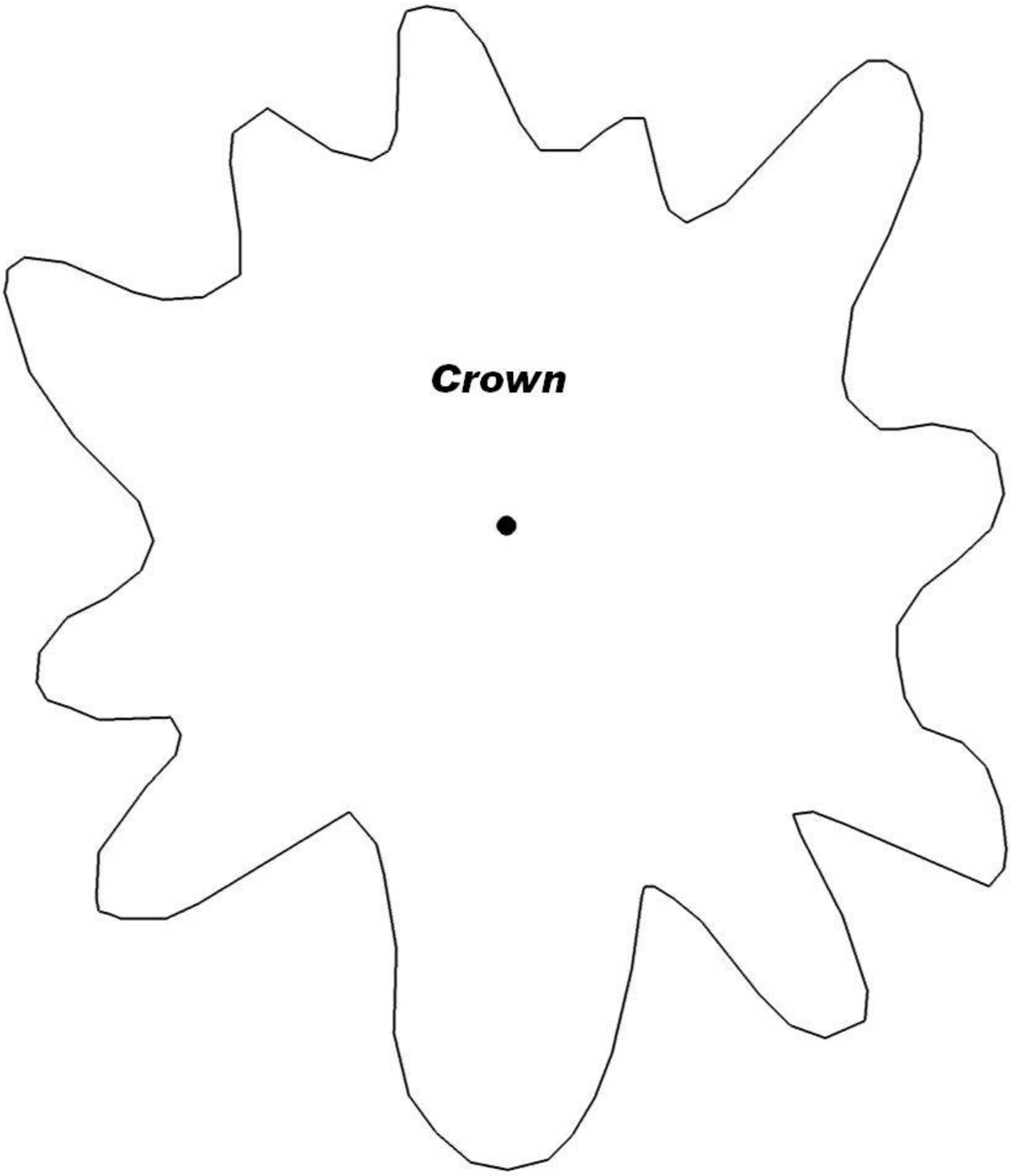


Fig. 8: Corona to cut out.

Finally you can paste one above each other; in the right order (the size of each piece also indicates the order).

Sunspots

Frequently, dark spots, called sunspots, are observed in the photosphere. A sunspot typically consists of a dark central region called the umbra, surrounded by an area of bright and dark filaments which radiate out from the umbra.

The filaments of sunspots are surrounded by the typical granules of the photosphere (figure 9).

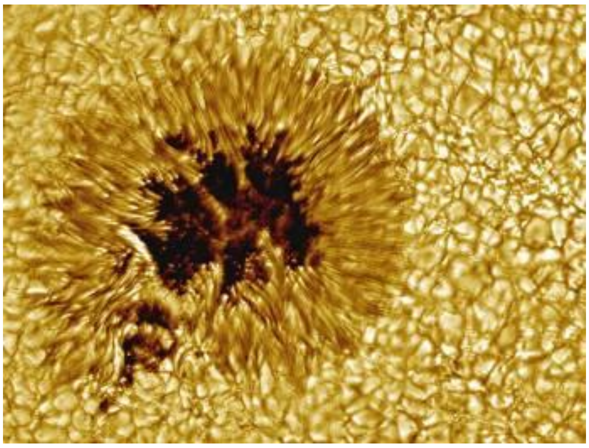


Fig. 9: Close-up of a sunspot. (Photo: Vacuum Tower Telescope, NSO, NOAO)

The spots appear black with a small telescope, but that is only a contrast effect. If you could observe the spot in isolation, it would actually be brighter than the full moon. The difference in intensity of the spots is because the spot’s temperature is 500 to 2,000° C lower than the surrounding photosphere. Sunspots are the result of the interaction of strong vertical magnetic fields with the photosphere.

Sunspots have a great historical importance as they allowed Galileo Galilei to determine the Sun's rotation period and verify that its rotation was differential, i.e., spinning faster at the equator (rotation period 25.05 days) than at the poles (34.3 days rotational period).

Activity 3: Determination of the rotation period of the Sun

A simple experiment you can perform in the classroom is to measure the period of solar rotation using sunspots. In this experiment, you must keep track of sunspots for several days in order to measure the Sun’s rotation. The solar observations should always be done by projection through a telescope (figure 10a), or binoculars (figure 10b). We can never stress enough that one should never look at the Sun directly and even less so with binoculars or telescopes, since it can cause permanent damage to the eyes.

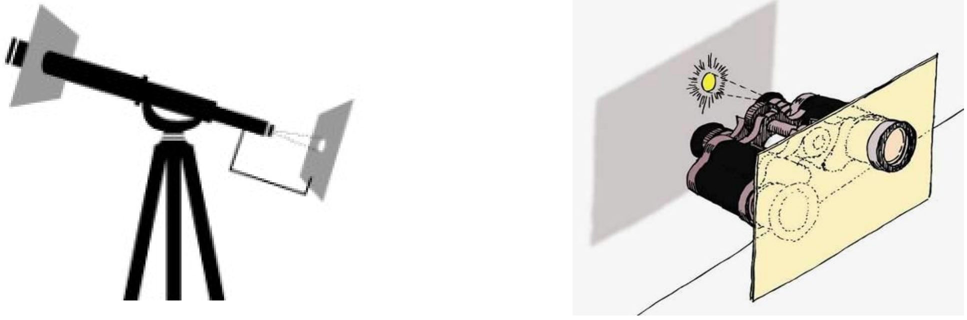


Fig. 10a: Solar observation by projection with a telescope (never look directly at the Sun), Fig. 10b: Observation by projection with binoculars (never look directly at the Sun).

Remember you should never look directly at the sun with the unaided eye, binoculars or telescopes because it can cause irreparable damage to the eyes.

If you observe sunspots for several days, the movement of a spot will look like the example in figure 11.

Fig. 11: Change of position of a sunspot over several days.

Superimpose the observations on a transparency as shown in figure 12. The period may then be calculated simply through a simple proportion:

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

Where t indicates the time interval between two observations of the same sunspot, α is the central angle between the displacement of the two spots considered (figure 12) and P is the solar rotation period we want calculate. This calculation gives a good level of accuracy.

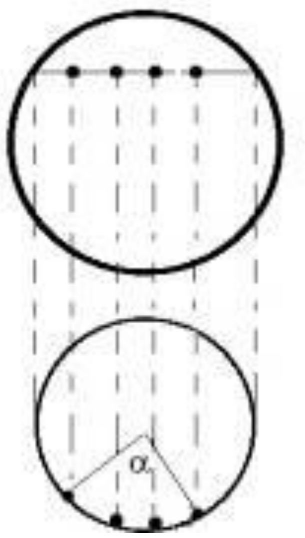


Fig. 12: Calculation of the angular rotation of sunspots.

Here is an actual example: figure 13 is a superposition of two photographs, taken on August 12th, 1999 and the 19th of that same month and year. We draw the circle for the Sun and mark a line from the center to each of the spots. We then measure the angle between the two lines and we get 92 º. Therefore the solar rotation will be:

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

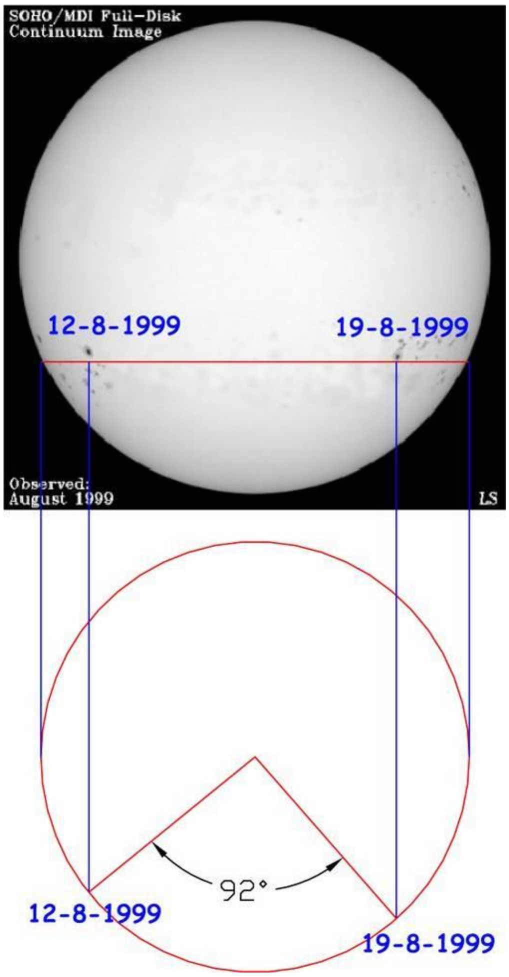


Fig. 13: Determination of solar rotation period.

The radiation coming from the Sun

The Sun is a large nuclear reactor where huge amounts of energy are continuously produced and transported to the surface in the form of photons. Photons are the particles responsible for electromagnetic radiation and the amount of energy they carried can be calculated by the expression

$$E = h \cdot v$$

where E is the photon energy, h is Planck's constant ($h = 6{,}626 \cdot 10^{-34}\ J \cdot s$) and v the frequency of electromagnetic radiation associated with the photon. The photons generated by the Sun are responsible for its spectrum.

The total luminosity (or power) of the Sun is enormous: every second it emits more energy than trillions of atomic bombs. We can imagine the transmission of that energy through space as a bubble that becomes bigger and bigger with distance. The area of this bubble is $4\pi R^2$. If the power of the sun is P, the energy reaching a square meter at a distance R is:

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

In other words, energy is transmitted as an inverse square of the distance. And if we know the distance of the object, we can calculate its total power.

Activity 4 : Determination of Solar Luminosity

The luminosity, or power, of the sun is the energy emitted by it in a second. And the sun really is a very powerful light source. Let us calculate its power compared with a 100 W bulb (figure 14).

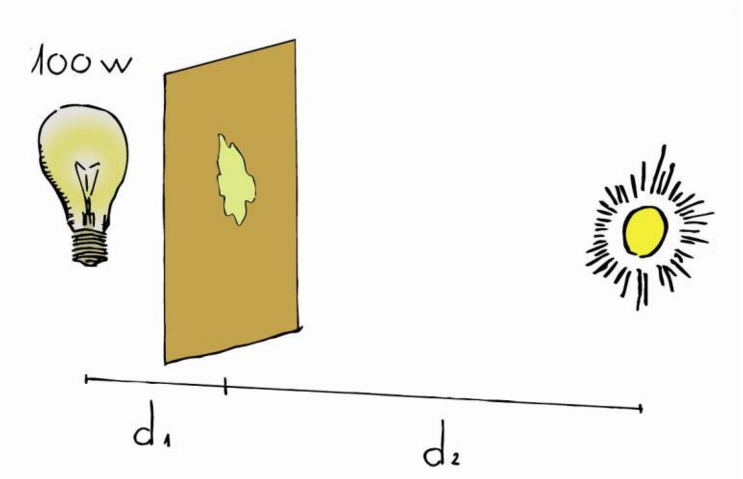


Fig. 14: Comparison between the Sun's power and a 100W light bulb.

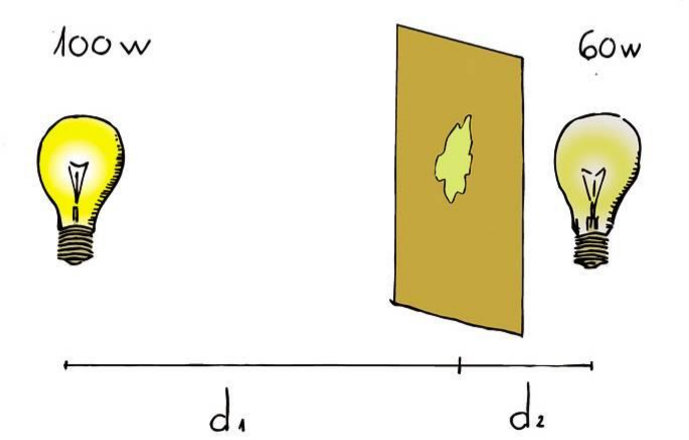


Fig. 15: If the light that reaches each side is the same, the oil slick is not seen.

We can build a photometer that will allow us to compare the brightness of two light sources. To do this, put a couple of drops of oil in the middle of a sheet of wrapping paper (plain white paper will work too). The stain that forms makes the paper a bit transparent and this will be our photometer. By putting it between two light sources (figures 14 to 16), the distance can be adjusted until we cannot see the stain. Aligned this way, the lighting on either side of the paper and the energy arriving at each side is equal.

In this case:

$$\frac{100}{4 \cdot \pi \cdot d_1^2} = \frac{60}{4 \cdot \pi \cdot d_2^2}$$

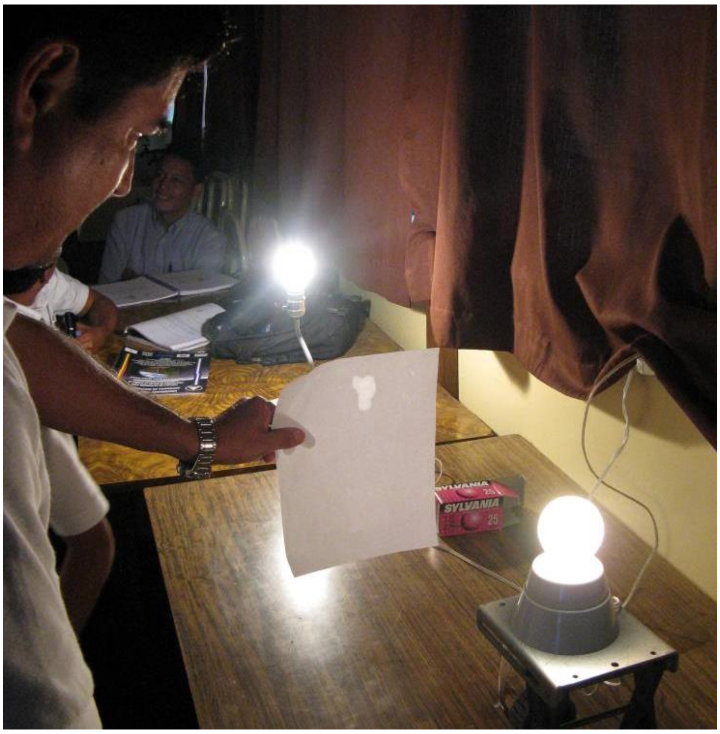


Fig. 16: Oil slick photometer, between two light bulbs.

On a sunny day, take the photometer outdoors with a light bulb of at least 100 W (brighter is better). Put the photometer between the sun and the light bulb at a distance such that the two sides of the photometer appear equally bright. Measured the distance d1, in meters, from the photometer to the filament of the light bulb.

Knowing that the distance from the Sun to Earth is approximately d_2 = 150,000,000 km, we can calculate the power of the Sun P with the inverse square law (the term 4π is cancelled out because it is on both sides of the equation):

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

The result should be close to the actual luminosity of the Sun, which is $3.83 \cdot 10^{26}$ W.

Opacity

The energy associated with a high energy photon produced in the Sun's core will take up to 1 million years to reach the photosphere, since it is produced in the innermost parts of the Sun where photons interact with very dense matter. The interactions between the photons and the matter occur in great numbers in the core but decrease as they approach the photosphere. The photons take a zig-zag (figure 17) path from the core to the outer parts of the Sun, which can take thousands of years.

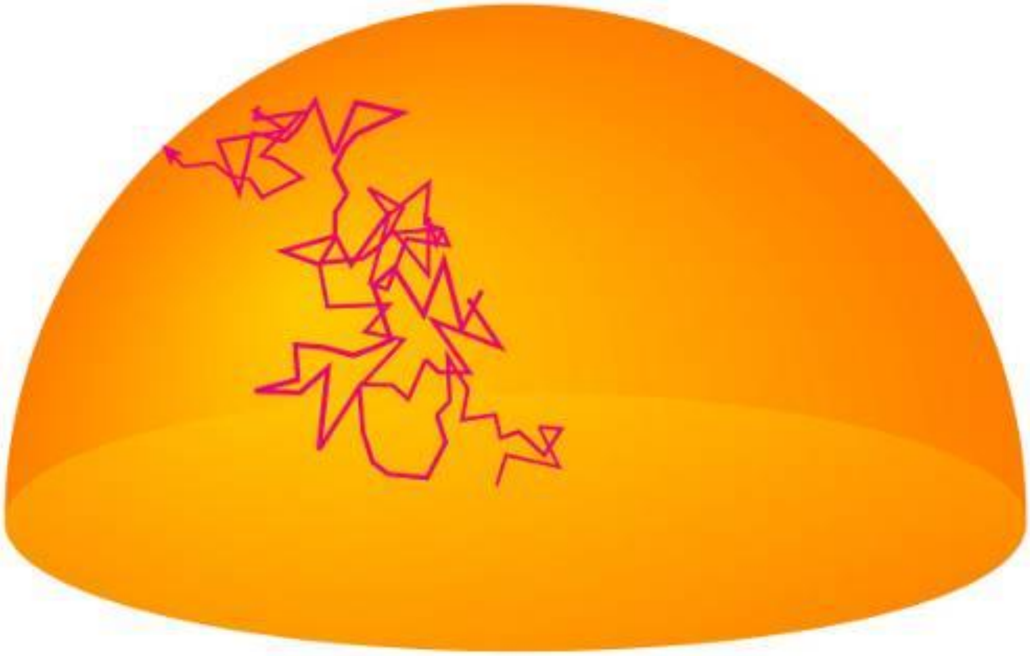


Fig. 17: Photons take 1 million years to leave the photosphere.

When radiation reaches the photosphere, and therefore the sun's atmosphere, it is radiated outward with almost no interactions and in most wavelengths, creating the continuous spectrum we see from the photosphere. That's because the core and the sun's interior is opaque to all wavelengths of radiation and its atmosphere is transparent. In astronomy, the concepts of opaque and transparent are somewhat different from everyday use.

A gas can be transparent or opaque depending on how it absorbs or scatters the photons that pass through it. For example, our atmosphere is transparent to visible wavelengths. However, on a foggy day we cannot see much, so it is opaque.

It should be pointed out that transparent does not mean invisible. A flame of a burner or candle is transparent to the wavelengths of an overhead projector.

Activity 5: Transparency and opacity

You can show these concepts using a burner or a candle (the burner is better than the candle because the candle will sometimes produce opaque black smoke due to incomplete combustion, which will be seen coming out of the candle flame).

The demonstration is very simple. Put transparent and opaque objects in the light projected onto a wall or screen by an overhead projector and ask if it is transparent or opaque. For common objects, most people will know the answer for the objects.

The flame of a candle, a Bunsen burner or a lighter is also transparent and it is surprising for students to see that the flame produces no shadow on the wall (figure 11). You can explain that this is like the Sun’s photosphere, which is nearly transparent to any radiation.

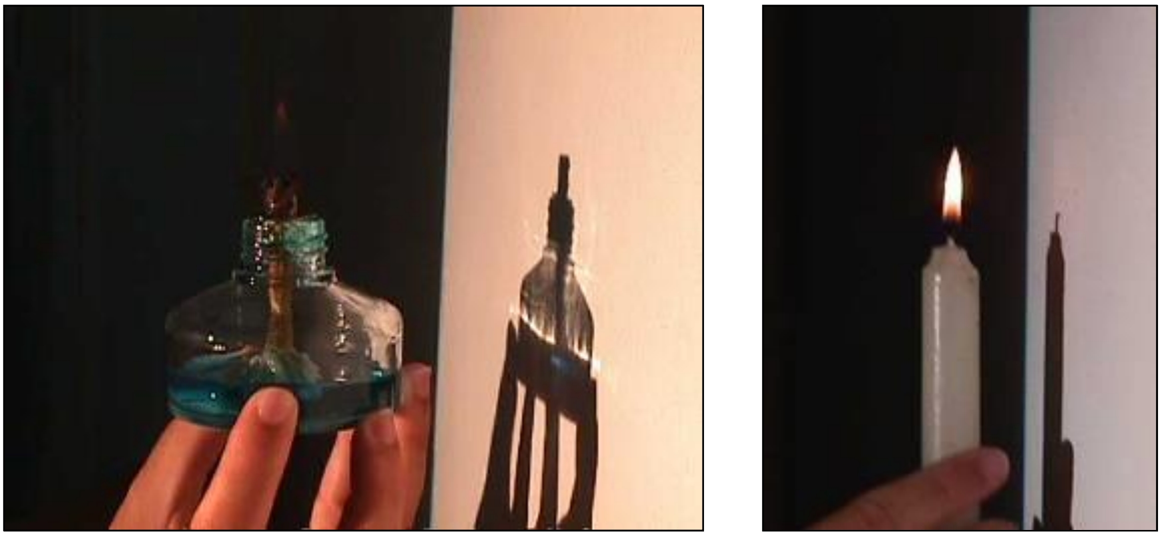


Fig. 18a and 18b: Alcohol lamp or candle flames do not produce a shadow on the wall. Observe that the glass is not completely transparent.

Spectra

In 1701, Newton used a prism for the first time to break sunlight into its component colors. Any light can be dispersed with a prism or a diffraction grating, and what you get is its spectrum. Spectra can be explained by the three laws that Gustav Kirchhoff and Robert Bunsen discovered in the nineteenth century. The three laws are represented in figure 19.

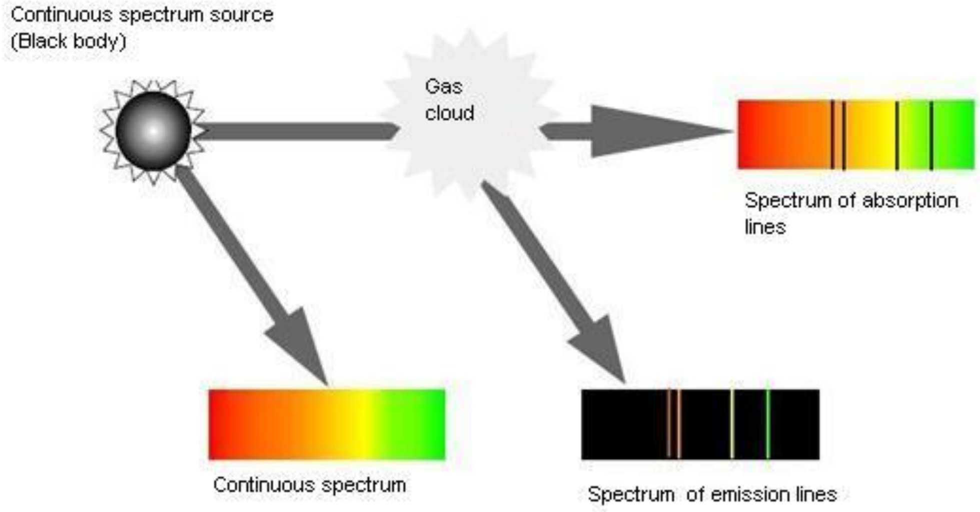


Fig. 19: Laws of Kirchhoff and Bunsen.

- 1st Law - An incandescent solid object produces light in a continuous spectrum.
- 2nd Law - A hot tenuous gas produces light with spectral lines at discrete wavelengths depending on the chemical composition of the gas (emission spectrum).
- 3rd Law - An incandescent solid object surrounded by a low pressure gas produces a continuous spectrum with gaps at discrete wavelengths whose positions depend on the chemical composition of the gas, and coincide with those of the 2nd Law (absorption spectrum).

The gas emission lines are due to electron transitions between two energy levels, which occurs when photons interact with matter. As was later explained by Niels Bohr, the energy levels in atoms are perfectly quantized and the frequencies emitted are always the same because the energy difference between levels is constant (figure 20).

A cold gas can absorb the same energy it emits when is hot. Therefore, if you put gas between an incandescent source and a spectroscope, the gas absorbs the same lines out of the continuous spectrum of the source that it emits the when the gas is hot, generating an absorption spectrum.

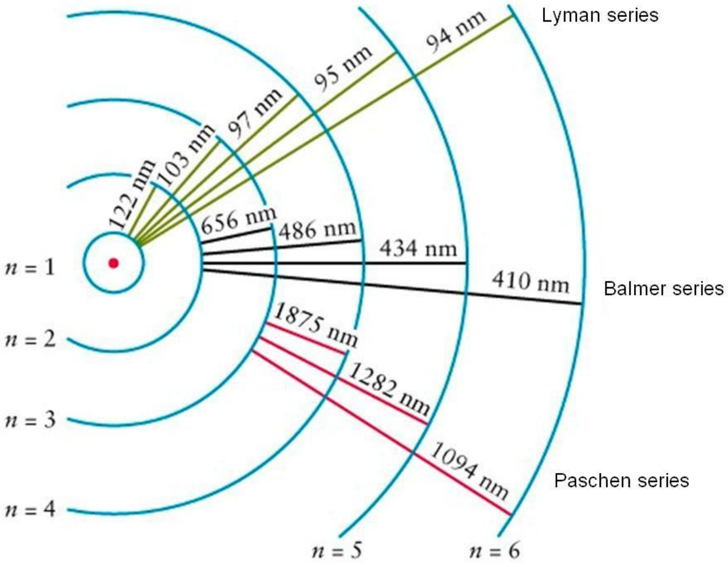


Fig.20: Spectral series for emission of the Hydrogen atom. Possible transitions always have the same amount of energy between levels.

This is what happens in the atmosphere of the Sun. The chemical elements contained in the gas of the solar atmosphere absorb the frequencies associated with the spectral lines of these elements. This fact was verified by Joseph Fraunhofer in 1814, thus the sun's spectral lines are called Fraunhofer lines and are listed in the table below, according to the original designations by Fraunhofer (1817) of letters to the absorption lines in the solar spectrum.

Letter	Wavelength (nm)	Chemical Origin	Color range
A	7593,7	O_2 atmospheric	dark red
B	6867,2	O_2 atmospherico	red
C	6562,8	Hidrogen alpha	red
D1	5895,9	Neutral Sodiumo	oranged-red
D2	5890,0	Neutral Sodium	yellow
E	5269,6	Neutra Iron	green
F	4861,3	H beta	cyian
G	4314,2	CH molecular	blue
H	3968,5	Ionized Calcium	dark violet
K	3933,7	Ionized Calcium	dark violet

Table 1: Fraunhofer' s lines for the Sun.

It is important to realize that by analyzing the light coming from the sun or a star, we know what it is made of without having to go there. Today spectra are taken with high resolution instruments to detect many lines .

Blackbody Radiation

When a metal is heated sufficiently, it becomes red. In a dark place, the metal becomes visible at a temperature of 400 °C. If the temperature continues rising, the color of the metal turns orange, yellow and even becomes blue after passing through the emission of white light at about 10,000 ° C. An opaque body metal or not, will radiate with these characteristics.

When a blackbody (an idealized object which does not reflect light) is heated, it emits radiation in many wavelengths. If we measure the intensity of that radiation at each wavelength, it can be represented by a curve called Planck curve. In figure 21, the curves are shown for for a variety of blackbody temperatures. The curve has a peak at a certain wavelength, which gives us the object's the dominant color. That λ max is related to the body's temperature according to Wien's Law:

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

where T is the temperature of the body. Note that because of this law, by studying the radiation that comes to us from a distant object, we can know its temperature with no need to go there and measure it directly.

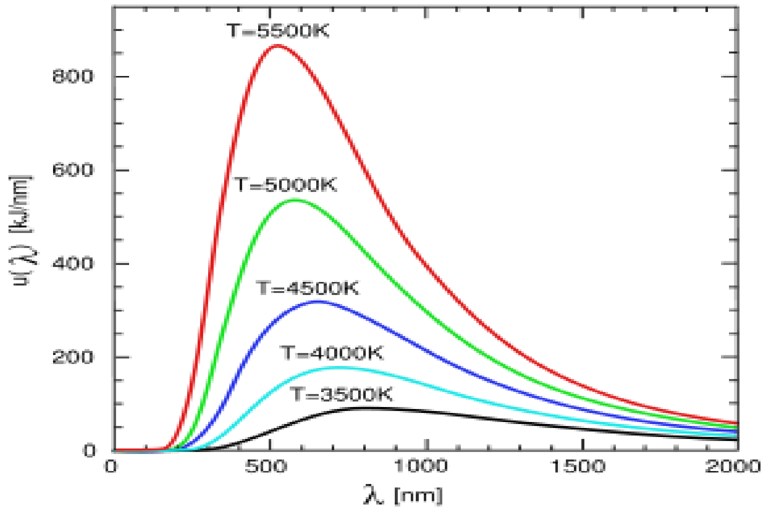


Fig. 21: Planck curves for black bodies at different temperatures.

Examples of astronomical objects that can be called opaque blackbodies are the stars (except for its atmosphere and corona), planets, asteroids or radiation from the cosmic microwave background.

Wien's Law is a general law for the thermal emission of opaque bodies. For example, the human body radiates in the infrared region with a maximum emission at a wavelength of 9.4 μm, as Wien’s law says (using a temperature of 37º C (= 310 K)). So the military uses devices for night observation in these wavelengths.

Returning to the Sun, since the atmosphere is transparent, blackbody radiation is determined by the temperature at the photosphere, where the sun becomes transparent (about 5800 K) so its blackbody radiation should not exceed a wavelength around 500 nm, as shown in figure 22.

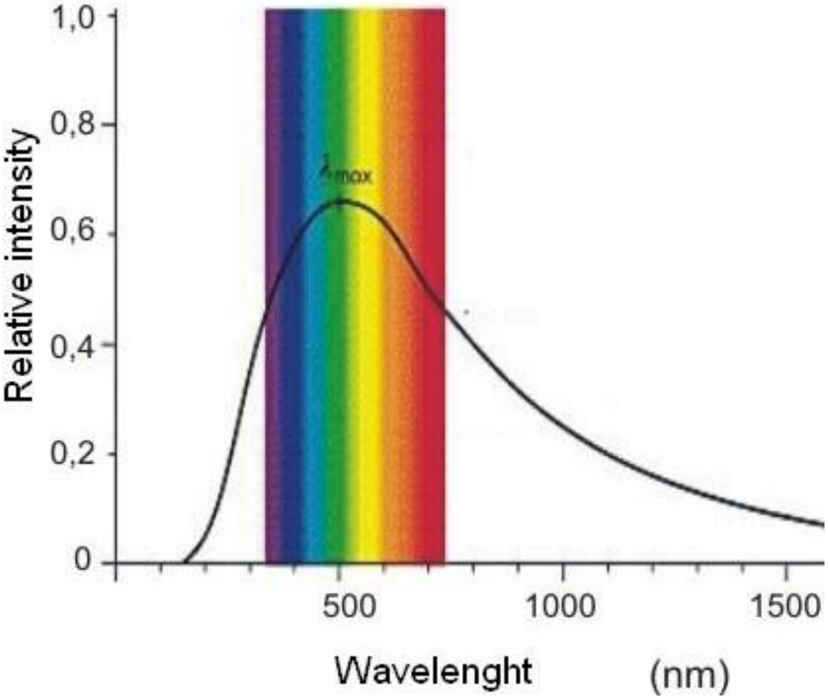


Fig. 22: Emission curve for the “continuous spectrum” of the Sun.

Our atmosphere absorbs infrared and ultraviolet radiation. Interestingly, the human eye has evolved to see just the visible portion of sunlight that reaches the Earth's surface.

Scattering of sunlight

When a beam of white light passes through a gas containing particles larger than the light's wavelength, the light does not spread and all wavelengths are scattered. This occurs when sunlight passes through a cloud containing small droplets of water: it looks white. The same thing happens when light passes through grains of salt or sugar.

But if the light is scattered by particles of similar size to the wavelength (color) of the photons, those photons are dispersed but not the rest. This is called *Rayleigh* scattering.

In our atmosphere, blue light scatters more than red light, and photons reach us from all directions. This causes us to see the sky blue (figure 23) instead of black, as seen in space. At dusk, the light passes through much more of the atmosphere and contains less blue light so it appears more yellow. Sunsets also disperse red photons.

This is also the reason that when light passes through large thicknesses of gas (e.g., nebula) it is red (because blue is going to scatter in all directions and only red is going to come in full intensity to the observer). This is the Rayleigh dispersion.

Fig. 23: The color of the sky depends on the Rayleigh scattering.

Activity 6: Extinction and scattering

This experiment is done with an overhead projector (or any other intese light source), a dilute solution of milk, a piece of black cardboard and a tall glass. Prepare a solution of milk of about 1 drop of milk in 50 ml of water (that's the most important thing, you need to test the concentration of the solution before class).

Cut a circle in the black cardboard with the shape and size of the glass bottom. Put the empty glass on the open circle and turn on the projector (figure 24a). The light reaching the wall will be white.

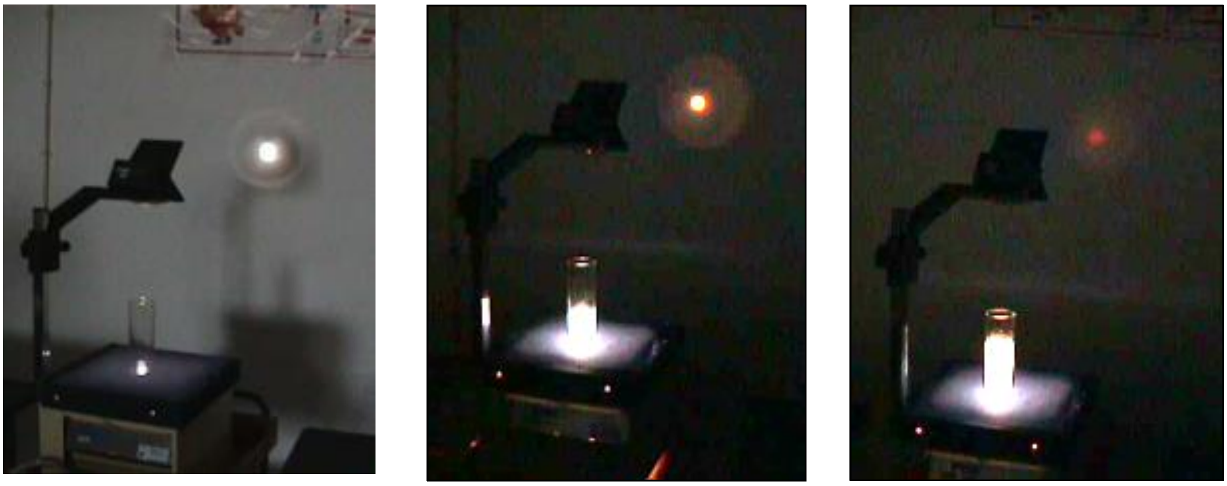


Fig. 24a: At the beginning, the light reaching the wall is white, Fig. 24b: With a bit of solution, the light will be yellow, Fig. 24c: When the glass is full, the light reaching the wall is red

Fill the glass with the dilute milk solution. The light reaching the wall is increasingly red (figures 24b and 24c). The sides of the glass show bluish-white light.

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Stellar Lives

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Summary

To understand the life of the stars it is necessary to understand what they are, how we can find out how far away they are, how they evolve and what are the differences between them. Through simple experiments, it is possible to explain to students the work done by scientists to study the composition of the stars, and also build some simple models.

Goals

This workshop complements the stellar evolution NASE course, presenting various activities and demonstrations centered on understanding stellar evolution. The main goals are to:

- Understand the difference between apparent magnitude and absolute magnitude.
- Understand the Hertzsprung-Russell diagram by making a color-magnitude diagram.
- Understand concepts such as supernova, neutron star, pulsar, and black hole.

Activity 1: The Parallax Concept

Parallax is a concept that is used to calculate distances in astronomy. We will perform a simple activity that will allow us to understand what parallax is. Face a wall at a certain distance, which has landmarks: wardrobe, tables, doors, etc. Stretch your arm in front of you, and hold your thumb vertically (figures 1a and 1b).

First close your right eye, see the example with the finger on the center of a picture. Without moving your finger, close your right eye and open the left eye. The finger moved, it no longer coincides with the center of the picture but with the edge of the box.

For this reason, when we observe the sky from two distant cities, bodies that are closer, such as the moon, are offset with respect to the background stars, which are much more distant. The shift is greater if the distance between the two places where observations are taken is farther apart. This distance is called baseline.

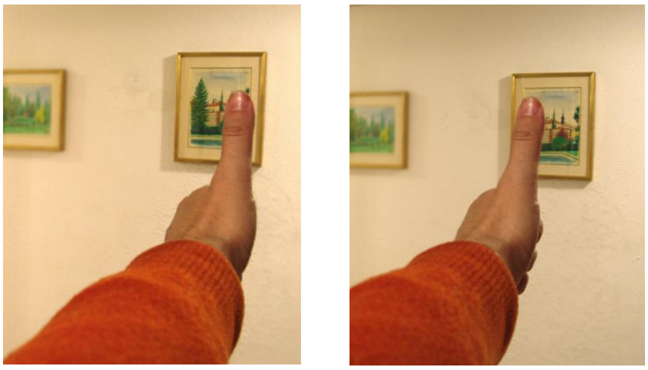


Fig. 1a: With your arm extended look at the position of your thumb relative to the background object, first with the left eye (closing the right one) and then, Fig. 1b, look with the right eye (with the left eye closed).

Calculation of distances to stars by parallax

Parallax is the apparent change in the position of an object, when viewed from different places. The position of a nearby star relative to background stars that are farther away seems to change when viewed from two different locations. Thus we can determine the distance to nearby stars.

The parallax is appreciable if the distance that is the baseline is maximized. This distance is the diameter of the orbit of the Earth around the sun (figure 2).

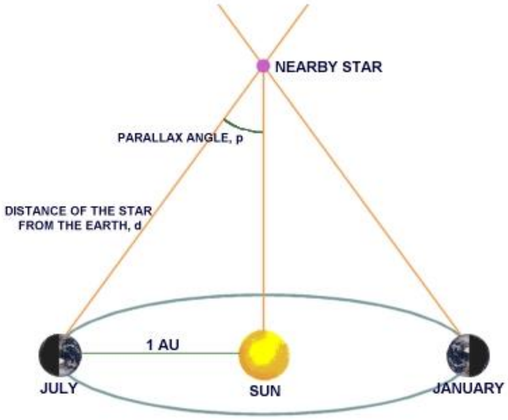


Fig. 2: The parallax angle p is the angular shift one sees when observing a star from two locations that are one Earth-Sun distance apart.

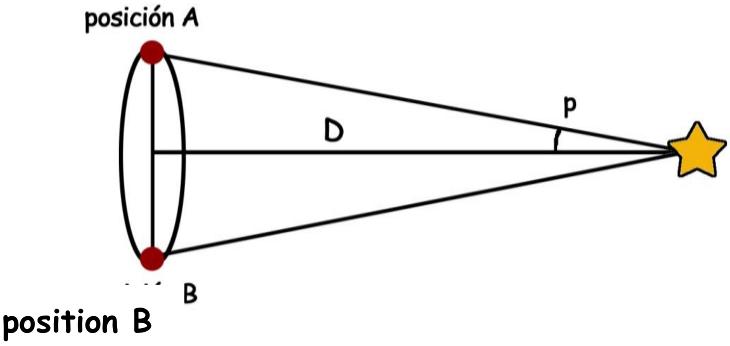


Fig. 3: By measuring the parallax angle, p, it is then possible to calculate the distance D to the object.

For example if we observe a nearby star with respect to background stars from two positions A and B of the Earth's orbit (figure 3), separated by six months, we can calculate the distance D that the star is at, giving:

$$\tan p = \frac{AB/2}{D}$$

Since p is a very small angle, the tangent can be approximated as the angle measured in radians:

$$D = \frac{AB/2}{p}$$

The base of the triangle AB / 2 is the Earth-Sun distance, 150 million km. If we have the parallax angle p, then the distance to the star, in kilometers, will be D = 150,000,000 / p, with the angle p expressed in radians. For example, if the angle p is an arc second, the distance to the star is:

$$D = \frac{150\,000\,000}{2\pi/(360\ 60\ 60)} = 30\,939\,720\,937\,064\ km = 3{,}26\ a.l.$$

This is the unit of distance that is used in professional astronomy. If you saw a star with a parallax of one arc second, it is at a distance of 1 parsec (par-sec), equivalent to 1pc = 3.26 light years. A smaller parallax implies a larger distance to the star. The relationship between distance (in pc) and parallax (in arcseconds) is:

$$d = \frac{1}{p}$$

The simplicity of this expression is the reason for which it is used. For example, the closest star is Proxima Centauri, has a parallax of "0.76, which corresponds to a distance of 1.31 pc, equivalent to 4.28 ly. The first parallax observation made of a star (61 Cygni) was made by Bessel in 1838. Although at the time it was suspected that the stars were so distant, that they could not be measured with accurate distances.

Currently, we use parallax to measure distances to stars that are within 300 light years of us. Beyond that distance, the parallax angle is negligible, so we must use other methods to calculate distances. However, these other methods are generally based on comparison with other stars whose distance is known from the parallax method. Parallax provides a basis for other distance measurements in astronomy, the cosmic distance ladder. Parallax is essentially the bottom rung of this distance ladder.

Activity 2: Inverse-square law

A simple experiment can be used to help understand the relationship between luminosity, brightness, and distance. It will show that the apparent magnitude is a function of distance. As shown in figure 11, you will use a light bulb and a card (or box) with a small square hole cut out of it. The card with the hole is placed to one side of the light bulb. The light bulb radiates in all directions. A certain amount of light passes through the hole and illuminates a mobile screen placed parallel to the card with the hole. The screen has squares of the same size as the hole in the card. The total amount of light passing through the hole and reaching the screen does not depend on how far away we put the screen. However, as we put the screen farther away this same amount of light must cover a larger area, and consequently the brightness on the screen decreases. To simulate a point source and reduce shadows, we can also use a third card with a hole very close to the light bulb. However, be careful not to leave that card close to the bulb for too long, as it might burn.

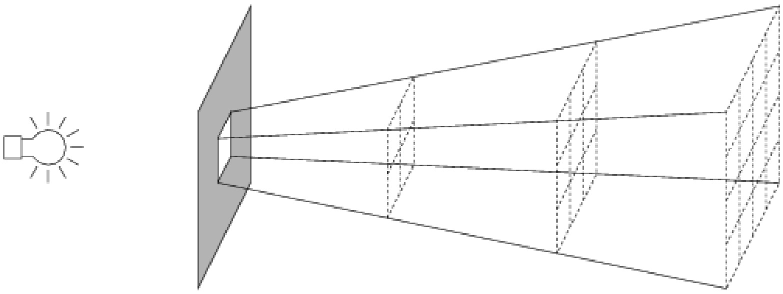


Fig. 4: Experimental setup

We observe that when the distance between the screen and the light bulb doubles, the area that the light illulminates becomes four times bigger. This implies that the light intensity (the light arriving per unit area) becomes one fourth of the original amount. If the distance is tripled, the area on the screen over which light is spread becomes nine times bigger, so the light intensity will be a ninth of the original amount. Thus, one can say that the intensity is inversely proportional to the square of the distance to the source. In other words, the intensity is inversely proportional to the total area that the radiation is spread over, which is a sphere of surface area $4\pi D^2$.

The magnitude system

Imagine a star is like a light bulb. The brightness depends on the power of the star or bulb and distance from which we see it. This can be verified by placing a sheet of paper opposite a lamp: the amount of light that reaches the sheet of paper depends on the power of the bulb, and the distance between the sheet and the bulb. The light from the bulb is spread out evenly across a surface of a sphere, which has an area of 4πR2, where R is the distance between the two objects. Therefore, if you double the distance (R) between the sheet of paper and the bulb (figure 5), the intensity that reaches the paper is not half, but is one-fourth (the area that the light is distributed over is four times higher). And if the distance is tripled, the intensity that reaches the paper is one-ninth (the area of the sphere that the light is distributed over is nine times higher).

The brightness of a star can be defined as the intensity (or flow) of energy arriving at an area of one square meter located on Earth (Fig. 5). If the luminosity (or power) of the star is L, then:

$$B = F = \frac{L}{4\pi D^2}$$

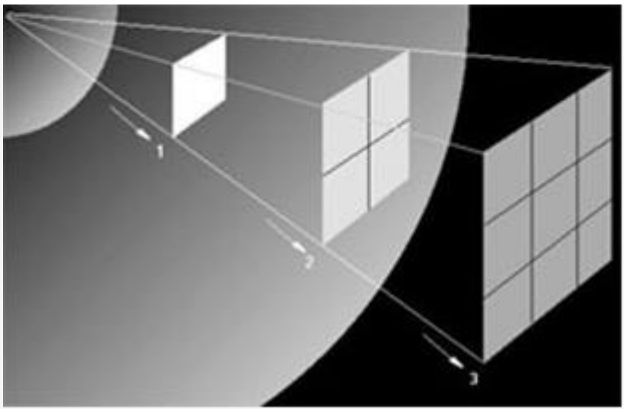


Fig. 5: The light becomes less intense the further away it is

Since the brightness depends on the intensity and distance of the star, one can see that an intrinsically faint star that is closer can be observed to be the same brightness as an intrinsically more luminous star but that is farther away.

Hipparchus of Samos, in the second century BC, made the first catalog of stars. He classified the brightest stars as 1st magnitude stars, and the faintest stars as 6th magnitude stars. He invented a system of division of brightness of the star that is still used today, although slightly rescaled with more precise measurements than what was originally made with the naked eye.

A star of magnitude 2 is brighter than a star with a magnitude of 3. There are stars that have a magnitude of 0, and even some stars that have negative magnitudes, such as Sirius, which has a magnitude of -1.5. Extending the scale to even brighter objects, Venus has a visual magnitude of -4, the full moon has a magnitude of -13, and the Sun has a magnitude of -26.8.

These values are properly called apparent magnitudes m, since they appear to measure the brightness of stars as seen from Earth. This scale has the rule that a star of magnitude 1 is 2.51 times brighter than a star of magnitude 2, and this star is 2.51 times brighter than another star of magnitude 3, etc. This means that a difference of 5 magnitudes between two stars is equivalent to the star with the smaller magnitude being $2.51^5 = 100$ times brighter. This mathematical relationship can be expressed as:

$$\frac{B_1}{B_2} = \left(\sqrt[5]{100}\right)^{m_2 - m_1}$$

or

$$m_2 - m_1 = 2.5 \log\left(\frac{B_1}{B_2}\right)$$

The apparent magnitude *m* is a measure related to the flux of light into the telescope from a star. In fact, *m* is calculated from the flux *F* and a constant *C* (that depends on the flow units and the band of observation) through the expression:

$$m = -2.5 \log F + C$$

This equation tells us that the greater the flux, the more negative a star's magnitude will be. The absolute magnitude *M* is defined as the apparent magnitude *m* that an object would have if it was seen from a distance of 10 parsecs.

To convert the apparent magnitude into an absolute magnitude it is necessary to know the exact distance to the star. Sometimes this is a problem, because distances in astronomy are often difficult to determine precisely. However, if the distance in parsecs *d* is known, the absolute magnitude *M* of the star can be calculated using the equation:

$$M = m - 5\log d + 5$$

The colors of stars

It is known that stars have different colors. At first glance with the naked eye one can distinguish variations between the colors of stars, but the differences between the colors of stars is even more apparent when stars are observed with binoculars and photography. Stars are classified according to their colors; these classifications are called spectral types, and they are labeled as: O, B, A, F, G, K, M. (figure 6).

Fig. 6: Spectral Types of Stars, according their colors

According to Wien's law (figure 7), a star with its maximum intensity peaked in blue light corresponds to a higher temperature, whereas if a star's maximum intensity peaks in the red then it is cooler. Stated another way, the color of the star indicates the surface temperature of the star.

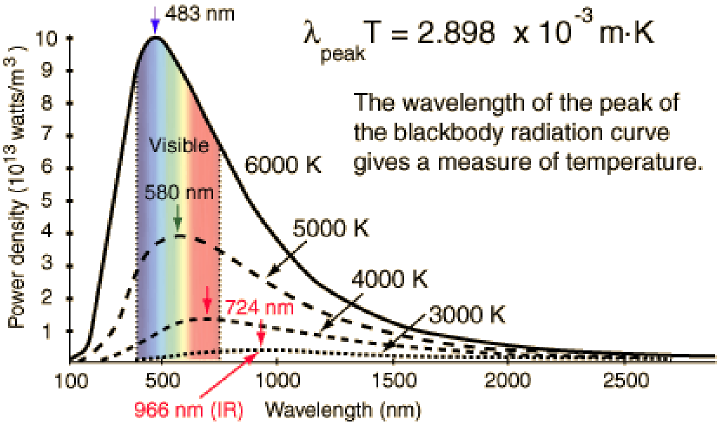
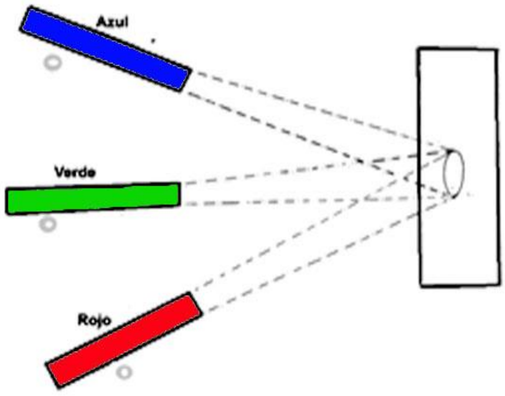


Fig. 7: If the temperature increases, the peak of the star's intensity moves from the red to the blue.

Activity 3: Stellar colors

First, you will use a simple incandescent lamp with a variable resistor to illustrate blackbody radiation. By placing colored filters between the lamp and the spectroscope, students can examine the wavelength of light transmitted through the filters. By comparing this to the spectrum of the lamp, students can demonstrate that the filters absorb certain wavelengths. Then, students can use a device similar to that in figure 3, which has blue, red, and green lights, and is equipped with potentiometers, to understand the colors of stars. This device can be constructed by using lamps, where the tubes of the lamps are made with black construction paper, and the opening opposite the bulb is covered with sheets of colored cellophane. Using this device, we can analyze figure 2 and try to reproduce the effect of stellar temperature rise. At low temperatures the star only emits red light in significant amounts.

If the temperature rises there will also be emission of wavelengths that pass through the green filter. As this contribution becomes more important the star's color will go through orange to yellow. As temperature rises the wavelengths that pass the blue filter become important and therefore the star's colors become white. If the intensity of the blue wavelengths continues to grow and becomes significantly greater than the intensities of the wavelengths that pass through the red and green filters, the star becomes blue. To show this last step, it is necessary to reduce the red and green lamp intensity if you used the maximum power of the lamps to produce white.



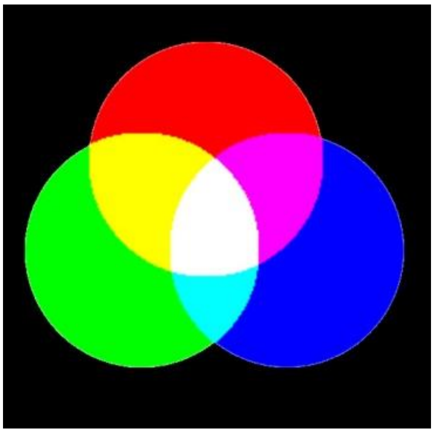


Fig. 8a: Device to explain the star color, Fig. 8b: Projection to explain the color of stars and the production of withe color.

How do we know that stars evolve?

Stars can be placed on a Hertzsprung-Russell diagram (figure 9a), which plots stellar intensity (luminosity or absolute magnitude) versus stellar temperature or color. Cool stars have lower luminosity (bottom right of the plot); hot stars are brighter and have higher intensity (top left of the plot). This track of stars that forms a sequence of stars from cool temperature / low luminosity up to high temperature / high luminosity is known as the Main Sequence. Some stars that are more evolved have “moved off “of the main sequence. Stars that are very hot, but have low luminosity, are white dwarfs. Stars that have low temperatures but are very bright are known as supergiants.

Over time, a star can evolve and "move" in the HR diagram. For example, the Sun (center), at the end of its life will swell and will become a red giant. The Sun will then eject its outer layers and will eventually become a white dwarf, as in figure 9b.

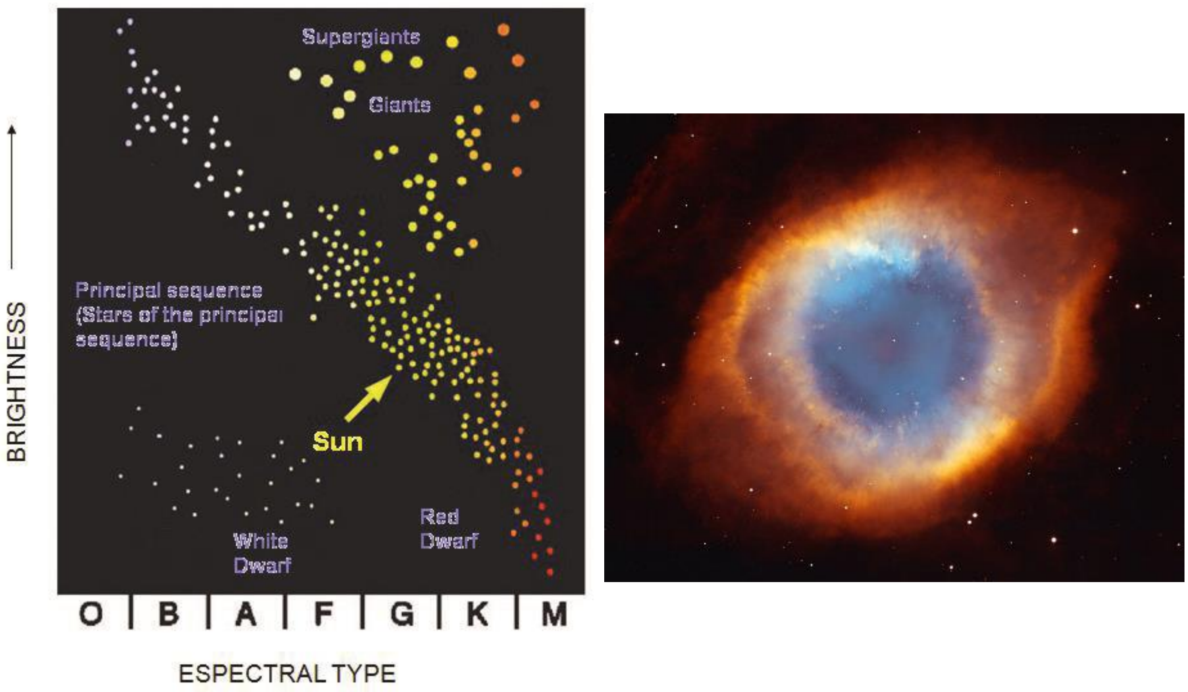


Fig. 9a: H-R Diagram, Fig. 9b: The Sun will shed its external atmosphere and will convert into a withe dwarf, like that which exists in the center of this planetary nebula

Activity 4: The age of open clusters

Analyze the picture (figure 10) of the Jewel Box cluster or Kappa Crucis, in the constellation of the Southern Cross. It is obvious that the stars are not all the same color. It is also difficult to decide where the cluster of stars ends. On figure 10, mark where you think the edge of the cluster is.

Fig. 10: Image of the Jewel Box cluster

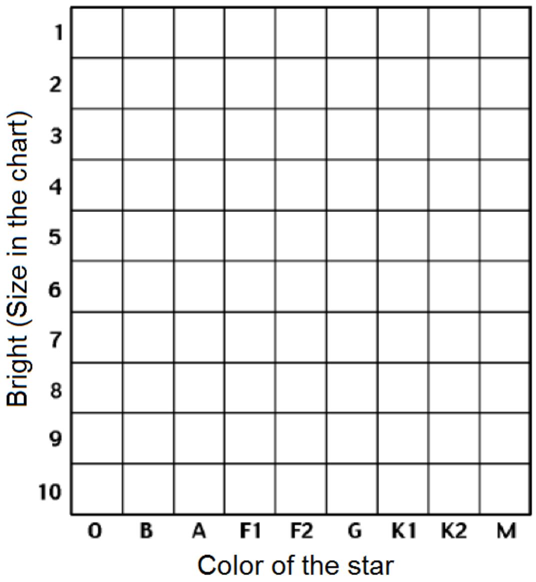


Fig. 11: Worksheet

In the same figure 10, mark with an "X" where you think the center of the cluster is. Then, use a ruler to measure and draw a square with a side of 4 cm around the center. Measure the brightness of the star closest to the upper left corner of your square, based on its size compared with the comparison sizes that are presented in the guide on the margin of figure 4. Estimate the color of the star with the aid of the color comparison guide located on the left side of figure 10. Mark with a dot the color and size of your first star on the color-brightness worksheet (figure 11). Note that color is the x-axis while brighness (size) is the y-axis.. After marking the first star, proceed to measure and mark the color and brightness (size) of all the stars within the square of 4 cm.

The stars of the Jewel Box cluster should appear to follow a certain pattern in the graph you have created in figure 11. In figure 10, there are also stars that are located in front and behind the cluster but are not actually a part of it. Astronomers call them “field stars”. If you have time, try to estimate how many field stars you have included in the 4 cm square that you used for your analysis, and estimate their color and brightness. To do this, locate the field stars in the color-magnitude diagram and mark them with a tiny “x” instead of a dot. Note that the field stars have a random distribution on the graph and don’t seem to form any specific pattern.

Most of the stars are located on a strip of the graph that goes from the top left to the bottom right. The less massive stars are the coldest ones and appear red. The most massive stars are the hottest and brightest, and appear blue. This strip of stars on the color-magnitude diagram is called the “main sequence”. Stars on the main sequence are placed in classes that go from the O class (the brightest, most massive, and hottest: about 40,000 K) to the M class (low brightness, low mass, and small stellar surface temperature: about 3500 K)

During most of the life of a star, the same internal forces that produce the star's energy also stabilize the star against collapse. When the star runs out of fuel, this equilibrium is broken and the immense gravity of the star causes it to collapse and die.

The star's transition between life on the main sequence and collapse is a part of the stellar cycle called the "red giant" stage. Red giant stars are bright because they have stellar diameters that can go from 10 to more than 300 times larger than the Sun. Red giants are also red because their surface temperature is low. In the worksheet they are classified as K or M stars but they are very bright. The most massive stars exhaust their fuel faster than lower-mass stars and therefore are the first to leave the main sequence and become red giants. Because of their large sizes that can be more than 1000 Sun diameters, the red giants with masses between 10 and 50 solar masses are called "red supergiants" (or red hypergiants if they came from an O class star). Red giants expand and cool down, becoming red and bright, and are therefore located in the top right of the color-magnitude diagram. As the cluster gets older, the amount of stars that leave the main sequence to become red giants grows. Therefore, the age of a star cluster can be determined by the color of the biggest and brightest star that still remains on the main sequence.

Many stars in old clusters have evolved beyond the stage of red giants to another stage: they become white dwarfs. White dwarfs are very small stars that are about the size of the Earth. They are also very faint, and therefore cannot be seen in this image of the Jewel Box.

Can you estimate an age for the Jewel Box star cluster from your graph in figure 11 by comparing to the graphs of star clusters of different ages shown in figures 12a, 12b and 12c?

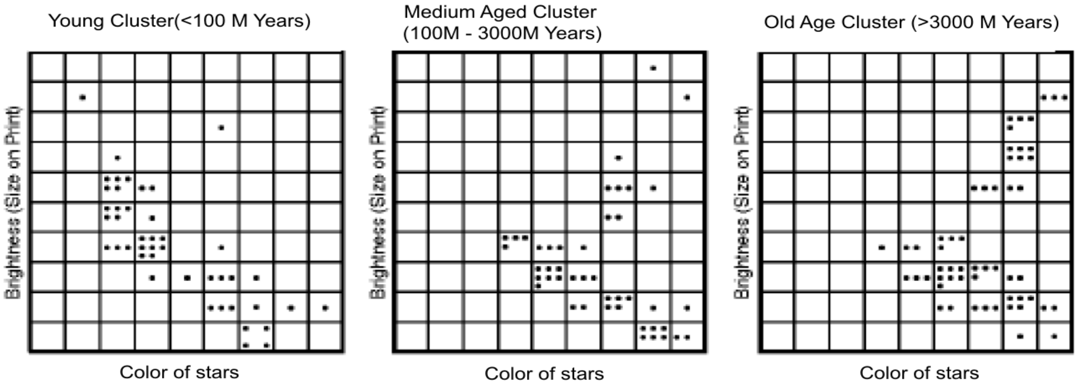


Fig .12a, 12b, and 12c: Reference cluster HR diagrams

If you understand the HR diagram and the relationship between color (surface temperature), brightness, and ages of stars, it is possible to explain how stars and star clusters evolve. You can compare the lives of O/B class stars with those of A/F/G and K/M stars. You can see that stars of the same mass evolve in the same way even in different star clusters. Because of this, you can see the differences in ages between different star clusters using the HR diagram. This is why you can tell that figure 12a shows a young cluster (it has O and B stars in the main sequence and we know that these stars rapidly evolve to red supergiants), and that figure 12c shows an old cluster (with almost only K/M stars in the main sequence and many stars in the red giant phase).

We can ask ourselves: "What would the Sun's position be in the Hertzsprung-Russell diagram?" The Sun is a star with a surface temperature of 5870 K and therefore it appears yellow. This would correspond to a G2 class (x-axis). It is in the main sequence stage of its evolution, where hydrogen is being fused into helium in the stellar core. This puts it in class 5 of luminosity, along with many other stars located on the main sequence.

Stellar death

The end of a star's life depends on the mass of the progenitor star, as is shown in figure 13.

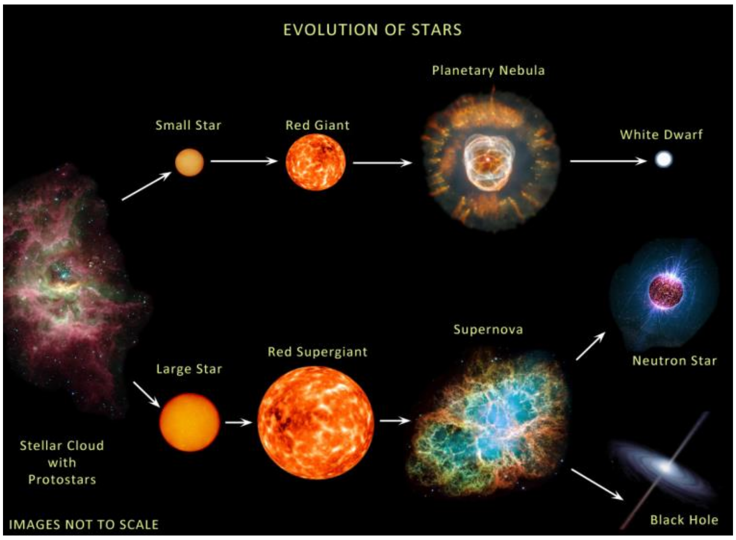


Fig. 13: Evolution of stars according their masses.

At a certain point in the evolution of star clusters the more massive stars disappear from the Hertzsprung-Russell diagram. While the low mass stars will evolve into white dwarfs, these massive stars will end their lives as one of the most violent phenomena in the universe: supernovae. The remnants of these kinds of phenomena will be objects that have no thermal emission (pulsars and black holes) and therefore are not visible in the Hertzsprung-Russell diagram.

What is a supernova?

Is the dead of a massive star the stellar main sequence is characterized by the fusion of hydrogen to produce helium, subsequently progressing to the production of carbon and increasingly heavier elements. The final product is iron. The fusion of iron is not possible because this reaction would require energy to proceed instead of releasing energy. The fusion of different elements proceeds until the supply of that element is exhausted. This fusion happens outwards from the core, so after time the star acquires a layered structure somewhat like an onion (figure 14b), with heavier elements in the deeper layers near the core.

A 20 Solar mass star has these stages:

10 milion years burning Hydrogen in the core (main sequence)
1 million years burning Helium

300 years burning Carbon
200 days burning Oxygen
2 days to consume Silicon: the supernova explosion is imminent.

Fig. 14a: Supernova remnant.

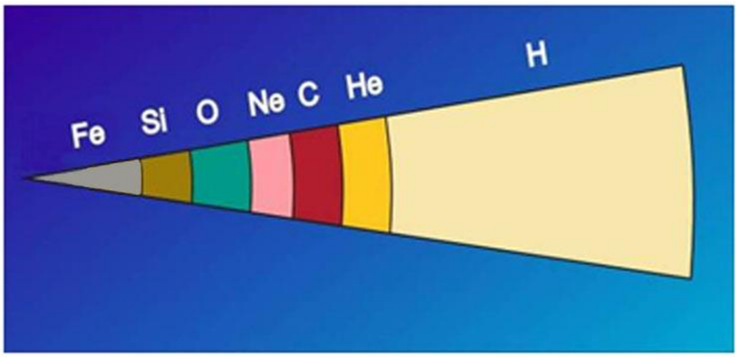


Fig. 14b: Structure of a star's interior just prior to the supernova explosion.

When the star finally has an iron core, no further nuclear reactions are possible. Without radiation pressure from fusion to balance gravity, the star's collapse is unavoidable, without the possibility of any further nuclear ignition. During the collapse, atomic nuclei and electrons are pushed together to form neutrons and the central part of the core becomes a neutron star.

Neutron stars are so dense that a teaspoonful would weigh as much as all the buildings in a large city. As neutrons are squeezed together, no further contraction that can take place. Particles infalling from the outer layers of the star at speeds of about a quarter of the speed of light hit the neutron core and are suddenly stopped. This causes them to bounce back in the form of a shock wave, resulting in one of the most energetic processes known in the universe (figure 14a): single exploding star can outshine an entire galaxy consisting of billions of stars.

During this rebound the energies are so large that some elements heavier than iron are created (such as lead, gold, uranium, etc.). These elements emerge violently during the explosion and are ejected along with all the outer matter of the star. In the center of the ejected material there remains a neutron star spinning at high speed, or if the original star was massive enough, a black hole.

Activity 5: Simulation of a supernova explosion

When a star explodes as a supernova, the light atoms in the outer layers fall toward the heavier elements in the interior and finally bounce off the solid central core. A simplified model of this process can be represented in an easy and rather spectacular way with a basketball and a tennis ball, by dropping them together onto a hard surface such as the floor (figure 15). In this model, the floor represents the dense stellar core, the basketball represents a heavy atom that bounces back from the core and pushes the light atom right behind it, represented by the tennis ball.

Fig. 15: We dropped at the same time both a tennis ball and a basketball.

To present the model, hold the basketball at eye level with the tennis ball just above it, as vertical as possible. Drop the two balls together. You might guess that the balls would rebound to the same height from which they started, or maybe even lower because of friction and energy dissipation to the floor. However, the result is quite surprising.

When you drop the two balls, they arrive almost simultaneously to the floor. The big ball bounces elastically back nearly at the same speed it had when it reached the floor. At that moment it collides with the little tennis ball that was falling with the same speed as the basketball. The tennis ball bounces off the basketball at high speed and reaches much higher than the height from which the balls were dropped. If this experiment were repeated, using a large number of even lighter balls, their rebound speeds would be fantastic.

In the model presentation, the tennis ball rebounds to twice the original height from which the two balls were dropped. In fact, be careful not to break something if you do this experiment indoors.

This experiment can be done in the classroom or in another enclosed area, but preferably it should be done outdoors. It can be done from a high window, but this will make it difficult to make sure the balls drop vertically and the balls can bounce with great force in unpredictable directions.

Some toy stores or science museum shops sell a toy called the "Astro Blaster" that is based on the same principle. It consists of four small rubber balls of different sizes linked by an axis. The smaller balls shoot into the air, rebounding after the system hits the ground.

What is a neutron star?

A neutron star is the remnant of a very massive star that has collapsed and has shed its outer layers in a supernova explosion. Neutron stars are usually no bigger than a few dozen kilometers. As the name implies, they consist of neutrons stacked together to an incredible density: a single thimble of this matter would weigh millions of tons.

A neutron star forms if the remnant of a supernova is between 1.44 and about 8 solar masses.

What is a pulsar?

A pulsar is a neutron star spinning at extremely high speed (figure 16). When a massive star collapses, the outer layers fall toward the core and start spinning faster due to conservation of angular momentum. This is similar to how a skater spins faster by drawing her arms toward her body. The star's magnetic field generates strong electromagnetic synchrotron emission in the direction of its axis. However because the magnetic field axis does not usually coincide with the axis of rotation, (as is also the case on Earth) the rotating neutron star acts like a giant cosmic lighthouse. If this emission happens to be directed toward the Earth, we detect a pulse at regular intervals.

In 1967, Jocelyn Bell (Burnell) and Antony Hewish discovered the first pulsar. The pulse signal came from a point in space where nothing was observed pulsing in visible light. The rapid pulse repetition was striking - several times per second with amazing precision.

Fig. 16: A pulsar is a rotating neutron star

At first it was thought that pulsars could be intelligent extraterrestrial signals. Then more pulsating radio sources were discovered, including the center of the Crab Nebula. Scientists knew that this nebula was produced by a supernova and could finally explain the origin of pulsars. The pulsar PSR B1937+21 is one of the fastest known pulsars and spins over 600 times per second. It is about 5 km in diameter and were it spinning about 10% faster, it would be broken apart by the centrifugal force. Hewish won the Nobel Prize in 1974.

Another very interesting pulsar is a binary system called PSR 1913+16 in the *Eagle* constellation. The mutual orbital motion of the stars in a very intense gravitational field produces some slight delays in the emissions we receive. Russell Hulse and Joseph Taylor have studied this system and confirmed many predictions of the theory of relativity, including the emission of gravitational waves. These two Americans were awarded the Nobel Prize in 1993 for their research.

Activity 6: Pulsar simulation

A pulsar is a neutron star that is very massive and spinning quickly. It emits radiation but the source is not fully aligned with the axis of rotation, so the emitted beam of radiation spins like a lighthouse. If this beam is oriented toward Earth, we observe a radiation pulse several times per second.

We can simulate a pulsar with a flashlight (figure 17a) tied with a rope to the ceiling. If we turn it on and spin it (figure 17b), we will see light intermittently whenever the flashlight is pointing in our direction (figure 17c).

If you tilt the flashlight so that it is not horizontal, you will no longer be able to see the beam of light from the same position. Therefore, we can only observe the emission of a pulsar if we are well aligned with its rotation.

Fig. 17a: Assembly, Fig. 17b: Spinning the flashlight, Fig.17c: As it spins we observe the beam of light in a periodic way

What is a black hole?

If we throw a stone upwards, gravity slows it down until it returns back to the ground. If we throw the stone with a larger initial speed, the stone goes higher before it falls back down. If the initial speed is 11 km/s, the escape velocity of Earth, the stone would not fall back down (assuming there is no air friction).

If Earth collapsed while maintaining its mass, the escape velocity at its surface would increase because we would be closer to the center of the Earth. If it collapsed to a radius of 0.8 cm, the escape velocity would become greater than the speed of light. Since nothing can exceed the speed of light, nothing would be able to escape from the surface, not even light. The Earth would have become a black hole the size of a tiny marble.

Theoretically, it is possible for black holes to have very small masses. In reality however, there is only one known mechanism that can concentrate mass to the necessary densities: gravitational collapse. In order for gravitational collapse to take place, a very large amount of mass is needed. We learned that neutron stars are the remnants of stars of mass 1.44 to about 8 solar masses. However, if the original star is even more massive, gravity is so strong that its interior may continue collapsing until it becomes a black hole. Therefore, this type of black hole will have a mass several times larger than our Sun. Black holes' densities are very impressive. A tiny marble made of matter this dense would weigh as much as the whole Earth.

Although we cannot observe them directly, we know of several candidates for black holes in the universe through the emission from material revolving around the black hole at high speeds. For example, right in the center of our galaxy we see nothing, but we can detect a ring of gas swirling around the center at incredible speed. The only possible explanation is that there is a huge invisible mass at the center of this ring, weighing as much as three or four million suns. This can only be a black hole, with a Schwarzschild radius slightly larger than our Sun. These types of black holes, which are located at the centers of many galaxies, are called supermassive black holes.

Activity 7: Simulation of space curvature and a black hole

It's easy to simulate the two-dimensional curvature of space created by a black hole using a piece of elastic fiber sheet called Lycra (figure 18) or a large piece of gauze.

Fig. 18: The tennis ball's trajectory isn't a straight line but a curve.

First, stretch the fiber sheet or mesh. Now, roll a small ball (or marble) along the sheet. This represents a photon of light and its trajectory simulates the straight path of a light ray in the absence of curvature. However, if you place a heavy ball at the center of the sheet and then roll the smaller ball (or marble) its path will follow a curve. This simulates the path of a light ray in a curved space caused by the presence of a gravitating mass. How much the path of the light ray curves depends on how close the light beam passes to the gravitating body and how massive this body is. The angle of deflection is directly proportional to the mass and inversely proportional to the distance. If we loosen the tension in the sheet, it simulates a deeper gravity well, which makes it more difficult for the smaller ball to leave. It becomes a model of a black hole.

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Astronomy beyond the visible

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Summary

Celestial objects radiate in many wavelengths of the electromagnetic spectrum, but the human eye only distinguishes a very small part: the visible region.

There are ways to demonstrate the existence of these forms of electromagnetic radiation that we do not see through simple experiments. In this presentation, you will be introduced to observations beyond what is observable with a telescope that can be used in a primary or secondary school.

Goals

This activity aims to show certain phenomena beyond what may be observable with amateur telescopes, such as the existence of:

- Celestial bodies that emit electromagnetic energy that our eye can not detect. Astronomers are interested in these other wavelengths because visible raditation alone does not offer a complete picture of the Universe.
- Visible emissions in the regions of radio waves, infrared, ultraviolet, microwave and X-rays.

Electromagnetic spectrum

Electromagnetic waves cover a wide range of frequencies or wavelengths and can be classified by their main source of production. The classification does not have precise boundaries. The set of all wavelengths is called the electromagnetic spectrum.

Figure 1 shows the different regions of the spectrum with its various regions. It indicates the size between wave crests (wavelength λ) and some objects of these sizes: atoms, flies, mountains ... to get an idea of the waves' sizes. In the same figure we can appreciate how we "see" the Sun and Saturn if observed them at wavelengths that our eyes can not detect. These photographs were made with special detectors sensitive to these wavelengths.

In the Universe, there is material that is much lower temperatures than the stars, for example, clouds of interstellar material. These clouds do not emit visible radiation, but can be detected at long wavelengths such as infrared, microwaves and radio waves. Observing the Universe in all regions of the electromagnetic spectrum, which astronomers call "multi-wavelength observation”, gives us a much clearer picture of its structure, temperature and energy and make more realistic models related to their evolution.

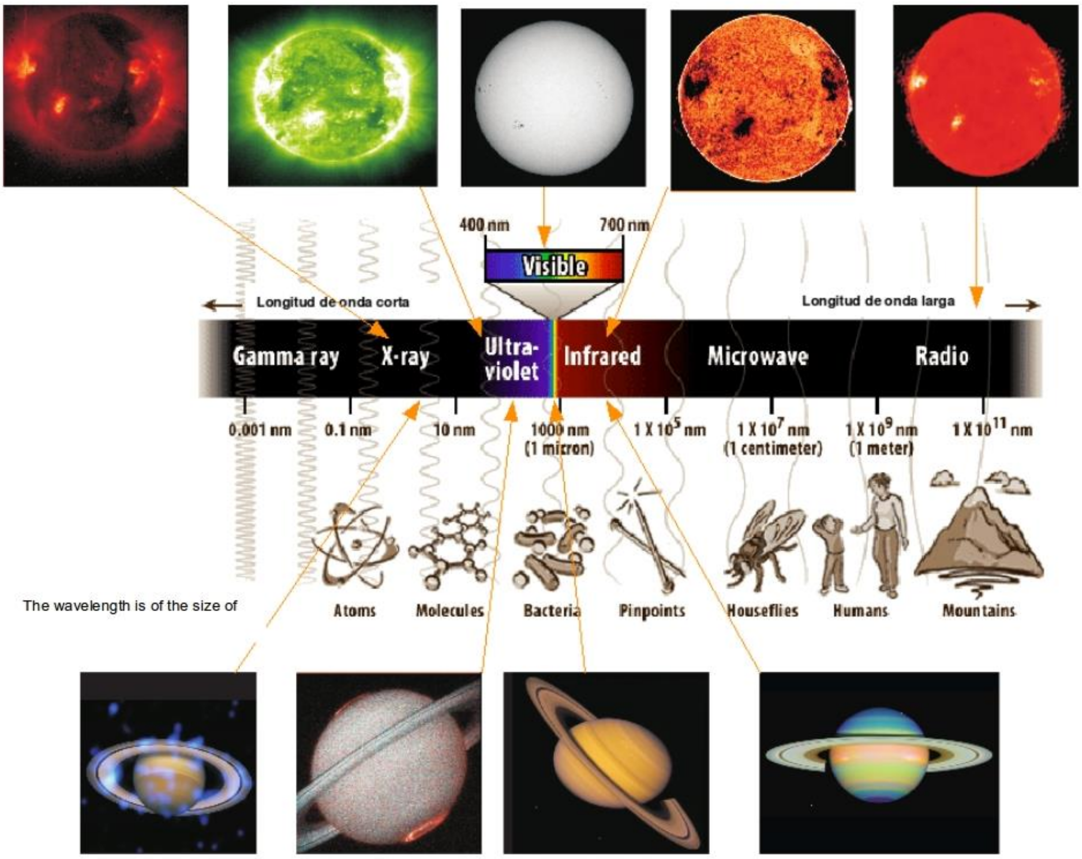

Fig. 1: Electromagnetic spectrum, with objects the size of these waves. The Sun (above) and Saturn (bottom) observed at different wavelengths (colors are simulated).

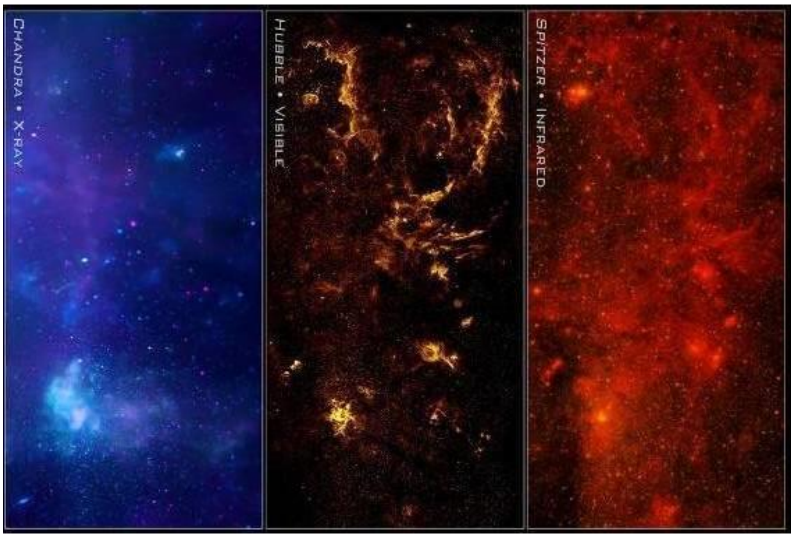

Fig. 2: The center of our Milky Way Galaxy imaged at different wavelengths

Figure 2 shows the center of our Milky Way Galaxy imaged by Spitzer space telescopes (infrared), Hubble (in visible) and Chandra (X-ray). In each of these we observed objects and details that are not visible in other wavelengths.

Activity 2: Building a Spectrometer

The white light from a bulb with a filament is composed of all colors while the light from bulbs that are gas (fluorescent tubes, energy-saving lamps, or street lamps) is composed of only certain colors. If we separate the colors of light, we obtain its spectrum, which in the case of gases consists of a set of colored lines. Each type of gas has its own spectrum, which is the "barcode" of the compounds in the gas. If we look with a spectroscope at the light of a distant galaxy, the lines characteristic of hydrogen and other gases are displaced toward the red (known as a “redshift”), with a greater displacement the farther away the galaxy is.

With strong scissors, cut pieces from a CD or DVD (figure 3a) that does not have a label. If you use a DVD, separate the upper layer from the bottom in the cut piece of plastic (you may need the scissors or a screwdriver to help) and you will have prepared the diffraction grating. If you use a CD, there is only one layer of plastic, and you must detach the metal layer with care. A craft knife or razor blade will be helpful.

Make a photocopy of the template in figure 4. If you do it at A3 size, it will be more accurate. Cut out the template, including the white part, the curved section, and make a thin slit in the flap with the scale. You do not need to cut out the scale. Assemble the box, putting the black on the inside, and paste the flaps. In the hole left by the curved section, paste the piece of CD or DVD.

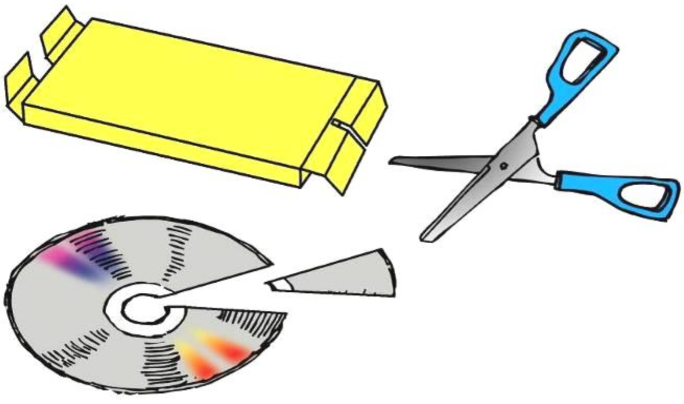

Fig. 3a: Material that you will need: DVD, scissors and paper box, Fig. 3b: Removing the metal layer of the CD, with tape.

Look through the piece of DVD and aim the slit of the box (not the scale) at a low energy lamp or a fluorescent tube (figure 11). You should see the emission lines from the gases in the bulbs on the scale. If you do not see at first, move the slit back and forth until the lines appear. The scale is labeled in hundreds of nanometers, ie, the mark 5 shows 500 nm (500×10^{-9} m). The narrower the slit is, the more accurately you can measure the wavelength of the lines.

Fig. 4: Looking at a fluorescent lamp.

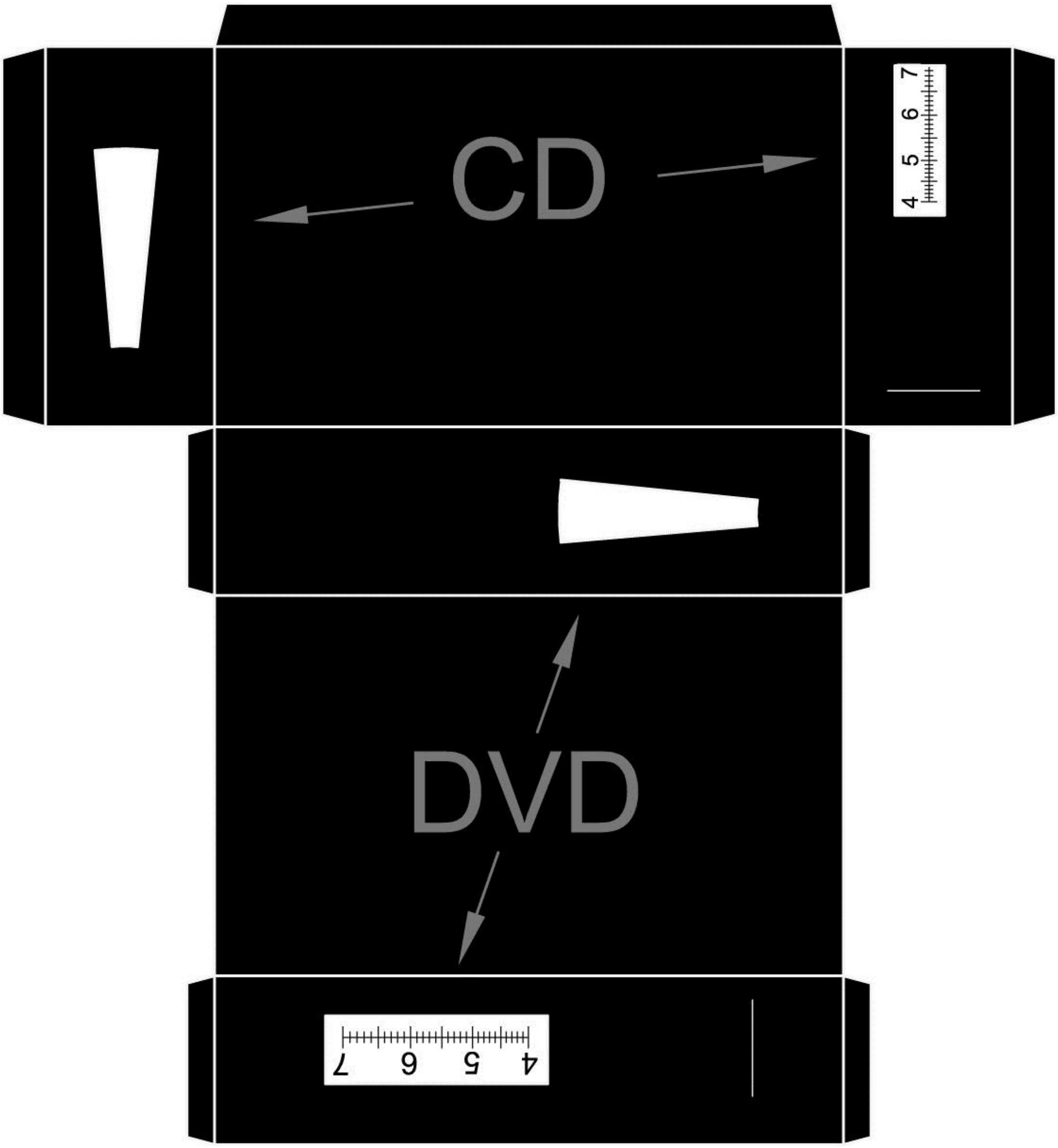

Fig. 5. Template for the spectrometer.

You can also make the box with cardboard, but if you do, you will need cut out the space for the scale and paste a paper copy over it so you will be able to see through the scale.

You can observe street lamps; both the orange (sodium) and white (mercury vapor) will work. Traditional incandescent bulbs produce a continuous spectrum.

Younger students can descompose the light and make a rainbow. Use a water hose with diffuser, and put the Sun behind (figure 6).

Fig. 6: Younger students can descompose the light into a rainbow

The infrared

The infrared region of the electromagnetic spectrum was discovered by William Herschel (the discoverer of the planet Uranus) in 1800 using a prism and a thermometer. He obtained a spectrum by passing the white sunlight through a prism and placed several thermometers, one in the blue region, another in the red one (both colors detected by the eye) and a third thermometer placed beyond red, immediately thereafter. With a fourth thermometer measured the temperature of the environment and found that the temperature that registered the thermometer in the area "below" the red (hence the name "infra" red) was greater than that of the environment.

Herschel did other experiments with "heat rays" (as he called them) that existed beyond the red region of the spectrum showing that they were reflected, refracted, absorbed and transmitted just like visible light. These "heat rays" were later called infrared rays or infrared radiation. These discoveries were followed by others that resulted in several technological applications.

The bodies found at low temperature do not emit in the visible region of the spectrum, but in longer lengths so that the energy released is lower. For example, our body and animals emit infrared radiation that we can not detect with the unaided eye but which is perceived as heat emitted by the body. All objects that are at a certain temperature emit infrared (figures 6 and 7). Night vision goggles allow one to detect this radiation that eye can not.

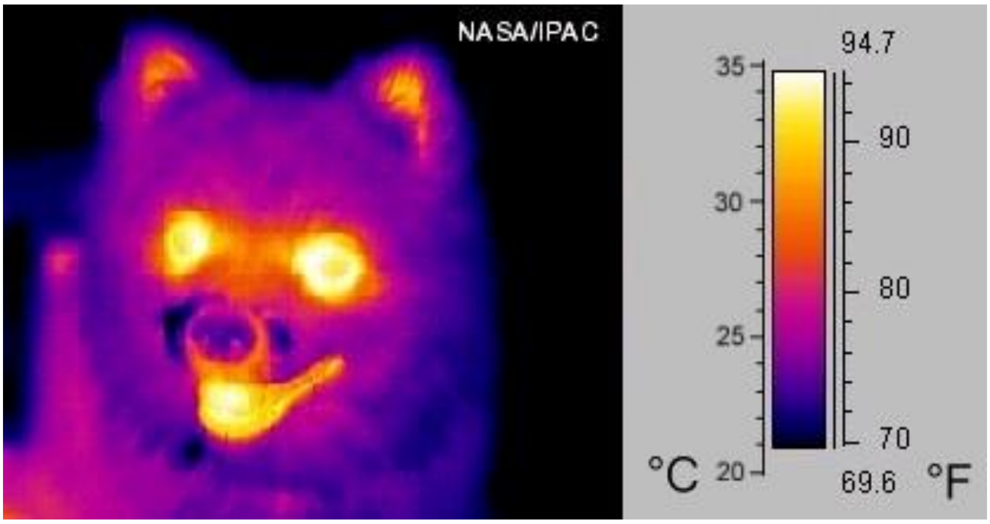

Fig. 7: Infrared photo. We distinguish hotter to cooler areas.

Activity 3: Herschel Experiment in the IR band

The goal is to repeat the experiment of 1800, by which the famous astronomer Sir William Herschel discovered a form of radiation other than visible light. We will need a glass prism, four thermometers, black permanent marker ink, scissors, tape, a cardboard box and a white sheet. We put tape on the bulbs of thermometers and paint with black marker to absorb heat better.

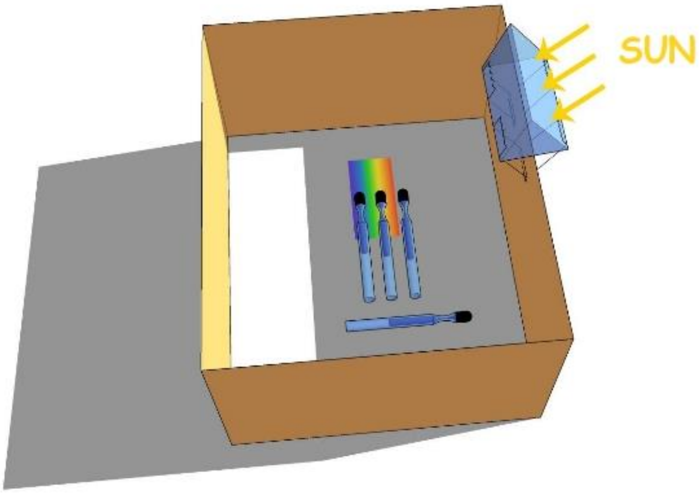

Fig. 8: Herschel device. The three thermometers in the spectrum mark higher temperature than the environment.

The experiment should be performed outdoors, in a VERY sunny. If windy, the experience can be inside, provided you have a window where the sunlight enters directly. Place a white sheet at the bottom of the carton box. The prism is placed carefully on the top edge of the box, so that it is the side of the Sun. Inside the box should be everything or almost everything in shadow (figures 8 to 9c). Rotate the prism carefully until a spectrum appears as wide as possible on the sheet at the bottom of the box.

After securing the prism with the tape in that position, place the three thermometers in the light spectrum, so that each bulb is in one color: one in the blue region, the other in the yellow and the third a little more beyond the visible red region. It should help see the graduated scale, not to move the thermometer when we take action. (figures 15 to 16c).

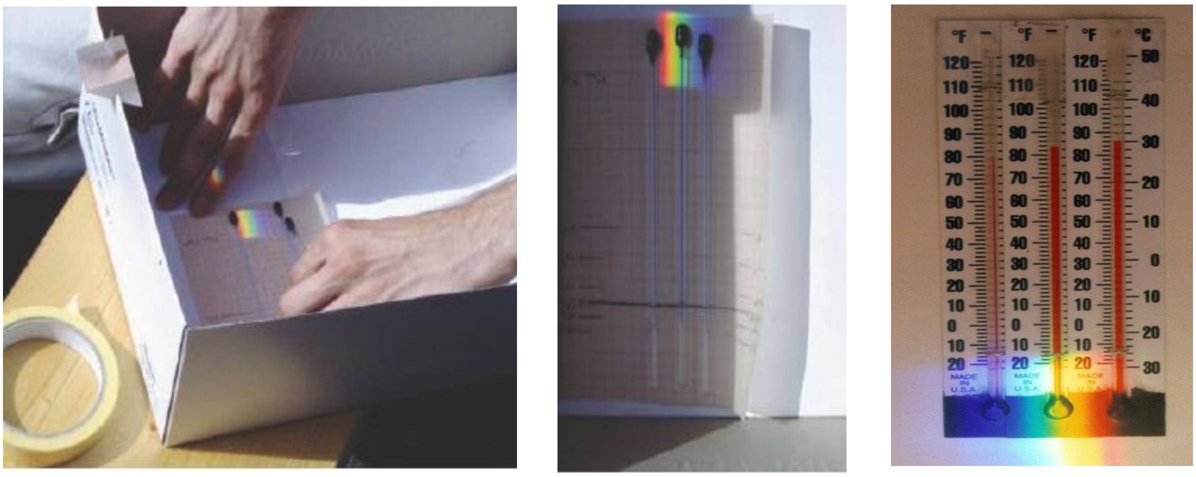

Fig.9a: Placing the three thermometers, with the black bulb, and the spectrum in the shadow part, Fig.9b: Thermometers in blue, in yellow and in red right after, Fig.9c: An example of the measures in 3 minutes. (www.spitzer.caltech.edu)

Temperatures take five minutes to reach their final values. We record temperatures every minute in the table (see Table 1) for each of the three regions of the spectrum and the environment. We must not move thermometers from their positions in the spectrum or block their light.

The thermometer in the yellow (figure 9c) should show a temperature somewhat higher than in the blue, and the one that is near the red should show a temperature still slightly higher, so it is logical that in the thermometer next to the red arrives some kind of radiation from the Sun, invisible to our eyes.

	Thermometer nº 1 in the blue	Thermometer nº 2 in the yellow	Thermometer nº 3 beyond red	Thermometer nº 4 in shadow
After 1 minute				
After 2 minutes				
After 3 minutes				
After 4 minutes				
After 5 minutes				

Table 1: Table of the data

Activity 4: Detection of the IR with a modern technological tool

If we want to detect the IR with modern technological tools, probably the first thing that comes to mind are the night sights, prepared to see the infrared emitted by our bodies. But that is not a remedy available to anyone. Consider a more economical and easy to get device.

Remote controls we use to turn on the TV, the stereo, or the microwave use infrared (do not use those that also have a red bulb). Will be there an easy way to see that non-visible radiation and it suddenly becomes detectable?

For that we must seek a detector sensitive to IR. There is a major technological product, which is due to development of the study of light in Astronomy, called CCD (as the initials of its name: Charged Coupled Device). This device can capture and collect photons over a determined period of time, so that we can detect objects that emit or reflect light. The CCD is more sensitive in the red region and, in some cases their efficiency range covers the near IR. Any modern camera or camcorder has a CCD for image acquisition. This enables taking pictures in conditions of very low level of illumination. The simplest arrangement, of everyday use, which has a modern camera and therefore a CCD detector, is the mobile phone.

Fig. 10a: Remote actived naked eye, Fig. 10b Remote activated by mobile phone.

Looking at the remote control with our eyes directly, we don't notice any difference between on and off, as in figure 10a. But if we take the photo with the same mobile phone, and remote control activated (figure 10b) ... Surprise! The device that uses the control to send the signal that turns on the television or other electronic equipment is an infrared light that our eye does not see but the phone camera does. The color of this light is false.

Activity 5: Detection of the infrared light of a bulb

Most of the bodies of the sky emit many wavelengths. If between them and us there is dust or gas, some wavelengths can be blocked, but not others. For example, dust in the center of our galaxy prevents us from seeing the intense visible light produced by the concentration of millions of stars there. If however the dust is transparent to infrared light that gets through it and reach us. The same applies to other dark dust clouds in our galaxy (figures 11a and 11b).

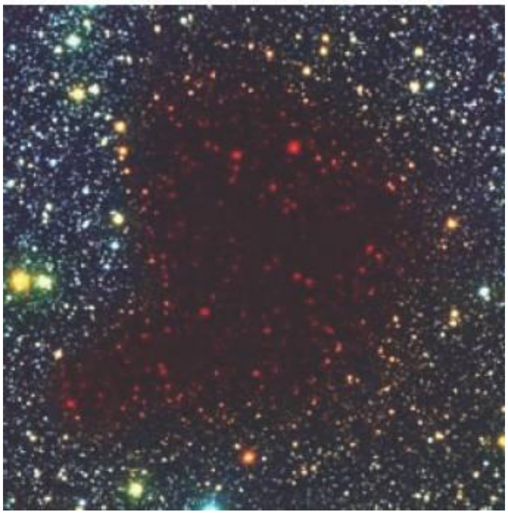

Fig. 11a: Cloud of dust in the visible region, Fig. 11b: By overlaying the infrared vision

In the emissions from an incandescent filament bulb, most energy is emitted in the visible region, but also emits in the infrared. Infrared radiation can pass though things that are opaque in the visible.

Let us take a flashlight and a cloth of felt (figure 12a and 12b). This material is not particularly well-woven and blocks visible light. Let us in a dark room and light the flashlight. Then we cover it with the felt and prove that we not see its light. If not, put another layer of felt (you can double) or even a third. Do not put more than necessary, because the infrared radiation can also be blocked if there is too much material. In that room as dark as possible, if we observe with a camera on our mobile phone, which captures the infrared radiation, we see that it distinguishes the bulb (figures 12a and 12b).

Fig. 12a and 12b: Felt completely blocks visible light but not infrared.

Activity 6: Constellation with infrared

In electronics stores or online, you may purchase infrared **LEDs**, similar to those used by remote controls TV, music devices, etc.. They are very cheap (about 0.2 euros or dollars). They operate with a stack of 3 or 9V batteries, or with a DC power supply. They are connected in parallel with a resistance between 100 and 500 Ω.

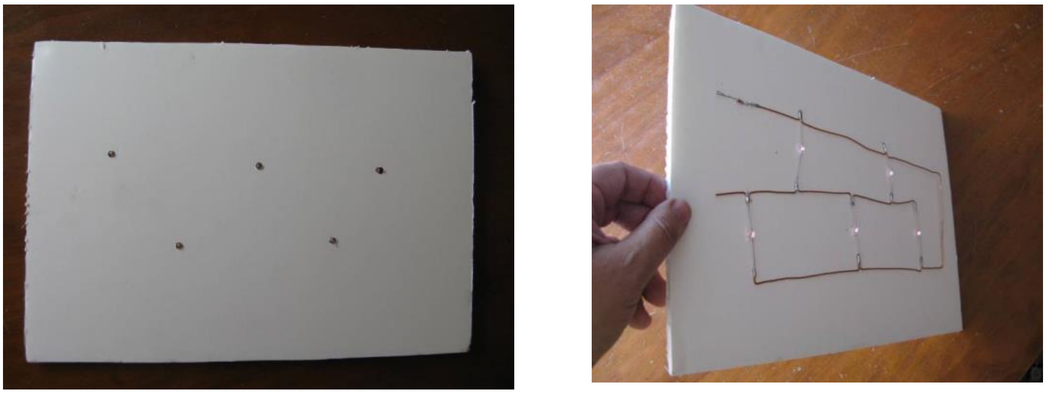

Fig. 13a and 13b: Casiopea made with infrared leds. They are connected in parallel .

You can make a small circuit with multiple LEDs, forming a well-known constellation, for example Cassiopea (figures 13a and 13b), Orion, the Southern Cross or Ursa Major (depending on the constellations you see from the hemisphere in which you live). Observed with a phone camera, you can see it in the infrared.

Activity 7. Constellation with remote controls

An easier demonstration than the previous one is to form a “constellation” using several infrared remote controls. If the remote controls are imaged in the dark with a digital camera, you can see the constellation (figures 14a and 14b).

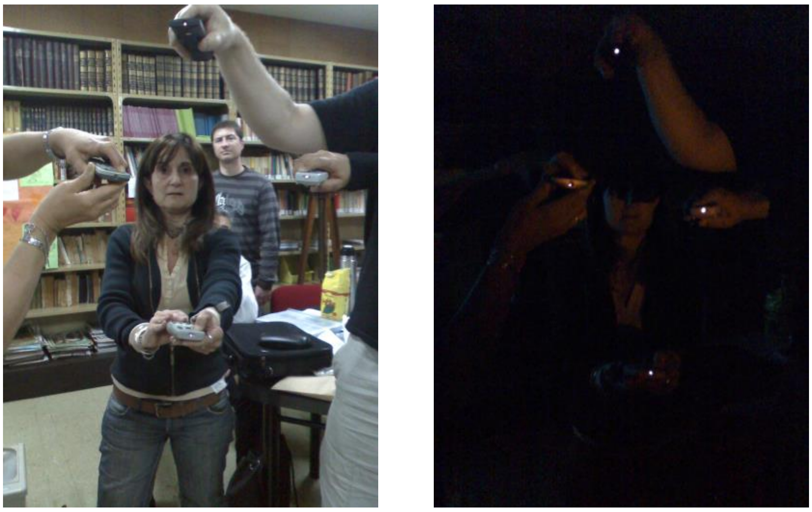

Fig. 14a and 14b: Making the Southern Cross constellation with remote controls

Electromagnetic energy in the radio region

Electromagnetic radiation with wavelengths from meters to kilometers are called radio waves. They are used on commercial stations, but also reach us from space. These radiations show morphologies that other wavelengths do not (figures , 15a, 15b and 15c).

Fig. 15a: This galaxy emits jets only detectable in radio (artificially colored red), Fig. 15b: Photograph of the galaxy NGC 4261 in the visible, Fig. 15 c: The same galaxy with the radio image superimposed. There are a few jets of matter artificially colored red.

In the Universe there are many strong radio sources such as the center of our galaxy, neutron stars in rapid rotation, or even some planets like Jupiter.

Activity 8: Producing radio waves

When you open and close an electric circuit, there are radio waves, similar to commercial broadcasting. You can capture them in a radio in the AM band, and transform them into sound, which is another type of waves. The power of these radio emissions decreases when the receptor moves away. Radio waves can pass through obstacles and even walls.

To perform the experiment, we take two pieces of wire about 20 cm each one. We removed the plastic at the two ends of one of the pieces. In another cable, also remove the plastic at one end and leave about 10 cm with plastic; remove the plastic in the rest. In the end where there is plenty of bare wire, make him a ball. Plug the other end to a terminal of a battery of 9V. We use a pencil with a tip at each end. We will use the graphite to make a source of radio radiation. On one end connect the tip to the first piece of wire, securing it with tape. The other end is connected to the second terminal of the battery (figure 16).

Turn on the radio and put it in the AM band (not FM). We hit with the free end of the pencil to the ball of wire. We move the line of the radio until you can hear on the radio that we are tapping the ball. We can try to move away the radio, to put obstacles of cardboard, wood, etc. We can also take the radio to another room and see if you hear or not. Take into account that the electromagnetic energy is transformed first into electric energy and after in sound.

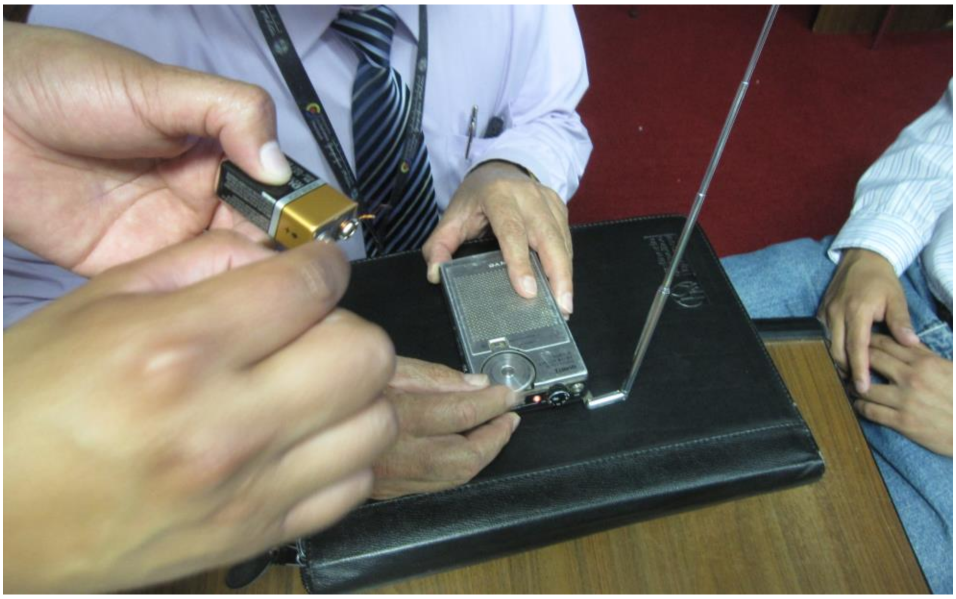

Fig. 16: Producing radio waves.

Activity 9: Listening to the voice of Jupiter

Jupiter emits radio waves at various frequencies. Its provenance is unclear, but it seems they have to do with its magnetic field and interactions with its moon Io. The broadcast is in the frequency band from 18 to 22 MHz, with a maximum at 21 MHz. These values are within the ability of many home receivers. You must have a Short Wave (SW) radio with sufficient range to reach these values.

Jupiter emissions are not continuous. Jupiter has three more or less equally spaced jets that rotate with the planet every ten hours. In addition, these jets are sometimes active and sometimes not, so we should arm ourselves with a good dose of patience.

To hear them take the shortwave radio. Situate the dial somewhere between 18 and 22 MHz where it has not much background noise, and wait. Emissions sound like ocean waves on a beach (or gusts of wind) , that reach a frequency of about three per second or so. Its intensity grows up until a maximum that lasts a few minutes, or seconds sometimes, and then decays. Experience says that if you spend 20 minutes listening, you have 1 chance in 6 of hearing them. Of course, Jupiter must be above the horizon, but clouds will not interfere.

The radio antenna itself is adequate, although it is omnidirectional and will capture waves coming from all directions. If we want to improve listening, and also to ensure that the signal proceeds from Jupiter, we must build a directional antenna to replace the radio antenna. This is done as follows: we take 165 cm of copper wire, and make a circle with it, without closing it. We hold it with four sticks 30 cm long. Line a piece of wood of 60 x 60 cm on one side with aluminum foil. We attach to it the circle of copper held by the four sticks. We take a coaxial cable and split it so that we can connect the interior wire to the circle of copper, and the exterior wire to the aluminum. The other end connects to the radio so that you can listen to the output. Finally, we direct our new antenna toward Jupiter.

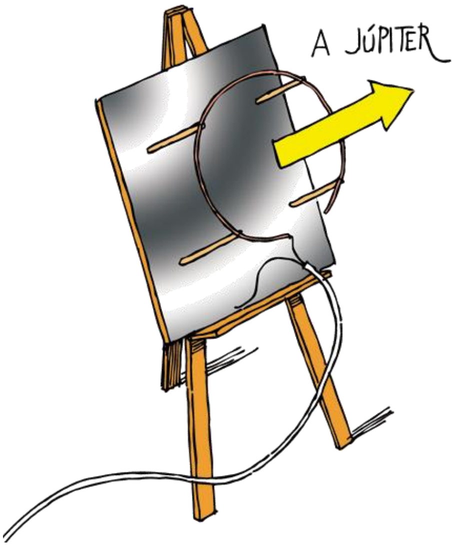

Fig. 17: Antenna to listen to Jupiter.

Ultraviolet Light

The ultraviolet photons have more energy than those of normal visible light. This allows this radiation, in high doses, to destroy chemical bonds of organic molecules, so that is deadly to life. In fact it is used to sterilize surgical equipment.

The Sun emits this radiation, but fortunately our atmosphere (particularly ozone) filters the most of it, and some is beneficial for life. This radiation is what makes our skin tan (although too much can cause skin cancer), is absorbed by plants for photosynthesis, and so on. But if the ozone layer decreases its thickness, Earth would receive too high a dose and cancer-type diseases would increase.

Activity 10: Black light (UV)

There are bulbs called black light that emit mostly in UV and are often used to support the growth of plants in greenhouses or in areas with little sunlight. The glass of these lamps is often almost black, and emits only a bit of dark blue visible light. Some synthetic fabrics white shirts (especialy shirts washed with "whitening agents" fluoresce with this light and reflect it in a bright purple. That's why this type of lighting is used in some discos, where white tissues turn aglimmer.

This property is also used to manufacture the paper of many currency notes: examine the small strips of fluorescent material which are visible when illuminated by UV light (figure 18). Thus it is proved that it is not a simple photocopy of the note. This light is built into the counterfeit detection devices (figure 19). Many official cards have marks or signs that are visible only under UV light.

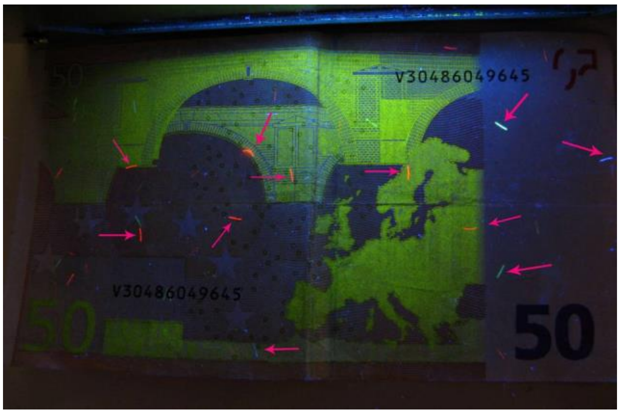

Fig. 18: A note of 50 € illuminated with UV light, shows small fluorescent strips marked here by arrows, Fig. 19: Counterfeit Detector, which uses ultraviolet light

X-Ray

More energetic than UV is the X-ray radiation. It is used in medicine in the radiographs and other forms of diagnostic radiology (figure 20a).

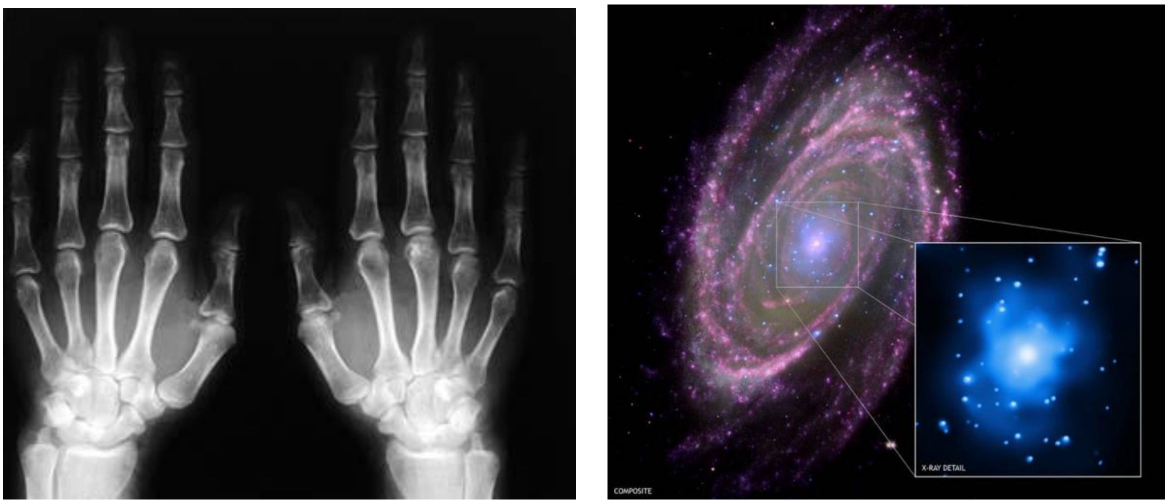

Fig. 20a: X-rays used in medicine. Fig. 20b: Galaxy M81 with the core photographed in X-ray, suggesting the presence of a very massive black hole

In the cosmos, X-rays are characteristic of very energetic events and objects: black holes, quasars, supernovae, etc.. The Chandra space telescope's mission is the detection and monitoring of these objects (figure 20b).

Gamma Rays

At the end of the spectrum, with wavelengths even shorter than X-rays is gamma ray radiation. It is the most energetic radiation and it is produced when matter (an electron) find antimatter (a positon). In the cosmos there are various sources (figure 21a), and it is not unusual to detect occasional violent eruptions which emit a powerful blast of gamma rays for a few minutes or hours.

As they are so short, the problem is to detect them and define their exact location to know what object is producting the radiation. Objects such as Active Galactic Nuclei, pulsars, and supernovae have been identified as gamma ray sources.

On Earth, this radiation is emitted by most of the radioactive elements. Like the X-rays, they are used both in medical imaging (figure 21b) and therapies to cure diseases like cancer.

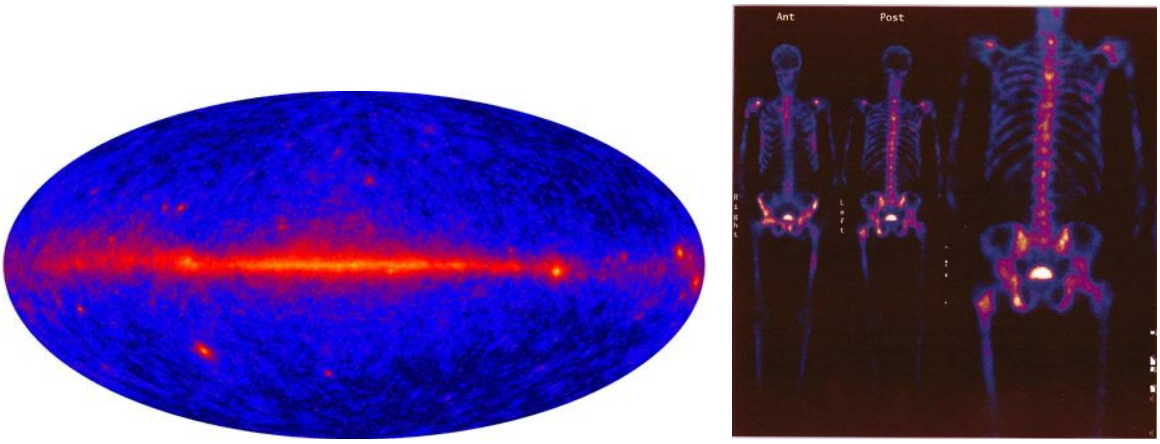

Fig. 21a: Map of the Universe as seen by the "Fermi Gamma-ray Space Telescope”. The center line is our galaxy. Fig. 21b: Bone scan with gamma of the human body

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Expansion of the Universe

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Summary

This workshop contains several simple activities to do in which we are going to work with the key concepts of the expanding universe. In the first activity we build a spectroscope to observe spectra of gases. In the second, third, and fourth we experiment qualitatively with the expansion of a rubber band, a balloon, and a surface of points, respectively. In the fifth activity we work quantitatively with the expansion of a surface and even calculate the Hubble constant for this case. In the sixth activity we detect the microwave background radiation.

Goals

- Understand the expansion of the universe.
- Understand that there is not a center of the universe.
- Understand Hubble's Law.
- Undstand the meaning of the dark matter and simulate gravitational lens

The Origin of the Universe

The theory of the origin of the universe that is most accepted today is known as the Big Bang, a huge explosion that began an expansion of space itself. There are not galaxies moving through space, but it is the space between them which expands, dragging the galaxies. For that reason, we may not speak of a center of the universe, as nobody can speak of a country that is in the center of the earth's surface.

The recession velocity of a galaxy is proportional to the distance it is from us. The constant that relates is called the Hubble constant. Hubble's law relates linearly the distance of a galaxy to the speed with which it moves away.

The first verification of the Big Bang came with the observation of redshifts in the spectra of galaxies, and the final proof to the Big Bang theory was the detection of the cosmic microwave background.

Redshift

If at the laboratory we look with a spectroscope at the light coming from a hot gas, e.g., hydrogen, we will see some colored lines that are typical of that gas at a determined wavelength. If we do the same with the light coming from a distant galaxy, we will see these lines slightly displaced (figure 1). It's called redshift, because in most galaxies the lines are moving towards that color.

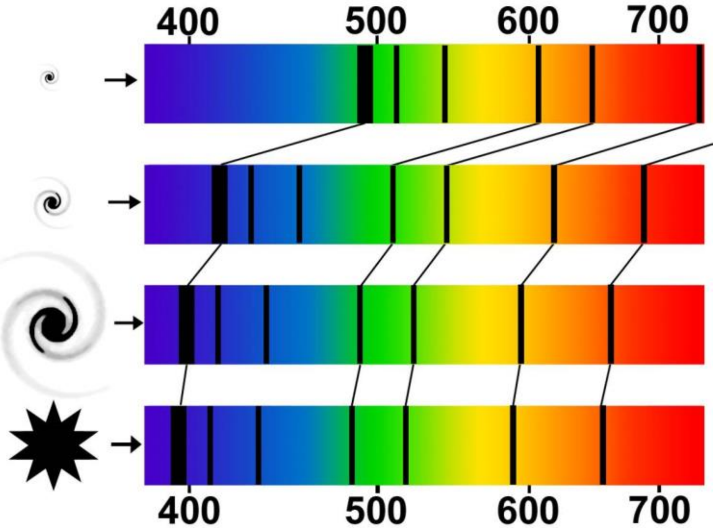


Fig.1: The farther the galaxy, the more the spectrum shifts towards red, which tells us that the galaxy is moving away from us faster.

The redshift of light is due to the flight of the galaxy away from us, similar to a locomotive whose whistle tone changes when it moves towards or away from us, and the larger the shift, the greater the speed.

Studying the spectrum of our local group galaxies, we find that the Large Magellanic Cloud is receding from us at 13 km/s, and the Small one is receding at about 30 km/s. Andromeda moves about 60 km/s towards us, while M 32 (one of its satellites) recedes at 21 km/s. In other words, nearby galaxies have small and irregular relative movements.

But if we look at the Virgo cluster, at an average distance of 50 million light years (ly) away, we see that all are receding from us at speeds between 1000 and 2000 km/s. And in the Coma of Berenice supercluster 300 million ly away, the speed rates are between 7000 and 8500 km/s. But looking in the opposite direction, we find that M 74 is receding from us at 800 km/s and M 77 at 1130 km/s. And if we look at galaxies more and more distant and faint, the recession velocity is even greater: NGC 375 moves at 6200 km/s, NGC 562 at 10,500 km/s, and NGC 326 at 14,500 km/s. All but the very close galaxies are moving away from us. Are they angry with us?

Activity 1: Doppler effect

In the Doppler effect the wavelength of a sound varies when the source is moving. We experience it in the sound of motorbikes or cars in a race: the sound is different when approaching and moving away from us. Other familiar examples are a fire truck that passes by us, the whistle of a moving train, etc.

You can reproduce it spinning on a horizontal plane a buzzer, for example, an alarm clock. We place it into a cloth bag (figure 2a) and tie it with a string. When we spin it over our heads (figure 2b), we can hear it when it approaches the viewer: λ is shortened and the sound is higher pitched. When it goes away from us, the λ is stretched and the sound is more bass, or lower pitched. The one in the center of rotation does not experience it.

Fig. 2a: Alarm clock, bag and string, Fig. 2b: We revolve over our heads. Spectators off to one side notice the differences in the ringtone

This is the Doppler effect due to displacement. But it is not the one that galaxies have with the expansion. The galaxies don't move through space, it is the space between them that expands.

Activity 2: The "stretch" of the photons

The Universe, when it expands, "stretches" the photons in it. The longer the duration of the photon trip, the more stretching it undergoes.

You can make a model of that stretch with a semi-rigid cable, which is used in electrical installations of houses. Cut about one meter of cable, and bend it by hand making several cycles of a sinusoid, representing various waves (figure 3a).

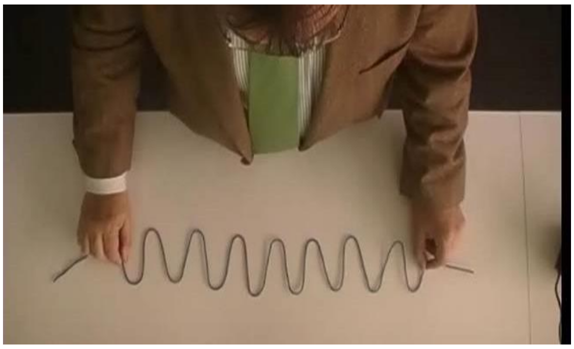


Fig. 3a: Made waves with rigid cable.

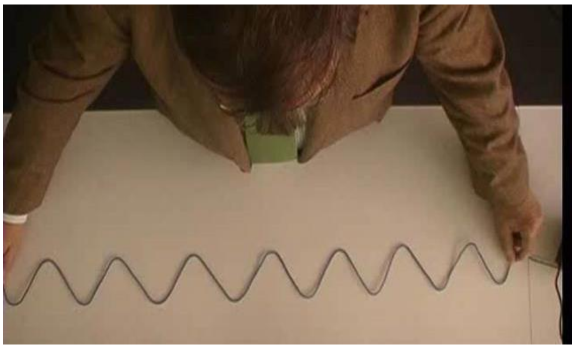
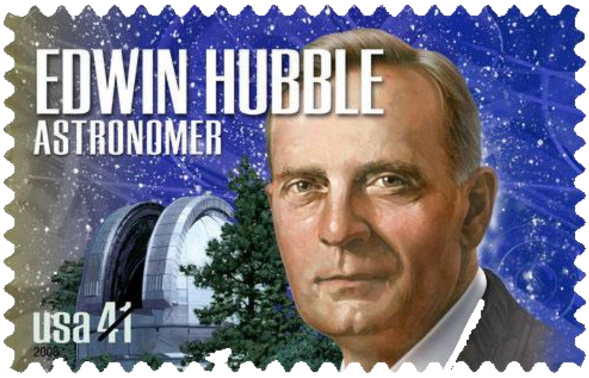


Fig. 3b: Same waves showing a longer wavelength.

Take the cable with both hands and stretch (figure 3b) and observe that the wavelength increases, as occurs in the radiation that comes from a galaxy. The parts farther away from us have had more time to stretch and moved further into the red (λ larger).

Hubble's Law

It was Edwin Hubble (figure 4) who, leaning on these data, established in 1930 the law that bears his name: the more distant a galaxy is the faster it moves away from us. This indicates that the universe expands in all directions, so that all bodies that are in it are receding from each other. The movement away from us we see in all the galaxies does not mean that we are in the middle of them: an alien would look the same from anywhere in the universe, as happens in an explosion of fireworks: all light particles will be moved apart by the explosion of gunpowder.



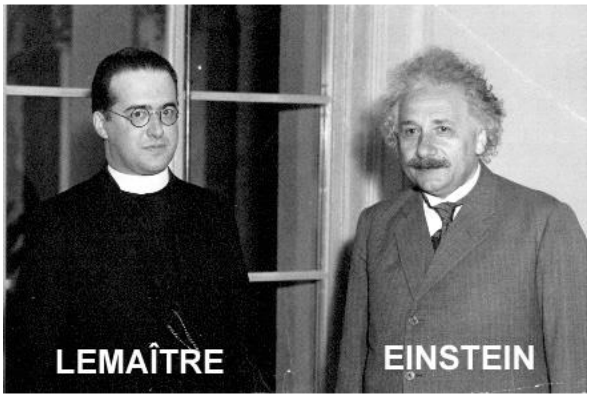


Fig. 4: Edwin Hubble, Fig. 5: George Lemaître and Albert Einstein.

However, the real model is not a galaxy moving through space, but it is the space between them which expands, dragging the galaxies.

If space expands in all directions, it means that if time were turned back, the matter should be focused on some initial moment where everything started.

That was how the Belgian priest and astronomer George Lemaître (figure 5) established the most widely accepted model of the universe today: there was an original big explosion, and in it we are still involved. In this expansion it is the space itself that expands. To understand this, imagine a rubber balloon with a series of points drawn on its surface, representing galaxies (figure 6). As it bulges, the elastic space between the speckles increases. Likewise, as time passes, the space will expand, and the contained substance itself is separating.

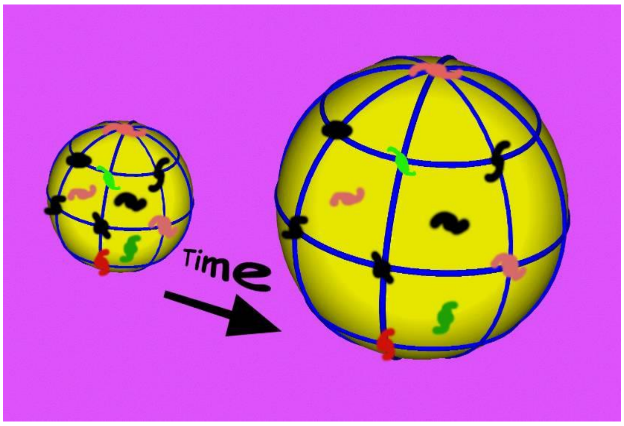


Fig. 6: As time passes, the space expand, and the material contained there in is separating from each other

Therefore, the recession velocity of a galaxy and its distance from us appears to be proportional. The constant that relates is called the Hubble constant. The Hubble law relates the distance of a galaxy with the speed with which it departs:

$$v=H\cdot d$$

One can roughly determine its value by knowing the speed and distance of some galaxies. The rate at which a galaxy is moving away is easy to measure accurately by the redshift, but measuring the distance, especially in the case of the more remote galaxies, is more difficult. Scientists do not agree on the value of the Hubble constant. Using one method or another, the emerging values generally range between 50 and 100 km/s per Megaparsec. The currently accepted value is approximately 70, indicating the age of the Universe to be 13,700 million years.

Activity 3: The Universe in a rubber band

Edwin Hubble discovered that all galaxies are receding from us. The farther they are, the faster they do it. The so-called Hubble's Law states that the recession velocity of a galaxy relative to us is proportional to its distance. It is a logical consequence of the expanding universe. And although all galaxies are receding from us, it does not mean that we are the center of the universe.

With a marker, make a mark every centimeter on a rubber band. Each mark represents a galaxy (A, B, C, …). Our galaxy will be the first one. Place the rubber next to the ruler (figure 7a), and allow our galaxy to coincide with the mark of 0 cm. The other galaxie A, B, C, … coincide with the marks 1, 2, 3, 4 ... cm.

Stretch the rubber band (figure 7b) so that our galaxy remains at the 0 cm mark and that the following galaxy (A) be put on the 2 cm mark. The distance of this galaxy to our own has doubled. What happened to the distance between the other galaxies B, C, D and our own? Have they also doubled?

Fig. 7a: Rubber band without stretch.

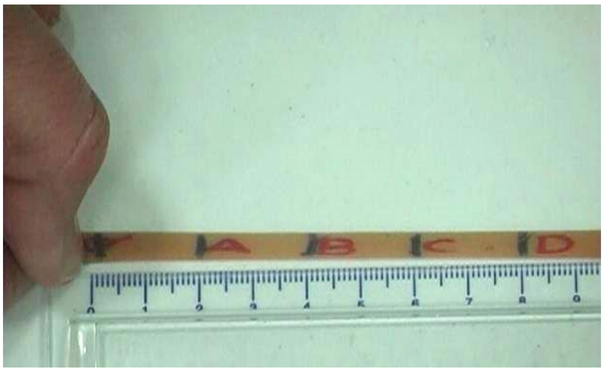


Fig. 7b: Stretched rubber band.

Suppose that the time spent on the stretch of the rubber was 1 sec. Are the receding rates of the other galaxies all the same, or are some moving away faster than others? How does an inhabitant of the next "galaxy" see our galaxy and other galaxies? Do they also have all of them moving away?

Activity 4: The universe in a balloon

Within the expanding universe, there is space between galaxies that expands. The galaxies themselves do not expand, nor do our houses. What is tightly bound by gravity does not increase in size.

There's a simple experiment that can demonstrate this. Just use a balloon and inflate it a little at first. Then paste a few pieces of cotton onto the surface with masking tape (coins also work). Then inflate the balloon until it is full. The pieces of cotton will be separated from each other (figures 8a and 8b). Some appear to go farther than others, but none become closer. It is a very simple model of the expanding universe.

Fig. 8a: Pieces of cotton glued to a slightly inflated balloon, Fig. 8b: The pieces of cotton move away when the balloon is more swollen

Activity 5: Calculation of the Hubble constant

Hubble's Law says that the velocity *v* of a galaxy is proportional to the distance from us:

$$v=H\cdot d$$

The constant H is called Hubble constant, and you can calculate it using distances and velocities of some galaxies. From the formula above:

$$H=\frac{v}{d}$$

The diagram of figure 9 shows space, represented by a blue grid of dashed lines, with us in the center and several blue galaxies at a distance from us. After some time, say 10 seconds, space has expanded and both the grid (in solid lines) and galaxies are represented in red.

Fill in table 1 beneath the drawing. In each row put in the data for each galaxy. For example, the coordinates are calculated with the blue squares (dashed lines) or red (solid lines) as galaxy A or A' respectively, and the distance d is obtained by measuring the length in centimeters with a ruler, starting at the center of our galaxy. The column data Δd must be obtained by subtracting the distance from A' and A. In the last column we must use the distance before expanding (eg A, not A') in the denominator.

Check that:
a) The coordinates of each galaxy do not vary with the expansion (galaxies do not move through space).
b) The value of H is fairly constant regardless of the galaxies.

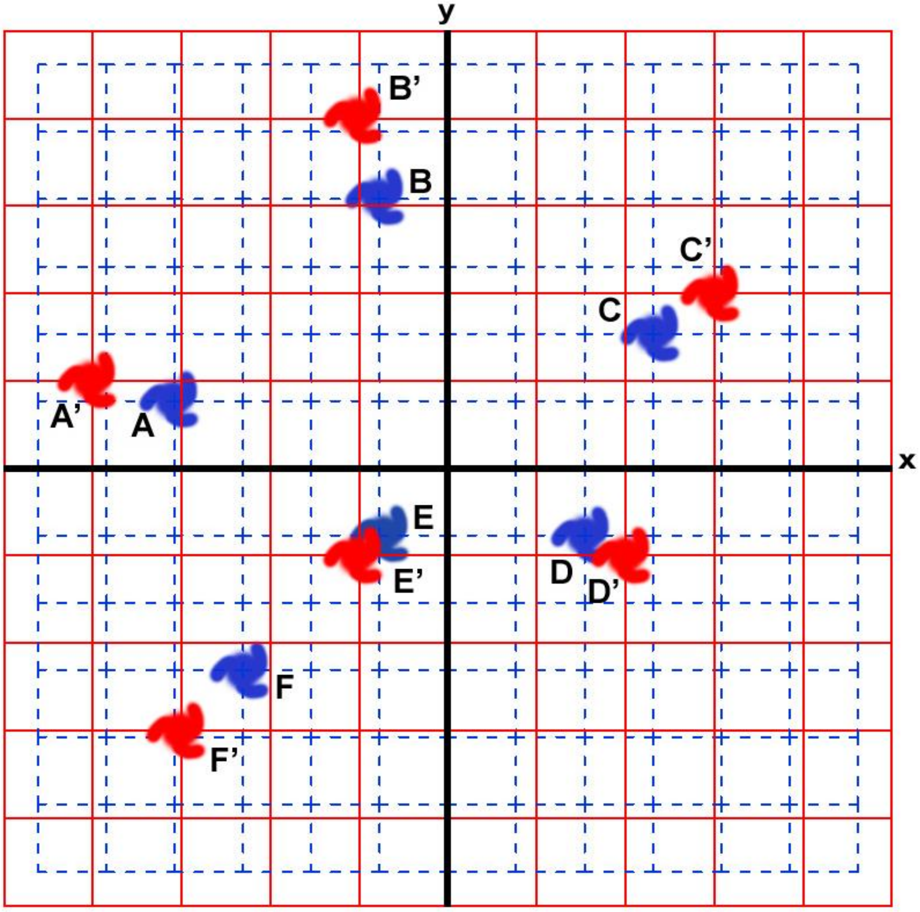


Fig 9: The grid of solid lines (red) is the same as the dashed one (blue) but expanded. The galaxies are attached to the grids.

Galaxia	Coordenadas x,y	d=distancia al origen	Δd	$v = \frac{\Delta d}{\Delta t}$	$H = \frac{v}{d}$
A	(-4, 1)				
A'	(-4, 1)				
B	(-1, 4)				
B'	(-1, 4)				
C	(3, 2)				
C'	(3, 2)				
D	(2, -1)				
D'	(2, -1)				
E	(-1, -1)				
E'	(-1, -1)				
F	(-3, -3)				
F'	(-3, -3)				

Table 1: with the coordinates written as an example

Galaxy	*Coordinates x,y*	*d=distance from origin*	Δd	$v=\frac{\Delta d}{\Delta t}$	$H=\frac{v}{d}$
A					
A'					
B					
B'					
C					
C'					
D					
D'					
E					
E'					
F					
F'					

Table 2: To be completed with data from figure 9.

The Big Bang

Currently, the theory of the origin of the universe as a huge explosion is widely accepted in the scientific community, although there are those who doubt and feel that there are still details left unexplained. In 1994 the American magazine *Sky & Telescope* had a contest to rename it again. 12000 submissions were received, but none could unseat the one it already had: the Big Bang theory. The name was chosen as a disparaging one by the astronomer Fred Hoyle, who, with certain anti-religious bias, thought it seemed too consistent with the idea of a Creator.

With the observation of an expanding universe, it shows that in turning back the time there was a principle on which the explosion occurred, giving rise to space and time as we know it now. We may ask how it happened and why it happened. Science does not have an answer because it only works with the functioning of what already exists. Science can try to explain how things worked from the Big Bang, but not why matter exists. That kind of question is for the philosophers, who study the meta-physical (beyond physics).

Some attempts to explain the cause by resorting to some physical concepts such as quantum fluctuations of vacuum confuse the vacuum with nothing: the quantum vacuum exists, it has space and some energy. The concept of nothing, meaning absence of all existence, including space, is not scientific, it is metaphysical. Into nothing, anything can not exist and fluctuate. Other theories talk of multi-universes but by definition are impossible to verify (if we could in some way observe other universes, then they would be part of ours, because our universe is all matter that is within reach in some way). For that reason, those theories are not really scientific.

Let's return to science. At the initial instant, all matter and energy was infinitely small and dense. The Big Bang was the explosion of space at the beginning of time, and from that moment, the matter became operational, with laws that were written in it, and that led the universe to the current state.

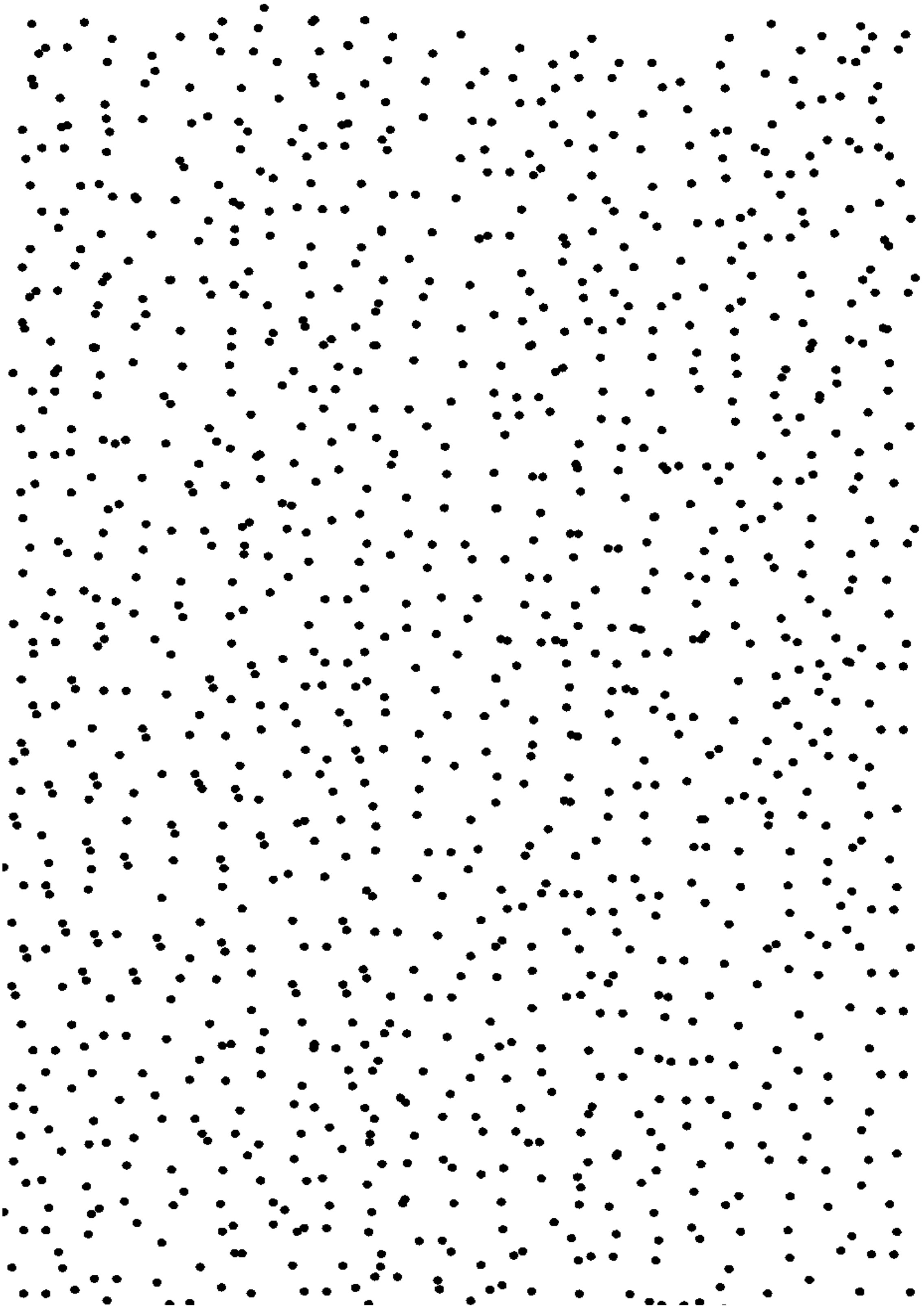


Fig. 10:Photocopy this page on a transparency and then another enlarged 105%.

Activity 6: There is no center of expansion

On the next page is a drawing (figure 12) with many points that simulate galaxies at a given time. First make a copy on transparent paper and then another on a different transparent paper, slightly expanded (e.g. 105%).

If superimposed on an overhead projector (figure 11a), we get an image that represents the expansion of space over time: match the images at one point, and you can observe the displacement of all radial points very well, which is greater the farther you are from the coincident point. It seems as if the points move away faster the farther they are from the coincident point.

But if the matching is at another point (figure 11b), it is the same. So it is in space: from our galaxy we see that all move away from us, and they move faster the farther away they are from the observer. We think we are in the center of the universe, but we're not, as an observer in another galaxy would see the same thing and that would seem to be in the center. There really is no center.

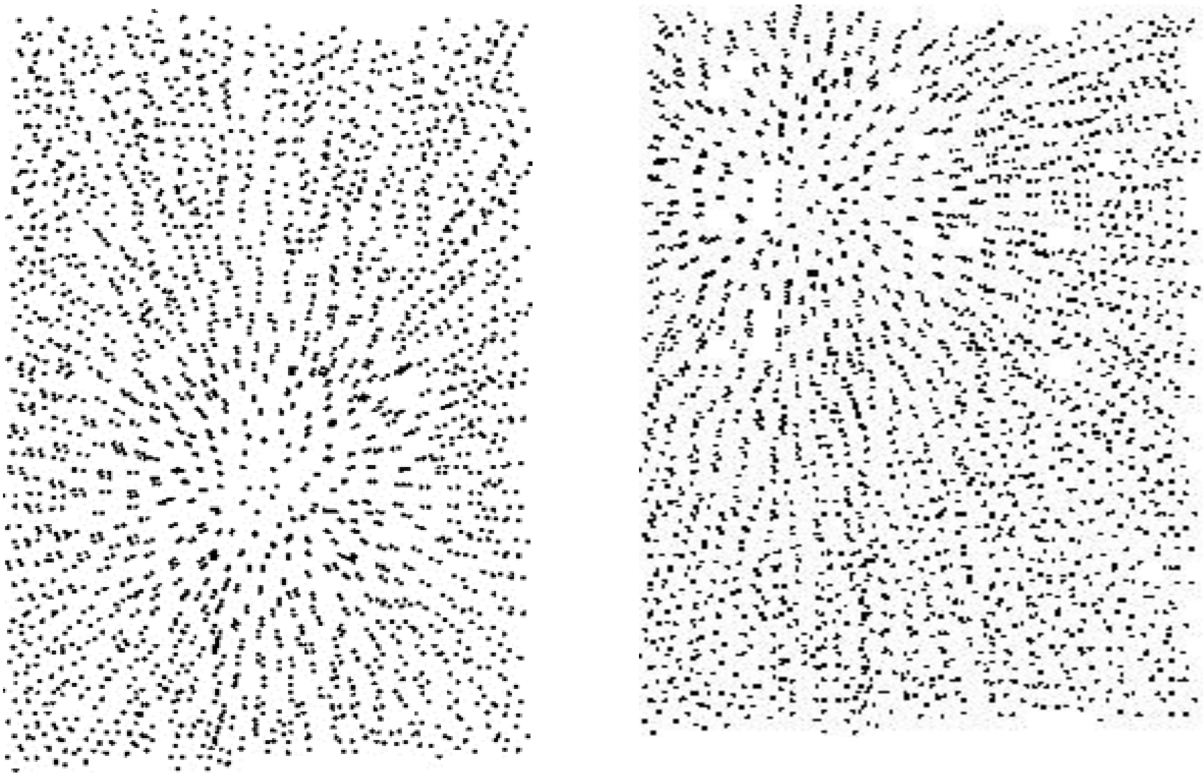


Fig. 11a: Superposition of two slides, one enlarged by 105%, Fig. 11b: To an observer in another point, it also seems that everything moves away of him: there is no a center of the universe.

Development of the Universe

To get an idea of the later history of the universe, assume that all the time since the Big Bang is compressed into one year from January 1 to December 31 (see figure 12).

In April our Milky Way was formed. In August the sun formed, and the Earth was spherical by end of the month. But it is not until October that oxygen is present in our atmosphere. Although very simple living cells appear on Earth immediately, nucleated cells appear on December 2, and on Dec 12th the first multicellular organisms are present. On the 19th the first fish appear, as do the plants, insects and amphibians on the 21st through the 22nd. On the 25th dinosaurs appear, lasting until the 28th. On the 30th the mammals are living on Earth, but it's not until December 31st, at 11 pm, when man appears. At 11:57 pm is when Neanderthal man lived, and the painting of the caves of Altamira happened in the last minute. Five seconds before twelve o'clock at night is when Jesus Christ was born. The last century is in the last two tenths of a second.

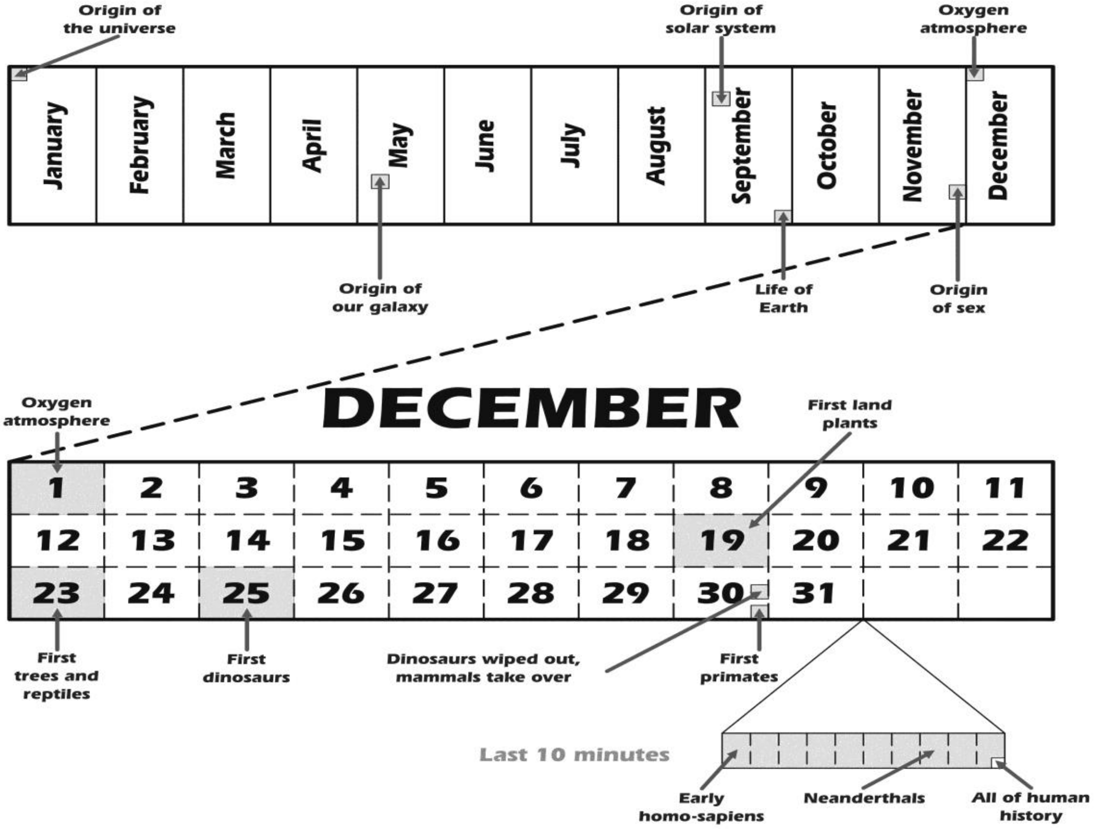


Fig. 12:. The Cosmic Calendar. The history of the Universe compressed to one year. All of recorded history (human civilization) occurs in last 21 seconds

Microwave background radiation

In the beginning, at very high temperatures, the four forces we now know were unified. Gravity, electromagnetic force, strong and weak nuclear forces (the latter two only act within atoms) were united. Then they separated and formed photons, electrons, protons and other elementary particles. While the universe is expanding, it is getting cooler. After 300,000 years, the temperature dropped enough to allow atom formation, mostly hydrogen and helium. The density decreased, and the photons were free to move in all directions: there was light. Scientists say that the universe became transparent. These photons are now traveling through space, although it has cooled, so the wavelength has increased dramatically (figure 13), and they become much colder photons, which transmit an energy of only 2.7 degrees Kelvin. This is called Cosmic Microwave Background or CMB.

This background radiation was first detected in 1964 by Amo Penzias and Robert Wilson in the United States. They were trying to remove all the noise in their radio telescope when they caught a 7.35 cm wavelength emission which was always present, regardless of where the huge antenna pointed. They reviewed all the installation and even thought that some birds that nested in the antenna could be the cause, but they could not eliminate this background noise. They concluded that it came from a body transmitter, which had a temperature of 2.7 Kelvin – the current temperature of the universe – and was not in any particular place. It was the universe itself that this background radiation emitted, a relic of the Big Bang. Anyone can detect it with an analog TV tuned to a free channel: about one in every ten points you see on screen comes from that background radiation. Those emissions are in the field of microwaves, similar to home ovens, but with very little energy:it could only heat food 2.7 K.

Fig. 13: Over time as space expands, the photons expand in wavelength. This is the microwave background radiation.

Although this radiation appeared remarkably uniform, G. Smoot, R. Mather and his colleagues were able to see very slight variations in measurements made by the COBE satellite (figure 14a), to the order of millionths of a degree. Simultaneously these fluctuations were detected in the ground in the experiment of Tenerife in the Canary Islands Institute of Astrophysics. And in 2001 NASA launched the WMAP telescope to study the background radiation with considerably more resolution (figure 14b).

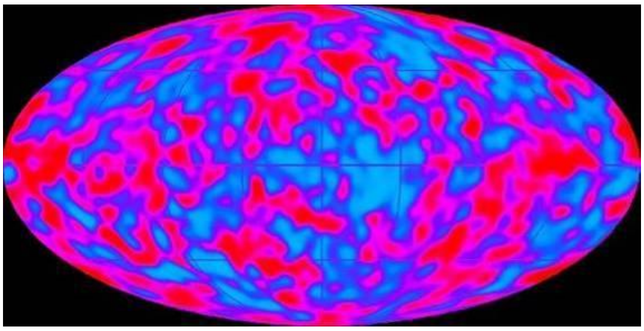


Fig. 14a: COBE image.

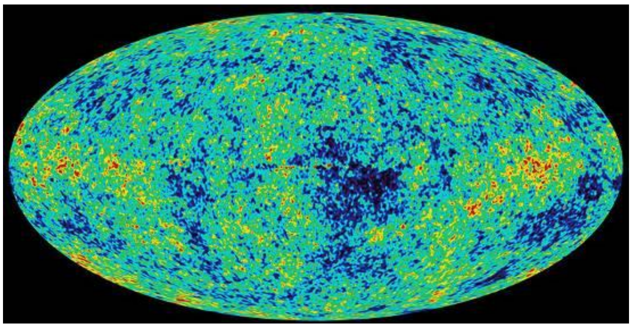


Fig. 14b: WMAP image.

Although small, these variations are the imprints of lumps of matter from which galaxies began to form. We do not know what had caused these fluctuations in density. What we can say is that the "wrinkles" in this area occurred, and condensation began to occur in the proto-galaxies only a few hundred million years after the Big Bang. Almost simultaneously the first stars had formed in these early galaxies.

Activity 7: Detection of microwave background radiation

Around 300,000 years after the Big Bang, photons were separated from matter and began to travel freely through the universe. When the space expanded, these photons were extending their wavelength. Now we estimate they have a wavelength of about 2 mm wavelength, which corresponds to the microwave region, and is equivalent to that emitted by a black body that was at 2.7 degrees Kelvin.

Also we can detect this background radiation with a simple television (figure 15). To do this, tune the TV to an analog empty channel. The image is composed of a multitude of constantly changing points. Approximately 10%, ie one in ten come from the background radiation of the universe.

Fig 15: Some of the points of an analogue untuned television screen comes from microwave background.

Why is it dark at night?

This was the title of an interesting article that the German Heinrich Olbers released in 1823. Previously, in 1610, Kepler had considered it as a evidence that the universe could not be infinite. Edmund Halley, a century later, noticed some particularly bright areas in the sky and suggested that the sky is not uniformly bright during the night because, although the universe is infinite, the stars are not evenly distributed. Even the writer Edgar Allan Poe (1809-49), wrote on the subject[1]. However, the issue went down in history as the Olbers's Paradox.

Fig. 16a Johannes Kepler, Fig. 16b Edmund Halley, Fig. 16c Heinrich Olbers and Fig. 16d Edgar Allan Poe

The answer seems trivial, but not so after reading the article from Olbers. Olbers's reasoning led to the paradox that the night sky should be as bright as the most glorious day. Let's see the reasoning.

Olbers's reasoning was based on the following principles:

1 .- The universe is infinite in extent.
2 .- The stars are distributed more or less evenly throughout the Universe.
3 .- All the stars have a similar average brightness across the universe.

Look at the universe from Earth. Suppose a first spherical shell of stars in the sky at a distance R_1. The number of stars it contains will be N_1. Suppose a second spherical shell at a greater distance R_2. Each of its stars will be illuminated by far less, yet the layer is larger and contains more stars, according to principle No. 2, and counteracts the lesser light (the light intensity decreases proportionally to $1/R^2$, and the area of the layer, and therefore the number of stars increases as R^2). The conclusion is that the second layer illuminates the Earth just like the first. And according to principle No. 1, there are infinite layers, so the conclusion is that the sky should appear bright at night.

Another way of putting it: if we observe the night sky, where there are countless stars, our eye should always be seeing the surface of a star, and therefore we should see a bright spot there. And if that happens across the sky, it should appear totally brilliant.

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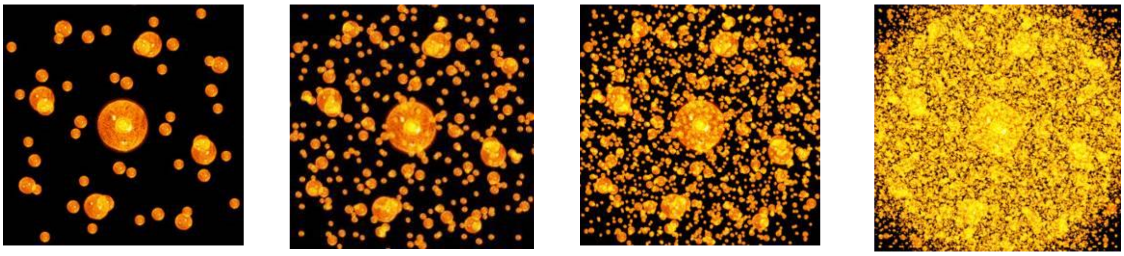
[1] In "*Eureka"*, a scientific essay published in February 1848, he gave the following explanation for the "empty" dark between the observed stars: "*We could comprehend the voids which our telescopes find in innumerable directions assuming that the distance from the invisible bottom is so immense that no ray of light from there has yet been able to catch us".*

Obviously this is not true. This paradox of Olbers caused a lot of controversy and could not be resolved properly until the early twentieth century with the Big Bang theory. The argument itself is correct, but it fails in its principles. Indeed, with the expansion of the universe, the light from distant stars are at a larger redshift then the further away they are. That implies a weakening in the intensity of radiation, so the principle No. 3 is not correct. We also know that the farther away the star, the longer ago the light left it, so we see it as it was long ago. The more distant stars were formed shortly after the Big Bang, but we can't observe more than that because there aren't infinite layers of stars — the principle No. 1 is also false.



The light coming from nearby stars

But there are also further stars who send us their light

The further, more stars

From any point in the sky we should reach the light of a star

Fig. 17: By wikimedia commons

In the twentieth century, the solution to Olbers's Paradox was resolved with the understanding of the expansion and particularly with the age of the universe, which is not infinite. Fortunately, the night could still be dark!

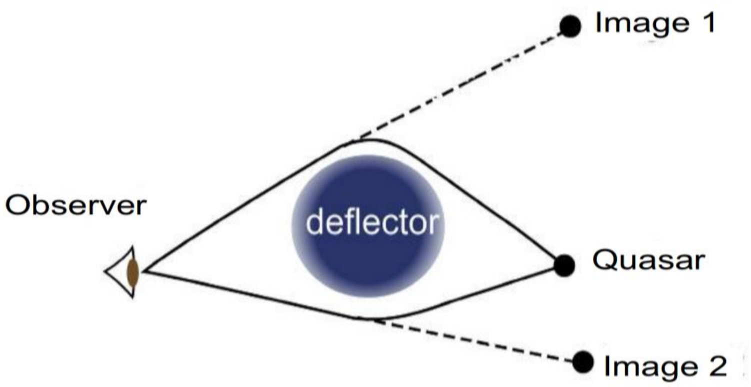
Gravitational lenses

Light always follows the shortest possible path between two points. But if a mass is present, then space is curved and the shortest possible path is a curve as seen in figure 18a. This idea is not difficult for students. We can easily show it on a terrestrial globe (figure 18c). Obviously they can understand that on the surface of the Earth the distance between two points always follows a curve.

Fig. 18a and 18b: If the space is curved, the shortest path between two points is a curve, Fig. 18c: The shortest path above the terrestrail surface is not a straight line.

In general, we can imagine a gravitational lens as an ordinary lens, but in which the deflection of light is produced by a large mass that is in the path of the light, called deflector (figure 19a).

Gravitational lenses produce a curvature in the beams of light that are emitted by astronomical objects. If these objects are point sources (stars or quasars), they appear to be in a different place from where they actually are, or sometimes even multiple images of the object are produced (figure 19b). If the emitting objects are extended (e.g., galaxies), the images appear distorted as bright arcs (figures 20a, 20b and 20c).



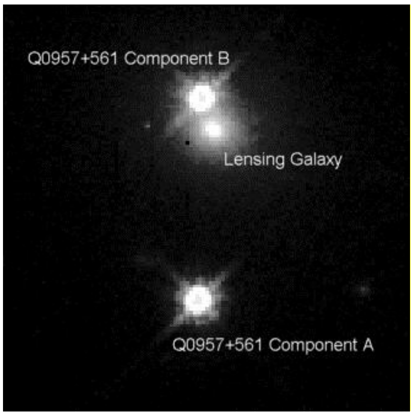
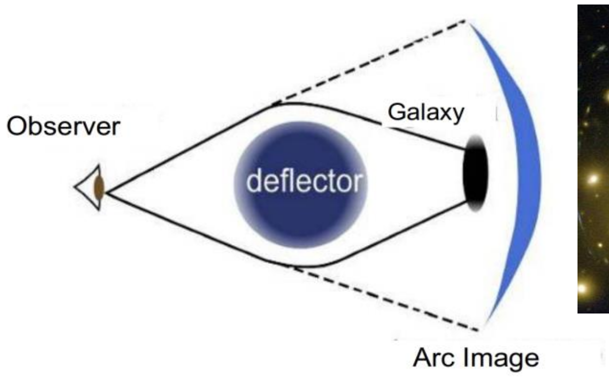
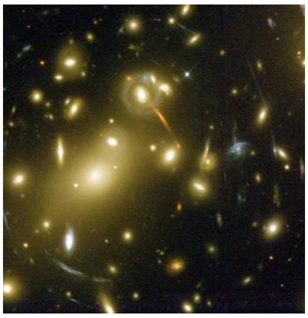


Fig. 19a: The observer sees two images, because it appears as though the light is coming from two different places, Fig. 19b: Picture of the double quasar Q0957+561 image. The deflector is the galaxy close to the B component.





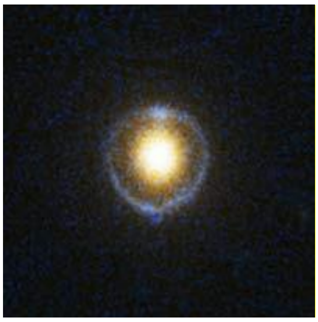


Fig. 20a: If the body diverted is an extended object, the images obtained are a set of bright arcs or a complete ring, Fig. 20b: Giant luminous arcs formed by the galaxy cluster Abell 2218, Fig. 20c: Complete ring of a galaxy behind the deflector.

Activity 8: Simulation of gravitational lens with a glass of wine (red and white).

We can simulate a gravitational lens using a glass of wine. This experiment allows you to "show" how matter can introduce distortions in the images observed. Now let’s simulate the Einstein ring or multiple images.

Take a flashlight, place it on the other side of a glass full of red wine or juice and observe the ray of light passing through it.

It is easy to see that this simulation leads to the "distortion of space" that is observed. Simply place the glass on graph paper and look through the white wine (or apple juice). We see the distortion of the graph lines (figures 21a and 21b).

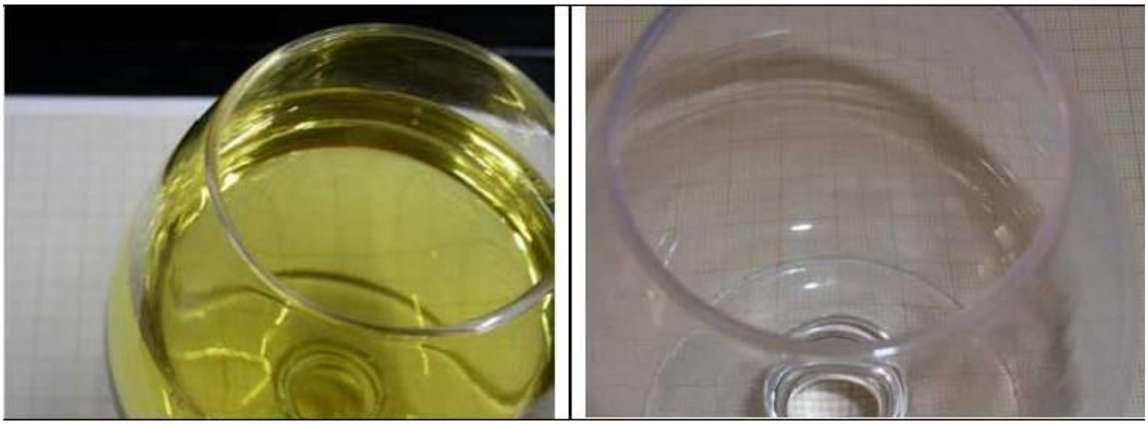


Fig. 21a and 21b: We only can see the distortion of the graph paper if the glass is full of white vine.

Looking at the ray of light, we move it from right to left and from top to bottom. We note that the light is not a point: the wine produces images repeatedly and in some cases some arches. This is a consequence of the glass acting as a lens that distorts the light trajectory. In particular, we can sometimes see an amorphous figure, or a bright red dot, four red dots or a red bow between points (figures 22a, 22b and 22c).

Fig. 22a: The flashlight beam is distorted as an arc between two bright red spots, Fig. 22b: like an amorphous rectangle, and Fig. 22c: the Einstein cross.

Fig. 23: Grid deformation.

We can also simulate the gravitational lens looking through the glass foot of the wine glass. If we put the foot of the glass on a graph paper and look through it, we can see the deformation of the grid (figure 23).

Moving the foot of the glass slowly from right to left above an object, (e.g., a red circle about 3 cm), we can reproduce the shapes observed through gravitational lenses (figures 24a, 24b and 24c).

Fig. 24a, Fig. 24b and Fig. 24c: The glass foot can simulate various shapes made by gravitational lenses: arc segments, images of points, and Einstein rings.

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Preparing for Observing

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Summary

A star party can be a way to learn and have fun, especially if you do it with a friend or with a group of friends. You have to prepare for it, especially if you plan to use some instruments. But don't neglect the simple joy of watching the sky with the unaided eye or binoculars.

Goals

- Explain how to choose the correct place, time, and date, what equipment you will take and how to plan the event.
- Learn to use the program Stellarium.
- Recognize the Light Pollution problem.

Choosing the place and date

Atmospheric light greatly affects our perception of the sky. In cities you can only see the sun, the moon, a few planets, and a few bright stars and satellites. It is far better to observe from a dark location, although you might have to give up the advantage of being able to do it at school or from home.

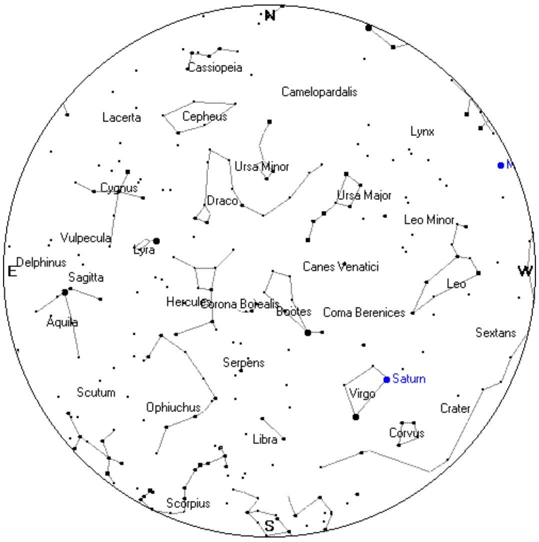
If you want to see more stars and nebulae, you must go to a site away from roads and towns, because cities send up a halo of light that prevents proper vision. This phenomenon is known as "light pollution". Also avoid the vicinity of isolated lamps or lights. Stay away from roads where cars can dazzle us with their headlights; look for a clear area where large trees don't interfere with your view of the sky.

In choosing a date, of course, you want clear weather without clouds. It's even better when the temperatures are comfortable (we recommend checking the weather by Internet). The phase of the Moon is very important. The worst days are when the moon is full, since it will produce a lot of ambient light and we will see only the brightest stars. When is waning, the moon will rise later, we will not see it unless we stay watching until dawn, but dark skies are assured in the early evening. Perhaps the most interesting are the days when the moon is just under first quarter, since the early hours of the night we can see the craters of the moon, and as the moon sets under the horizon, a few hours later, dark sky for our observing session.

If we have a telescope we should go to chosen location before sunset while we have enough natural light to set up the equipment before darkness.

Equipment needed

Planning the observations. We need to remember that the sky changes as the observer's latitude. You can get the program Stellarium (www.stellarium.org, See the Annex to this unit for a quick guide), look in astronomy magazines, or examine books. On the web there are many places to obtain sky charts, for example www.heavens-above.com/skychart or in www.skyandtelescope.com. To obtain any of these sky maps you must indicate the location, (usually latitude and longitude), date, and time of day.



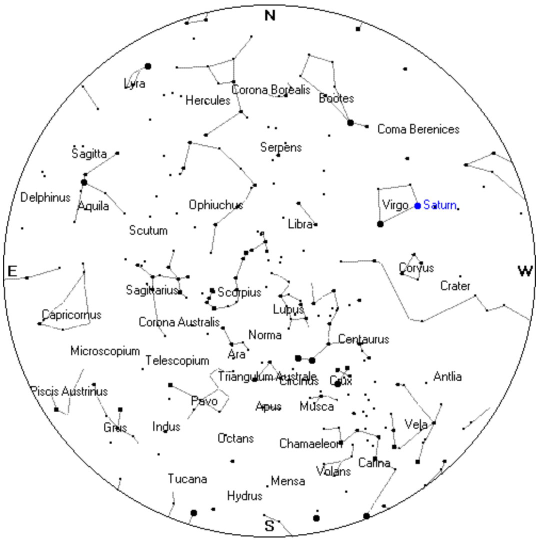


Fig. 1: Example of plane of the sky (SkyChart). This is for a mid-latitude north, at the middle of July at 22 h, Fig. 2: Example of the plane of the sky (SkyChart). This is for a mid-latitude southern, at the middle of July at 22h.

Red flashlight. In the darkness, our eyes slowly open to let in more light, which ensures us to "see" at night; this ability is called "night vision". Night vision is related to one of the two types of photo sensitive cells in the retina: the rods. In the retina there are two types of cells: the cones, sensitive to color and that are activated in bright light, and rods, which are only active at low light levels. If suddenly the area where we are looking become illuminated, the pupil is closed immediately and the rods are disabled. If entering the dark again, the pupil will take a short time to open fully again, but the rods will take at least 10 minutes to allow night vision back. The rods are less sensitive to red light, so using a red light fools the eye into acting as if it was much darker. They will retain night vision better. To create a red flashlight we use a normal flashlight and we add a simple filter using a piece of transparent red paper.

Food. We have to consider the real time of the activity will be several hours, counting travel, material preparation, observation, collection and the return journey. The activity will be more pleasant if we share some food and drink (hot or cold depending on the seasonal temperature).

Green laser pointer. It is useful to point out constellations, stars, etc. Be very careful with this type of pointer. Never point towards the eyes of the participants in the observation or to anyone, it can damage them. Never point at airplanes. This tool only can be manipulated by adults.

Clothes. Even in summer, in the evening, the temperature always goes down, the wind often blows, and we must keep in mind that we need to be there for a few hours and the weather could change. Plan for it to be much cooler than the daytime temperature.

Binoculars, telescopes, camera (see below) these materials change depending the observations that we plan.

If there are clouds. A cloudy sky can upset the whole plan. However we have provided an alternative plan: telling stories about mythology of constellations or talk about any astronomical topic. If we have Internet, we can enjoy the popular Google-Earth, but watching the sky (Google Sky) or Mars, or any other simulation program of the sky, or can see a video about something astronomical in YouTube.

Unaided eye

It is essential to know the sky with the naked eye. That means knowing the names of the major constellations and the bright stars, you only need a chart of the sky, and if it is possible, a green laser pointer. They are also very useful applications for the iPhone/iPad or Android that can line up with the constellations and planets help you orient to the rest of the sky, using the phone GPS. The phone is not affected by clouds so can serve as an alternative if the sky is covered.

The stars that you see depend on where we are: near the North Pole would see only 50% of the stars across the sky, those in the northern celestial hemisphere. Near the equator will see all of the sky eventually, but which ones on a single night depends on the time of the year. Near the South Pole, we see only half again, in this case the ones which are in the southern hemisphere.

The constellations and stars that we recommend knowing are:

NORTHERN HEMISPHERE
Constellations: Ursa Major, Ursa Minor, Cassiopeia are usually circumpolar, so always visible. In summer also see Cygnus, Lyra, Hercules, Bootes, Corona Borealis, Leo, Sagittarius and Scorpio. The ones you see in winter are: Orion, Canis Major, Taurus, Auriga, Andromeda, Pegasus, Gemini, and the cluster, the Pleiades.
Stars: Polaris (near the North Celestial Pole), Sirius, Aldebaran, Betelgeuse, Rigel, Arcturus, Antares, etc..

SOUTHERN HEMISPHERE
Constellations: Southern Cross, Sagittarius, Scorpio, Leo, Carina, Puppis and Vela (the three constellations formed the ancient constellation of Argo, the ship of the Argonauts). It is also possible to see Orion and Canis Major from this hemisphere.
Star: Antares, Aldebaran, Sirius, Betelgeuse. In the southern hemisphere there is no star that marks the location of the South Celestial Pole.

The constellations that are in the region called the "Zodiac", can be seen from most of the northern and southern hemispheres although they change orientation on the celestial sphere.

It is interesting to follow the changing phases of the moon every day, and its changing position against the background of stars. This last can be done also with the planets, noting its slow movement on other planets near or on the stars. This is especially noticeable in the faster moving like Venus or Mercury, when you see at sunset. These planets also may be visible at sunrise and then you can continue recognizing them in the sky beyond the night of observation.

For a couple of hours after sunset, you can see shooting stars (meteors) at any time, with a frequency of about 5 to 10 per hour. At certain times of the year there are "falling stars", which are many more. For example around January 3 are the Quadrantids, with about 120 per hour, on August 12 Perseids, with 100 / h, on 18 November is the peak of the Leonids, with about 20 / h, and between 12 and 14 December are the Geminids, with 120 / h. The Perseids are not visible from the southern hemisphere.

There are many satellites orbiting the Earth and when they are illuminated by the sun can be seen from Earth, slowly across the sky. As the altitude is usually not much, you just see them just before sunrise or just after sunset, for example, the ISS is very bright and takes about 2-3 minutes to cover the visible sky. The times of these and many other satellites can be predicted over a given geographical location with a week in advance (see www.heavens-above.com).

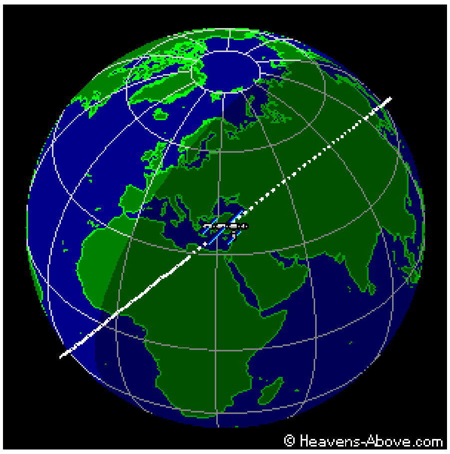


Fig. 3: Path of the ISS

Fig. 4: Expansion and diameter of the objective

Observations with binoculars

A useful and easily available astronomical instrument is binoculars. Although its ability to magnify is usually small, they collect much more light than our pupil, and help us see objects that at first glance are very faint such as star clusters, nebulae, and double stars. Also binoculars have the advantage of increasing the color differences of stars, especially if slightly out of focus.

They usually bear inscriptions such as 8x30 or 10x50. The first figure gives the magnification and the second the diameter of the front lens in mm. One highly recommended size for this activity is the 7x50. At higher magnifications, the image moves a lot, because it is difficult to keep steady, and larger apertures increase the price enough.

Interesting objects to see with binoculars are the Andromeda Galaxy (M31), the Hercules Cluster (M13), the double cluster in Perseus, the Praesepe (M44), the Orion Nebula (M42), the entire area of Sagittarius (nebulae such as the Lagoon M8, Trifid M20, Omega M17, several globular clusters M22, M55, etc..) and in general the Milky Way, seen with many more stars than the naked eye. In the southern hemisphere Omega Centauri and 47 Tucanae are spectacular globular clusters.

Observational telescope

Most people know that the mission of a telescope is to enlarge distant objects, but fewer people know that has another mission as important as this: to capture more light than the human eye. This will allow one to see faint objects that would remain faint even if we increased the magnification.

A telescope has two main parts: the objective and the eyepiece. The objective is a large diameter lens that bends light (refracting telescopes) or a mirror that reflects light (reflecting telescopes). Most objective mirrors are parabolic in shape. The eyepiece is a small lens where, as its name suggests, we place the eye to see. It is usually removable, so that different sizes of eyepiece allow more or less magnification.

The larger the objective is, more light gets collected, and we can see fainter objects. High quality lenses are more expensive than mirrors of the same diameter, so larger telescope are more frequent reflecting telescopes. The most common type is the Newtonian, consisting of a concave mirror at the bottom of the tube, which returns the rays of the top of the tube, where there is a small secondary mirror at an angle of 45º, which deflects the rays to a point outside the tube, where the eyepiece is placed. The secondary mirror blocks some of the incoming light, but is not significant. Another design is the Cassegrain type, which sends the secondary light toward a central hole of the primary mirror. The eyepiece is placed behind that central hole. Finally, there are catadioptics, typically like a Cassegrai but adding a thin lens at the entrance of the tube, there by greatly reduce the length of the tube and make it more light weight and portable.

The magnification of a telescope is given by the ratio of the focal length of objective (either lens or mirror) and focal length of the eyepiece. For example, if we have a telescope with a lens focal length of 1,000 mm and we put an eyepiece of focal length 10 mm, we obtain a magnification of 100. If we want to double the magnification, we will need either a longer focal length objective or put shorter focal length eyepiece. This has a practical limit because eyepieces with small focal lengths are difficult to manufacture and give blurred images.

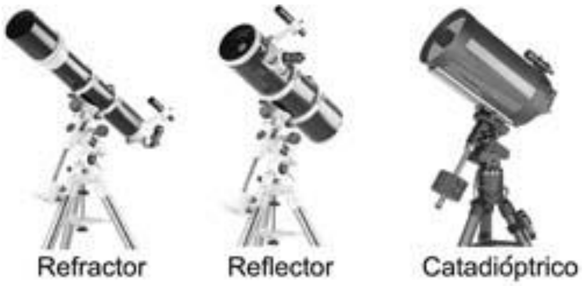


Fig.5: Different optical telescopes

Manufacturers often describe telescopes in terms of focal ratio, for example f / 6 or f / 8. The focal ratio is the focal length of lens or the primary mirror divided by the aperture and if we know two quantities, can calculate the other. For example, if we have a refractor f / 8 and the objective lens is 60 mm in diameter, the actual focal length of the telescope will be multiplied by aperture, namely 8x60 = 480 mm. At the same lens aperture, the larger focal ratio, the smaller field of view and magnification.

The larger the aperture of a telescope will capture more light, and therefore be brighter, and allow you to see fainter objects. Also, it offers a higher level of resolution, which is the ability to see details: when resolution is low you will see a blurred image, and when it is high it looks very clear, with many details. It also influences the darkness of the night: in the days of full moon or light around you can’t see faint stars.

Another important limitation is the atmospheric stability. We've all seen how the warm atmosphere of a desert shakes the vision in movie scenes shot with telephoto lenses. When we look through a telescope, small air disturbances make the image move. Astronomers refer to this as the concept of "seeing". The atmosphere is what makes stars twinkle.

The image that you see with a telescope is reversed, but this does not matter much: in the Cosmos up and down positions are relative. There are accessories that flip the image and put it correctly, but at the cost of slightly lower brightness.

The mount is an important piece of a telescope. A poor quality mount allows the telescope tube to swing every time you touch. The result is a dance in the view, apart from feeling dizzy, you will be unable to see the details. It is important that mounts are rigid and stable.

There are two types of mounts: the azimuth and equatorial. The azimuth mount is the simplest but least useful. It can be rotated left and right about its vertical axis, and up and down around a horizontal axis. The Dobsonian mount is a azimuthal type that is easy to transport and use. In the equatorial mount there are two inclined axes situated at 90 degrees to each other. One, the polar, must be directed to rotational pole of the Earth. It turns in right ascension. The other axis, the equatorial axis, gives us the declinations. This is used by professional astronomers and by many amateur astronomers. They may include a motor in the equatorial axis that compensates for the rotation of the Earth. If not, especially with large magnification, the image leaves the field of vision in a surprisingly short time.

Azimuth mount Equatorial mount Dobsonian mount

Fig. 6: Different mounts support telescopes

If you have an equatorial mount, you should orient it so that the polar axis is aligned with the North Pole (or South) of the sky. That takes time, but is necessary for the equatorial tracking motor, that serves to look at the object, does not move over time, something essential in photography. If we have no motor, exact alignment is less important, but will serve to keep the object in the field of view by moving a single wheel.

Finally, computerized telescopes, with a database of positions of celestial objects and two motors. Once you are set up correctly, these are easier to use. However, you must align it with three known stars in order to set it up, and beginners often are confused by this step.

The sky’s movements

Basically the sky's movements that we observe respond to relative motions of rotation and translation of the Earth. This situation makes that us perceive the sky as a set with two basic movements: daily and yearly.

The diurnal movement is very important, that is very fast and hardly allows us to perceive the annual movement that is much slower. The Earth rotates around 360º in 24 hours; this is 15º every hour. This movement is very noticeable although not we are making not careful observations. The translational motion is 360º every 365 days, which means about one degree every day (just under one degree per day). If we imagine that there were no rotation, we could see in the night sky from one day to the next, the same star at the same time in the same place but run only one degree (i.e. the thickness of a index finger at the extended arm) compared to the previous day. This observation can only be done if we take as a reference one antenna or a post that allows us to relate the observation of a date on the next day. This movement is almost negligible if we do not have a reference and therefore not visible to the naked eye, but what we notice is that the sky of one day of the year is completely different after three months or six months. After three months the translation corresponds to 90º, or about 1/4 the sky and in half a year is ½ sky that is the other side of heaven, diametrically opposed. This movement has been masked night after night because the rotation, but even then we all know that watching naked eye after three months the constellations of the night sky are very different.

Activity 1: Celestial Dome Umbrella

A simple umbrella can allow us to visualize the movements of the sky explained previously. The umbrella used routinely placed over our heads a dome where we can draw the desired constellations. We will use a black gentleman umbrella and on it will draw with white paint.

In this model we will not draw all the constellations, but only we will draw some constellations and only the more important stars in its. We do not search for beautiful result; we want a working model with which we can think.

Each umbrella will serve to display for one of the two hemispheres. The intersection point between the umbrella's cane and the umbrella's fabric is the pole of the hemisphere considered. The area of the edge of the fabric umbrella (where the ends of the rods are protected with a piece of plastic), tacos rods, corresponds approximately to the celestial Ecuador.

Then, the best is to prepare two umbrellas one for each hemisphere.

In the northern hemisphere will draw:

- In the vicinity of the North Pole (close to the cane of the umbrella) the Big Dipper, Cassiopeia and the polar star which is precisely where the umbrella’s cane passes through the fabric
- In the area of the outer edge of the umbrella will draw four constellations, one for each season, the most common and easily recognized:
  - Spring: Leo
  - Summer: Cygnus
  - Autumn: Pegasus
  - Winter: Orion:

Definitely it is possible to choose any other, but must be distributed in an equidistant way, each one located about 90 ° from the previous one.

In the southern hemisphere represent:

- In the environment of the South Pole (close umbrella’s cane) the Southern Cross and the southern celestial pole is located exactly umbrella’s cane passes through the fabric
- In the area of the outer edge of the umbrella we will draw four constellations, one for each season, the best known:
  - Spring: Acuarius
  - Summer: Orion
  - Autumn: Leo
  - Winter: Scorpio:

The idea is to choose great constellations and usually above the horizon. This depends a bit of the place of observation, but this proposal can be adapted to each case.

If the city where we are is located is in the equatorial zone between 20º north latitude and 20º south latitude, it is necessary to draw the two umbrellas. If we are located in the northern hemisphere, at latitude ranges between 30º and 90º we will draw only the umbrella for this hemisphere and the same thing happens if we are in the southern hemisphere.

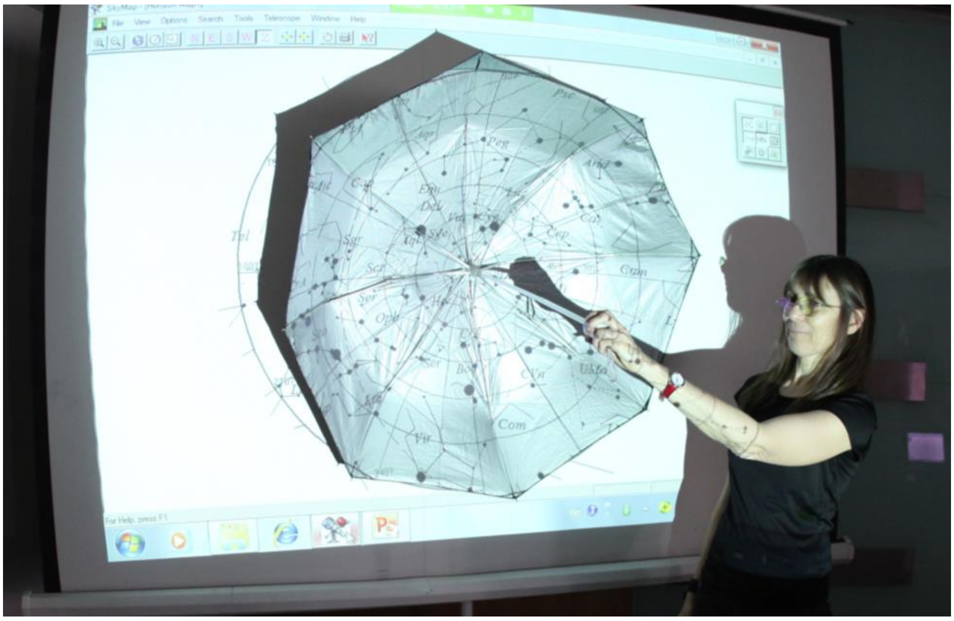


Fig.7: Projecting the stars of the northern hemisphere on a screen to draw the desired constellations. We recommend preparing the model over a black umbrella; although to photography have used one of another color in order to explain the process.

To draw constellations with white paint is very convenient to use Stellarium or a similar software and project the light with a multimedia projector on the umbrella's fabric putting the polo exactly at the point of intersection of the umbrella's cane with the fabric. We will project the corresponding hemisphere (figure 7). Once completed each umbrella we can use it with students placing it above their heads (figure 8).

Fig. 8: Using the northern hemisphere’s umbrella with students

We will put the umbrella’s cane inclined in the direction of the pole corresponding hemisphere (like the rotation axe of the Earth). Imagine the floor of the room up to our neck, this would be the horizon, so that part of the fabric of the umbrella would be below this horizon. Then we distinguish two parts in this imaginary horizon. The part that is near the pole where the sky observed throughout the year is always more or less the same (when looking at the area of intersection stick umbrella fabric). The Ecuador’s area that remains higher above the horizon is the most interesting part because the constellations change throughout the year (figure 9).

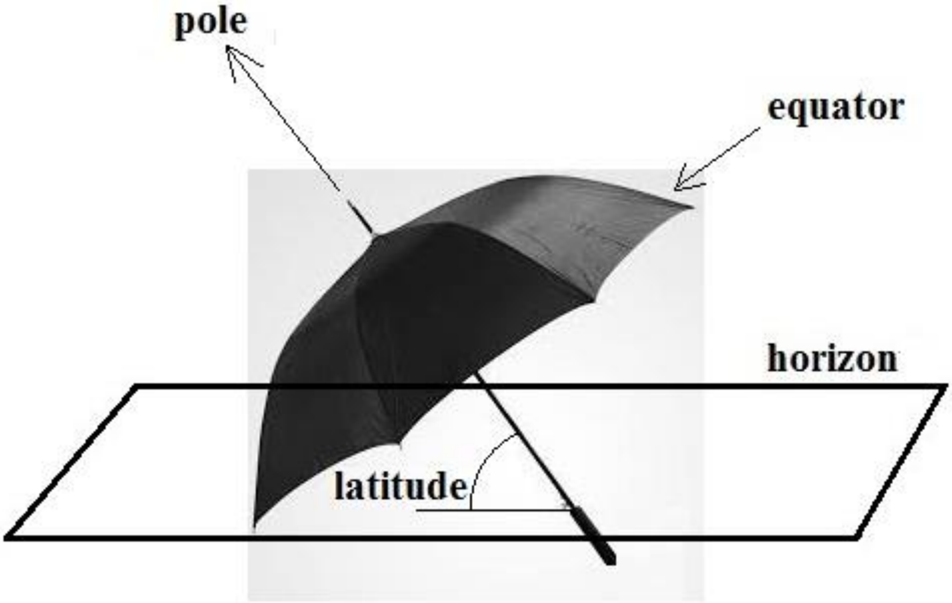


Fig. 9: Umbrella's cane inclined in the direction of the pole according to the latitude. We imagine the plane of the horizon that covers part of the umbrella.

We have to insist that the model explains the translational motion. We imagine that there is no rotation, something equivalent to observe every day more or less at the same time. We also noticed that in this simplified model, we visualize the movement of the sky 90º to 90º discretely, ie every 3 months. As the sky movement is continuous and every day, when it is mentioned that a particular constellation is visible during a season, we must understand that is about the constellation that we see in the center of the horizon in the middle months of the season.

HOW TO USE

We like to use the umbrella to understand the translational motion.

Northern Hemisphere

To fix ideas, suppose that we are in a place of latitude 40 ° North. We put the umbrella of the northern hemisphere with cane North Pole (40º inclined above ground) above our heads.

In the northern hemisphere the polar star is practically located at the North Pole. It is easy to recognize the constellation of the Ursa Major or Cassiopeia. From the Ursa Major or Big Dipper prolong 4 times the distance between the two farthest stars of the tail of the constellation and locates the polar star. Using Cassiopeia, the polar is in the intersection of the two bisectors of each V of the double W representing Cassiopeia.

Northern Horizon

We look to the polar star area. If we introduce a slight rotation we observe the constellations of Ursa Major and Cassiopeia rotate around the North Pole throughout the year (figure 10).

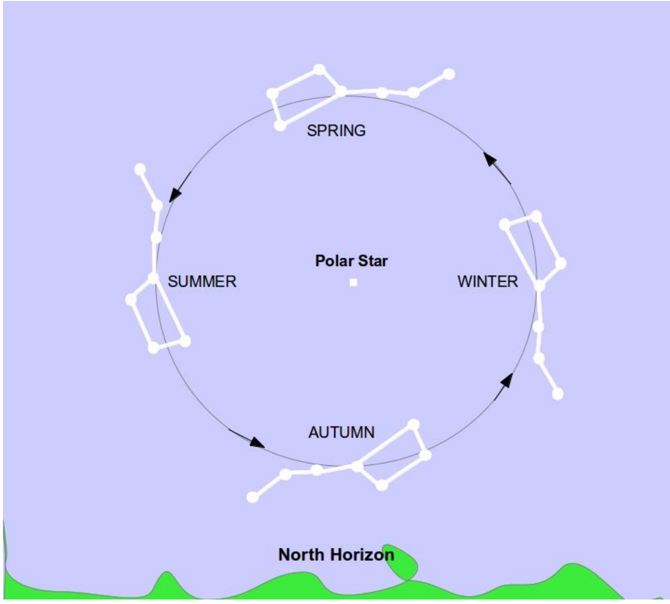


Fig. 10: Relative positions of the Ursa Major around the North Pole throughout the year

We begin by placing the Ursa Major on the top and Cassiopeia down (which happens in spring), we turn the handle of the umbrella 90º in order to have the Ursa Major in the left and Cassiopeia in the right (then we have the situation of summer). Again we rotate the handle 90° in the same direction, then the Ursa Major is down and Cassiopeia is up (this is the position corresponding to autumn) and finally we rotate 90º leaving the Ursa Major on the right and Cassiopeia left (this is in winter). If we rotate again 90º we reproduce the initial situation and begin the four seasons of a new year (figure 10)

As described at the whole process, it is understood that this area of the sky, which is called the northern horizon, this is the area of the horizon corresponding to the North, the constellations that we see throughout the year are always the same and there is more variation

Southern Horizon

We consider now the equatorial area, the area of the tips of the rods now. The constellations in this area of the southern horizon vary by season. The central spring constellation is Leo, and then we place the umbrella with Leo in the highest part of the horizon. Then we rotate ¼ turn umbrella, or 90º and we have over the southern horizon, the central constellation of summer: the swan is with Lira and Aquila summer triangle. With another ¼ turn we are in autumn and the central constellation will be the great quadrilateral of Pegasus. And we turn another 90º we are in winter, and dominates the horizon sky the constellation Orion with his hounds dominates the horizon sky.

Southern Hemisphere

Consider, for example, latitude of 40º South. We put the umbrella of the southern hemisphere with cane headed south pole (inclined at about 40º from the floor) over our heads.

In the southern hemisphere there is no polar star that allows visualizing the position of the South Pole. The Southern Cross constellation is used to mark the position of the southern celestial pole; this should be extended to the major axis of the cross towards the foot of the cross 4.5 times. This constellation makes one revolution around the pole in 24 hours. The position changes throughout the year for the same time, as shown in figure 10. We assume that is the same time to obviate the rotation of Earth and observe only the sky rotation due to the translation.

Southern Horizon

Look to the area of the intersection between umbrella's cane and umbrella's fabric, where is the South Pole. We rotate slowly the handle and note that the constellation of the Southern Cross rotates around the South Pole throughout the year. We begin by placing the Southern Cross above (what happens in winter), we rotate the handle of the umbrella 90º until to have the Southern Cross on the right (the position on spring). We rotate again 90º in the same direction, then the Southern Cross is down (this is the position corresponding to the summer) and, finally rotate 90º leaving the Southern Cross on the left of the South pole (as it is in autumn). If we rotate again 90º we reproduce the initial situation and begin the four seasons of a year (figure 11).

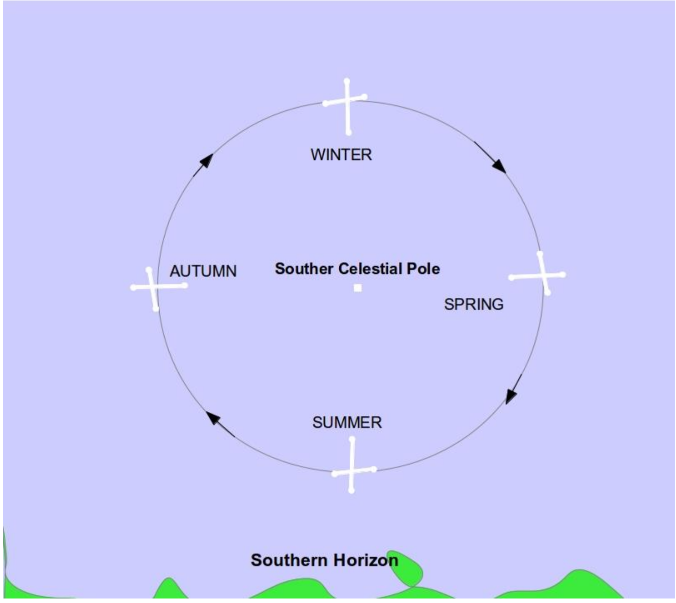


Fig. 11: Relative positions of the Southern Cross around the South Pole during the year

After the described process it is understood that in that area of the sky, called the northern horizon (the area of the horizon corresponding to the North cardinal point), the constellations that we see throughout the year are always the same and there is more variation.

Northern Horizon

We look at the fabric of the umbrella in the equatorial zone, i.e., the northern horizon. This area is where the constellations vary more. Those which are visible in summer, are not visible in winter. Zeus, King of the gods in Greek mythology, put the giant Orion in the sky after his death from the bite of a scorpion. And also, Zeus put this constellation in the sky, but diametrically opposed, so he could not attack Orion again.

The central constellation during spring is Acuarius. We rotate the umbrella 90º, ie after three months and we have Orion with his hounds on the northern horizon which is the central constellation of summer. With another ¼ turn we are in autumn and the central constellation is Leo. If we rotate the umbrella 90º is winter, and we have the beautiful Scorpios constellation on the horizon sky

Conclusions for both hemispheres

Following the scheme presented earlier in both hemispheres for two horizons we can understand the variations in the night sky due to translational motion.

If we want to include the rotation movement in the activity, we have to consider that in addition to the annual motion described a daily movement due to the Earth's rotation makes. In a day both the Ursa Major and the Southern Cross give a complete turn to their respective poles.

To examine just the translation movement is why we have simplified the activity imagining that we always carry out observation at the same time, so it is as the rotation were deleted.

Dark skies and light pollution

To observe the stars, we must have a dark sky. But this is only possible if we turn away from the cities. Humans have forgotten about the starry sky because we can not see it. This problem occurs because most of public lighting produces huge amounts of wasted energy lighting up the sky, which is unnecessary. Light pollution is one form of environmental pollution less known than most others. It affects the visibility of the night sky, but also alters the balance of the ecosystem and affects human health, since it breaches the biological clocks that are coordinated with periods of light and darkness. To be alert on this subject, learn to recognize the problem, warn others of the consequences, and find solutions.
There are three types of light pollution:

a) The glow is a phenomenon that occurs, in general, by the public lighting outside. It is evident when we have the opportunity to travel at night and approach a city. We see that a light wraps around the city. The light produced by the light glow is wasted, it is spent on lighting up the sky, which is not needed and, therefore, not only affects out seeing the stars but spends energy unnecessarily. This type of contamination is reduced by choosing careful light fixtures and bulbs.

b) The intrusion: the external light is projected in all directions and some of them entered, even unwittingly, to our homes. If the light is projected into the rooms, we will have to block the windows with curtains or shades at night.

c) The glare: This type of pollution is linked to the lights of cars and even outdoor lighting in cities and homes. It is evident in places with slopes, as the glare occurs when someone finds an unexpected lamp or a reflector. In the past, traffic lights based on LED can also produce this king of light pollution.

It is possible from various programs on the Internet to compile a series of practical activities for working on this issue, we propose only one that is interactive and easy to perform in any setting.

Activity 2: Light pollution

The objectives of this workshop are to show the polluting effect of unshielded lighting, recognizing the beneficial effect from the astronomical point of view, the choice of a baffle designed to control light pollution and highlight the possibility of improving the view of the stars, while we illuminate those places where we desire more light.

To carry out this experience obtain one cardboard box of certain dimensions that will allow the student to look inward. To draw the constellation that you select (in this example is that of Orion) and mark the stars as points first; later the holes will be made taking into account the diameter of each, depending on stellar magnitude (figures 12a and 12b). The constellation as drawn on the outside of the box should be the mirror image of the constellation, so that it will be seen as it appears in the sky when you look inside the box.

Fig 12a and Fig 12b: Cardboard Box, design of the constellation Orion on one side

The box must be painted black on the inside so that if one looks directly inside , the constellation have the appearance of what is shown in figure 12a and 12b. The "stars", or points that represent them, will be illuminated by the input of the external light inside the box.

Fig. 13: View of Orion from inside the box. Each hole represents a star

Prepare two tennis table balls, making a hole that would allow it to fit over a flashlight. One of the balls is left as it is, and the other is painted with synthetic enamel of any color in the upper hemisphere, representing thus a so-called "shield" that prevents that light from projecting up (figures 14a and 14b).

Fig. 14a: Tennis table ball unshielded, Fig. 14b: Tennis table ball with a hemisphere painted.

To perform the experiment you need to use flashlights in which you can remove the protective top and leave the light bulb as shown in figures 15a and 15b. The tennis table ball is inserted into the flashlight.

Fig. 15a: We removed the protector of the flashlight, Fig. 15b: Flashlight with the tennis table ball simulating the street lamp

Fig. 16a: Lamp without shielded, Fig. 16b: Shielded Lamp

The experiment was performed in two stages: First with just the box. At this time, turn off the lights during the experiment. Both models are tested with the same flashlight to avoid variations in the intensity of light. Project the light both unshielded (figure 16a) and shielded (figure 16b) projecting the light onto a smooth nearby surface, for example a wall or piece of cardboard.

Second, see what happens inside the box. The situation shown in figures 17a and 17b, for cases with and without shield respectively. You can use a digital camera to take photos of what happens inside the box if it is not possible that participants can look inside. External lights in the room where the experiment takes place should be on.

You will notice what is happening very clearly. In the first situation, in the case of outdoor lighting, we see the situation with the baffle controls light pollution: the emission into the sky is greatly reduced.

In the second situation, when using both types of flashlight inside the box, we are simulating the situation of a night with unshielded lamp that sends extra lighting in the sky, called the glow, which obscures the view of the stars. In the case of digital camera, using automatic exposure, you can not even focus properly at the stars. By contrast, the flashlight adapted to control light pollution, it is clear that this device allows the sky to be much darker and the camera is able to clearly record the constellation of Orion.

Fig. 17a: Appearance of the night sky with lanterns without shielded. Fig. 17b: Appearance of the night sky with lights shielded

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APPENDIX: How to Use Stellarium 0.10.6.1

To fix or not the toolbar (to bring the cursor to the lower left corner)	
Location. You can enter by cities, by coordinates or by clicking on a map	
Date and time that is displayed the sky	
Setting the view of the sky. In turn has four menus, which are explained below	
Number of stars, planets ...and to display or not the atmosphere	Cielo
Coordinate lines show in the sky, constellations ... Type of projection of the sky. We recommend Stereo graphic or Orthographic	Marcas
Show the landscape, soil, fog.	Paisaje
Names and figures of the constellations and stars in each culture. The best known are the Western.	Leyenda estelar
Look for an object (i.e. Saturn, M13, NGC 4123, Altair)	
Setting the language and information of the objects shown on screen	
Help (shortcut keys, etc.).	?
Normal rate of time	▶
Speed up time. Can be given several times	▶▶
Speed downtime.	◀◀
Back to the current time	
Lines of constellations	
Names of constellations	orion
Figures constellations	

Grid equatorial	
Grid azimuth + horizon	
Ground/Horizon	
Show cardinal Points	
Atmosphere	
Nebulae and names	
Names of the planets	
Equatorial mount / azimuth	
Center on selected object	
Night mode	
Full screen/ window	
Ocular (like looking to the selected object through a telescope)	
Show satellites in orbit	
Getting around the view	←,→,↑,↓
ZOOM +	**Repág**
ZOOM –	**Avpág**
Define selected planet as the planet from which to see. To return to Earth, look for Earth, and then click Ctrl G (command) to select the planet Earth from which it looks.	**CTRL G**
Leave / omit trace the path of the planets	**May+T**
Screen capture	**CTRL S** **ó** *PrintScreen*
Exit(complete with Stellarium)	**ó** **CTRLQ**

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