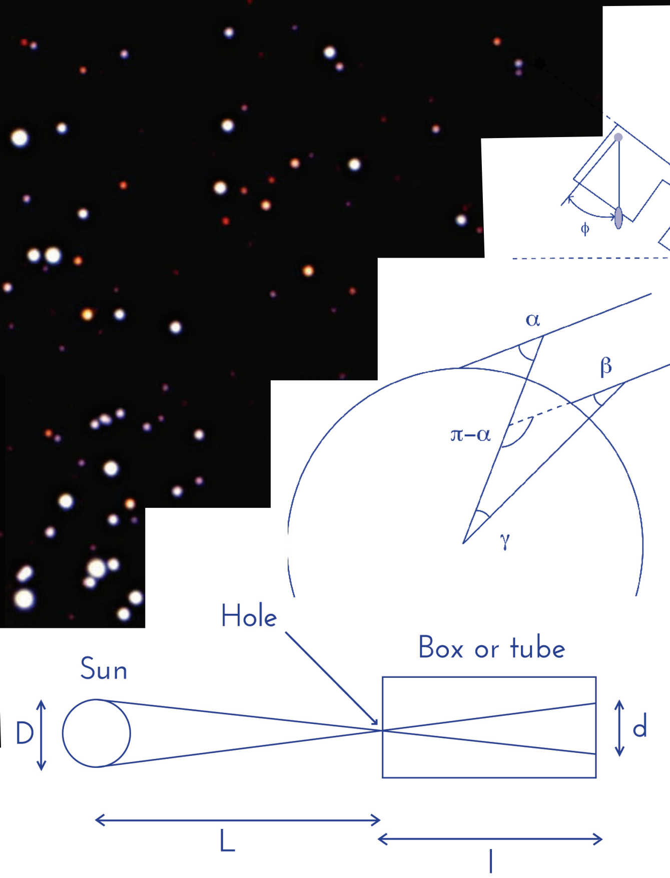
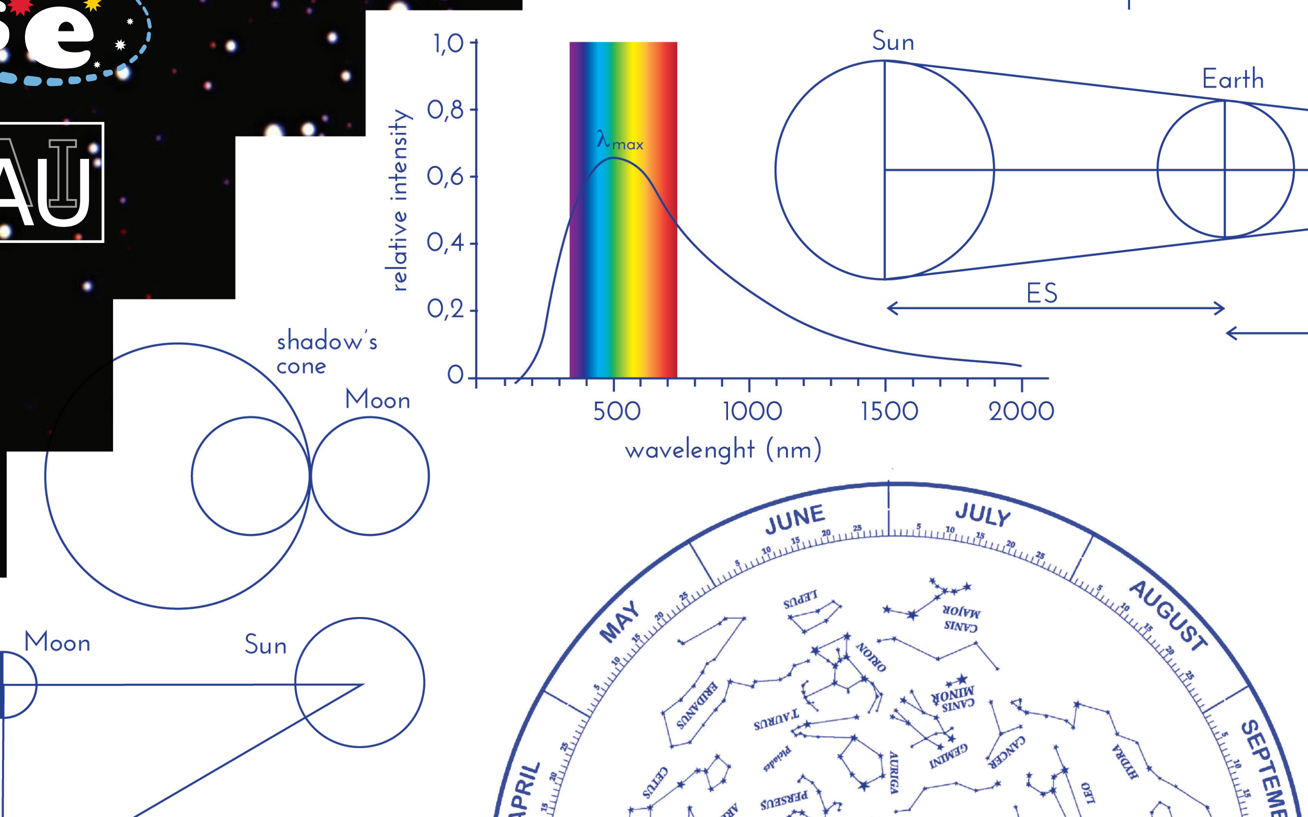
14 steps to the Universe

Astronomy course for teachers and science graduates

Network for Astronomy School Education NASE
International Astronomical Union IAU

Editors: Rosa M. Ros and Mary Kay Hemenway





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Introduction

To increase the presence of astronomy in schools, it is essential to educate the teachers. NASE's main purpose is the development of high level teacher professional development in all countries that are interested in astronomy education at different levels, incorporating issues related to the discipline in different curriculum areas, or introducing young people in science through the study of the universe. These courses are articulated using 14 sections (including conferences and workshops) that constitute an initial teacher training in astronomy. These 14 initial steps that lead to an understanding of the Universe as compiled in this publication represent the work of a number of professional astronomers and teachers who have developed courses through several years, as can be found on the NASE website.

It should be noted that all proposed activities enhance active participation, observation, and if applicable, the construction of models to better understand the scientific content. All schools have a school-yard; it is proposed to use this court as a "laboratory of astronomy" in order to make astronomical observations and transform the students to become the major players in the task of their own learning.

We thank all the authors for their help in preparation of materials. Also note the great help received for translation and assistance for the two versions of this book (English/ Spanish) and preparation and review of figures and graphics from: Ligia Areas, Barbara Castanheira, Lara Eakins, Jaime Fabregat, Keely Finkelstein, Irina Marinova, Néstor Marinozzi, Erin Mentuch Cooper, Isa Oliveira, Cristina Padilla, Silvina Pérez Álvarez, Claudia Romagnolli, Colette Salyk, Viviana Sebben, Oriol Serrano, Rubén Trillo, and Sarah Tuttle and Ederlinda Viñuales.

To learn more about the courses developed so far, activities and new courses that have resulted from the formation of local working groups during the initial courses, we invite the reader to consult the NASE website. The program does not merely provide training, but after the initial intervention, the local groups form working groups with their teachers to keep the flame alive by creating more materials and new activities that become available in full on the web.

On the Internet you can also find many supplemental materials that offer a universe of possibilities to the teacher who has followed the course of NASE, to expand their knowledge and activities.

We end this presentation with a quote from Confucius (551 BC. - 479. BC) which fits very well the project and its objectives:

> I hear and I forget,
> I saw and I remembered,
> I did and I understood

The primary objective of NASE is to bring astronomy to all, to allow everyone to understand and enjoy the process of assimilation of new knowledge.

The Evolution of the Stars

John Percy
International Astronomical Union, University of Toronto (Canada)

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-Russell 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 en-ergy. 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 under-stand the origin of our solar system, and of the at-oms and molecules of which everything, including life, is made. It helps us to answer such fundamen-tal 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 rea-sons, stellar evolution is an interesting topic for students.

The Properties of the Sun and Stars

The first step to understand the origin and evo lution of the Sun and stars is to understand the-ir 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 con sider 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 en-able 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 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 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 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 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 brightnes. 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 classi-fied 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: $B = P/D^2$.

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

Fig. 1: The constellation of Orion. How it is observed in the HN. Betelgeuse, the star of the upper left, it's cold, so it seems flushed. Deneb, the lower star right it's hot, so it looks bluish.

and cold water taps in your bathroom!) Becau-se 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.

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 atmos-phere 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 temperature.

A century ago, astronomers discovered an important relation between the power of a star, and its temperature: for most (but not all) stars,

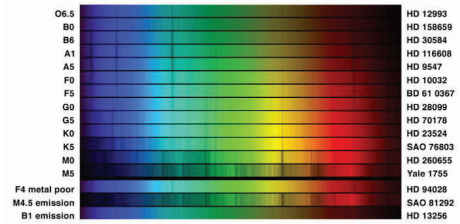

Fig. 2: The spectra of many stars, from the hottest (O6.5: top) to the coolest (M5: fourth from bot-tom). The different appearances of the spectra are due to the different temperatures of the stars. The three bot tom spectra are of stars that are peculiar in some way. Source: National Optical Astronomy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

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 Hertzprung-Russell diagram (figure 3). It is very important for students to learn to construct graphs (Activity 8) and to interpret them (figure 3).

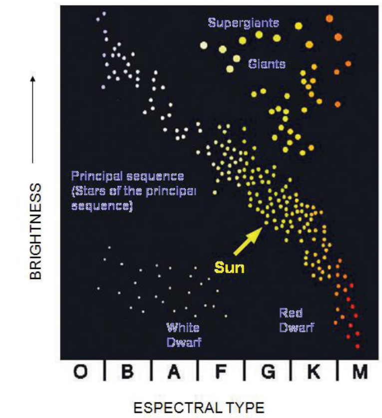

Fig. 3: The Hertzsprung-Russell Diagram, a graph of stellar power or luminosity versus stellar tem-perature. For historical reasons, the temperature increases to the left. The letters OBAFGKM are descriptive spectral types which are related to tem-perature. The diagonal lines show the radius of the stars; 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: $B = P/D^2$.

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 of hydrogen, 1/4 helium, 2% heavier elements, mostly carbon, nitrogen, and oxygen.

About half of the stars in the Sun's neigh-bourhood are binary or double stars – two stars in orbit about each other. Double stars are important because they

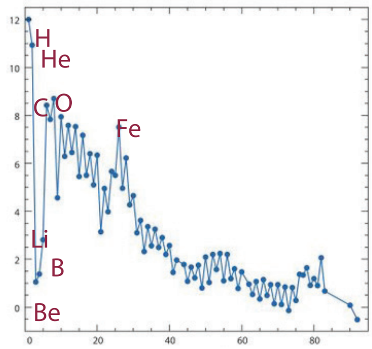

Fig. 4: The abundances of the elements in the Sun and stars. Hydrogen and helium are most abundant. Lithium, beryllium, and boron have very low abundances. Carbon, nitrogen, and oxygen are abundant. The abundances of the other elements decreases greatly with increasing atomic number. Hydrogen is 10^{12} 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.

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 approxi-mately 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 hot-test 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 power-ful 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 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 thermo-nuclear fusion, described below.

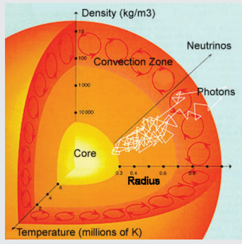

Fig. 5: A cross-section of the Sun, as determined from physical models. In the outer convection zone, energy is transported by convection; below that, it is transported by radiation. Energy is produced in the core. Source: Institute of Theoretical Physics, University of Oslo.

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 ener-gy 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 ob served 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, astroseismology. 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 1026 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 Newton, who developed the Law of Universal Gravitation, scientists realized that the Sun and stars might generate energy by slowly contracting. Gravitational (potetial) energy would be con-verted into heat and radiation. This sour-ce 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 dis covered radioactivity, or nuclear fission. Ra-dioactive elements, however, are very rare in the Sun and stars, and could not provide power for them for billions of years.

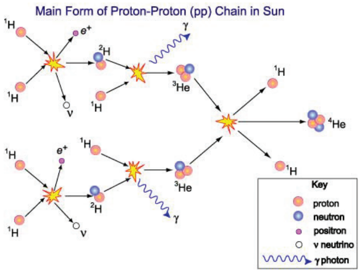

Fig. 6: The proton-proton chain of reactions by which hydrogen is fused into helium in the Sun and other low-mass stars. In this and the next figure, note that neutrinos (ν) are emitted in some of the reac-tions. Energy is emitted in the form of gamma rays (γ-rays) and the kinetic energy of the nuclei.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

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 enougho power the Sun and stars. The element with the most potential fusion energy was hydro-gen, 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 tempeature) and often (high density).

If nuclear fusion powers the Sun, then the fusion reactions should produce large numbers of sub-

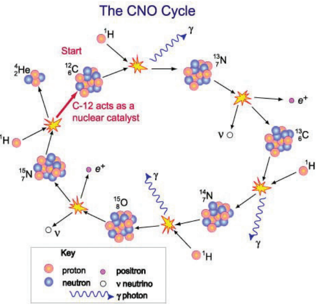

Fig. 7: The CNO cycle by which hydrogen is fused into helium in stars more massive than the Sun. Carbon-12 (marked "start") acts as a catalyst; it par-ticipates in the process without being used up itself. Source: Australia National Telescope Facility.

-tomic particles called neutrinos. These norma-lly pass through matter without interacting with it.

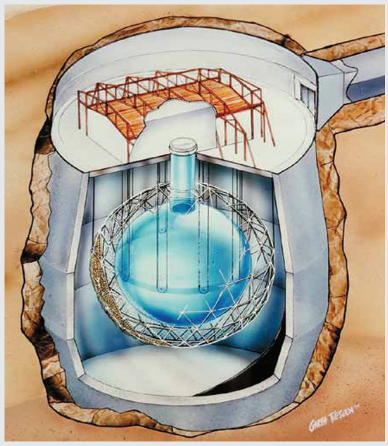

Fig. 8: The Sudbury Neutrino Observatory, where scientists confirmed the models of nuclear fusion in the Sun by observing the predicted flux of neutrinos. The heart of the observatory is a large tank of heavy water. The deuterium nuclei (see text) occasionally interact with a neutrino to produce an observable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

There are billions of neutrinos passing through our bodies each second. Special "neutrino obser-vatories" 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 Obser-vatory (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 deute-rium. 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.

The Lives of the Sun and Stars

Because "the scientific method" is such a funda-mental 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 lo gical "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 luminosity, 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

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.

from the star, and join with other gas and dust to form new nebulae from which new stars will be born.

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 grav-ity is balanced by the outward pressure of elec-trons. 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 volumen 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 Chandra-xsekhar 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

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.

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 ele-ments 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 superno-va (figure 10). These outer layers are ejected with speeds of up to 10,000 km/sec. A supernova, at maximum brightness, can be as bright as a who-le 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 pro-ved otherwise. No supernova has been observed in our Milky Way galaxy for 400 years. A supernova, visible with the unaided eye, was oberved 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

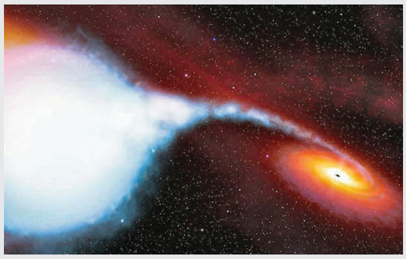

Fig. 11: An artist's conception of the binary-star X-ray source Cygnus X-1. It consists of a massive normal star (left), and a black hole (right), about 15 times the mass of the Sun, in mutual orbit. Some of the gases from the normal star are pulled into an accretion disc around the black hole, and eventually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

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 discove-red 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.

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

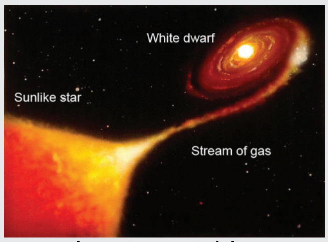

Fig.12: A cataclysmic variable star. Matter is being pulled from the normal star (left) towards the white dwarf (right). It strikes the accretion disc around the white dwarf, which causes a flickering in brightness. The matter eventually lands on the white dwarf, where it may flare up or explode. Source: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

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.

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 angu lar 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 ob-served 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 univer!

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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 also a fascinating subject in its own right. Even though we are anchored to the neighborhood of the Earth, understanding that we know as much as we do -about so much- 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 will 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 (10^{10}) 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, i.e., with the ability to 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 ellipticals (although there are also small ellipticals). It is believed that these, as

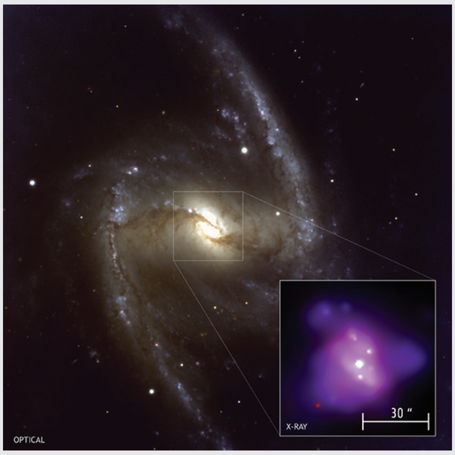

Fig. 2a: Optical image of the galaxy NGC 1365 taken with the ESO VLT and Chandra image of X-ray material close to the central black hole. (Photo: NASA, ESA, the Hubble Heritage (STScI / AURA) -ESA/Hubble Collaboration, and A. Evans). Fig. 2b: Samples of galactic cannibalism where two merging galaxies interact in a very spectacular process. University of Virginia, Charlottesville / NRAO / Stony Brook University).

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.
Galaxies form clusters of galaxies, with thousands

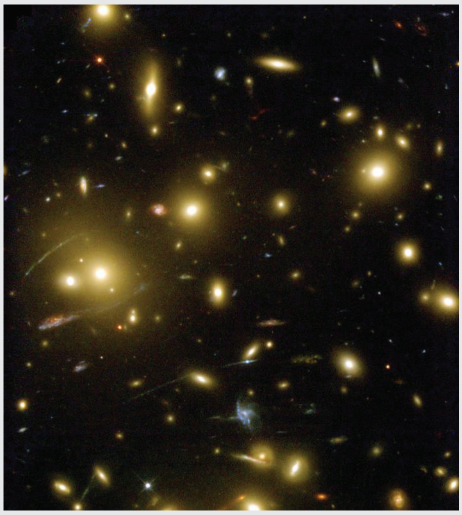

Fig. 3: Abell 2218 cluster of galaxies. Arcs can be seen, caused by a gravitational lensing effect. (Photo: NASA, ESA, Richard Ellis (Caltech) and Jean-Paul Kneib (Observatoire Midi-Pyrenees, France).

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

Clusters and superclusters of galaxies are distributed in the universe in filamentous 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 evolve. 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 reasonable 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 and 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 (an one followed by 12 zeros) times greater than the distance from the Earth to the Sun.

The age of the universe

Our universe begans 13.7 (13 700 000 000) billion years ago. The solar system was formed much later at 4.6 billion years ago. Life on Earth emerged 3.8 billion years ago and the dinosaurs became extinct 65 million years ago. Modern humans arose as recently as 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 the space was all 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 ussing 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.

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 o r 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 w e are in the center of the expansion because all the inhabitants of other cities would observe the expansions the same way.

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.

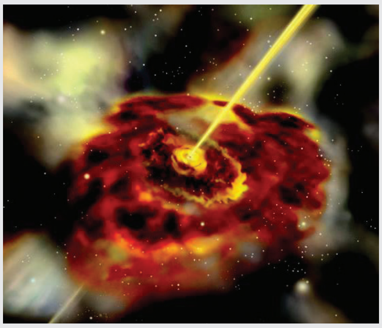


Fig. 4a: Artistic illustration of a black hole in the center with of a galaxy. (Photo: NASA E / PO - Sonoma State Univ.). Fig 4b: Galaxy M87, an example of real galaxy a jet. (Photo: NASA and Hubble Heritage Team).

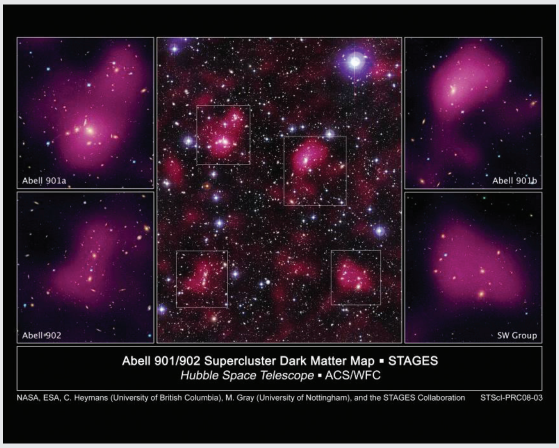

Fig. 5: To date, over 300 dark and dense clouds of dust and gas have been located, where star formation processes are occurring. Super Cluster Abell 90/902. (Photo: Hubble Space Telescope, NASA, ESA, C. Heymans (University of British Columbia) and M. Gray (University of Nottingham)).

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.

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 has motion around apparently empty space, we are certain that something is attracting it. Just as the solar sy stem is held together by the Sun's gravitational force, which keeps the planets in their orbits, the galaxy in question has an orbit be cause 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 struc ture 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 o f 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.

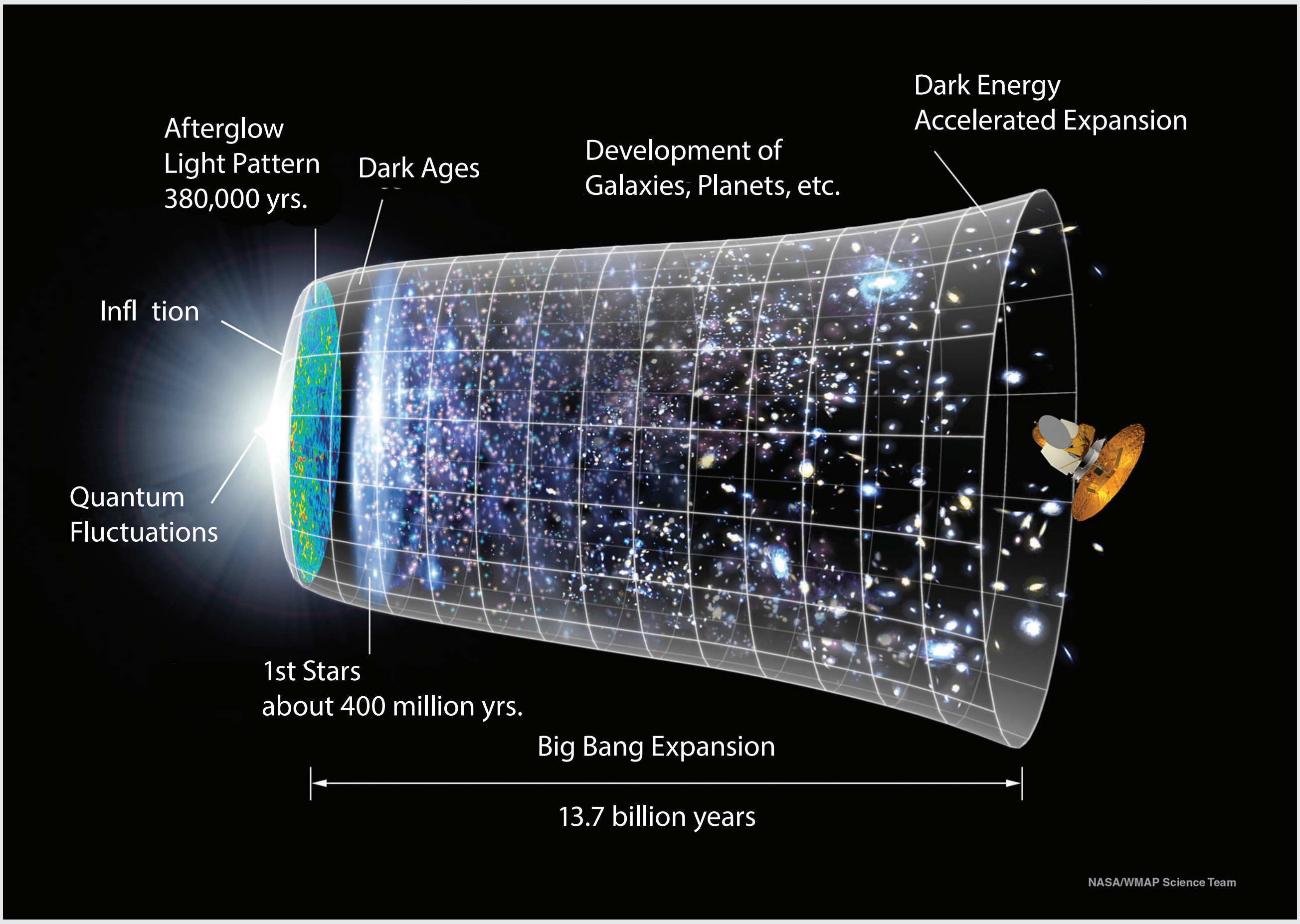

Fig. 6: Expansion of the Universe. (Photo: NASA).

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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History of Astronomy

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Summary

This short survey of the History of Astronomy provides a brief overview of the ubiquitous nature of astronomy at its origins, followed by a summary of the key events in the development of astronomy in Western Europe to the time of Isaac Newton.

Goals

• Give a schematic overview of the history of astronomy in different areas throughout the world, in order to show that astronomy has always been of interest to all the people.
• List the main figures in the history of astronomy who contributed to major changes in approaching this discipline up to Newton: Tycho Brahe, Copernicus, Kepler and Galileo.
• Conference time constraints prevent us from developing the history of astronomy in the present day, but more details can be found in other chapters of this book.

Pre-History

With dark skies, ancient peoples could see the stars rise in the eastern part of the sky, move upward, and set in the west. In one direction, the stars moved in tiny circles. Today, for those in the northern hemisphere, when we look north, we see a star at that position – the North Star, or Polaris. It isn't a very bright star: 48 stars in the sky are brighter than it, but it happens to be in an interesting place. In ancient times, other stars were aligned with Earth's north pole, or sometimes, there were no stars in the vicinity of the pole.

Since people viewed the sky so often, they noticed that a few of the brighter objects didn't rise and set exactly with the stars. Of course, the Moon was by far the brightest object in the night sky. It rose almost an hour later each night, and appeared against a different background of stars. Its shape also changed in cycles (what we now call phases).

But some of these lights in the sky moved differently from the others. These came to be called wanderers or planets by the Greeks. Virtually every civilization on Earth noticed, and named, these objects.

Some ancient people built monuments such as standing circles, like Stonehenge in England, or tombs such as the ones in Menorca in Spain that aligned with the Southern Cross in 1000 BCE. The Babylonians were great recorders of astronomical phenomena, but the Greeks built on that knowledge to try to "explain" the sky.

The Greeks

Most ancient Greeks, including Aristotle (384 BCE – 322 BCE), thought that Earth was in the center of the universe, and it was made of four elements: Earth, Air, Fire, and Water. Beyond the Earth was a fifth element, the aether (or quintessence), that made up the points of light in the sky.

How did these wanderers move among the stars? Mostly, they went in the same direction that the stars went: rising in the east and moving toward the west. But sometimes, they seemed to pause and go backwards with respect to the stars. This backward motion is called "retrograde" motion, to tell it apart from the forward motion, called "prograde."

The Greek astronomer Claudius Ptolemy (c. CE 90 – c. CE 168) worked in Alexandria in North Africa in the second century CE. Ptolemy wanted to be able to predict the positions of planets and came up with a mathematical solution. Following Aristotle, he placed the Earth at the center of the universe. The Moon and the planets go around it in nested circles that got bigger with distance from Earth. What if the planets really move on small circles whose centers are on the big circles? Then, on some of the motion on the small circles, they'd be moving faster backwards than the centers of these circles move forward. For those of us on Earth, we'd see the planets move backwards.

Those small circles are called "epicycles," and the big circles are called "deferents." Ptolemy's idea of circles moving on circles held sway over western science for over a thousand years. Going from observation to theory using mathematics was a unique and important step in the development of western science.

Although they didn't have the same names for the objects they observed, virtually every culture on Earth watched the skies. They used the information to set up calendars and predict the seasonal cycles for planting, harvesting, or hunting as well as religious ceremonies. Like the Greeks, some of them developed very sophisticated mathematics to predict the motions of the planets or eclipses, but this does not mean that they attempted what we would call a scientific theory. Here are some examples:

Africa

The standing stones at Nabta in the Nubian Desert pre-date Stonehenge by 1000 years. Egyptians used astronomy to align their pyramids as well as extend their religious beliefs to include star lore. Petroglyphs at Namoratunga (Kenya) share aspects of modern cattle brands. Star lore comes from all areas of Africa, from the Dogon region of Mali, to West Africa, to Ethiopia, to South Africa.

Islamic Astronomy

Many astronomical developments were made in the Islamic world, particularly during the Islamic Golden Age (8th-15th centuries), and mostly written in the Arabic language. It was developed most in the Middle East, Central Asia, Al-Andalus, North Africa, and later in the Far East and India. A significant number of stars in the sky, such as Aldebaran and Altair, and astronomical terms such as alidade, azimuth, almucantar, are still referred to by their Arabic names. Arabs invented Arabic numbers, including the use of zero. They were interested in finding positions and time of day (since it was useful for prayer services). They made many discoveries in optics as well. Many works in Greek were preserved for posterity through their translations to Arabic.

The first systematic observations in Islam are reported to have taken place under the patronage of Al-Maâmun (786-833 CE). Here, and in many other

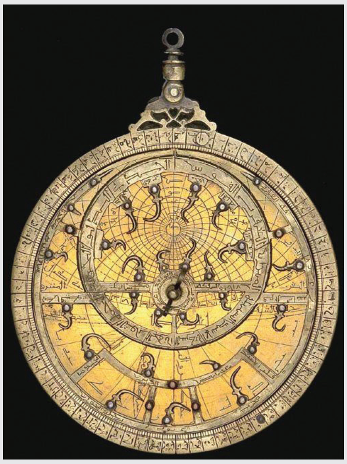


Fig. 1: Arabic astrolabe.

private observatories from Damascus to Baghdad, meridian degrees were measured, solar parameters were established, and detailed observations of the Sun, Moon, and planets were undertaken.

Instruments used by the Islamic astronomy were: celestial globes and armillary spheres, astrolabes, sundials and quadrants.

The Americas

North America

Native peoples of North America also named their constellations and told sky stories which were passed down through oral tradition. Some artifacts, such as stone wheels or building alignments, remain as evidence of their use of astronomy in every-day life.

Mayan Astronomy

The Maya were a Mesoamerican civilization, noted for the only known fully developed written language of the pre-Columbian Americas, as well as for its art, architecture, mathematical and astronomical systems. Initially established during the Pre-Classic period (c. 2000 BCE to 250 CE), Mayan cities reached their highest state of development during the Classic period (c. 250 CE to 900 CE), and continued throughout the Post-Classic period until the arrival of the Spanish. The Mayan peoples never disappeared, neither at the time of the Classic period decline nor with the arrival of the Spanish conquistadors and the subsequent Spanish colonization of the Americas.

Mayan astronomy is one of the most known ancient astronomies in the world, especially due to its famous calendar, wrongly interpreted now as predicting the end of the world. Maya appear to be the only pre-telescopic civilization to demonstrate knowledge of the Orion Nebula as being fuzzy, i.e. not a stellar pinpoint.

Fig. 2: Chichén Itzá(Mexico) is an important archaeological remains of the Maya astronomy.

The Maya were very interested in zenithal passages, the time when the Sun passes directly overhead. The latitudes of most of their cities being below the Tropic of Cancer, these zenithal passages would occur twice a year equidistant from the solstice. To represent this position of the Sun overhead, the Maya had a god named Diving God.

Venus was the most important astronomical object to the Maya, even more important to them than the Sun. The Mayan calendar is a system of calendars and almanacs used in the Mayan civilization of pre-Columbian Mesoamerica, and in some modern Maya communities in highland Guatemala and Oaxaca, Mexico.

Although the Mesoamerican calendar did not originate with the Mayan, their subsequent extensions and refinements of it were the most sophisticated. Along with those of the Aztecs, the Mayan calendars are the best documented and most completely understood.

Aztec Astronomy

They were certain ethnic groups of central Mexico, particularly those groups who spoke the Nahuatl language and who dominated large parts of Mesoamerica in the 14th, 15th and 16th centuries, a period referred to as the late post-classic period in Mesoamerican chronology.

Aztec culture and history is primarily known through archeological evidence found in excavations such as that of the renowned Templo Mayor in Mexico City and many others, from indigenous bark paper codices, from eyewitness accounts by Spanish conquistadors or 16th and 17th century descriptions of Aztec culture and history written by Spanish clergymen and literate Aztecs in the Spanish or Nahuatl language.

The Aztec Calendar, or Sun Stone, is the earliest monolith that remains of the pre-Hispanic culture in Central and South America. It is believed that it was carved around the year 1479. This is a circular monolith with four concentric circles. In the center appears the face of Tonatiuh (Sun God), decorated with jade and holding a knife in his mouth. The four suns or earlier “worlds” are represented by square-shaped figures flanking the Fifth Sun, in the center. The outer circle consists of 20 areas that represent the days of each of the 18 months that comprised the Aztec calendar. To complete the 365-day solar year, the Aztecs incorporated 5 sacrificial, or Nemontemi, days.

Like almost all ancient peoples, the Aztecs grouped into associations the apparent bright stars (constellations): Mamalhuaztli (Orion’s Belt), Tianquiztli (the Pleiades), Citlaltlachtli (Gemini), Citlalcolotl (Scorpio) and Xonecuilli (The Little Dipper, or Southern Cross for others, etc.). Comets were called “the stars that smoke”.

The great periods of time in the Aztec cosmology are defined by the eras of different suns, each of whose end was determined by major disasters such as destruction by jaguars, hurricanes, fire, flood or earthquakes.

Inca Astronomy

Inca civilization is a civilization pre-Columbian Andean Group. It starts at the beginning of the 13th century in the basin of Cuzco in Peru and the current then grows along the Pacific Ocean and the Andes, covering the western part of South America. At its peak, it extends from Colombia to Argentina and Chile, across Ecuador, Peru and Bolivia.

The Incas considered their King, the Sapa Inca, to be the “child of the Sun”. Its members identified various dark areas or dark nebulae in the Milky Way as animals, and associated their appearance with the seasonal rains. Its members identifi d various dark areas or dark nebulae in the Milky Way as animals, and associated their appearance with the seasonal rains

The Incas used a solar calendar for agriculture and a lunar calendar for the religious holidays. According to chronicles of the Spanish conquistadors, on the outskirts of Cuzco in present day Peru there was a big public schedule that consisted of 12 columns each 5 meters high that could be seen from afar. With it, people could set the date. They celebrated two major parties, the Inti Raymi and Capac Raymi, the summer and winter solstice respectively.

They had their own constellations: the Yutu (Partridge) was the dark zone in the Milky Way that we call the Coal Sack. They called the Pleiades cluster Qollqa. With the stars of the Lyra constellation they did a drawing of one of the most known animals to them, and named it Little Silver Llama or colored Llama, whose brightest star (Vega) was Urkuchillay, although according to others, that was the name of the whole constellation. Moreover there were the Machacuay (snake), the Hamp'atu (toad), the Atoq (Fox), the Kuntur, etc.

Major cities were drawn following celestial alignments and using the cardinal points.
On the outskirts of Cuzco there was an important temple dedicated to the Sun (Inti), from which came out some lines in radial shape that divided the valley in 328 Temples. That number is still a mystery, but one possible explanation relates it to the astronomy: it coincides with the days that contain twelve lunar months. And the 37 days that are missing until the 365 days of the solar year coincides with the days that the Pleiades cluster is not observable from Cuzco.

India

The earliest textual mention that is given in the religious literature of India (2nd millennium BCE) became an established tradition by the 1st millennium BCE, when different ancillary branches of learning began to take shape.

During the following centuries a number of Indian astronomers studied various aspects of astronomical sciences, and global discourse with other cultures followed. Gnomons and armillary spheres were common instruments.

The Hindu calendar used in ancient times has undergone many changes in the process of regionalization, and today there are several regional Indian calendars, as well as an Indian national calendar. In the Hindu calendar, the day starts with local sunrise. It is allotted five "properties," called angas.

The ecliptic is divided into 27 nakshatras, which are variously called lunar houses or asterisms. These reflect the moon's cycle against the fixed stars, 27 days and 72 hours, the fractional part being compensated by an intercalary 28th nakshatra. Nakshatra computation appears to have been well known at the time of the Rig Veda (2nd to 1st millennium BCE).

China

The Chinese were considered as the most persistent and accurate observers of celestial phenomena anywhere in the world before the Arabs. Detailed records of astronomical observations began during the Warring Sates period (4th century BCE) and flo rished from the Han period onwards.

Some elements of Indian astronomy reached China with the expansion of Buddhism during the Later Han dynasty (25-220 CE), but the most detailed incorporation of Indian astronomical thought occurred during the Tang Dynasty (618-907).

Astronomy was revitalized under the stimulus of Western cosmology and technology after the Jesuits established their missions. The telescope was introduced in the 17th century. Equipment and innovation used by Chinese astronomy: armillary sphere, celestial globe, the water-powered armillary sphere and the celestial globe tower.

Chinese astronomy was focused more on the observations than on theory. According to writings of the Jesuits, who visited Beijing in the 17th century, the Chinese had data from the year 4,000 BCE, including the explosion of supernovae, eclipses and the appearance of comets.

In the year 2300 BCE, they developed the first known solar calendar, and in 2100 BCE recorded a solar eclipse. In 1200 BCE they described sunspots, calling them "specks dark" in the Sun. In 532 BCE, they left evidence of the emergence of a supernova star in the Aquila constellation, and in the 240 and 164 BCE passages of Halley comet. In 100 BCE Chinese invented the compass with which they marked the direction north.

And in more recent times, they determined the precession of the equinoxes as one degree every 50 years, recorded more supernovae and found that the tail of comets always points in the opposite direction to the Sun's position

In the year 1006 CE they noted the appearance of a supernova so bright that could be seen during the day. It is the brightest supernova that has been reported. And in 1054, they observed a supernova, the remnants of which would later be called the Crab Nebula.

Their celestial sphere differed from the Western one. The celestial equator was divided into 28 parts, called "houses", and there were a total of

284 constellations with names such as Dipper, Three Steps, Supreme Palace, Tripod, Spear or Harpoon. Chinese New Year starts on the day of the first new moon after the sun enters the constellation Aquarius.

The polymath Chinese scientist Shen Kuo (1031-1095 CE) was not only the first in history to describe the magnetic-needle compass, but also made a more accurate measurement of the distance between the Pole Star and true North that could be used for navigation. Shen Kuo and Wei Pu also established a project of nightly astronomical observation over a period of five successive years, an intensive work that would even rival the later work of Tycho Brahe in Europe. They also charted the exact coordinates of the planets on a star map for this project and created theories of planetary motion, including retrograde motion.

Europa Occidental

Following the fall of Rome, the knowledge complied by the Greeks was barely transmitted through the work of monks who often copied manuscripts that held no meaning for them. Eventually, with the rise of Cathedral schools and the first universities, scholars started to tackle the puzzles that science offers. Through trade (and pillaging), new manuscripts from the East came through the Crusades, and contact with Islamic scholars (especially in Spain) allowed translations to Latin to be made. Some scholars attempted to pull the information into an order that would fit it into their Christian viewpoint.

Mathematical genius: Nicholas Copernicus of Poland

In the early 1500s, Nicholas Copernicus (1473 – 1543) concluded that Universe would be simpler if the Sun, rather than the Earth, were at its center. Then the retrograde motion of the planets would occur even if all the planets merely orbited the Sun in circles. The backward motion would be an optical illusion that resulted when we passed another planet. Similarly, if you look at the car to your right while you are both stopped at a traffic light, if you start moving first, you might briefly think that the other car is moving backwards.

Copernicus shared his ideas with mathematicians, but did not publish them until a young scientist, Georg Rheticus, convinced him and arranged for the publication in another town. A printed copy of De Revolutionibus Orbium Celestium arrived just as Copernicus was dying in 1543. He may have never seen the unsigned preface written by the publisher that suggested that the book was a mathematical way to calculate positions, not the actual truth. Following Aristotle, Copernicus used circles and added some epicycles. His book followed the structure of Ptolemy's book, but his devotion to mathemati-

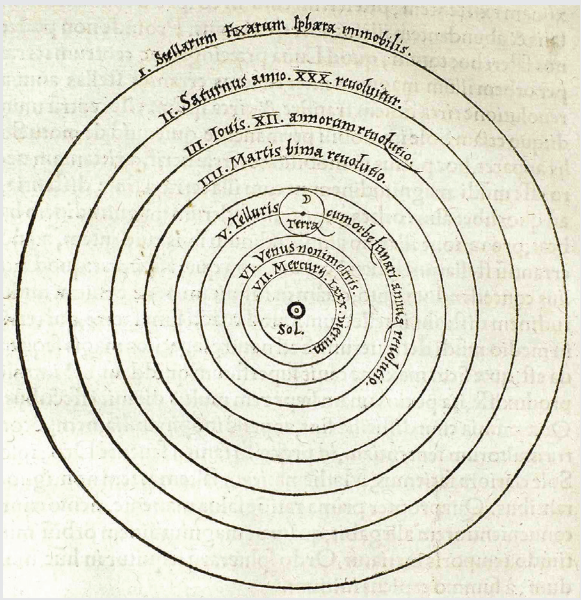


Fig. 3. Copernicus's diagram first showing the Sun at the center of what we therefore now call the Solar System. This diagram is from the first edition of De Revolutionibus Orbium Celestium (On the Revolutions of the Celestial Orbs), published in 1543.

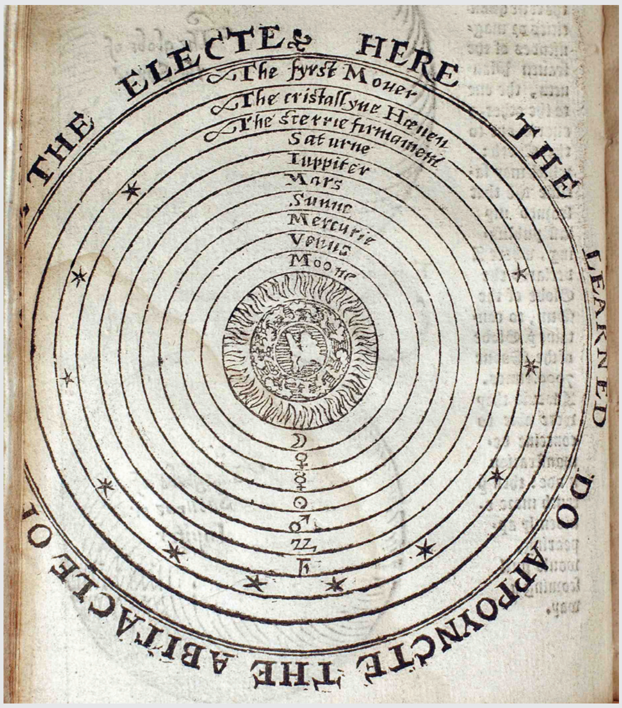


Fig. 4. The first Copernican diagram in English, from Thomas Digges's appendix to A prognostication everlasting, a book by his father first published in 1556. It contained only a Ptolemaic diagram. Thomas Digges's appendix first appeared in 1576; this diagram is from the 1596 printing.

cal simplicity was influenced by Pythagorus.

Copernicus's book contains (figure 3) perhaps the most famous diagram in the history of science. It shows the Sun at the center of a series of circles. Copernicus calculated the speeds at which the planets went around the Sun, since he knew which went fastest in the sky. Thus he got the planets in the correct order: Mercury, Venus, Earth, Mars, Jupiter, Saturn, and he got the relative distances of the planets correct also. But, his calculations really didn't predict the positions of the planets much better than Ptolemy's method did.

In England, Leonard Digges wrote a book, in English, about the Earth and the Universe. In 1576, his son Thomas wrote an appendix in which he described Copernicus's new ideas. In the appendix, an English-language version of Copernicus's diagram appeared for the first time (figure 4). Digges also showed the stars at many different distances from the solar system, not just in one celestial sphere.

Observational genius: Tycho Brahe of Denmark

The Danish aristocrat Tycho Brahe (1546 – 1601) took over an island off the coast of Copenhagen, and received rent from the people there. On this island, Hven, he used his wealth to build a great observatory with larger and better instruments. Though these were pre-telescopic instruments, they were notable for allowing more precise measurements of the positions of the stars and planets than had previously been possible.

Tycho ran his home as a forerunner of today's university, with visiting scientists coming to work with him. He made better and better observing devices to measure the positions of stars and planets, and kept accurate records.

But in his scientific zeal, he neglected some of his duties to his monarch, and when a new king and queen came in, he was forced out. He chose to move to Prague, on the continent of Europe, taking even his printing presses and pages that had already been printed, his records, and his moveable tools.

Tycho succeeded in improving the accuracy of scientific observations. His accurate observations of a comet at various distances showed him that the spheres did not have to be nested with the Earth at the center. So, he made his own model of the universe -a hybrid between Ptolemy's and Copernicus': the Sun and the Moon revolve around the Earth, while the other planets revolve around the Sun. Tycho still had circles, but unlike Aristotle, he allowed the circles to cross each other.

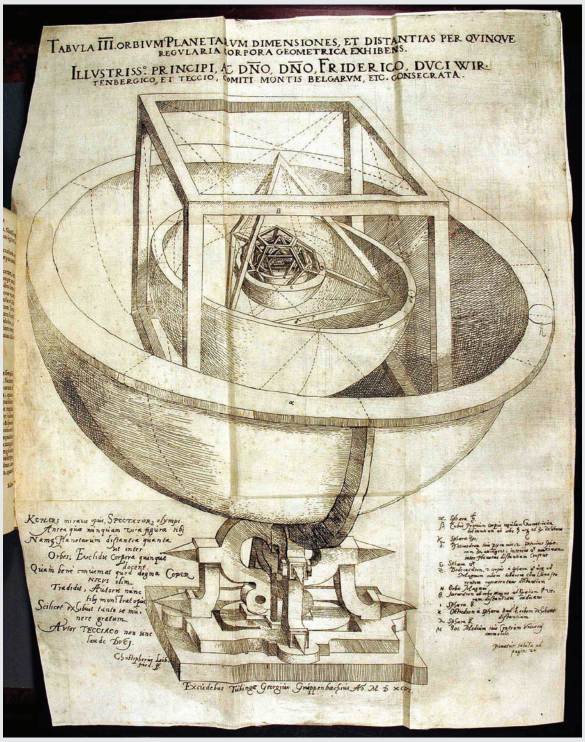


Fig. 5: Kepler's foldout diagram from his Mysterium Cosmographicum (Mystery of the Cosmos), published in 1596. His thinking of the geometric arrangement of the solar system was superseded in the following decade by his arrangements of the planets according to the first two of his three laws of planetary motion.

We value Tycho mainly for the trove of high-quality observations of the positions among the stars of the planet Mars. To join him in Prague, Tycho invited a young mathematician, Johannes Kepler. It is through Kepler that Tycho's fame largely remains.

Using Mathematics: Johannes Kepler of Germany

As a teacher in Graz, Austria, young Johannes Ke-pler (1571 – 1630) remembered his childhood inter-est in astronomy, fostered by a comet and the lunar eclipse that he had seen. He realized that there are fi e solid forms made of equally-shaped sides, and that if these solids were nested and separated by spheres, they could correspond to the six known planets. His book on the subject, Mysterium Cos-mographicum (Mystery of the Cosmos), published in 1596, contained one of the most beautiful dia-grams in the history of science (figure 5). In it, he nested an octahedron, icosahedron, dodecahedron, tetrahedron, and cube, with eight, twelve, twenty, four, and six sides, respectively, to show the spacing of the then known planets. The diagram, though very beautiful, is completely wrong.

But Kepler's mathematical skill earned him an interview with Tycho. In 1600, he became one of several assistants to Tycho, and he made calculations using the data that Tycho had amassed. Then Tycho went to a formal dinner and drank liberally. As the story goes, etiquette prevented him from leaving the table, and he wound up with a burst bladder. His quick and painful death was carefully followed in a diary, and is well documented.

But Kepler didn't get the data right away. For one thing, the data was one of the few valuable things that Tycho's children could inherit, since Tycho had married a commoner and was not allowed to bequeath real property. But Kepler did eventually get access to Tycho's data for Mars, and he tried to make it fit his calculations. To make his precise calculations, Kepler even worked out his own table of logarithms.

The data Kepler had from Tycho was of the position of the Mars in the sky, against a background of stars. He tried to calculate what its real motion around the Sun must be. For a long while, he tried to fit a circle or an egg-shaped orbit, but he just couldn't match the observations accurately enough. Eventually, he tried a geometrical fi ure called an ellipse, a sort of squashed circle. It fit! The discovery is one of the greatest in the history of astronomy, and though Kepler first applied it to Mars and other planets in our solar system, we now apply it even to the hundreds of planets we have discovered around other stars.

Kepler's book of 1609, Astronomia Nova (The New Astronomy), contained the first two of his three laws of motion:

Fig. 6: From Kepler's Harmonices Mundi (The Harmony of the World), published in 1619.

Kepler's first law: The planets orbit the Sun in ellipses, with the Sun at one focus.

Kepler's second law: A line joining a planet and the Sun sweeps out equal areas in equal times.

An ellipse is a closed curve that has two key points in it; they are known as the foci. To draw your own ellipse, put two dots on a piece of paper; each is a focus. Then take a piece of string longer than the distance between the foci. Tape them down on the foci. Next, put a pencil in the string, pulling it taut, and gently move it from side to side. The curve you generate will be one side of an ellipse; it is obvious how to move the pencil to draw the other side. This experiment with the string shows one of the key points defining an ellipse: the sum of the distances from a point on the ellipse to each focus remains constant. A circle is a special kind of ellipse where the two dots are on top of each other.

Mercury	0.387 AU	0.240 years
Venus	0.723 AU	0.615 years
Earth	1 AU	1 year
Mars	1.523 AU	1.881 years
Jupiter	5.203 AU	11.857years
Saturn	9.537 AU	29.424 years

Table 1: Distances from the Sun and periods of the planets in Kepler's time.

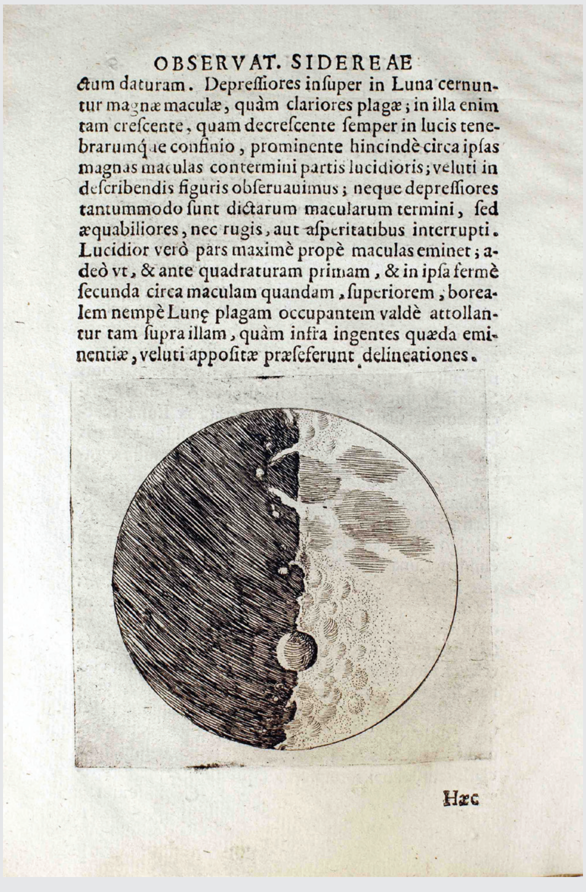
Kepler kept searching for harmonies in the motions of the planets. He associated the speeds of the planets with musical notes, the higher notes corresponding to the faster-moving planets, namely, Mercury and Venus. In 1619, he published his major work Harmonices Mundi (The Harmony of the Worlds). In it (figure 6), he included not only musical staffs with notes but also what we call his third law of planetary motion:

Kepler's Third Law of Planetary Motion: The square of the period of a planet's orbit around the sun is proportional to the cube of the size of its orbit.

Astronomers tend to measure distances between planets in terms of the Astronomical Units, which corresponds to the average distance between the Earth and the Sun, or 150 million kilometers.

Try squaring the first column and cubing the second column. You will see that they are pretty equal. Any differences come from the approximation, not from the real world, though with more decimal places the influences of the other planets could be detected.

Fig. 7a: One of Galileo's two surviving telescopes came to the Franklin Institute in Philadelphia in 2009, on its first visit to the United States. Note that the outer part of the lens is covered with a cardboard ring. By hiding the outer part of the lens, which was the least accurate part, Galileo improved the quality of his images. (Photo: Jay M. Pasachoff).



OBSERVAT. SIDEREAE

ctum daturam. Depreſſiores inſuper in Luna cernuntur magnæ maculæ, quàm clariores plagæ; in illa enim tam creſcente, quam decreſcente ſemper in lucis tenebrarumq; ue confinio, prominente hincindè circa ipſas magnas maculas contermini partis lucidioris; veluti in deſcribendis figuris obſeruauimus; neque depreſſiores tantummodo ſunt dictarum macularum termini, ſed æquabiliores, nec rugis, aut aſperitatibus interrupti. Lucidior verò pars maximè propè maculas eminet; adeò vt, & ante quadraturam primam, & in ipſa fermè ſecunda circa maculam quandam, ſuperiorem, borealem nempè Lunę plagam occupantem valdè attollantur tam ſupra illam, quàm infra ingentes quæda eminentiæ, veluti appoſitæ præſeferunt delineationes.

Hæc

Fig. 7b: A page from Galileo's Sidereus Nuncius (The Starry Messenger), published in 1610, showing an engraving of the Moon. The book was written in Latin, the language of European scholars. It included extensive coverage of the relative motion of the four major moons of Jupiter.

Discoveries with the Telescope: Galileo Galilei of Italy

The year 2009 was the International Year of Astronomy, declared first by the International Astronomical Union, then by UNESCO, and finally by the General Assembly of the United Nations. Why? It commemorated the use of the telescope on the heavens by Galileo 400 years previously, in 1609.

Galileo (1564 - 1642) was a professor at Padua, part of the Republic of Venice. He heard of a Dutch invention that could make distant objects seem closer. Though he hadn't seen one, he figured out what lenses it must have contained and he put one together. He showed his device to the nobles of Venice as a military and commercial venture, allowing them to see ships farther out to sea than ever before. His invention was a great success.

Then he had the idea of turning the telescope upward. Though the telescope was hard to use, had a very narrow field of view, and was hard to point, he succeeded in seeing part of the Moon and realizing that there was a lot of structure on it. Because of his training in drawing in Renaissance Italy, he realized that the structure represented light and shadow, and that he was seeing mountains and craters. From the length of the shadows and how they changed with changing illumination from the Sun, he could even figure out how high they were. A few months earlier, the Englishmen Thomas Harriot had pointed a similar telescope at the Moon, but he had drawn only some hazy scribbles and sketches. But Harriot wasn't interested in publication or glory, and his work did not become known until after his death.

One lens Galileo used for his discoveries remains, cracked, in the Museum of the History of Science in Florence, Italy, and two full telescopes he made survive, also there (figure 7a).

Galileo started writing up his discoveries in late 1609. He found not only mountains and craters on the moon but also that the Milky Way was made out of many stars, as were certain asterisms. Then, in January 1610, he found four "stars" near Jupiter that moved with it and that changed position from night to night. That marked the discovery of the major moons of Jupiter, which we now call the Galilean satellites. He wrote up his discoveries in a slim book called Sidereus Nuncius (The Starry Messenger), which he published in 1610 (figure 7b). Since Aristotle and Ptolemy, it had been thought that the Earth was the only center of revolution. And Aristotle had been thought to be infallible. So the discovery of Jupiter's satellites by showing that Aristotle could have been wrong was a tremendous blow to the geocentric notion, and therefore a strong point in favor of Copernicus' heliocentric theory.

Galileo tried to name the moons after Cosmo de Medici, his patron, to curry favor. But those names didn't stick.

Within a few years, Simon Marius proposed the names we now use. (Marius may even have seen the moons slightly before Galileo, but he published much later.) From left to right, they are Io, Europa, Ganymede, and Callisto (figure 9). Even in a small, amateur telescope, you can see them on a clear night, and notice that over hours they change positions. They orbit Jupiter in periods of about two to sixteen days.

Even in the biggest and best ground-based telescopes, astronomers could not get a clear view of structure on the surfaces of the Galilean satellites. Only when the NASA satellites Pioneer 10 and 11, and then Voyager 1 and 2, flew close to the Jupiter system did we see enough detail on the satellites to be able to characterize them and their surfaces. From ground-based and space-based observations, astronomers are still discovering moons of Jupiter, though the newly discovered ones are much smaller and fainter than the Galilean satellites.

Fig. 8. In 2009, to commemorate the 400th anniversary of Galileo's first use of the telescope on the heavens, a plaque was put on a column at the top of the Campanile, a 15th-century tower (re-erected in the early 20th century after it collapsed in 1902) in Venice. The commemoration here is of Galileo's demonstrating his telescope to the nobles of Venice by observing ships relatively far out at sea; it was before he turned his telescope upward. The writing on the plaque can be translated approximately as "Galileo Galilei, with his spyglass, on August 21, 2009, enlarged the horizons of man, 400 years ago."(Photo: Jay M. Pasachoff).

Fig. 9. Galileo himself would have been amazed to see what his namesake spacecraft and its predecessors showed from the "Medician satellites" that he discovered in 1609. Here they show in images at their true relative scale. From left to right, we see Io, newly resurfaced with two dozen continually erupting volcanoes. Second is Europa, a prime suspect for finding extraterrestrial life because of the ocean that is under the smooth ice layer that we see. Third is Ganymede, the largest moon in the solar system, showing especially a fascinatingly grooved part of its surface. And at right is Callisto, farther out than the others and covered with hard ice that retains the scarring from overlapping meteorite strikes that occurred over billions of years. (Photo:NASA, Galileo Mission, PIA01400).

Galileo used his discoveries to get a better job with a higher salary, in Florence. Unfortunately, Florence was closer to the Papal authority in Rome, serving as bankers to the Pope, and was less liberal than the Venetian Republic. He continued to write on a variety of science topics, such as sunspots, comets, floating bodies. Each one seemed to pinpoint an argument against some aspect of Aristotle's studies. He discovered that Venus had phases -which showed that Venus orbited the Sun. This did not prove that Earth orbited the Sun, since Tycho's hybrid cosmology would explain these phases. But, Galileo saw it as support of Copernicus.

In 1616, he was told by Church officials in Rome not to teach Copernicanism, that the Sun rather than the Earth was at the center of the Universe. He managed to keep quiet for a long time, but in 1632 he published his Dialogo (Dialogue on Two Chief World Systems) that had three men discussing the heliocentric and geocentric systems. He had official permission to publish the book, but the book did make apparent his preference for the Copernican heliocentric system. He was tried for his disobedience and sentenced to house arrest, where he remained for the rest of his life.

The New Physics: Isaac Newton of England

Many believe that the three top physicists of all time are: Isaac Newton, James Clerk Maxwell, and Albert Einstein. A summary: Newton discovered the law of gravity, Clerk Maxwell unified electricity and magnetism, and Einstein discovered special and general relativity.

In a mostly true story, young Isaac Newton (1642 – 1727) was sent home from Cambridge University to Woolsthorpe, near Lincoln, in England, when the English universities were closed because of plaque. While there, he saw an apple fall off an apple tree, and he realized that the same force that controlled the apple's fall was, no doubt, the same force that controlled the motion of the Moon.

Eventually, Newton was back at Trinity College, Cambridge, on the faculty. In the meantime, a group of scientists in London got together in a coffeehouse to form a society (now the Royal Society), and young Edmond Halley was sent to Cambridge to confirm a story that a brilliant mathematician, Isaac Newton, could help them with an important scientific question. The trip from London to Cambridge by stagecoach was a lot longer and more difficult than the hour's train trip is nowadays.

Halley asked Newton if there were a force that fell off with the square of the distance, what shape would an orbit have? And Newton replied that it would be an ellipse. Excited, Halley asked if he had proved it, and Newton said it was on some papers he had. He said he couldn't find them, though perhaps he was merely allowing time to judge whether he really wanted to turn over his analysis. Anyway, Newton was moved to write out some of his mathematical conclusions. They led, within a few years, to his most famous book, the Philosophiæ Naturalis Principia Mathematica (the Mathematical Principles of Natural Philosophy), where what they then called Philosophy includes what we now call Science.

Newton's Principia came out in 1687, in Latin. Newton was still a college teacher then; it was long before he was knighted for his later work for England's mint. Halley had to pay for the printing of Newton's book, and he championed it, even writing a preface.

The Principia famously included Newton's law that showed how gravity diminishes by the square of the distance, and his proof of Kepler's laws of planetary orbits. The book also includes Newton's laws of motion, neatly shown as "laws," in Latin, whereas Kepler's laws are buried in his text.

Newton's laws of motions are:

Newton's first law of motion: A body in motion tends to remain in motion, and a body at rest tends to remain at rest.

Newton's second law of motion (modern version): force = mass times acceleration.

Newton's third law of motion: For every action, there is an equal and opposite reaction.

Newton laid the foundation though mathematical physics that led to the science of our modern day.

Astronomy Research Continues

Just as the ancient peoples were curious about the sky and wanted to find our place in the universe, astronomers of the present day have built on the discoveries of the past with the same motivation. Theoretical and observational discoveries moved our understanding of our place in the universe from Ptolemy's geocentric vision, to Copernicus's heliocentric hypothesis, to the discovery that the solar system was not in the center of our galaxy, to our understanding of galaxies distributed across the universe.

Contemporary astronomy grapples with the programs of finding the nature of dark matter and dark energy. Einstein's theory of relativity indicates that not only is our galaxy not in the center of the universe, but that the "center" is rather meaningless. More recent discoveries of hundreds of exoplanets orbiting other stars have shown how unusual our solar system may be. New theories of planet formation parallel new observations of unexpected planetary systems. The path of discovery lies before astronomers of the modern age just as it did for those from thousands or hundreds of years ago.

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Solar System

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Summary

Undoubtedly, in a universe where we talk about stellar and solar systems, planets and exoplanets, the oldest and the best-known system is the solar one. Who does not know what the Sun is, what planets are, comets, asteroids? But is this really true? If we want to know about these types of objects from a scientific point of view, we have to know the rules that define this system.

Which bodies fall into these catagories (according to the resolution of the International Astronomical Union of 24 August 2006)?

- eight planets
- 162 natural satellites of the planets
- dwarf planets
- other smaller bodies:
    - o asteroids
    - o meteorites
    - o comets
    - o dust
    - o Kuiper belt objects
    - o etc.

By extension, any other star surrounded by bodies according to the same laws is called a stellar system.

What is the place of the Solar system in the universe? These are only some of the questions we will try to answer now.

Goals

- Determine the place of the Sun in the universe.
- Determine which objects form the solar system.
- Find out details of the various bodies in the solar system, in particular of the most prominent among them.

Solar System

What is a system?

A system is, by definition, an ensemble of elements (principles, rules, forces, etc.), mutually interacting in keeping with a number of principles or rules.

What is a Solar System?

To define it we shall indicate the elements of the ensemble: the Sun and all the bodies surrounding it and connected to it through the gravitational force.

What is the place of the Solar System in the Universe?

The Solar System is situated in one of the exterior arms of our Galaxy, also called the Milky Way. This arm is called the Orion Arm. It is located in a region of relatively small density.

The Sun, together with the entire Solar system, is orbiting around the center of our Galaxy, located at a distance of 25,000 –28,000 light years (approximately half of the galaxy radius), with an orbital period of approximately 225-250 million years (the galactic year of the Solar system). The travel dis-tance along this circular orbit is approximately 220 km/s, while the direction is oriented towards the present position of the star Vega.

Our Galaxy consists of approximately 200 billion stars, together with their planets, and over 1000 nebulae. The mass of the entire Milky Way is approx. 750-1000 billion times bigger than that of the Sun, and the diameter is approx. 100,000 light years.

Close to the Solar System is the system Alpha Centauri (the brightest star in the constellation Centaurus). This system is actually made up of three stars, two stars that are a binary system (Alpha Centauri A and B), that are similar to the Sun, and a third star, Alpha Centauri C, which is probably orbiting the other two stars. Alpha Centauri C is a red dwarf with a smaller luminosity than the sun, and at a distance of 0.2 light-years from the other two stars. Alpha Centauri C is the closest star to the Sun, at a distance of 4.24 light-years that is why it is also called "Proxima Centauri".

Our galaxy is part of a group of galaxies called the Local Group, made up of two large spiral galaxies and about 50 0ther ones.

Our Galaxy has the shape of a huge spiral. The arms of this spiral contain, among other things, interstellar matter, nebulae, and young clusters of stars, which are born out of this matter. The center of the galaxy is made up of older stars, which are often found in clusters that are spherical in shape, known as globular clusters. Our galaxy numbers approximately 200 such groups, from among which only 150 are well known. Our Solar System is situated 20 light years above the galactic equatorial plane and 28,000 light years away from the galactic center.

The galactic center is located in the direction of the constellation Sagittarius, 25,000 – 28,000 light years away from the Sun.

Sun

The age of the Sun is approx. 4.6 billion years. At present the Sun has completed about half of its

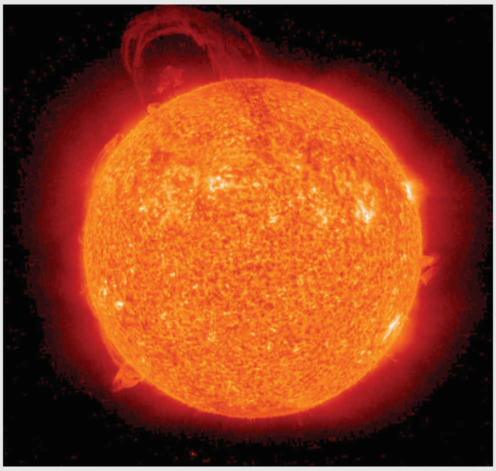

Fig. 1: The Sun.

main evolutionary cycle. During the main stage of its evolution the Sun's hydrogen core turns into helium through nuclear fusion. Every second in the Sun's nucleus, over four million tons of matter are converted into energy, thus generating neutrinos and solar radiation.

The Sun's life cycle
In about 5 billion years the Sun will turn into a red giant, and then into a white dwarf, a period when it will give birth to a planetary nebula. Finally, it will exhaust its hydrogen, which will lead to radical changes, the total destruction of the Earth included. Currently, solar activity, more specifically its magnetic activity, produces a number of phenomenon including sun spots on its surface, solar flares and solar wind variations, which carry matter into the entire solar system and even beyond.

The Sun's composition is made up of mostly hydrogen and helium. Hydrogen accounts for approx. 74%, and helium accounts for approximately 25% of the Sun, while the rest is made up of heavier elements, such as oxygen, and carbon.

The formation and the evolution of the Solar System.
The birth and the evolution of the solar system have generated many fanciful theories in the past. Even in the beginning of the scientific era, the source of the Sun's energy and how the Solar System formed was still a mystery. However new advances in the space era, the discovery of other worlds similar to our Solar system, as well as advances in nuclear physics, have all helped us to better understand the fundamental processes that take place inside a star, and how stars form.

The modern accepted explanation for how the Sun and Solar System formed (as well as other stars) was first proposed back in 1755 by Emmanuel Kant and also separately by Pierre-Simon Laplace. According to this theory stars form in large dense clouds of molecular hydrogen gas. These clouds are gravitationally unstable and collapse into smaller denser clumps, in the case of the Sun this is called the "solar nebula"; these initial dense clumps then collapse even more to form stars and a disk of material around them that may eventually become planets. The solar nebula may have originally been the size of 100 AU and had a mass 2-3 times bigger than that of the Sun. Meanwhile as the nebula was collapsing more and more, the conservation of angular momentum made the nebula spin faster as it collapsed, and caused the center of the nebula to become increasingly warmer. This took place about 4.6 billion years ago. It is generally considered that the solar system looks entirely different today than it originally did when it was first forming.

But let's take a better look at the Solar System, as it is today.

Planets

We shall use the definition given by the International Astronomical Union at its 26th General Meeting, which took place in Prague, in 2006.

In the Solar System a planet is a celestial body that:

1. is in orbit around the Sun,
2. has sufficient mass to assume hydrostatic equilibrium (a nearly round shape), and

3. has "cleared the neighborhood" around its orbit.

A non-satellite body fulfilling only the first two of these criteria is classified as a "dwarf planet".

According to the IAU, "planets and dwarf planets are two distinct classes of objects". A non-satellite body fulfilling only the first criterion is termed a "small solar system body" (SSSB).
Initial drafts planned to include dwarf planets as a subcategory of planets, but because this could potentially have led to the addition of several dozens of planets into the Solar system, this draft was eventually dropped. In 2006, it would only have led to the addition of three (Ceres, Eris and Makemake) and the reclassification of one (Pluto). Now, we recognize has five dwarf planets: Ceres, Pluto, Makemake, Haumea and Eris.

According to the definition, there are currently eight planets and five dwarf planets known in the Solar system. The definition distinguishes planets from smaller bodies and is not useful outside the Solar system, where smaller bodies cannot be found yet. Extrasolar planets, or exoplanets, are covered separately under a complementary 2003 draft guideline

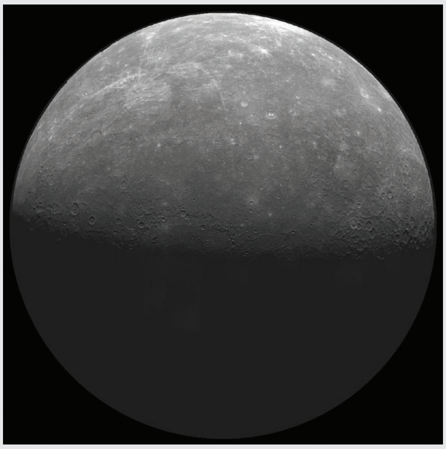

Fig. 2: Mercury.

for the definition of planets, which distinguishes them from dwarf stars, which are larger.

Let us present them one by one:

MERCURY
Mercury is the closest planet to the Sun and the smallest planet in the Solar system. It is a terrestrial[1] planet in the inner solar system. It gets its name from the Roman god Mercury.

It has no natural satellite. It is one of the five planets that can be seen from the Earth with the naked eye. It was first observed with the telescope only in the 17th century. More recently it was surveyed by two space probes: Mariner 10 (three times in 1974-1975) and Messenger (two times in 2008).

Although it can be seen with the naked eye, it is not easily observable, precisely because it is the closest planet to the Sun. Its location on the sky is very close to the Sun and it can only be well observed around the elongations, a little before sunrise or a little after sunset. However, space missions have given us sufficient information, proving surprisingly that Mercury is very similar to the Moon.

It is worth mentioning several characteristics of the planet: it is the smallest one in the Solar system and the closest one to the Sun. It has the most eccentric orbit (e = 0.2056) and also the most inclined one against the ecliptic (i = 7.005°). Its synodic period is of 115.88 days, which means that three times a year it is situated in a position of maximum elongation west of the Sun (it is also called "the morning star" and when it is three times in maximum elongation position east of the Sun it is called "the evening star". In either of these cases, the elongation does not exceed 28°.

It has a radius of 2440 km, making it the smallest planet of the Solar system, smaller even than two of Jupiter's Galilean satellites: Ganymede and Callisto.
A density of 5.427 g/cm^3 makes it the densest planet after the Earth (5.5 g/ cm^3). Iron might be the main heavy element (70% Iron and 30% rocky matter), which contributes to Mercury's extremely high density.

It is generally asserted that Mercury has no atmosphere, which is not quite correct as its atmosphere is extremely rarified.

Mercury is the only planet (besides the Earth) with a significant magnetic field, which, although it is of the order of 1/100 of that of the terrestrial magnetic field, it is sufficient enough to create a magnetosphere which extends up to 1.5 planetary radii, compared to 11.5 radii in the case of the Earth. Finally, there is another analogy with the Earth: the magnetic field is created by a dynamo effect and the magnetic is also dipolar like Earth's, with a magnetic axis inclined at 11° to the rotation axis.

[1] A terrestrial planet is a planet that is primarily composed of silicate rocks. Within the Solar system, the terrestrial (or telluric) planets are the inner planets closest to the Sun.

Orbital characteristics, Epoch J2000	
Aphelion	69,816,900 km, 0.466697 AU
Perihelion	46,001,200 km, 0.307499 AU
Semi-major axis	57,909,100 km, 0.387098 AU
Eccentricity	0.205630
Orbital period	87.969 days, (0.240 85 years), 0.5 Mercury solar day
Synodic Period	115.88 days
Average orbital speed	47.87 km/s
Mean anomaly	174.796°
Inclination	7.005° to Ecliptic
Longitude of ascending node	48.331°
Argument of perihelion	29.124°
Satellite	None

Physical Characteristics	
Mean radius	2,439.7 ± 1.0 km; 0.3829 Earths
Flattening	0
Surface area	7.48 10^7 km^2; 0.147 Earths
Volume	6.083 10^{10} km^3; 0.056 Earths
Mass	3.3022 10^{23} kg; 0.055 Earths
Mean density	5.427 g/cm^3
Equatorial surface gravity	3.7 m/s^2; 0.38 g
Escape velocity	4.25 km/s
Sideral rotation period	58.646 d; 1407.5 h
Albedo	0.119 (bond); 0.106 (geom.)
Surface temperature 0°N, 0°W 85°N, 0°W	min mean max 100 K 340 K 700 K 80 K 200 K 380 K
Apparent magnitude	-2.3 to 5.7
Angular momentum	4.5" – 13"

On Mercury the temperatures vary enormously. When the planet passes through the perihelion, the temperature can reach 427° C on the equator at noon, namely enough to melt the metal zinc. However, immediately after night fall, the temperature can drop down to 183°C, which makes the diurnal variation rise to 610 C!. No other planet undergoes such a difference, which is due either to the intense solar radiation during the day, the absence of a dense atmosphere, and the duration of the Mercurian day (the interval between dawn and dusk is almost three terrestrial months), long enough time to stock heat (or, similarly, cold during an equally long night).

Atmosphere:
Surface pressure trace.

Composition:
42% Molecular oxygen, 29.0% sodium, 22.0% hydrogen, 6.0% helium, 0.5% potassium. Trace amounts of argon, nitrogen, carbon dioxide, water vapor, xenon, krypton, and neon.

We have to say a few things about the planetary surface
Mercury's craters are very similar to the lunar ones in morphology, shape and structure. The most remarkable one is the Caloris basin, the impact that created this basin was so powerful that it also created lava eruptions and left a large concentric ring (over 2 km tall) surrounding the crater.

The impacts that generate basins are the most cataclysmic events that can affect the surface of a planet. They can cause the change of the entire planetary crust, and even internal disorders. This is what happened when the Caloris crater with a diameter of 1550 km was formed.

The advance of Mercury's perihelion
The advance of Mercury's perihelion has been confirmed. Like any other planet, Mercury's perihelion is not fixed but has a regular motion around the Sun. For a long time it was considered that this motion is 43 arcseconds per century, which is faster by comparison with the forecasts of classical "Newtonian" celestial mechanics. This advance of the perihelion was predicted by Einstein's general theory of relativity, the cause being the space curvature due to the solar mass. This agreement between the observed advance of the perihelion and the one predicted by the general relativity was the proof in favor of the latter hypothesis's validity.

VENUS
Venus is one of the eight planets of the Solar system and one of the four terrestrial planets in the inner system, the second distant from the Sun. It bears the name of the Roman goddess of love and beauty.

Its closeness to the Sun, structure and atmosphere density make Venus one of the warmest bodies in the solar system. It has a very weak magnetic field and no natural satellite. It is one of the only planets with a retrograde revolution motion and the only one with a rotation period greater than the revolution period.

It is the brightest body in the sky after the Sun and the Moon.

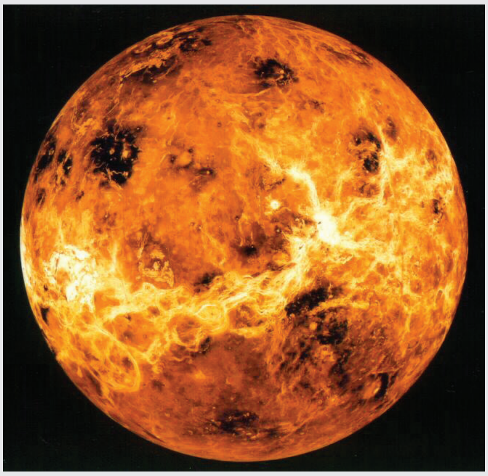

Fig. 3: Venus.

It is the second planet distant from the Sun (situated between Mercury and the Earth), at approximately 108.2 million km from the Sun. Venus' trajectory around the Sun is almost a circle: its orbit has an eccentricity of 0.0068, namely the smallest one in the Solar system.

A Venusian year is somewhat shorter than a Venusian sidereal day, in a ratio of 0.924.
Its dimension and geological structure are similar to those of the Earth. The atmosphere is extremely dense. The mixture of CO2 and dense sulfur dioxide clouds create the strongest greenhouse effect in the Solar system, with temperatures of approx. 460°C. Venus' surface temperature is higher than Mercury's, although Venus is situated almost twice as far from the Sun than Mercury and receives only approx. 25% of solar radiance that Mercury does. The planet's surface has an almost uniform relief. Its magnetic field is very weak, but it drags a plasma tail 45 million km long, observed for the first time by SOHO in 1997.

Remarkable among Venus' characteristics is its retrograde rotation; it rotates around its axis very slowly, counterclockwise, while the planets of the Solar system do this often clockwise (there is another exception: Uranus). Its rotation period has been known since 1962. This rotation – slow and retrograde – produces solar days that are much shorter than the sidereal day, sidereal days are longer on the planets with clockwise rotation[1]. Consequently, there are less than 2 complete solar days through-out a Venusian year.

The causes of Venus' retrograde rotation have not been determined yet. The most probable explanation would be a giant collision with another large body during the formation of the planets in the solar system. It might also be possible that the Venusian atmosphere influenced the planet's rotation due to its great density.

Orbital characteristics, Epoch J2000	
Aphelion	108,942,109 km, 0.728 231 28 AU
Perihelion	107,476,259 km, 0.718 432 70 AU
Semi-major axis	108,208,930 km, 0.723 332 AU
Eccentricity	0.006 8
Orbital period	224.70069 days; 0.6151970 years; 1.92 Venus solar days
Synodic period	583.92 days
Average orbital speed	35.02 km/s
Inclination	3.39471° to ecliptic, 3.86° to Sun's equator
Longitude of ascending node	76.67069°
Argument of perihelion	54.85229°
Satellite	None

Venus – the Earth's twin sister. The analogy
• They were born at the same time from the same gas and dust cloud, 4.6 billion years ago.

• both are planets in the inner solar system.

• their surfaces have a varied ground: mountains,

Properties	Venus	Earth	Ratio Venus/Earth
Mass	$4.8685\ 10^{24}$ kg	$5.9736\ 10^{24}$ kg	0.815
Equatorial Radius	6,051 km	6,378 km	0.948
Mean density	5.204 g/cm^3	5.515 g/cm^3	0.952
Semi-major axis	108,208,930 km	149,597,887 km	0.723
Average orbital speed	35.02 km/s	29.783 km/s	1.175
Equatorial surface gravity	8.87 m/s^2	9,780327 m/s^2	0.906

[1]. The solar day is the (average) interval between two suceeding passages of the Sun at the meridian. For instance, the Earth has a solar (average) day of 24 h and a sidereal day of 23 h 56 min 4,09 s. On Venus the solar day has 116.75 terrestrail days (116 days 18 hours), while the sidereal day has 243.018 terrestrial days.

Physical characteristics	
Mean radius	6,051.8 ± 1.0 km, 0.949 9 Earths
Flattening	0
Surface area	4.60 10^8 km^2, 0.902 Earths
Volume	9.38 10^{11} km^3, 0.857 Earths
Mass	4.8685 10^{24} kg, 0.815 Earths
Mean density	5.204 g/cm^3
Equatorial surface gravity	8.87 m/s^2, 0.904 g
Escape velocity	10.46 km/s
Sideral rotation period	-243.018 5 d
Albedo	0.65 (geometric) or 0.75 (bond)
Surface temperature (mean)	461.85 °C
Apparent magnitude	up to -4.6 (crescent), -3.8 (full)
Angular momentum	9.7" – 66.0"

fields, valleys, high plateaus, volcanoes, impact craters, etc.

• both have a relatively small number of craters, a sign of a relatively young surface and of a dense atmosphere.

• they have close chemical compositions

Venus' transit
Venus' transit takes place when the planet passes between the Earth and the Sun, when Venus' shadow crosses the solar disk. Due to the inclination of Venus' orbit compared to the Earth's, this phenomenon is very rare on human time scales. It takes place twice in 8 years, this double transit being separated from the following one by more than a century (105.5 or 121.5 years).

The last transits were 8 June 2004 and 6 June 2012, and the next one will be 11 December 2117

Fig. 4: Earth.

Atmosphere:
Surface pressure 93 bar (9.3 MPa)
Composition:
~96.5% Carbon dioxide, ~3.5% Nitrogen, 0.015% Sulfur dioxide, 0.007% Argon, 0.002% Water vapor, 0.001 7% Carbon monoxide, 0.001 2% Helium, 0.000 7% Neon.

EARTH
The Earth is the third planet from the Sun in the Solar system, and the fifth in size. It belongs to the inner planets of the solar system. It is the largest terrestrial planet in the Solar system, and the only one in the Universe known to accommodate life. The Earth formed approx. 4.57 billion years ago. Its only natural satellite, the Moon, began to orbit it shortly after that, 4.533 billion years ago. By comparison, the age of the Universe is approximately 13.7 billion years. 70.8 % of the Earth's surface is

Orbital characteristics, Epoch J2000	
Aphelion	152,097,701 km; 1.0167103335 AU
Perihelion	147,098,074 km; 0.9832898912 AU
Semi-major axis	149,597,887.5 km; 1.0000001124 AU
Eccentricity	0.016710219
Orbital period	365.256366 days; 1.0000175 years
Average orbital speed	29.783 km/s; 107,218 km/h
Inclination	1.57869
Longitude of ascending node	348.73936°
Argument of perihelion	114.20783°
Satellite	1 (the Moon)

Physical characteristics			
Mean radius	6,371.0 km		
Equatorial radius	6,378.1 km		
Polar radius	6,356.8 k		
Flattening	0.003352		
Surface area	510,072,000 km^2		
Volume	1.0832073 10^{12} km^3		
Mass	5.9736 10^{24} kg		
Mean density	5.515 g/cm^3		
Equatorial surface gravity	9.780327 m/s^2[9]; 0.99732 g		
Escape velocity	11.186 km/s		
Sideral rotation period	0.99726968 d; 23h 56m 4.100s		
Albedo	0.367		
Surface temperature (mean)	min 89 °C	mean 14 °C	max 57.7 °C

covered with water, the rest of 29.2% being solid and "dry". The zone covered with water is divided into oceans, and the land is subdivided into continents.

Between the Earth and the rest of the Universe there is a permanent interaction. For example, the Moon is the cause of the tides on the Earth. The Moon also continuously influences the speed of Earth's rotational motion. All bodies that orbit around the Earth are attracted to the Earth; this attraction force is called gravity, and the acceleration with which these bodies fall into the gravitational fi ld is called gravitational acceleration (noted with "g" = 9.81 m/s^2).

It is believed that creation of the Earth's oceans was caused by a "shower" of comets in the Earth's early formation period. Later impacts with asteroids added to the modification of the environment decisively. Changes in Earth's orbit around the Sun may be one cause of ice ages on the Earth, which took place throughout history.

Atmosphere:
Surface pressure 101.3 kPa (MSL)

Composition:
78.08% nitrogen (N2), 20.95% oxygen (O2), 0.93% argon, 0.038% carbon dioxide; about 1% water vapor (varies with climate).

MARS
Mars is the fourth distant planet from the Sun in the Solar System and the second smallest in size after Mercury. It belongs to the group of terrestrial planets. It bears the name of the Roman god of war, Mars, due to its reddish color.

Several space missions have been studying it starting from 1960 to find out as much as possible about its geography, atmosphere, as well as other details. Mars can be observed with the naked eye. It is not as bright as Venus and only seldom brighter than Jupiter. It overpasses the latter one during its most favorable confi urations (oppositions).

Among all the bodies in the Solar System, the red planet has attracted the most science fiction stories. The main reason for this is often due to its famous channels, called this for the first time in 1858 by Giovanni Schiaparelli and considered to be the result of human constructions.

Mars' red color is due to iron oxide III (also called hematite), to be found in the minerals on its surface.

Mars has a very strong relief; it has the highest mountain in the solar system (the volcano Olympus Mons), with a height of approx. 25 km, as well as the greatest canyon (Valles Marineris) with of an average depth of 6 km.

The center of Mars is made up of an iron nucleus with a diameter of approx. 1700 km, covered with an olivine mantel and a basalt crust with an average width of 50 km.

Mars is surrounded by a thin atmosphere, consisting mainly of carbon dioxide. It used to have an active hydrosphere, and there was water on Mars once.

It has two natural satellites, Phobos and Deimos, which are likely asteroids captured by the planet.

Mars' diameter is half the size of the Earth and its surface area is equal to that of the area of the continents on Earth. Mars has a mass that is about one-tenth that of Earth. Its density is the smallest among those of the terrestrial planets, which makes its gravity only somewhat smaller than of Mercury, although its mass is twice as large.

The inclination of Mars' axis is close to that of the Earth, which is why there are seasons on Mars just like on Earth. The dimensions of the polar caps vary greatly during the seasons through the exchange of carbon dioxide and water with the atmosphere.

Another common point, the Martian day is only 39 minutes longer than the terrestrial one. By contrast, due to its relative distance from the Sun, the Martian year is longer than an Earth year, more than 322 days longer than the terrestrial year.

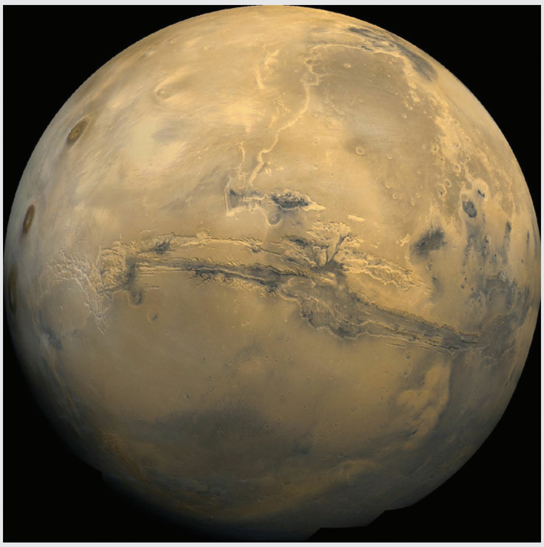

Fig. 5: Mars.

Orbital characterisitics, Epoch J2000	
Aphelion	249,209,300 km; 1.665861 AU
Perihelion	206,669,000 km; 1.381497 AU
Semi-major axis	227,939,100 km; 1.523679 AU
Eccentricity	0.093315
Orbital period	686.971 day; 1.8808 Julian years
Synodic period	779.96 day; 2.135 Julian years
Average orbital speed	24.077 km/s
Inclination	1.850° to ecliptic; 5.65° to Sun's equator
Longitude of ascending node	49.562°
Argument of perihelion	286.537°
Satellite	2

Physical characteristics	
Equatorial radius	3,396.2 ± 0.1 km; 0.533 Earths
Polar radius	3,376.2 ± 0.1 km; 0.531 Earths
Flattening	0.00589 ± 0.00015
Surface area	144,798,500 km^2; 0.284 Earths
Volume	1.6318 10^{11} km^3; 0.151 Earths
Mass	6.4185 10^{23} kg; 0.107 Earths
Mean density	3.934 g/cm^3
Equatorial surface gravity	3.69 m/s^2; 0.376 g
Escape velocity	5.027 km/s
Sideral rotation period	1.025957 days
Albedo	0.15 (geometric) or 0.25 (bond)
Surface temperature	min mean max -87 °C -46 °C -5 °C
Apparent magnitude	+1.8 to -2.91
Angular diameter	3.5—25.1″

Mars is the closest exterior planet to the Earth. This distance is smaller when Mars is in opposition, namely when it is situated opposite the Sun, as seen from the Earth. Depending on ellipticity and orbital inclination, the exact moment of closest approach to Earth may vary with a couple of days.

On 27 August 2003 Mars was only 55,758 million km away from Earth, namely only 0.3727 AU away, the smallest distance registered in the past 59,618 years. An event such as this often results in all kinds of fantasies, for instance that Mars could be seen as big as the full Moon. However, with an apparent diameter of 25.13 arcseconds, Mars could only be seen with the naked eye as a dot, while the Moon extends over an apparent diameter of approx. 30 arcminutes. The following similar close distance between Mars and Earth will not happen again until 28 August 2287, when the distance between the two planets will be of 55,688 million km.

Atmosphere:
Surface pressure 0.6–1.0 kPa).

Composition:
95.72% Carbon dioxide; 2.7% Nitrogen; 1.6% Argon; 0.2% Oxygen; 0.07% Carbon monoxide; 0.03% Water vapor; 0.01% Nitric oxide; 2.5 ppm Neon; 300 ppb Krypton; 130 ppb Formaldehyde; 80 ppb Xenon; 30 ppb Ozone;10 ppb Methane.

JUPITER

Jupiter is the fifth distant planet from the Sun and the biggest of all the planets in our solar system. Its diameter is 11 times bigger than that of the Earth, its mass is 318 times greater than Earth, and its volume 1300 times larger than those of our planet.

- orbit: 778,547,200 km from the Sun
- diameter: 142,984 km (equatorial)
- mass: $1.8986x10^{27}$ kg

Jupiter is the fourth brightest object in the sky (after the Sun, Moon, Venus and sometimes Mars). It has been known from prehistoric times. The discovery of its four great satellites, Io, Europe, Ganymede and Callisto (known as Galilean satellites) by Galileo Galilei and Simon Marius in 1610 was the first discovery of an apparent motion center not centered on Earth. It was a major point in favor of the heliocentric theory of planetary motion of Nicolaus Copernicus. Galileo's endorsement of the Copernican motion theory brought him trouble with the Inquisition. Before the Voyager missions, only 16 of its satellites were known, it is now known to have over 60 satellites.

Fig. 6: Jupiter.

Composition: Jupiter probably has a core of solid material that amounts up to 10 - 15 Earth masses. Above this core, is a deep layer of liquid metallic hydrogen. Due to the temperature and pressure inside Jupiter, its hydrogen is a liquid and not a gas. It is an electric conductor and the source of Jupiter's magnetic field. This layer probably contains some helium and some traces of "drifts of ice". The surface layer is mainly made up of molecular hydrogen and helium, liquid inside and gaseous outside. The atmosphere we see is only the superior part of this deep stratum. Water, carbon dioxide, methane, as well as other simple molecules are also present in small quantities.

Atmosphere: Jupiter consists of approx. 86% hydrogen and 14% helium (according to the number of atoms, approx. 75/25% by mass) with traces of methane, water, ammonia and "stone". This is very close to the original composition of the Solar Nebula, from which the entire solar system formed. Saturn has a similar composition, while Uranus and Neptune have less hydrogen and helium.

The Great Red Spot (GRS) was observed for the first time by the telescopes on Earth, more than 300 years ago. It is an oval of approximately 12000 by 25000 km, large enough to encompass two or three Earths. It is a region of high pressure, whose superior clouds are much higher and colder than the surrounding zones. Similar structures have been observed on Saturn and Neptune. The way in which such structures exist for such a long time has not been fully understood yet.

Jupiter and the other gaseous planets have winds of great speed in large bands at different latitudes. The winds blow in opposite directions in two adjoining bands. The small temperature or chemical composition differences are responsible for the different coloring of the bands, an aspect that dominates the image of the planet. Jupiter's atmosphere is very turbulent. This proves that the winds are driven, to a great extent, by the internal heat of the planet and not by coming from the Sun, as is the case with the Earth.

The Magnetosphere Jupiter has a huge magnetic field, 14 times stronger than that of Earth's magnetic field. Its magnetosphere extends over 650 million km (beyond Saturn's orbit). Jupiter's satellites are included in its magnetosphere, which partially explains the activity on Io. A possible problem for future space voyages, as well as a great problem for the designers of the probes Voyager and Galileo, is that the medium in the neighborhood of Jupiter has large quantities of particles caught by Jupiter's magnetic field. This "radiation" is similar, but much more intense than that observed in the Van Allen belts of the Earth. It would be lethal for any unprotected human being.

The Galileo probe discovered a new intense radiation between Jupiter's rings and the upper layer of the atmosphere. This new radiation belt has an intensity approx. 10 times higher than that of the Van Allen belts on Earth. Surprisingly, this new belt contains helium ions of high energy, of unknown origins.

Orbital characteristics, Epoch J2000	
Aphelion	816,520,800 km (5.458104 AU)
Perihelion	740,573,600 km (4.950429 AU)
Semi-major axis	778,547,200 km (5.204267 AU)
Eccentricity	0.048775
Orbital period	4,331.572 days; 11.85920 years; 10,475.8 Jupiter solar days
Synodic period	398.88 days
Average orbital speed	13.07 km/s
Mean anomaly	18.818°
Inclination	1.305° to ecliptic; 6.09° to Sun's equator
Longitude of ascending node	100.492°
Argument of perihelion	275.066°
Satellite	66

Physical characteristics	
Equatorial radius	71,492 ± 4 km; 11.209 Earths
Polar radius	66,854 ± 10 km; 10.517 Earths
Flattening	0.06487 ± 0.00015
Surface area	$6.21796\ 10^{10}$ km^2; 121.9 Earths
Volume	$1.43128\ 10^{15}$ km^3; 1321.3 Earths
Mass	$1.8986\ 10^{27}$ kg; 317.8 Earths; 1/1047 Sun
Mean density	1.326 g/cm^3
Equatorial surface gravity	24.79 m/s^2; 2.528 g
Escape velocity	59.5 km/s
Sidereal rotation period	9.925 h
Albedo	0.343 (bond); 0.52 (geom.)
Apparent magnitude	-1.6 to -2.94
Angular diameter	29.8" — 50.1"

The planet's rings Jupiter has rings just like Saturn, but much paler and smaller. Unlike those of Saturn, Jupiter's rings are dark. They are likely made up of small grains of rocky material. Unlike Saturn's rings, Jupiter's ring seem unlikely to contain ice. The particles from Jupiter's rings likely do not remain there for long (because of the atmospheric and magnetic attraction). The Galileo probe found clear evidence that indicates that the rings are continuously supplied by the dust formed by the impacts of micrometeorites with the inner four moons.

Atmosphere:
Surface pressure 20–200 kPa[12] (cloud layer)
Scale height 27 km
Composición:
89.8±2.0% Hydrogen (H2), 10.2±2.0% Helium, ~0.3% Methane, ~0.026% Ammonia, ~0.003% Hydrogen deuteride (HD), 0.0006% Ethane, 0.0004% water. Ices: Ammonia, water, ammonium hydrosulfide(NH4SH).

SATURN
Saturn is the sixth distant planet from the Sun in the Solar system. It is a gas giant planet, the second in mass and volume after Jupiter. It has a diameter approx. nine times greater than that of the Earth and is made up of mostly hydrogen. It bears the name of the Roman god Saturn.

Mass and dimensions Saturn has the form of a flattened spheroid: it is flattened at the poles and swollen at the equator. Its equatorial and polar diameters differ approx. by 10%, as a result of its rapid rotation around its axis and of an extremely fluid internal composition. The other gas giant planets in the solar system (Jupiter, Uranus, Neptune) are also flattened, but less so.

Saturn is the second most massive planet in the Solar system, 3.3 times smaller than Jupiter, but 5.5 times bigger than Neptune and 6.5 times bigger than Uranus. It is 95 times more massive than the Earth. Its diameter is almost 9 times larger than the Earth's.

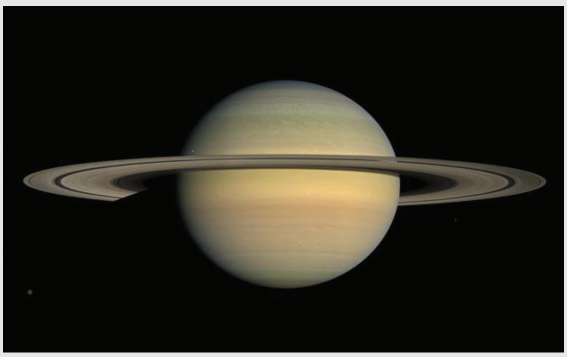

Fig. 7: Saturn.

Saturn is the only planet in the Solar system whose average density is smaller than that of water: 0.69 g/cm3. Although Saturn's core is denser than water, its average density is smaller than that of water because of its large hydrogen gaseous atmosphere.

Atmosphere Just like Jupiter, Saturn's atmosphere is organized in parallel bands, however these are less visible than Jupiter's and are wider near the equator. Saturn's cloud systems (as well as the long lasting storms) were first observed by the Voyager missions. The cloud observed in 1990 is an exam-

Orbital characteristics, Epoch J2000	
Aphelion	1,513,325,783 km; 10.115958 AU
Perihelion	1,353,572,956 km; 9.048076 AU
Semi-major axis	1,433,449,370 km; 9.582017 AU
Eccentricity	0.055723
Orbital period	10,759.22 days; 29.4571 years
Synodic period	378.09 days
Average orbital speed	9.69 km/s
Mean anomaly	320.346750°
Inclination	2.485240° to ecliptic; 5.51° to Sun's equator
Longitude of ascending node	113.642811°
Argument of perihelion	336.013862°
Satellite	~ 200 observed (61 with secure orbits)

Physical characteristics	
Equatorial radius	60,268 ± 4 km; 9.4492 Earths
Polar radius	54,364 ± 10 km; 8.5521 Earths
Flattening	0.09796 ± 0.000 18
Surface area	4.27 10^{10} km^2; 83.703 Earths
Volume	8.2713 10^{14} km^3; 763.59 Earths
Mass	5.6846 10^{26} kg; 95.152 Earths
Mean density	0.687 g/cm^3; (less than water)
Equatorial surface gravity	10.44 m/s^2; 1.065 g
Escape velocity	35.5 km/s
Sideral rotation period	10.57 h; (10 h 34 mi)
Equatorial rotation velocity	9.87 km/s; 35 500 km/h
Axial tilt	26.73°
Albedo	0.342 (bond); 0.47 (geom.)
Apparent magnitude	+1.2 to -0.24
Angular diameter	14.5" — 20.1" (excludes rings)

ple of a great white spot, an ephemeral Saturnian phenomenon that takes place every 30 years. If periodicity remains the same, the next storm will probably take place in 2020. In 2006 NASA observed a storm of hurricane dimensions, stationed at the Southern pole of Saturn that had a well defined eye. It is the only eye observed on another planet other than Earth.

Saturn's atmosphere undergoes a differential rotation.

Saturn's rings are one of the most beautiful phenomena in the solar system, making up its defining characteristic. Unlike the other gas giant planets with rings, they are extremely bright (albedo between 0.2 and 0.6) and can also be seen with a pair of binoculars. They are dominated by permanent activity: collisions, matter accumulations, etc.

Saturn has a great number of satellites. It is difficult to say how many there are, as any piece of ice in the rings can be considered a satellite. In 2009 62 satellites were identified. 53 were confirmed and were given names. Most of them are small: 31 have diameters fewer than 10 km, while 13 are smaller than 50 km. Only seven are big enough to take on a spheroidal shape under the influence of their own gravity. Titan is the largest one, bigger than Mercury and Pluto, and the only satellite in the solar system with a dense atmosphere.

Atmosphere:
Scale height: 59.5 km
Composition:
~96% Hydrogen (H2), ~3% Helium, ~0.4% Methane, ~0.01% Ammonia, ~0.01% Hydrogen deuteride (HD), 0.000 7% Ethane, Ices: Ammonia, water, ammonium hydrosulfide ((NH_4SH)

URANUS

Uranus is a gas giant planet. It is the seventh distant planet from the Sun in the solar system, the third in size and the fourth in mass. It bears the name of Chronos' father (Saturn) and of Zeus' grandfather (Jupiter). It is the first planet discovered in the modern epoch. Although it can be seen with the naked eye like the other 5 classical planets, because of its low luminosity it was not easily identified as being a planet. William Herschel announced its discovery on 13 March 1781, thus enlarging the frontiers of the Solar system for the first time in the modern epoch. Uranus is the first planet discovered by means of the telescope.

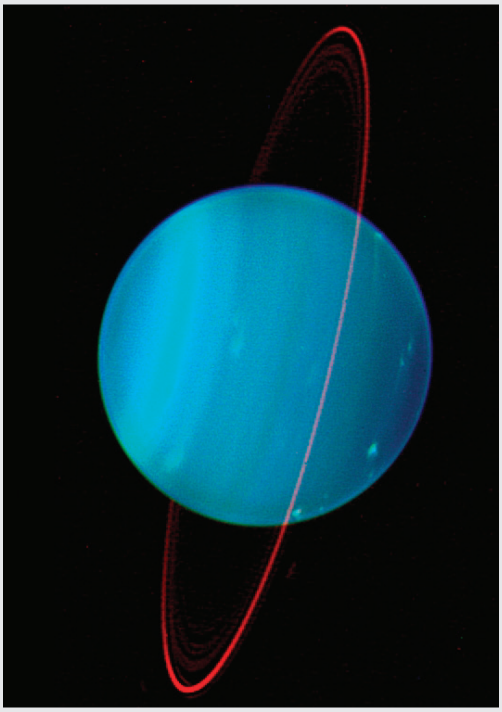

Fig. 8 Uranus.

Uranus and Neptune have internal and atmospheric compositions different from those of the other great gaseous planets, Jupiter and Saturn. That is why astronomers sometimes place them in a different category, that of the frozen giants or subgiants.

Uranus' atmosphere, although made up mainly of hydrogen and helium, also contains large quantities of water ice, ammonia and methane, as well as the usual traces of hydrocarbons. Uranus has the coldest atmosphere in the solar system, which reaches a minimum of – 224 ºC. It has a complex structure of clouds: the clouds in the lower layers might be made up of water, those in the upper layers of methane.

Like the other gas giant planets, Uranus has a system of rings, a magnetosphere and numerous natural satellites. The Uranian system is unique in the Solar system because its rotation axis is tilted sideways and is almost into the plane of its revolution about the Sun. Its northern and southern poles therefore lie where the other planets have their equator. In 1986, Voyager 2 took images of Uranus that show a planet almost featureless in visible light, without cloud bands or storms as on the other gaseous planets. However, recent observations have shown signs of seasonal change and an increase of the meteorological activity, in a period when Uranus approached its equinox of December 2007. The wind on Uranus can attain speeds of 250 m/s on its surface.

Orbital characteristics, Epoch J2000	
Aphelion	3,004,419,704 km, 20.083305 AU
Perihelion	2,748,938,461 km, 18.375518 AU
Semi-major axis	2,876,679,082 km, 19.229411 AU
Eccentricity	0.044405
Orbital period	30,799.095 days, 84.3233 years
Synodic period	369.66 day
Average orbital speed	6.81 km/s
Mean anomaly	142.955717°
Inclination	0.772556° to ecliptic, 6.48° to Sun's equator
Longitude of ascending node	73.989821°
Argument of perihelion	96.541318°
Satellite	27

Physical characteristics	
Equatorial radius	25,559 ± 4 km, 4.007 Earths
Polar radius	24,973 ± 20 km, 3.929 Earths
Flattening	0.0229 ± 0.0008
Surface area	8.1156 10^9 km^2, 15.91 Earths
Volume	6.833 10^{13} km^3, 63.086 Earths
Mass	(8.6810 ± 0.0013) 10^{25} kg, 14.536 Earths
Mean density	1.27 g/cm^3
Equatorial surface gravity	8.69 m/s^2, 0.886 g
Escape velocity	21.3 km/s
Sideral rotation period	0.71833 d; 7 h 14 mi 24 s
Equatorial rotation velocity	2.59 km/s, 9,320 km/h
Axial tilt	97.77°
Albedo	0.300 (bond), 0.51 (geom.)
Apparent magnitude	5.9 to 5.32
Angular diameter	3.3"–4.1"

Orbit and rotation Uranus' revolution period around the Sun is 84 terrestrial years. Its average distance from the Sun is of approx. 3 billion km. The solar flux intensity on Uranus is of approx. 1/400 of that received on Earth.

The rotation period of Uranus' interior is 17 hours and 14 minutes. In the upper atmosphere violent winds take place in the rotation direction, as is the case with all the giant gaseous planets. Consequently, around 60 latitude , visible parts of the atmosphere travel faster and make a complete rotation in less than 14 hours.

Uranus is a giant planet, like Jupiter, Saturn and Neptune. Even if we know very few things about its internal composition, we do know that it is certainly different from that of Jupiter or Saturn. Models of the internal structure of Uranus show that it should have a solid nucleus of iron silicates, with a diameter of approx. 7500 km, surrounded by a mantle made up of water ice mixed with helium, methane and ammonia that is 10,000 km wide, followed by a superficial atmosphere of hydrogen and liquid helium, of approx. 7600 km. Unlike Jupiter and Saturn, Uranus is not massive enough to preserve hydrogen in a metallic state around its nucleus.

The bluish-green color is due to the presence of methane in the atmosphere, which absorbs especially in the red and the infrared.
Uranus has at least 13 main rings.

Unlike any other planet in the solar system, Uranus is very inclined to its axis, as the latter one is almost parallel to its orbital plane. We might say that it rolls on its orbit and exposes to the Sun its north pole and its southern pole successively.

One consequence of this orientation is that the polar regions receive more energy from the Sun than the equatorial ones. Nevertheless, Uranus remains warmer at the equator than at the poles, a mechanism still unexplained. Any theory for the formation of Uranus that also accounts for its inclination, usually incorporates the idea of a cataclysmic collision with another body before its present formation.
Uranus has at least 27 natural satellites. The first two were discovered by William Herschel on 13 March 1787 and were called Titania and Oberon.

Atmosphere:

Composition:
(below 1.3 bar): 83 ± 3% Hydrogen (H_2), 15 ± 3%

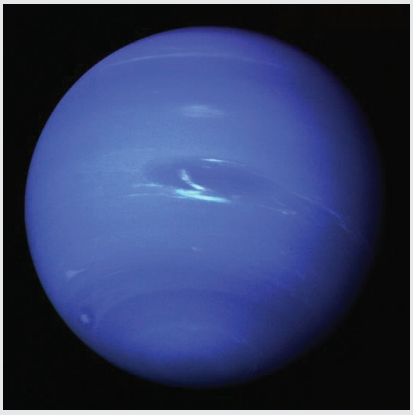

Fig. 10: Neptune.

Helium, 2.3% Methane, 0.009% (0.007–0.015%) Hydrogen deuteride (HD). Ices: Ammonia, water, ammonium hydrosulfide (NH_4SH), methane (CH_4).

NEPTUNE

Neptune is the eighth and the farthest planet from the Sun in the Solar system. It is also the last gaseous giant planet.

It was discovered by the German astronomer Johann Gottfried Galle on 23 September 1847, following the predictions of Urban Le Verrier who, like the English astronomer John Couch Adams, had found through matematical calculations the region in the sky where it could likely be found.

Orbital characteristics, Epoch J2000	
Aphelion	4,553,946,490 km, 30.44125206 AU
Perihelion	4,452,940,833 km, 29.76607095 AU
Semi-major axis	4,503,443,661 km, 30.10366151 AU
Eccentricity	0.011214269
Orbital period	60,190 days, 164.79 years
Synodic period	367.49 days
Average orbital speed	5.43 km/s
Mean anomaly	267.767281°
Inclination	1.767975° to ecliptic, 6.43° to Sun's equator
Longitude of ascending node	131.794310°
Argument of perihelion	265.646853°
Satellite	13

Physical characteristics	
Equatorial radius	24,764 ± 15 km, 3.883 Earths
Polar radius	24,341 ± 30 km, 3.829 Earths
Flattening	0.0171 ± 0.0013
Surface area	$7.6408\ 10^9\ km^2$, 14.98 Earths
Volume	$6.254\ 10^{13}\ km^3$, 57.74 Earths
Mass	$1.0243\ 10^{26}$ kg, 17.147 Earths
Mean density	$1.638\ g/cm^3$
Equatorial surface gravity	$11.15\ m/s^2$, 1.14 g
Escape velocity	23.5 km/s
Sideral rotation period	0.6713 d, 16 h, 6 mi, 36 s
Equatorial rotation velocity	2.68 km/s, 9,660 km/h
Axial tilt	28.32°
Albedo	0.290 (bond), 0.41 (geom.)[7]
Apparent magnitude	8.0 to 7.78
Angular diameter	2.2"-2.4"

It bears the name of the Roman god of the seas, Neptune.

Neptune is not visible with the naked eye and does not appear as a bluish-green disk through the telescope. It was visited only once by a space probe, Voyager 2, who passed by it on 25 August 1989. Its largest satellite is Triton.

Its internal composition is similar to that of Uranus. It is believed that it has a solid nucleus made of silicates and iron, almost as big as the mass of the Earth. Its nucleus, just like Uranus', is supposedly covered with a rather uniform composition (fused rocks, ice, 15% hydrogen and a few helium); it does not have any structure in "layers" like Jupiter and Saturn.

Its bluish color comes mainly from methane, which absorbs light in the wavelengths of red. It seems that another composition give Neptune its bluish color, but that has not been defined yet.

Like the other giant gaseous planets, it has an aeolian system made up of very rapid winds in bands parallel to the equator, of immense storms and vortexes. The fastest winds on Neptune blew at speeds over 2,000 km/h.

During the survey of Voyager 2, the most interesting formation discovered was the "Dark Great Spot", which was about the size of the "Red Great Spot" on Jupiter. This spot was not observed about 5 years later when the Hubble Space Telescope took observations of Uranus. The winds on Uranus might have speeds as high as 300 m/s (1080 km/h) or even up to 2500 km/h. This spot might be a dark giant hurricane that supposedly travels at 1000 km/h.

Neptune has fewer visible planetary rings. They are dark and their origin is yet unknown.

Neptune has at least 13 natural satellites, among them the largest is Triton, discovered by William Lassell only 17 days after the discovery of Neptune.

Atmosphere:

Composition:

80±3.2% Hydrogen (H2), 19±3.2% Helium, 1.5±0.5% Methane, ~0.019% Hydrogen deuteride (HD), ~0.00015 Ethane. Ices: Ammonia, water, (NH_4SH), Methane.

Other Bodies in the Solar System

The interplanetary environment

Besides light, the Sun radiates a continuous flux of charged particles (plasma) called solar wind. This flux dissipates at a speed of 1.5 millions km/h, thus creating the heliosphere, a thin atmosphere which surrounds the Solar system out to a distance of approx. 100 AU (marking the heliopause). The matter that makes up the heliosphere is called interplanetary medium. The solar cycle of 11 years, as well as the frequent solar flares and coronal mass ejections, disturb the heliosphere and create a space climate. The rotation of the solar magnetic field acts upon the interplanetary medium, creating the stratum of heliospheric current, which is the greatest structure of the Solar system.

The terrestrial magnetic field protects the atmosphere from the solar wind. The interaction between the solar wind and the terrestrial magnetic fi ld brings about the polar aurora.

The heliosphere ensures a partial protection of the Solar system from cosmic rays, that is higher on the planets with a magnetic field.

The interplanetary medium accommodates at least two regions of cosmic dust under the form of a disk. The first one, the cloud of zodiacal dust, is in the internal Solar system and produces the zodiacal light. It probably formed through a collision inside the asteroid belt caused by the interactions with the planets. The second one extends between 10 and 40 AU and was probably created during similar collisions in the Kuiper belt.

THE BELT OF ASTEROIDS

Asteroids are mainly small bodies in the solar system made up of rocks and non-volatile metallic minerals. The asteroid belt occupies an orbit located between Mars and Jupiter, at a distance of 2.3 up to 3.3 AU from the Sun. The asteroid belt formed from the primordial solar nebula as a group of planetesimals, the smaller precursors of planets. These planetesimals were too strongly perturbed by Jupiter's gravity to form a planet.

Fig. 11: Halley Comet

Asteroids range between several hundred kilometers down to microscopic dust. All, except the greatest one, Ceres, are considered small bodies. A few of the other large asteroids such as Vesta and Hygeia are also still considered small bodies, they could be classified as dwarf planets at some point, if in the future it can be determined that they have reached hydrostatic equilibrium.

The asteroid belt contains thousands, even millions of bodies with a diameter of over one kilometer. Nevertheless, the total mass of the belt is only 4% of the Moon's mass.

Ceres (2.77 AU) is the largest body in the asteroid belt and the only dwarf planet (classified thus in 2006). With a diameter of almost 1000 km, and enough mass that it is in hydrostatic equilibrium and has a spherical shape.

COMETS

Comets are small bodies in the Solar system, with diameters on the order of kilometers, comets are generally made up of volatile ices. They have very eccentric orbits, with the perihelion sometimes situated in the inner Solar system, while the aphelion is beyond Pluto. When a comet enters the inner Solar system, its close approach to the Sun leads to the sublimation and ionization of its surface, creating a tail: a long trail made up of gas and dust.
Short period comets (e.g. Halley Comet) complete their orbits in less than 200 years and seem to originate in the Kuiper belt. Long period comets (e.g. Hale-Bopp comet) have a periodicity of several thousands years and seem to originate in Oort's cloud. Finally, there are some comets that have a hyperbolic trajectory, suggesting they may eventually escape the Solar system. Old comets have lost the greatest part of their volatile components and today are often considered asteroids.

Centauri, situated between 9 and 30 AU, are icy bodies analogous to the comets, that orbit between Jupiter and Neptune. The greatest centaur known, Chariklo, has a diameter ranging between 200 and 250 km. The first centaur discovered, Chiron, was considered in the beginning to be a comet because it developed a cometary tail. Some astronomers

Fig. 12: Pluto and dwarf planets.

classify centaurs as bodies of Kuiper belt.

The Kuiper belt is a great ring made up of debris belonging to a large debris ring, similar to the asteroid belt, but made up mainly of ice. The first part of the Kuiper belt extends between 30 and 50 AU from the Sun and stops at "Kuiper's cliff ", from there begins the second part of the belt out to 100 AU. This region is believed to be the source of short period comets.
It is mainly made up of small bodies, as well as of some rather big ones, like Quaoar, Varuna or Orcus, which might be classified as dwarf planets.
The Kuiper belt can be divided largely into "classical" objects and objects in resonance with Neptune. An example to this effect would be the plutinos that complete two orbits for every three that Neptune has completed.

PLUTO AND CHARON
Pluto (39 AU on average), a dwarf planet, is the largest known body of the Kuiper belt. Discovered in 1930, it was considered a planet and re-classified in August 2006. Pluto has an eccentric orbit inclined by 17º to its ecliptic plane. Pluto's orbital distance extends up to 29.7 AU at the perihelion and 49.5 AU at the aphelion.

Pluto's largest satellite, Charon, is massive enough so that the two orbit around each other, around a common center of mass that is situated above the surface of each of the bodies. Four other small satellites, (Nix, Styx, Kerberos and Hydra), orbit the Pluto. Pluto is in an orbital resonance of 3:2 with Neptune (the planet orbits the Sun twice, for every three times Neptune orbits the Sun). The other bodies of the Kuiper belt that participate in this resonance with Neptune are called plutinos (namely small Plutos).

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Local Horizon and Sundials

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Summary

The study of the horizon is crucial to facilitate the students' first observations in an educational center. A simple model that may be made in each center allows us to study and comprehend the first astronomical rudiments easier. The model is also presented as a simple model of an equatorial clock and from it, we can make other models (horizontal and vertical).

Goals

- Understand the diurnal and annual movement of the Sun.
- Understand the celestial vault movement.
- Understand the construction of an elemental Sun watch.

The Earth rotates and revolves

As it is well known, Earth rotates around its axis, which results in day and night. The rotation axis is what ancient astronomers called the axis of the Earth as it seemed that the sky moved around this axis (the daytime sky and the night sky). But Earth revolves in an ellipse, with the Sun in one of its focus. As first approximation, we can suppose that it is a circular motion (as the ellipse's eccentricity is almost zero, i.e. the orbit is almost a circle).

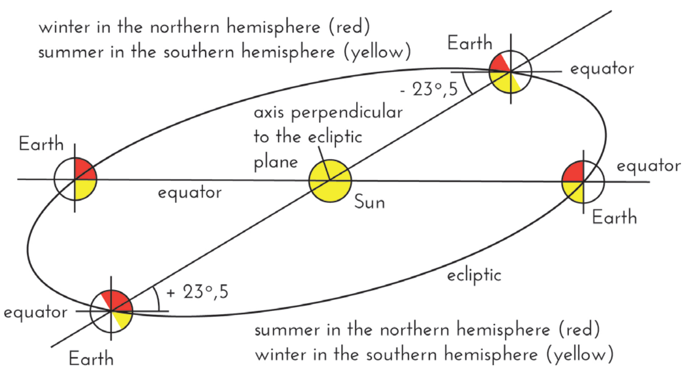

Fig. 1: Scheme of Earth's revolution. The angle between the terrestrial equator and the ecliptic plane is 23.5º. The angle between the rotational terrestrial axis and the axis perpendicular to the ecliptic plane is also 23.5º.

Earth needs a year to make a full orbit around the Sun, but it does so in a plane, the ecliptic plane, which is not perpendicular to the rotational terrestrial axis; it is inclined. Specifically, the angle between the rotational terrestrial axis and the axis perpendicular to the ecliptic is 23.5º. Similarly, the angle between the terrestrial equator plane and the ecliptic plane is 23.5º (figure 1). This inclination causes the seasons. To visualize this phenomenon we are going to build a little model (figure 2).

We illustrate this effect with four spheres and a light bulb, representing the Sun, to be placed in the center. It is good to draw the terrestrial surface to distinguish the equator and the poles. Then, we give some values of distances relative to the sphere's size that represents the Earth models. In our case, we use 8 cm diameter models. We will get a little square tablecloth or paper that is about 25 cm across the diagonal. We situate the four spheres

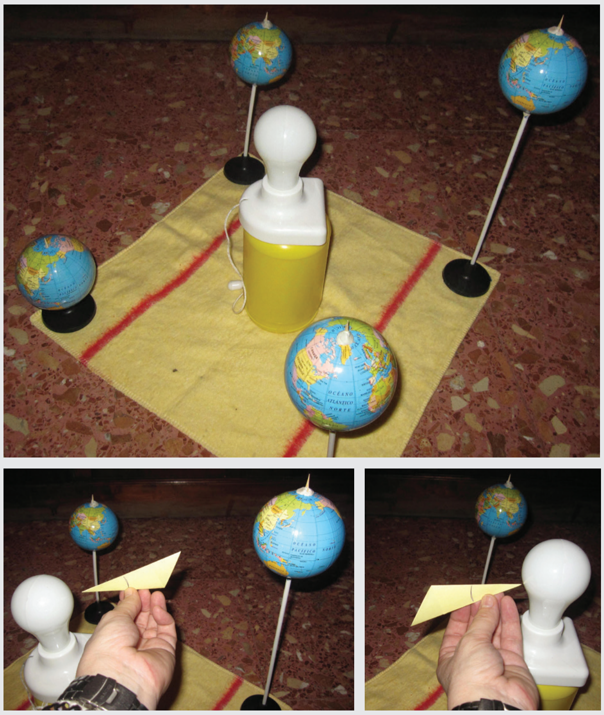

Fig. 2a, 2b and 2c: Distribution of the four spheres representing Earth and the light bulb representing the Sun, in the middle. It is necessary to distribute the relative positions so that the angle of the line from the center of the Sun to the center of the Earth is 23º with respect the ground that represents the equatorial plane.

in a cross shape (each one in front of the other, figure 2) elevated using 4 sticks of 3, 15, 25 and 15 cm of height respectively. The values are calculated so that the inclination of the plane of the equator with respect the ecliptic plane is about 23º.

We will situate the model in a dark room and turn on the light bulb (it could be a candle, but always be aware that the relative heights are important). It is obvious that the sphere at position A receives more light in the northern hemisphere than the one at the position C (figure 3), while the illuminated area of the southern hemisphere is greater in C than in A. At positions B and D, both hemispheres are equally illuminated; these correspond to spring and autumnal equinoxes. At the times when there

Fig. 3: Model of the revolution motion that explains seasons. When the Earth is at position A it is summer in the northern hemisphere and winter in the southern hemisphere. When the Earth is at position C it is winter in the northern hemisphere and summer in the southern hemisphere. And when the Earth is at positions B and D hemispheres are equally illuminated and equinoxes take place. Then, daytime and nighttime are equal.

is more illuminated area we say that it is summer and when there is less, it is winter. We deduce that when the Earth is at position A, it is summer in the northern hemisphere and winter in the southern hemisphere.

When the Earth is at position C, it is winter in the northern hemisphere and summer in the southern hemisphere.

This model offers many opportunities for study because if we imagine that a person lives in one of the hemispheres, we will see that he/she sees the Sun in different heights depending on the season. We imagine, for example, that we have a person in the northern hemisphere when we are at position A, this person sees the Sun above the equatorial plane 23.5º (figure 4a). However, if he/she is in the northern hemisphere but in the position C, he/she sees the Sun below the equator at -23.5º (figure 4b). When he/she is at positions B and D, he/she sees it exactly on the Equator, i.e. 0º above the equator.

Fig. 4a: At the position A it is summer in the northern and the Sun is 23.5º above equator. However, in the southern hemisphere it is winter.

Fig. 4b. At the position C it is winter in the northern hemisphere and the Sun is 23.5 below the equator. However, in the southern hemisphere it is summer.

The Parallel Earth

The position that we enjoy in the previous model "Earth from outside" is not easy to observe from our city. In fact it seems quite impossible since we are glued to the Earth and only an astronaut from his space ship could see the Earth from outside. But there is a simple strategy that allows you to view the Earth from outside and lit area every day and every hour. Let's use a parallel Earth for it. That is, an illuminated globe in the same way that Earth by the same source that is the Sun.

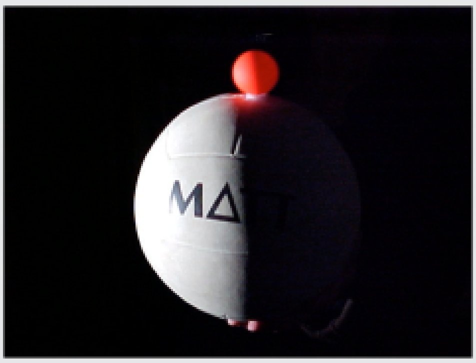

Fig. 5: A spotlight illuminates two spheres in the same way and produces the same areas of light and shadow.

If a spotlight illuminates two spheres produces on them the same areas of light and shadow (figure 5), so if we orient correctly the globe will be the same area on the globe that is our planetand we can look at it as if we were an astronaut located more far from what is the ISS.

We will use as a globe of the usual, except that we will remove the foot and will place on a glass, with the axis of rotation of the globe in the same direction as it really has the Earth (we help of a compass to indicate us north-south). We also know that the position of our city should be at the top of the globe, because, anywhere in the world where we live, if we straight move in any direction for many km long, it is clear that whenever we will finally come down on the surface of the globe. So our position is always the top.

Consecuently, we will use a compass that tells us the north-south direction to guide the axis of the globe and our city will place the highest position (figure 6a). To verify that the globe is properly positioned can leave a pencil on the city in balance, if the pencil is above it will not fall, but if the pencil falls must be corrected slightly until stable position. We can illustrate this position by placing a doll to represent us (figure 6b).

With bits of "clay" we can make the sun/shade line and see what it will slowly moving across the surface of the globe as they pass the hours and it arrive at a time when it will be night. We can put small pieces of sticks as a gnomon and see how the shadows are and how they move throughout the day and you visualize effects of rotational motion on Earth (figure 6b).

Fig. 6a: The globe, with the usual support, does not serve as a model. The globe should be placed outside, on a glass and oriented, with the place from where we observe at the top to be a perfect model.
Fig. 6b: We can put a doll indicating our position and bits of clay to indicate the line of light/shadow area. With the passing of the hours this light/shadow line will go away. Also you can put some pieces of chopsticks to study their shadows.

But the most interesting is to visualize the translation movement, this is how the sun/shade line is situated throughout the year. Thus it can be seen that in summer (figure 7a), winter (figure 7b) and equinox (figure 7c) as could check in the initial model with the four globes (figure 3).

Fig. 7a: In the northern hemisphere, the north pole is in the sunny area therefore means it's summer for this hemisphere and we are observing the phenomenon of the midnight sun. In the southern hemisphere, the south pole is in the shade and winter. Fig. 7b: The north pole is within the area of the night, so in the northern hemisphere's winter. In the southern hemisphere, the south pole illuminated and therefore is summer for them. Fig. 7c: The line separating the day and night passes both poles, that is, the first day of spring or the first day of autumn.

But after considering these two models we believe it is necessary to introduce the "real" model for the observer who is linked to the Earth and observed that every day the stars move relative to the horizon. We build a model on the local horizon of the observer, A MODEL REALLY OBSERVATIONAL.

Observation

Teachers from different science fields (mechanics, electricity, chemistry, biology, etc.) tend to say that it is not possible to work correctly in a secondary science center without a laboratory. In this sense, astronomy teachers tend to be happy because they always have an astronomical laboratory. All institutes and schools have a place where students play: the outdoor playground or yard. But these are not only playtime places, they are also astronomical laboratories: a place that offers the possibility to carry out practical astronomical activities. If we have a laboratory in every school or institute, it seems opportune to use it!

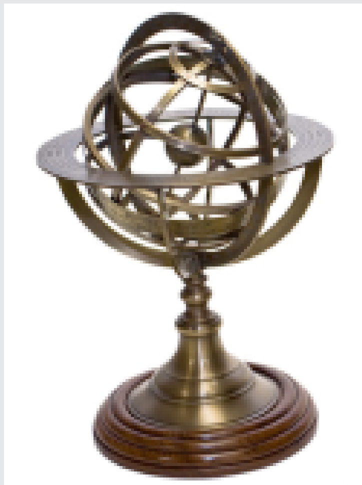

Fig. 8: Classical representation of the celestial sphere.

A problem that appears when a student uses the school yard to do practical astronomical activities is the lack of connection with the teacher's explanations of the celestial sphere inside the classroom and outside.

When the teacher talks about meridians and parallels or position coordinates on the blackboard, in texts, or in models, he/she presents figures like figure 8. This is not very difficult and students tend to understand it without a problem. Figures that students have before their eyes are analogues to the ones that they have used when were studying geography (figure 9).

Problems begin when we are viewing the sky and there is no line. It is impossible to see the rotation axis, and it is not really easy to find references in the sky. Now the principal problem is that a student is inside the celestial sphere while in classroom, but we have presented all the information viewing the sky from the exterior of the celestial sphere. Then, it is not simple to understand the new situation of being inside the sphere (figure 10).

Obviously, after this experience we could think how to change our presentation in the classroom. It is possible to do the presentation from the internal point of view of the sphere. This way is much more similar to the real situation of the observer, but it is not interesting to offer only this presentation. Students have to be able to read any astronomy book and understand the correspondent abstraction of the celestial sphere observation from the exterior, a normal situation in the scientific literature. In these circumstances, it is possible to think about making a model for the students that allows the comparison of both points of view and that also "makes the sky lines visible" and provides a better comprehension of the horizon.

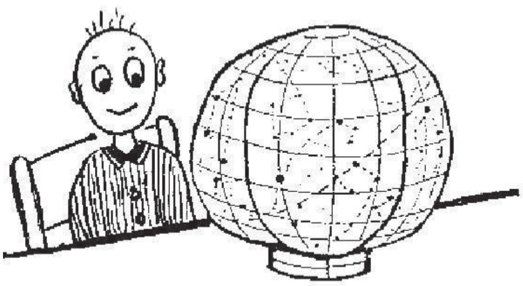

Fig. 9: Celestial sphere from the exterior.

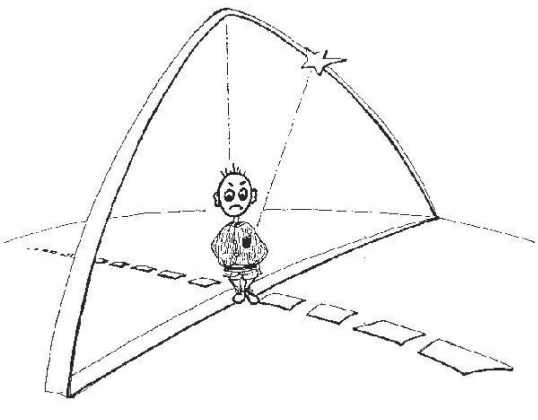

Fig. 10: Celestial sphere from the interior.

Local model of the horizon

We begin by taking a photograph of the horizon. It is very easy to take some photographs of the horizon with a camera and a tripod from any place of the school yard – if local buildings allow us to do it - or from any balcony with a clearer view of the horizon.

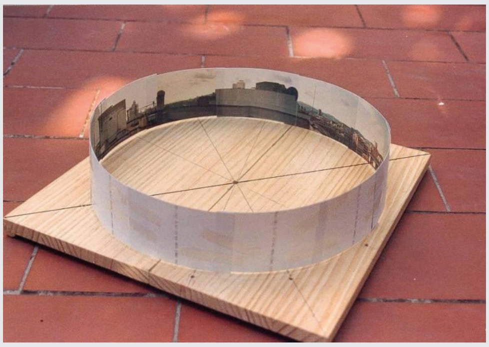

Fig. 11: The local horizon.

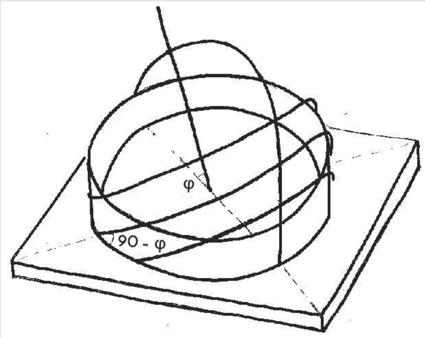

Fig. 12: Model showing the horizon and polar axis.

(We will mark the tripod position with paint or chalk on the ground). It is very important to select a good place, because the idea is to situate the model there during every observation. When tak-ing the photo, it is necessary that it has a common area with the next one, and then we can join all the photographs in order to get the horizon as a chain of photographs continuously.

When we have all the photos, we can connect them. Place one copy next to another in a continuous way, and then make a cylinder that will be fixed in a wood square base in the same place that we took the photos (figure 12).

It is very important to situate all photos according to the real horizon.

Later, we introduce the terrestrial rotation axis. Taking the latitudinal value of the place, we can introduce a wire with the corresponding inclination (latitude) on the model (figure 13).

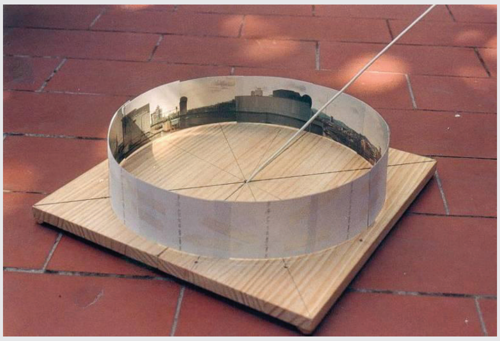

Fig. 13: Model with horizon ring and polar axis

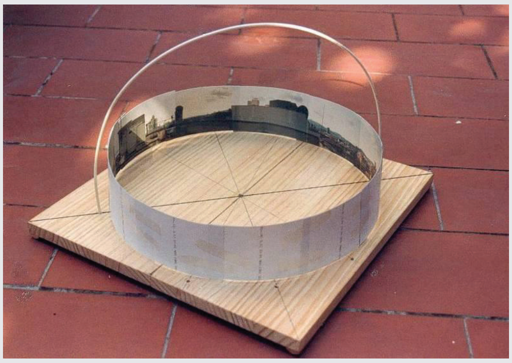

Fig. 14: Model with the local meridian

With this value, it is possible to fix the rotational axis of the model. As the model is oriented according to the local horizon, the elongation of the wire is used to see the real axis, to locate the South Pole, and also to imagine the position of the cardinal point south (figure 13). Obviously, to introduce the cardinal point north and the North Pole results easily. Later, we can draw the North-South straight line in the model and also in the court or balcony ground where we took the pictures (using the normal process to determinate the north-south straight line). This is very important because every time we use this model, we will have to orient it, and it is very useful to have this real north-south straight line to facilitate the work. (We can verify this direction with a compass).

The next step consists of locating the meridian of the place. The local meridian is very easy to define, but it is not a simple concept to assimilate for the students (maybe because everyone has his own meridian). We can fix a wire that passes for the cardinal points north and south and the rotation axis of Earth (figure 14). This wire is the meridian visualization of the location of the model, but allows us to imagine the local meridian line in the sky. Now it is very easy to imagine because it begins in the same places that student sees in the model. The local meridian begins in the same building as it does in the photo but on the real horizon. When the meridian passes above his head, it will end in the same building that we see, thanks to the wire in the horizon of the photos.

The process to introduce the equator is more complicated. One possibility consists of the east-west line. This solution is very simple, but it does not reach anything from the pedagogic point of view. For educational purposes, it is more convenient to use photography again. We can situate the camera on the tripod again in the same position that it was in when we took the first photos of the horizon. (This is why we painted the corresponding marks on the ground, so we could situate the tripod in the same place again). With the camera on the tripod, we take a photo of the sunrise and the sunset on the first day of spring and autumn. In this case, we will have two photos of the precise position of east and west cardinal points respectively, with respect to the horizon in the photos and obviously above the real horizon.

We simulate the equator with a wire perpendicular to the terrestrial rotation axis; it is fastened at the east and west cardinal points (in the horizontal plane that is perpendicular to the north-south line). However, it is not easy to fix this wire to the wire that symbolizes the rotation axis because it is inclined, and obviously it is inclined to the equator also. This leaves the question as to what inclination to use. We will take four or five pictures of the sunrise on the first day of spring or

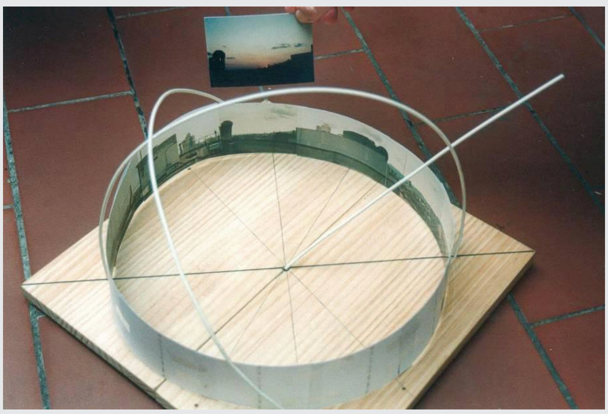

Fig. 15: Sunset point the day of the spring or autumn equinox.

summer. Photographing the sun is dangerous when it is quite high in the sky, but it is safe during sunrise or sunset when the Earth's atmosphere acts like a filter.

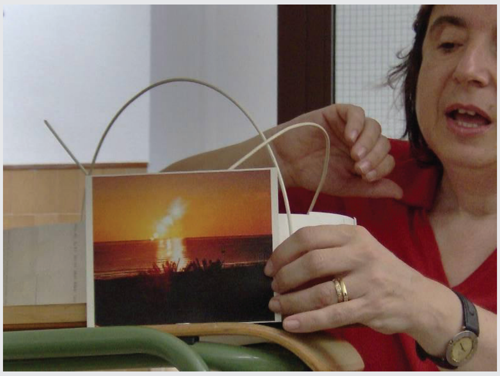

Fig. 16: Trace of the sunrise

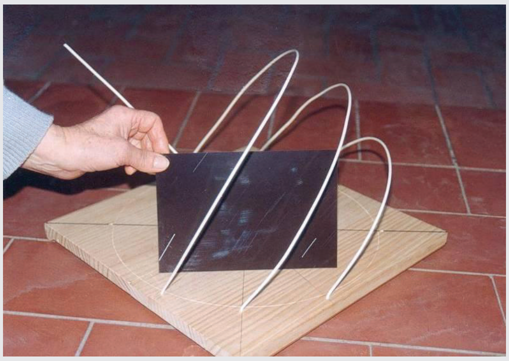

Fig. 17: Traces of the stars in the east

We will use all the photographs and use the appropriate software on put them together (using some reference to the horizon), and we can distinguish the inclination of the sun itself on the horizon. This picture will serve to introduce the proper slope on the wire representing the equator in the model (figure 16). Using the two photographs of the cardinal points East and West, it is possible to know the inclination of the traces of the stars in equator, and therefore it is possible to locate the wire that symbolizes equator smoothly. We now know the fixed points and also the inclination, so the wire can be fastened on the frame and also hold the local meridian (figure 16).

If we consider the Sun as a normal star (the Sun is the most important star for us because it is the nearest, but its behavior is not very different from other stars), we can obtain the inclined motion of stars when they rise or set with respect to the horizon. To do this we only have to take two pictures of this instant near the cardinal point east and west (figure 17).

It may be impossible to take the pictures mentioned in the previous paragraph from the city where the school is built.

We have to go to the countryside, in a place that is not affected by light pollution, and take pictures with a single-lens reflex camera on a tripod with a cable release. About 10 minutes of exposure is enough. It is very important to place the camera parallel to horizon (we can use a level to do this operation).

Take this opportunity to get a small portfolio of photographs. For example, you can take one of the pole area giving a 15 minute exposure, another one of the area above it along the local meridian, another one following the same meridian and so forth, until you get to the picture that is on the horizon. The idea is to photograph all the local meridian from north to south, passing over our heads. Obviously, the local meridian of the place where we have decided to take pictures is not the same as that of the school, but students can easily understand this small difference.

When we have all the pictures, we can build a meridian strip with them all. With this strip, students can better understand the movement of the celestial sphere around Earth's axis of rotation. Interestingly, with the same exposure time, the trajectories drawn by stars change their length. It is at a minimum around the pole and maximum at the equator. It also changes shape. At the equator, the trajectory draws a straight line. In the area near the pole, lines are concave curves above the equator and are convex below. If we make paper copies of the pictures large enough, we can put the strip over the head of the students, allowing them to visualize and understand the movement better.

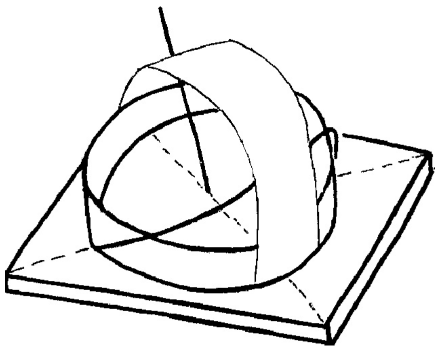

Fig. 18: The local meridian pictures

Using the two photographs of east and west cardinal points, it is possible to know the inclination of the traces of stars at the equator, and therefore it is possible to locate the wire that symbolizes the equator without problems. We know the points where we have to fix it and also the inclination, so the wire can be attached to the wood and to the local meridian (figure 11).

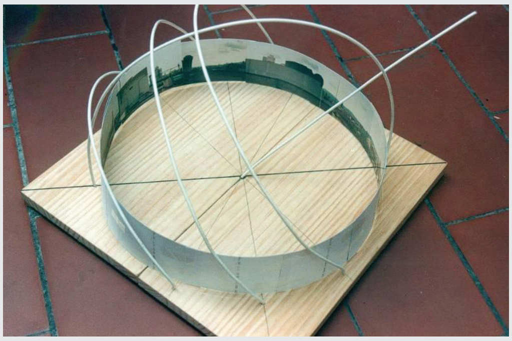

Fig. 19: Sun trajectories the first day of each season. Sunset and sunrise points do not coincide except two days: Equinox days.

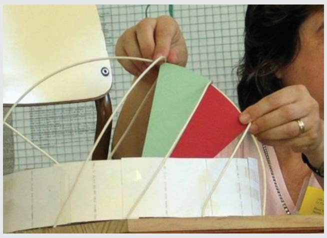

Fig. 20: The angle between two trajectories of the first day of two consecutive seasons is 23.5º.

It is clearly possible to introduce the strip of pictures of the local meridian on the model. It is sufficient to make some copies and make a hole in them at the point that indicates the pole, in order to introduce the axis of rotation. Note that the wire of the equator corresponds to the straight-line traces that are on the tape (figure 18).

With this model, we can offer the students the two possibilities of viewing the celestial sphere from the inside and from the outside.

If we again take two pictures of the first day of winter and summer when the Sun rises and sets, students will be able to see that the locations are very different in their city. The difference between them is amazing. You can also set the parallels of Cancer and Capricorn with the pictures that give the slope of the equator, since the parallels follow this same inclination. With a simple conveyor, it is possible to verify that the internal angle between the Tropic of Cancer and the equator is about 23º, and this is also the angle formed between the equator and the Tropic of Capricorn (figures 19 and 20).

For training students, it is interesting for them to see that sunrises and sunsets do not always coincide with the east and west, respectively. There are many books that mention that the Sun rises in the east and sets in the west. Students can see that this is true only twice a year, and it is not true on the remaining days (figures 19 and 20).

Thus, students see in a practical and simultaneous way the sphere from the inside (the real sphere) and from the outside (the model). With such model, students can understand their environment better, and questions about it can be resolved easily. They can also display the area that corresponds the motion of the sun (between the parallels of the model) and imagine it above the sky and real horizon of the city. The orientation becomes piece of cake.

Sundials

There are other possible applications of the model. This model is no more than a large sundial. It is great for explaining the construction of a clock in a simple and didactic way, considering only the horizon and the motion of the Sun. Firstly, it is very easy to see that the Earth's axis of rotation becomes the stylus of the clock.

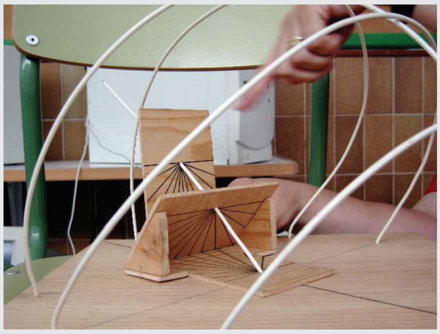

Fig. 21: The model is a huge sundial. We can consider three types.

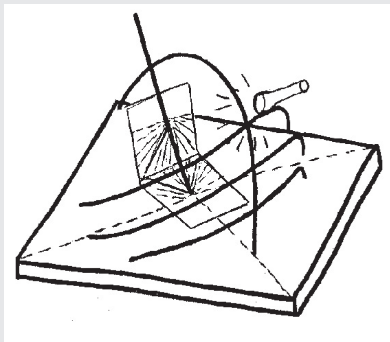

Fig. 22: The clocks and seasons.

If we introduce a plane in the direction of the equatorial plane and move a flashlight on the Tropic of Cancer, we can see the shadow of the stylus (the wire that represents the Earth's rotation axis) crossing the plane of the equatorial quadrant. On the other hand, when we move the flashlight on the Tropic of Capricorn, the shadow appears in the area below the plane, and it is clear that when the flash-light is placed on the equator, no shadow occurs. Thus, it is easy to verify that the equatorial clock works in summer and spring, showing hours on the clock's plane, in winter and autumn showing hours below it, and that two days per year, on the two equinoxes days, it does not work.

Considering the equatorial plane, the horizontal and vertical (oriented east-west), we can see that the flashlight indicates the same hours in the three quadrants (figure 21). In addition, we can see when the morning and afternoon hours are for the same stylus (the Earth's rotation axis). Obviously, it's the same time in the three clocks. It is easily verified in which area we have to draw the morning and afternoon hours for each clock.

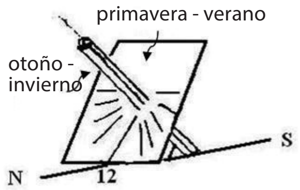

Fig. 23: Equatorial clock used in northern hemisphere.

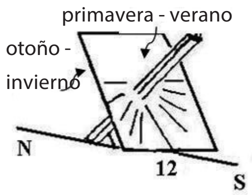

Fig. 24: Equatorial clock used in southern hemisphere.

(All teachers have at some point received badly drawn hours on a sundial, but using this model this no longer happens).

Moving the flashlight a long the Tropics of Capricorn and Cancer makes it easy to see that the path of light emitted from the flashlight produces a different conic section on the plane. In the first case (the first day of summer), the conic is almost a circle, and the enclosed area is clearly smaller than in the second case. When followed by the other parallel (first day of winter), the section is elliptical, and the enclosed area is much greater. Then the students can understand that radiation is more concentrated in the first situation, i.e., the surface temperature is higher in summer, and it is also evident in the model that the number of hours of solar insolation is greater. The natural consequence is that it is warmer in summer than in winter (figure 22).

We will take this opportunity to mention some elements that must be known to construct a sundial.

The equatorial clock is very easy to create. Just put the stylus in the direction of Earth's rotation axis, i.e., in the north-south direction (a compass can help us do so), and with a height above the plane of the horizon equal to the latitude of the site (figure 20 and 21).

The stylus of any clock always will be placed in the same way.

The equatorial clock hour lines are drawn at 15 degrees (figure 25a and 25b), since the Sun gives a 360 degree turn in 24 hours. If we divide 360 by 24, we get 15 degrees each hour.

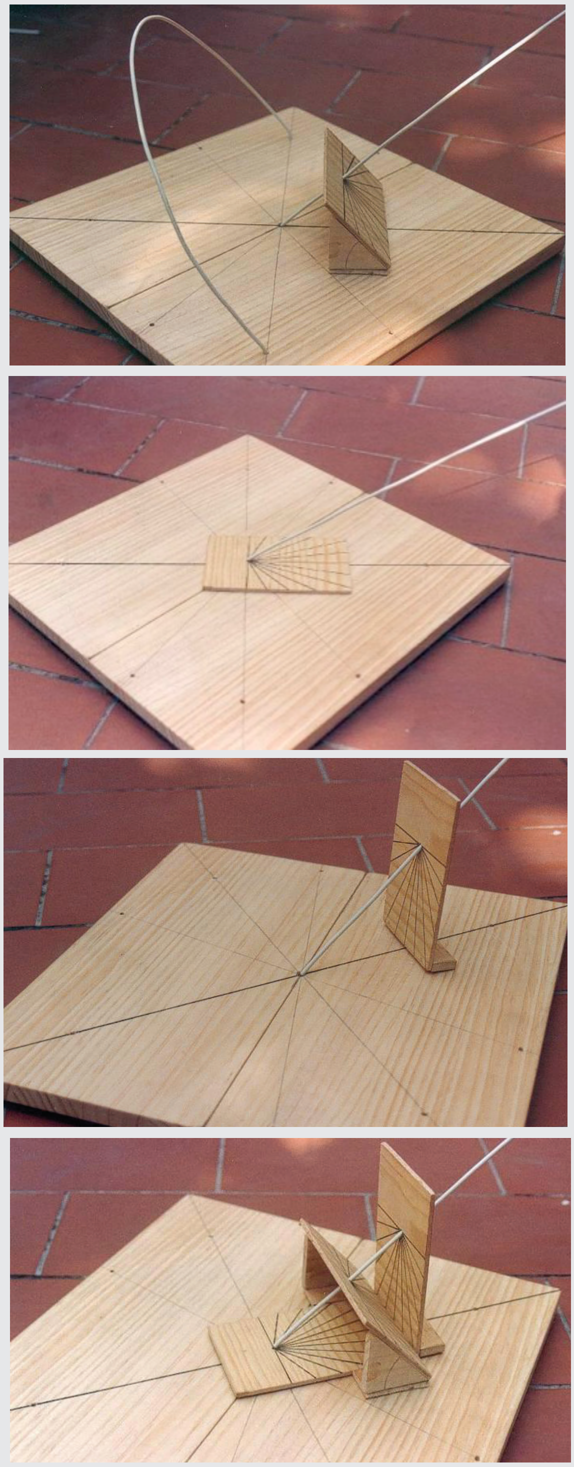

Fig. 26a, 26b, 26c and 26d: Some images of the clocks.

The hour lines of a horizontally or vertically oriented clock are obtained by projecting the equatorial lines and simply considering the latitude of the place (figures 26a, 26b, 26c and 26d).

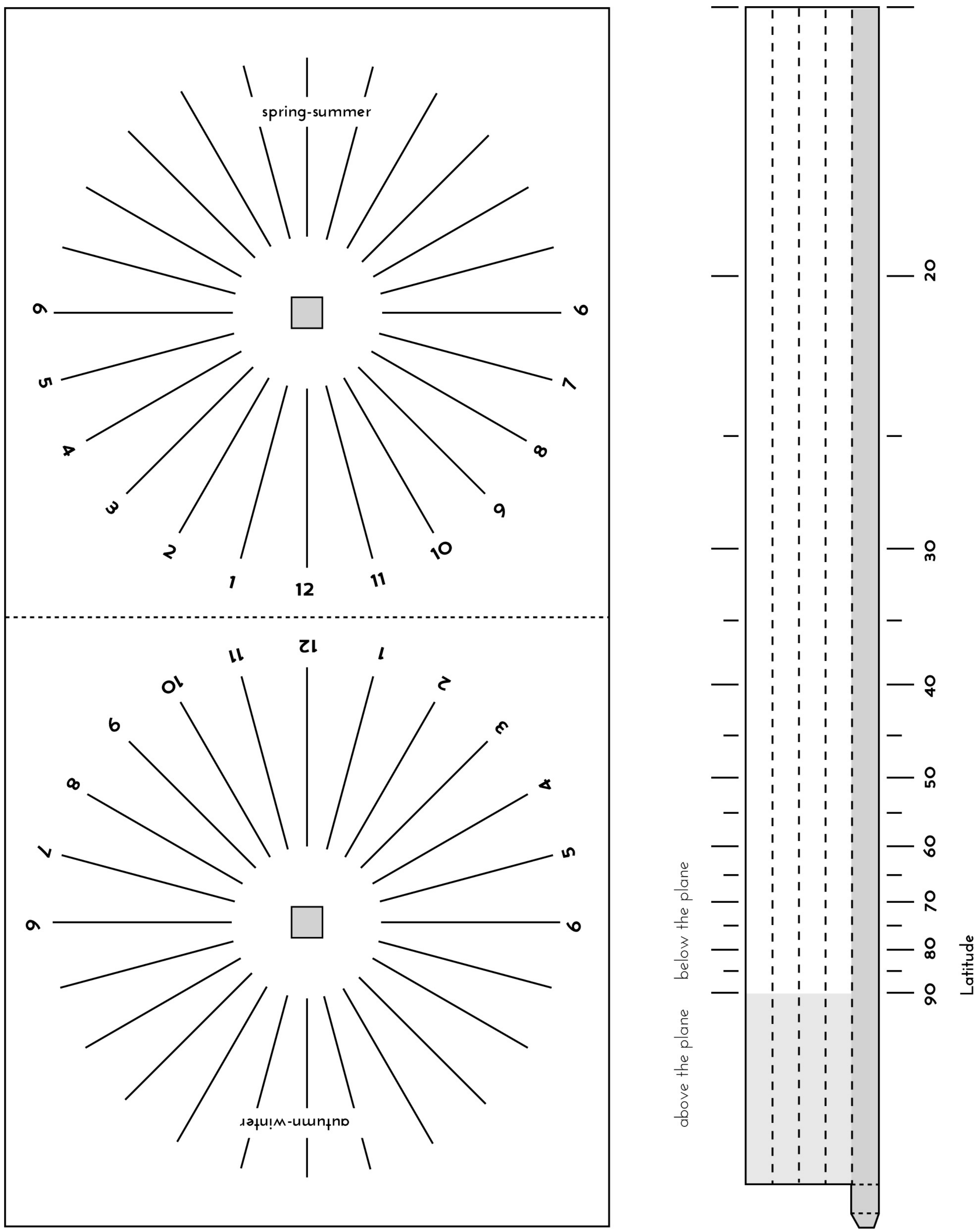

Fig. 25a and Fig. 25b: Cut of the equatorial clock

Solar time and clock time of wristwatches

Sundials give solar time, which is not the same as that on the watches that we all use on our wrist. We must consider several adjustments:

Longitude adjustment

Earth is divided into 24 time zones from the prime meridian or Greenwich meridian. To make the longitude adjustment it is necessary to know the the local longitude and the longitude of the "standard" meridian in your area. A "+" sign is added to the east and signed "-" to the west. We must express the lengths in hours, minutes and seconds (1 degree = 4 minutes).

Adjustment	Comment	Result
1. Longitude	Barcelona is in the same "standard" zone as Greenwich.	-8.7 m
2. DST	May has DST +1h	+ 60 m
3. Time equation	Read the table for the date May 24	-3.6 m
Total		+47.7 m

Adjustment	Comment	Result
1. Longitude	The "standard" meridian of Tulsa is at 90° W.	+24 m
2. DST	November has none	
3. Time equation	We read the table for the date November 16	-15.3 m
Total		+ 8.7 m

Summer/winter-adjustment

Almost all countries have a summer ("daylight savings") and winter times. An hour is usually added in the summer. The time change in summer/winter is a decision of the country's government.

Time equation adjustment

Earth revolves around the Sun according to Kepler's law of areas for an eclipse, i.e., it is not a constant motion, which creates a serious problem for mechanical watches. Mechanical clocks define the average time as the average over a full year of time. The Equation of Time is the difference between "Real Solar Time" and "Average Time".

This equation is tabulated on Table 1.

Solar time + Total adjustment = Wristwatch clock time

Example 1**:** Barcelona (Spain) on May 24th**.**

For example, at 12:00 solar time, our wristwatch says:

(Solar time) 12h + 47.7 m = 12h 47.7 m (Wrist watch time).

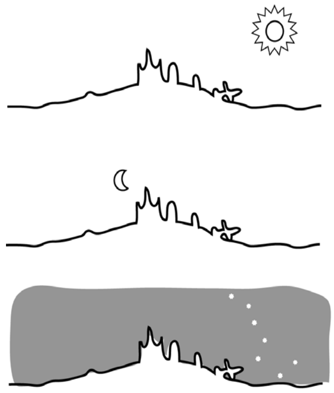

Fig. 27a: North-East horizon of Barcelona.

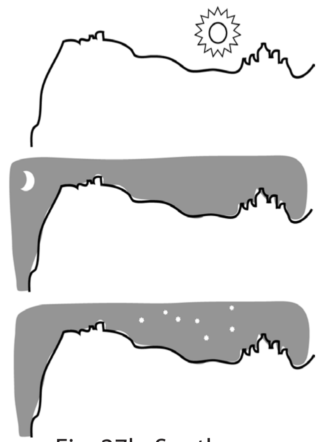

Fig. 27b: South-West horizon of Barcelona.

Example 2**:** Tulsa, Oklahoma (United States) November 16th.

For example, at 12:00 solar time, our wristwatch says:

(Solar time) 12h + 8.7 m = 12h 8.7 m (Wrist-watch clock time)

Orientation

Another difficulty for students is orientation. In a general astronomy course, we have to introduce a sense of direction. It is possible that our students will never study astronomy again. For students in the northern hemiphere, the minimum outcome to be expected from a course of astronomy is that students are able to recognize where the North is, know that the trajectory of the Sun is above the southern horizon, know that the planets move across the horizon, and in particular learn to locate the

date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	+3.4	+13.6	+12.5	+4.1	-2.9	-2.4	+3.6	+6.3	+0.2	-10.1	-16.4	-11.2
6	+5.7	+5.1	+11.2	+2.6	-3.4	-1.6	+4.5	+5.9	-1.5	-11.7	-16.4	-9.2
11	+7.8	+7.3	+10.2	+1.2	-3.7	-0.6	+5.3	+5.2	-3.2	-13.1	-16.0	-7.0
16	+9.7	+9.2	+8.9	-0.1	-3.8	+0.4	+5.9	+4.3	-4.9	-14.3	-15.3	-4.6
21	+11.2	+13.8	+7.4	-1.2	-3.6	+1.5	+6.3	+3.2	-6.7	-15.3	-14.3	-2.2
26	+12.5	+13.1	+5.9	-2.2	-3.2	+2.6	+6.4	+1.9	-8.5	-15.9	-12.9	+0.3
31	+13.4		+4.4		-2.5		+6.3	+0.5		-16.3		+2.8

Tabla 1: Time equation

various geographical features of their city. For example, over the horizon of Barcelona (figures 24a and 24b) students can consider various options regarding the position of the Sun, Moon, and certain constellations on the horizon. The two mountains that we see are approximately in opposite positions, but that does not mean anything for the students, and they usually have troubles distinguishing that certain drawings are possible while others are not They know the theory, but the practice is not enough if they do not understand the different possibilities.

Fig. 28a: The model prepared with primary school students. Fig. 28b: The large-scale model in the Science Park of Granada.

Using the model designed to resolve the drawbacks mentioned in the previous section was very effective in clarifying many issues related to orientation on the local horizon in a way that was not initially planned.

It is worth mentioning that this model is useful in explaining the local position of the celestial sphere during the day and night. It really helps to better understanding the movement of the Sun (and other members of the Solar System moving in the near area). Using the proposed model, students understand that a bright star in the Polaris area can never be a planet.

It is a good investment to make a large-scale model. In this case, students and even adults can get into it and check the Sun's position compared to the Equator and the parallels that correspond to the first day of summer and winter solstice (figure 28a). Some science museums have built this type of model (figure 28b).

After using the model, students can discern things that they previously would not have. For example, now it is very clear that the Sun does not rise and set perpendicular to the horizon except at the equator.

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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

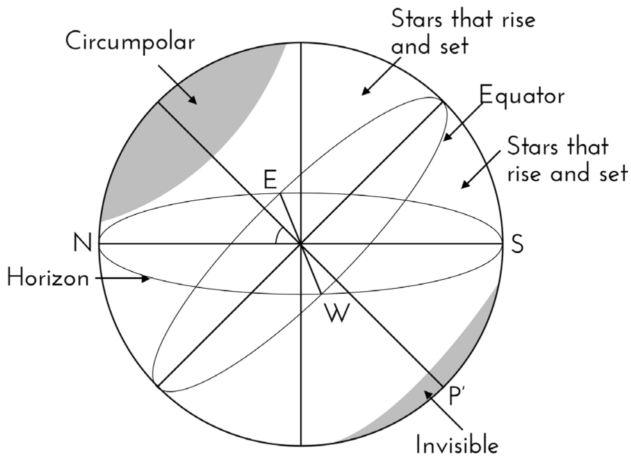


Fig. 1: Three different types of stars (as seen from a specific latitude): circumpolar, stars that rise and set, and invisible stars.

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.

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).

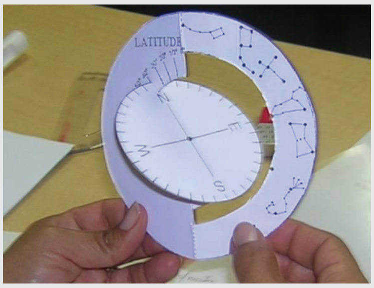


Fig. 2: Using the demonstrator: this is an example of a demonstrator for the Northern Hemisphere using constellations from Table 1.

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).

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

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.

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.

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 (figures 3a and 3b), 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.

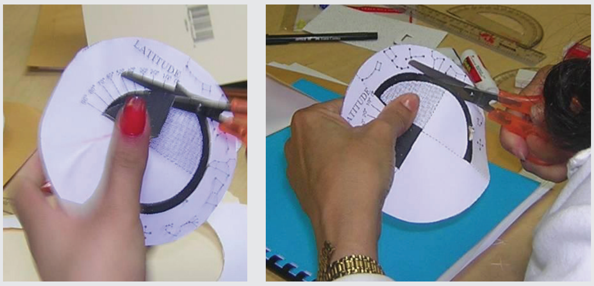


Fig. 3a and 3b: Making the stellar demonstrator.

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.

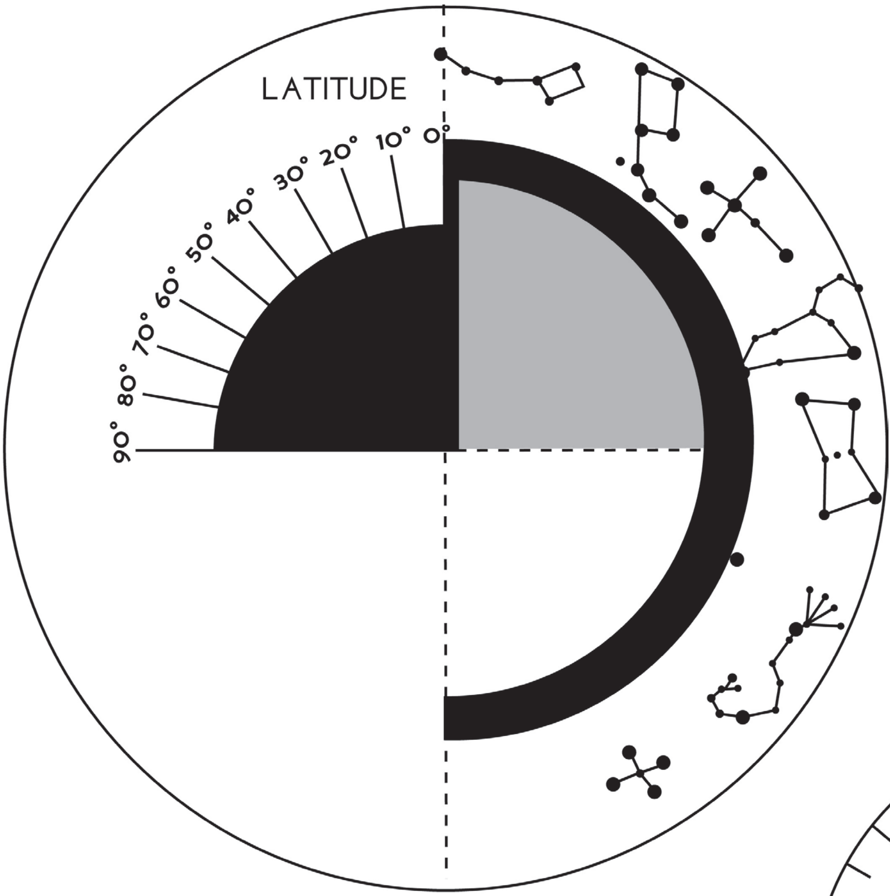


Fig. 4: The main part of the stellar demonstrator for the Northern Hemisphere.

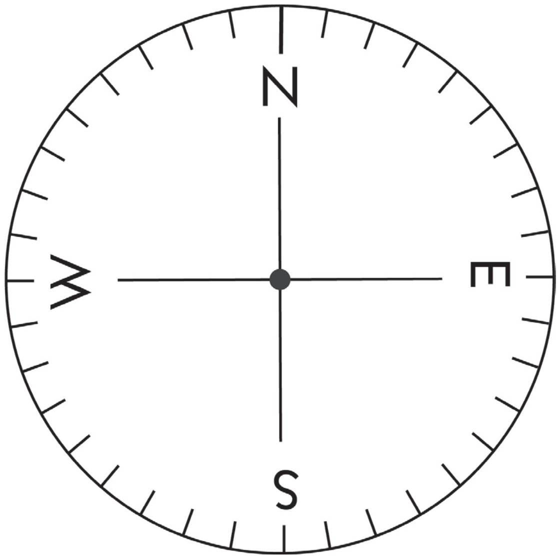


Fig. 5: The horizon disc.

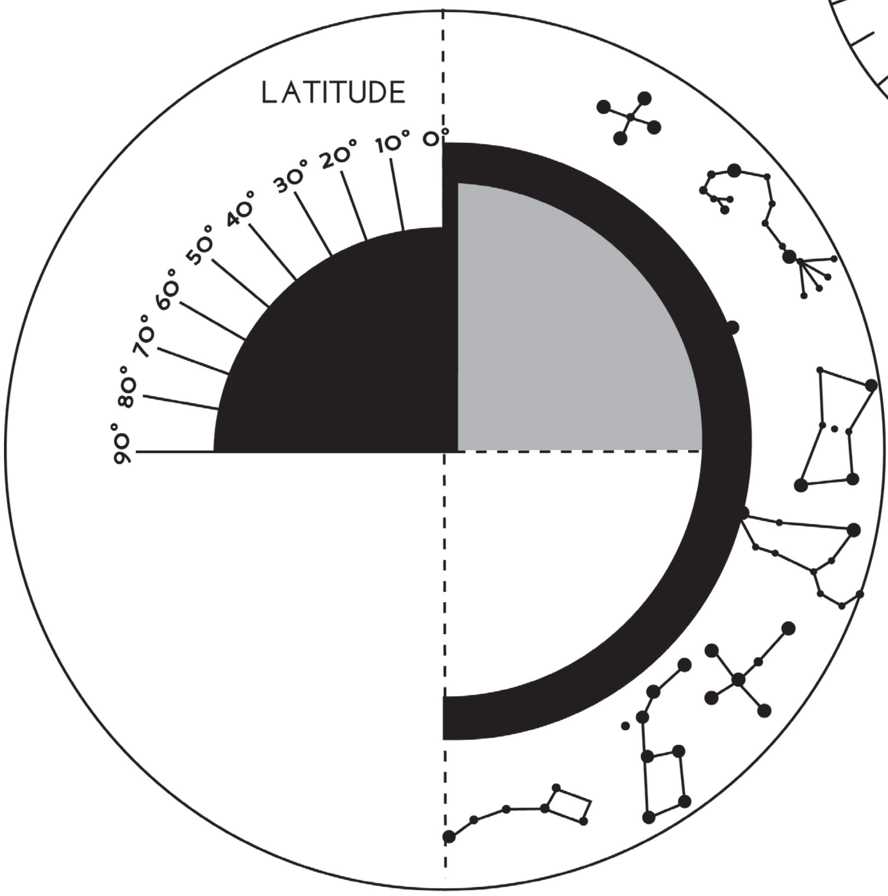


Fig. 6: The main part of the stellar demonstrator for the Southern Hemisphere.

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.

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).
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 latitu-

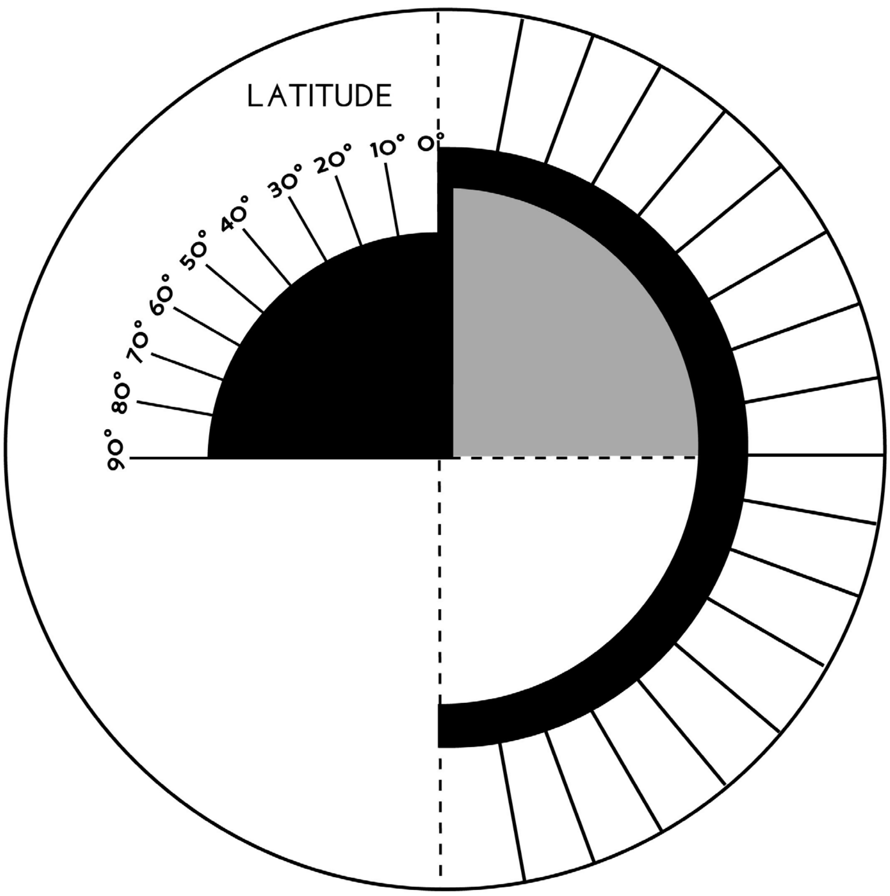


Fig. 7: The main part of the stellar demonstrator for the Northern or Southern Hemispheres.

de 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).

- *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, 9 and 10).

If the observer lives on the equator (latitude 0º) this angle is 90º. On the other hand, if the observer is liv-ing at the North or South Pole, (latitude 90º N or 90º º 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.

Fig. 8a and 8b: Stars setting in Enontekiö 68ºN 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).

Fig. 9a and 9b: Stars rising in Montseny 47ºN (near Barcelona, Spain). The angle of the star path relative to the horizon is 90º minus the latitude (Photo: Rosa M. Ros).

Fig 10a and 10b. Star traces close west point in Matehuala (Mexico) 23ºN, the angle of the trajectories of the stars on the horizon is 90-latitude (the colatitude). (Photo: Luis J de la Cruz, Mexico).

We can verify this by looking at figures 8, 9 and 10. The photo in figure 8a was taken in Lapland (Finland), the one in figure 9a in Montseny (near Barcelona, Spain) and in figure10a in San Luis Potosi (Mexico). Lapland is at a higher latitude than Barcelona and San Luis Potosi so the star path inclination is smaller.

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). 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.

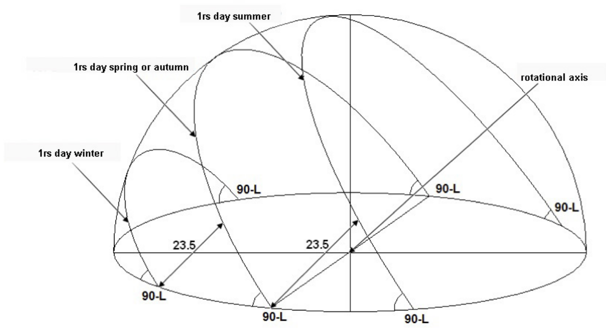
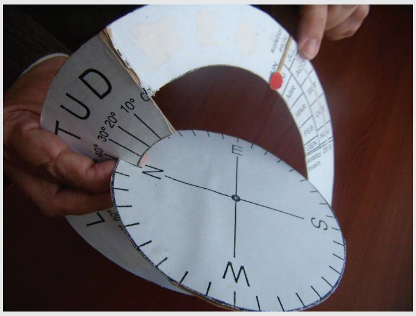


Fig. 11: Three different solar paths (1st day of spring or autumn, 1st day of summer, and 1st day of winter).

Making the demostrator

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.



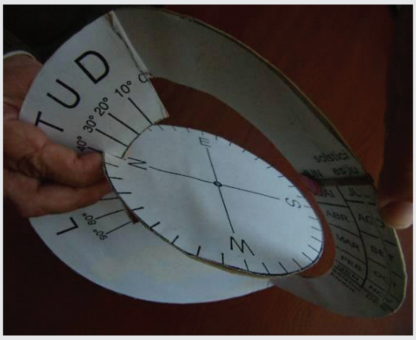


Fig.12a and 12b: Preparing the solar demonstrator for the Northern Hemisphere at latitude +40º.

To obtain a sturdy demonstrator (figures 12a and 12b), 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.

The build instructions listed below.

Demonstrator for Northern 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 "N" on the horizon disk (figure 14). The notch should be large enough for the cardboard to pass through it.
f) Glue the North-East quadrant of the horizon disk (figure 14) onto the grey quadrant of the main piece (figure 13). 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 (figure 14) 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 13. 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.

To build the solar demonstrator in the Southern Hemisphere you can follow similar steps, but replace figure 13 with figure 15.

Demonstrator for Southern Hemisphere

a) Make a photocopy of figures 14 and 15 on cardboard.
b) Cut both pieces along the continuous line (figures 14 and 15).
c) Remove the black areas from the main piece (figure 15).
d) Fold the main piece (figure 15) 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 14). The notch should be large enough for the cardboard to pass through it.
f) Glue the South-West quadrant of the horizon disk (figure 14) onto the grey quadrant of the main piece (figure 15). 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 (figure 14) 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 15. The idea is that it should be easy to move this strip up and down in

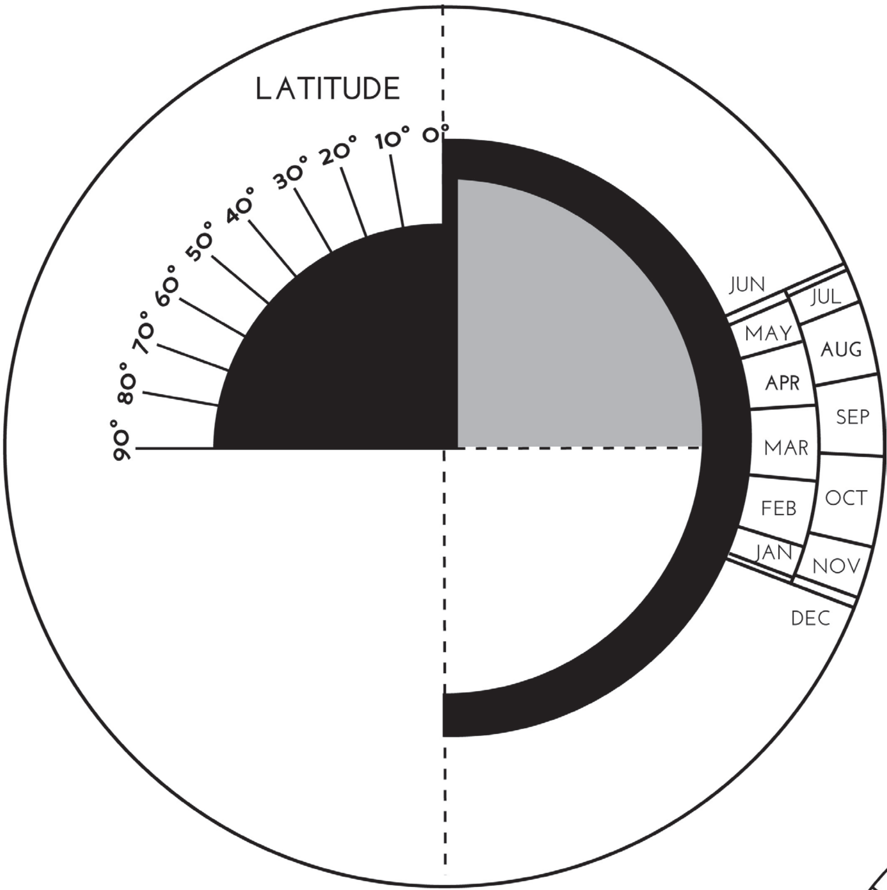


Fig. 13: The main part of the solar demonstrator for the Northern Hemisphere.

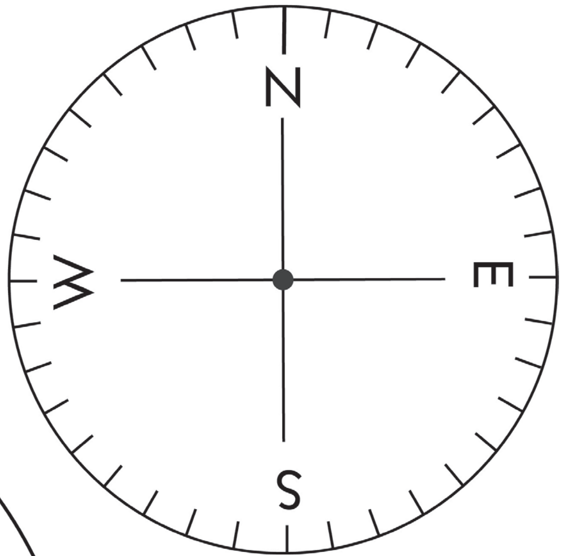


Fig. 14: The horizon disk.

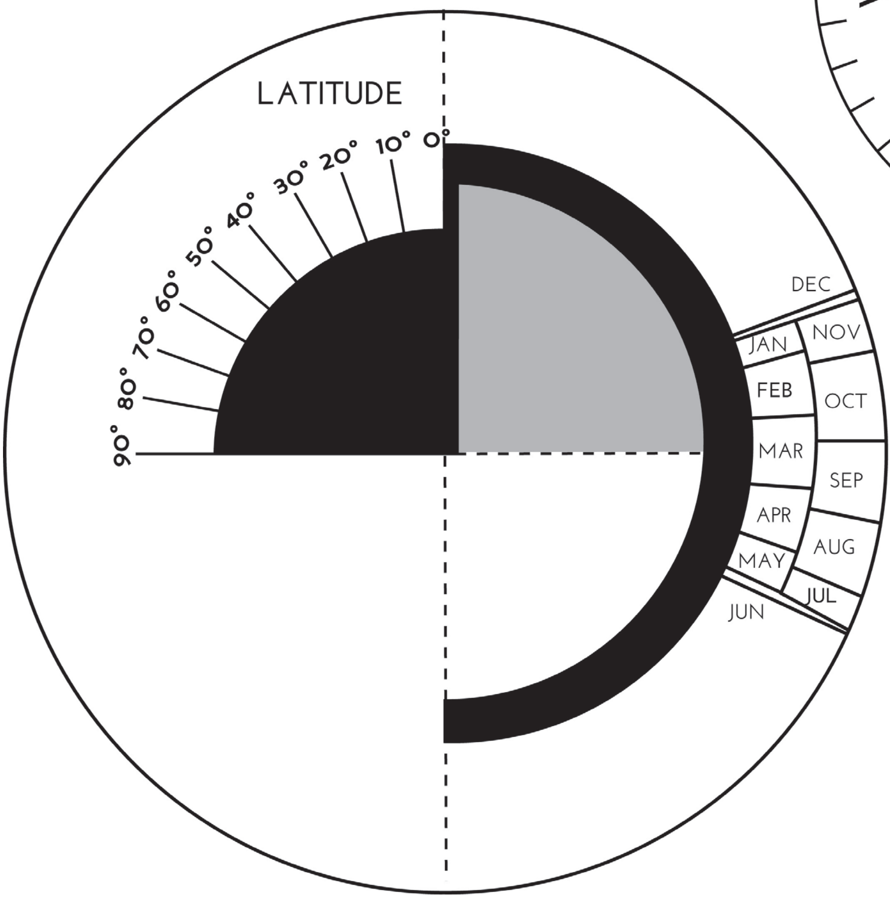


Fig. 15: The main part of the solar demonstrator for the Southern Hemisphere.

order to situate the red point on the month of choice.

Using the solar demostrator

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 16a and 16b. The picture in figure 16a was taken in Lapland (Finland), and the one in figure 17a in Gandia (Spain). Lapland is at higher latitude than Gandia, so the inclination of the Sun's path is smaller. The photograph of figure 18a was made in Ladrilleros (Colombia) with a latitude of 4º and consequently the inclination of the Sun's path is close to the perpendicularity, is 86º.

- 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 alti-tude (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.

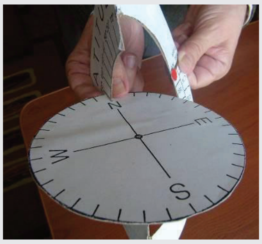
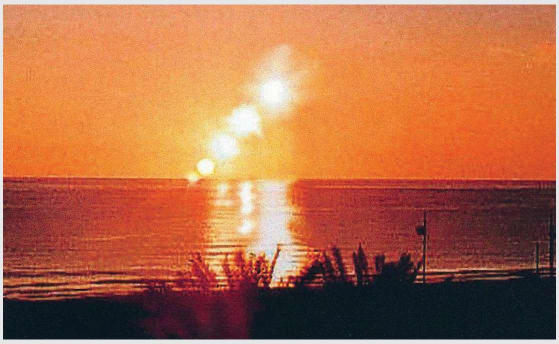


Fig. 16a and 16b: Sun rising in Enontekiö in Lapland (Finland). The angle of the Sun's path relative to the horizon is the co-latitude (90º minus the latitude) (Photo: Sakari Ekko, Finland).



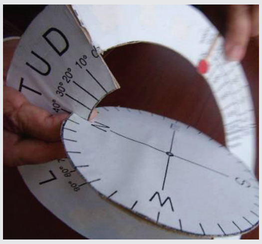
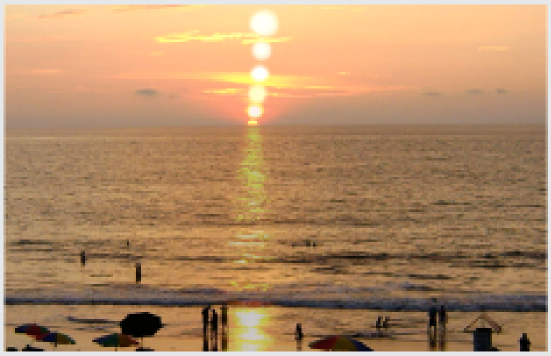


Fig. 17a and 17b: Sun rising in Gandia (Spain) 41ºN. The angle of the Sun's path relative to the horizon is 90 minus the latitude (Photo: Rosa M. Ros, Spain).



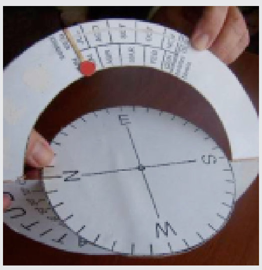


Fig 18a and 18b: Sunrise in Ladrilleros (Colombia), the angle of the path of the sun above the horizon is the co-latitude (90º-4º = 86º). (Photo: Mario Solarte, Colombia).

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

Fig. 19a and 19b: 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.

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.

Of course if we change the latitude, altitude paths of the Sun changes, but the highest always corresponds to the first day of summer and the lowest the first day of winter (figures 19a and 19b).

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.

Fig. 20a, 20b and 20c: Sunsets in Riga 57º (Latvia), Barcelona 41º (Spain) and Popayán 2º (Colombia) 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 and more than Popayán (Photos: Ilgonis Vilks, Latvia, Rosa M. Ros, Spain and Juan Carlos Martínez, Colombia).

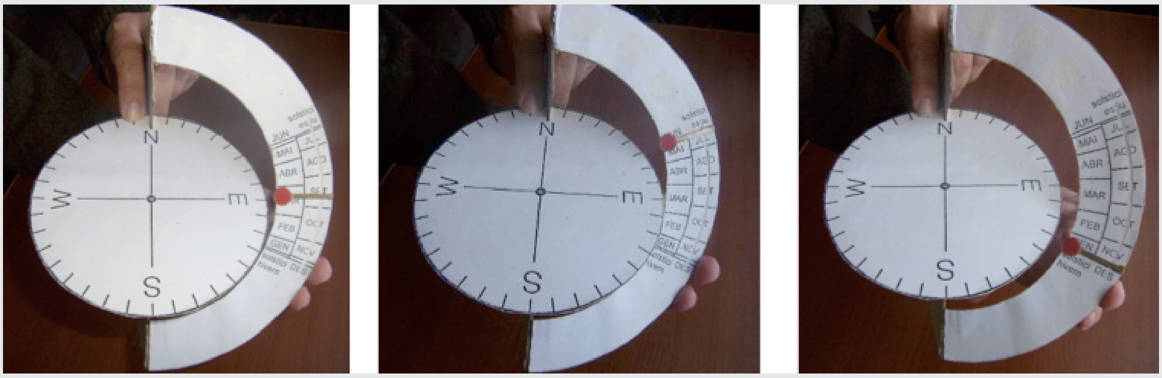


Fig. 21a: Sunrises on the first day of 1st day of spring or autumn, Fig. 21b: Sunrises on the first day 1st day of summer, Fig. 21c: Sunrises on the first day of 1st day of winter.

Fig. 22a, 22b and 22c: Sunsets in Popayán 2º (Colombia), La Paz -19º (Bolivia) and Esquel -43º (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, Gonzalo Pereira, Bolivia and Nestor Camino, Argentina).

- 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 (figures 20a, 20b and 20c).

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, 40º and 0º (figure 21a, 21b y 21c).

The illustrations in figures 20a, 20b and 20c are for the Northern Hemisphere, but the same concepts hold for the Southern Hemisphere (figures 22a, 22b and 22c). The only difference is the timing of the seasons.

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.

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.

Fig. 23a and 23b: 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).

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 (figures 22a and 22b).

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 (figures 24a and 24b).

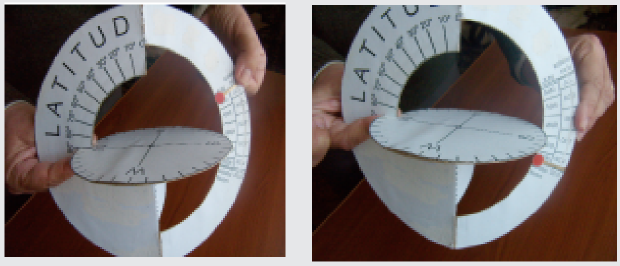


Fig. 24a and 24b: The demonstrator showing the Sun over the horizon for half a year and below the horizon for a half a year.

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 25a, 25b and 25c).

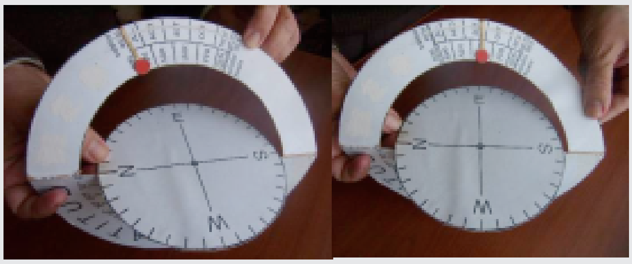


Fig. 25a and 25b: The Sun rises on the first day of each season: left 1st day of summer; right 1st day of spring or autumn (in the Northern Hemisphere).

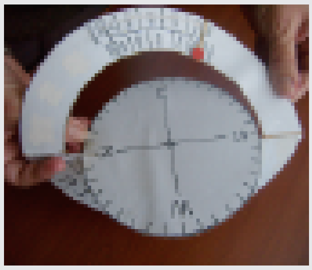


Fig. 25c: 1st day of winter (in the Northern Hemisphere).

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 20a, 20b, 20c, 22a, 22b and 22c).

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 26a). 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 26b).

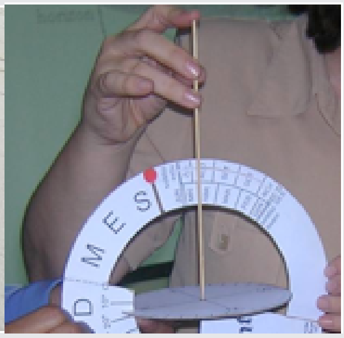


Fig. 26a: Small shadow (the Sun is almost at the zenith in a place near the equator). Fig. 26b: Simulating the Sun at the Zenith in Honduras (latitude 15º N).

For example (figure 26b), 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 in figura 26b 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 27a). 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 27b).

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 28 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 29), 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 29. However, depending on the

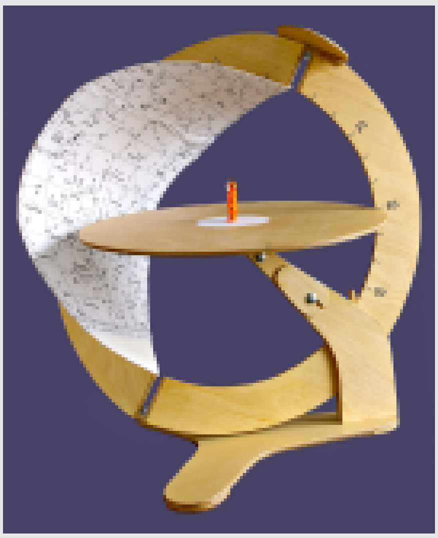


Fig. 27a: XXL wooden demonstrator. Fig. 27b: Stellar wooden demonstrator. Fig. 27c: With a camera it is possible to photograph the solar path using a large exposure time. (Photos: Sakari Ekko).

Fig. 28: Moon phases.

Fig. 29: Moon phases observed at the horizon.

country, it is possible to observe the Moon as an inclined “C”, an inclined “D” (figure 30a) 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.

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 declina-tion 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 -18 º and -29 º). The diurnal mo-tion 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. 30a: Slanting crescent Moon, Fig. 30b: 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 13 and 14 for the Northern Hemisphere and 13 and 15 for the Southern Hemisphere and 13 and 15 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 31b (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

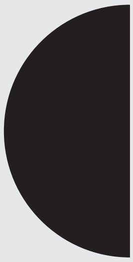


Fig. 31a: Using the demonstrator, Fig.31b: the Moon in the transparent strip Moon quarter.

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.

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 (figures 32a and 32b) 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 31b). 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.

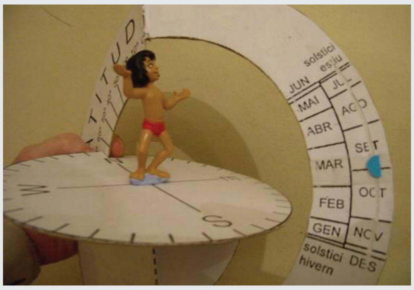


Fig. 32a: Demonstrator for latitude 70º N,
Fig. 32b: latitude 20º S.

-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 sea-sons the Moon looks like a "C" (figure 32a).

-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 32b). 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: "∩".

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 remem-

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 33a).

- If the latitude is -20 ° (figure 32b) 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 32b). 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 them to produce other demonstrators.

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Earth-moon-sun system: Phases and eclipses

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Summary

The following work deals with moon phases, solar eclipses, and lunar eclipses. These eclipses are also used to find distances and diameters in the Earth-Moon-Sun system.

Finally, a simple activity enables one to measure longitudes and heights along the moon's surface. The origin of tides is also explained.

Goals

- To understand why the moon has phases.
- To understand the cause of lunar eclipses.
- To understand why solar eclipses occur.
- To determine distances and diameters of the Earth-Moon-Sun system.
- To understand the origin of the tides..

Relative positions

The term "eclipse" is used for very different phenomena, but in all cases an eclipse takes place when one object crosses in front of another object; for this unit, the relative positions of the Earth and the Moon (opaque objects) cause the interruption of sunlight.

A solar eclipse happens when the Sun is covered by the Moon when it is located between the Sun and our planet. This kind of eclipse always takes place during new Moon (figure 1).

Lunar eclipses take place when the Moon crosses the shadow of the Earth. That is when the Moon is on the opposite side of the Sun, so lunar eclipses always occur at full moon phase (figure 1).

The Earth and the Moon move along elliptical orbits that are not in the same plane. The orbit of the Moon has an inclination of 5 degrees with respect to the ecliptic (plane of Earth's orbit around the sun). Both planes intersect on a line called the Line of Nodes. The eclipses take place when the Moon is near the Line of Nodes. If both planes coincided, the eclipses would be much more frequent than

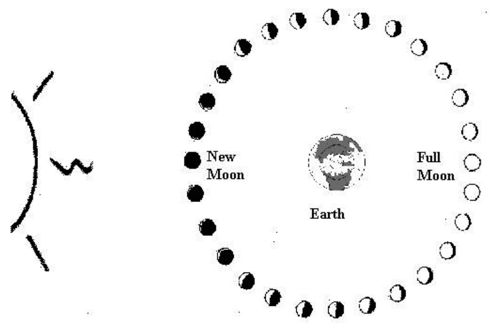

Fig.1: Solar eclipses take place when the Moon is located between the Sun and the Earth (new Moon). Lunar eclipses occur when the Moon crosses the shadow cone of the Earth (that is, the Earth is located between the Sun and the full Moon).

the zero to three times per year.

Models with mask

Model of hidden Face

The Moon has two movements: rotation and translation which has approximately the same duration, that is to say about four weeks. This is the reason that from the Earths we can see always the same half lunar superfice.

We will see this situation with a simple model. We begin by placing the volunteer who plays the role of Earth and only one "Moon" volunteer with a white mask. We place the "Moon" volunteer in front of Earth, looking to the Earth, before starting to move. So if the Moon moves 90 degrees in its orbit around the Earth, it also must turn 90 degrees on itself and therefore will continue looking in front of the Earth, and so on. We will ask to the Earth volunteer if he/she can see the same face of the Moon or can see a differnet part. We repeat the same situation four times, always moving 90º. It is evident that each 90º, that is to say each week, the Earth can see always the same part of the moon, the back of the head of the voluteer is never visible.

Moon Phases model

To explain the phases of the Moon it is best to use a model with a flashlight or with a projector (which will represent the Sun) and a minimum of five volunteers. One of them will be located in the

Fig. 2: Earth-Moon model with volunteers (to explain the phases and the visible face of the Moon).

center representing the Earth and the others will situate themselves around "the Earth" at equal distances to simulate different phases of the Moon. To make it more attractive it is a good idea for each "Moon" to wear a white mask that mimics the color of the moon. They should all face the "Earth" because we know that always the Moon offers the same side to the Earth (figure 2). We will place the flashlight above and behind one of these volunteers, and begin to visualize the phases (as seen from the Earth, that is in the center). It is very easy to discover that sometimes the mask is completely light, sometimes only a quarter and sometimes not at all (because the flashlight "Sun" is behind that "Moon" and its light dazzles the scene).The greater the number of volunteer "Moons", the more phases can be seen.

Earth-Moon Model

It is not so easy to clearly understand the geometry underlying the phases of the moon, and solar and lunar eclipses. For that reason, a simple model is proposed in order to facilitate the understanding of all of these processes.

Earth diameter	12,800 km	4 cm
Moon diameter	3,500 km	1 cm
Earth-Moon distance	384,000 km	120 cm
Sun diameter	1,400,000 km	440 cm = 4.4 m
Earth-Sun distance	150,000,000 km	4,700 cm = 0.47 km

Table 1: Distances and diameters of the Earth-Moon-Sun system.

Insert two nails (about 3 or 4 cm) into a 125 cm. piece of wood. The nails should be separated by 120 cm. Two balls whose diameters are 4 and 1 cm should be placed on them (figure 3). It is important to maintain these relative sizes as they represent a scale model of the Earth-Moon system.

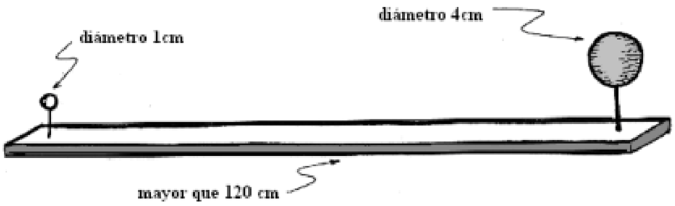

Fig. 3: Earth and Moon model.

Reproduction of Moon phases

In a sunny place, when the Moon is visible during the day, point the model towards the Moon guiding the small ball towards it (figure 4). The observer should stay behind the ball representing the Earth. The ball that represents the Moon will seem to be as big as the real Moon and the phase is also the same. By changing the orientation of the model the different phases of the Moon can be reproduced as the illumination received from the Sun varies. The Moon-ball has to be moved in order to achieve all of the phases.

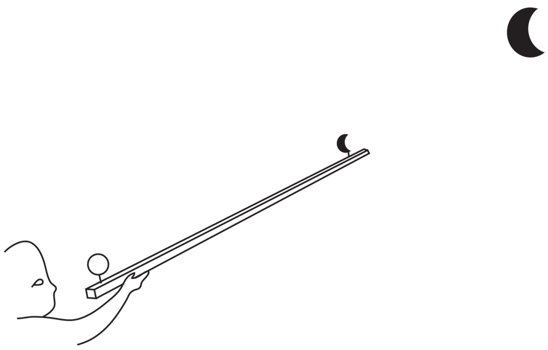

Fig. 4: Using the model in the patio of the school.

It is better to do this activity outdoors, but, if it's cloudy, it can also be done indoors with the aid of a projector as a light source.

Reproduction of Lunar eclipses

The model is held so that the small ball of the Earth is facing the Sun (it is better to use a projector or a flashlight avoid looking at the Sun) and the shadow of the Earth covers the Moon (figure 5) as it is larger than the Moon. This is an easy way of reproducing a lunar eclipse.

Fig.5: Lunar eclipse simulation.

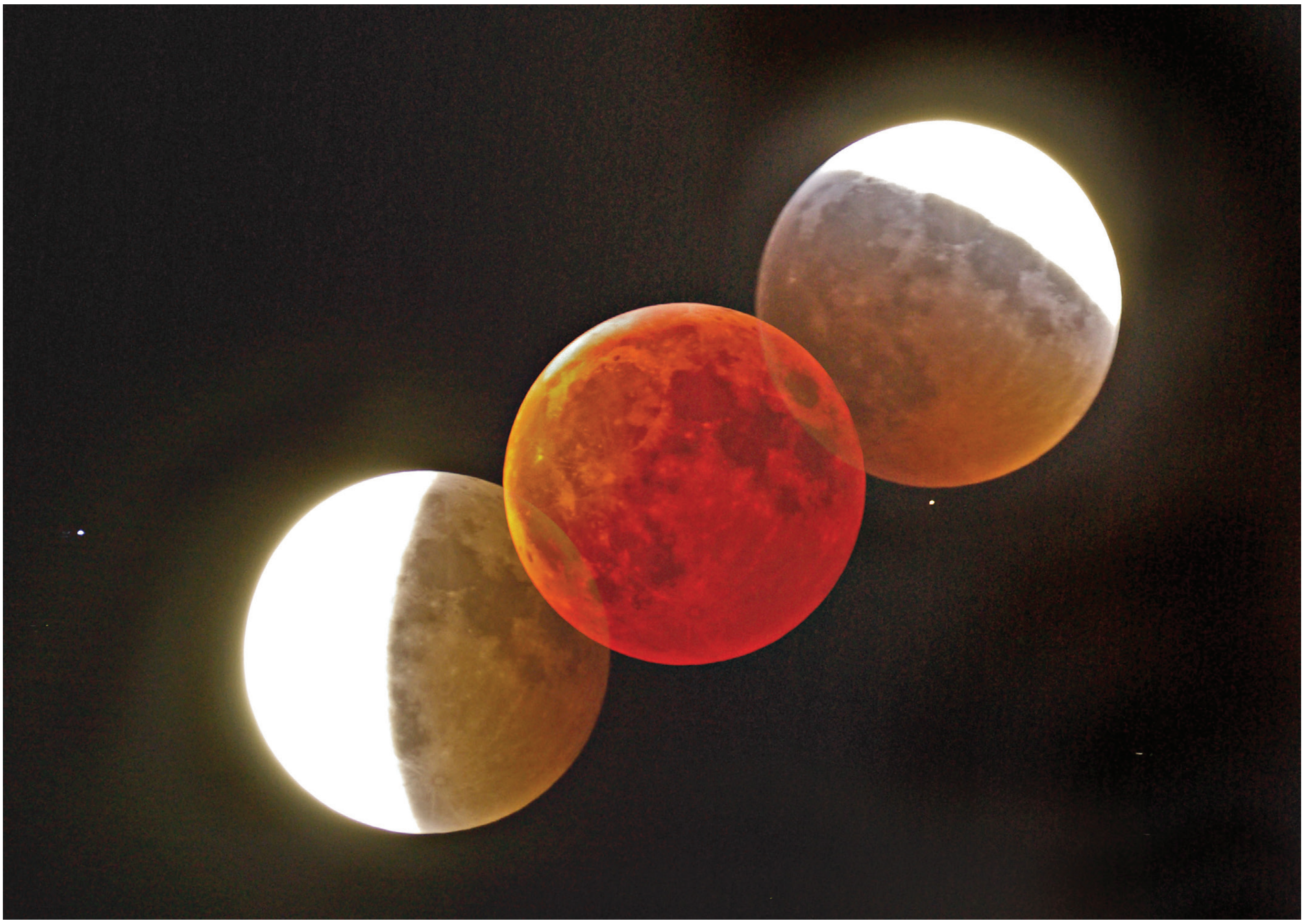

Fig. 6: Photographic composition of a lunar eclipse. Our satellite crosses the shadow cone produced by the Earth.

a flashlight to avoid looking at the Sun) and the shadow of the Earth covers the Moon (figure 5a and 5b) as it is larger than the Moon. This is an easy way of reproducing a lunar eclipse.

Reproducing the eclipses of the Sun

or the flashlight) and the shadow of the Moon has to be projected on the small Earth ball. By doing this, a solar eclipse will be reproduced and a small spot will appear over a region of the Earth (figures 7 and 8).

Fig. 7: Solar eclipse simulation.

It is not easy to produce this situation because the inclination of the model has to be finely adjusted (that is the reason why there are fewer solar than lunar eclipses).

Fig. 8: Detail of the previous figure 7.

Fig. 9: Photograph taken from the MIR of the solar eclipse in 1999 over a region of the Earth's surface.

Observations

- A lunar eclipse can only take place when it is full Moon and a solar eclipse when it is new Moon.
- A solar eclipse can only be seen on a small region of the Earth's surface.
- It is rare that the Earth and the Moon are aligned precisely enough to produce an eclipse, and so it does not occur every new or full Moon.

Model Sun-Moon

In order to visualize the Sun-Earth-Moon system with special emphasis on distances, we will consider a new model taking into account the terrestrial point of view of the Sun and the Moon. In this case we will invite the students to draw and paint a big Sun of 220 cm diameter (more than 2 meters diameter) on a sheet and we will show them that they can cover this with a small Moon of 0.6 cm diameter (less than 1 cm diameter).

It is helpful to substitute the Moon ball for a hole in a wooden board in order to be sure about the posiion of the Moon and the observer.

In this model, the Sun will be fixed 235 meters away from the Moon and the observer will be at 60 cm from the Moon. The students feel very surprised that they can cover the big Sun with this small Moon. This relationship of 400 times the sizes and distances is not easy to imagine so it is good to show them with an example in order to understand the scale of distances and the real sizes in the universe.

Earth Diameter	12,800 Km	2.1 cm
Moon Diameter	3,500 Km	0.6 cm
Distance Earth-Moon	384,.000 Km	60 cm
Sun Diameter	1,400,000 Km	220 cm
Distance Earth-Sun	150,000,000 Km	235 cm

Table 2: Distances and diameters of system Earth-Moon-Sun.

All these exercises and activities help them (and maybe us) to understand the spatial relationships between celestial bodies during a solar eclipse. This method is much better than reading a series of numbers in a book.

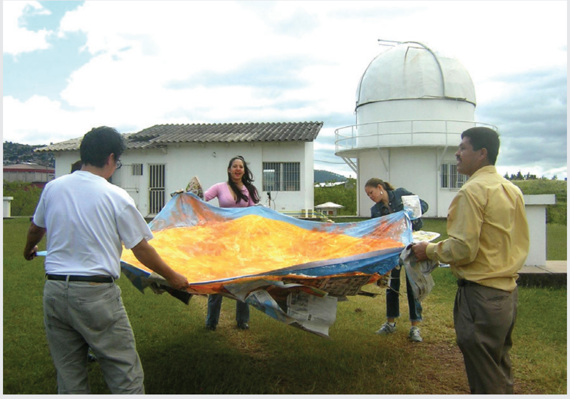

Fig. 10: Sun model.

Fig. 11: Observing the Sun and the Moon in the model.

Measuring the Sun's diameter

We can measure the Sun's diameter in different ways. Here we present a simple method using a pinhole camera. We can do it with a shoebox or a cardboard tube that serves as a central axis for aluminum foil.

1. We covered one end with semi-transparent vellum graph paper and the other end with a strong piece of paper or aluminum foil, where we will make a hole with a thin pin (figures 12 and 13).

2. We must point the end with the small hole towards the Sun and look towards the other end which is covered by the graph paper. We measure the diameter, d, of the image of the Sun on this graph paper.

To calculate the diameter of the Sun, just consider figure 14, where we show two similar triangles.

Here we can establish the relationship:

$$\frac{D}{L} = \frac{d}{l}$$

Fig. 12 and 13: Model of the pinhole camera.

And can solve for the diameter of the Sun, D:

$$D = \frac{d \cdot L}{l}$$

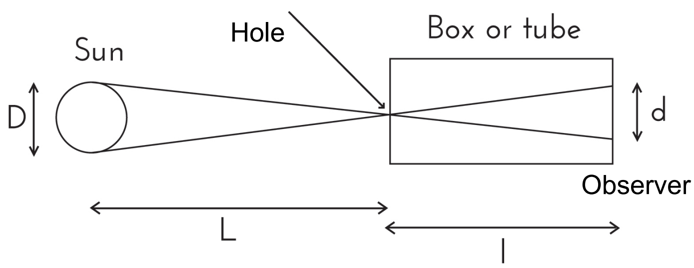

Fig. 14: Underlying geometry of calculation.

Knowing the distance from the Sun to the Earth L = 150,000,000 km the tube's length l and the di-ameter d of the Sun's image over the screen of the graph semi-transparent paper, we can cal-culate the diameter D of the Sun. (The answer should be about 1,392,000 km).
We can repeat the exercise with the Full Moon knowing that it is 400,000 km away from the Earth.

Sizes and Distances in the Earth-Moon-Sun

Aristarchus (310 to 230 BC) deduced the pro-portion between the distances and radii of the Earth-Moon-Sun system. He calculated the ra-dius of the Sun and Moon, the distance from the Earth to the Sun and the distance from the Earth to the Moon in relation to the radius of the Earth. Some years after-wards, Eratosthenes (280-192 BC) determined the radius of our planet and it was possible to calculate all the distances and radii of the Earth-Moon-Sun system.

The proposal of this activity is to repeat both ex-periments as a student activity. The idea is to repeat the mathematical process and, as closely as possible, the observations designed by Aristarchus and Eratosthenes.

Aristarchus's experiment again

Relationship between the Earth-Moon and Earth-Sun distances

Aristarchus determined that the angle between the Moon-Sun line and the Earth-Sun line when the moon is in quarter phase is $\alpha = 87^o$ (figure 15).

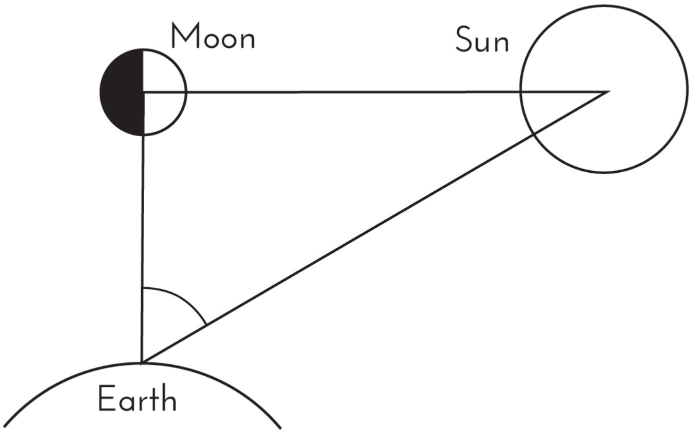

Fig.15: Relative position of the Moon in quarter phase.

Nowadays we know that he was slightly wrong, possibly because it was very difficult to determine the precise timing of the quarter moon. In fact this angle is α = 89º 51', but the process used by Aristarchus is perfectly correct. In figure 15, if we use the definition of secant, we can deduce that

$$\cos \alpha = \frac{ES}{EM}$$

where ES is the distance from the Earth to the Sun, and EM is the distance from the Earth to the moon. Then approximately,

$$ES = 400\ EM$$

(although Aristarchus deduced ES = 19 EM).

Relationship between the radius of the Moon and the Sun

The relationship between the diameter of the Moon and the Sun should be similar to the formula previously obtained, because from the Earth we observe both diameters as 0.5º.

So both ratios verify:

$$R_S = 400\ R_M$$

Relationship between the distance from the Earth to the Moon and the lunar radius or between the distance from the Earth to the Sun and the solar radius

Aristarchus supposes the orbit of the moon as a circle around the Earth.Since the observed diameter of the Moon is 0.5 degrees, the circular path (360°) of the Moon around the Earth would be 720 times the diameter. The length of this path is 2π times the Earth-Moon distance, i.e. 2 R_M 720 = 2 π EM. Solving, we find

$$EM = \frac{720\ R_M}{\pi}$$

Using similar reasoning, we find

$$ES = \frac{720\ R_S}{\pi}$$

This relationship is between the distances to the Earth, the lunar radius, the solar radius and the ter-restrial radius.

During a lunar eclipse, Aristarchus observed that the time required for the moon to cross the Earth's shadow cone was twice the time required for the moon's surface to be covered (figure 16). Therefore, he concluded that the shadow of the Earth's diameter was twice the diameter of the moon, that is, the ratio of both diameters or radius was 2:1. Today, it is known that this value is 2.6:1.

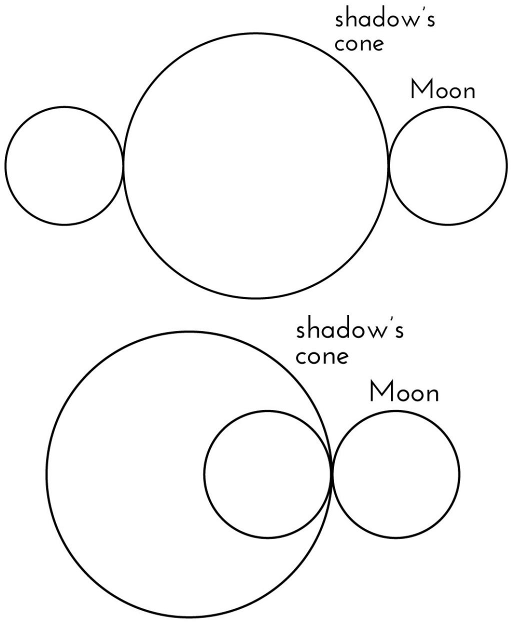

Fig. 16a: Measuring the cone of shadow.
Fig. 16b: Measuring the diameter of the moon.

Final Summary

Taken into accon the last results, Then (figure 17)

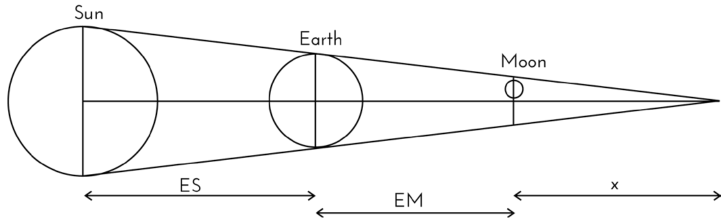

Fig. 17: Shadow cone and relative positions of the Earth-Moon-Sun system.

we deduce the following relationship:

$$\frac{x}{2.6\ R_M} = \frac{x+EM}{R_E} = \frac{x+EM+ES}{R_S}$$

where x is an extra variable.

Introducing into this expresion the relationships ES = 400 EM and $R_S = 400\ R_M$, we can delete x and after simplifying we obtain,

$$R_M = \frac{401}{1440}\ R_E$$

This allows us to express all the sizes mentioned previously as a function of the Earth's radius, so

$$R_S = \frac{2005}{18} R_E \qquad ES = \frac{80200}{\pi} R_E \qquad EM = \frac{401}{2\pi}\ R_E$$

where we only have to substitute the radius of our planet to obtain all the distances and radii of the Earth-Moon-Sun system.

Measurements with students

It's a good idea to repeat the measurements made by Aristarchus with students. In particular, we first have to calculate the angle between the Sun and the quarter moon. To make this measurement it is only necessary to have a theodolite and know the exact timing of the quarter moon.

So we will try to verify if this angle measures α= 87º or α= 89º 51' (although this precision is very difficult to obtain).

Secondly, during a lunar eclipse, using a stopwatch, it is possible to calculate the relationship between the following times: "the first and last contact of the Moon with the Earth's shadow cone", i.e., measure the diameter of the Earth's shadow cone (figure 17) and "the time necessary to cover the lunar surface," that is a measure of the diameter of the moon (figure 16b). Finally, it is possible to verify if the ratio between both is 2:1 or is 2.6:1 or it is different.

The most important objective of this activity is not the result obtained for each radius or distance. The most important thing is to point out to students that if they use their knowledge and intelligence, they can get interesting results with few resources. In this case, the ingenuity of Aristarchus was very important to get some idea about the size of the Earth-Moon-Sun system.
It is also a good idea to measure with the students the radius of the Earth following the process used by Eratosthenes. Although the experiment of Eratosthenes is well known, we present here a short version of it in order to complete the previous experience.

Eratosthenes' experiment, again

Eratosthenes was the director of the Alexandrian Library. In one of the texts of the library, he read that in the city of Syena (now Aswan) the day of the summer solstice, the solar noon, the Sun was reflected in the bottom of a well, or what it is the same the stick did not produce shadow. He noted that the same day, at the same time, a stick produced no shadow in Alexandria. From this, he deduced that the surface of the Earth could not be flat, but it should be a sphere (figures 18a and 18b)

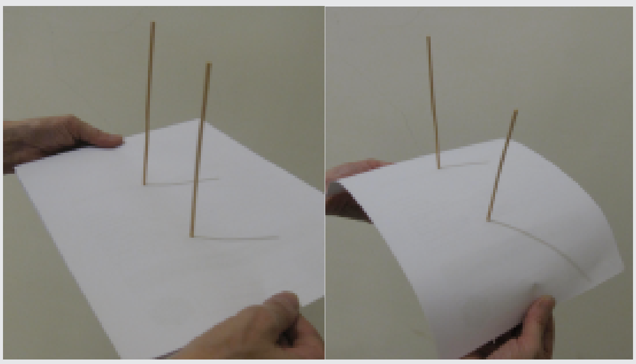

Fig. 18a an 18b: In the flat surface the two sticks produce the same shadow, but when the surface is corved sahdows are differents.

Consider two stakes placed perpendicular to the ground, in two cities on the Earth's surface on the same meridian. The sticks should be pointing toward the center of the Earth. It is usually better to use a plumb where we mark a point of the wire to measure lengths. We should measure the length of its shadow from the base of the plumb to the shadow of the mark.

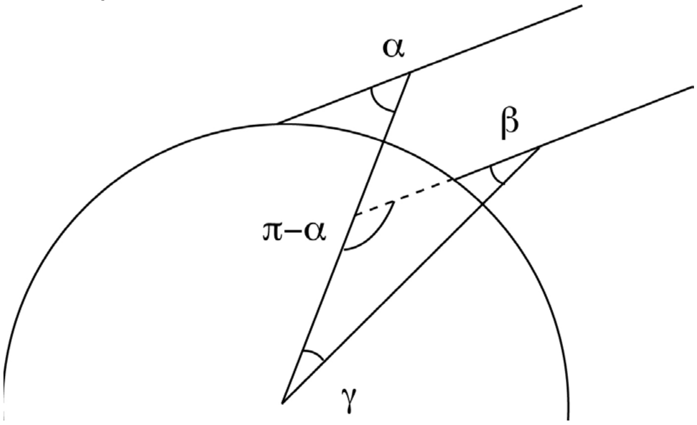

Fig. 19: Placement of plumbs and angles in the Eratosthenes experiment.

We assume that the solar rays are parallel. The solar rays produce two shadows, one for each plumb. We measure the lengths of the plumb and its shadow and using the tangent definition, we obtain the angles α and β (figure 19). The central angle γ can be calcu-lated imposing that the sum of the three angles of the triangle is equal to π radians. Then $\pi = \pi - \alpha + \beta + \gamma$ and simplifying

$$\gamma = \alpha - \beta$$

where α and β have been obtained by the plumb and its shadow.

angle γ, the length of its arc d (determined by the distance above the meridian between the two cities), and 2π radians of the meridian circle and its length $2\pi R_E$, we find:

$$\frac{2\pi R_E}{2\pi} = \frac{d}{\gamma}$$

Then we deduce that:

$$R_E = \frac{d}{\gamma}$$

where γ has been obtained by the observation and d is the distance in km between both cities. We can find d from a good map.

In the Eratosthenes situation, the angle β was zero and $\gamma = \alpha$, and the distance between Alejandria and Syena route, he can ontain a good result of the terrestrial radius.

It should also be mentioned that the purpose of this activity is not the accuracy of the results. Instead, we want students to discover that thinking and using all of the possibilities you can imagine can produce surprising results.

Tides

Tides are the rise and fall of sea level caused by the combined effects of Earth's rotation and gravitational forces exerted by the Moon and the Sun. The shape of the sea bottom and shore in the coastal zone also influence the tides, but to a lesser extent. Tides are produced with a period of approximately 12 ½ hours.

The tides are mainly due to the attraction between the Moon and Earth. High tides occur on the sides of the Earth facing the moon and opposite the moon (figure 120). Low tides occur in the intermediate points.

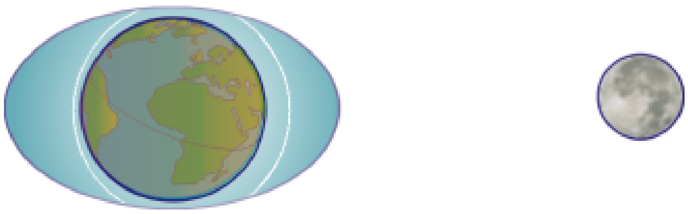

Fig. 20: Tide's effect.

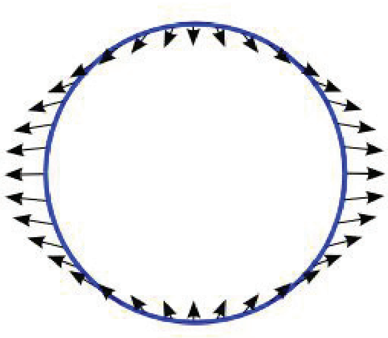

Fig. 21: Effect on water of the differential relative acceler-ation of the Earth in different areas of the ocean.

Tidal phenomena were already known in antiquity, but their explanation was only possible after the discover of Newton's law of the Universal Gravitation (1687).

$$F_g = G \frac{m_T \cdot m_L}{d^2}$$

The moon exerts a gravitational force on Earth. When there is a gravitational force, there is a gravitational acceleration according to Newton's second law (F = m a). Thus, the acceleration caused by the moon on Earth is given by

$$a_g = G \frac{m_L}{d^2}$$

Where m_L is the moon mass and d is the distance from the moon to a point on the Earth.

It's a good idea to repeat the measurements made by Aristarchus with students. In particular, we first have to calculate the angle between the Sun and the quarter moon. To make this measurement it is only necessary to have a theodolite and know the exact timing of the quarter moon.

The solid part of Earth is a rigid body and, therefore, we can consider all the acceleration on this solid part applied to the center of the Earth. However, water is liquid and undergoes a distinct acceleration that depends on the distance to the moon. So the acceleration of the side closest to the moon is greater than the far side. Consequently, the ocean's surface will generate an ellipsoid (figure 21).

That ellipsoid is always extended towards the Moon (figure 20) and the Earth will turn below. Thus every point on Earth will have a high tide followed by low tide twice per day. Indeed the period between tides is a little over 12 hours and the reason is that the moon rotates around the Earth with a synodic period of about 29.5 days. This means that it runs 360º in 29.5 days, so the moon will move in the sky nearly 12.2º every day or 6.6 º every 12 hours. Since each hour the Earth itself rotates about 15°, 6.6° is equivalent to about 24 minutes, so each tidal cycle is 12 hours and 24 minutes. As the time interval between high tide and low tide is about half this, the time it take for high tides to become low tides, and vice versa, will be about 6 hours 12 min.

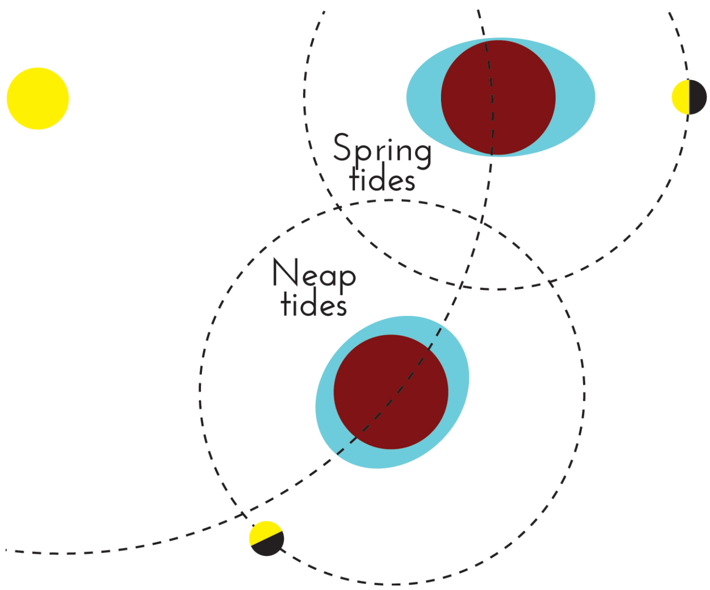

Fig. 22: Spring tides and neap tides.

Due to its proximity, the Moon has the strongest influence on the tides. But the Sun also has influence on the tides. When the Moon and Sun are in conjunction (New Moon) or opposition (Full Moon) spring tides occur. When the Moon and the Sun exercise perpendicular gravitational attraction (First Quarter and Last Quarter), the Earth experiences neap tides (figure 22).

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Young Astronomer Briefcase

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Summary

To further observation it is necessary that students have a set of simple tools. It is proposed that they construct some of them and then use them in observing the sky from the school itself.

Students should understand in a basic way how various instruments have been introduced over the centuries, how they have developed, and have become necessary. It is an important part of astronomy, noting the great ability to build them and the skill to use them to do readings of the observations. These requirements are not easy to develop with students and for that reason here we propose very simple instruments.

Objetivos

• Understand the importance of making careful observations.
• Understand the use of various instruments thanks to the fact that students do the construction by themselves.

The Observations

We can acquire some practice in the measurement of time and positions of celestial bodies with prepared artifacts “ad hoc”. Here we give some information to gather a collection of tools for observation in a suitcase. The suitcase and contents are generally made of cardboard using glue, scissors, etc.. The topic may offer the possibility to investigate many other ancient and modern instruments.

The artistic and imaginative ability of students will allow very personal suitcases.
This activity can be easily modified and adapted to the students depending on their age, with more or less sophisticated tools.

In particular, this suitcase contains:

• A ruler for measuring angles
• A simplified quadrant
• A horizontal goniometer
• A planisphere
• A map of the Moon
• An equatorial clock
• A spectroscope

We propose a suitcase with very simple tools. The small suitcase can be easily taken to school or during free time, ready for use. It is important this is not too large or fragile (especially if it is to be used by very young students). We emphasize that exactness in the measurements is not the end of this activity.

Contents

We obviously can only simulate this on a schoolyard in the summer. The idea is to get practice with the tools that we will do here now.

First, we need a cardboard box like the ones you receive by mail with a book inside (this will be the suitcase). It is necessary only to place a handle on the narrow side and that the wide side could be opened. Inside the box, we will post the following instruments:

- A "**ruler to measure angles**" that can be used to give us the angular distance between two stars of that constellation. It is very easy to use if we don’t want to introduce the coordinates.

- A **simplified quadrant** can be used to obtain the height of the stars. When students see an object through the viewfinder the string indicates the angular position related to its horizon.

- A simple **horizontal goniometer** can be used to determine the azimuth of the stars. Obviously you need to use a compass to orient the instrument in the North-South direction.

- A **planisphere** with the constellations photocopied very clearly onto a disc of white paper and a cardboard pocket with the “hole” of the latitude to put the disk of the sky inside. Turning the disc we find the date and time of obser vation to recognize the major constellations at the latitude of the "hole" that we use.

- A **spectroscope** to separate light into the seven colors that compose it.
- A **map of the Moon** with the names of seas and some craters that are easily recognizable through binoculars.
- A **flashlight** (red light) to illuminate the maps before looking at the real sky. Bright white light will make it difficult for the students' eyes to adjust to the darkness. If students bring a flash-light in their suitcase, you need to put a red fil-ter on the front. A group of students with white flashlights can produce a lot of light pollution making the obsevations more difficult.
- A **compass** for aligning the different instruments.
- And of course all the accessories that needs every student: notebook, pen, a watch and, if it is possible, a camera.

Following the instructions and drawings we can get our tools in a very simple way and use them outdoors. During the day we'll measure, for example, with the quadrant the position (angular height) of a tree, a hill, and so on. At night, we can measure the position of two different stars or the Moon in order to understand the periodic cycle of its phases. We encourage students to take data.

For the first nighttime observations it is better to use simple maps prepared in advance to become familiar with the most important constellations. Of course the astronomical maps are very accurate but the experience of teachers suggests that sometimes, without assistance, they are initially confusing.

A ruler to measure angles

Considering a simple proportion we can build a basic instrument for measuring angles in any situation.

Our main aim is to answer the following question: "What is the distance (radius R) that I need in order to obtain a device that 1º is equivalent to 1 cm?".

In figure 1 we consider the relationship between the circumference of length $2\pi R$ in centimeters to 360 degrees, with 1 cm to 1º:

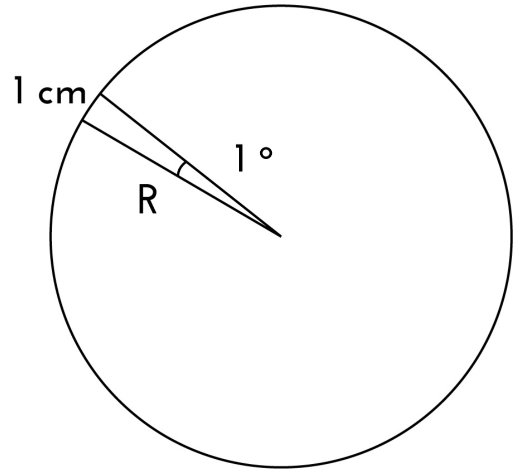

Fig. 1: The radius R in order to obtain an instrument where 1º is equivalent to 1 cm.

$$\frac{2\pi R\ \text{cm}}{360^\circ} = \frac{1\ \text{cm}}{1^\circ}$$

So, $$R = \frac{180}{\pi} = 57\ \text{cm}$$

To build the instrument

We take a ruler, where we fix a string of 57 cm of length. It is very important that the string doesn't stretch.

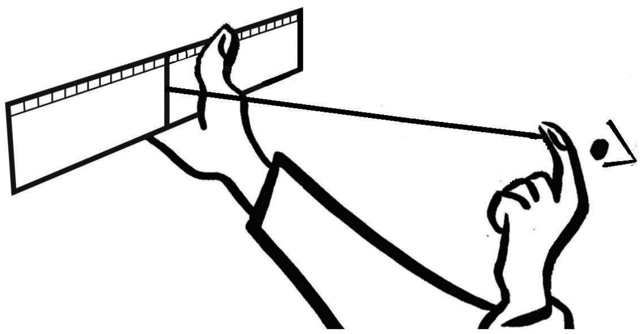

Fig. 2: Using the instrument (a ruler and a piece of string 57 cm long), we can measure angles with the equivalence "1cm = 1º".

How we use it:

- We watched with the end of the string almost touching our eye "on the cheek, under the eye".

• We can measure using the rule and the equivalence is 1cm = 1 degree if the string is extended (figure 2).

Proposed exercises:

What is the angular distance between two stars of the same constellation?
Use the "ruler to measure angles" to compute the distance (in degrees) between Merak and Dubne of Ursa Major.

A simplified quadrant: quadrant "gun"

A very simplified version of the quadrant can be very useful for measuring angles. Here we present the "gun" version that is user friendly which en-courages their use by students.

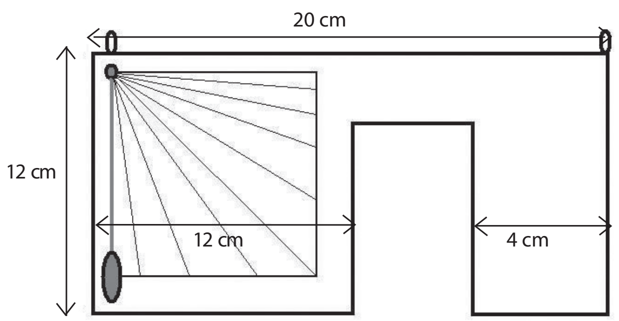

Fig. 3: Quadrant "Gun".

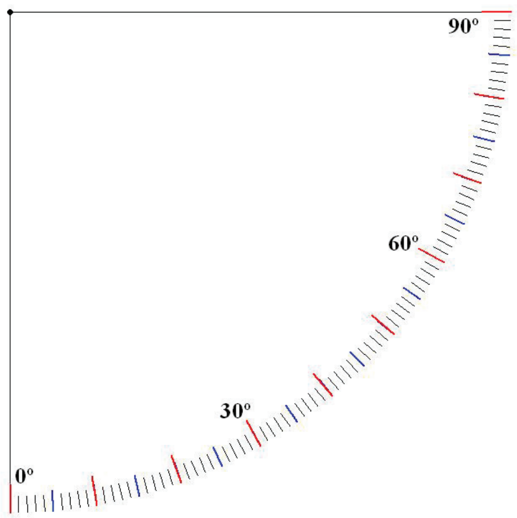

Fig. 4: Graduation of 90 ° to stick on the quadrant.

To build it: You need a rectangular piece of cardboard (about 12x20cm). We cut out a rectangular area as in figure 3 in order to hold the instrument. We place two round hooks on the side (figure 3).

In a paper quadrant (figure 4) with the stick angles shown (figure 3) so that one of the hooks is on the position 0° (figure 3). Tie a string on the top and at the other end attach a small weight.

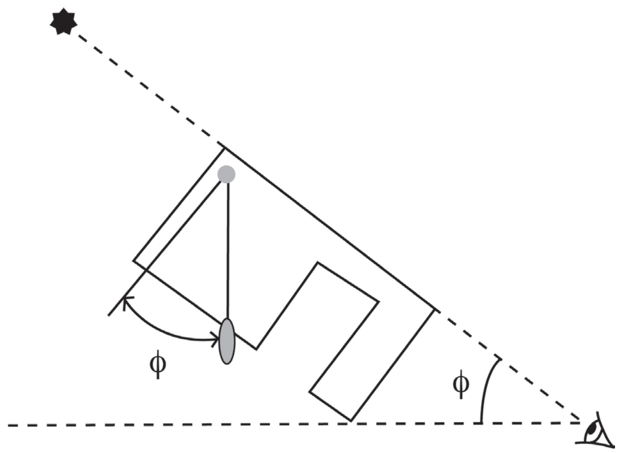

Fig. 5a and 5b: Using a "gun" style quadrant.

How to use it?:

• When viewing the object through the two hooks the string indicates the angular position 0° refers to the horizon (figure 5b).

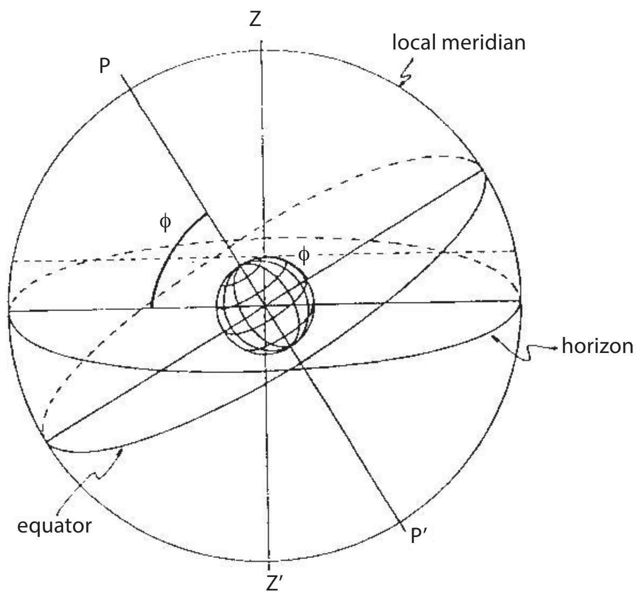

Fig. 6: The latitude of the place ϕ is equal to the height of the Pole.

• A straw passing through the hooks is an excellent viewer that will allow us to measure the height of the Sun by projecting the image onto a piece of white cardboard. CAUTION: DO NOT EVER LOOK DIRECTLY AT THE SUN!!!

Exercises proposed:

What is the latitude of the school?
We will use the quadrant to measure the height of Polaris. The latitude of a place is equal to the height of the Pole at that place (figure 6).

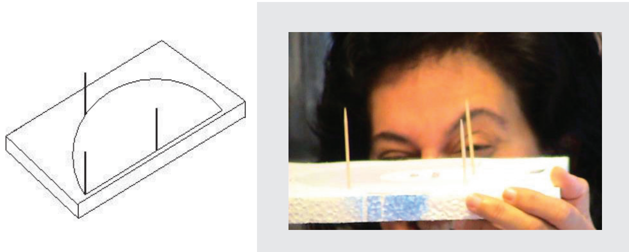

Fig. 7a and 7b: Using the horizontal goniometer.

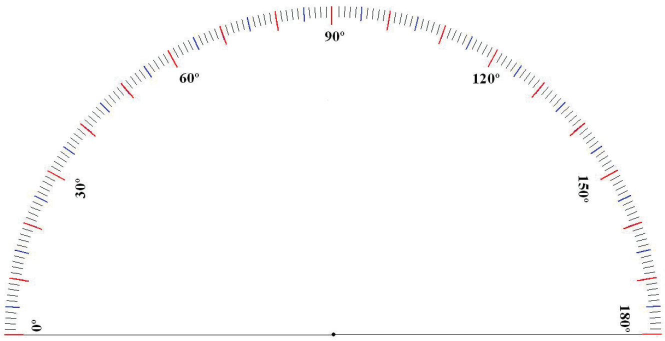

Fig. 8: Graduation of 180° to stick on the horizontal goniometer.

You can also use the quadrant to compute (in math class) the height of the school or another nearby building.

Horizontal Goniometer.

A simplified version of horizontal goniometer can be used to know the second coordinate needed to determine the position of a celestial body.

To build the tool: Cut a cardboard rectangle about 12x20cm (figure 7a). We stick a semicircle of paper (figure 8) with the angles indicated so that the di-ameter of the semicircle is parallel to the longest side of the rectangle. Using 3 "needles" we can mark two directions in the goniometer (figure 7b).

How is it used:
• If we want to measure the azimuth of a star we align the starting line of the semicircle in the North-South direction.

• The azimuth is the angle between the North-South line and the line through the center of the circle and the direction of the body.

Exercises proposed:

What is the position of the moon tonight?
Use the quadrant and the horizontal goniometer to calculate the height and azimuth of the moon. To study the motion of the moon at night, you can determine the two coordinates three times every hour. This way you can compare the motion of the moon with the stars in the sky.

The planisphere

We use star maps -which depend on the latitude- to recognize the constellations. We build one of them but we recommend extending it with a photocopier.

To build the planisphere:
We will use a photocopy of the constellations of the sky in a "white" disc and will place into a holder depending on your latitude close to the equator.

Northern Hemisphere

For places in the northern hemisphere with latitudes between 0 and 20 degrees you should prepare two planispheres, one for each horizon. To build the northern horizon we cut the window of figure 9a by the continuous line corresponding latitude and fold it on the dotted line to form a pocket. We will place the star map of figure 10a inside. Now we have the planisphere of the northern horizon. We proceed analogously to build the planisphere of the southern horizon. Cutting and bending, as before, the window of figure 9b in placing inside the star map in figure 10a. We will use both planispheres as we are looking towards the horizon north or south.

When we wish to observe in the northern hemisphere with latitudes between 30 and 70 degrees it is enough to cut the window in figure 9e by the solid line and fold the dotted line to get a pocket where it will place the circle of stars that we cut above (figure 10a).

Southern Hemisphere

For places in the southern hemisphere with latitudes between 0 and 20 degrees we should prepare two planispheres, one for each horizon. At first we build the northern horizon. We cut the window of figure 9c by the continuous line corresponding latitude and fold it by the dotted line to form a pocket. We will place the star map of figure 10b inside. With this operation we have the planisphere

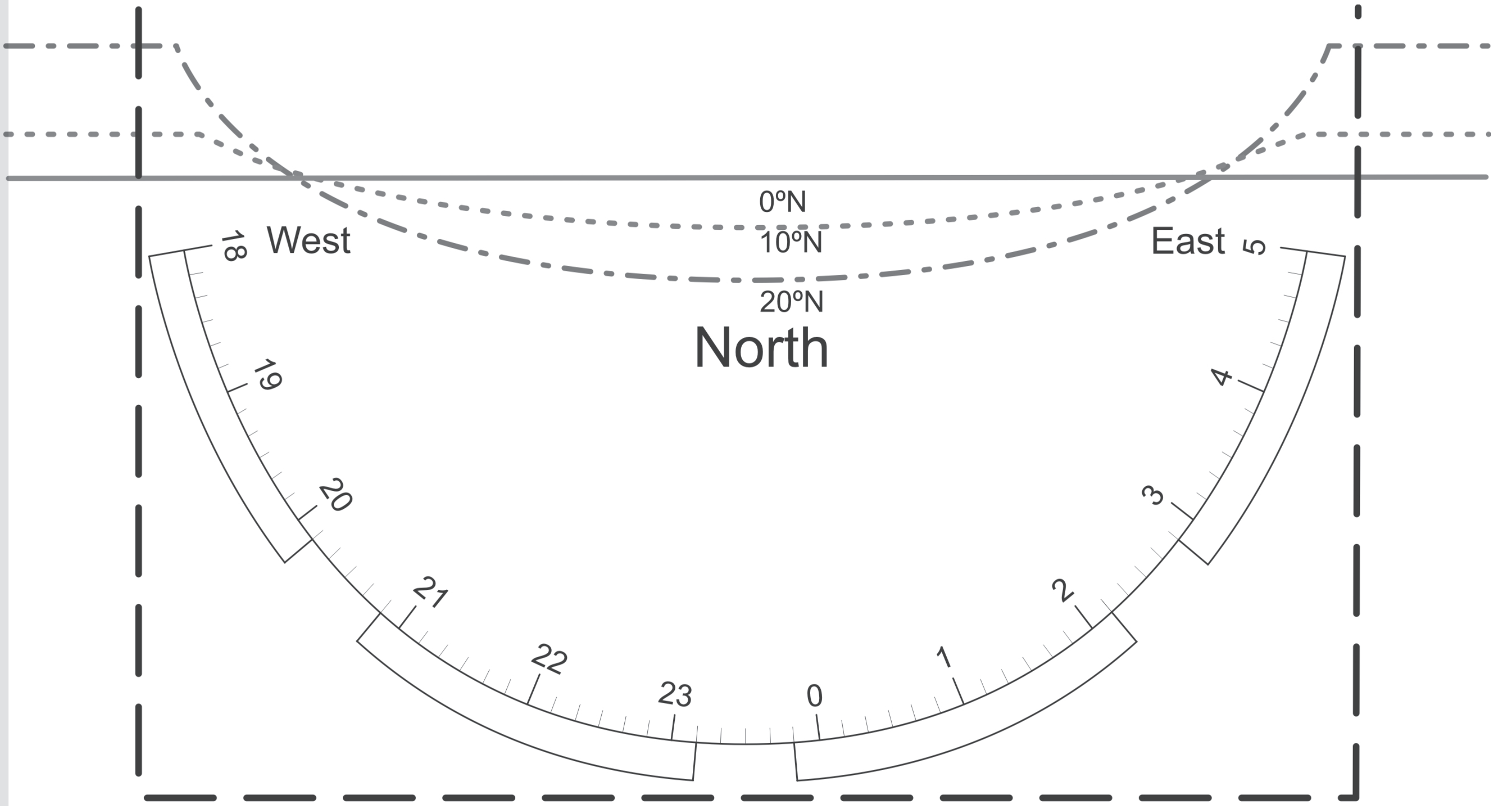

Fig. 9a: Pocket for the northern horizon in northern hemisphere (latitude 0, 10 and 20 North).

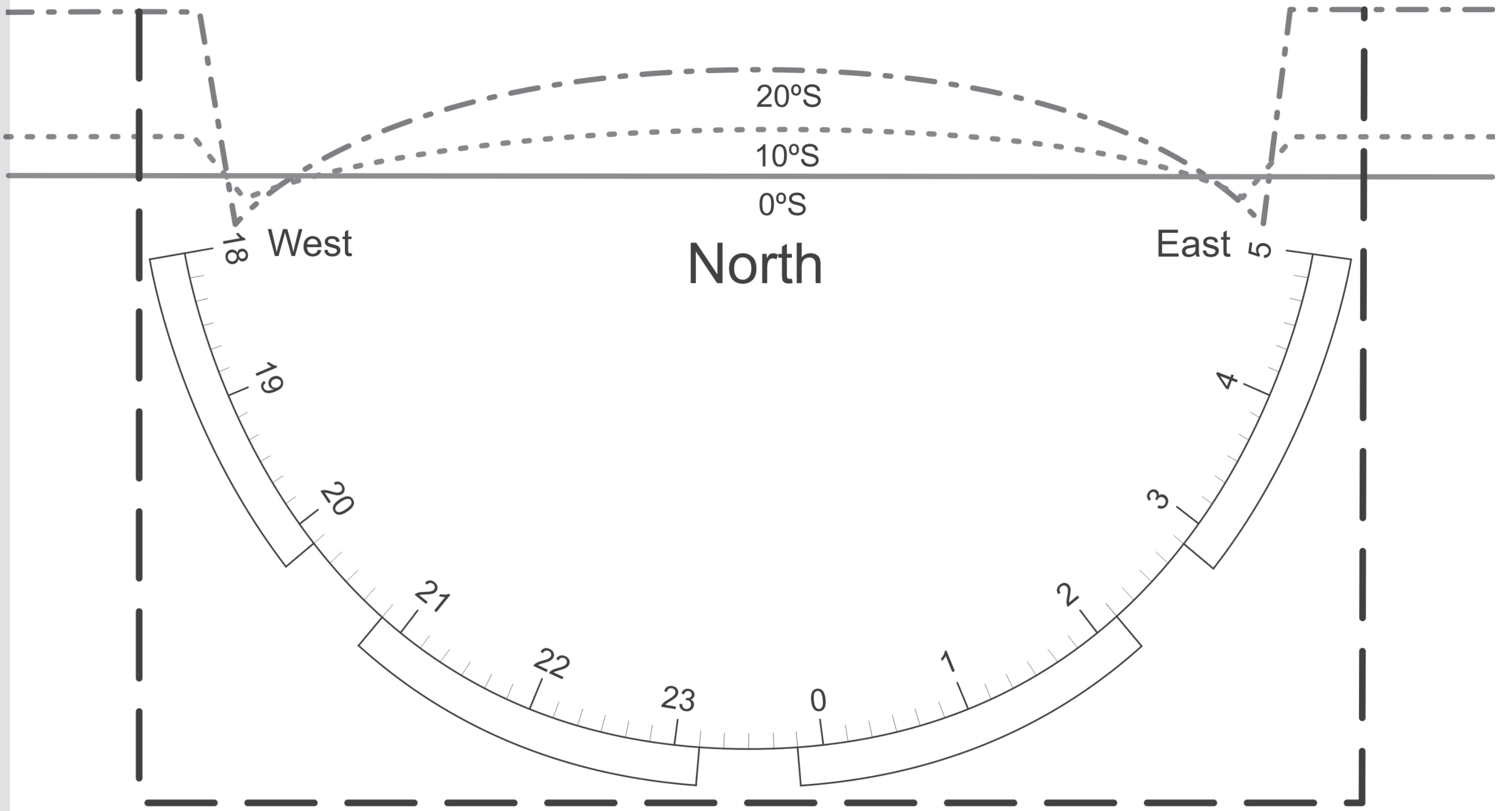

Fig. 9b: Pocket for the southern horizon in northern hemisphere (latitude 0, 10 and 20 North).

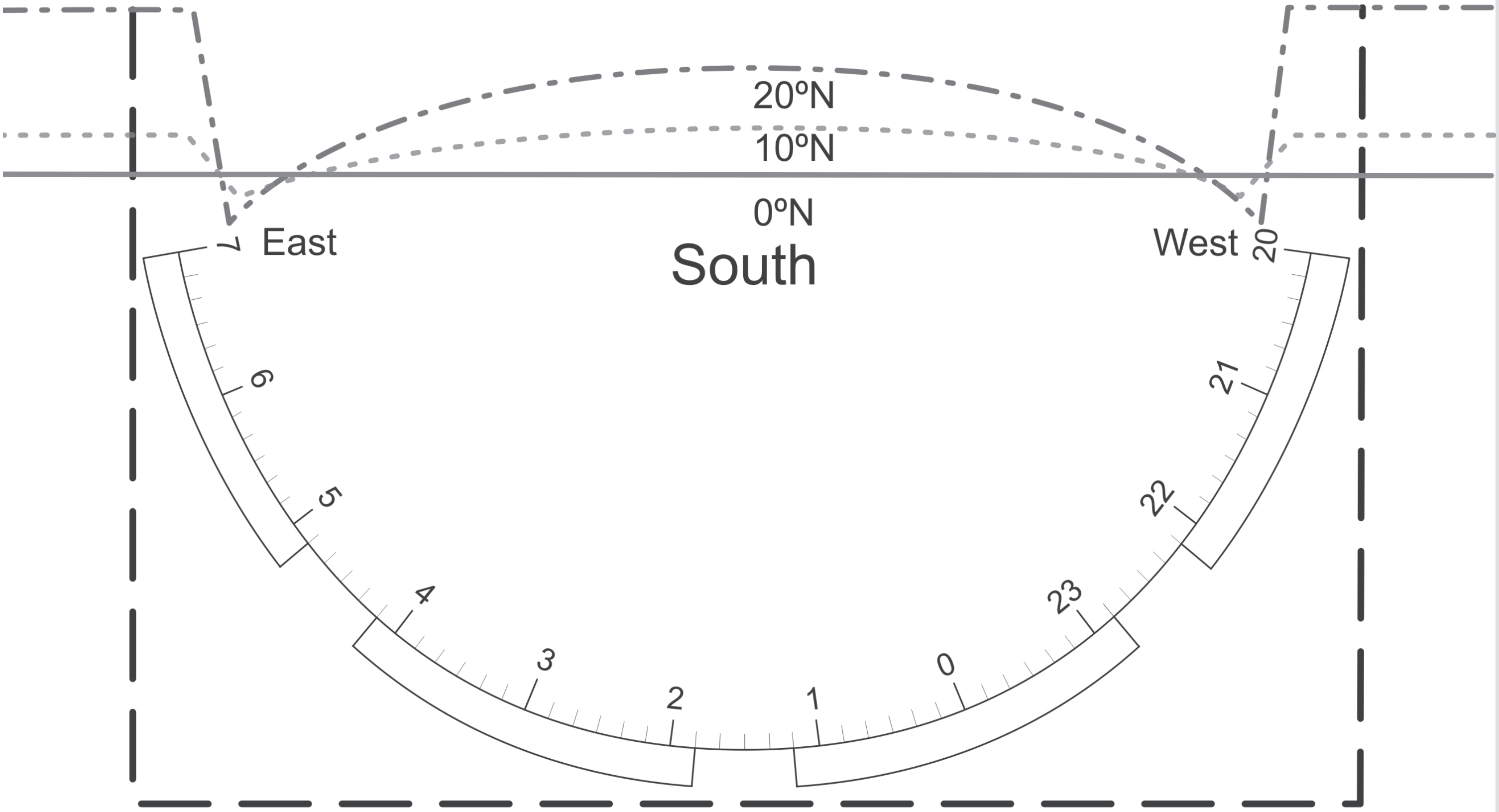

Fig. 9b: Pocket for the northern horizon in southern hemisphere (latitude 0, 10 and 20 South).

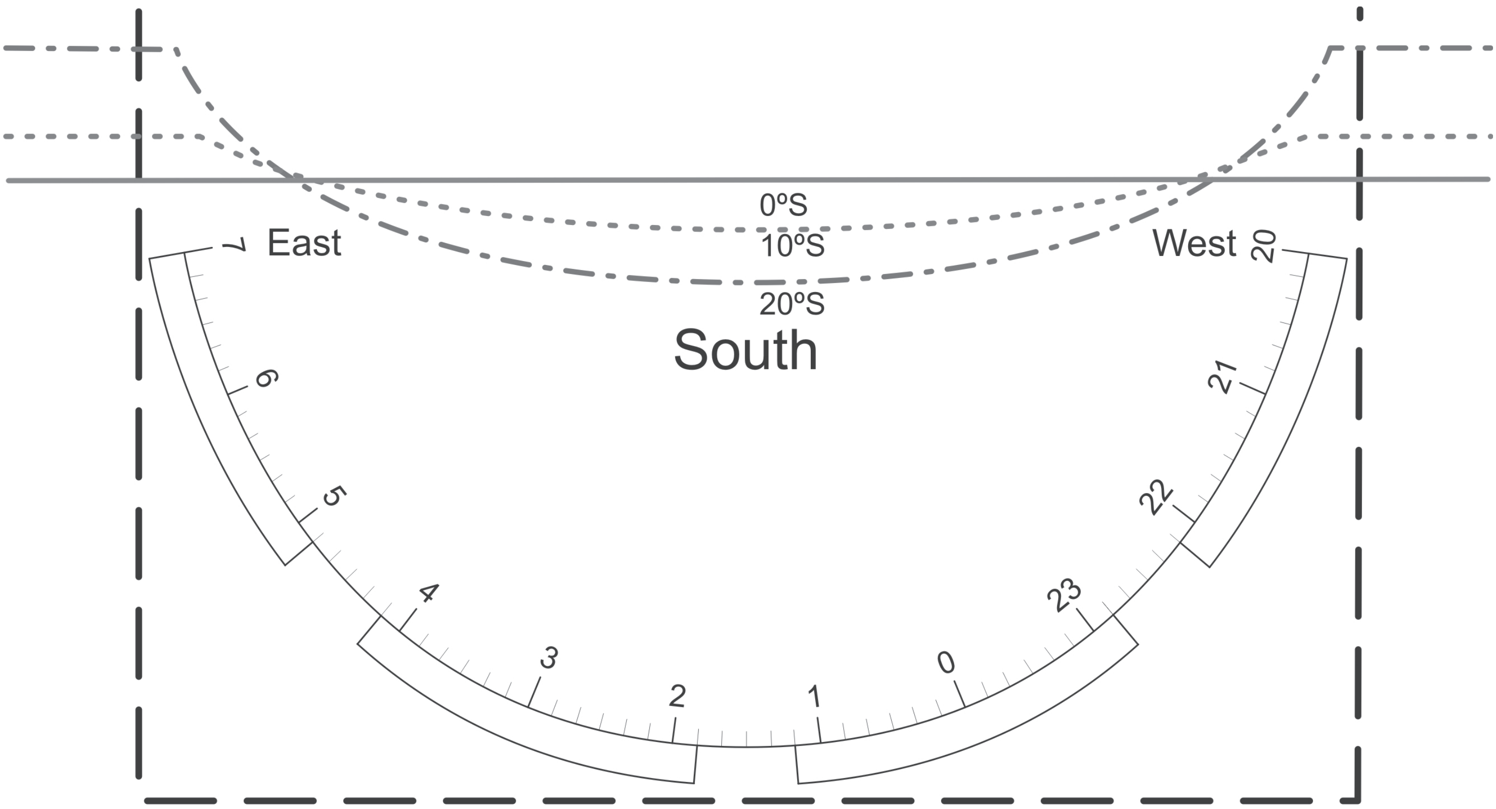

Fig. 9d: Pocket for the southern horizon in southern hemisphere (latitude 0, 10 and 20 South).

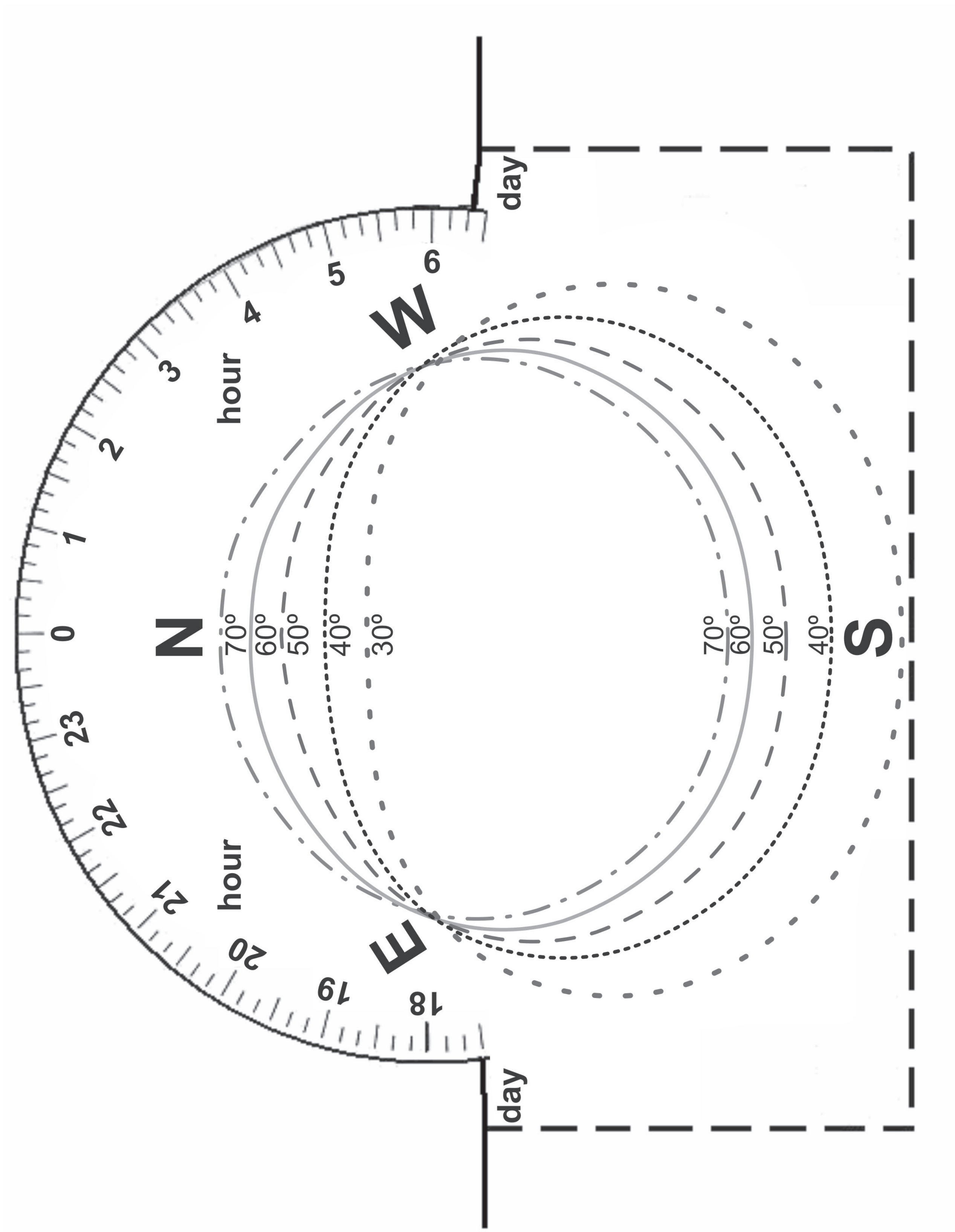

Fig. 9e: Pocket for both horizons in northern hemisphere. Latitudes 30, 40, 50, 60 and 70 North.

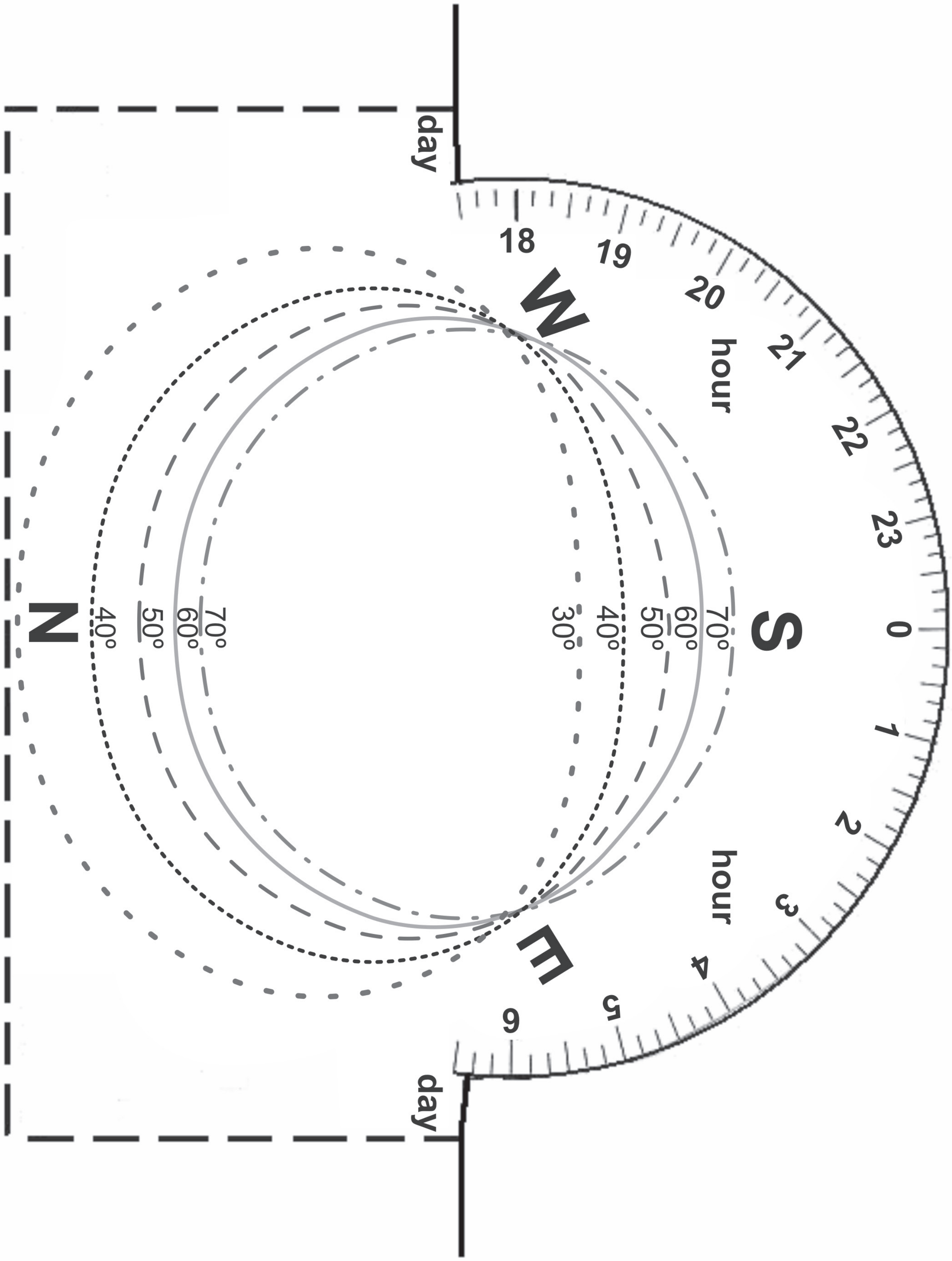

Fig. 9f: Pocket for both horizons in southern hemisphere. Latitudes 30, 40, 50, 60 and 70 South.

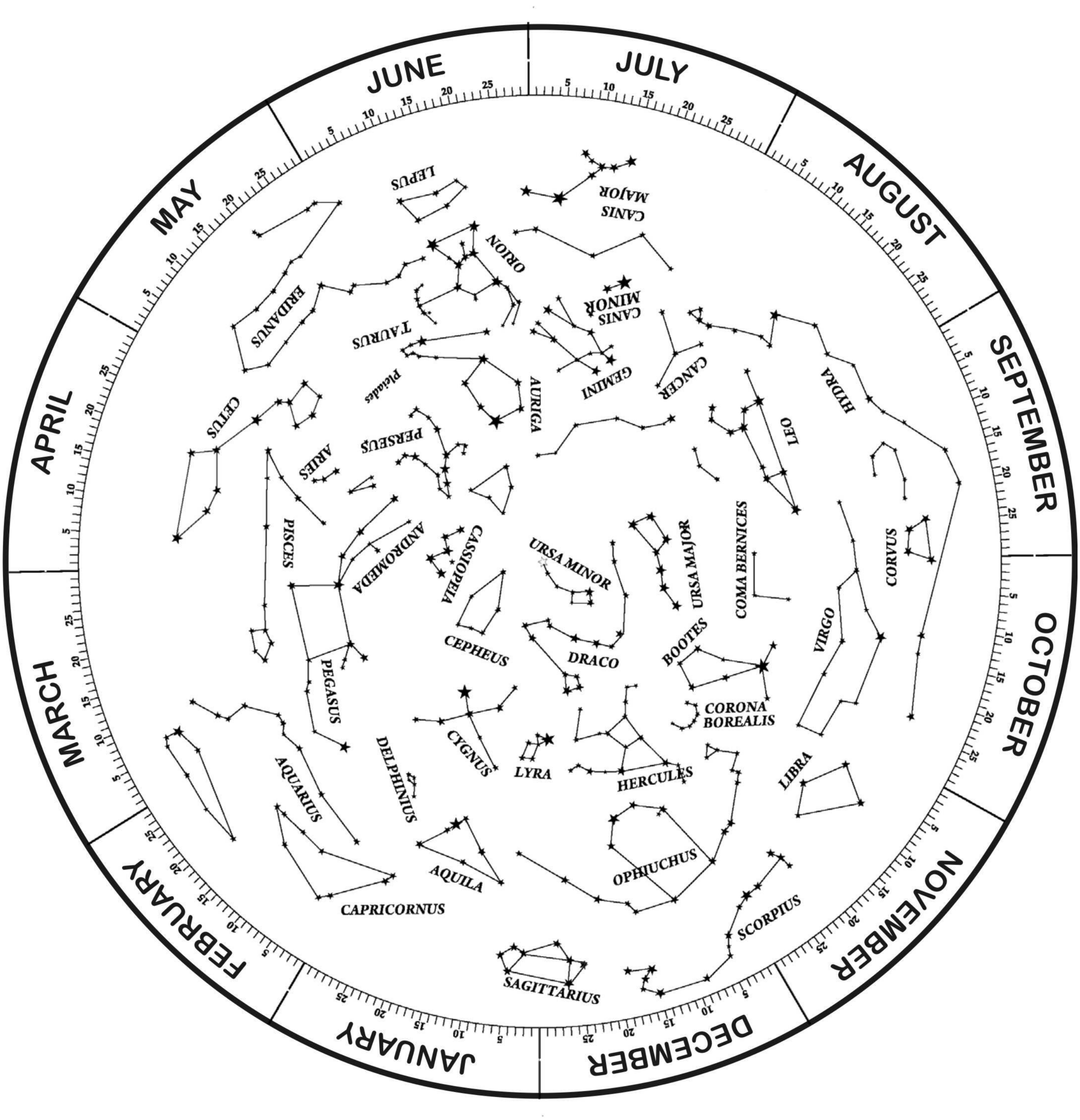

Fig. 10a: The disk or stellar map that is placed inside the pocket. Northern Hemisphere.

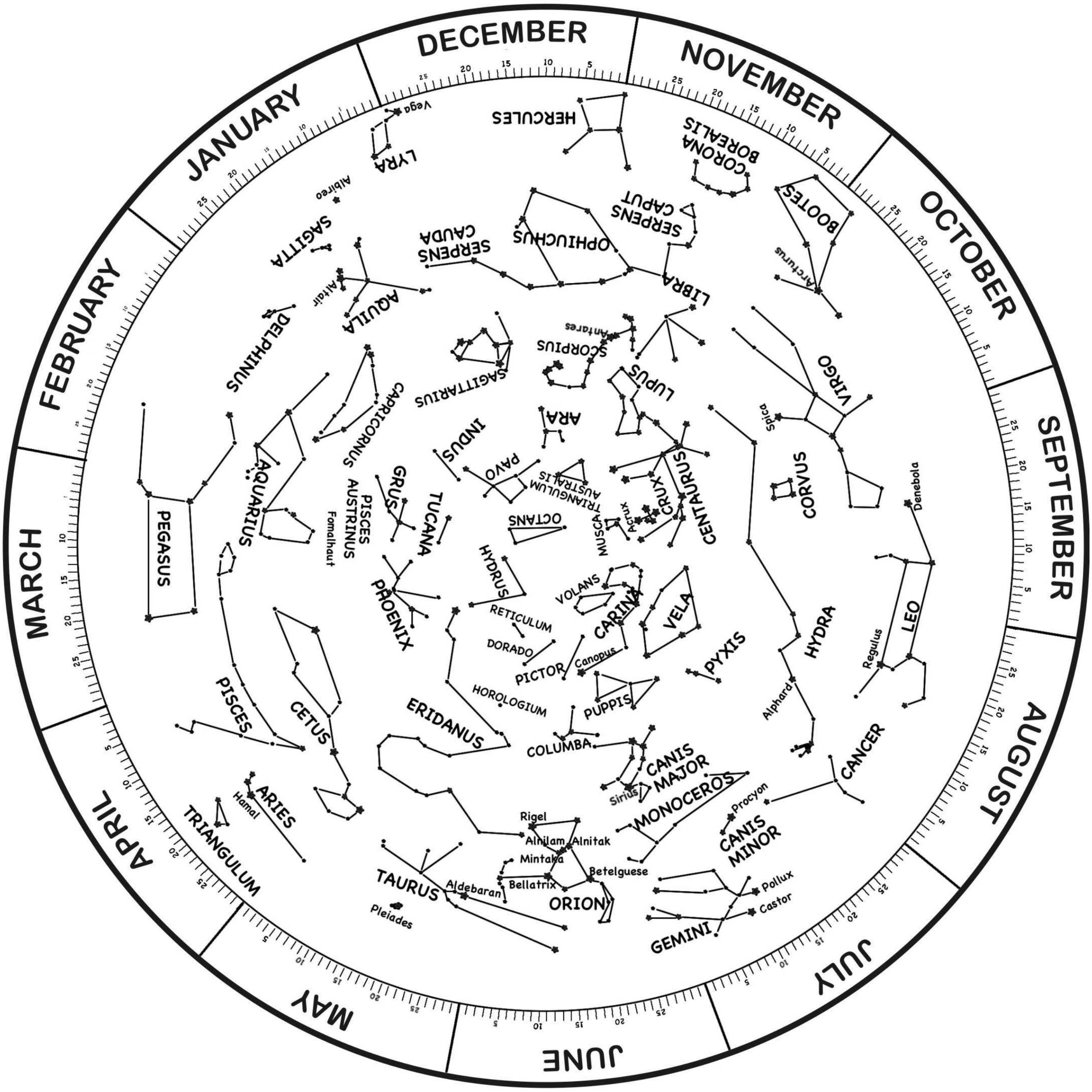

Fig. 10b: The disk or stellar map that is placed inside the pocket. Southern Hemisphere.

of the northern horizon. We proceed analogously to build the planisphere of the southern horizon. Cutting and bending, as before, the window of figure 9d in placing inside the star map in figure 10b. We will use both planispheres as we are looking towards the horizon north or south.

When we wish to see in the southern hemisphere with latitudes between 30 and 70 degrees it is enough to cut the window in figure 9f by the solid line and fold the dotted line to get a pocket where it will place the circle of stars that we cut above (figure 10b).

How to use:
Place the date of the day when we will look in line with the observation time by rotating the circle of stars and use the world map looking at the sky in the direction indicated. The part of the sky that is visible in the sky is shown.

Note: A planisphere is used as an umbrella. It is a map of the sky and you place it above your head to recognize constellations.

Proposed exercises:
Which sky can we see tonight?
Using the planisphere you've made for the latitude of your school, turn the stellar disc until today's date coincides with the time you plan to go out and observe.

Note that the planisphere is a "stellar map" and you have to lift it over your head "as an umbrella" (it is not a map of your city!).

Spectroscopy

By passing the light of the sun through this sensitive instrument, the student will be able to visualize the spectral decomposition of the light. This is a simple way for the students to observe the stellar spectrum with an instrument constructed with their own hands.

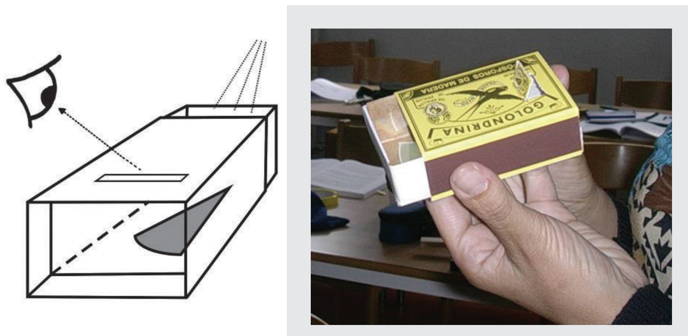

Fig. 11a and 11b: How to use the spectroscope.

How to make the spectroscope
Paint the interior of a large matchbox (of the size typically used in a kitchen). Make a longitudinal cut (figure 11b) through which the observer can view the spectrum. Cut a damaged (or otherwise unusable) CD into 8 equal parts, and place one of the pieces inside the box, on the bottom, with the recordable surface facing up. Close the box, leaving only a small section open, opposite from where you constructed the viewing slit.

How to use it?:
- Orient the matchbox so that the sunlight falls through the open section, and observe through the viewing slit (figure 11a).
- Inside the matchbox, you will see the sunlight split into the colors of its spectrum.

Proposed exercises:
Compare the solar spectrum with a fluorescent or other lamps that are in school. *You will be able to observe variations that appear in the spectrum depending on the type of lamp that you're viewing.*

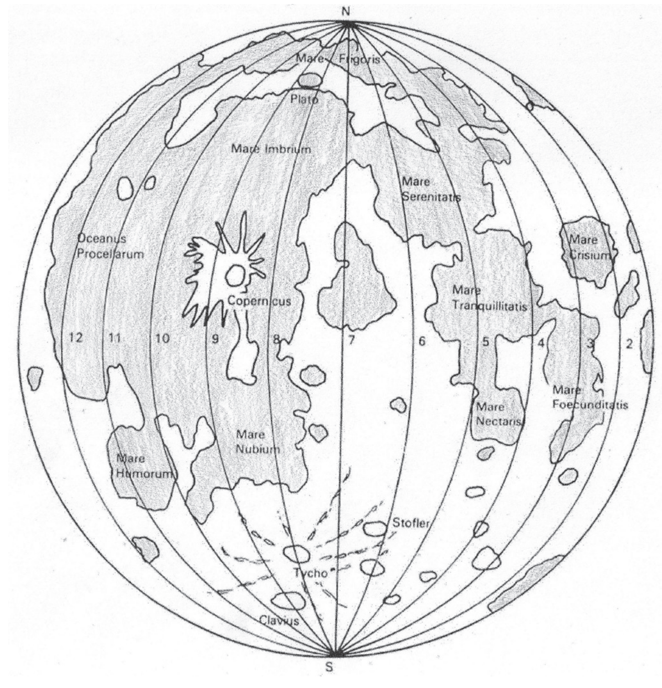

Fig. 12: Schematic map of the Moon.

Map of the Moon

It's good to include in your briefcase a simplified version of a lunar map that includes the name of the seas and some of the craters that can be seen with binoculars or with small telescopes.

To build it:
You need a square piece of cardboard (about 20x20 cm) (figures 12 or 13).

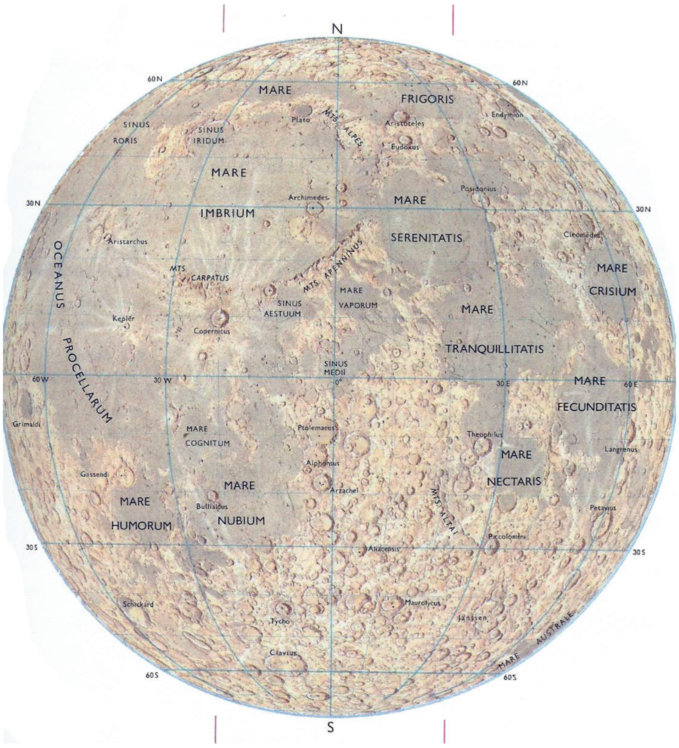

Fig. 13: Simplified map of the Moon.

How to use it?:

Be aware that the orientation will change depending on if you are using the naked eye, if you are using binoculars or a telescope (inverted image), and whether you are watching from the Northern or Southern Hemisphere. It is easiest to begin by identifying the seas, verify that the position is correct and then continue to identify other lunar features.

Proposed exercise:

Which is the Tycho crater?

Look at the moon when it is more than half illuminated and identify in the central zone a crater with a large system of rays (lines that leaves the crater and head in all directions across the surface of the satellite).

Fig. 14: The suitcase.

Organizing your Briefcase

Place a paper bag with a sheet on the upper side of the box open (figure 14) to store the planisphere, the map of the Moon, the sundial, etc.

In the deep part of the box place the instruments so that they can not move, using clips, pins, and small belts. The screw of the quadrant should be set around the center because the suitcase contains delicate instruments and can be balanced when handling it. A group of students proposed putting a list on the outside of the case indicating its contents, so we would be sure to have gathered everything at the end of the activity. In addition, of course, labeled with your name and any decorations you can think of, in order to customize the suitcase.

Conclusions

Observing how the sky moves during the night, the day and throughout the year is a must for young astronomers. With these kind of projects, students will be able:

- To gain confidence with the measures;
- To take responsibility for their own instruments;
- To develop their creativity and manual ability;
- To understand the importance of systematic collection of data;
- To facilitate the understanding of more sophisticated instruments;
- To recognize the importance of observation with the naked eye, then and now.

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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 characterstics 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

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

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.

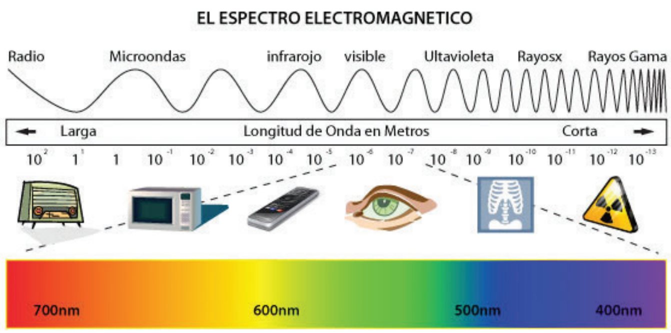

Fig. 1: Solar Spectrum.

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.

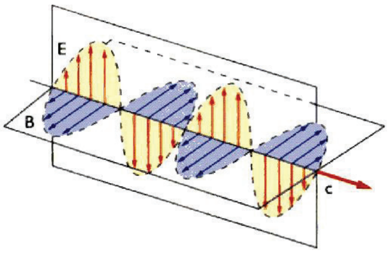

Fig. 2: Polarized light.

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).

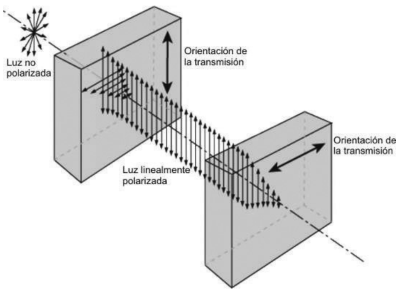

Fig. 3: When two filters have a perpendicular transmition orientation, the light which passes through the first is blocked by the second.

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.

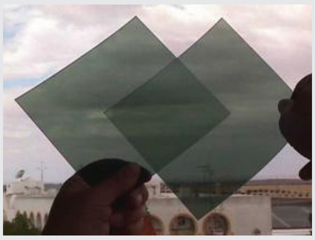

Fig. 4a: If the filters have the same orientation, light passes through.

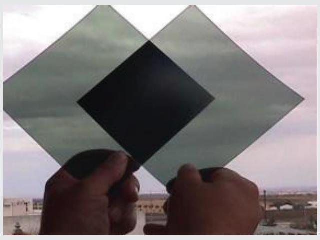

Fig. 4b: If one of the filters is turned 90º, light is blocked.

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.

Stick several strips of tape on a piece of glass (such as from a photo frame) so that in some are-

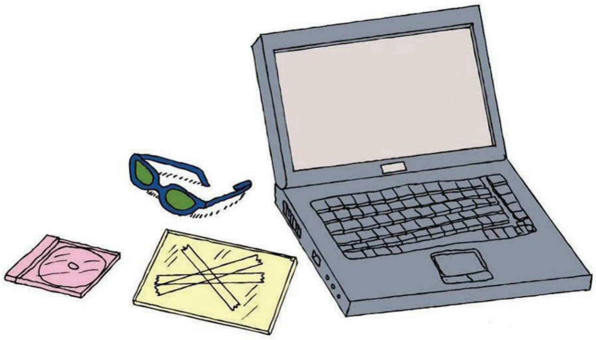

Fig. 6: The light from the TFT screen of a computer is polarized, and the tape rotates the polarization angle. Colors are seen when viewed with polarized sunglasses.

as 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.

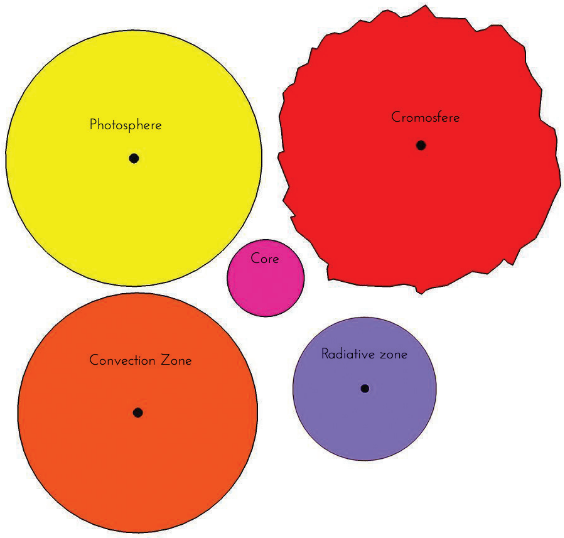

Fig 7: Sun's parts to cut out.

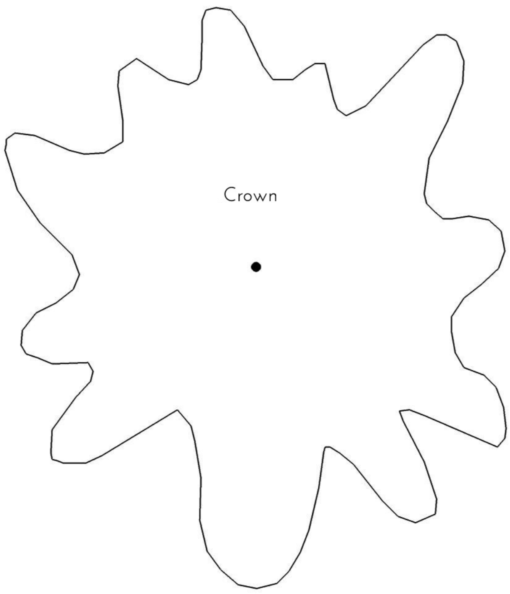

Fig 8: Corona to cut out.

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).

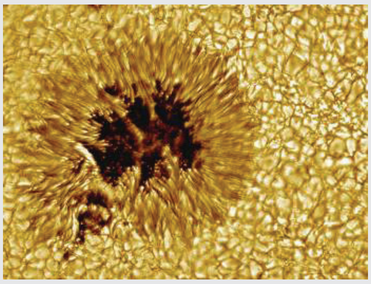

Fig. 9: Close-up of a sunspot. (Photo: Vacuum Tower Telescope, NSO, NOAO).

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 photo-sphere. Sunspots are the result of the interaction of strong vertical magnetic fields with the photo-sphere.

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).

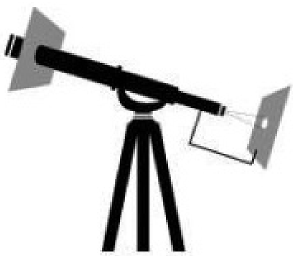

Fig. 10a: Solar observation by projection with a telescope (never look directly at the Sun).

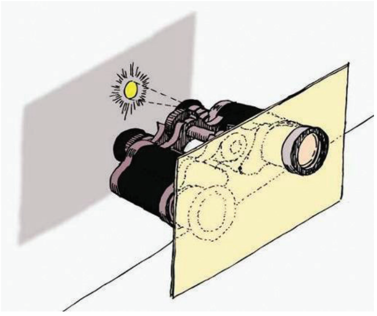

Fig. 10b: Observation by projection with binoculars (never look directly at the Sun).

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.

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.

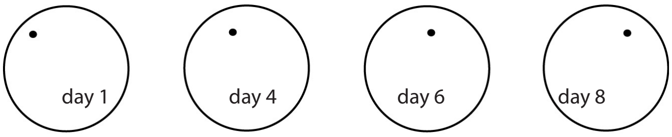

Fig. 11: Change of position of a sunspot over several days.

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

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

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

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.

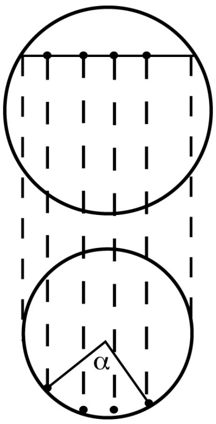

Fig. 12: Calculation of the angular rotation of sunspots.

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:

$$T = \frac{360^{o} \cdot 7 \text{ days}}{92^{o}} = 27.3 \text{ days}$$

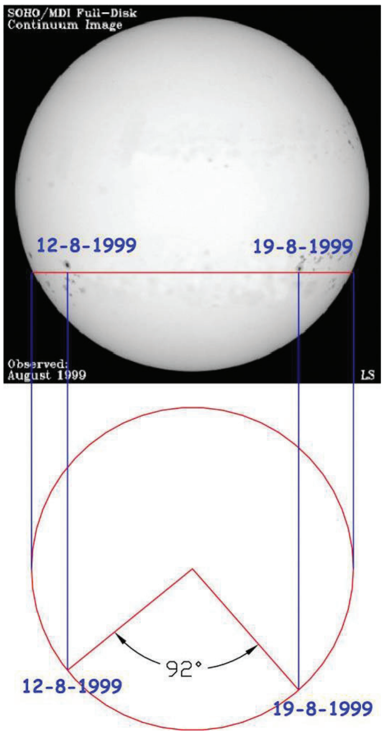

Fig. 13: Determination of solar rotation period.

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 electro-magnetic radiation and the amount of energy they carried can be calculated by the expression

$$E = h \cdot \nu$$

where E is the photon energy, h is Planck's constant ($h = 6{,}626 \cdot 10^{-34}$ J · s) and ν 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:

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

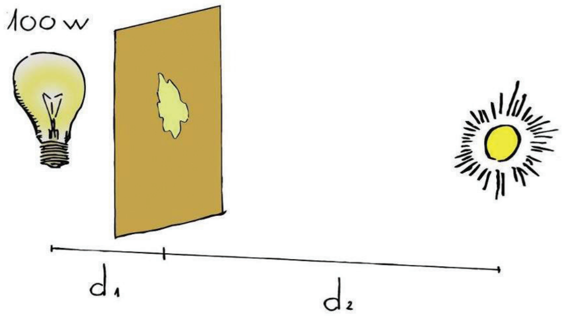

Fig. 14: Comparison between the Sun's power and a 100W light bulb.

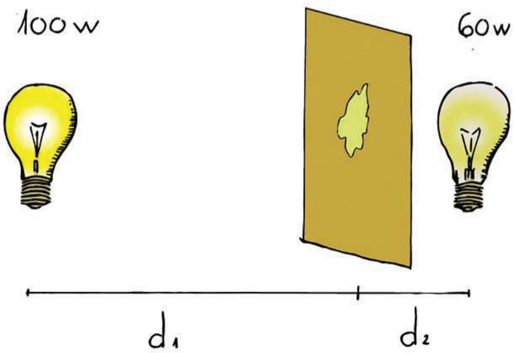

Fig. 15: If the light that reaches each side is the same, the oil slick is not seen.

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).

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 ei-

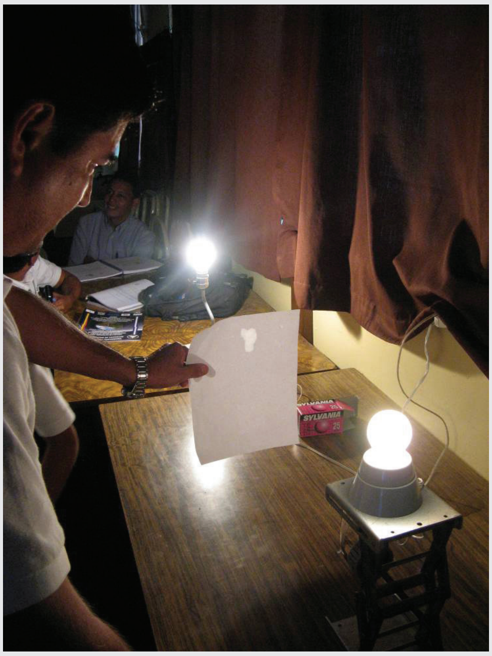

Fig. 16: Oil slick photometer, between two light bulbs.

ther side of the paper and the energy arriving at each side is equal.

In this case: $$\frac{100}{4 \cdot \pi \cdot d_1^2} = \frac{60}{4 \cdot \pi \cdot d_2^2}$$

On a sunny day, take the photometer outdoors with a light bulb of at least 100 W (brighter is better). Put the photomemeter 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 d2 = 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):

$$\frac{100\text{ W}}{d_1^2} = \frac{P_{Sol}}{d_2^2}$$

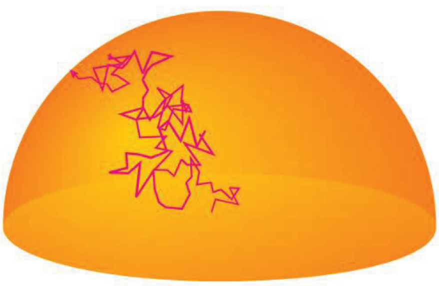

Fig. 17: Photons take 1 million years to leave the photosphere.

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.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).

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.

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.

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.

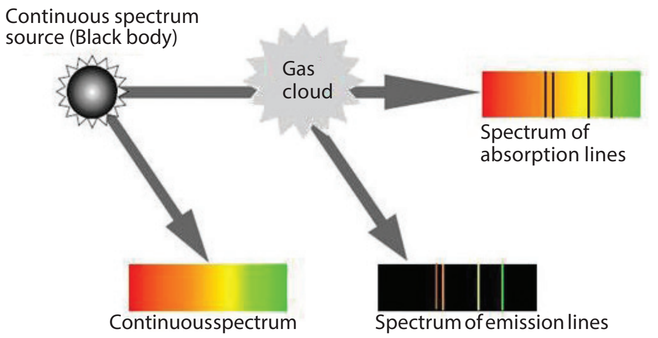

Fig. 19: Laws of Kirchhoff and Bunsen.

• 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 surronded 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 differ-ence between levels is constant (figure 20).

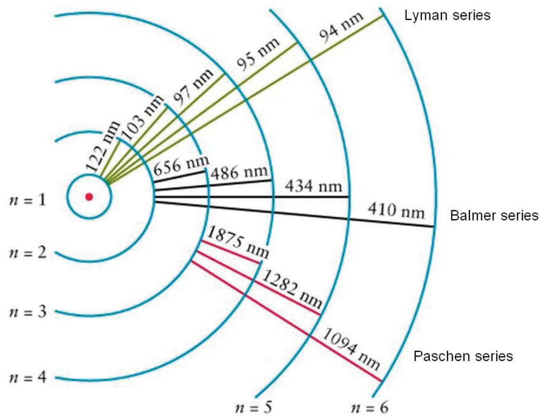

Fig. 20: Spectral series for emission of the Hydrogen atom. Possible transitions always have the same amount of energy between levels.

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.

Letter	Wavelength (nm)	Chemical Origin	Color range
A	759	O_2 atmospheric	dark red
B	687	O_2 atmospherico	red
C	656	Hidrogen alpha	red
D1	590	Neutral Sodiumo	oranged-red
D2	589	Neutral Sodium	yellow
E	527	Neutra Iron	green
F	486	H beta	cyian
G	431	CH molecular	blue
H	397	Ionized Calcium	dark violet
K	393	Ionized Calcium	dark violet

Table 1: Fraunhofer' s lines for the Sun.

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.

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

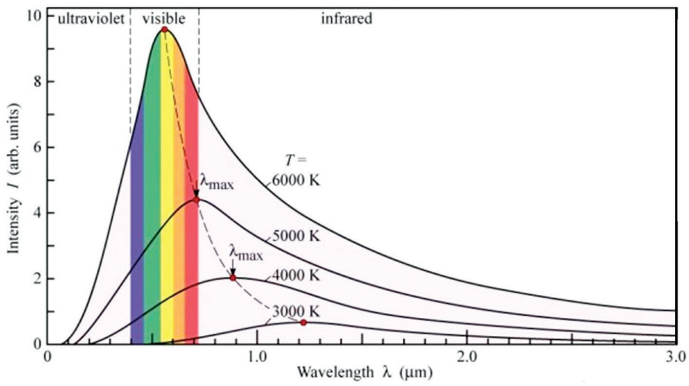

Fig.22: Emission curve for the "continuous spectrum" of the Sun.

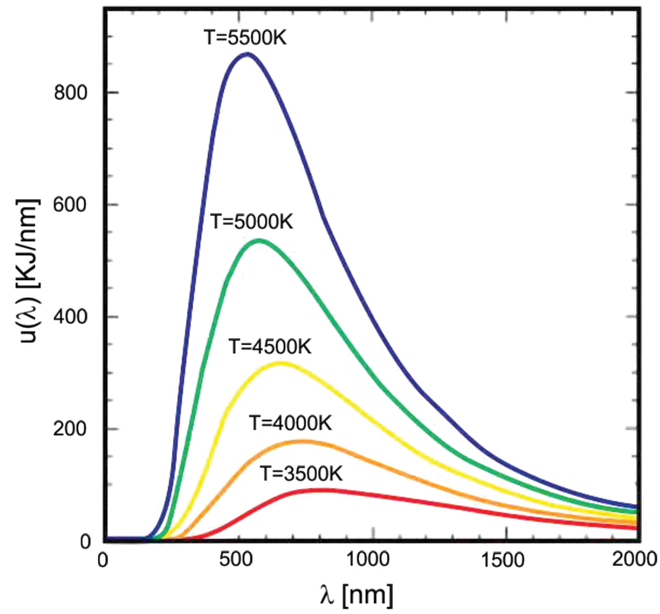

Fig. 21: Planck curves for black bodies at different temperatures.

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 $\lambda_{máx}$ is related to the body's temperature according to Wien's Law:

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

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.

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 μ, as Wien's law says (using a temperature of 37° 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.

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

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

wavelength, the light does not spread and all wave-lengths 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.

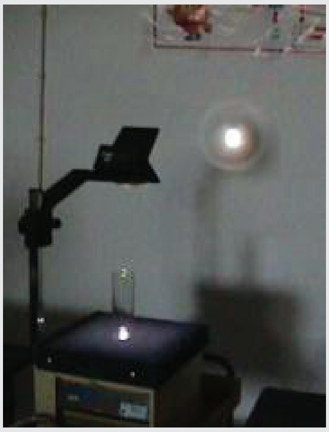

Fig. 24a: At the begining, the light reaching the wall is white.

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.

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. nebulae) 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.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.

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

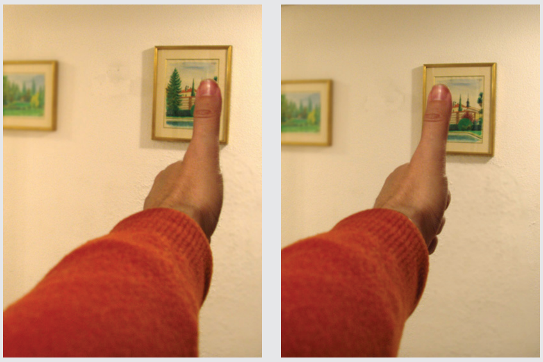

Fig. 1a: With your arm extended look at the position of your thumb relative to the background object, first with the left eye (closing the right one) and then, Fig. 1b: Look with the right eye (with the left eye closed).

greater if the distance between the two places where observations are taken is farther apart. This distance is called baseline.

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.

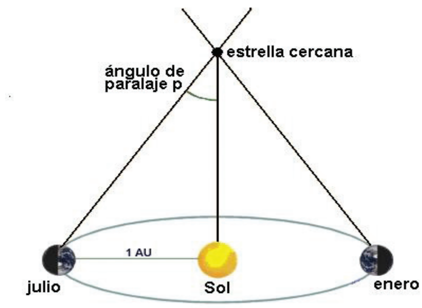

Fig. 2: The parallax angle p is the angular shift one sees when observing a star from two locations that are one Earth-Sun distance apart.

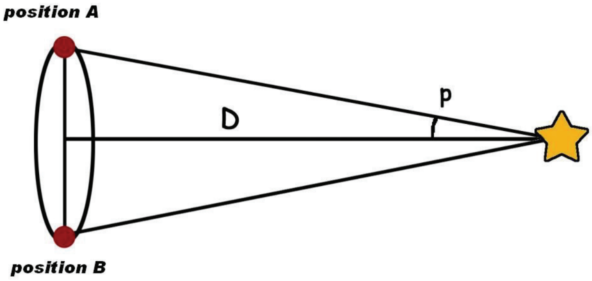

Fig. 3: By measuring the parallax angle, p, it is then possible to calculate the distance D to the object.

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:

$$D = \frac{150000000}{2\pi/(360\ 60\ 60)} = 30939720937064\ k$$

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 (pc), 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

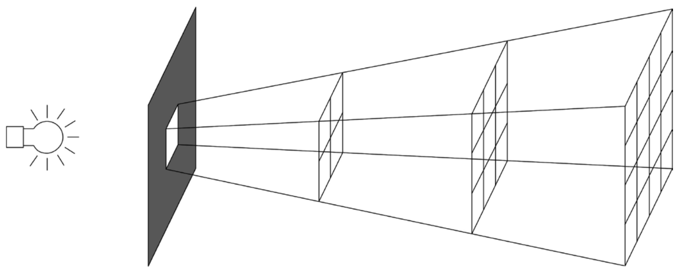

Fig. 4: Experimental setup.

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.

We observe that when the distance between the screen and the light bulb doubles, the area that the light illuminates 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 $4\pi R^2$, 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,

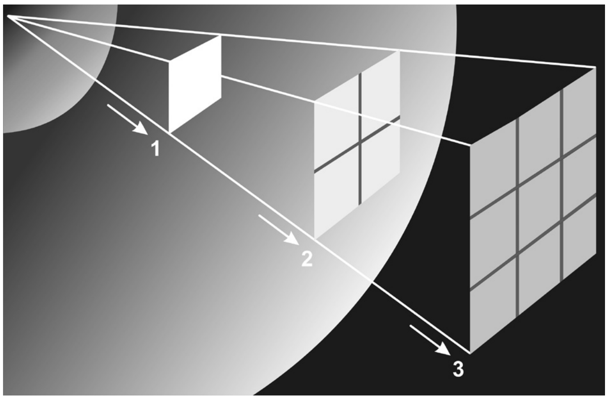

Fig. 5: The light becomes less intense the further away it is.

the intensity that reaches the paper is one-ninth (the area of the sphere that the light is distributed over is nine times larger).

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:

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

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 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 2.515 = 100 times brighter. This mathematical relationship can be expressed as:

$$\frac{B_1}{B_2} = (\sqrt[5]{100})^{m_2 - m_1} \quad \text{or} \quad m_2 - m_1 = 2,5 \log\left(\frac{B_1}{B_2}\right)$$

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:

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

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

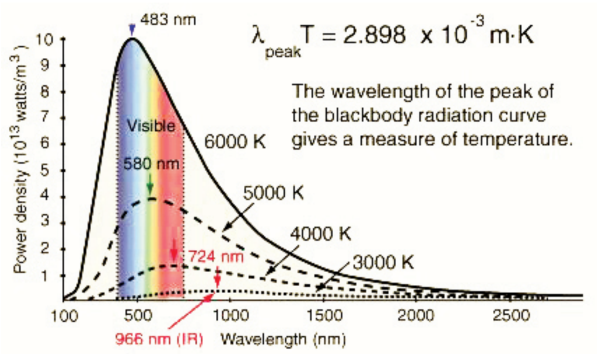

Fig. 7: If the temperature increases, the peak of the star's intensity moves from the red to the blue.

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).
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.

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, stu-

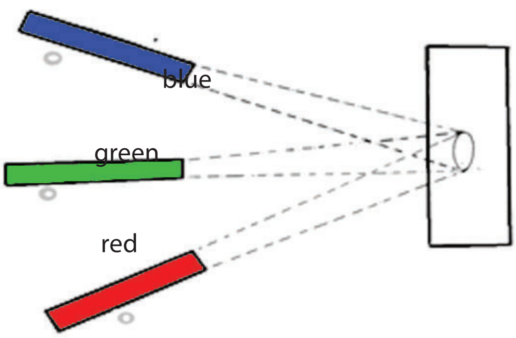

Fig. 8a: Device to explain the star color.

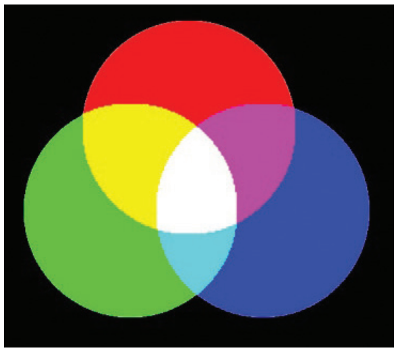

Fig. 8 b: Projection to explain the color of stars and the production of withe color.

dents 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

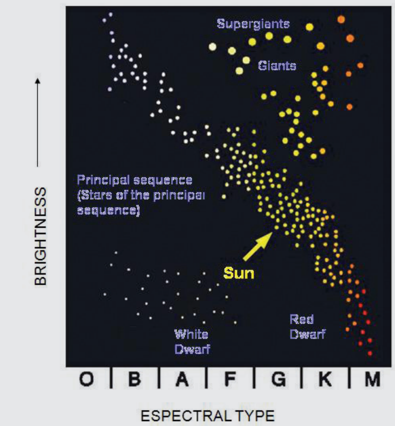

Fig. 9a: H-R Diagram. Fig. 9b: The Sun will shed its external atmosphere and will convert into a withe dwarf, like that which exists in the center of this planetary nebula.

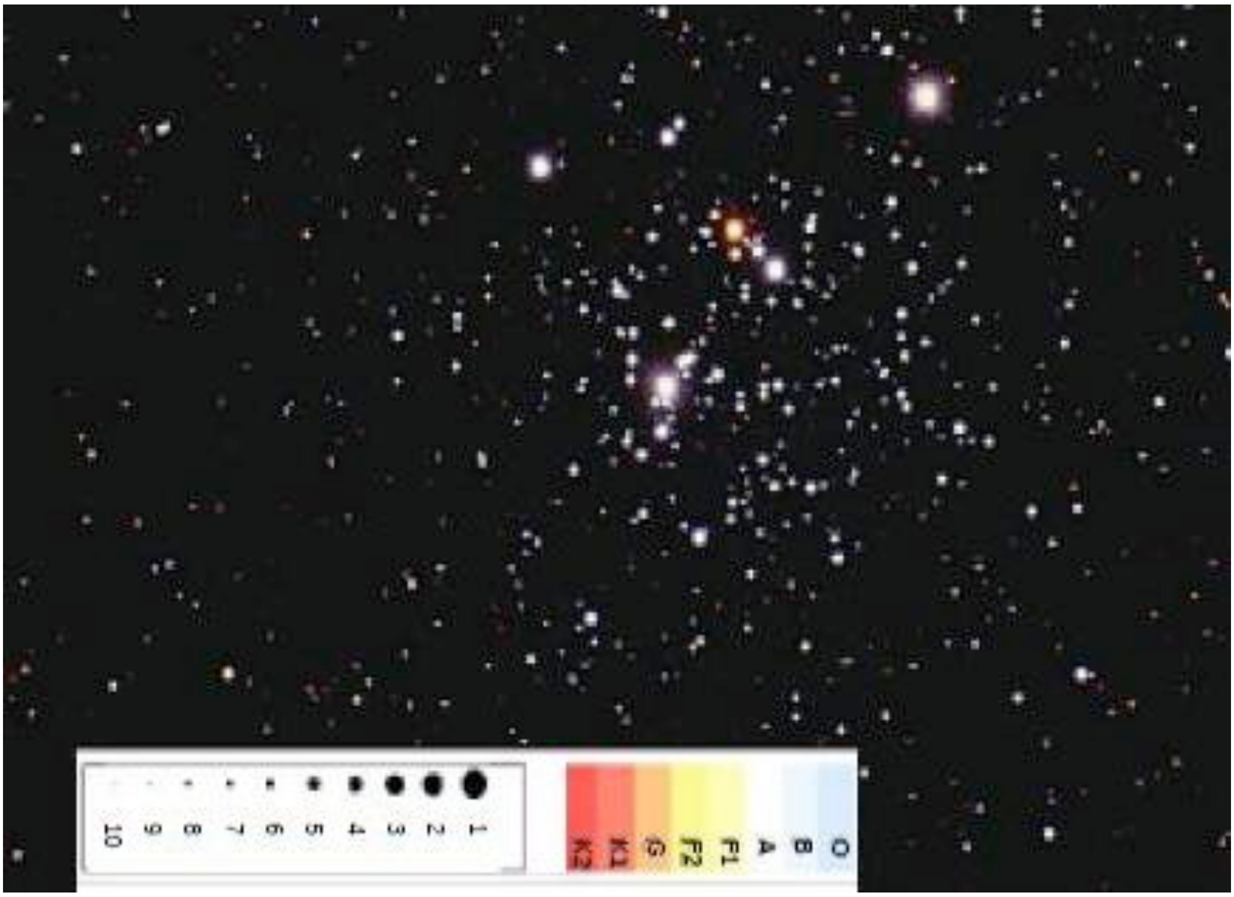

Fig. 10: Image of the Jewel Box cluster.

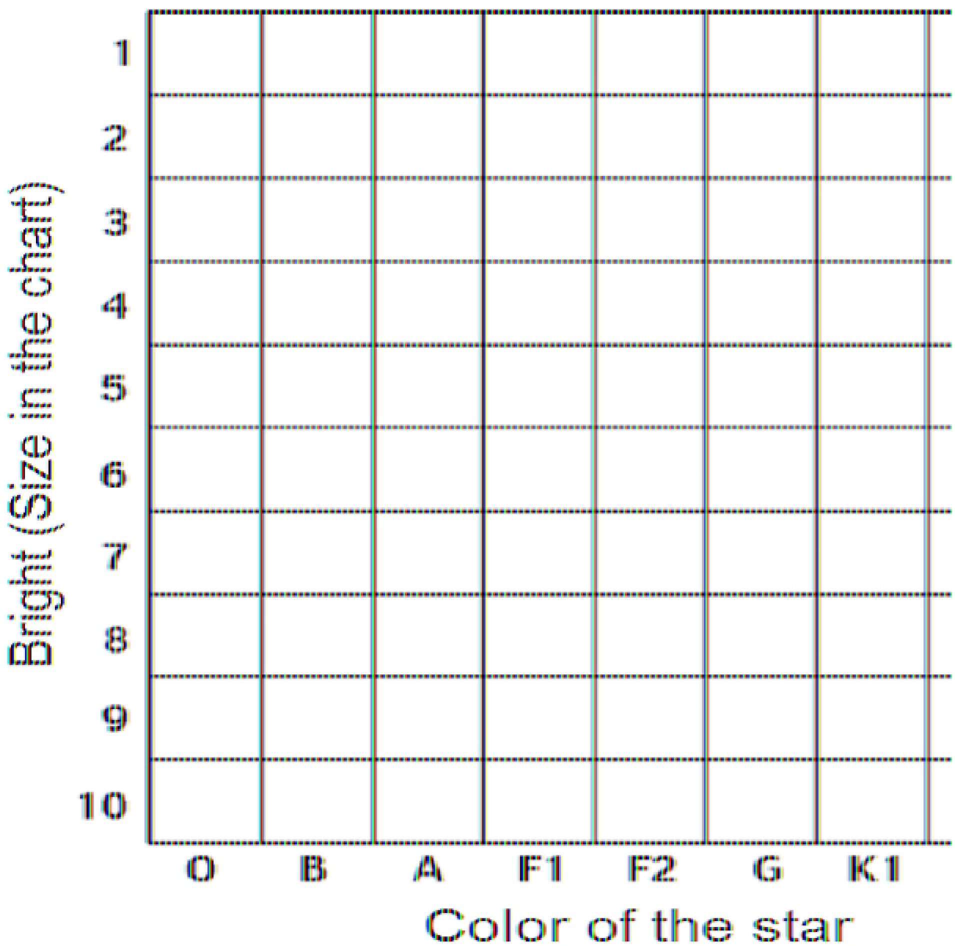

Fig. 11:Worksheet.

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.

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.

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.

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

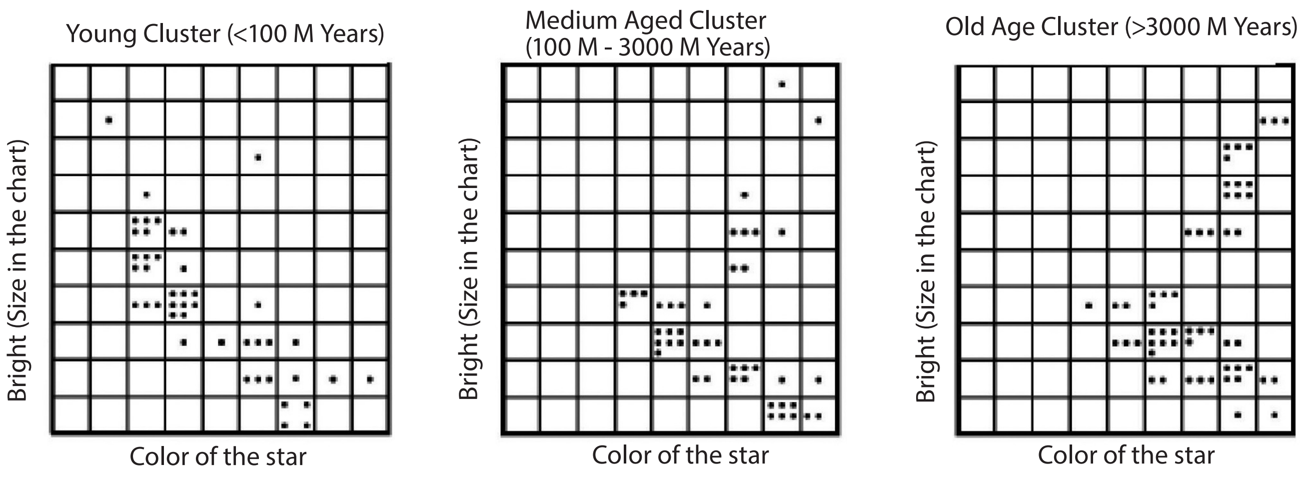

Fig. 12a, 12b and 12c: Reference cluster HR diagrams.

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?

Stellar death

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

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.

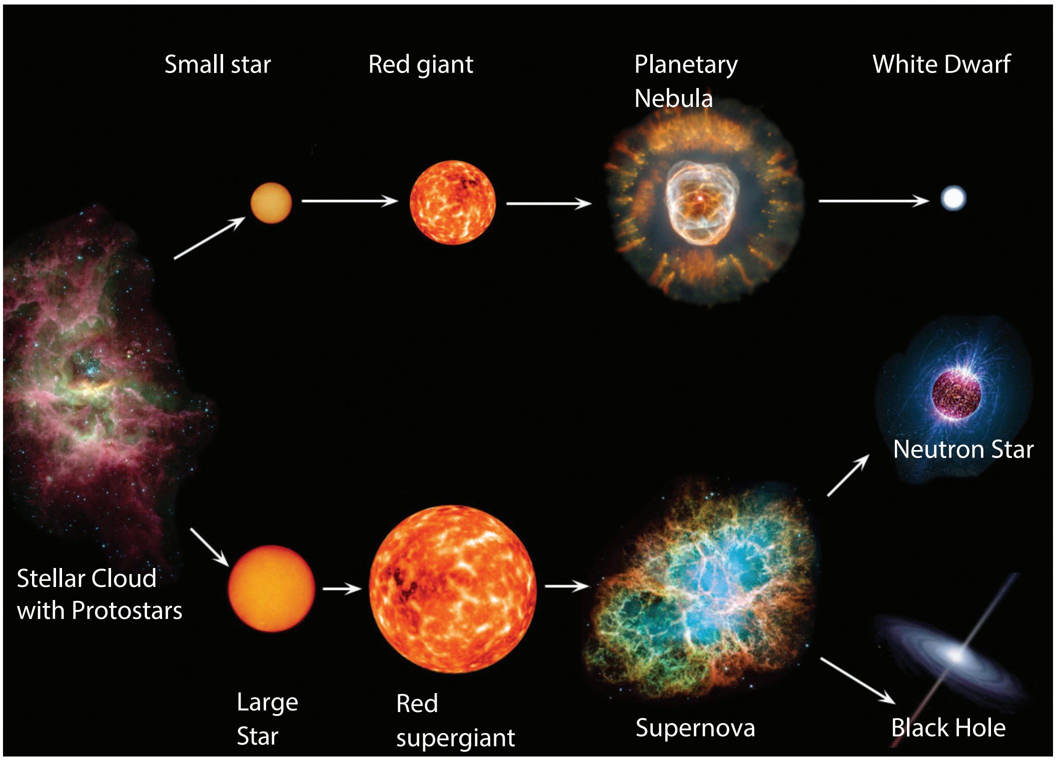

Fig 13: Evolution of stars according their masses.

Fig. 14a: Supernova remnant.

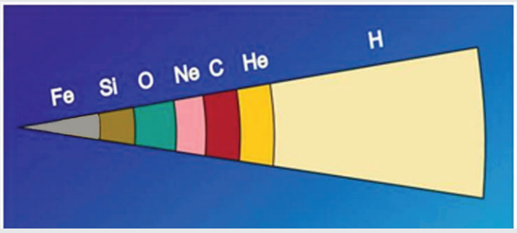

Fig. 14b: Structure of a star's interior just prior to the supernova explosion.

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:

0 million 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.

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 (Fig 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

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

(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.

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. This toy can be found at http://www.exploreco.es

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.

Fig. 16: A pulsar is a rotating neutron star.

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, Joceyln 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.

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.

Fig. 17a: Assembly.

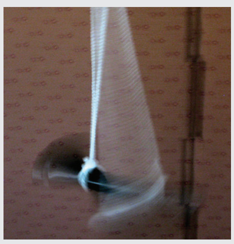

Fig. 17b: Spinning the flashlight.

Fig.17c: As it spins we observe the beam of light in a periodic way.

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.

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

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

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.

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 radiation 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 wave-

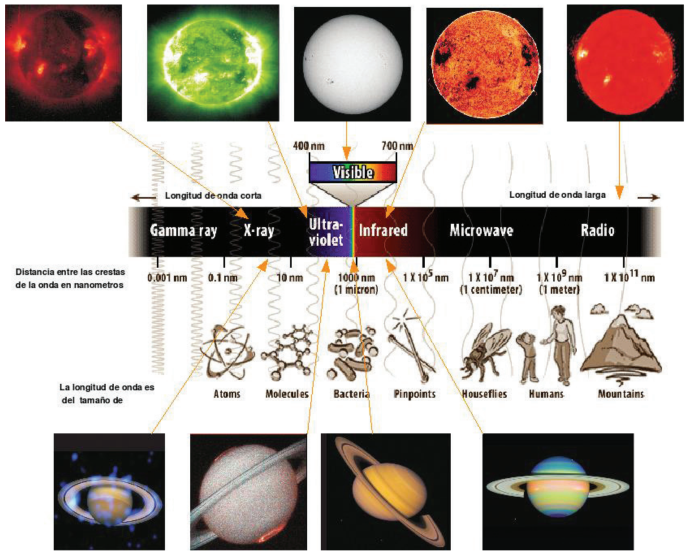


Fig. 1: Electromagnetic spectrum, with objects the size of these waves. The Sun (above) and Sat-urn (bottom) observed at different wavelengths (colors are simulated).

lengths 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 wave-lengths such as infrared, micro-waves and radio waves.

Observing the Universe in all regions of the elec-tromagnetic 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.

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.

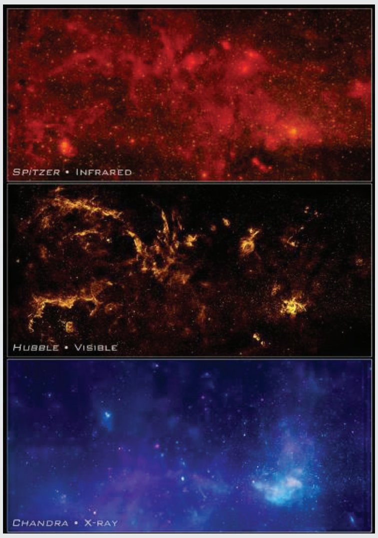


Fig. 2: The center of our Milky Way Galaxy imaged at different wavelengths.

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.

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 10). 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.

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).

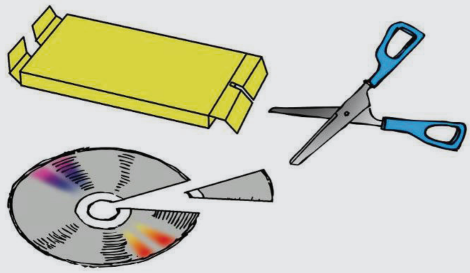


Fig. 3a: Material that you will need: DVD, scissors and paper box.

Fig. 3b: Removing the metal layer of the CD, with tape.

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

Fig. 4: Looking at a fluorescent lamp.

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.

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

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.

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.

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.

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.

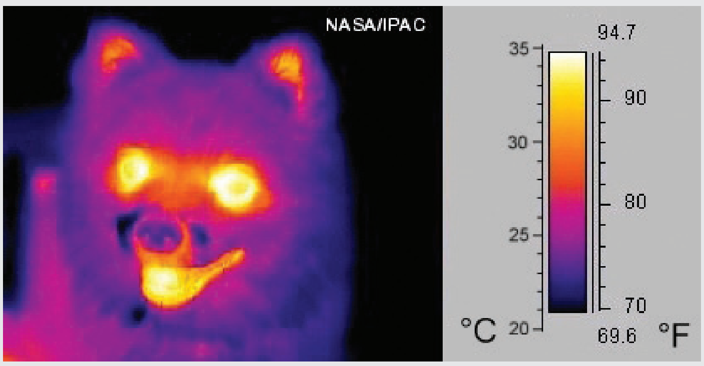


Fig. 7: Infrared image. We distinguish hotter to cooler areas.

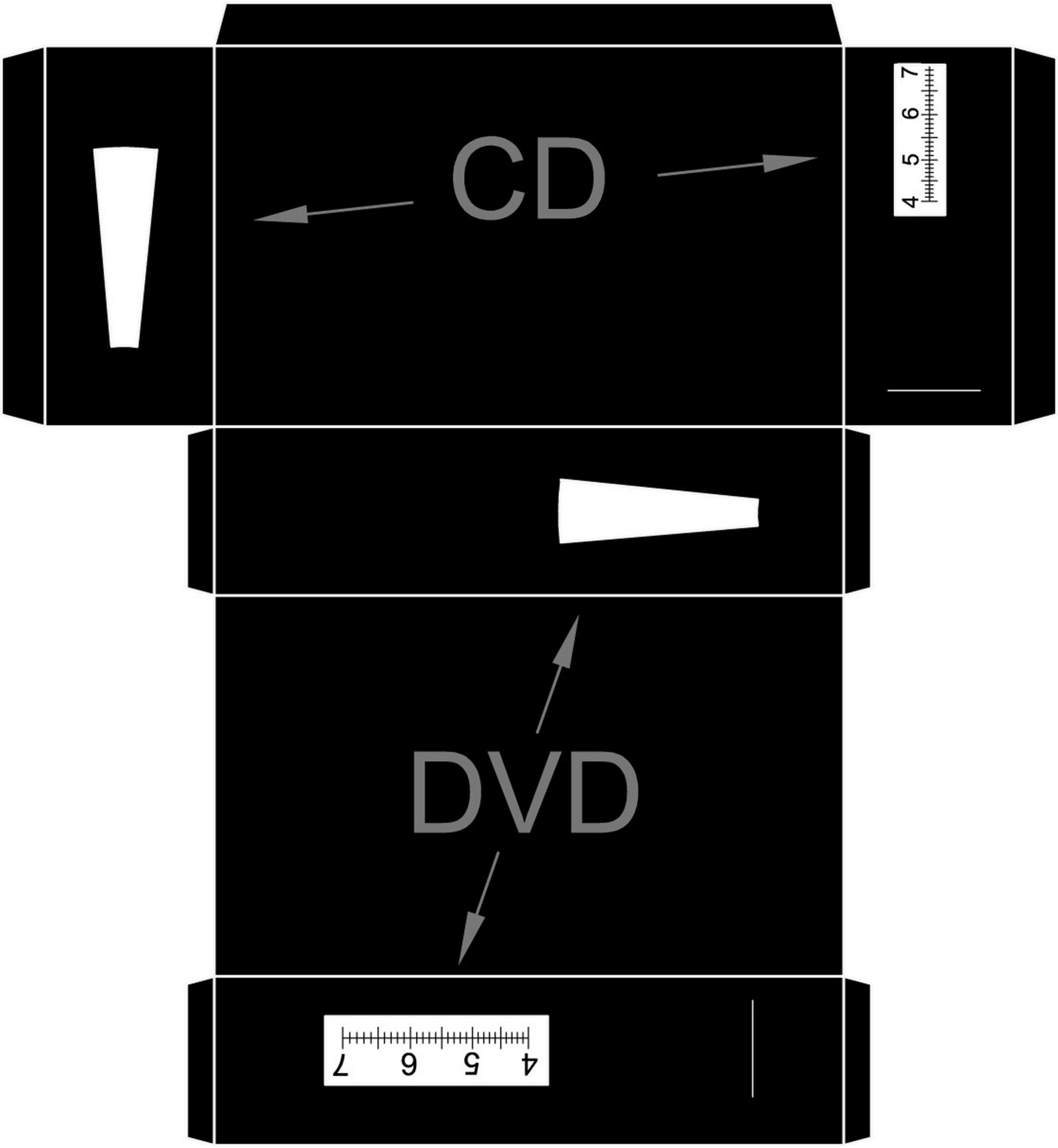


Fig. 5: Template for the spectrometer.

	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				
After 5 minutes				

Table 1: Table of the data.

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.

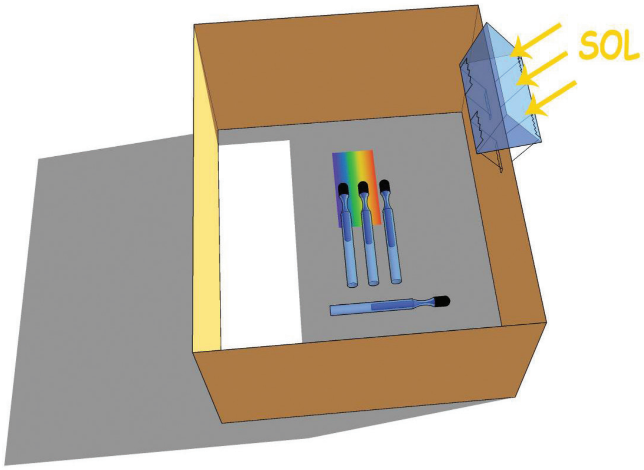


Fig. 8: Herschel device. The three thermometers in the spectrum mark higher temperature than the environment.

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.

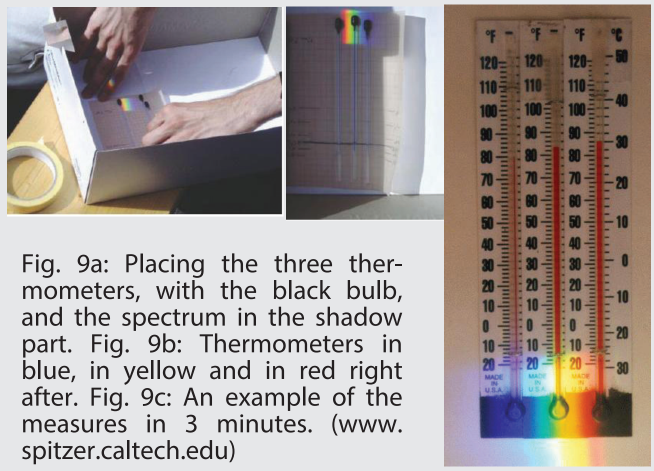


Fig. 9a: Placing the three thermometers, with the black bulb, and the spectrum in the shadow part. Fig. 9b: Thermometers in blue, in yellow and in red right after. Fig. 9c: An example of the measures in 3 minutes. (www.spitzer.caltech.edu)

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).

In the emissions from an incandescent filament bulb, most energy is emitted in the visible

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

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

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

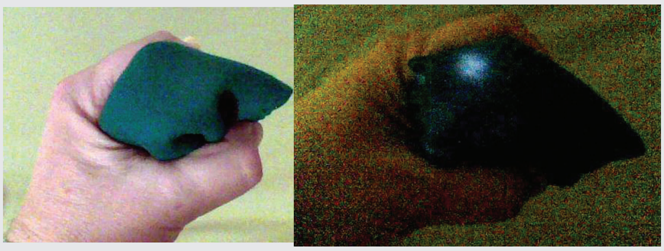


Fig. 12a and 12b: Felt completely blocks visible light but not infrared.

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).

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.
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.

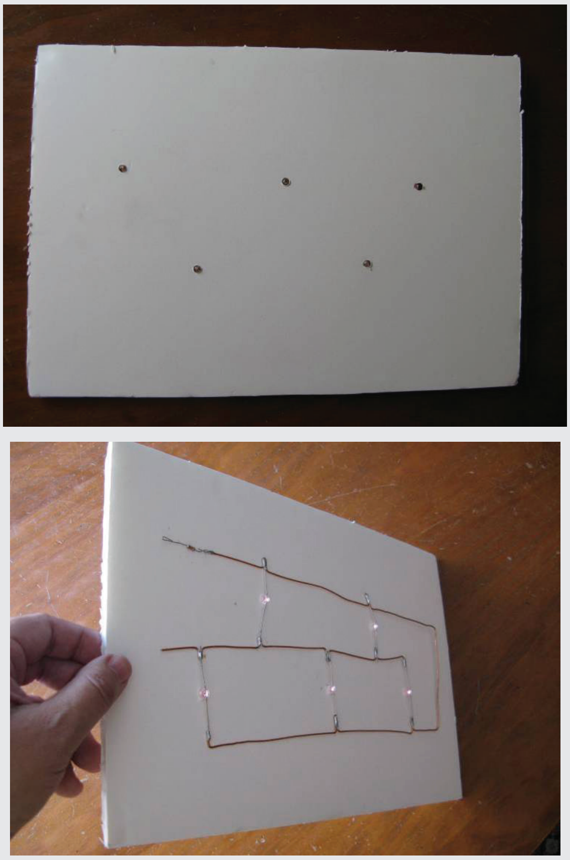


Fig. 13a and 13b: Casiopea made with infrared leds. They are connected in parallel .

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).

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. Thiese radiations show morphologies that other wavelengths do not (figures 15a, 15b and 15c).

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.

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

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 the 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).

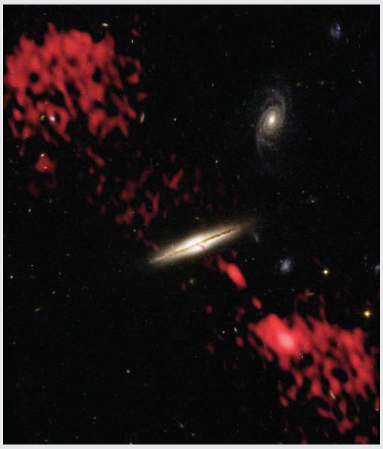
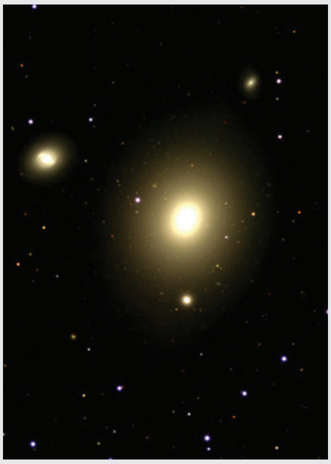


Fig. 15a: This galaxy emits jets only detectable in radio (artificially colored red).



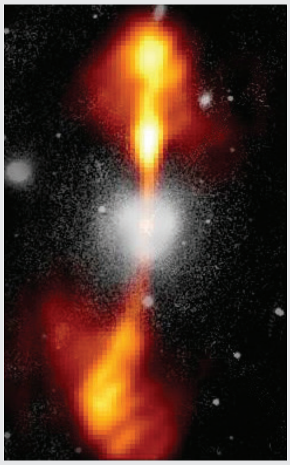


Fig. 15b: Photograph of the galaxy NGC 4261 in the visible. Fig. 15c: The same galaxy with the r-dio image superimposed. There are a few jets of matter artificially colored red.

Turn on the radio and put it in the AM band (not FM). We hit the ball of wire with the free end of the pencil. 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.

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.

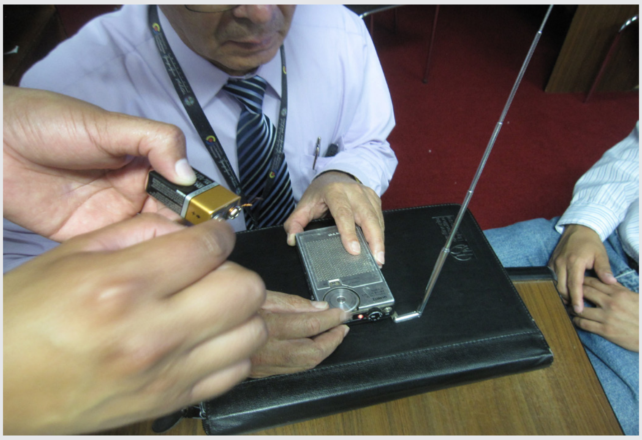


Fig. 16: Producing radio waves.

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.

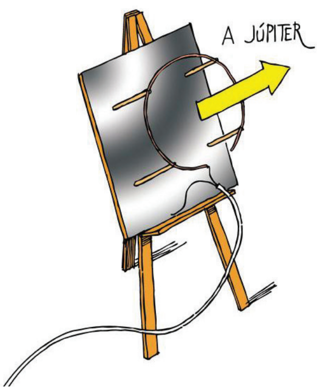


Fig. 17: Antenna to listen to Jupiter.

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.

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.

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.

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.

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).

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).

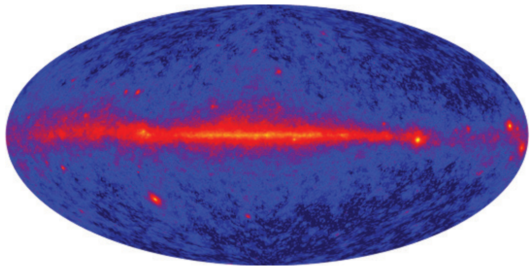


Fig. 21a: Map of the Universe as seen by the “Fermi Gamma-ray Space Telescope”. The center line is our galaxy.

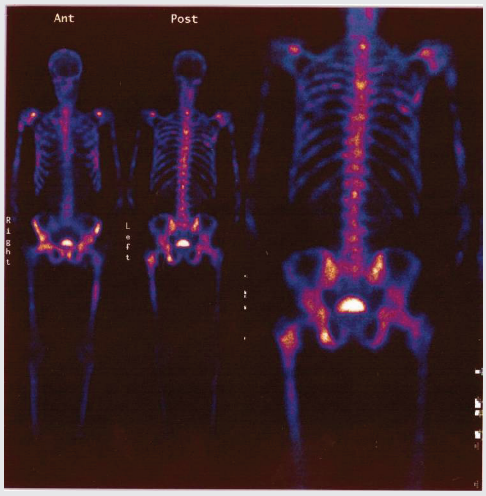


Fig. 21b: Bone scan with gamma of the human body.

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 ob-ject 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.

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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.
- Understand 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, eg. 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.

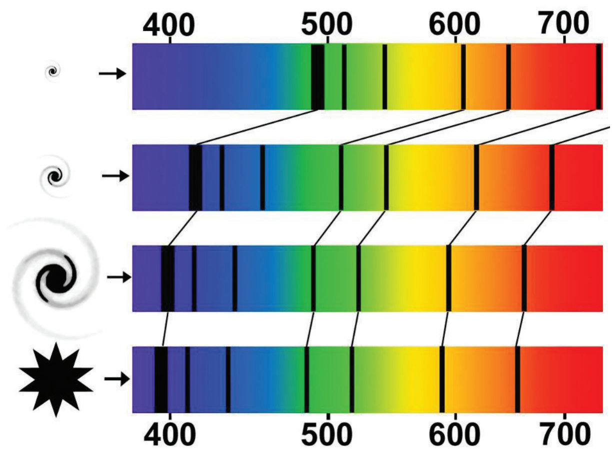


Fig.1: The farther the galaxy, the more the spectrum shifts towards red, which tells us that the galaxy is moving away from us faster.

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 Bernecies 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),

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.

we can hear it when it approaches the viewer: l is shortened and the sound is higher pitched. When it goes away from us, the l is stretched and the sound is more bass, or lower pitched. The one in the center of rotation does not experience it.

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 photon

The Universe, when it expands, "stretches" the photons in it. The longer the duration of the pho-

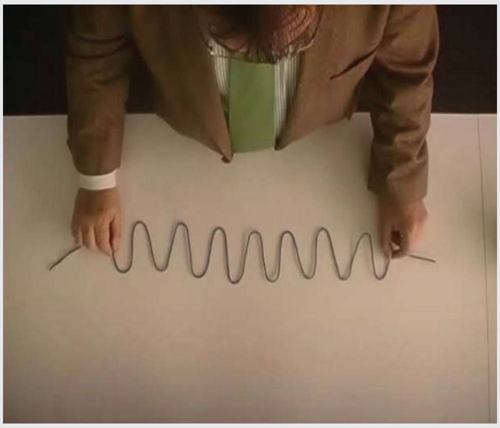


Fig. 3a: Made waves with rigid cable.

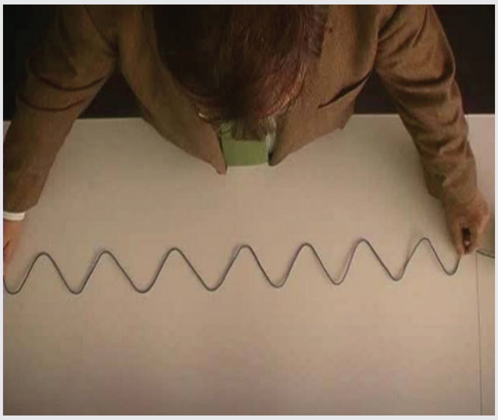


Fig. 3b: Same waves showing a longer wave-length.

ton 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).

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 (larger).

Hubble's Law

It was Edwin Hubble (figure 4) who, learning about 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:

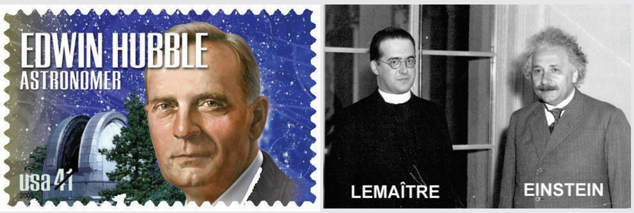


Fig. 4: Edwin Hubble. Fig. 5: George Lemaître and Albert Einstein

all light particles will be moved apart by the explosion of gunpowder.

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 Georges Lemaître (figure 5) established the most widely accepted model of the universe today:

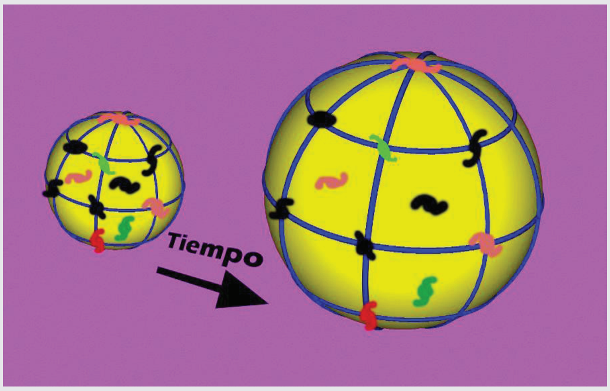


Fig. 6: As time passes, the space expand, and the material contained therein is separating from each other.

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.

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 re-

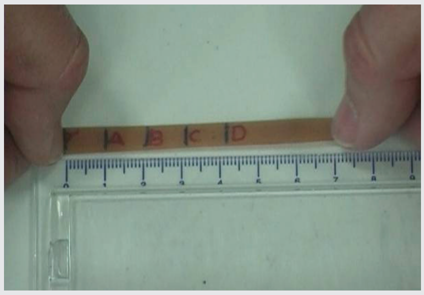


Fig. 7a: Rubber band without stretch.

Fig. 7b: Stretched rubber band.

ceding 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?

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

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.

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.

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:

$$H=v/d$$

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.

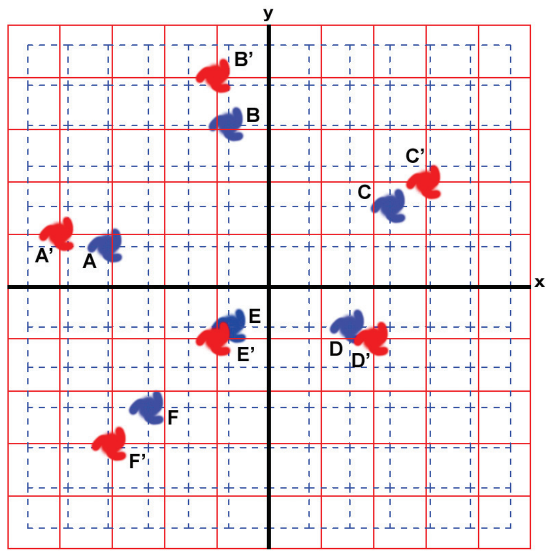


Fig 9: The grid of solid lines (red) is the same as the dashed one (blue) but expanded. The galaxies are attached to the grids.

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).

Galaxy	Coordinates x,y	d=distance to origin	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 to 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.

b) The value of H is fairly constant regardless of the galaxies.

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 and 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.

Activity 6: There is no center of expansion

On the next page is a drawing (figure 10) 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%).

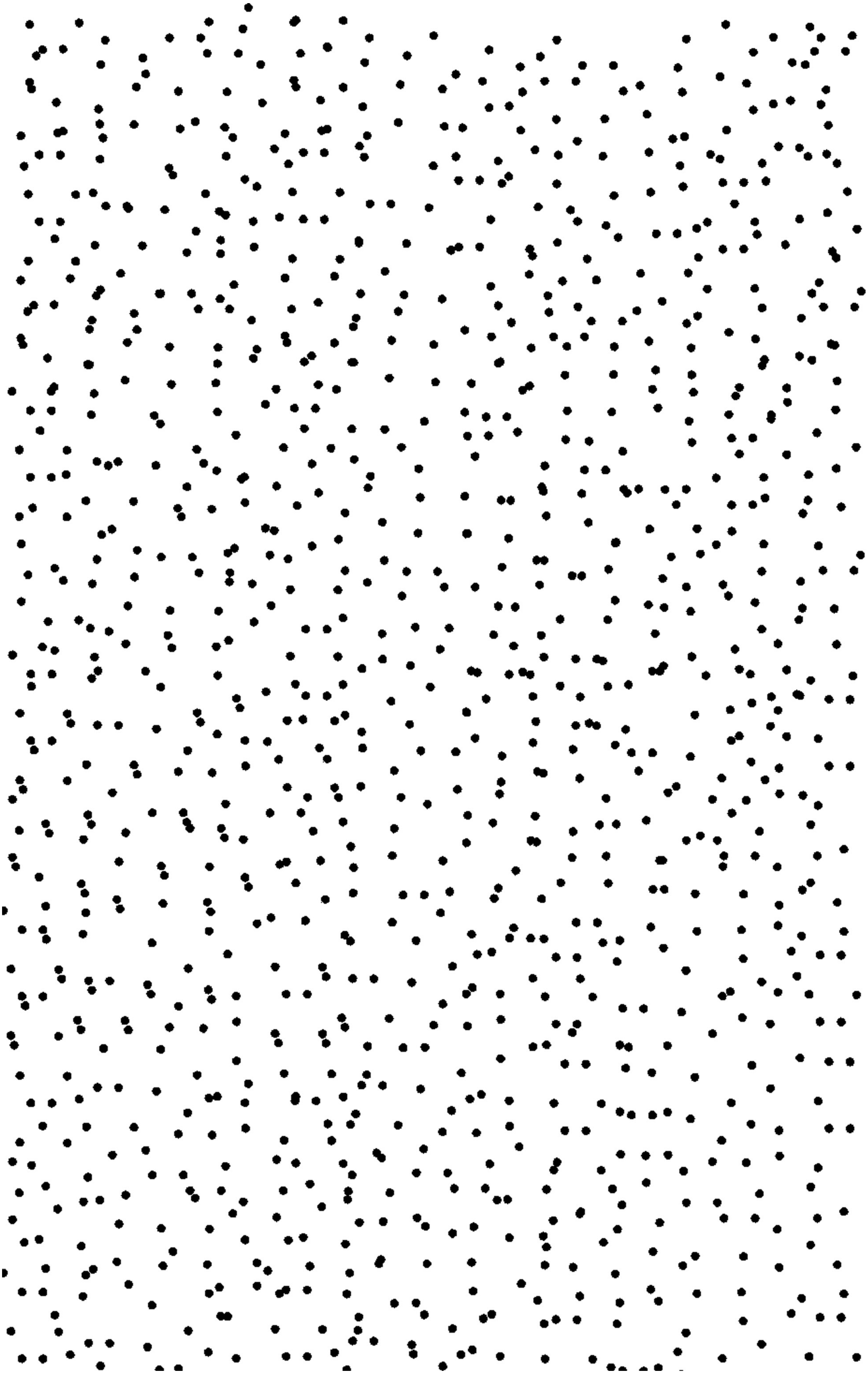


Fig. 10: Photocopy this page on a transparency and then another enlarged 105%.

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.

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).

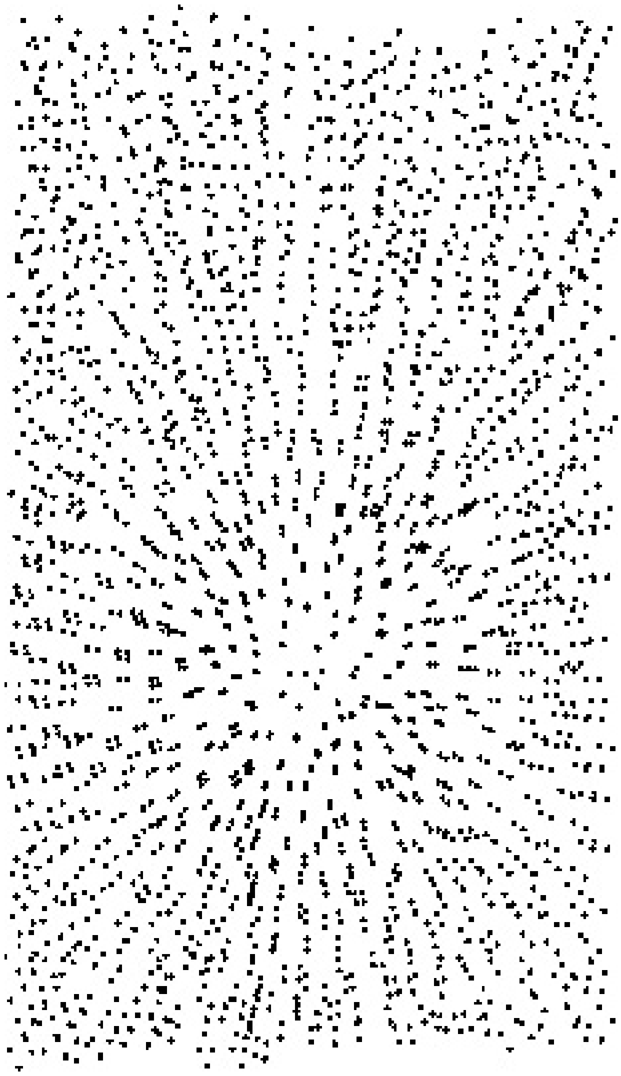


Fig. 11a: Superposition of two slides, one enlarged by 105%.

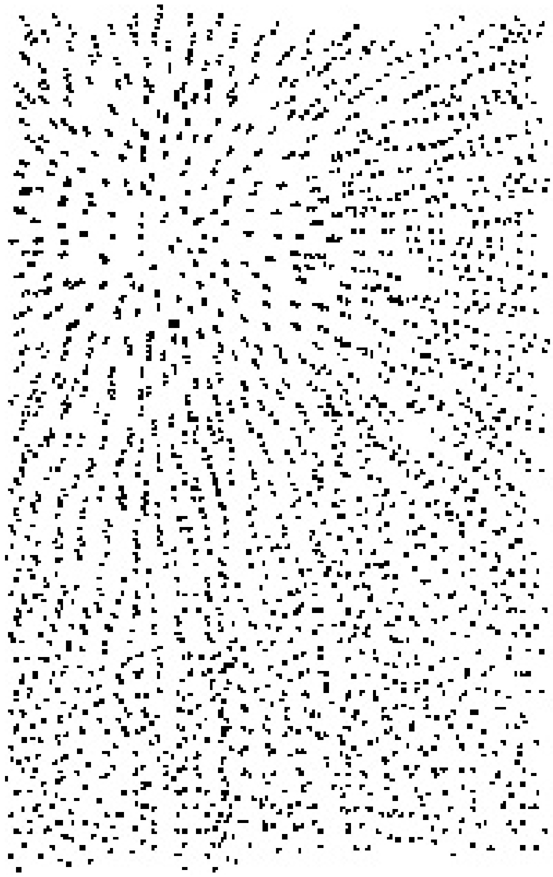


Fig. 11b: To an observer in another point, it also seems that everything moves away of him: there is no a center of the universe.

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.

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

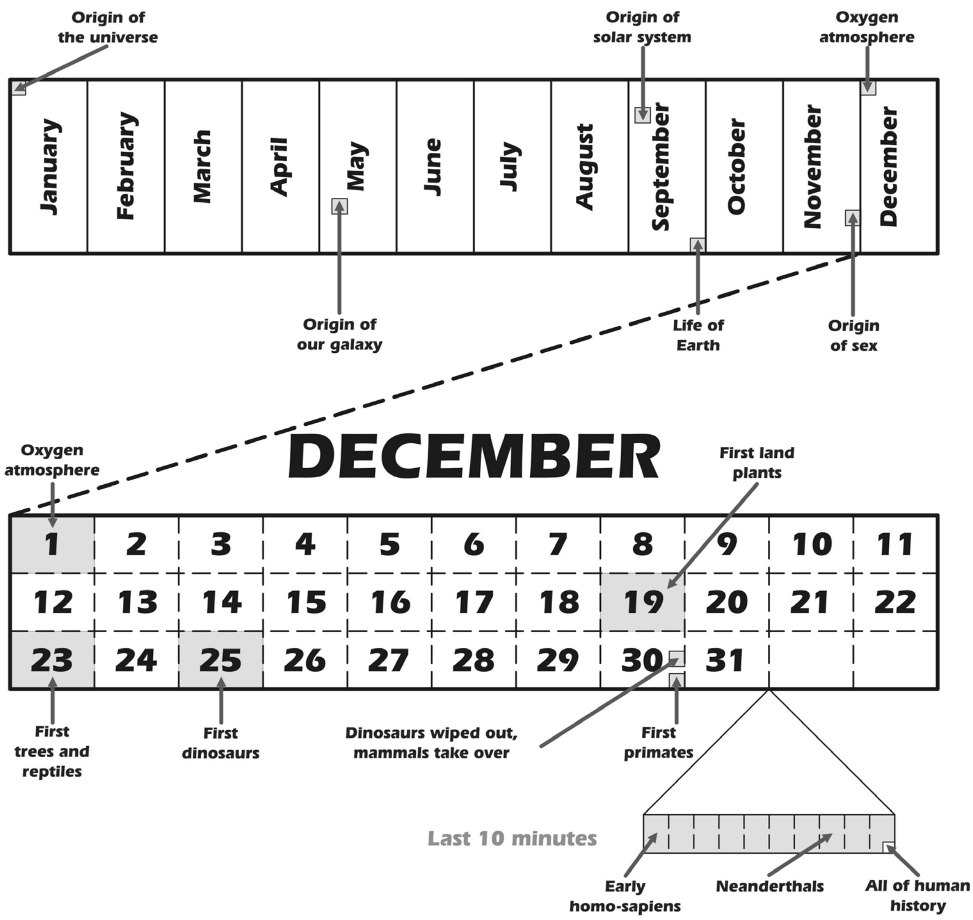


Fig.12: The history of the Universe compressed to one year.

The Cosmic Calendar - The history of the Universe compressed to one year. All of recorded history (human civilization) occurs in

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.

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

This background radiation was first detected in 1964 by Arno 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

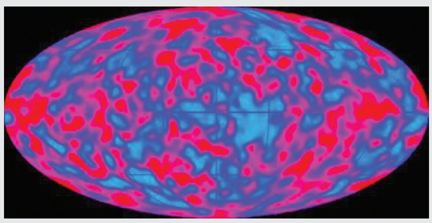


Fig. 14a: COBE image.

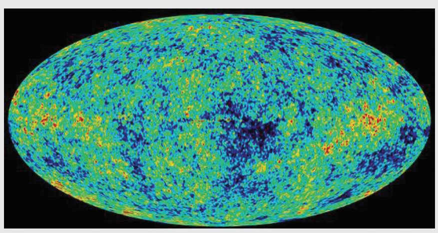


Fig. 14b: WMAP image.

with very little energy:it could only heat food 2.7 K.

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 (fi ure 14b).

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.

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

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 com-posed of a multitude of constantly changing points.

Fig. 16a: Johannes Kepler. Fig. 16b: Edmund Halley.

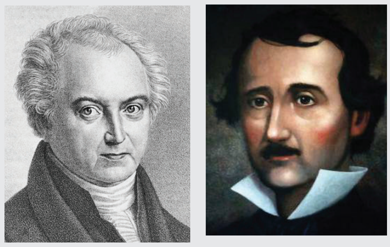


Fig. 16c: Heinrich Olbers. Fig. 16d: Edgar Allan Poe.

Approximately 10%, ie one in ten come from the background radiation of the universe.

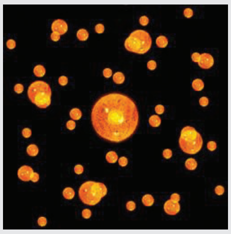
Why is it dark at night?

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.
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:

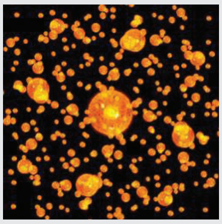
1 .- The universe is infinite in extent.
2 .- The stars are distributed more or less evenly throughout the Universe.
3 .- All the stars have a similar average brightness across the universe.

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.

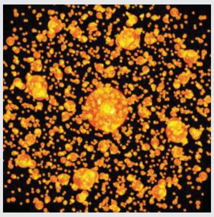
[1] In "Eureka", a scientific essay published in February 1848, he gave the following explanation for the "empty" dark between the observed stars: "We could comprehend the voids which our telescopes find in innumerable directions assuming that the distance from the invisible bottom is so immense that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



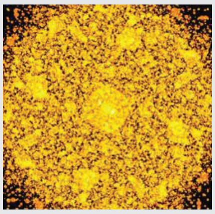
The light coming from nearby stars.



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.

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.

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 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.

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.

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. 18a and 18b: If the space is curved, the short-est path between two points is a curve.

Fig. 18c: The shortest path above the terrestrail surface is not a straight line.

Activity 8: Simulation of gravitational lens with a glass of wine

We can simulate a gravitational lens using a glass of wine. This allows you to "show" how matter can introduce distortions in the images observed.

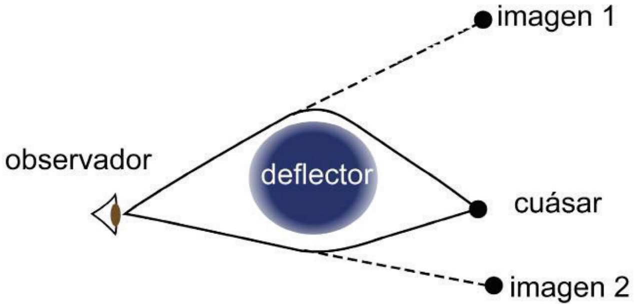


Fig. 19a: The observer sees two images, because it appears as though the light is coming from two different places.

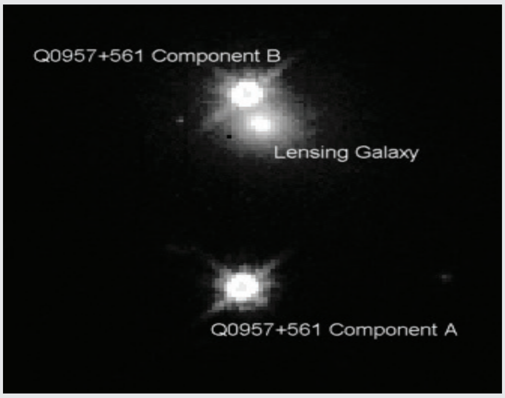


Fig. 19b: Picture of the double quasar Q0957 +561 image. The deflector is the galaxy close to the B component.

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).

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.

Looking at the ray of light, we move it from right to left and from top to bottom. We note that the light 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).

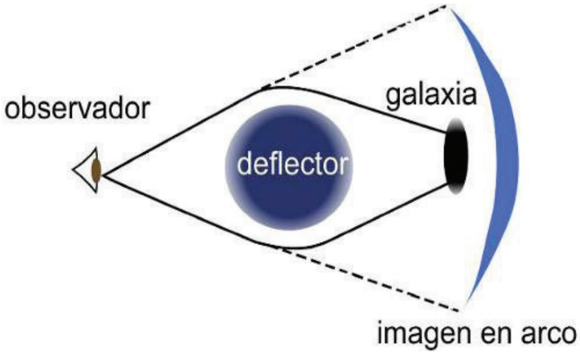


Fig. 20a: If the body diverted is an extended object, the images obtained are a set of bright arcs or a complete ring.

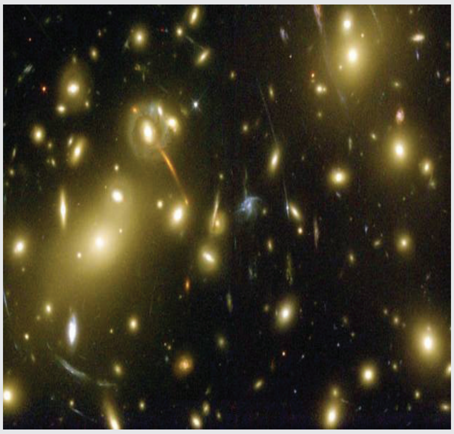


Fig. 20b: Giant luminous arcs formed by the galaxy cluster Abell 2218

Fig. 20c: Complete ring of a galaxy behind the deflector.

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

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

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).

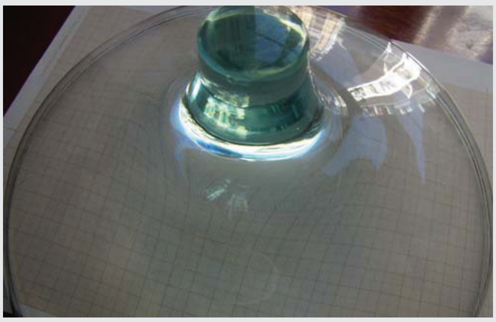


Fig. 23: Grid deformation.

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

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Planets and exoplanets

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Summary

This workshop provides a series of activities to compare the many observed properties (such as size, distances, orbital speeds and escape velocities) of the planets in our Solar System. Each section provides context to various planetary data tables by providing demonstrations or calculations to contrast the properties of the planets, giving the students a concrete sense for what the data mean. As a final activity, some properties of extrasolar planetary systems are explored and compared to the Solar system. At present, several methods are used to find exoplanets, more or less indirectly. It has been possible to detect almost 100 multiple planetary systems. A famous example is shown in figure 1.

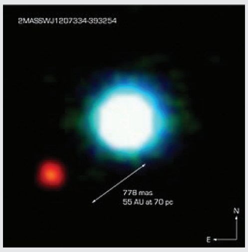


Fig. 1: The first planet directly observed 2M1207b in March 16th 2003. It has a mass 3.3 times the mass of Jupiter and orbits at 41 AU from the brown dwarf. In 2006, a disk of dust was found around the parent star, providing evidence that planet formation may proceed in a way similar to that observed around more massive solar-type stars. (Photo: ESO).

Goals

• Understand what the numerical values in the Solar Sytem summary data table mean.

• Deduce the orbital radii and orbital periods of the Galilean satellites of Jupiter using a set of photographic observations.

• Calculate Jupiter's mass using Kepler's third law.

• Understand the main characteristics of extrasolar planetary systems by comparing their properties to the orbital system of Jupiter and its Galilean satellites.

The Solar System

By creating scale models of the solar system, the students will compare the different planetary parameters. To perform these activities, we will use the data in Table 1.

Planets	Diameter (km)	Distance to Sun (km)
Sun	1,392,000	
Mercury	4,878	57.9 10^6
Venus	12,180	108.3 10^6
Earth	12,756	149.7 10^6
Mars	6,760	228.1 10^6
Jupiter	142,800	778.7 10^6
Saturn	120,000	1,430.1 10^6
Uranus	50,000	2,876.5 10^6
Neptune	49,000	4,506.6 10^6

Table 1: Data of the Solar System bodies.

In all cases, the main goal of the model is to make the data understandable. Millions of kilometers are not distances that are easily grasped. However, if translated to scaled distances and sizes, the students usually find them easier to comprehend.

Model of the Solar System

Models of diameters

Using a large piece (or multiple pieces if necessary) of yellow paper cut a circle representing the Sun. The Sun is scaled to be 139 cm in diameter such that 1 cm is 10 000 km. Cut the different planets out of plain cardboard or construction paper and draw their morphological characteristics. By placing the planets near the solar disk, students can grasp the different planetary scales.

With a scale of 1 cm per 10 000 km, use the following planetary diameters:

Sun 139 cm, Mercury 0.5 cm, Venus 1.2 cm, Earth 1.3 cm, Mars 0.7 cm, Jupiter 14.3 cm, Saturn 12.0 cm, Uranus 5.0 cm and Neptune 4.9 cm.

Suggestion: It is also possible to complete the previous model by painting the planets on a shirt, keeping the scale of the planets but only painting a fraction of the Sun.

Model of distances

By comparing the distances between the planets and the Sun we can produce another model that

Fig. 2a and 2b: xamples of shirts providing Solar and planetary diameter scale comparisons.

is easy to set up in any school hallway. First, simply cut strips of cardboard 10cm wide, linking them up to obtain a long strip of several meters (figure 3). Then, place the cutouts of the planets on it at their correct distances. Remind the students that the distance between the planets are not to scale with diameters. At the suggested scale, the planets would be one thousand times smaller as here we are using 1 cm per 10 000 000 km, while in the first activity above we used 1 cm per 10 000 km. If

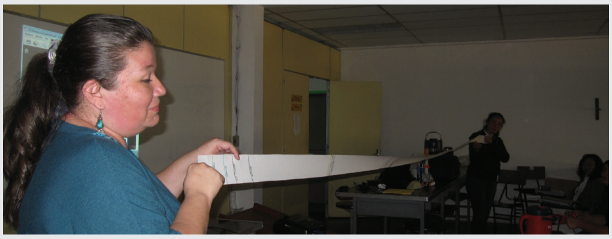


Fig. 3: Model of distances.

using a scale of 1cm per 10 million km the scaled distances are: Mercury 6 cm, Venus 11 cm, the Earth 15 cm, Mars 23 cm, Jupiter 78 cm, Saturn 143 cm, Uranus 288 cm and Neptune 450 cm.

Suggestion: A fun variation of this model is to use a toilet paper roll each sheet for scale. For example, you can take as scale a portion of paper for every 20 million km.

Model of diameters and distances

The next challenge is to combine the two above activities and make a model representing the bodies to scale, as well as the corresponding distances between them. It is not actually that easy to define a scale that allows us to represent the planets with objects that are not too small and still have distances that are not overly large, in which case the sizes and distances are not easily assimilated, and the model is not very useful for students. As a suggestion, it may be a good idea to use the schoolyard to make the model and use balls for the planets as balls of varying diameters are available as appropriate.

As an example, we provide a possible solution. At one end of the schoolyard we put a basketball about 25 cm in diameter that represents the Sun. Mercury will be the head of a needle (1 mm in diameter) located 10 m from the Sun. The head of a slightly larger needle (2 mm in diameter) will represent Venus at 19 m from the Sun, while Earth will be the head of another needle similar to the previous one (2 mm) at 27 m from the Sun. Mars is a slightly smaller needle head (1mm), located 41 m from the Sun. Usually, the schoolyard ends here, if not sooner. We will have to put the following planets in other places outside the schoolyard, but at landmarks near the school, so that the students are familiar with the distances. A ping-pong ball (2.5 cm diameter) corresponds to Jupiter at 140 m from the Sun. Another ping-pong ball (2 cm in diameter) will be Saturn at 250 m from the Sun, a glass marble (1 cm in diameter) will represent Uranus at 500 m from the Sun, and a final marble (1 cm), located at 800 m, will represent Neptune.

Fig. 4: The Sun and the planets of the model of diameters and distances.

It should be emphasized that this planetary system does not fit into any school. However, if we had reduced the distances, the planets would be smaller than the head of a needle and would be almost impossible to visualize. As a final task, you can calculate what scale has been used to develop this model.

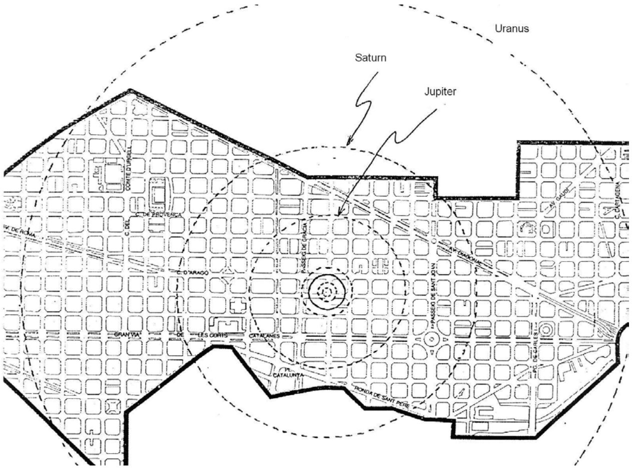


Fig. 5: Map of the "Ensanche de Barcelona" with some planets.

Model on a city map

The idea is simple - using a map of the city to locate the positions of the different planets, assuming the Sun is located at the entrance to the school. As an example, we present the map of Barcelona with different objects (specifically fruits and vegetables) that would be located on the different streets, so you can better imagine their size. As an exercise,

Fig. 6a and 6b: Snapshots of the city of Metz.

we suggest that you do the same activity with your own city.

Using the map shown here, Mercury would be a grain of caviar, Venus and the Earth a couple of peas, Mars a peppercorn, Jupiter an orange, Saturn a tangerine and Uranus and Neptune a pair of walnuts. For the Sun, since there is no vegetable large enough, students should imagine a sphere roughly the size of a dishwasher. The instructor can do the same activity using their own city.

In the city of Metz (France) there is a solar system spread out on its streets and squares, with corresponding planets accompanied by information panels for those walking by.

Models of light distances

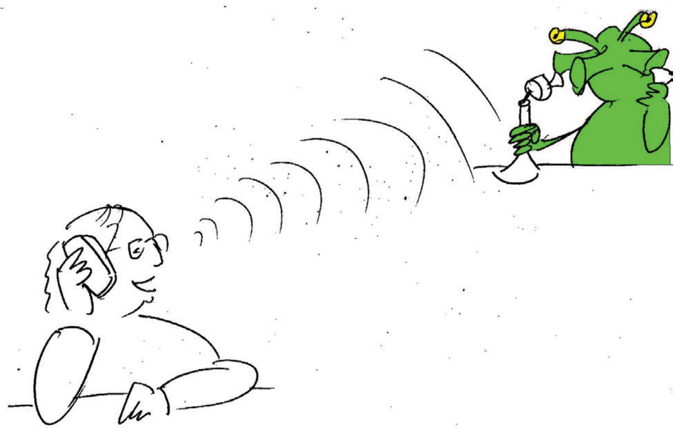


Fig. 7: Another example.

In astronomy it is common to use the light year as a unit of measurement, which can often be confused as a measurement of time. This concept can be illustrated using a model of the Solar System. Since the speed of light is c = 300,000 km/s., the distance that corresponds to 1 second is 300,000 km. For example, to travel from the Moon to the Earth, which are separated by a distance of 384,000 km, it takes light 384,000/300,000 = 1.3 seconds.

$$\frac{384{,}000}{300{,}000} = 1.3 \text{ seconds}$$

Using these units, we will instruct the students to calculate the time required for sunlight to reach each of the planets of the Solar System. (For the instructor, here are the times required: the time it takes sunlight to reach Mercury is 3.3 minutes to Venus it takes 6.0 minutes, to Earth 8.3 minutes, to Mars 12.7 minutes, to Jupiter 43.2 minutes, to Sat-urn 1.32 hours, to Uranus 2.66 hours and to Neptune, 4.16 hours. You may want to ask the students to imagine what a video conference between the Sun and any of the planets would be like.

We introduce here also the distance to the nearest star because it is very useful to visualize the enormous distances to other stars, which is the reason why it is so difficult to detect extrasolar planets. The closest to us is Alpha Cetauri at a disctance of 4.37 light years or 4.13 1013 km. You may ask the students to calculate the distance to this star in any of the planet system models that were previously mentio-ned. In the "school yard model", with a scale 1 cm per 56000 km, the star would be at a distance of 7375 km!

Model of the apparent size of the solar disk from each planet

From a planet, for example the Earth, the Sun subtends an angle α (figure 8). For very small values of α, we take tan α≈α (in radians)

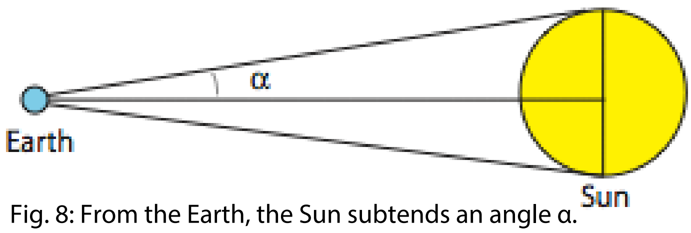


Fig. 8: From the Earth, the Sun subtends an angle α.

Knowing that the solar diameter is 1.4×10^6 km, i.e. a radius of 0.7×10^6 km, and that the Earth-Sun is 150×10^6 km, we deduce:

$$\alpha = \tan\alpha = \frac{0.7 \cdot 10^6}{150 \cdot 10^6} = 0.0045 \text{ radians}$$

And in degrees: $$\frac{0.0045\ 180}{\pi} = 0.255^{\circ}$$

That is, from the Earth, the Sun has a size of 2 x 0.255º=0.51°, i.e., about half a degree. Repeating the same process for each planet, we get the Sun-sizes in Table 2 and we can represent the Sun's relative sizes (figure 9).

Planets	tan α	α (º)	α (º)aprox
Mercury	0.024	1.383	1.4
Venus	0.0129	0.743	0.7
Mars	0.006	0.352	0.4
Jupiter	0.0018	0.1031	0.1
Saturn	0.000979	0.057	0.06
Uranus	0.00048	0.02786	0.03
Neptune	0.0003	0.0178	0.02

Table 2: Results for the different planets.

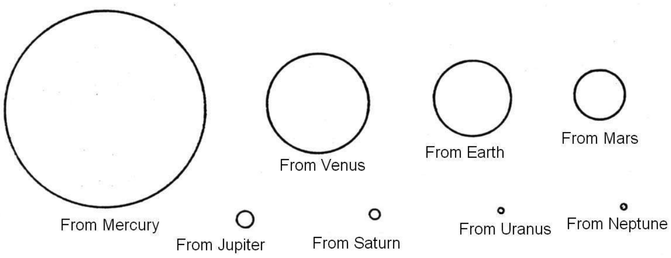


Fig. 9: The Sun seen from each planet: Mercury, Venus, The Earth, Mars, Jupiter, Saturn, Uranus and Neptune.

Model of densities

The objective of this model is to look for samples of materials that are easily manipulated and have a density similar to each of the solar system bodies, in order to be able to "feel it in our hands."

Planets	Density (g/cm^3)
Sun	1.41
Mercury	5.41
Venus	5.25
Earth	5.52
Moon	3.33
Mars	3.9
Jupiter	1.33
Saturn	0.71
Uranus	1.3
Neptune	1.7

Table 3: Densities of the bodies in the Solar System.

Fig. 10: Model of densities.

Minerals	Density	Other materials	Density
Plaster	2.3	Glycerin	1.3
Orthoclase	2.6	Cork	0.24
Sulfur	1.1-2.2	Aluminium	2.7
Alite	2	Iron	7.86
quartz	2.65	Cement	2.7 - 3.1
Borax	1.7	Glass	2.4 - 2.8
Blende	4	Tin	7.3
Pyrite	5.2	Clay	1.8 - 2.5
Erythro-cytes	5.4	Bakelite	1.25
Calcite	2.7	Oak	0.90
Galena	7.5	Pinewood	0.55

Table 4: Examples of densities of some materials

From Table 3 of planetary densities, simply compare with the densities of various minerals (in every school there is usually a collection of materials) or with samples of other materials that are easy to find such as glass, ceramics, wood, plastics, etc.. The following Table 4 presents some examples of materials and their densities.

When using materials not included in Table 4, it is very easy to calculate its density. Simply take a portion of this material, weigh it to find its mass, m, and put it in a container of water to measure its volume, V. The density d of the material will be,

$$d = \frac{m}{V}$$

Students should notice that Saturn would “float” in water, because its density is less than 1.

Flattening model of planets

To visualize the deformation (flattening) of gas planets due to the centrifugal force generated by their rotation, we will build a simple model.

Fig. 11: Model to simulate flattening due to rotation.

As we can see in figure 9, with a stick and some cardboard strips, we can build this simple model that reproduces the flattening of Solar System planets due to rotation.

1. Cut some cardboard strips 35 per 1 cm in size.
2. Attach both ends of the strips of cardboard to a 50 cm-long cylindrical stick. Attach the top ends to the stick so that they cannot move, but allow the bottom ends to move freely along the stick.
3. Make the stick turn by placing it between two hands, then rotating it quickly in one direction and then the other. You will see how the centrifugal force deforms the cardboard bands (figure 11) in the same way it acts on the planets.

Model about planetary orbital periods

Planets orbit the Sun with different speeds and orbital periods (table 5). Known the period and the average distance from the Sun can be deduced the mean orbital velocity of the planet to explore its orbit. See for example the case of Earth, but you can repeat the same reasoning to any other planet.

Fig. 12a, 12b and 12c: Simulating the circular movement of planets.

The length of an orbital revolution is $L = 2\pi R$, so the average orbital velocity is $v = L / T = 2\pi R / T$.

Planet	Orbital period (days)	Distance from the Sun (km)	Orbital average speed (km/s)	Orbital average speed (km/h)
Mercury	87.97	57.9 10^6	47.90	172440
Venus	224.70	108.3 10^6	35.02	126072
Earth	365.26	149.7 10^6	29.78	107208
Mars	686.97	228.1 10^6	24.08	86688
Jupiter	4331.57	778.7 10^6	13.07	47052
Saturn	10759.22	1 430.1 10^6	9.69	34884
Uranus	30.799.10	2 876.5 10^6	6.81	24876
Neptune	60190.00	4 506.6 10^6	5.43	19558

Table 5: Orbital data of the Solar System bodies

For Earth, the period is 365 days, then v = 2,582,750 km / day = 107,740 km / h = 29.9km / s, where the distance from Earth to the Sun R = 150 106 km. We emphasize that the Sun also revolves around the galactic center with a speed of 220 km / s, or what is the same about 800,000 km / h.

The fastest is Mercury, the closest to the Sun, and the slowest is Neptune, the most distant one. Romans had already noticed that Mercury was the fastest of all and so it was identified as the messenger of the gods and represented with winged feet. An orbital period or a 'year' on Mercury lasts only 88 days. Even if observing with the naked eye, over several weeks it is possible to tell that Jupiter and Saturn move much more slowly across the zodiacal constellations than do Venus and Mars, for example.

There is also a simple way to experience the relationship between distance and orbital period.

We begin by tying a heavy object, such as a nut, onto a piece of string. Holding the string from the end opposite the heavy object, we spin the object in a circular motion above our heads. We can then see that if we release string as we spin it (making the string longer), the object takes longer to complete an orbital period. Conversely, if we take in string (making it shorter), it takes less time.

We can then develop a solar system model with nuts and bits of string proportional in length to the radii of the planetary orbits (assuming, again, that they all travel in circular orbits). However, instead of cutting a separate piece for each planet, cut all pieces to a length of about 20 cm. Then, using the appropriate scaling, measure the correct distance from the heavy object and make a knot at this point. Then, the string can be held at the location of the knot while spinning the heavy object.

To use the model we must hold one of the strings at the location of the knot and turn it over our heads in a plane parallel to the ground with the minimum speed possible speed that will keep it in orbit. We will see that this velocity is greater in cases where the radius is smaller.

Model of surface gravities

The formula for gravitational force,

$$F = G \cdot \frac{M \cdot m}{d^2}$$

allows us to calculate the surface gravity that acts on the surface of any planet. Considering a unit mass (m = 1) on the planet's surface (d = R), we obtain the surface gravity

$$g = \frac{G \cdot M}{R^2}$$

where $G = 6.67 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$ is the universal gravitational constant. If we then substitute the planet mass by $M = 4/3\ \pi\ R^3\ \rho$, where ρ is the planet's density and R its radius, we find:

$$g = 4/3\, \pi \cdot G \cdot \rho \cdot R$$

Substituting these last two variables for the values listed in table 6 (after converting the radius to meters and the density to kg/m3, with 1000 kg/m3 = 1 g/cm3), we can calculate the value of the surface gravity g for all planets.

Let's see a couple of examples:

$$g_{mercury} = 4/3\, \pi\, G\, .\ 2439 \times 10^3\ m\ \ .\ 5400\ kg/m^3 = $$
$$= 3.7\ m/s^2,$$

$$g_{venus} = 4/3\, \pi\, G\, .\ 6052 \times 10^3\ m\ \ .\ 5300\ kg/m^3 =$$
$$= 8.9\ m/s^2$$

Similarly, we can calculate g for the rest of the planets. As in table 7, surface gravities are often

Planet	R equatorial radius (km)	ρ density (g/cm^3)	g surface gravity ($m \cdot s^{-2}$)
Moon	1738	3.3	1.62
Mercury	2439	5.4	3.70
Venus	6052	5.3	8.87
Earth	6378	5.5	9.81
Mars	3397	3.9	3.71
Jupiter	71492	1.3	24.8
Saturn	60268	0.7	8.96
Uranus	25559	1.2	8.69
Neptune	25269	1.7	11.00

Table 6: Size, density and surface gravity of Solar System bodies.

given relative to the Earth's, and indicated by the tter g.

Model of bathroom scales

In this case, the goal of the model is to develop a set of 9 bathroom scales (8 planets and the Moon) so that students can simulate weighing themselves on each of the planets and the moon.

Since the process is the same for each planet, we will only describe one of them. The idea, essentially, is to open up a bathroom scale and repla-ce the disk labeled with weights with another with weights calibrated for a particular planet.

1. First, we open the scale. In most scales, there are two springs that secure the base. Remember that we have to put it back together again (figures 13a and 13b).

2. Once open, the weight disk should be removed, either to be replaced, or drawn over with the appropriate planetary weights.

3In the following table we have surface gravities ofthe moon and various planets of the Solar System. In one column, they are listed in absolute values (m s-2), and in the other in relative values with respect to terrestrial gravity.

	g surface gravity ($m \cdot s^{-2}$)	*g* surface gravity (relative to Earth)
Moon	1.62	0.16
Mercury	3.70	0.37
Venus	8.87	0.86
Earth	9.81	1.00
Mars	3.71	0.38
Jupiter	24.79	2.53
Saturn	8.96	0.91
Uranus	8.69	0.88
Neptune	11.00	1.12

Table 7: Absolute and relative surface gravities for Solar System bodies.

Fig. 13a and 13b: Bathroom scale with the replaced disk.

These values are the ones we will use to convert units of "terres-trial" weight to proportional units of weight on other planets.

4. Finally, we close the scale again, and can now see what we would weigh on one of the planets.

Fig. 14: Solar System model with bathroom scales.

Models of craters

Most craters in the solar system are not volcanic but are the result falling meteoroids onto the surfaces of planets and satellites.

1. First, cover the floor with old newspapers, so that it doesn't get dirty.

2. Put a 2-3 cm layer of flour in a tray, distributing it with a strainer/sifter so that the surface is very smooth.

3. Put a layer of a few millimeters of cocoa powder above the flour with the help of a strainer/sifter (figure 15a).

4. From a height of about 2 meters, drop a projectile: a tablespoon of cocoa powder. The fall leaves marks similar to those of impact craters (figure 15b).

Fig. 15a: Simulating craters. Fig. 15b: Resulting craters.

5. You may want to experiment with varying the height, type, shape, mass, etc. of the projectiles. In some cases, you can get even get a crater with a central peak.

Model of escape velocities

If the launch speed of a rocket is not very large, the gravitational force of the planet itself makes the rocket fall back on its surface. If the launch speed is large enough, the rocket escapes from the planet's gravitational field. Let's calculate the speed above which a rocket can escape, ie the minimum launch speed or escape velocity.

Considering the formulas of uniformly accelerated motion,

$$e = \tfrac{1}{2} at^2 + v_0 t$$
$$v = at + v_0$$

if we replace the acceleration by g and we consider the initial velocity v_0 to be zero, we find that on the planet's surface, $R = \tfrac{1}{2} gt^2$ and, moreover, $v = gt$. After removing the time variable, we find,

$$v = \sqrt{2gR}$$

where we can replace the values g and R by the values that are listed in the next table to calculate the escape velocity for each planet.

As an example, we calculate the escape velocities of some planets. For example:

For the Earth,

$v_{earth} = \sqrt{2 \cdot g \cdot R} = (2\ 9.81\ 6378)^{1/2}$ km/s.

For the smallest planet, Mercury,

$v_{mercury} = (2\ 9.81\ 0.378\ 2439)^{1/2} = 4.2$ km/s

And for the greatest planet, Jupiter,

$v_{jupiter} = (2\ 9.81\ 0.378\ 2439)^{1/2} = 60.9$ km/s

It is clear that it is easier to launch a rocket from Mercury than from the Earth, but it is most difficult to launch a rocket on Jupiter, where the escape velocity is about 60 km/s.

(To be able to compare the results, the accepted escape velocity for each body in the Solar System are the following: Mercury 4.3 km/s, Venus 10.3 km/s, Earth 11.2 km/s, Mars 5.0 km/s, Jupiter 59.5 km/s, Saturn 35.6 km/s, Uranus 21.2 km/s, Neptune 23.6 km/s. As we can see, our simple calculations give us acceptable results.)

Model of a rocket with an effervescent tablet

As an example of a rocket that can be launched safely in the classroom, we propose the following rocket, which uses an effervescent aspirin tablet as a propellant. We begin by cutting out the rocket model on the solid lines, and pasting on the dotted lines like in the photo.

Fig. 16a, 16b, 16c and 16d: The process in four pictures.

We will use a plastic capsule, such as a film canister, making sure that the capsule can fit inside the cylinder of the rocket. Then, we put the three triangles as supports on the body of the rocket and finally,

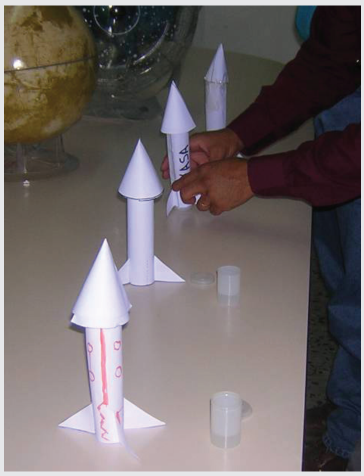


Fig. 17: Some rockets.

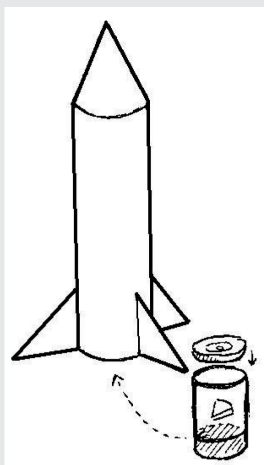


Fig. 18: Simplified scheme.

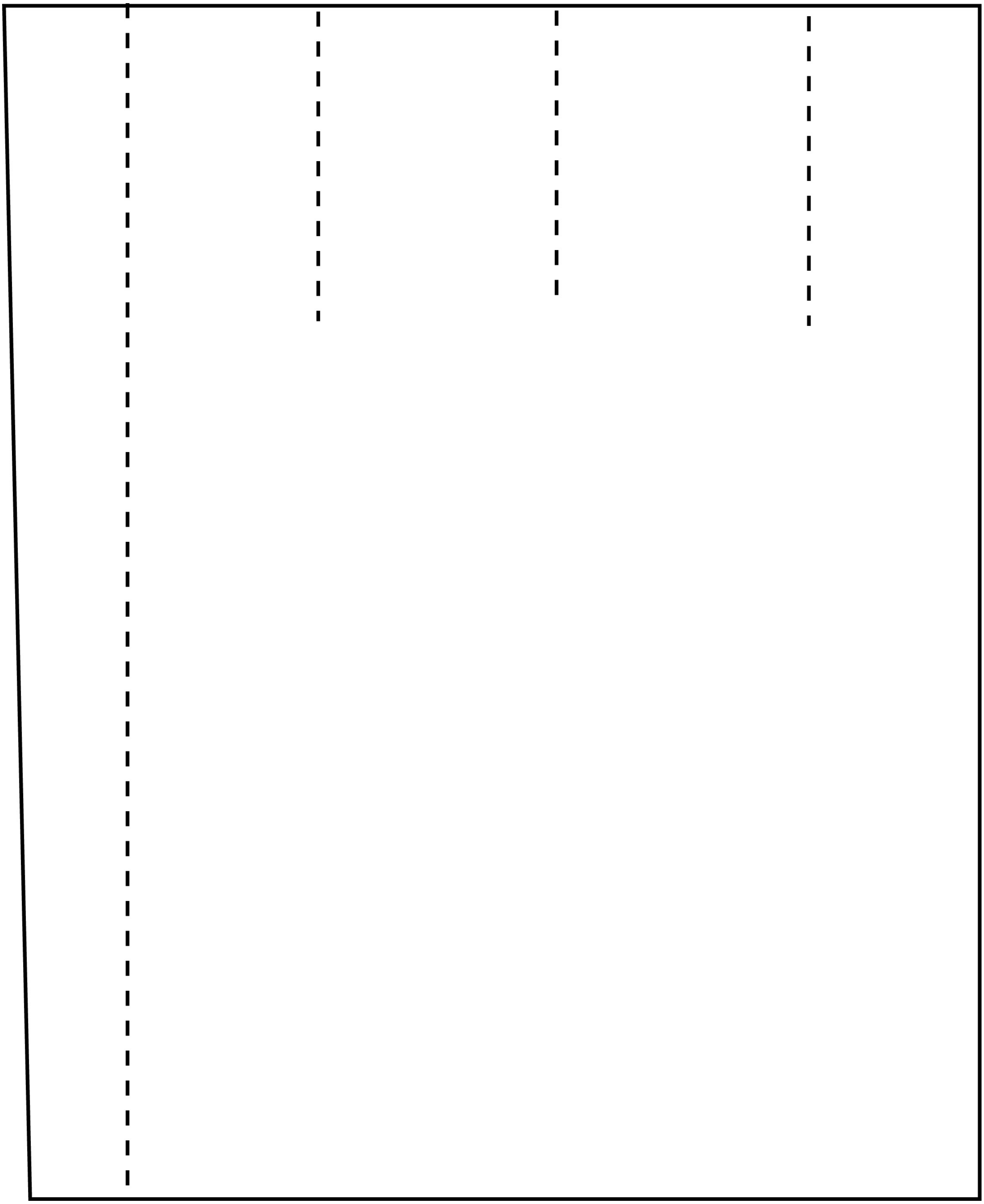
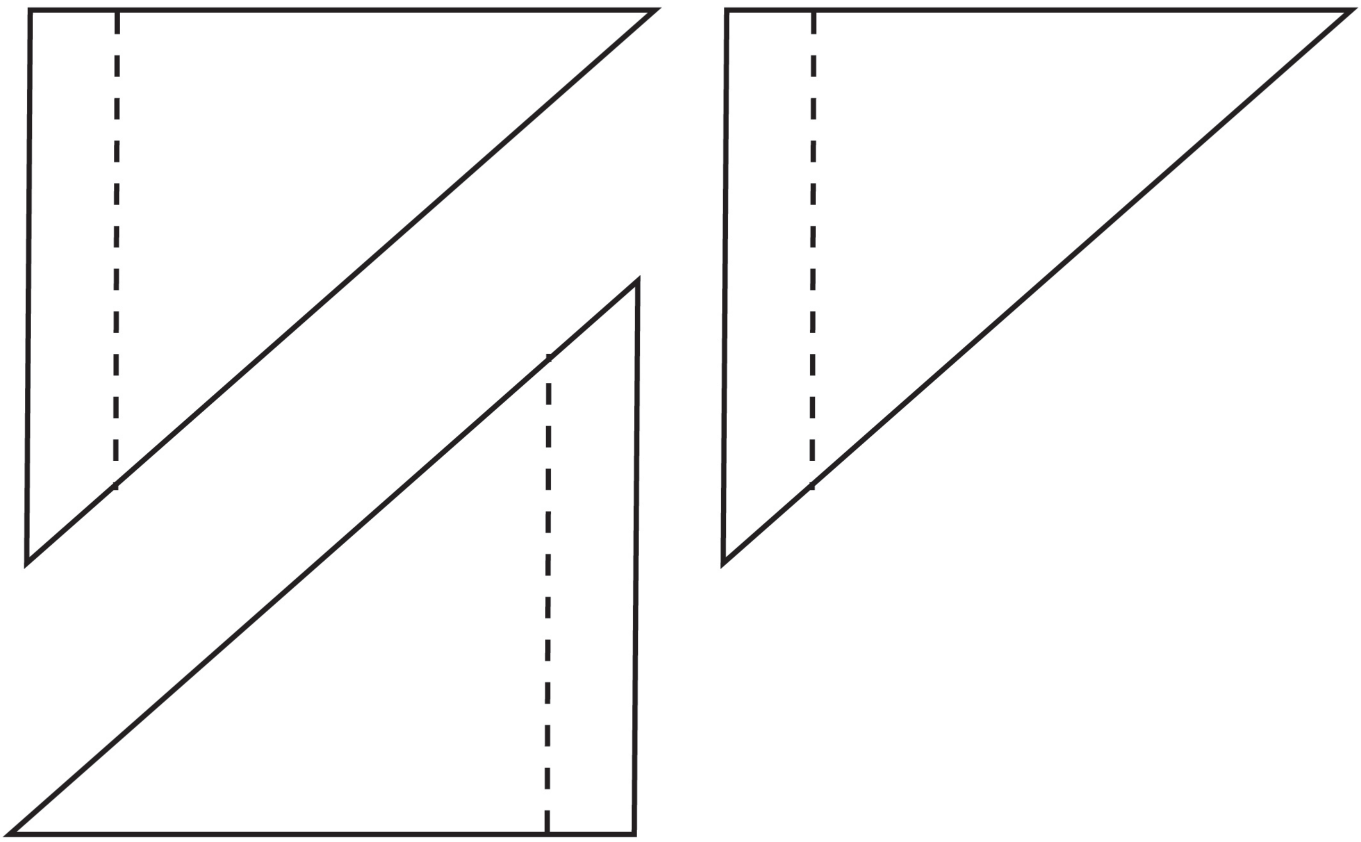


Fig. 19a: Body of the rocket. Paste the fins in the dotted zone.



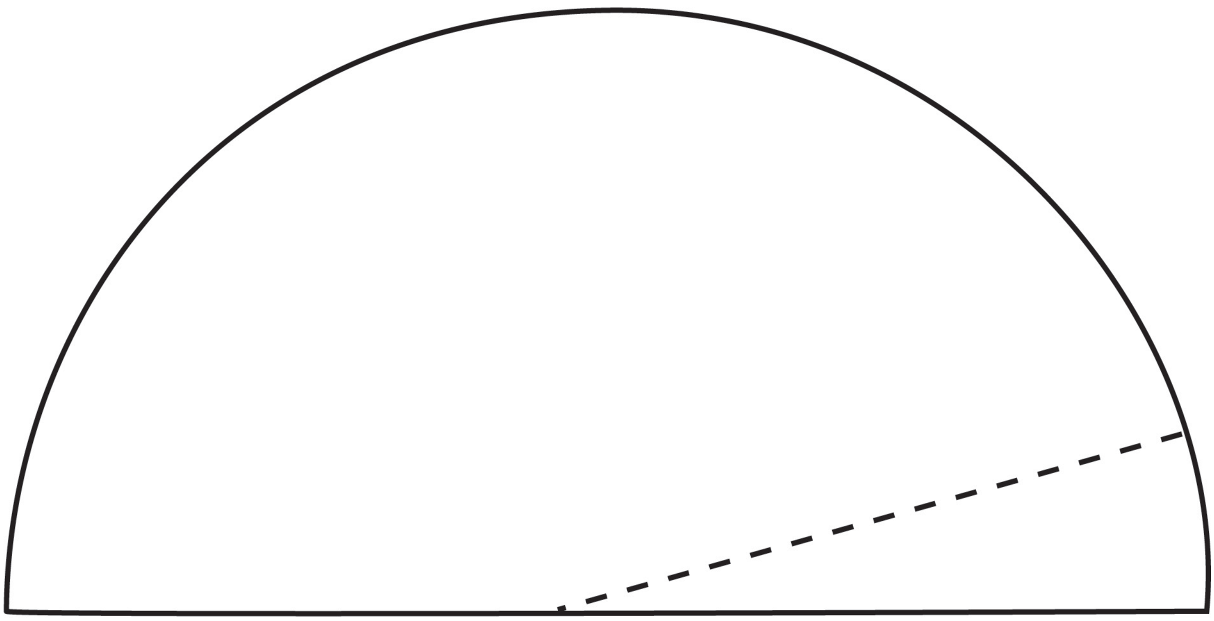


Fig. 19b: Model for the three fins. Fig.19c: Top cone of the rocket.

add the cone on the top of the cylinder (figures 16a, 16b, 16c, 16d, 17, 18, 19a, 19b, 19c).

After constructing the rocket, we have to carry out the launch. For this, we will put water into the plas-tic capsule, up to about 1/3 of its height (about 1 cm). Add 1/4 of an effervescent tablet. Put the tape and the rocket above the capsule. After about 1 minute, the rocket takes off. Obviously we can re-peat as many times as we would like (at least 3/4 of the aspirin tablet remains, so enjoy launching rockets!).

It is also possible to lanch rockets using bicarbonate and vinager.

Models of exoplanetary systems

As we have seen before, the distance to Alpha Centauri, the closest star to us, is huge compared to the distance to the planets in our Solar System. In fact, Alpha Centauri is about 10 000 times further away than Neptune, our most distant planet. These huge distances made the detection of planets around other stars impossible until sophisticated observing techniques were developped, near the end of the last century.

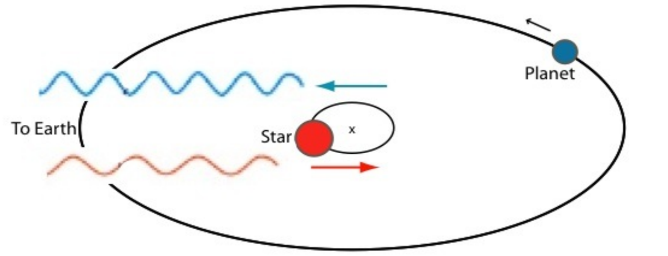


Fig. 20a: The radial velocity (RV) method for planet detection

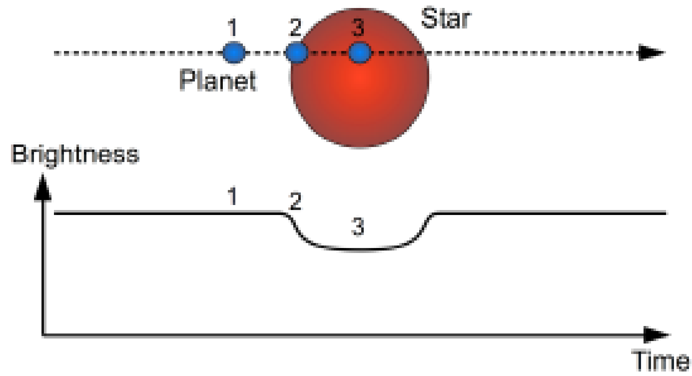


Fig. 20b: The transit method for planet detection

Introduction to Exoplanets

Currently, two methods are dominating the discovery of exoplanets. Both are indirect methods, where the presence of a planet system is implied from the observation of the system's central star.

Planet name	Average Distane, AU	Orbital period, days	Mass*, Jupiter masses	Discovery year	Radius
Ups And b	0,059	4,617	0,69	1996	0.9 R_{Jup}, 62 000km*
Ups And c	0,83	241,52	1,98	1999	1.2 R_{Jup}, 88 000km*
Ups And d	2,51	1274,6	3,95	1999	1.5 R_{Jup}, 110 000 km*
Gl 581 e	0,03	3,149	0,006	2009	1,2 R_E, 8 000 km*
Gl 581 b	0,04	5,368	0,049	2005	2,5 R_E, 16 000 km*
Gl 581 c	0,07	12,929	0,016	2007	1,7 R_E,11 000 km*
Kepler-62 b	0,0553	5,714932	<0,03	2013	1,3 R_E , 8400km
Kepler-62 c	0,0929	12,4417	<0,013	2013	0,5 R_E , 3400 km
Kepler-62 d	0,12	18,16406	<0,044	2013	1,9 R_E , 12000 km
Kepler-62 e	0,427	122,3874	<0,113	2013	1,6 R_E ,10000 km
Kepler-62 f	0,718	267,291	<0,11	2013	1,4 R_E , 9000 km

Table 8: Three representative extrasolar systems with multiple planets. Data from the Extrasolar Planets Catalog2 (except the last column). * These planets do not transit and their diameter has been calculated assuming that the density of the planet is equal to the density of Jupiter (1330 kg / m3) for gaseous planets. For planets considered to be terrestrial, the diameter was calculated using the density of the Earth (5520 kg / m3).

Planet name	Average distance, AU	Orbital period, years	Mass, Jupiter masses	Diameter, km
Mercury	0.3871	0.2409	0.0002	4,879
Venus	0.7233	0.6152	0.0026	12,104
Earth	1.0000	1.0000	0.0032	12,756
Mars	1.5237	1.8809	0.0003	6,794
Jupiter	5.2026	11.8631	1	142,984
Saturn	9.5549	29.4714	0.2994	120,536
Uranus	19.2185	84.04	0.0456	51,118
Neptune	30.1104	164.80	0.0541	49,528

Table 9: Solar System planets.

The Radial Velocity (RV) method was the first one that found an exoplanet around a normal star, with the discovery of 51 Pegasus b in 1995. In this method, the wobble of the central star due to its motion around the star-planet barycenter is measured. This motion of the central star induces very small changes in the light of the star towards the red or blue (Fig. 20a), due to the Doppler-shift. With this method, we can determine a planet's mass relative to the mass of the central star. In practice however, we do not know the orientation of most planet systems detected with the RV method, and the planet-masses we can derive are minimum masses (meaning that the real masses might be larger). The other important method, called **'Transit method'** is based on the observation of a star's brightness change when one of its planets passes ('transits') in front of the star, thereby occulting a small part of its stellar disk (Fig. 20b). With the transit method, a planet's size Rp, relative to its central star's size R*, can be measured and is given approximately by:

$$Rp / R_* = \sqrt{dF}$$

where dF/F is the relative change in observed brightness during the transit of a planet (e.g. dF/F = 0.01 if a star gets 1% fainter during transit).

We can achieve this goal by assuming that we know the density of the exoplanet. For our study, we consider that gaseous planets have the density of Jupiter and that terrestrial exoplanets have the same density as the planet Earth. By definition, the density of a body of mass m is given by : $\rho = m/V$.

NASA (http://exoplanetarchive.ipac.caltech.edu/) keeps an actualized catalog of planetary objects discovered outside our own Solar System. In 2016, there were over 3000 confirmed planets. They are called exoplanets (short for extrasolar planets). The nomenclature of exoplanets is simple. A letter is placed after the name of the star, beginning with "b" for the first planet found in the system (e.g. 51 Pegasi b). The next planet detected in the system is labeled with the following letters of the alphabet such as, c, d, e, f, etc (51 Pegasi c, d 51 Pegasi 51, Pegasi 51, Pegasi e or f).

Most known planets have masses comparable to Jupiter, which is the largest planet in our Solar System. This is why we often indicate the masses and sizes of extrasolar planets in units of Jupiter-masses M_{Jup} (1,90 x1027 kg) and Jupiter-radii R_{Jup} (71492 km).

Only very few planets (about 20) are known to have masses comparable to the Earth. There are however more planets (about 600, or 20% of all known ones) with sizes comparable to the Earth, of up to 1.5 RE (Earth Radii). We expect that these planets are the most common ones, but current detection techniques are more sucessfull at detecting more massive or larger objects.

In this section, we consider some examples of extrasolar planetary systems which have more than three known planets. table 8 shows planets around the star Ups Andromeda, Gliese 581 and of the Kepler-62 system. The planet system of Ups Andromeda and Gliese 581 were discovered with the RV method and of these planets we know their minimum masses, but not their sizes. For Gliese 581, the planet 'd' is missing, as its discovery has been retracted, it was likely caused by a spurious signal in the data. The planets of the Kepler-62 system were discovered from transits. Hence, their sizes are known. Of their masses we know only upper limits (maximum masses), as they are too small (and lightweight) to be detectable with the RV method. There are however also many planets which have been detected with both the transit and the RV method, and we know both their masses and sizes.

Many exoplanets are very close to the central star, like most from above table, with orbits that are much closer than the one of Mercury around the Sun. Others have more distant planets (HD 8799 has a planetary system with three planets about as far as Neptune is from the Sun.) One possible way to display these data is to build scale models of the chosen planetary system. This allows us to easily compare them among each other and with our Solar System.

Today we know that there are exoplanets around different types of stars. In 1992, radio astronomers announced the discovery of planets around the pulsar PSR 1257 +12. In 1995, the first detection of an exoplanet around a 'normal' Solar-type star, 51 Pegasi, was announced, and since then exoplanets have been detected in orbit around: a red dwarf star (Gliese 876 in 1998), a giant star (Iota Draconis in 2001), a brown dwarf star (2M1207 in 2004), an A–type star (Fomalhaut in 2008), a disintegrating planet around a white dwarf star (WD1145-1017), among others.

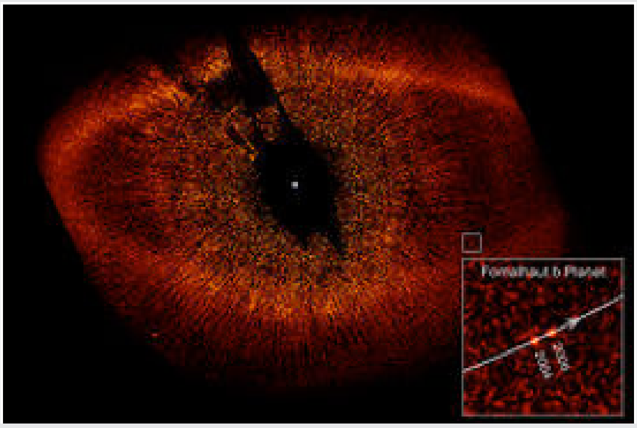


Fig. 21: Planet Fomalhaut b located in a debris disk, in an image of Fomalhaut taken by the Hubble Space Telescope (Photo:NASA).

Determination of the diameter of exoplanets

For planets like those around Ups And, found by the method of radial velocities, we do not know their size. Here we will estimate the diameter of a couple of exoplanets included in table 8.

We can achieve this goal by assuming that we know the density of the exoplanet. For our study, we consider that gaseous planets have the density of Jupiter and that terrestrial exoplanets have the same density as the planet Earth. By definition, the density of a body of mass m is given by : $\rho = m/V$

The mass, m, of the exoplanet appears in table 8, and the volume V can be obtained considering the planet to be a sphere: $V = 4\,\pi\,R^3/3$ If we substitute this formula in the previous one, we can obtain the radius of the exoplanet:

$$R = \sqrt[3]{\frac{3m}{4\pi\rho}}$$

We suggest that the reader calculate the diameter of Gliese 581c (terrestrial exoplanet) assuming its density is ρ = 5520 kg/m3 (the density of the Earth). Then repeat the calculation for a non-terrestrial exoplanet such as the first multiple planetary system that was discovered around a main sequence star, Upsilon Andromedae. This system consists of three planets, all of them similar to Jupiter: Ups planets b, c and d. Calculate their diameters assuming ρ = 1330 kg/m3 (the density of Jupiter) and compare the results with those in table 8.

Using these results and the average distance taken from table 8, we can produce a model in the next section.

Determination of the central star mass

Using the values of table 8 and Kepler's third law, we can determine the mass of the central star M. Kepler's third law states that for a planet with period P and an orbit of radius a, a^3/P^2 is a constant. We can show that this constant is the mass of the central star, expressed in solar masses. If we consider the motion of exoplanets around the star in a circular orbit of radius a, we can write:

$$m \cdot \frac{v^2}{a} = \frac{G \cdot M \cdot m}{a^2}$$

For circular motion, the speed is

$$v^2 = \frac{G \cdot M}{a}$$

The period, for circular motion, is

$$P = \frac{2 \cdot \pi \cdot a}{v}$$

Then, when we introduce the value of v, we deduce:

$$P^2 = \frac{4 \cdot \pi^2 \cdot a^3}{G \cdot M}$$

And, for each exoplanet, using Kepler's third law,

$$\frac{a^3}{P^2} = \frac{G \cdot M}{4 \cdot \pi^2}$$

Writing the previous relation for the Earth's motion around the Sun, using P=1 year and a=1 AU, we deduce the following equation:

$$1 = \frac{G \cdot M_S}{4\,\pi^2}$$

Dividing the last two equalities, and taking the Sun's mass as unity, we obtain:

$$\frac{a^3}{P^2} = M$$

where a is the radius of the orbit (in AU), P is the period of revolution (in years) and M is the central star mass (in units of Solar Masses). This relation allows us to determine the mass of the central star in units of solar masses. For example, calculate the mass of the stars Ups And and Gl 581 in solar masses (the result should be equal to 1.03 and 0.03 solar masses, respectively).

Scale model of an exoplanetary system

First we choose the model scale. For distances, the appropriate scale is: 1 AU = 1 m. In this case all exoplanets can fit inside a typical classroom, as well as the first five planets in our Solar System. If the activity is carried out outside (e.g. in the school yard), we can build a complete model. A different scale needs to be used for the size of the planet, for example: 10,000 km = 0.5 cm. In this case, the largest planet, Jupiter, is 7 cm in diameter and the smallest (Mercury) will be 0.2 cm in size. Now we can build the Solar System, or any of the systems in Table 9 using the average distance values included in Tables 9 and 10, and the previously-calculated diameters. For the central stars, we can calculate their sizes from the stellar radius-mass relation, with R and M in solar units,

$$R \approx 1.06\ M$$

and using the mass derived from the previous exercise.

In the past few years we have learned that the planetary systems configurations are diverse. The inner part of the Solar System is populated by the small, rocky planets and the first of the gas giant planets, Jupiter, is at 5.2 AU from the Sun. Many of the exoplanets, however, orbit around their stars much closer than any planet in our own Solar System orbits around the Sun. This means they are very hot. Another difference is that many of these close orbiters are large gaseous planets.

These differences are believed to be mainly due to an observational bias. The radial velocity method is more sensitive when the planets are in smaller orbits and are more massive. Also, the transit method is more likely to detect planets on short orbits that are close to their central star. But we may assume that most exoplanets have much larger orbits. It seems plausible that in most exoplanetary systems, there are one or two giant planets with orbits similar in size to those of Jupiter and Saturn. We also expect that a large fraction of stars have Earth-like planets on orbits similar to our Earth. Their detection is however very difficult and in consequence, only very few of them are known.

Habitability of exoplanets

We now consider the habitability of exoplanets. The habitable zone is the region around a star where a planet with sufficient atmospheric pressure can maintain liquid water on its surface. This is a conservative definition and it is restricted to life as we know it on Earth. Some planetary scientists have suggested to include equivalent zones around stars where other solvent compounds such as ammonia and methane could exist in stable liquid forms.

Rough calculations indicate that the solar system's habitable zone, where liquid water can exist (i.e. where the temperature ranges from 0º to 100º C), ranges from 0.7 to ~2 AU. The inner edge of this zone lies near the orbits of Venus and the outer edge is near the orbit of Mars (the green area in figure 22). Many different estimates for the Solar System's habitable zone exist however (see Wikipedia on Habitable Zone) with a recent one by Kopparapu in 2013 placing the inner edge at a distance of 0.99 AU, just inside the Earth's orbit. As we know, only the Earth is inhabited, since Venus is too hot, with a strong greenhouse effect on the planet, while Mars has no surface water and at best, might have some very basic microbic life. Knowing a star's energy-output, estimates of the habitable zone from our Solar System can easily be scaled to other planet systems. A list of potentially habitable planets is given in http://phl.upr.edu/projects/habitable-exoplanets-catalog. They also give a table were these planets are ordered by an 'Earth similarity index =ESI'

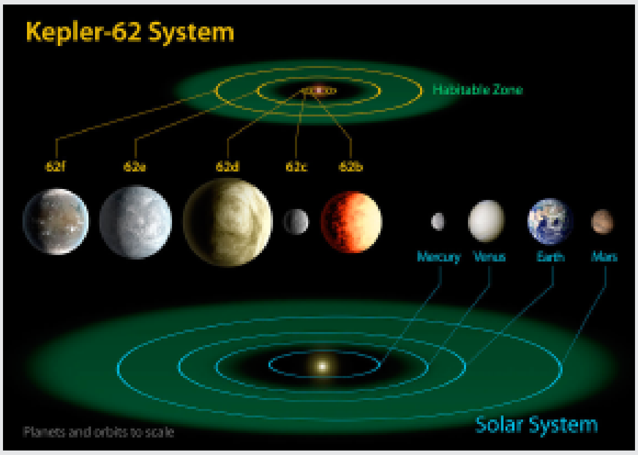


Fig. 22: The Kepler-62 systems in comparison with the inner Solar System. The green region indicates the habitable zone – the zone where life as we know it could exist. Source NASA Ames/JPL-Caltech

Possibly the most interesting example of a potentially habitable planet system is the one of Kepler-62, whose transits were discovered by the Kepler space mission in 2013. This system contains at least 5 planets, all with radii between 0.54 and 1.95 Earth radii.

Of particular interest are the planets e and f, as they are the best candidates for solid planets falling into the habitable zone of their star. Their radii, 1.61 and 1.41 Earth radii respectively, put them in a radius range where they may be solid terrestrial planets. Their positions within the Kepler-62 system, on the other hand, means that they fall within Kepler-62's habitable zone: the distance range where at least for some atmospheric conditions, these two planets could have liquid water on their surfaces, perhaps completely covering them. For Kepler-62e, which lies near the inner range of the habitable zone, this would require a reflective cloud cover that reduces the radiation that heats the surface. Kepler-62f, on the other hand, lies in the outer zone of the habitable zone, as does Mars in our Solar System. There, significant amounts of carbon dioxide would be require to keep a planet's surface warm enough for liquid surface water. Consider the sizes of Mars and Kepler-62f: Which planet is more likely to harbour life, and why?

There are still many unanswered questions about the properties of exoplanets. To find more of them and to learn more about their properties and characteristics has been the motivation for several current and future space missions, such as NASA's Kepler and TESS missions and the European CHEOPS and PLATO missions, the latter one being targeted for launch in 2024.

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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 how 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 at 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 our 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

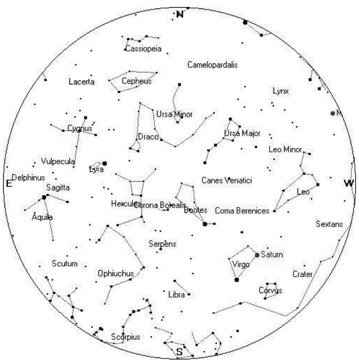

Fig 1: Example of plane of the sky (SkyChart). This is for a mid-latitude north, at the middle of July at 22 h.

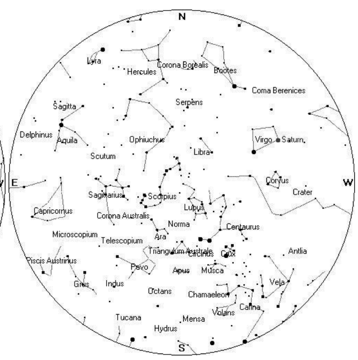

Fig. 2: Example of the plane of the sky (SkyChart). This is for a mid-latitude southern, at the middle of July at 22h.

www.skyandtelescope.com. To obtain any of these sky maps you must indicate the ocation, (usually latitude and longitude), date, and time of day.

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 constel-lations, 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 unaided 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.

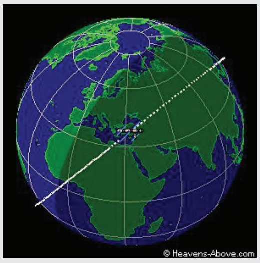

Fig. 3: Path of the ISS.

Fig. 4: xpansion and diameteroftheobjective.

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 high, you just see them if it is not long 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).

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 to which, 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 frequently 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

Fig. 5: Different optical telescopes.

mirror. The eyepiece is placed behind that central hole. Finally, there are catadioptics, typically like a Cassegrain but adding a thin lens at the entrance of the tube, there by greatly reduce the length of the tube and making 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.

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 opening and it works to meet one of these two quantities, if it know 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

Azimuth mount Equatorial mount Dobsonianmount

Fig. 6: Different mounts support telescopes.

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.

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 grade (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 (or a corrector using by students).

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.

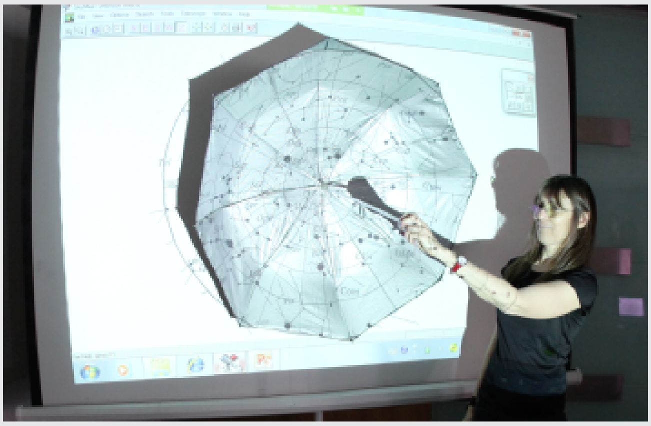

Fig.7: Projecting the stars of the northern hemisphere on a screen to draw the desired constellations. We recommend preparing the model over a black umbrella; although to photography have used one of another color in order to explain the process.

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).

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.

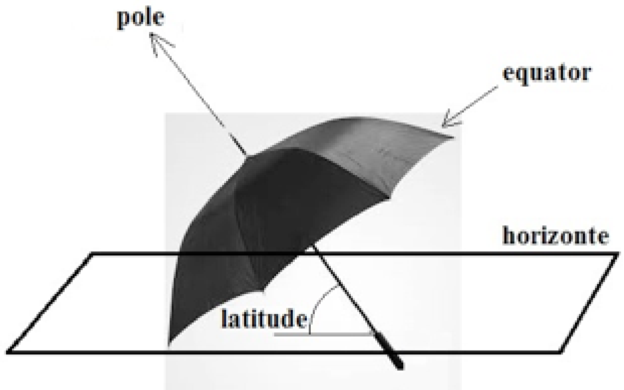

Fig. 9: Umbrella's cane inclined in the direction of the pole according to the latitude. We imagine the plane of the horizon that covers part of the umbrella.

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 (at the same hour).

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 lugs 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, t 10).hen 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).

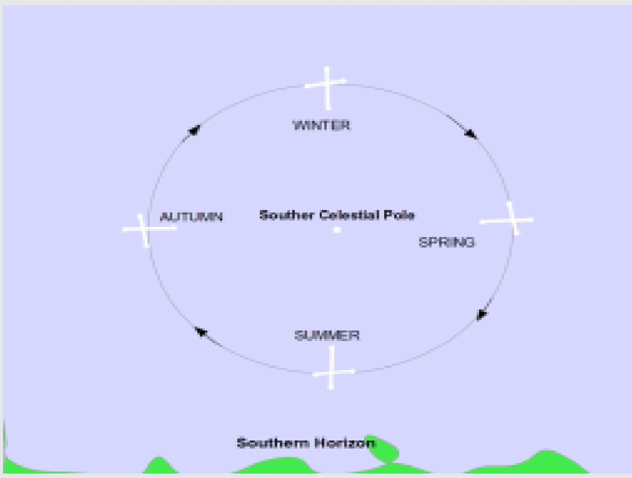

Fig. 11: Relative positions of the Southern Cross around the South Pole during the year (at the same hour).

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, ie the northern horizon. This area is where the constellations vary more. Which are visible in summer, are not 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 s 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 let go of the traslation movement of rotation 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 last times, the 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, recog rnizing the beneficial effect from the astronomical point of view, the choice of a baffle desig ned 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.

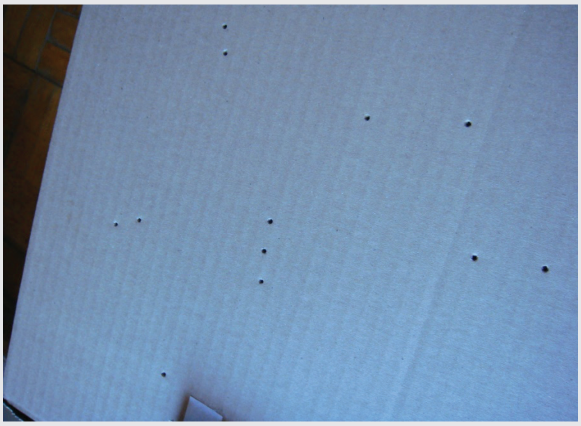

Fig. 12a and 12b: Cardboard Box, design of the con-stellation Orion on one side.

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.

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).

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.

The experiment was performed in two stages:

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

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

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

Fig. 15a: We removed the protector of the flash-light. Fig. 15b: Flashlight with the tennis table ball simulat-ing the street lamp.

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. 16a: Lamp without shield. Fig. 16b: Shielded Lamp.

Fig. 17a: Appearance of the night sky with lan-terns 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 position the toolbar (to bring the curser 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.	
Setting the view of the sky. There are 4 menus as explained below.	
Number of stars, planets...and to adjust the atmosphere.	Cielo
Coordinate lines shown in the sky, constellations…Type of projection of the sky. We recommend Stereographic or Orthographic.	Marcas
Show the landscape, ground, 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 the screen.	
Help (shortcut keys, etc).	?
Normal rate of time.	
Speed up time. Can be used several times.	
Speed down time.	
Back to the current time.	
Lines of constellations.	
Names of constellations.	orion
Figures of constellations.	

Equatorial grid.	
Azimuth-horizon grid.	
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.	
Occular (like looking at the selected object through a telescope).	
Show satellites in orbit.	
Moving around in the view.	←,→,↑,↓
ZOOM +	Repág
ZOOM -	Avpág
Define selected planet as the viewing location. To return to Earth, look for Earth and then click CtrlG (command) to change back to Earth as viewing location.	CTRL G
Leave/omit trace of planet path.	May+T
Screen capture.	CTRL S ó *PrintScreen*
Exit (Done with Stellarium)	ó CTRLQ

Archaeoastronomy and its educational potencial

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Introduction

Archaeoastronomy, astroarchaeology, cultural astronomy, ethnoastronomy, history of astronomy, ... In recent years, the scientific world, and by extension the academic audience in general, has begun to recognize a number of subdisciplines that in one way or another strive to relate the science of astronomy to the traditional humanities (archaeology, history, ethnography, anthropology, art history or philosophy, etc.) or, more properly, to the social sciences.

The Archaeoastronomy supplement to the Journal for the History of Astronomy created by Michael Hoskin -unfortunately no longer published- popularized the term "archaeoastronomy" in the mid-1980s. (To make matters confusing, however, an equally valid term "astroarchaeology", relating the astronomical orientation of archaeological remains, has wound up being applied to attempts to relate archaeological sites to visits of supposed extraterrestrial beings. The blurring of scientific terminology with pseudoscience is, unfortunately a long tradition. That's why astronomers call themselves by a prosaic term meaning "namers of stars" rather than the more appropriate "astrologers", as biologists, ecologists, anthropologists and a long list of other "treaters of" sciences do.)

What then is archaeoastronomy? In the *History of Astronomy: an Encyclopedia,* the "archaeoastronomer" Edwin Krupp, Director of the Griffith Observatory in Los Angeles, proposes the following definition of the term: *archaeoastronomy is the interdisciplinary study of the prehistoric astronomy, ancient and traditional all over the world, in the frame of its cultural context. In this study both written and archaeological sources are included, covering the following topics: calendars; practical observation; cults and celestial myths; symbolic representation of events, concepts and astronomical objects; astronomical orientation of graves, temples, sanctuaries and urban centres; traditional cosmology and the ceremonial application of astronomical traditions.*

Granted, this definition is broad enough to cover a wide variety of topics. However, "archaeoastronomy" defined in this way ignores two very important areas where astronomy fully relates to the social sciences, the history of astronomy and ethnoastronomy. The first area of study, which has already a long tradition, properly chronicles the advance of astronomy as a scientific discipline and the evolution of astronomical thought and practice starting around the time of classical Greece. Ethnoastronomy, complements this by tracing astronomy in the oral traditions of cultures that currently exist and, according to some researchers, the written sources (chronicles of conquest, ancient anthropological studies) of extinct cultures, covering a range of topics that largely coincide with the ones of archaeoastronomy proper. Actually, the boundaries between these three disciplines are extremely ill-defined and studies that fall into two or all of these categories are more the rule than the exception.

For this reason, the general term "cultural astronomy" seems most appropriate to any study in which astronomy is related to the social sciences. This is why specialists in this field today call themselves the "European Society for Astronomy in Culture (SEAC)"
www.archeoastronomy.org.

Where is archaeoastronomy located?

One of the most important distinctions between archaeoastronomy and the "hard" physical sciences is the replacement of "astronomical" language by language more compatible with the epistemological point of view of social sciences. Archaeoastronomy, one must keep in mind, is not another branch of modern astrophysics, nor is its fundamental purpose the advance of physical knowledge of the Universe. Rather, archaeoastronomy is a specialty more closely allied with anthropological studies, serving disciplines such as landscape archaeology (in the all-embracing sense of the term landscape), the history of religions or the archaeology of power. Therefore, an astronomer trained primarily in the quantitative sciences may find it difficult to know how to answer the questions that interest archaeologists--- or even to pose the questions themselves. Yet it is important for people interested in astronomy to become familiar with their roots and to understand how different cultures have used the observation of the sky to shape their vision of the universe around them into a coherent and meaningful worldview.

It has been argued that close collaboration between archaeologists and astronomers is necessary to carry out substantial research in archaeoastronomy. This interdisciplinary symbiosis is a natural consequence of the need for archaeologists, anthropologists, and historians of astronomy to master astronomical techniques such as positional astronomy or celestial mechanics and mathematical tools such as spherical trigonometry, that go well beyond their customary training.

However, my current opinion, after more than two decades of experience in the field is that both the astronomer and the anthropologist need to transform themselves into a substantially different type of scholar, an archaeoastronomer, forgetting many of the epistemological habits of long years of disciplinary training and establishing quite new patterns of thought. Not everything which is studied in archaeoastronomy can necessarily be considered interdisciplinary, although a certain multidisciplinary approach may be necessary. It is, in short, a legitimate field in and of itself.

Archaeoastronomy has another important problem: it is a sort of no-man's-land in which astronomers and astrophysicists feel out of place (although this, fortunately is beginning to change), and archaeologists and historians often cannot see anything in it that is useful to their understanding of the past. This contrasts with other intersections of the humanities with the experimental sciences as, for example, the use of C14 in dating, which is widely accepted by scientists, historians, and archaeologists alike. The problem is compounded when the title "archaeoastronomer" is applied to scientists interested applying their knowledge to historical subjects and who use (and abuse) the considerable physical and mathematical tools at their command to propose absolutely preposterous historical theories, to the horror of both archaeologists and anthropologists. Efforts by conscientious scientists to gain degree of recognition for astronomical approaches to archaeology can be frustrated by a few prominent members of what British scientists call the *lunatic fringe*.

The border between what is science and what is not should be based on the application of basic rules such as Ockham's Razor, the simplest formulation of the Principle of Economy (faced with two possible answers to a scientific problem, the simplest is often true). However we must recognize that these rules are not universally applicable.

Archaeoastronomy and NASE

The potential of archaeoastronomy in the teaching of astronomy is that it can inspire the hearts and consciousness of young apprentices to see their own culture reflected in the way of understanding the cosmos of their ancestors. In this sense, archaeoastronomy can provide a direct connection to their immediate environment as opposed to the apparent remoteness of the sky and the universe in general. If this is true, it would be interesting to conduct research on the pedagogical effects of either archaeoastronomy or ethnoastronomy or even a combination of both.

These approaches open up opportunities for students to stimulate dialogue with elders to learn traditional knowledge of the sky, particularly if they are located near or in agricultural or hunter-gatherer societies. In modern urban societies knowledge is transmitted more formally through schools and the media. For students interested in this approach, a typical interview outline that could serve as a guide is attached (see Appendix 1).

On the other hand, it is almost certain that in the immediate environment of the young astronomy apprentice, wherever he or she is located, there will be a series of buildings that could have a marked symbolic character and which already have a religious or secular function. Those buildings, or urban spatial planning, are potential objects of archaeoastronomical experimentation. We quote some examples:

• Churches in a Christian environment.
• Mosques in a Muslim environment.
• Temples in a Hindu environment, Buddhist or Shinto (pagodas or gopurams included).
• Urban plans, especially those with a clear organized orthogonal frame (very common around the world).
• Sanctuaries of indigenous societies (Polynesia or America)
• Other places of worship in tribal societies.
• Ancient monuments if there were any.

The existent astronomical iconography in these places can also be studied, for instance the analysis of rock carvings stations which often show elaborate astral representations. Therefore, cultural astronomy can become an effective and valuable approach that can bring astronomy to the general public, and especially to young people.

Appendix I
(Adapted from "El Cielo de los Magos")

INTERVIEW TYPE FOR FIELDWORK ETHNO-ASTRONOMY

The set of questions proposed is a general nature type and can be applied in most cases. However, experience shows that, in this type of research, once a conversation starts, countless more specific questions related more directly to the subject being treated will arise. Consequently, though this outline can serve as a guide, it is expected that most of the interviews will naturally take on a more open character.

1. *First, have the interviewee explain what we know and why, starting with general questions such as:*

- Here are you recently looked up in the sky for something?
- Do you use it as a guide, a sign, symbol, or guide for something?

2. *Then ask specifically about each object that can be used for predictive purposes:*

a) Questions focused on the Stars

- Are you guided by the stars at night?
- What stars do you know in the sky?
- Do you know "this or that" star (*)?
- Ask questions about the place and time of year you go out to observe and what stars you look at, in order to clarify which star or stars the interviewee is referring to.
- Do you remember the names of other groups of stars?
- Does it indicate you something about the stars?
- Is rain associated with any star?
- Are observations most commonly made at night or early in the morning?
- Do you use observations of stars to decide when and where to do agricultural work?
- On what basis do you make these decisions... whether a star is seen or not seen at a given time? Whether a star is in a particular position? etc. ...?
- How does the interviewee tell the time at night?
- Is there any importance to the rising of a particular star?
- Do cattle do something or does something happen that is associated with the stars?
- Do cattle get restless or nervous because of the position or behaviour of the stars?

(*) Note: Specific reference will be made to any star, known by the previous interviews or collected in the previous bibliography on the subject.

b) Questions related to the Moon:

- Have you looked at the Moon?
- Do you use the Moon as a guide for something?
- Have you looked at or noticed where the Moon sets?
- Have you notice the position, form , or phase of the Moon recently?
- Does the position of the Moon indicate something?
- Have you looked at the Moon to help you with farm work?
- Have you anything special you noticed about the Moon?
- Is any phase or seasonal Moon more important than the others?
- Does the moon have any influence on rain?
- Does the moon affect animals?

c) Questions related to the Sun:

- Have you looked at the Sun?
- Do you use the Sun as a guide for anything?
- Have you looked at or noticed where the Sun sets?

- Do you use the Sun to tell the time? ... How?
- Have you looked at the Moon to help you with farm work?
- Have you heard something about seeing the Sun dance?

d) Questions related to meteorological phenomena:

- How do you know if it will rain or not?
- Do you know of some sign of something, somewhere, that indicates that it will rain.?
- What other known signs relate to the winds, clouds or celestial events?
- Was there any sign for this or that mountain?
- Do you have any way of knowing what the weather will do in the sea (fishing)?
- If it's going to rain, can you tell by watching the sky what time it's going to happen, ... (*)?
- When, at that time do you watch (*)?

(*) Note: The intention of these last two questions is to find out if they know the Cabañuelas without expressly mentioning the name. Otherwise ...

e) Questions related to the Cabañuelas and the Aberruntos (traditional methods for meteorological predictions):

- Is there some special time to look for signs of the weather during the rest of the year?
- Do you know the Cabañuelas?
- What do you know about the Cabañuelas?
- On what date?
- What does the method consist of?
- Do you know any Aberrunto?
- What does that mean?
- Do these methods work or not?
- Is there any Cabañuela which is more accurate than other methods?
- Is there any Cabañuela associated with the Sun or the Moon?

f) Questions related with holidays and the saint's days

- What fiestas do you have here?
- When are they?
- What are the most important?
- What is your Patron Saint?
- What does your Saint do?
- What do you do on the special day?
- Do you do anything related to the sky on that date?

3. *Questions of a general nature to do so sandwiched along interview:*

- Do you remember a song, singing or saying related to the things of heaven?
- Do you have someone who knows how to predict the weather?
- What's his or her name?
- Are the predictions very accurate?
- What other signs do you know?
- Do you trust all these signs?
- These days do you still follow thse signs?
- These days, do people still look for those things?
- Do you think that the signs are trustworthy?
- Who taught you this lore?
-Where was he or she born? Where did he he or she grew up? From where was his (father, grandfather, father, ...)?

Appendix II
Adapted from "La Orientación como seña de identidad cultural: Las Iglesias Históricas de Lanzarote)

Abstract

The orientation of the Christian churches is a distinctive element of its architecture which repeats patterns from Christian times. There is a general trend to orient their apses in the solar range, with a predilection of geographical east (nearby astronomical Equinox), although alignments in opposite directions, with the apse to the West, even though they are exceptional because they do not follow the canonical pattern, are not unusual.

The case of the churches built in the Northwest of Africa before the arrival of Islam is paradigmatic in this respect and could reflect previous traditions. The Canary Islands represents the western end of the North African cultural koinè, so it has been considered relevant to address a study of a compact set of ancient churches in one of the Islands, choosing Lanzarote. The orientation of a total of 30 churches built prior to 1810, as well as some more examples of later periods, are measured. Sample indicates that a pattern of decisive orientation on the island followed, but unlike the standard found so far in the rest of the Christian world, this prototype is twofold.

On the one hand, appears the standard East (or West) direction, but the sample is also a marking orientations towards North-Northeast, for now, exclusive of Lanzarote. The annex discusses why this strange rule, considering several possibilities mostly discarded. We found that the explanation may be very prosaic, in such a way that, sometimes, the earthly needs are most relevant than decision-making needs of the cult.

Introduction: Prolegomena

The study of the arrangement and orientation of Christian churches has interested since old times and has recently gained a new boom in the specialized literature. This is an important factor of their architecture. According to the texts of writers and early Christian apologists, the churches should be following a certain orientation, i.e. the priest had to stand facing the East during the cult. Recognized by Origenes, Clement of Alexandria and Tertullian, the Council of Nicaea (325) determined this as a priority fact. Atanasius of Alexandria, also in the fourth century, expressed that the priest and the participants should be directed towards the East, where Christ, the Sun of Justice, will shine at the end of time (ecclesiarum situs plerumque talis erat, ut fideles altare facie versa orientem solem, symbolum Christi qui est Sun iustitia et lux mundi [...] interentur; for an in-depth analysis of the early sources and methods of orientation you can follow Vogel (1962).

However, these commandments are not entirely clear making it possible to choose between different interpretations: is it oriented towards the rising Sun the day that begins the construction of the church? Or towards the Sun another day that is considered important, such as on the day of the patron saint of the church? Either the orientation towards the East, would be considered in the strict sense? Churches were orientated towards sunrise at the Equinox? in that case, towards which Equinox? Initially, the early Christian basilicas were not built with the apse, or the head of the Church, diverted to the East. In this regard, Delgado-Gomez (2006) indicates that of the 20 first Christian basilicas built during the time of Constantine and his successors in Rome, Jerusalem, Constantinople, and the North of Africa, 18 are located approximately on the East-West line, but the apses of 11 of them is directed towards the West. However, it is interesting to note that in these cases the Chair and the priests are positioned looking towards East, hence the altar is located between it and the mourners.

Between the 3rd and 7th centuries recommendations were imposed and thus the Apostolic constitutions indicate that churches should be built facing the East (const. Apost., II, 7). In the 5th century, Sidonius Apolinar and Paulinus of Nola indicated that the apse should look towards the East, i.e. to the Equinox, something later confirmed both by the Pope Virgilius and by Isidoro of Seville in his Etymologiae (XV, 4) (McCluskey 1998). This would be confirmed during the Middle Ages by Honorius Augustodunensis (11th-12th centuries: [...] ecclesiae ad orientem vertuntur ubi sol oritur [...]) and by other authors such as William Durando (12th -13th centuries: [...] versus orientem, hoc est, versus solis ortum aequinoctialem, nec vero against aestivale solstitium [...]), that clearly indicates the direction to follow: the Equinox, preventing the sue of the solstices. The orientation towards the East has a clear symbology, as we discussed earlier. It is in that direction where the sun rises and thus Christ, as Sun of Justice, will emerge from there in the Last Judgment (McCluskey 2004, 2010). On the other hand, the non-preference of the solstices could be linked to the importance of these dates in the previous periods and the numerous pagan temples targeted in these directions (see, for example, Belmonte, 2012).

However, in these prescriptions, ambiguity still persists. Which Equinox must be considered? As it is mentioned by McCluskey (2004), there are several possibilities: the Roman vernal equinox occurred on March 25, while the Greek happened on March 21 – as it was reflected in the Council of Nicea -; but you can use other definitions, such as the entrance of the Sun in the sign of Aries or the autumnal Equinox. Each of these definitions would offer various dates and, therefore, slightly different orientations (Ruggles 1999, González-García & Belmonte 2006).

Another important point to consider is the use of the Julian Calendar during the Middle Ages and part of the Modern one. The nature of this would drive to the fact that, if we look at an Equinox calendar - i.e. in a specific date - such time would be displaced in time, something which would be reflected in a systematic change of orientation, if this was done by observation of sunrise on that day.

Along with the pyramids of Egypt and the European megaliths, the study of the orientation of European medieval churches is one of oldest trials that have been faced on Archaeoastronomy. González-García (2013) recently conducted a collection of works in this field. It shows that prescriptions for the orientation toward the East followed a quite systematic pattern throughout Europe during the Middle Ages, as can be seen in Figure 1. All areas studied by González-García (2013) follow this pattern of orientation with a clear maximum predominantly focused on the East, stressing that on numerous occasions, especially in Western Europe, such maximum is slightly moved northward of the astronomical east, perhaps indicating a use of specific dates for the equinox (March 25) that, with the passage of time, were moving as described above, although in each region there are particular characteristics.

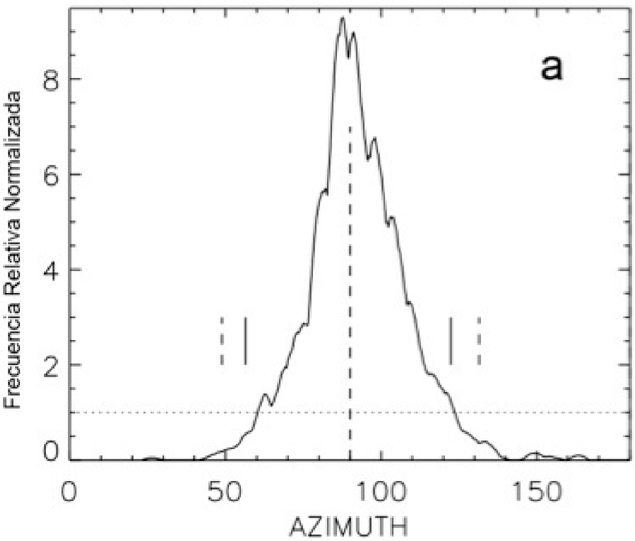

Fig. 1: Azimuth Histogram of a simple of 1274 European medieval churches.

It is interesting to note that a constant in literature about the orientation of churches is that they are oriented towards the rising of the Sun in the ephemeris of the patron saint (which does not seem at all be the case of Lanzarote churches, as we shall see). However, in the early writings, and until well into the Middle Ages, does not exist an epigraphic endorsement for such an assertion. The works reviewed by González-García (2013) indicate that for areas of Germany and perhaps England and France there might be an interest by some Saints in some monuments, even though these buildings are generally Romanesque monastic churches or Gothic cathedrals and therefore late. An interesting and well documented case is given in Slovenia where Čaval (2009) has found evidence of a special predilection for the so-called feast of the Chair of Saint Peter, tilt that is reflected in the orientation of a significant number of churches in the direction of the sunrise on that day. McCluskey (2004) indicates that something similar happens in England in the Romanesque churches where, perhaps, the churches with Marian dedications and some few more saints can follow this standard, complementing the orientation toward the East.

In this context, and given the object of the present study, it is interesting to note that, except for a small number of works dedicated to particular churches, especially in England and Central Europe, there are no systematic studies on the orientation of temples in periods after the Middle Ages, as the present one. As we shall see, the vast majority of the churches and chapels of Lanzarote began to be erected decades after the conquest and colonization of the island by the Normans at the service of the Crown of Castile in the 15th century.

Interestingly, an exception to the rule of orientation is North Africa, where churches are built in opposite directions. The data shown in figure 2 were obtained by Esteban et al. (2001) and Belmonte et al. (2007), as well as others not published previously (González-García 2013) and includes a total of 23 churches, in particular in Africa Proconsularis and Tripolitania, possible places of origin of the aboriginal population of the Canary Islands (Belmonte et al.2010). It is interesting to observe that these churches show a good number with orientation towards the West, usual in the early times of Christianity, as noted above. It also highlights that most of the churches are located within the solar range, with concentrations on the equinoxes and solstices, which could give clues about the process of Christianisation in this region.

In Spain, both in the Iberian Peninsula and in the two archipelagos, while there are reports of particular events of light and shadow within Romanesque temples at special times such as the Equinox (as in Santa Marta de Tera or in San Juan de Ortega, in the respective provinces of

Zamora and Burgos), the question of the orientation of the churches has been little investigated in general from a statistical point of view, which has led to claims pilgrim explanations on the possible cause of deviations from some churches with respect to the canonical orientation (see for example Godoy-Fernández, 2004). Perez-Valcárcel (1998) has investigated the orientation of 187 Romanesque churches of the Camino de Santiago. Although his data do not include the measurement of the angular height of the horizon, something unfortunately very common in other European studies, what does seem clear is that he is does not establish a general relationship between the orientation of these churches and sunrise on the date of the patron saint of worship of the Church.

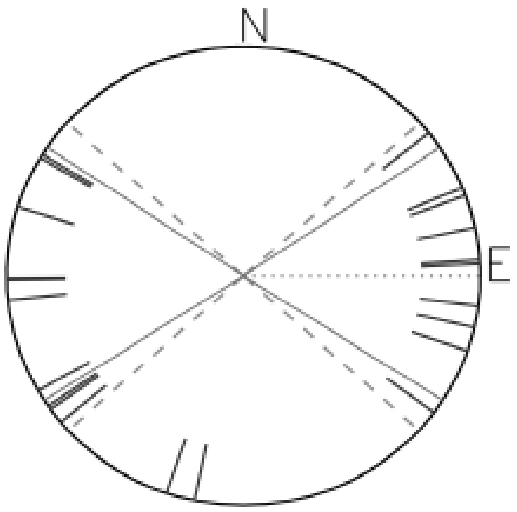

Fig. 2: Orientation diagram of 23 early Christian churches in the north of Africa.

Our team has decided to start a project on a large scale both in the Iberian Peninsula and the Canaries. In the latter, what it is shown here is the first systematic study developed so far. However, within a wider program to measure the orientations of the pre-Romanesque churches of the peninsular territory in a systematic way, González-García et al. (2013) have devoted special attention to the churches of the Asturian period and its interaction with the dominant Muslim power in the South of the Peninsula. In particular, there are 13 churches from the period still existing in Asturias which possess a canonical orientation, with the apse to the East, although generally deflected several degrees north of East. In addition, the authors found that the mosques of Al Andalus, although they could have been oriented towards Mecca, with qiblahs which could have been consistent with the canonical alignments of the churches. However it would seem that the mosques "avoid" possible orientations that may confound their temples with churches, while the Asturian churches, and perhaps the immediately subsequent Mozarabs also tend to avoid those positions that confuse these temples with mosques in an example of the interaction of religion, power and astronomy. Therefore, we see that in exceptional circumstances, the canonical patterns may be altered.

Lastly, García-Quintela et al. (2013) have investigated the introduction of Christianity in the Northwest of the Peninsula and the possible replacement of Indo-European (Celtic) elements by Christian factors, through the introduction of what it called a "martyr landscape": through the orientation of the churches and the Christianization of their environments, as well as the creation of myths and stories that channeled, modified or replaced the possible pagan cults. Thus, it would be interesting to analyze this same phenomenology in the Canary Islands and, in particular, on the island of Lanzarote, a particularly striking case since it was the first to be colonized by Europe and its size and number of population nuclei would allow a survey of a statistically significant sample in a very compact and small space.

Example: The churches and chapels of Lanzarote. Conclusions

After the conquest and colonization of the Canary Island of Lanzarote by European populations at the beginning of the 15th century, colonization in a large scale began in the centuries immediately following with the establishment of small farms and hamlets, alongside some older sites such as Femés or Teguise, where the construction of a significant number of Christian temples was accomplished that illustrated the new social and religious situation.

In some few places, it is possible that buildings were orientated imitating aboriginal worship patterns. In others, tradition canonical alignment of the temples to the East (with some exceptions to the West) was respected but with a degree of freedom larger than usual. In this regard, it should be mentioned that only the church of Mala appears to present an orientation that is compatible with the sun rising on the day of the (Marian) invocation of the temple (figure 3).

Fig. 3: Church of Ntra. Señora de las Mercedes in Mala.

Finally, in Lanzarote, there is a statistically significant number of churches oriented North-North-East, which is a notable exception to the rule. Various possibilities have been analyzed to explain this anomaly, reaching the conclusion that the most plausible answer is in turn the most prosaic. This pattern of orientation seems to obey a desire to avoid the strong prevailing winds on the island, precisely from that direction, and, in particular, to avoid the inconvenience caused by the sand displaced by wind in those buildings near or bordering El Jable, a sandy region in the north of the island.

This is only the first experiment of a project that we hope to be able to undertake in the coming years, by measuring the orientation of the oldest Christian temples in other islands of the Canary Archipelago. In this respect, we assume that study of the island of Fuerteventura, subjected to the same flow of wind, blowing even more intense, will be a very interesting case study to compare with the neighbouring island of Lanzarote.

Will Fuerteventura churches also have a double standard? Its builders dared to breach the canonical precept to impose the human needs of the cult? Time will say!.

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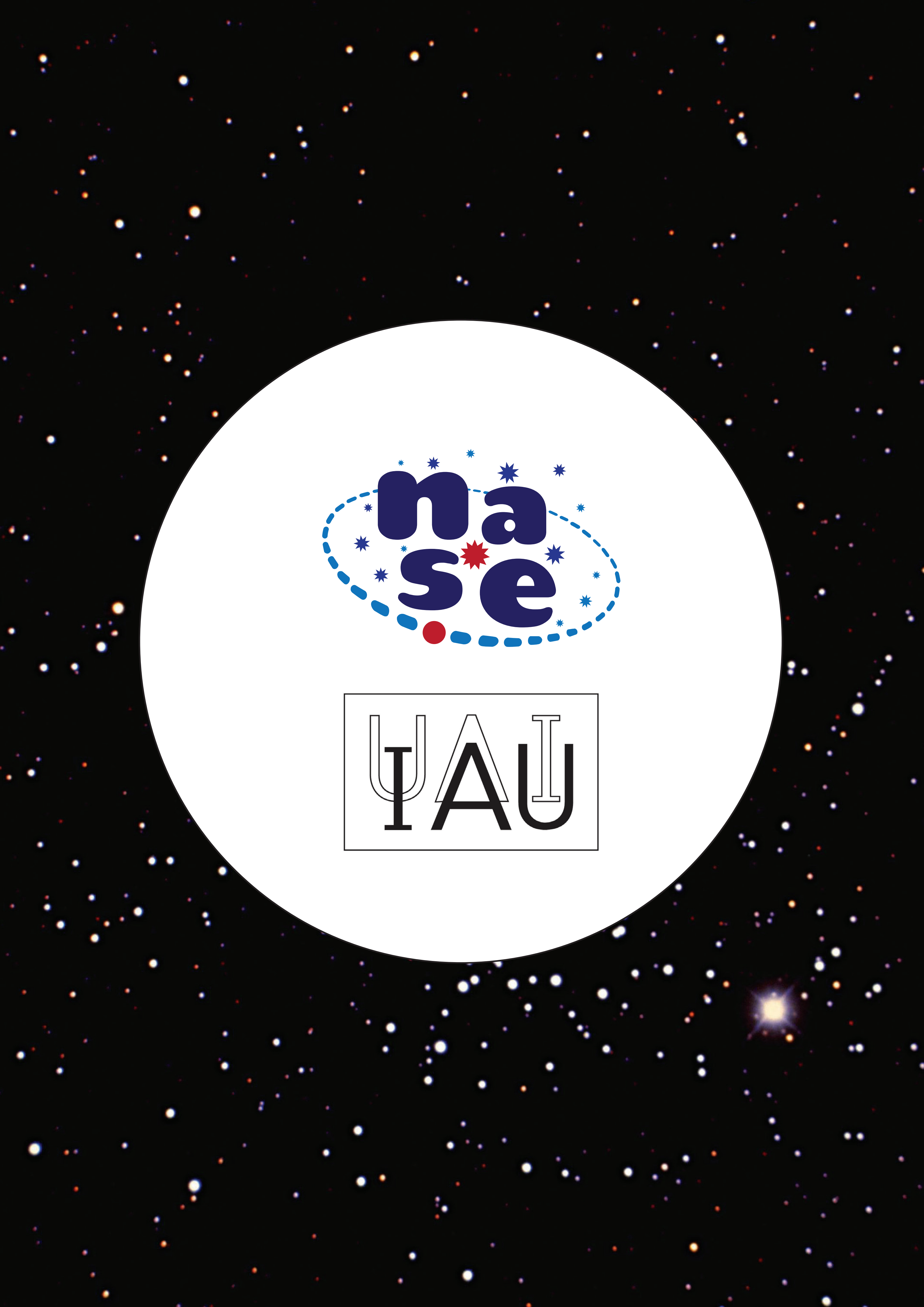
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