

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 has to be made in each center allows us to make the study and the comprehension of 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).

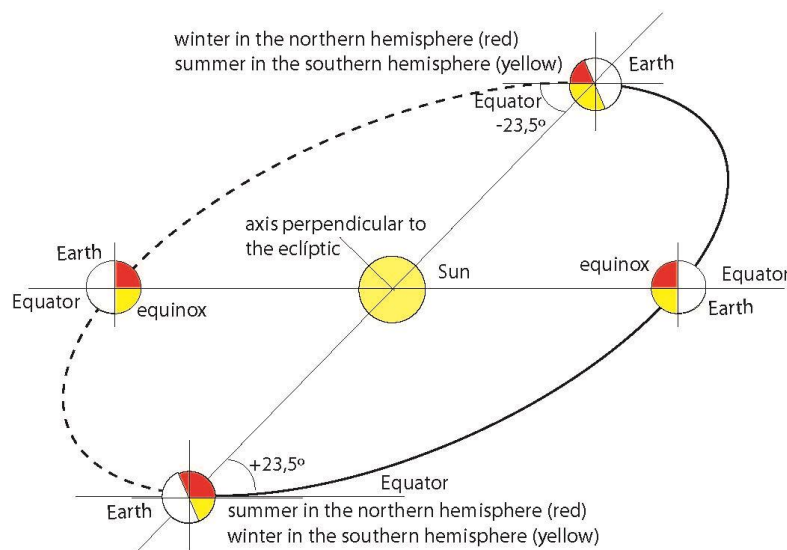


Fig. 1: Scheme of Earth's revolution. The angle between the terrestrial equator and the ecliptic plane is 23.5° . The angle between the rotational terrestrial axis and the axis perpendicular to the ecliptic plane is also 23.5° .

Earth needs a year to take 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 23.5° . Similarly, the angle between the terrestrial equator plane and the ecliptic plane is 23.5° (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 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 23° .



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 23° with respect the ground that represents the equatorial plane.

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 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.



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.

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 23.5° (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 -23.5° (figure 4b). When he/she is at positions B and D, he/she sees it exactly on the equator, i.e. 0° above the equator..



Fig. 4a: At the position A it is summer in the northern hemisphere and the Sun is 23.5° 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.

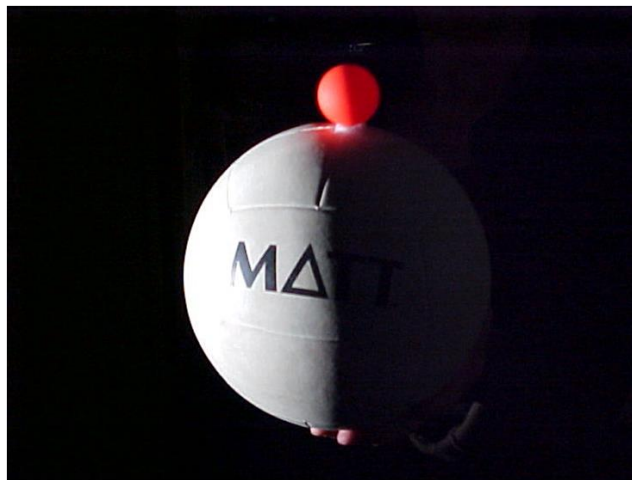


Fig. 5: A spotlight illuminates two spheres in the same way and produces the same areas of light and shadow

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 planet and we can look at it as if we were an astronaut located more far from what is the ISS.

We will use **as a usual globe**, except that we will remove the foot and will place **the globe** on a glass, with **its** axis of rotation in the same direction as it really has the Earth (we **add** a compass to indicate us **the direction** 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 **at** the top.

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

With bits of "clay" we can make the sun / **shadow** line and see how it will slowly moving across the surface of the globe as **the hours pass** and it will 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 so we can visualize effects of rotational motion on Earth (figure 6b).

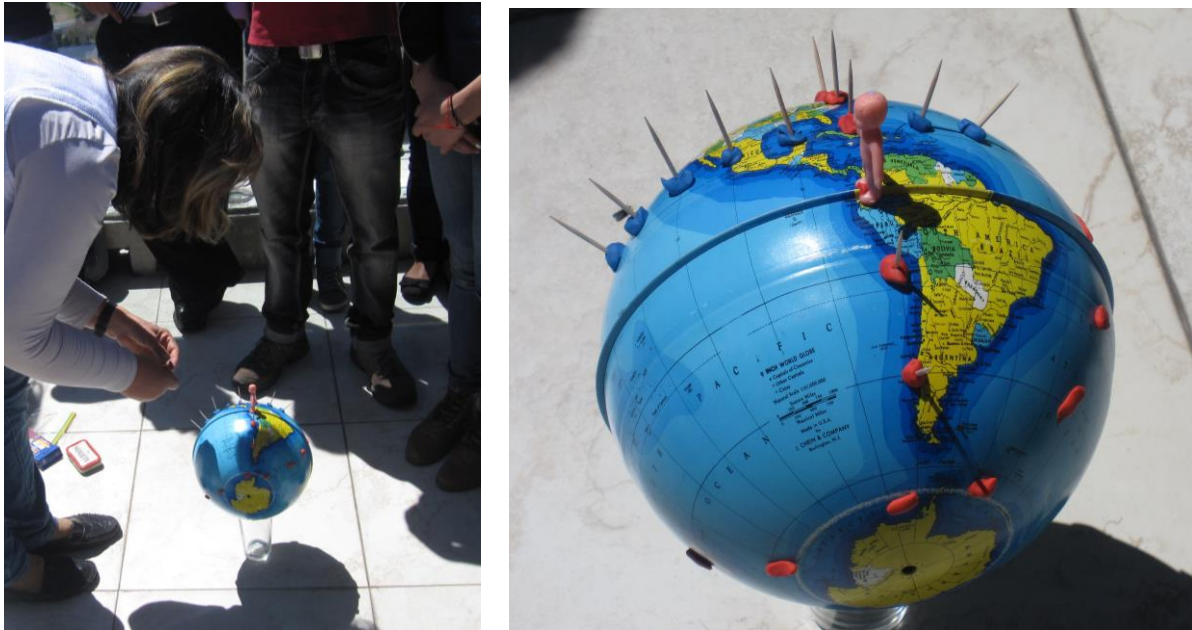


Fig. 6a: The globe, with the usual support, does not serve as a model. To be a perfect model, the globe should be placed outside, on a glass and oriented with the place from where we observe at the top. Fig. 6b: We can put a doll indicating our position and pieces of plasticine to mark the demarcation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



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 there it's winter. Fig. 7b: The north pole is within the area of the night, so in the northern hemisphere it's winter. In the southern hemisphere, the south pole is illuminated and therefore is summer for them. Fig. 7c: The line separating the day and night passes through both poles, so it's the first day of spring or the first day of autumn.

The most interesting is to visualize the translation movement, this **means to see** how the sun / shade line is situated throughout the year. Thus it can be **observed** that in summer (figure 7a), winter (figure 7b) and **at the equinoxes** (figure 7c) **the positions are the same** as you **can** check in the initial model with the four globes (figure 3).

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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 **who observes** that every day the stars move relative to the horizon. We will build a model **with** the local horizon of the observer, **A REAL OBSERVATIONAL MODEL.**

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 allow the comparison of both points of view and that also “makes the sky lines visible” and provides a better comprehension of the horizon.

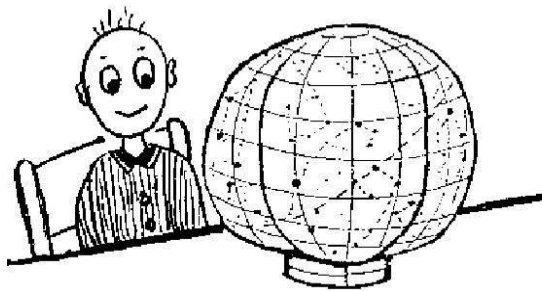


Fig. 9: Celestial sphere from the exterior.

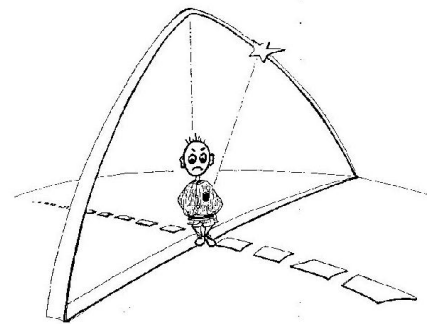


Fig. 10: Celestial sphere from the interior.

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 buildings allow us to do it – or from any balcony with a clearer view of the horizon. (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 taking 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.

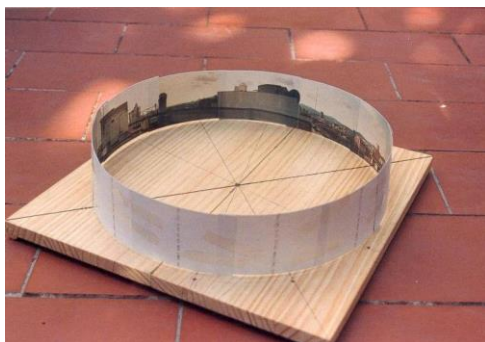


Fig. 11: The local horizon.

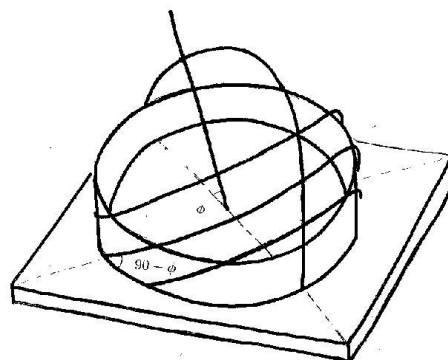


Fig. 12: Model showing the horizon and polar axis.

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 12).

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).

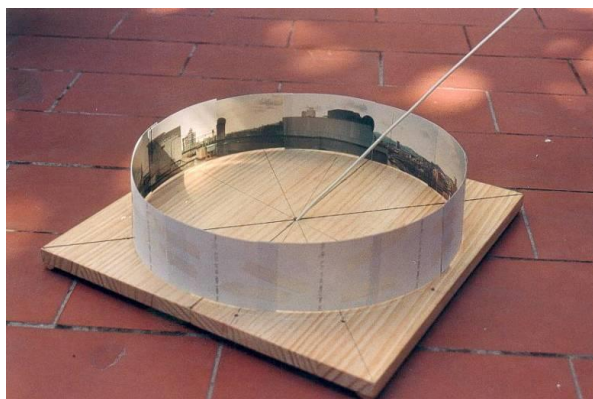


Fig. 13: Model with horizon ring and polar axis.



Fig. 14: Model with the local meridian.

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 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. 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).

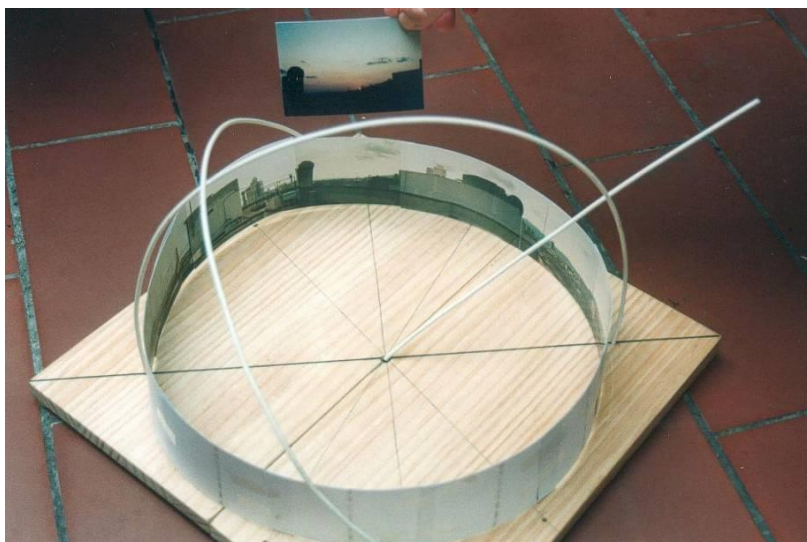


Fig. 15: Sunset point the day of the spring or autumn equinox.

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).

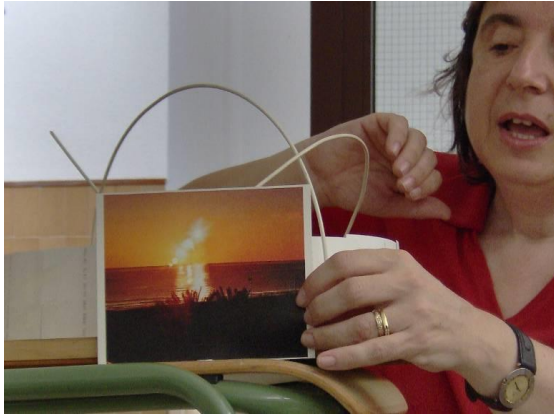


Fig. 16: Trace of the sunrise.

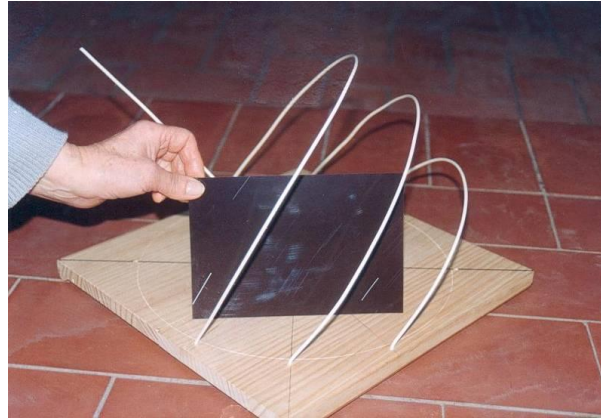


Fig. 17: Traces of the stars in the east.

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.

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).

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).

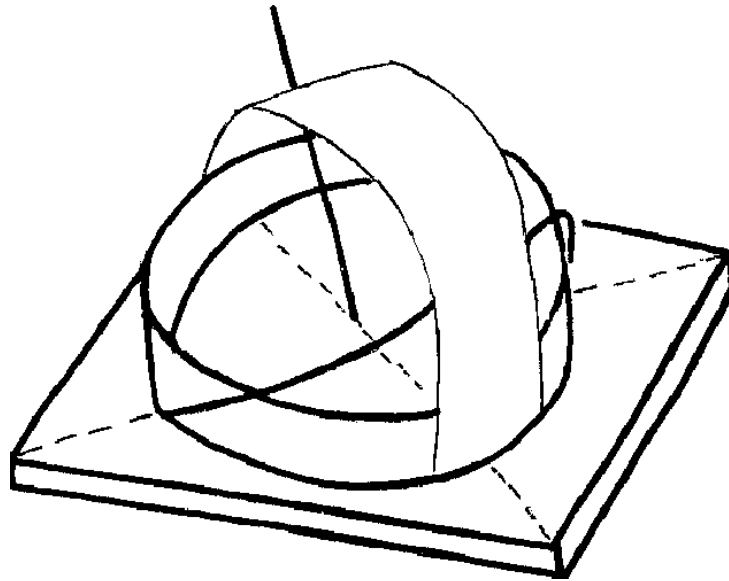


Fig. 18: The local meridian pictures.

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 23° , and this is also the angle formed between the equator and the Tropic of Capricorn (figures 19 and 20).

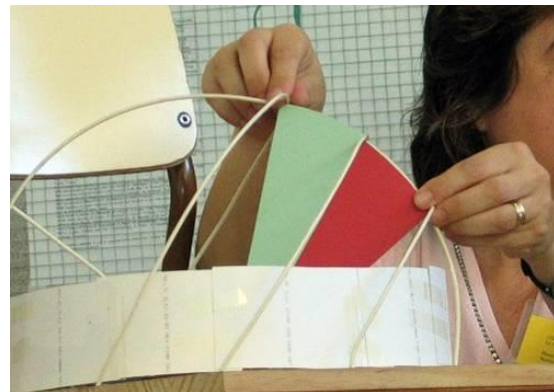
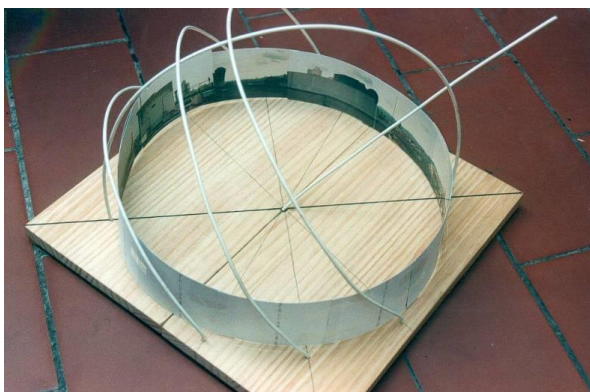


Fig. 19: Sun trajectories the first day of each season. Sunset and sunrise points do not coincide except two days: Equinox days. Fig. 20: The angle between two trajectories of the first day of two consecutive seasons is 23.5°

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).



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

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.

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

Moving the flashlight along 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).

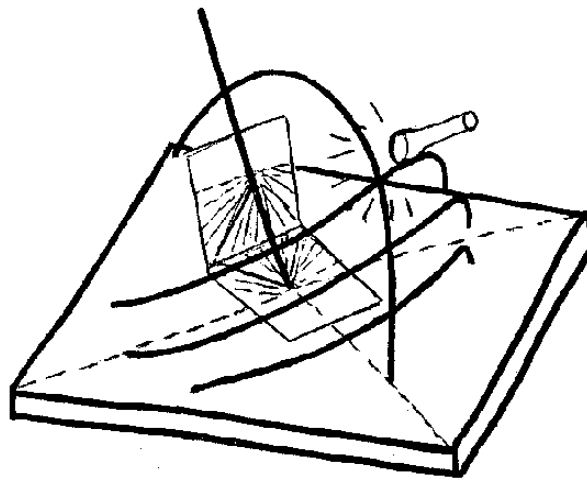


Fig. 22: The clocks and seasons.

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 23 and 24). The stylus of any clock always will be placed in the same way.

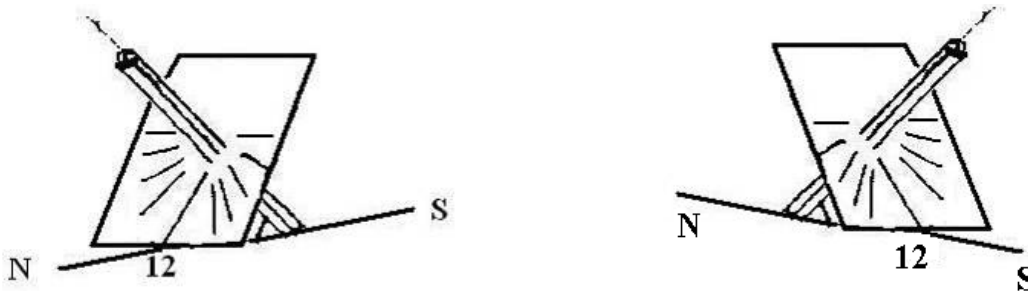


Fig. 23: Equatorial clock in used in northern hemisphere Fig. 24: Equatorial clock used in southern hemisphere

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.

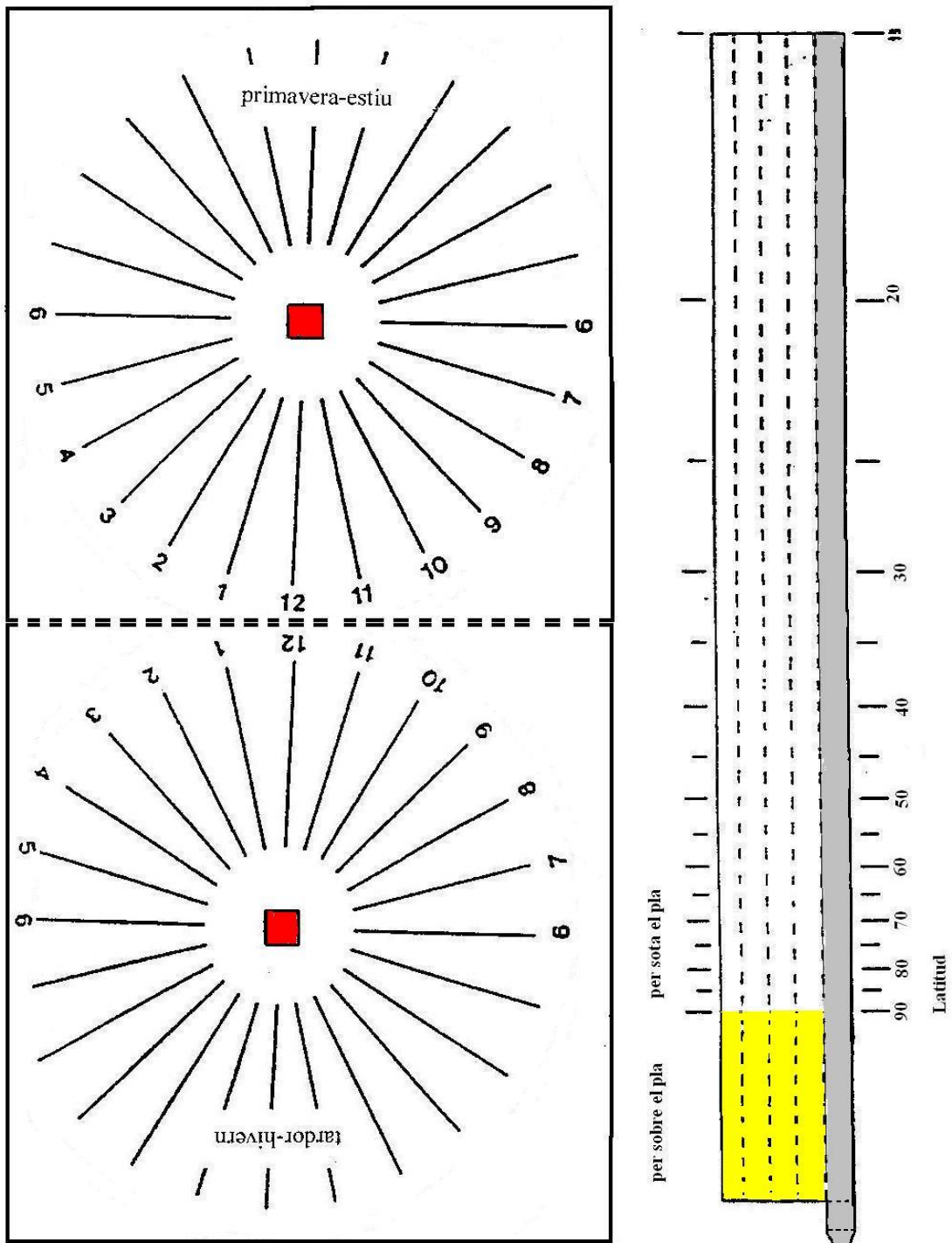


Fig. 25a and 25b: Cut of the equatorial clock.

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 y 26d).

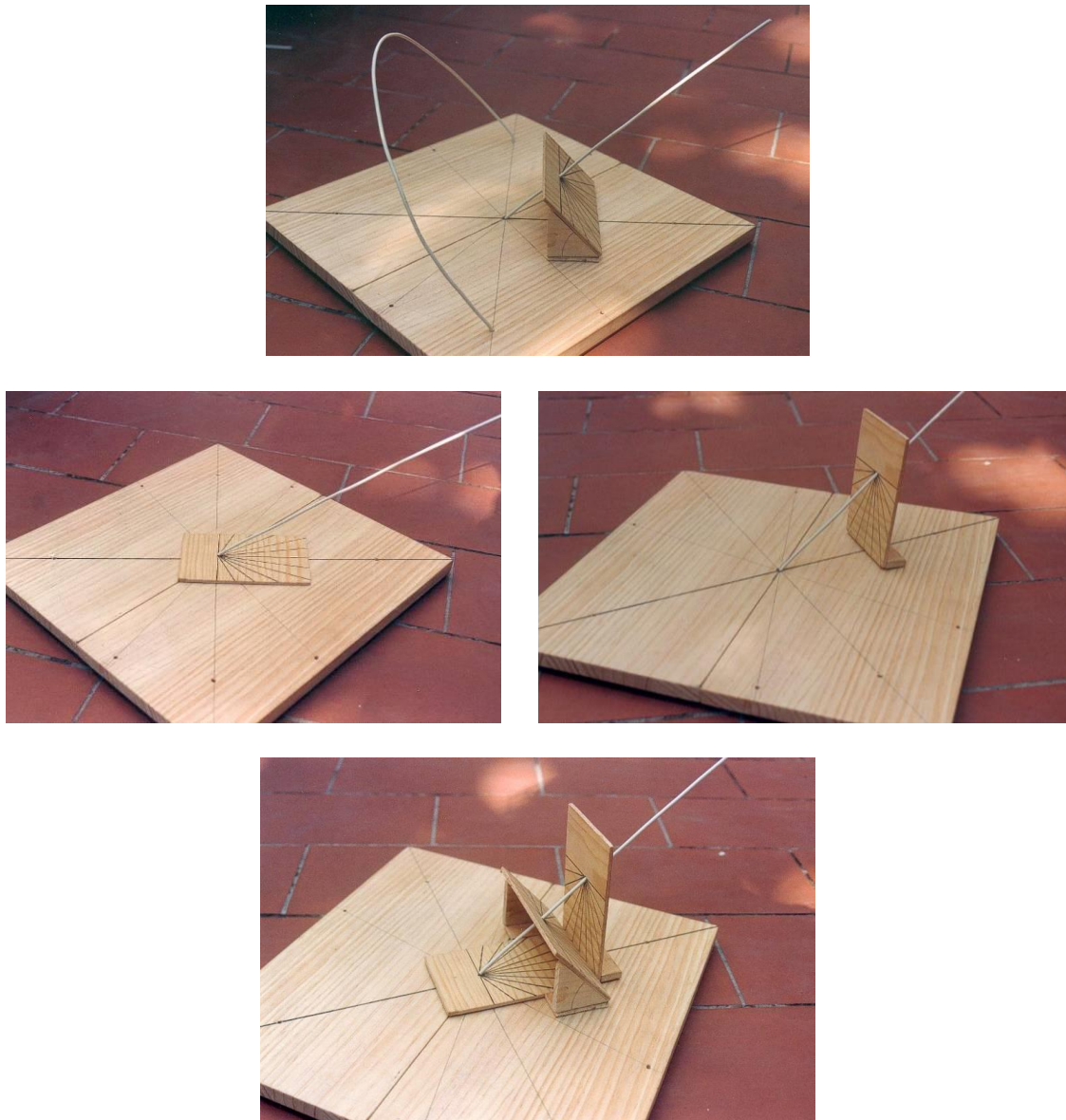


Fig. 26a, 26b, 26c y 26d: Some images of the clocks.

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 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).

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.

día	Gen	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	+3m 33s	+13m 35s	+12m 22s	+3m 54s	-2m 54s	-2m 12s	+3m 50s	+6m 21s	+0m 2s	-10m 18s	-16m 24s	-11m 1s
6	+5m 50s	+14 m 5s	+11m 17s	+2m 27s	-3m 23s	-1m 22s	+4m 45s	+5m 54s	-1m 23s	-11m 51s	-16m 22s	-9m 1s
11	+7m 55s	+14m 14s	+10m 3s	+1m 4s	-3m 38s	-0m 23s	+5m 29s	+5m 13s	-3m 21s	-13m 14s	-15m 31s	-6m 49s
16	+9m 45s	+14m 4s	+8m 40s	-0m 11s	-3m 40s	+0m 39s	+6m 3s	+4m 17s	-5m 7s	-14m 56s	-15m 15s	-4m 27s
21	+11m 18s	+13m 37s	+7m 12s	-1m 17s	-3m 27s	+1m 44s	+6m 24s	+3m 10s	-6m 54s	-15m 21s	-14m 10s	-1m 58s
26	+12m 32s	+12m 54s	+5m 42s	-2m 12s	-3m	+2m 49s	+6m 32s	+1m 50s	-8m 38s	-16m 1s	-12m 44s	+0m 31s
31	+13m 26s		+4m 12s		-2m 21s		+6m 24s	+0m 21s		-16m 22s		+2m 57s

Table 1: Time equation

Solar time + Total adjustment = Wristband clock time

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

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

For example, at 12:00 solar time, our wristwatch says:
(Solar time) 12h + 47.7 m = 12h 47.7 m (Wristwatch time)

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

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

For example, at 12:00 solar time, our wristwatch says:
(Solar time) 12h + 8.7 m = 12h 8.7 m (Wristband 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. 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 various geographical features of their city. For example, over the horizon of Barcelona (figures 27a and 27b) 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.

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.

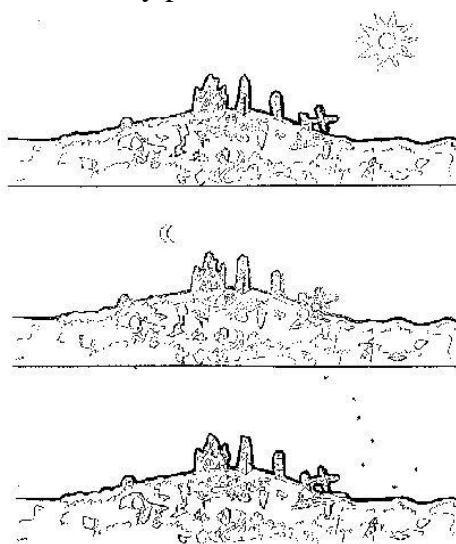


Fig. 27a: North-East horizon of Barcelona.

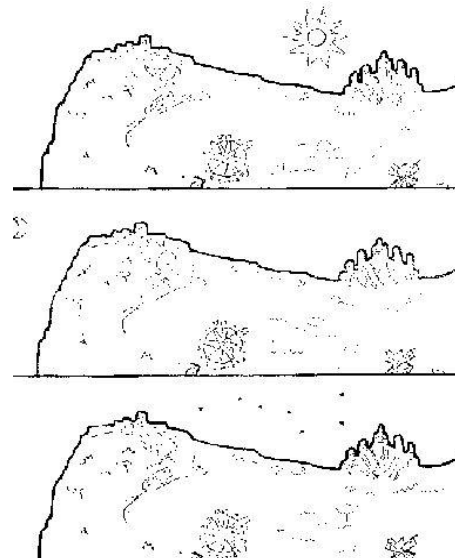


Fig. 27b: South-West horizon of Barcelona.

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).



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

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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