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 a simple model that allows us to demonstrate how these movements are observed from different latitudes.

Goals

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

The idea behind the demonstrator

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

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

The stellar demonstrator: why are there invisible stars?

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

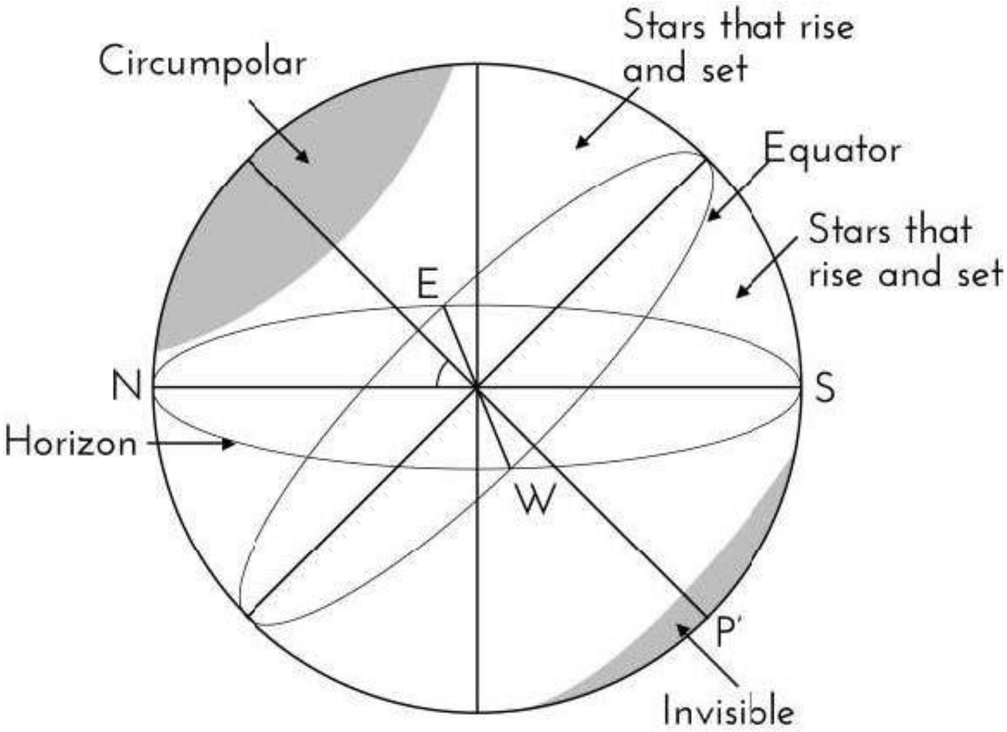

Fig 1: Three different types of stars (as seen from a specific latitude): circumpolar, stars that rise and set, and invisible stars.

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

The main goal of the demonstrator

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

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

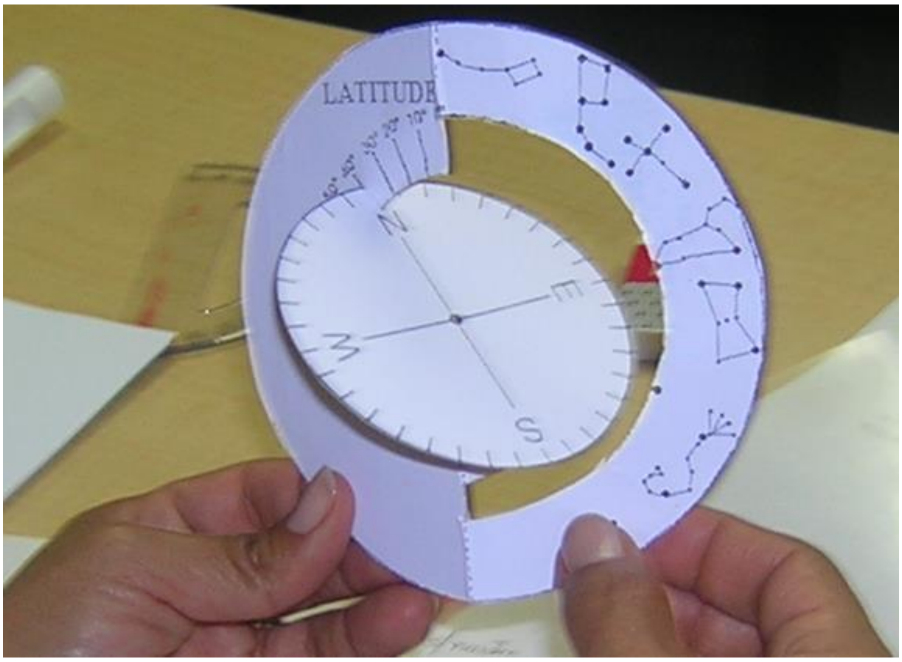

Fig 2: Using the demonstrator: this is an example of a demonstrator for the Northern Hemisphere using constellations from Table 1.

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

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

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

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

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.

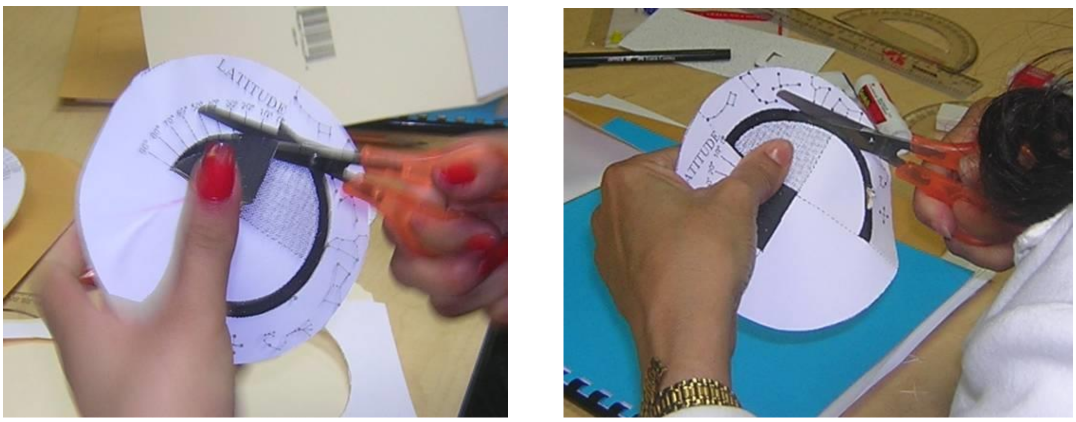

Fig. 3a and 3b: Making the stellar demonstrator.

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

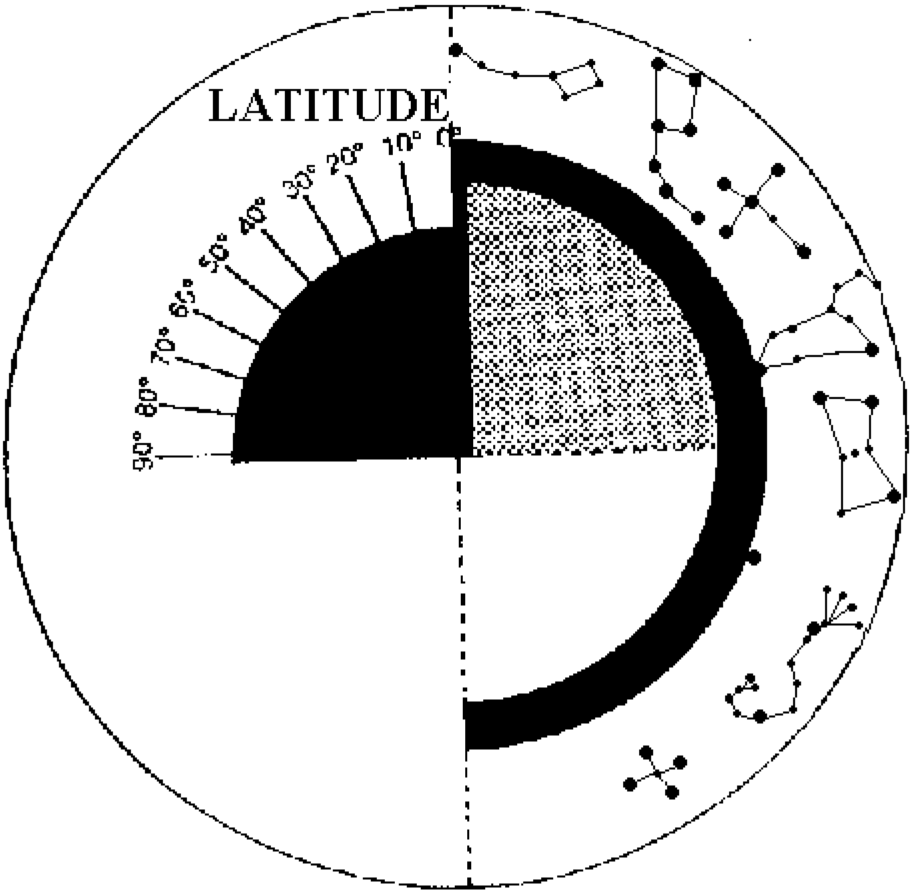

Fig. 4: The main part of the stellar demonstrator for the Northern Hemisphere.

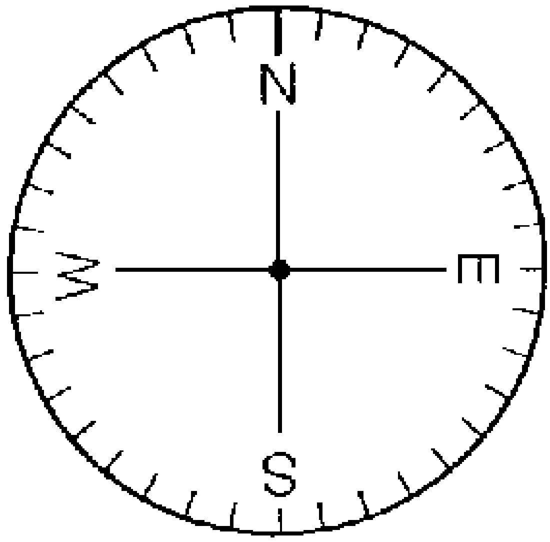

Fig. 5: The horizon disc.

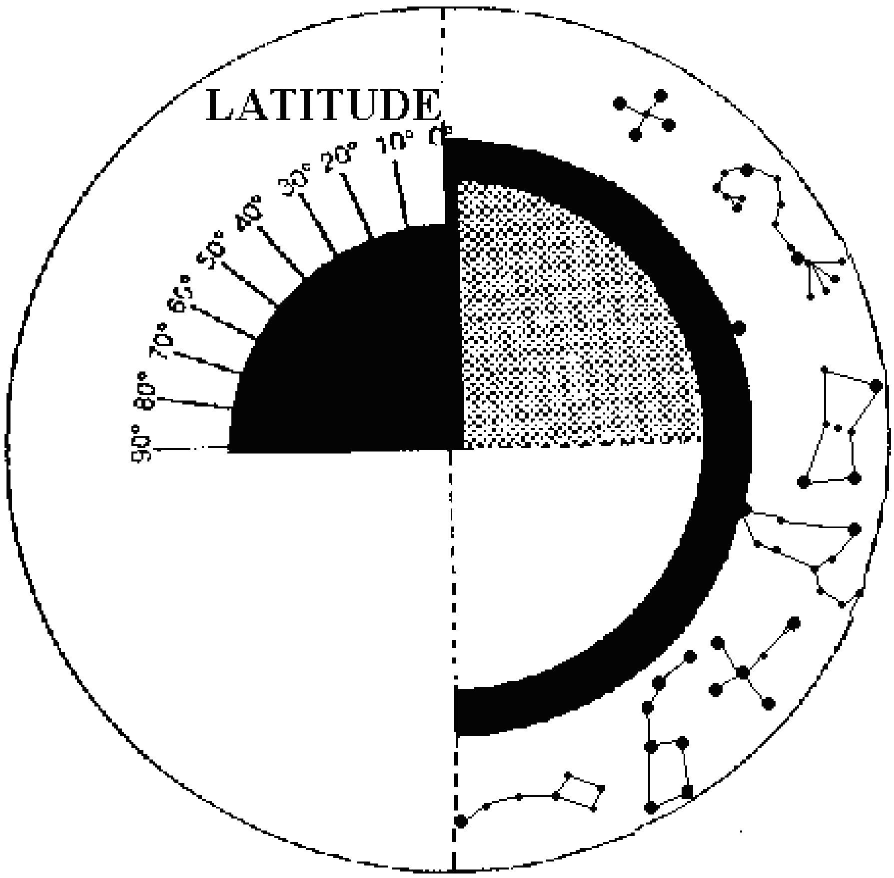

Fig. 6: The main part of the stellar demonstrator for the Southern Hemisphere.

Demonstrator for Southern Hemisphere

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

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

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

Demonstrator applications

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

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

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

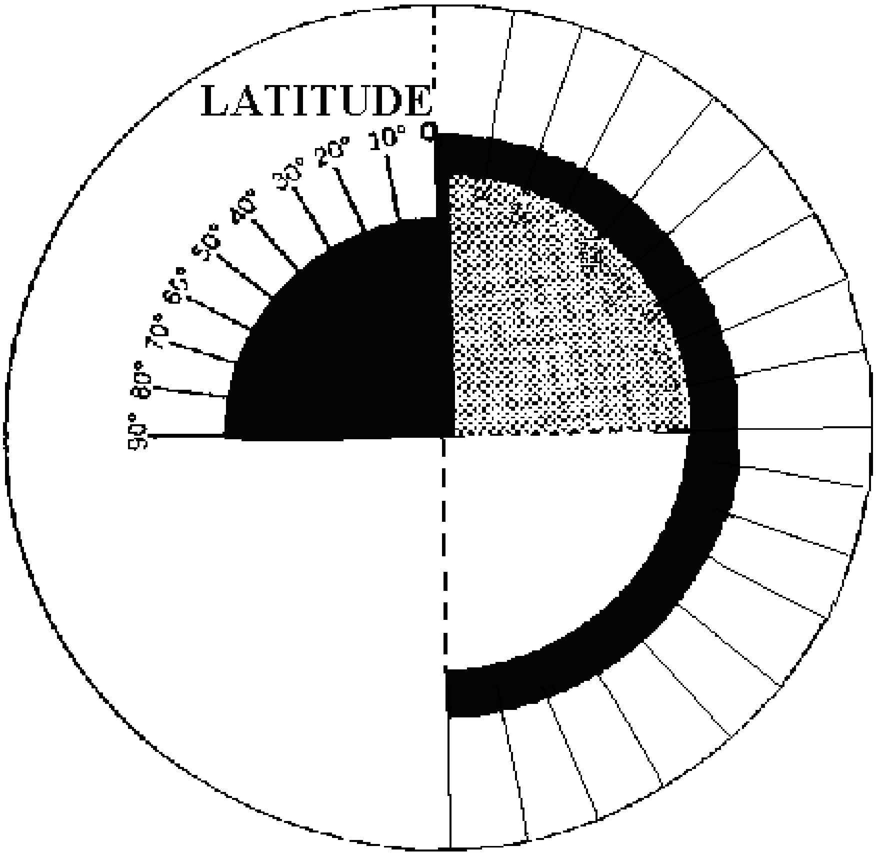

Fig. 7: The main part of the stellar demonstrator for the Northern or Southern Hemispheres.

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

With the demonstrator, it is very easy to observe how the angle of the star path relative to the horizon changes depending on the latitude (figures 8, 9 and 10).

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

We can verify this by looking at figures 8, 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.

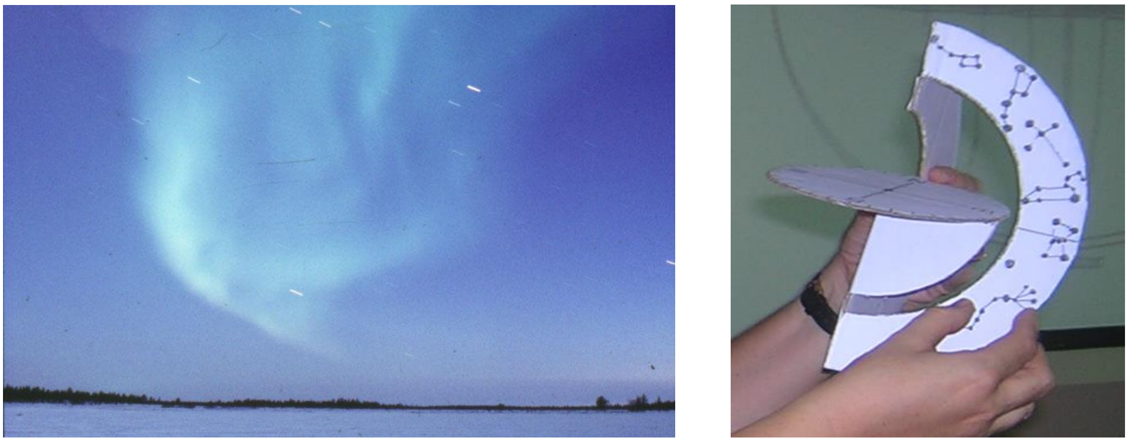

Fig. 8a and 8b: Stars setting in Enontekiö in Lapland 68ºN (Finland). The angle of the star path relative to the horizon is 90º minus the latitude. Note that the star paths are shorter than in the following photo because the aurora borealis forces a smaller exposure time (Photo: Irma Hannula, Finland).

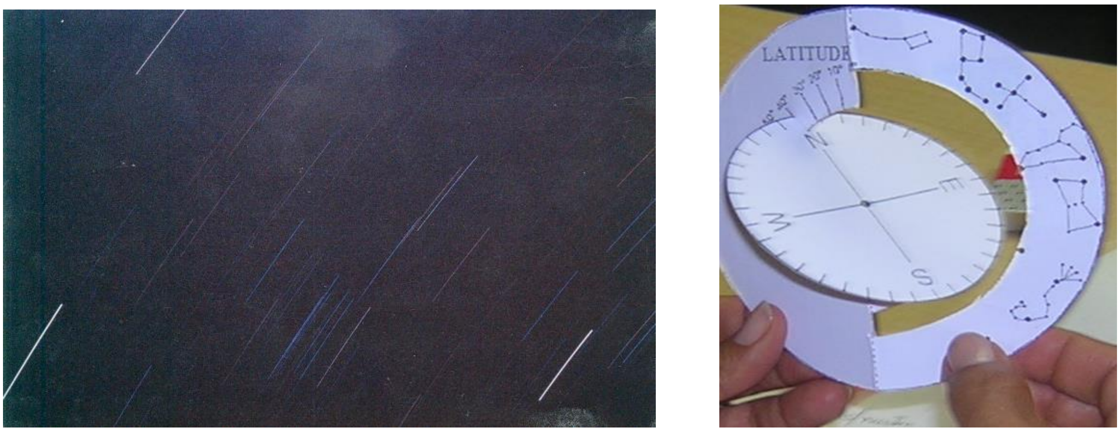

Fig. 9a and 9b: Stars rising in Montseny 41ºN (near Barcelona, Spain). The angle of the star path relative to the horizon is 90º minus the latitude (Photo: Rosa M. Ros, Spain).

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).

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

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

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

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

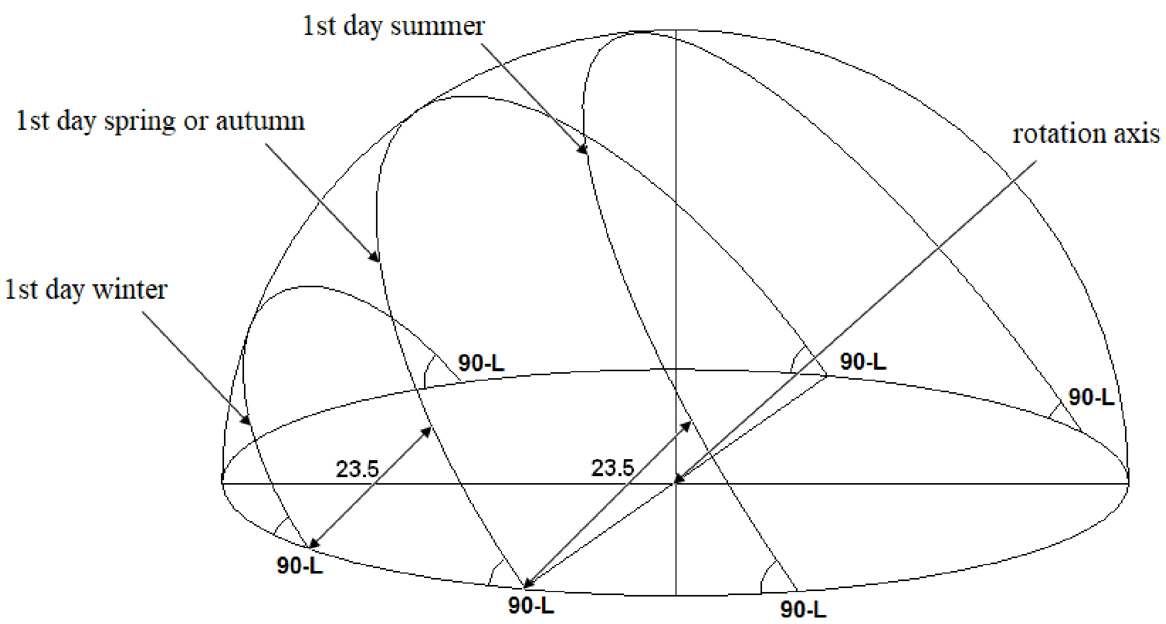

Fig. 11: Three different solar paths (1st day of spring or autumn, 1st day of summer, and 1st day of winter).

Making the demonstrator

To make the solar demonstrator, we have to consider the solar declination, which changes daily. Then we have to include the capability of changing the Sun's position according to the seasons. For the first day of spring and autumn, its declination is 0º and the Sun is moving along the equator. On the first day of summer (winter in the Southern Hemispheres), the Sun's declination is +23.5 º and on the first day of winter (summer in the Southern Hemisphere) it is -23.5º (figure 11). We must be able to change these values in the model if we want to study the Sun's trajectory.

To obtain a sturdy demonstrator (figures 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.

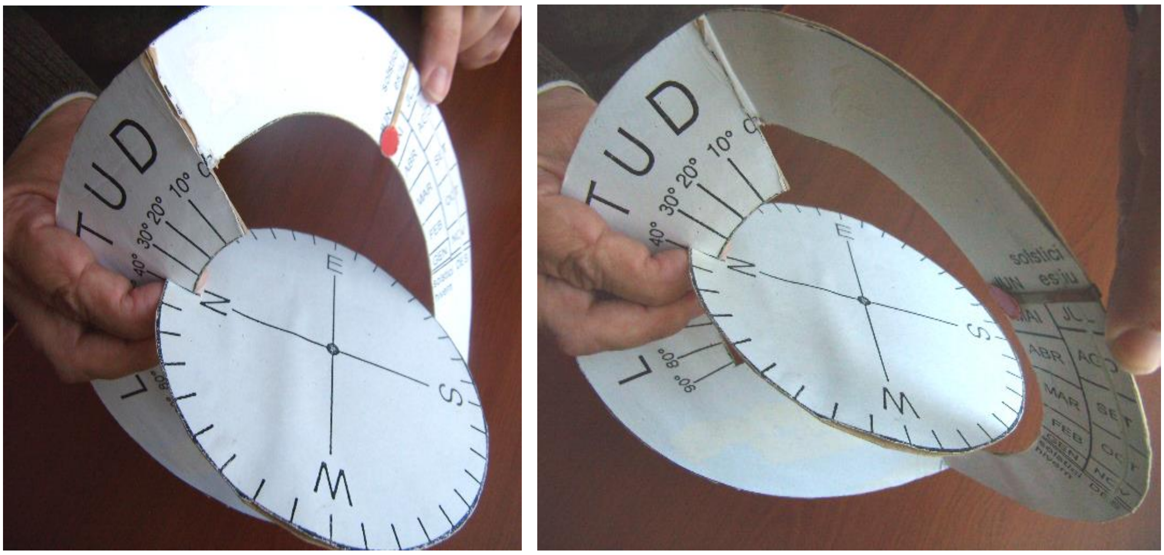

Fig. 12a and 12b: Preparing the solar demonstrator for the Northern Hemisphere at latitude +40º.

The build instructions listed below.

<u>Demonstrator for Northern Hemisphere</u>

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.

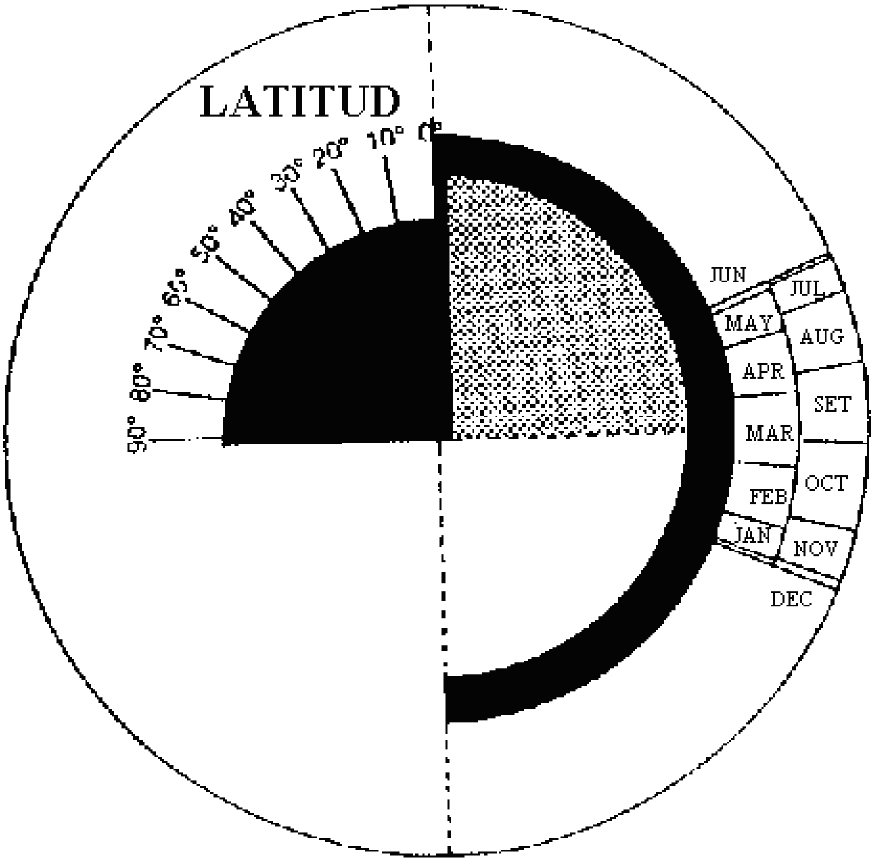

Fig. 13: The main part of the solar demonstrator for the Northern Hemisphere.

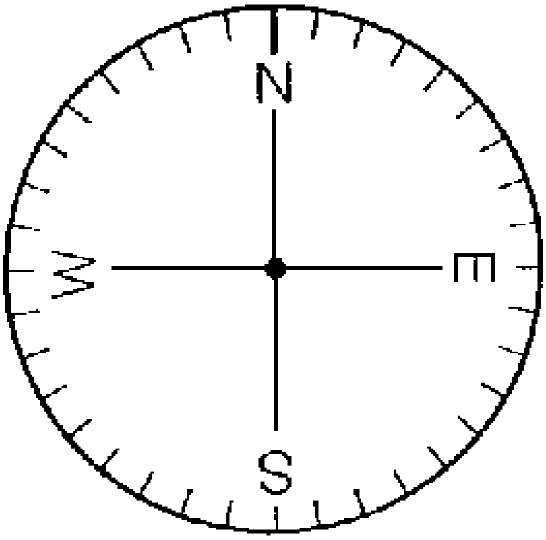

Fig. 14: The horizon disk.

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

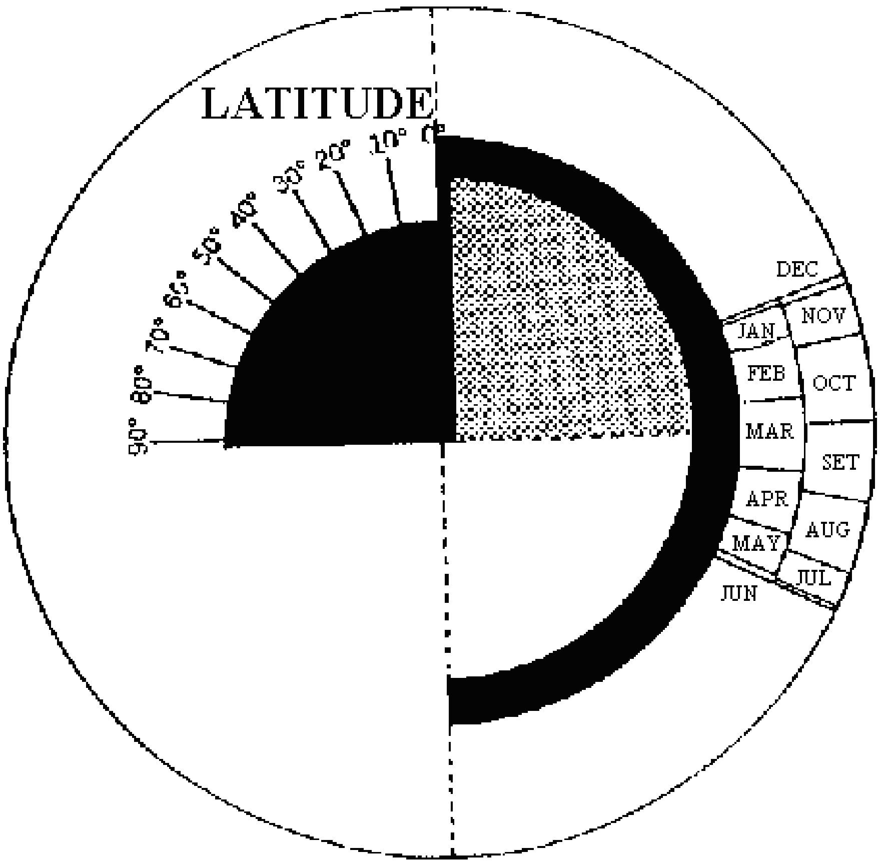

Fig. 15: The main part of the solar demonstrator for the Southern Hemisphere.

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

Using the solar demonstrator

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

We will consider three areas:

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

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

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

Using the demonstrator it is very easy to observe that the angle of the Sun's path relative to the horizon depends on the latitude. If the observer lives on the equator (latitude 0º) this angle is 90º. If the observer lives at the North or South Pole (latitude 90º N or 90º S), the Sun's path is parallel to the horizon. In general, if the observer lives in a city at latitude L, the inclination of the Sun's path relative to the horizon is 90 minus L every day. We can verify this by looking at figures 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.

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).

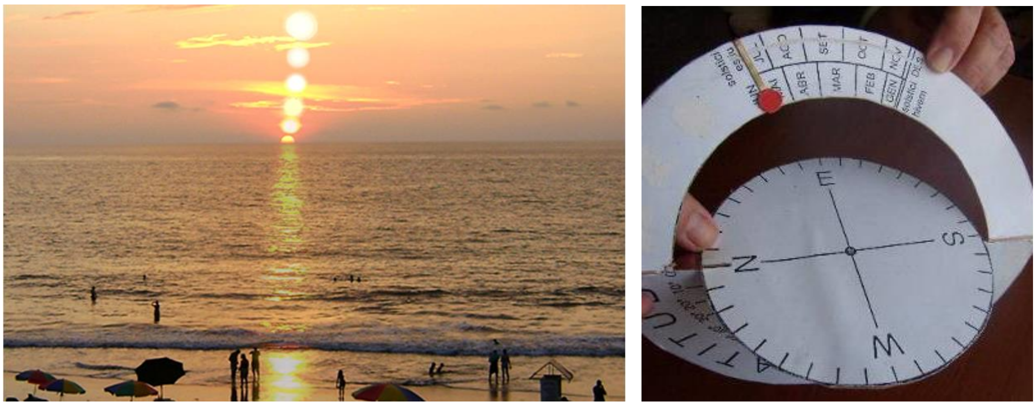

Fig 18a and 18b. Sunrise in Ladrilleros (Colombia), the angle of the path of the sun above the horizon is the co-latitude (90º- 4º = 86º). (Photo: Mario Solarte, Colombia).

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

<u>1a) the Northern Hemisphere</u>

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

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

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.

<u>1b) the Southern Hemisphere</u>

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

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

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

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

In the preceding experiments, if we had focused our attention on where the Sun rises and sets, we would have observed that it is not the same place every day. In particular, the distance on the horizon between the sunrise (or sunset) on the 1st day of two consecutive seasons increases with the increasing latitude (figures 20a, 20b and 20c).

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 more separated than in Barcelona and more than Popayán (Photos: Ilgonis Vilks, Latvia, Rosa M. Ros, Spain and Juan Carlos Martínez, Colombia).

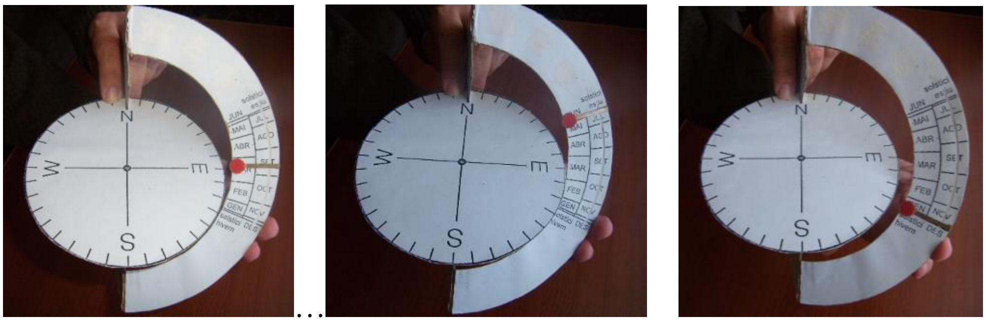

Fig. 21a: Sunrises on the first day of 1st day of spring or autumn, Fig. 21b: Sunrises on the first day 1st day of summer, Fig. 21c: Sunrises on the first day of 1st day of winter

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.

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).

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

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

2. - Polar regions: MIDNIGHT SUN

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

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

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

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

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

- ***Midnight Sun***

If we select on the demonstrator the latitude 70º N (or 70º S depending on the hemisphere under consideration), we can simulate the concept of the midnight sun. If we put the Sun on the 1st day of summer, the 21st of June, in the Northern Hemisphere (or the 21st of December in the Southern Hemisphere), we can see that the Sun does not rise and set on this day. The Sun's path is tangential to the horizon, but never below it. This phenomenon is known as the midnight Sun, because the Sun is up at midnight (figures 23a and 23b).

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).

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).

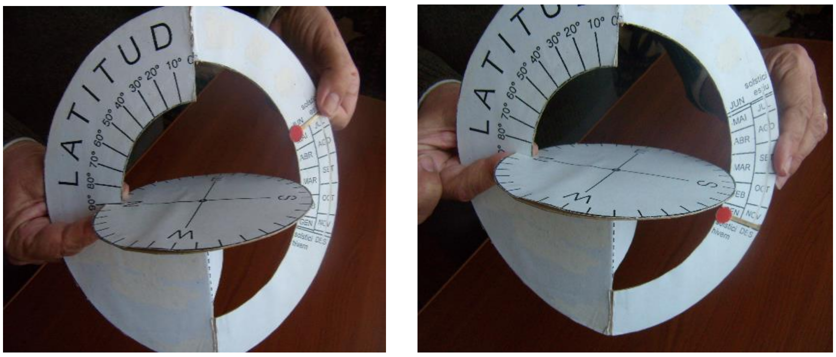

Fig. 24a and 24b: The demonstrator showing the Sun over the horizon for half a year and below the horizon for a half a year.

3. - <u>Equatorial areas: THE SUN AT THE ZENITH</u>

- ***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).

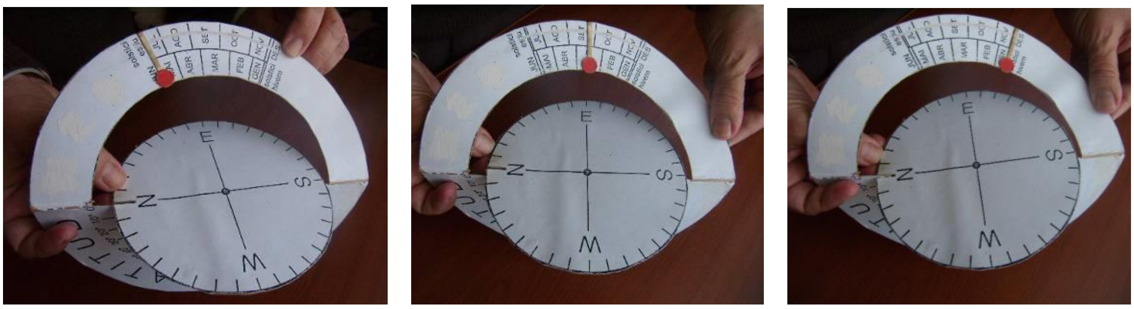

Fig. 25a, 25b and 25c: The Sun rises on the first day of each season: left - 1st day of summer, center - 1st day of spring or autumn, and right - 1st day of winter (in the Northern Hemisphere). On the equator the Sun's path is perpendicular to the horizon. The Sun rises at almost the same point every season. The angular distances between sunrises are only 23.5º (the ecliptic obliquity). In more extreme latitudes the Sun's path is more inclined and the distances between the three sunrise points increase (figures 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).

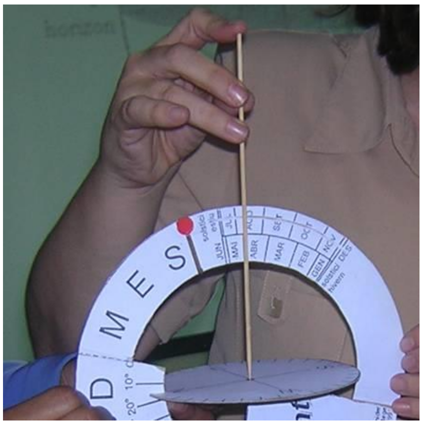

Fig. 26a: Small shadow (the Sun is almost at the zenith in a place near the equator). Fig. 26b: Simulating the Sun at the Zenith in Honduras (latitude 15º N).

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).

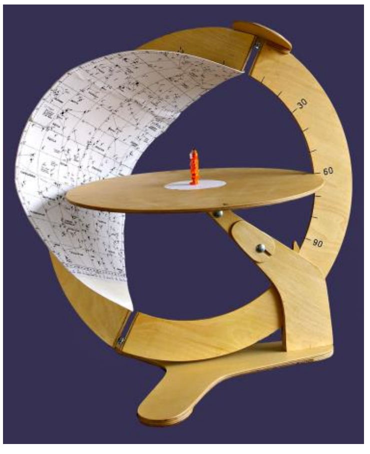

Fig. 27a: XXL wooden demonstrator. Fig. 27b: Stellar wooden demonstrator. Fig. 27c: With a camera it is possible to photograph the solar path using a large exposure time. (Photos: Sakari Ekko).

Demonstrator to show the parallel earth.

It is possible to introduce a ping pong ball in the demonstrator and thus be able to give simple explanations of the Sun's annual movement as is done with the parallel Earth model. To do this, we will use a ball similar to those of ping pong instead of the horizon circle and we will modify the main piece by introducing two supports to keep a rubber band that holds the centered ball taut (figure 28).

We will drill the ping-pong ball, or similar, diametrically as the axis of rotation and we will attach it to the main piece as you can see in figure 30.

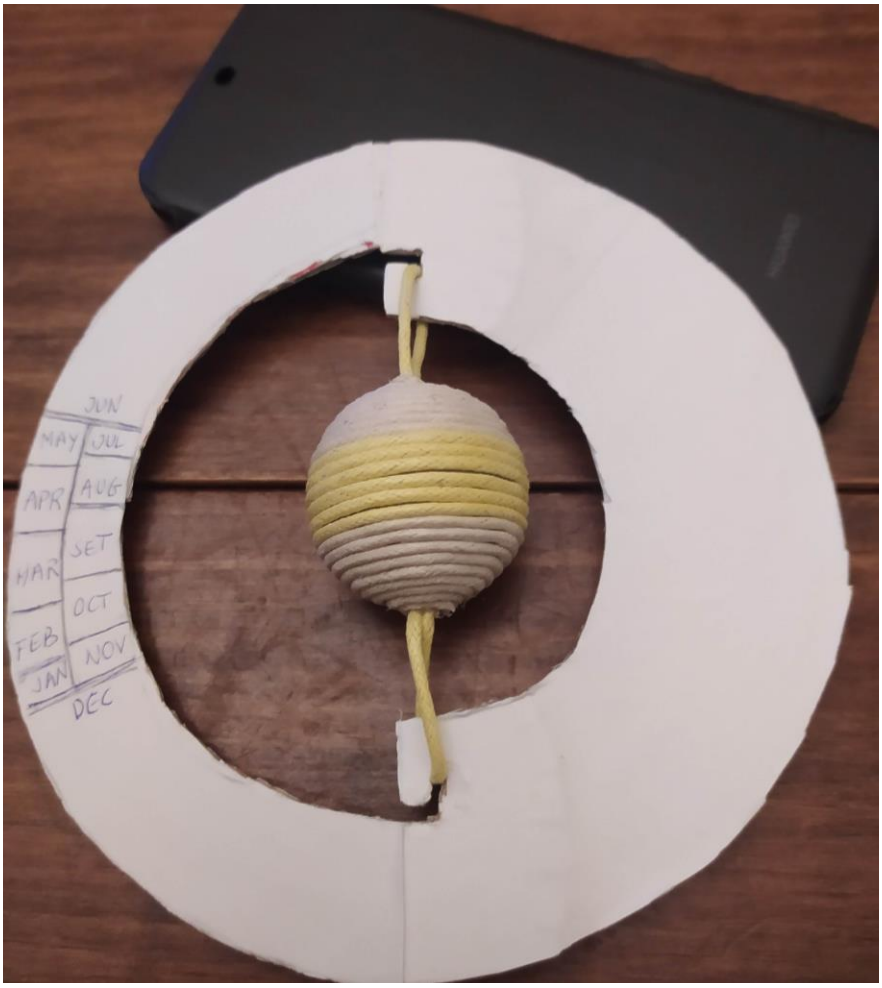

Fig. 28: Demonstrator with a ball to simulate parallel earth.

At the same time, the circle of latitudes is suppressed as it lacks interest on this occasion since the entire simulated terrestrial sphere is used with the ping pong ball (figure 29). We will then place a flashlight or the flashlight of a mobile in the month corresponding to the situation of the Sun (where the declination of the Sun is indicated). When we work in the SouthernHemisphere, this piece is analogous with the months arranged in reverse (figure 30).

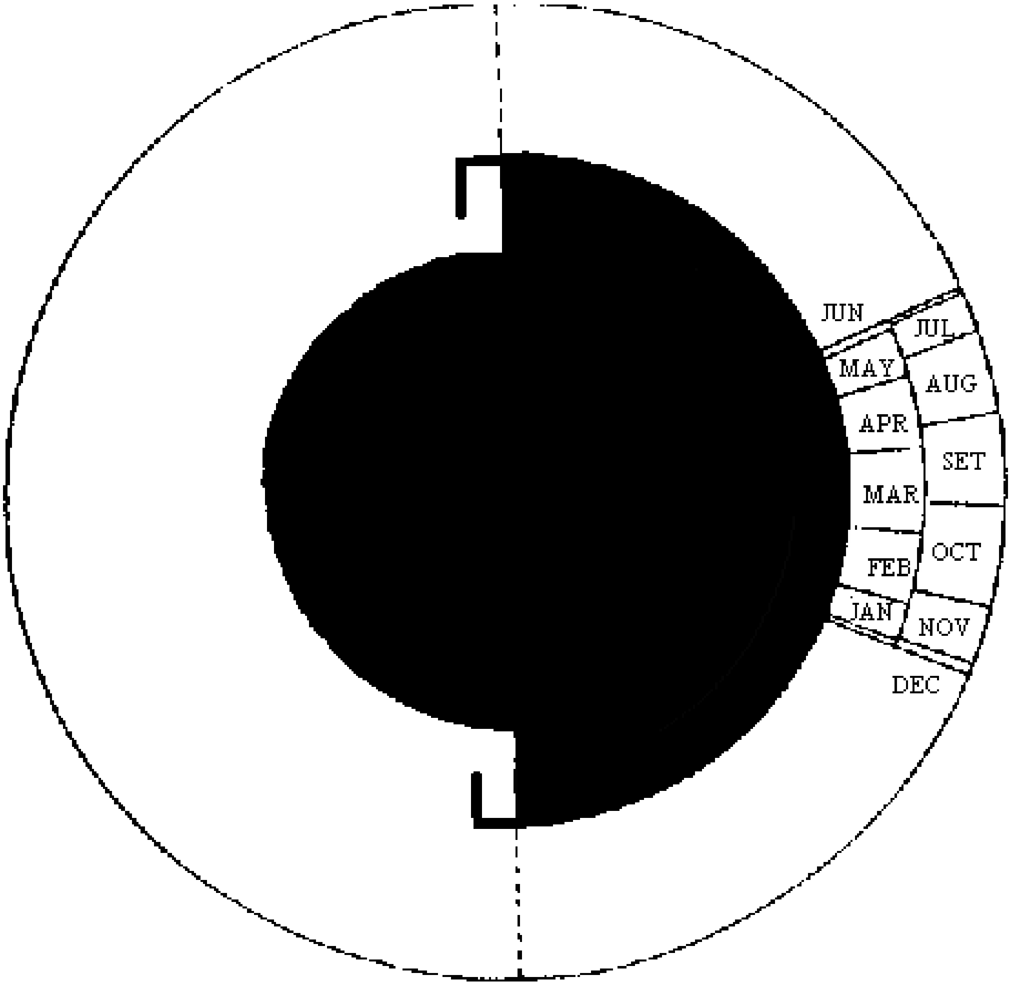

Fig. 29: Unique piece of the demonstrator where the ping pong ball is fixed, for the Northern Hemisphere. It is necessary to paste this photocopy on a slightly thick cardboard to have the strength to hold the ball.

Placing a flashlight in the position of the summer equinox, it was possible to observe that the area of the north pole is illuminated and that of the south pole is not (figure 31). With the lantern at the equinoxes, the light/shadow line passes exactly through the north and south poles (figure 32). Finally, placing the flashlight on the winter solstice, the illuminated south pole zone and the dark north zone are observed (figure 33).

Actually, this little simulator allows you to draw the Arctic and Antarctic polar circles as circles generated by the edges of the light/shadow zones.

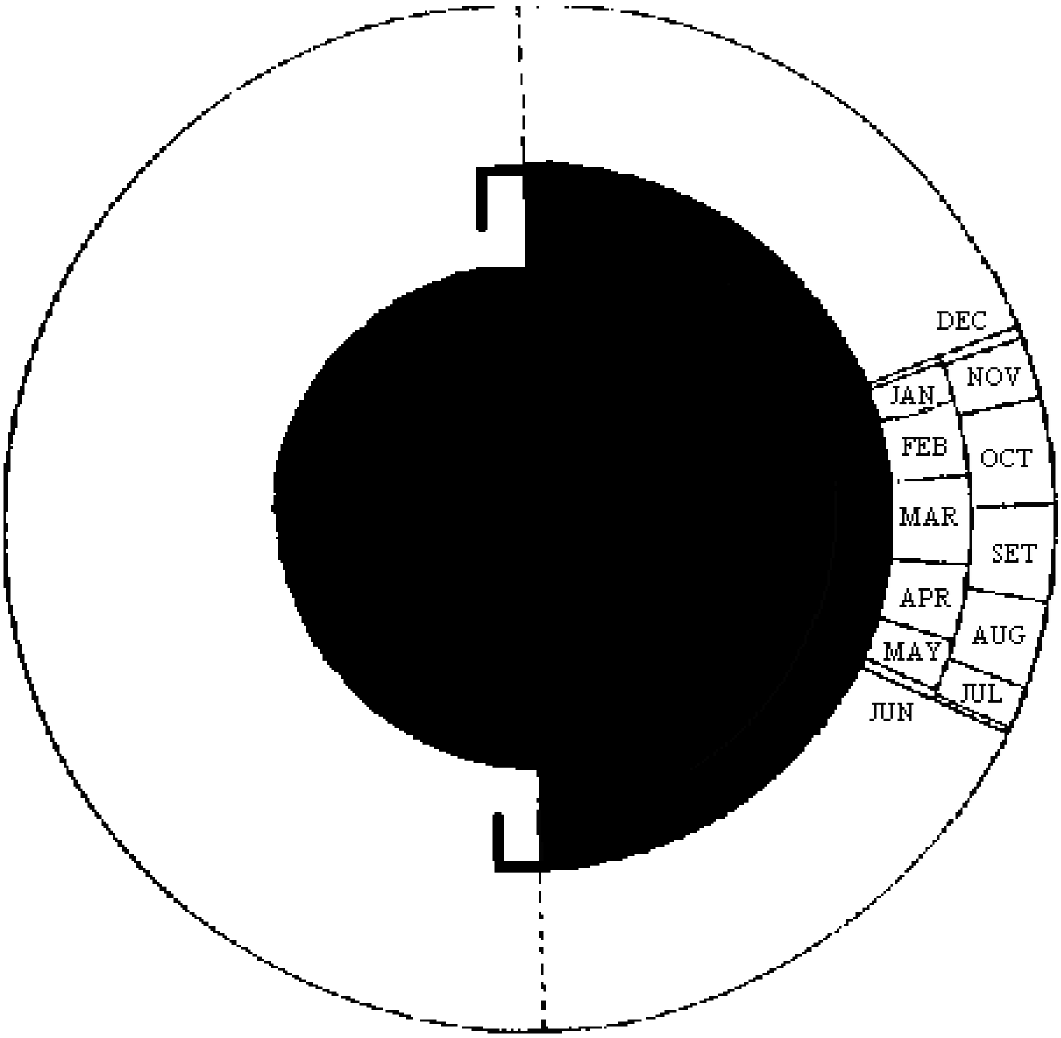

Fig. 30: Unique piece of the simulator where the ping pong ball is fixed, for the southern hemisphere. It is necessary to paste this photocopy on a slightly thick cardboard to have the strength to hold the ball.

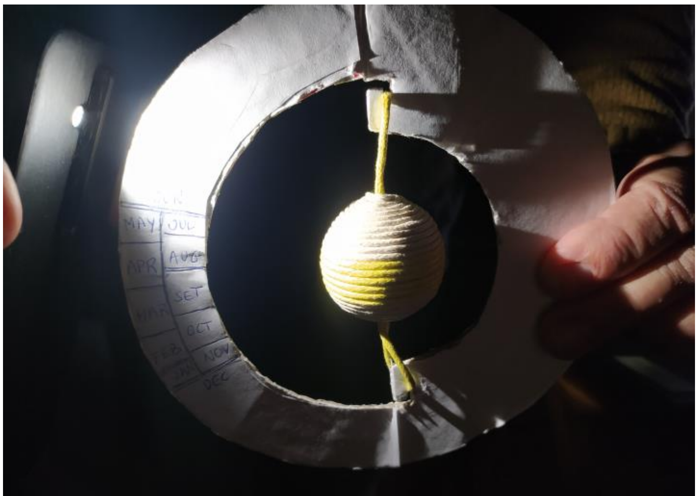

Fig. 31: Summer in the Northern Hemisphere and Winter in the Southern Hemisphere.

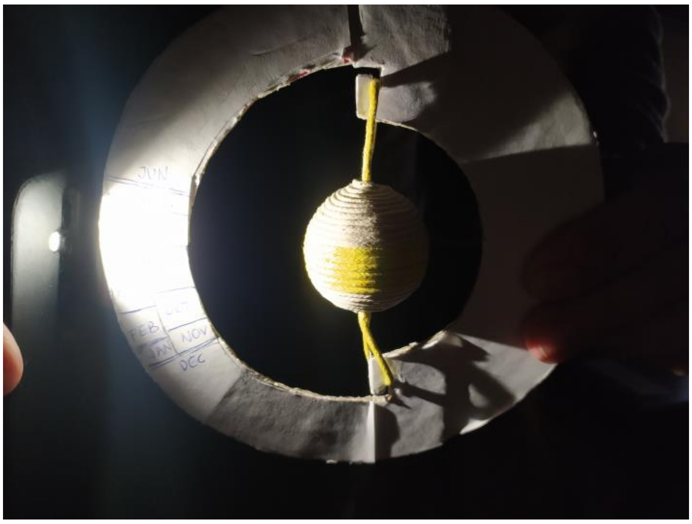

Fig. 32: Equinoxes in the two Hemispheres

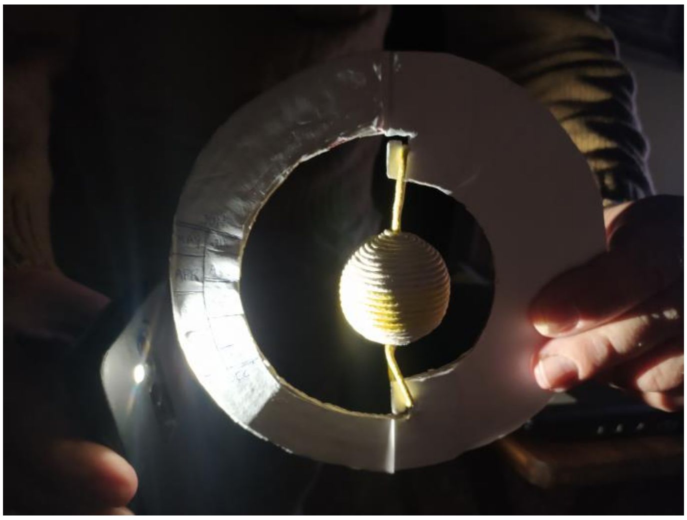

Fig. 33: Winter in the Northern Hemisphere and summer in the Southern Hemisphere.

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 34 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 34), 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 country, it is possible to observe the Moon as an inclined “C”, an inclined “D” (figure 36a) or in other cases as a “U” (called a “smiling Moon”; figure 36b). How can we explain this? We will use the lunar demonstrator to understand the varying appearance of the Moon’s quarter at different latitudes.

Fig. 34: Moon phases.

Fig. 35: Moon phases observed at the horizon.

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

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

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




Fig. 36a: Slanting crescent Moon, Fig. 36b: 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). 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 37b (quarter Moon) and glue two pieces of sticky tape on and under the cut-out of the Moon (blue half-dot). Place this transparent strip on the area of the demonstrator where the months are specified (figures 12 or 14 depending on the hemisphere). The idea is that it will be easy to move this strip up and down in this area in order to situate it on the month of choice.

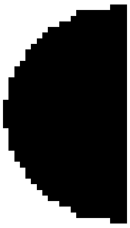

Fig. 37a: Using the demonstrator, Fig. 37b: the Moon in the transparent strip Moon quarter.

Uses of the lunar demonstrator

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

Using your left hand, hold the main piece of the demonstrator (figures 38a and 38b) 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 37b). The month that the moon is facing is where the sun will be in three months. Use your right hand to move the disk that holds the moon from east to west.

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

- If we select latitude around 70º N or 70º S we can see the quarter Moon as a “C” moving from East to West. The time of year does not matter. For all seasons the Moon looks like a “C” (figure 38a).
- 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 38b). The “U” shape does not change with the month. It looks like this all year round.
- If the latitude is 90º N or 90º S, the observer is at the Poles, and depending on the day considered:
  - -We can see the quarter Moon as a “C” moving on a path parallel to the horizon.
  - -We can’t see it, because its trajectory is below the horizon.
- If the latitude is 0º, the observer is on the equator, and we can see the quarter Moon smiling as a “U”. The Moon rises and sets perpendicularly to the horizon. It will hide (at midday) in “U” shape, and will return like this: “∩”

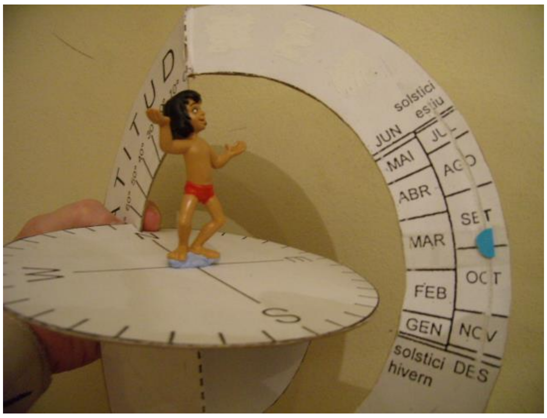

Fig. 38a: Demonstrator for latitude 70º N, Fig. 38b: latitude 20º S.

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

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

• If we introduce a -70 ° latitude (or 70 ° south) we can see the waning moon as a "D" that moves from east to west. This does not depend on the time of year. In all seasons the Moon appears as a "D" (figure 38a).

• If the latitude is -20 ° (figure 38b) 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 38b). The shape of "U" does not change depending on the month.

• If the latitude is - 90 °, the observer is at the South Pole and, according to the date, will be able to:

-View the Moon as a "D" that moves in a path parallel to horizon.
- Not see the Moon, because its path is below the horizon.

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

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

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

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

Bibliography

- Ros, R.M., *De l'intérieur et de l'extérieur*, Les Cahiers Clairaut, 95, 1, 5. Orsay, France, 2001.
- Ros, R.M., *Sunrise and sunset positions change every day*, Proceedings of 6th EAAE International Summer School, 177, 188, Barcelona, 2002.
- Ros, R.M., *Two steps in the stars' movements: a demonstrator and a local model of the celestial sphere*, Proceedings of 5th EAAE International Summer School, 181, 198, Barcelona, 2001.
- Snider, J.L., *The Universe at Your Fingertips*, Frankoi, A. Ed., Astronomical Society of the Pacific, San Francisco, 1995.
- Warland, W., *Solving Problems with Solar Motion Demostrator*, Proceedings of 4th EAAE International Summer School, 117, 130, Barcelona, 2000.