Latitude for traveling and navigate

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NASE's proposal is included in the International Day of Light, which remembers the day in which a laser beam created by human beings was turned on for the first time, it is about calculating the latitude where the participants are any day between March 20th and September 23rd, 2022, and fill the final table with data requested. This project appears in the website of International Day of light of UNESCO in the worldwide list https://www.lightday.org/events

The table with the data and results, and 2 or 3 photos of the experiment, must be sent before September 23, 2022 to newsletter.nase@gmail.com

Travel and navigate using astronomy

In 2022 NASE program proposes to return to the origins, inviting everyone to understand how the "silk road" (figure 1) emerges between two parallels, following the cities that are more or less on the same latitude to move quickly from east to west. The route linked Europe and China from Istanbul 41ºN (Turkey), Hecatompylos 36ºN (Iran), Samarkand 40ºN (Uzbekistan), Kashgar 39ºN (China) to Xi'an 34ºN (China).

Figure 1. Silk Road that linked China with Europe starting from Xian passing through Kashgar, Samarkand, the ancient Hecatompylos at the end of the Caspian Sea to Istanbul.

Likewise, we are going to discover how Columbus was able to reach America by sailing without references and trying to stay on the same parallel (figure 2) To do this, he had no complicated instruments, only a quadrant, and with it, he determined the altitude of the Polar star to follow one parallel. On the first trip he moved between the parallels of the Canary Islands (29º N) and San Salvador (25º N) and the altitude of the Polar served to determine his latitude in the northern hemisphere.

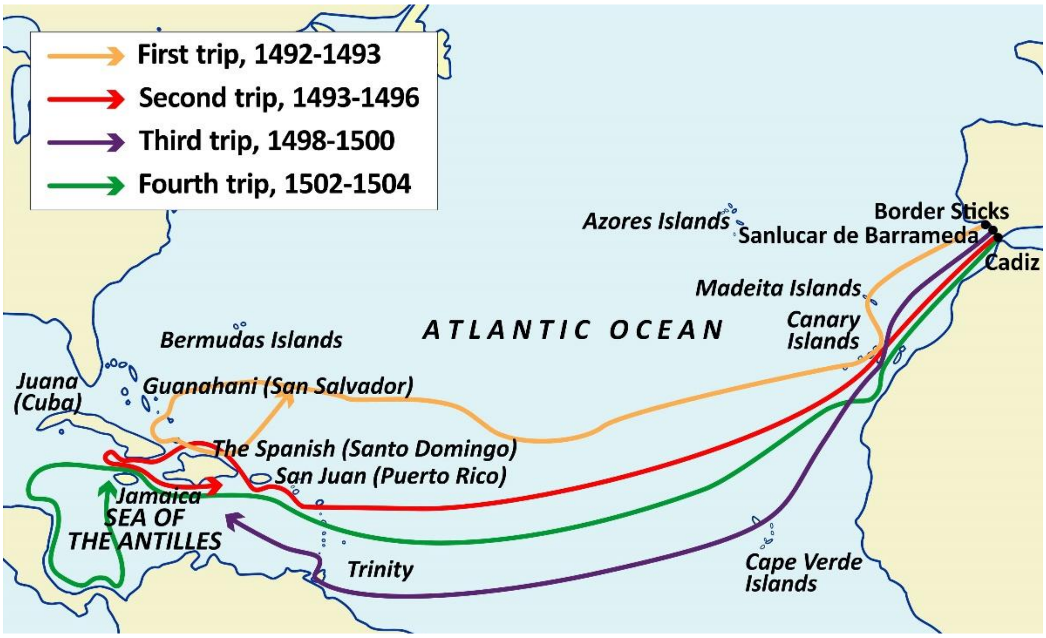


Figure 2. The four voyages of Columbus. They cross the Atlantic Ocean.
On the first voyage Columbus moves between the parallels of the Canary Islands 29ºN and San Salvador 25ºN

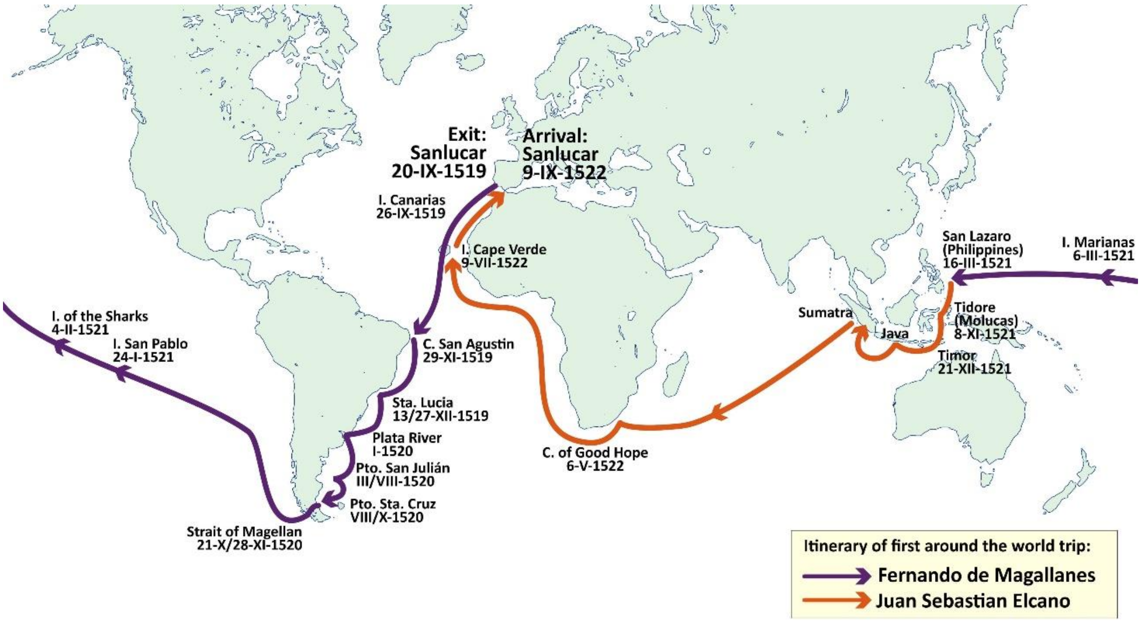


Figure 3: First circumnavigation of the world by Magellan and Elcano. In addition to the Atlantic Ocean and the Indian Ocean, they must cross the Pacific Ocean between the parallels of the Strait of Magellan (53ºS) and the parallel of the Philippines (14ºN).

On the first trip around the world (figure 3), Magellan and Elcano must cross several oceans and navigate through the equatorial zone where they cannot see the Northern Star. In this trip that lasted three years (September 20th, 1519 to September 6th, 1522) they must manage their astronomical knowledge. They used the quadrant and the solar declination tables to be able to determine the latitude by observing the altitude of the Sun. We are going to propose to the groups of students and teachers who wish to participate in the 2022 NASE project, that they determine their latitude using the same method than the ancient sailors who sailed around the world for the first time in the 16th century.

This is a project associated with the UNESCO International Day of Light, May 16th, the day when a laser was used successfully for the first time. The laser allows, among its many uses, to measure distances, therefore, it is a measuring instrument, like the quadrant. So we are going to give a more generous term, instead of just the 16th, to be able to calculate the latitude of the place of each one of the groups of ~~students~~ that collaborate in the project.

Following a few simple instructions, which will be detailed below, it is possible to determine the latitude of the place where we are in a similar way than centuries ago by Columbus, on his ships across the Atlantic. The group of observers is numerous, it will be more funny and with many measurements it will be possible to establish an average value of the latitude and calculate the dispersion in the data; finally, the group can share the experience globally, in an international event that will take place in October 2022 according the next schedule: on October 4th, 2022, the online final will take place with a group from each participating country (it is expected to have 20 or 30 countries) and on October 7th, 2022 the face-to-face final (with about 10 invited countries) will take place in Viladecans (Barcelona, Spain) as the closing of the great event for Science in Action.

How can latitude be determined?

The latitude L of the place is defined as the angle on the terrestrial meridian from the equator to the place of observation, that is, from the equator to the vertical plumb line through the place where the observer is. See figure 4; the drawing is not to scale, since the radius of the celestial sphere is infinite and the radius of the Earth is only a little over 6000 km, so the Earth is really just a point. Thus the observer's horizon is reduced to the horizon through the center of the celestial sphere. The altitude of the pole above the horizon is also the latitude because this angle is determined by the axis of rotation (which is perpendicular to the equator) and the horizon (which is perpendicular to the plumb line).

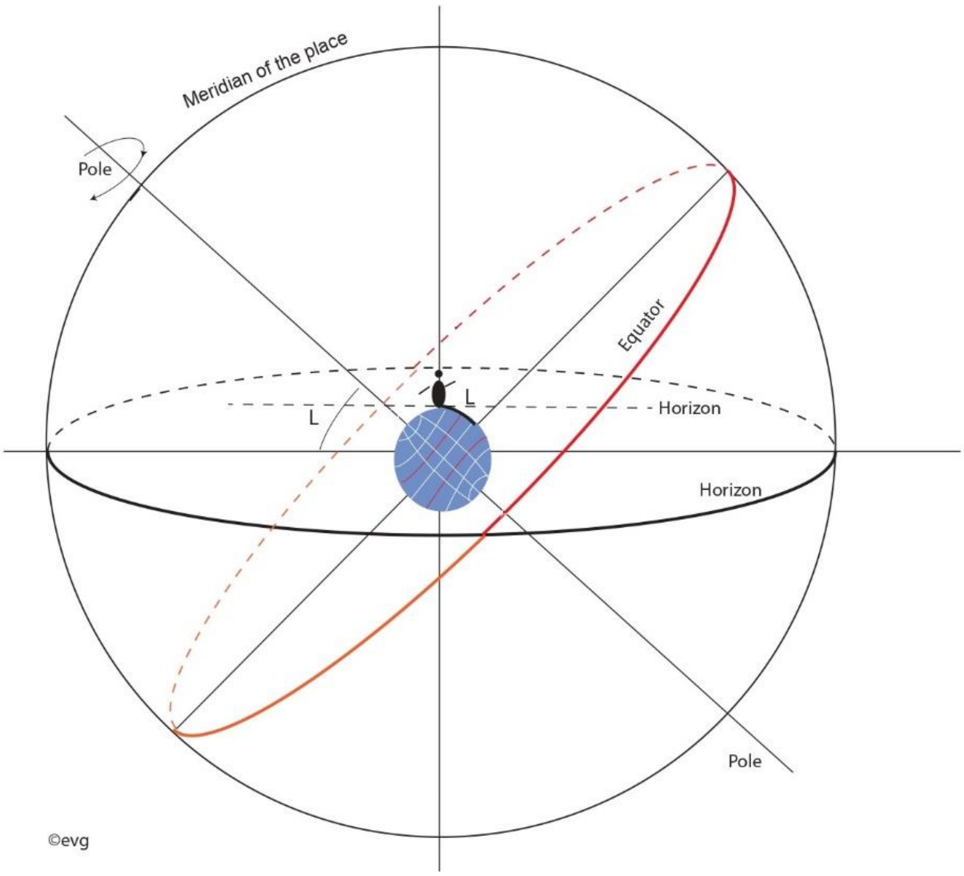


Figure 4. The latitude coincides with the altitude of the polar and the colatitude is the height of the equator at solar noon on the day of the equinox.

The determination of the latitude of the place can be done during the day or at night.

1) At night the altitude of the pole above the horizon can be determined by looking for the altitude of the Polar star, in the northern hemisphere, and for the southern hemisphere the altitude of the point corresponding to the south pole with the help of the Southern Cross, but at that point there is no star visible without telescope (in this second case the result is more approximate).
2) During the day, the altitude of the Sun can be determined at the measured day, when it passes through the meridian of the place (when it is at the highest point). On the day of the equinox, the Sun is exactly on the equator, so the altitude of the Sun that day is the co-latitude, 90-L.

The Sun always moves parallel to the equator (figure 5). Thus, at the spring and summer months it runs parallel above the equator and at the fall and winter months it runs parallel below the equator. From the equator to the day when it moves at a lower altitude (first day of winter) there is -23º.5 and from the equator at most it reaches a maximum of +23º.5 (first day of summer). The angle from the equator to parallel to where the Sun is on any given day of the year is called solar declination.

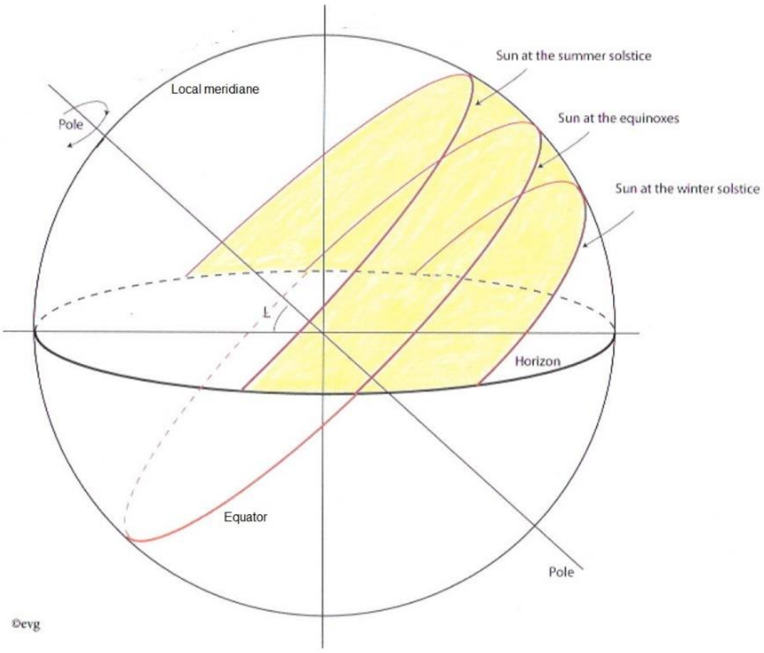
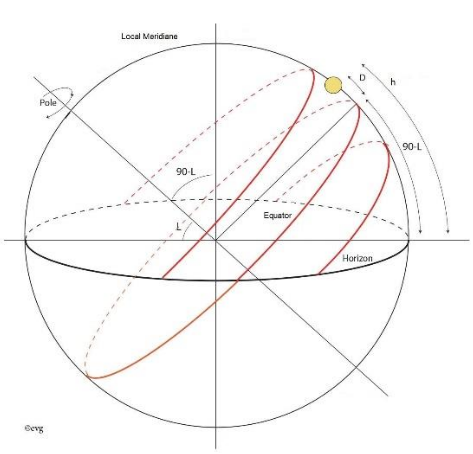


Figure 5. The Sun moves parallel to the equator where the Sun's declination varies from +23.5 degrees above to -23.5 degrees below the equator, giving rise to the two solstices.

In either of the two hemispheres, in spring or summer we see the Sun above the equator (figure 6) and its altitude h meets:

$$h-|D| = 90-|L|$$

(where D is positive or negative between 0 and +23.5º or between 0 and -23.5º depending on whether it is measured, the northern or southern hemisphere, respectively, by convention). In the same way and also by convention, latitude L is taken positive between 0º and 90º for the northern hemisphere and negative between 0º and 90º for the southern hemisphere.



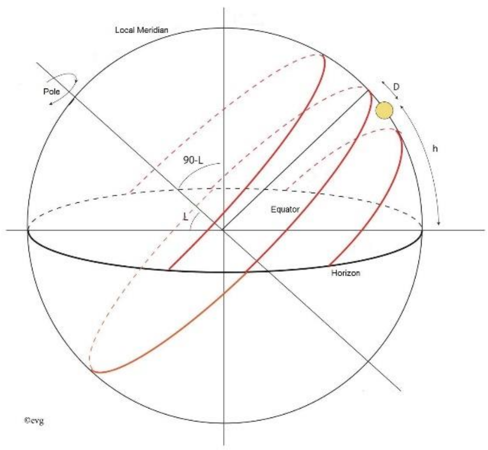


Figure 6. In spring or summer the Sun moves in parallel above the equator and its height is h-|D|=90-|L|.
Figure 7. The Sun moves in parallel below the equator and its height verifies h+|D|=90-|L|.

In both hemispheres, in autumn or winter, the Sun is seen below the equator (figure 7) and its altitude, h, verifies:

$$h+|D| = 90-|L|$$

(where D is negative or positive between 0 and -23.5º or between 0 and +23.5º depending on whether it is the northern or southern hemisphere, respectively, by convention). Latitude, N or S, as appropriate to the hemisphere where the height h of the Sun has been taken, is cleared:

L= 90-h+|D| if it is spring or summer
L= 90-h-|D| if it is autumn or winter

In summary, knowing the tabulated declination of the Sun, it is enough to obtain the altitude of the Sun with a quadrant when the sundial indicates the sun's noon (the mobile clock with the official time is not valid). Consequently, it is necessary to build a quadrant and a sundial so that it indicates to us at what moment the Sun is at solar noon and at that moment the altitude of the Sun must be measured with the quadrant.

	Enero	Febrero	Marzo	Abril	Mayo	Junio	Julio	Agosto	Septiem	Octubr	Noviem	Diciemb
1	-23 03 09	-17 17 10	-07 50 19	+04 16 57	+14 52 25	+21 57 37	+23 08 56	+18 10 51	+08 31 15	-02 55 32	-14 12 39	-21 41 35
2	-22 58 17	-17 00 09	-07 27 33	+04 40 07	+15 10 36	+22 05 50	+23 04 58	+17 55 49	+08 09 31	-03 18 49	-14 31 54	-21 50 59
3	-22 52 58	-16 42 51	-07 04 40	+05 03 11	+15 28 32	+22 13 39	+23 00 36	+17 40 28	+07 47 40	-03 42 03	-14 50 56	- 21 59 58
4	-22 47 11	-16 25 14	-06 41 41	+05 26 11	+15 46 13	+22 21 05	+22 55 50	+17 24 51	+07 25 41	-04 05 15	-15 09 43	-22 08 32
5	-22 40 57	-16 07 21	-06 18 37	+05 49 04	+16 03 38	+22 28 08	+22 50 39	+17 08 56	+07 03 34	-04 28 24	-15 28 15	-22 16 40
6	-22 34 16	-15 49 11	-05 55 27	+06 11 52	+16 20 48	+22 34 47	+22 45 05	+16 52 45	+06 41 21	-04 51 30	-15 46 32	-22 24 23
7	-22 27 08	-15 30 44	-05 32 13	+06 34 33	+16 37 41	+22 41 02	+22 39 08	+16 36 17	+06 19 01	-05 14 33	-16 04 34	-22 31 39
8	-22 19 34	-15 12 02	-05 08 53	+06 57 08	+16 54 17	+22 46 54	+22 32 46	+16 19 33	+05 56 34	-05 37 31	-16 22 19	-22 38 28
9	-22 11 33	-14 53 04	-04 45 30	+07 19 35	+17 10 37	+22 52 21	+22 26 01	+16 02 34	+05 34 02	-06 00 25	-16 39 48	-22 44 52
10	-22 03 06	-14 33 51	-04 22 03	+07 41 55	+17 26 39	+22 57 25	+22 18 53	+15 45 19	+05 11 24	-06 23 15	-16 56 60	-22 50 48
11	-21 54 14	-14 14 23	-03 58 33	+08 04 08	+17 42 24	+23 02 04	+22 11 22	+15 27 48	+04 48 40	-06 45 59	-17 13 55	-22 56 17
12	-21 44 55	-13 54 42	-03 34 59	+08 26 12	+17 57 51	+23 06 19	+22 03 28	+15 10 03	+04 25 52	-07 08 38	-17 30 32	-23 01 19
13	-21 35 12	-13 34 46	-03 11 23	+08 48 08	+18 13 01	+23 10 09	+21 55 11	+14 52 04	+04 02 59	-07 31 12	-17 46 51	-23 05 54
14	-21 25 03	-13 14 37	-02 47 45	+09 09 56	+18 27 51	+23 13 35	+21 46 32	+14 33 50	+03 40 02	-07 53 39	-18 02 51	-23 10 02
15	-21 14 29	-12 54 14	-02 24 05	+09 31 34	+18 42 24	+23 16 37	+21 37 30	+14 15 22	+03 17 01	-08 15 59	-18 18 32	-23 13 41
16	-21 03 31	-12 33 40	-02 00 23	+09 53 03	+18 56 37	+23 19 14	+21 28 07	+13 56 41	+02 53 57	-08 38 13	-18 33 55	-23 16 53
17	-20 52 09	-12 12 53	-01 36 40	+10 14 22	+19 10 31	+23 21 26	+21 18 21	+13 37 46	+02 30 49	-09 00 19	-18 48 57	-23 19 37
18	-20 40 23	-11 51 54	-01 12 56	+10 35 31	+19 24 06	+23 23 13	+21 08 14	+13 18 39	+02 07 38	-09 22 17	-19 03 39	-23 21 53
19	-20 28 13	-11 30 45	-00 49 13	+10 56 29	+19 37 21	+23 24 36	+20 57 45	+12 59 19	+01 44 25	-09 44 07	-19 18 01	-23 23 40
20	-20 15 41	-11 09 24	-00 25 29	+11 17 17	+19 50 16	+23 25 34	+20 46 55	+12 39 46	+01 21 09	-10 05 48	-19 32 02	-23 24 60
21	-20 02 45	-10 47 53	-00 01 45	+11 37 53	+20 02 50	+23 26 07	+20 35 44	+12 20 02	+00 57 52	-10 27 21	-19 45 41	-23 25 51
22	-19 49 27	-10 26 12	+00 21 57	+11 58 18	+20 15 04	+23 26 15	+20 24 12	+12 00 06	+00 34 33	-10 48 44	-19 58 59	-23 26 14
23	-19 35 47	-10 04 21	+00 45 39	+12 18 31	+20 26 57	+23 25 58	+20 12 20	+11 39 -59	+00 11 13	-11 09 58	-20 11 55	-23 26 09
24	-19 21 45	-09 42 21	+01 09 19	+12 38 31	+20 38 29	+23 25 17	+20 00 08	+11 19 40	-00 12 08	-11 31 01	-20 24 29	-23 25 36
25	-19 07 21	-09 20 13	+01 32 57	+12 58 19	+20 49 39	+23 24 11	+19 47 35	+10 59 11	-00 35 30	-11 51 54	-20 36 40	-23 24 34
26	-18 52 37	-08 57 56	+01 56 32	+13 17 54	+21 00 28	+23 22 40	+19 34 43	+10 38 32	-00 58 51	-12 12 36	-20 48 28	-23 23 04
27	-18 37 32	-08 35 31	+02 20 05	+13 37 16	+21 10 55	+23 20 44	+19 21 32	+10 17 43	-01 22 13	-12 33 06	-20 59 54	-23 21 06
28	-18 22 06	-08 12 58	+02 43 35	+13 56 24	+21 21 01	+23 18 24	+19 08 01	+09 56 44	-01 45 34	-12 53 26	-21 10 55	-23 18 40
29	-18 06 21		+03 07 01	+14 15 19	+21 30 43	+23 15 39	+18 54 11	+09 35 35	-02 08 55	-13 13 33	-21 21 33	-23 15 46
30	-17 50 16		+03 30 24	+14 33 59	+21 40 04	+23 12 30	+18 40 03	+09 14 17	-02 32 14	-13 33 28	-21 31 46	-23 12 24
31	-17 33 52		+03 53 43		+21 49 02		+18 25 36	+08 52 50		-13 53 10		-23 08 34

Table 1: Sun Declinations along the year. The + sign means that the Sun is towards the northern celestial hemisphere and the - sign means that it is towards the southern celestial hemisphere.

It is evident that any of the two equinoxes are the days when it is easier to calculate the latitude. On equinox days, the Sun is at the equator and therefore its declination is null, giving rise to the altitude of the Sun being exactly 90-L colatitude at solar noon, thus

L= 90-h **in the equinoxes**

And it is not necessary to use the declination tables.

How to build a quadrant?

The invitation is then to make a simple quadrant (figure 8). To build the NASE pistol quadrant (workshop 4), you only need:

1. Cut a 20x10 cm piece of cardboard with a handle (figure 8).
2. Cut and paste the figure 9 calibrated quadrant.
3. Fix a 20 cm thread at the origin of the quadrant.
4. Tie a washer or nut to the end of the thread (to keep the rope taut).
5. Place a straw, or paper cylinder on top; use paper tape to keep it fixed (figure 8).

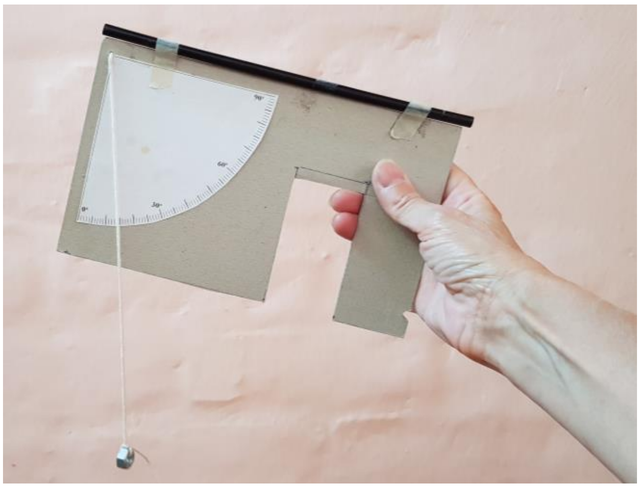


Figure 8. NASE quadrant finished

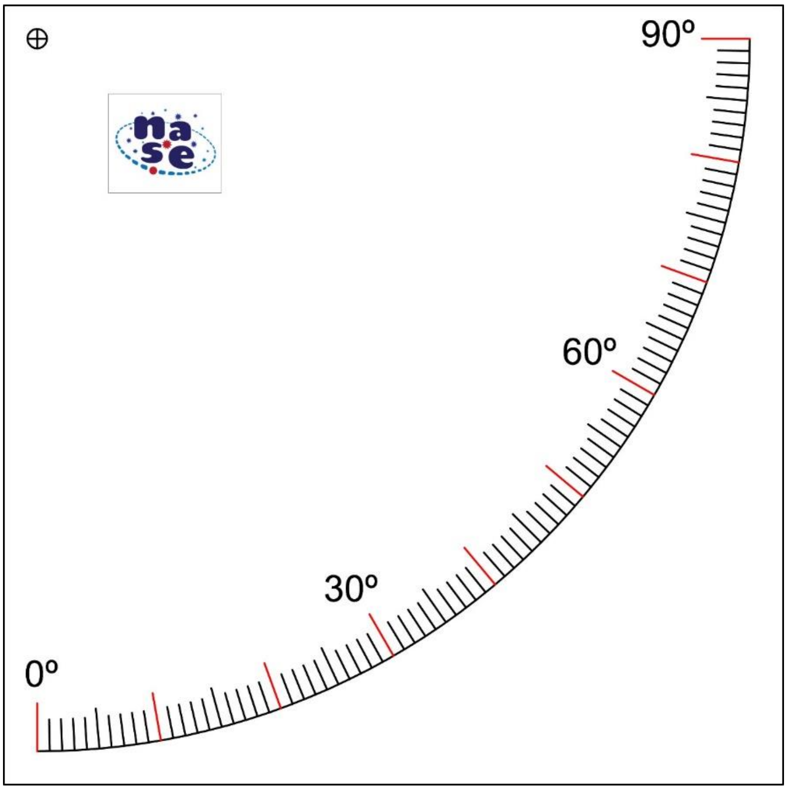


Figure 9: Graduated quadrant to glue on the cardboard.

A second, easier option to build a quadrant (NASE-workshop 1) consists of:

1. Use a rule of 20 or 30 cm.
2. Fix a protractor with blue-tac (figure 10).
3. Fix a 20 cm thread at the origin of the protractor graduation.
4. Tie a washer or nut to the end of the thread (to keep the rope taut).
5. Place a straw, or paper cylinder on top of the ruler with tape (figure 10).

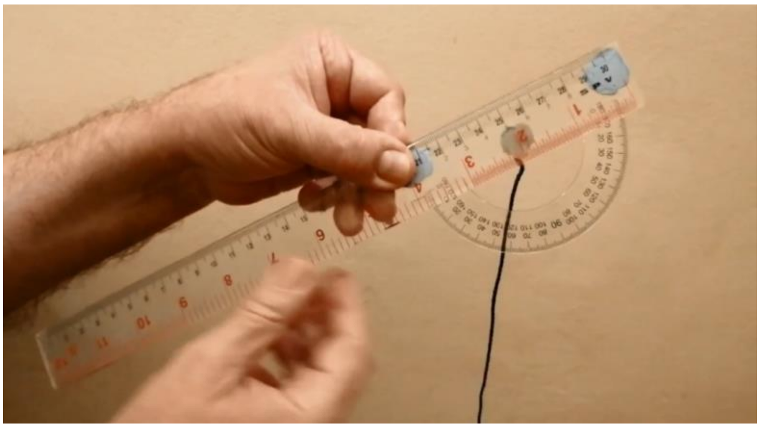


Figure 10: Quadrat with rule and protractor

Use of the Quadrant (NASE Workshop 4)

To determine the altitude of an object, you must point and look through the straw that acts as a scope (figure 11). The angle, which we read on the dial, gives us the angular altitude of the object above the horizon, since the plumb line is perpendicular to the horizon and the viewfinder is perpendicular to the 0 edge of the graduation.

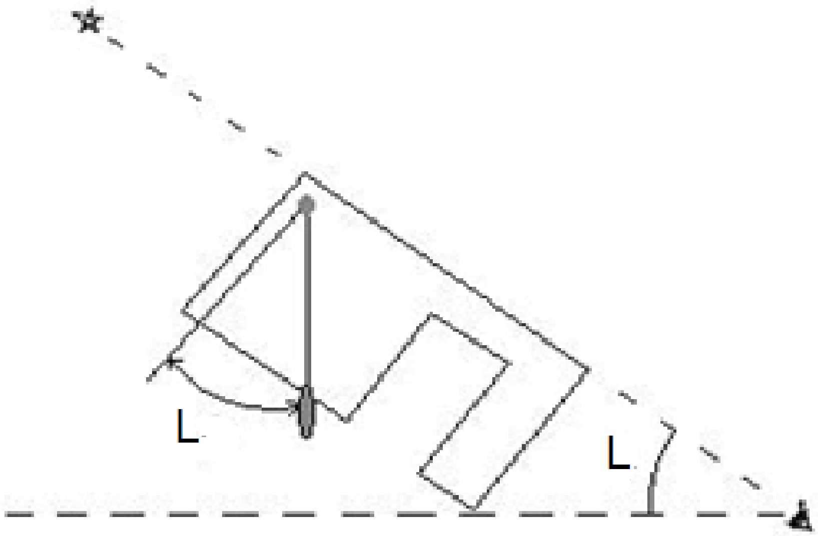


Figure 11: El ángulo que se lee en el cuadrante coincide con la altura del objeto sobre el horizonte.

If the object to be considered is the Polar star, it is observed directly through the viewfinder. But if it is the Sun, it is dangerous to look directly at it and the observation must be by projection as seen in figure 12.

Figure 12. Use of the quadrant by projection.

How is an equatorial sundial built? (NASE Workshop 1)

The Sun moves parallel to the equator, making a complete 360º turn in 24 hours, so dividing both, it follows that it travels 15º every hour. Since the apparent motion of the Sun revolves around the Earth's axis of rotation, we will use a gnomon as a stylus in the direction of the Earth's axis of rotation. When the sun passes exactly through the local meridian, it corresponds to solar noon, so the hour line of as 12 must be projected on the north south line. Consequently, we need to use a compass to orient the equatorial clock and place the stylus or gnomon in the direction of the north-south line.

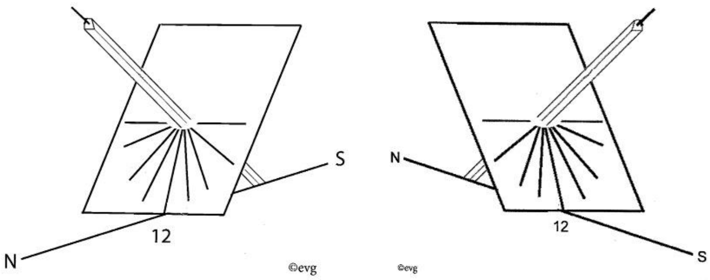


Figure 13. Orientation of an equatorial sundial in the northern hemisphere (left) and in the southern hemisphere (

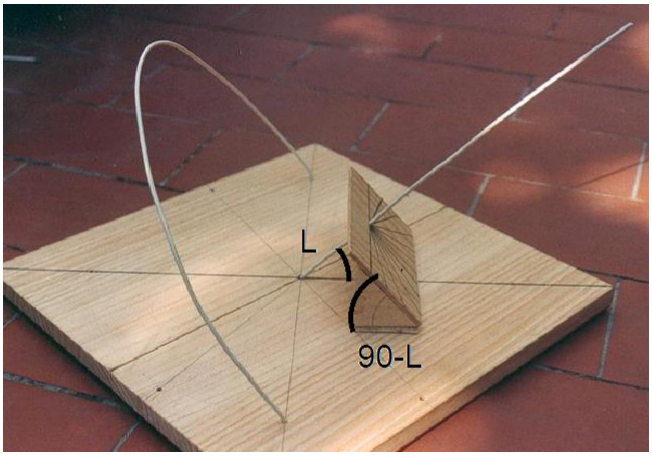


Figure 14: An equatorial clock has the stylus in the direction of the earth's axis of rotation and the plane must be parallel to the equator. Thus the angle of the pole height is the latitude of the place L, and the inclination of the plane (perpendicular to the stylus) is the colatitude of the place.

To build the sundial, just use the models in figures 15 and 16. To do this, just:

1. Fold the plane of the clock (figure 15) along the dotted line.
2. Glue both sides and insert a stylus (it can be a wooden stick) through the central hole.
3. Cut the stylus according to figure 16, leaving the yellow part above the plane and leaving the piece in the lower area depending on the latitude of the place.
4. Fix the watch plane perpendicular to the stylus.
5. Check that the plane forms an angle equal to the co-latitude with the ground.
6. Orient the projection of the stylus on the ground according to the north-south line indicated by the compass (figure 13).

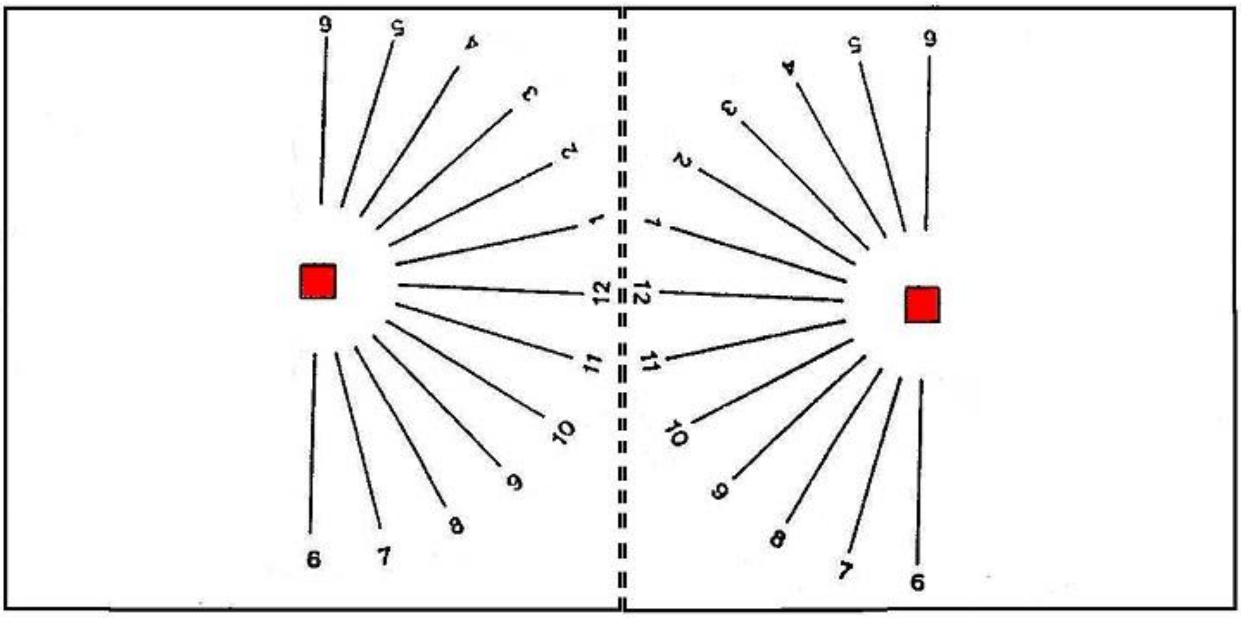


Figure 15. Plane of the ecuatorial sundial

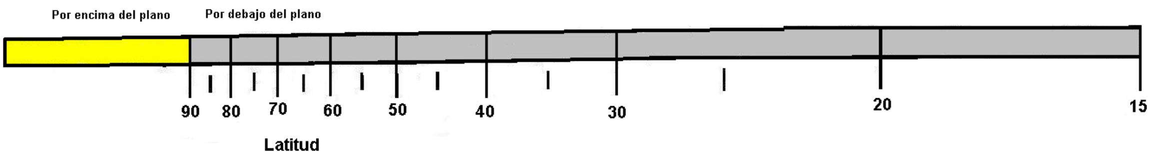


Figure 16. Reference to cut the gnomon according to the latitude of the place

Record latitude and other data

Location City, country	Day, Month	Hour	Solar Declination	Obtained Latitude using pole	Obtained Latitude using Sun	Real Latitude

Tabla2: Data collection and obtaining the Latitude of the place

Conclusions

This experience makes it possible to use an old instrument and demonstrate that to obtain important results, new or sophisticated technology is not always needed.

Think now of the sailors and adventurers of past centuries. What can you conclude about:

a) The silk road:
Did it unfold following exactly the same parallel?
Why do you think it was how we see it or detect it on the maps?
What remarkable things could you describe about this ancient road?
Have you heard or read recent news about the Silk Road?

b) The different voyages of Columbus:
Did they all follow the same path?
What is unique about the trajectory of the 1st trip?
Why do you think the trajectories were changed in the different expeditions?

c) The trip around the world of Magellan and Elcano:
What singular things could you mention regarding this trip beyond its duration?
Did this proposal help you understand how these true adventurers managed to circumnavigate the planet?
Would you dare to propose your own journey and explain how you would use the quadrant?

If you wish, write a short story that inspires other people!

We invite you to investigate, discuss with your teacher and classmates and send your results and conclusions to: newsletter.nase@gmail.com

Bibliography

- 14 Steps to the Universe, 2nd. Edition. Eds. Rosa M. Ros & Beatriz García, Editorial Antares, Barcelona, 2018.