NASE

Instituto de Tecnologías en Detección y Astropartículas - Mendoza, Argentina

[YouTube channel NASE-Virtual]

Editors: Rosa M. Ros & Beatriz García

International
Day of Light
16 May

2nd Bridges between Cultures

Latitude for traveling and navigate

NASE

Instituto de Tecnologías en Deteccion y Astropartículas
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Welcome

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Welcome to the second edition of "**Bridges Between Cultures"**, an initiative of the Network for Astronomy School Education for the UNESCO International Day of Light-March 16th, which first encounter was in 2021, in the middle of the very hard days of pandemic and as a way to continue establishing links between the people around the Globe.

In 2022, a new project is the center of attraction to establish the *"bridgest*", the use of Astronomy to determine the latitude, opening new possibilities for humans: travel and navigate beyond the very well known roads or having the shore permanently visible. One of these approaches connects with the discovery of America and the trip around the world, to the West, and on the other hand, the design of the ancient Silk Road, to the East.

As we mention, this proposal is based on the International Day of Light, proposed by UNESCO wth the purpose to remember the first successful use of the laser, but also, to enlighten the general uses of light to improve everyday life. In 2022 we propose to use the sunlight to, through its altitude at noon, to establish the local latitud using a simple quadrant. This is also the opportunity to remark the power of collaborative works in sciences, designing activities with a theoretical framework, which need measurements and clear results, as a global project.

Bridges between Cultures is also a Citizen Sciences proposal that follows three main goals: *engagement* of teachers, professors, students and general audiences, *promotion* of the sciences in general, and *innovation*.

In general, the students know the fantastic enterprise of Columbus in his trips to America, and the expedition planned and led by the explorer Fernando Magallanes, which departed from Spain on September 20th, 1519, and culminated with the first circumnavigation of the world by Juan Sebastián Elcano, who returned to Spain on September 6th, 1522. This year is the 500-year anniversary of this adventure!. And also, as the “Modern Silk Road” is an actual topic, these events can be part not only of the NASE invitation, but also of the yearly studies in all the schools on the Planet, acting as traction to perform the activity but also as attraction, in a moment when this themes are part of the everyday life.

We would like to give our special thanks to the presenters for the day of the workshop, the assistants, taking into account that we needed to coordinate the timeline for the meeting to permit the participation from all the Earth Time Zones, from America to Asia, and the future participants, which will develop the proposed activity between the equinoxes in 2022.

Thank you, welcome and enjoy this new *Bridges Between Cultures* edition!

Introduction

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This book is a wonderful collection of articles from across the globe that describe methods of navigation for travel and show how students may perform similar activities from which to learn.

Bridges between Cultures got its start in 2021 with a virtual workshop in March. Now, a year later, the International Astronomical Union's Network for Astronomy in School Education (NASE) continued this most successful event with a second session.

The pages ahead begin with Rosa M. Ros, Beatriz Garcia, Eder Viñuales, and Ricardo Moreno of NASE setting the stage for the articles in the sections that follow by introducing the use of astronomy for navigation with travel. They present good basics about the determination of latitude and then describe how to build quadrants and equatorial sundials that can be used in the classroom or at home.

The book is divided into three sections that were covered in this year's Bridges between Cultures workshop – the Silk Road, Journey around the World by Magellan and Elcano, and the Four Journeys of Columbus.

The Silk Road

Carlos Dorce of Spain begins with a description of medieval observatories along the Silk Road and he highlights early astrolabes and the determination of latitude. He gives good examples of such observatories.

Dongni Chen of China is much more direct with an experiment suitable as a student activity regarding latitude with self-made instrumentation.

Mongolia being along the Silk Road, Tsolmon Renchin and Altangerel Balgan tell us briefly of related Mongolian history and then describe the NASE student activity that they used to demonstrate the finding of latitude for travel navigation.

The Iranian Teachers Astronomy Union (ITAU) continues in this same direction. Parham Eisvandi, Mahdi Rokni, Rahimeh Foroughi, Fatemeh Salimi, Samaneh Tafazolinia, Siavash Eisvandi, Fatima Baghbani, and Anahita Zadsar describe students engaged in NASE programs using quadrants to find the altitude of the Sun at solar local noon. They added that this exercise was well suited for students during the Covid 19 pandemic.

Journey Around the World by Ferdinand Magellan and Sebastián Elcano.

Cesar Esteban starts the section about the world travel of Magellan and Elcano. He provides a good historical introduction and then discusses two methods for

determination of latitude and then proceeds with its importance for this expedition's navigation.
Pide Aristide Ahanhanzo next discusses primary and secondary school experiments in Benin where students learned to build a sundial and a quadrant and then explored their use for altitude and latitude.
In Togo, Doh Kof fi Addor continued in the same vein with a description if the construction and use of an equatorial sundial to be employed along with a quadrant to determine latitude during an astronomical tour for students and teachers that was called "Togo Under the Stars."
Aditya Abdilah Yusuf describes the maritime history of Indonesia and how its navigators used the stars to find their way. The Institut Teknologi Sumatera (ITERA) endeavors to keep these cultural traditions alive in students and the author shows the construction and use of NASE sundials and quadrants here as well.

The Four Journeys of Cristobal Columbus

Enrique Aparicio Arias of Spain begins the section on Columbus by describing the perceived need for a sea route for trade as an alternative to the Silk Road. He describes related cartography and goes into considerable detail regarding the instrumentation for determining latitude used by Columbus.
A student workshop for determining latitude was conducted in Nicaragua as described by Ligia Areas Zavala and Ricardo Canales Salinas. The experiment took place near the time of the vernal equinox on March 21, 2022 in Managua, once again using a self-made sundial and a self-made quadrant. The students later repeated the experiment on April 21, 2022 to record solar data at the time of the zenith Sun.
Edgar Cifuentes relates yet another example of the determination of latitude by students who used a sundial and quadrant, this time in Guatemala.
Madelaine Rojas of Panama began by describing Columbus' career at the time of his fourth voyage – by this time his privileges were in decline. She relates good history and continues with his astronomy and use of instrumentation for navigation.
Finally, Juan A. Prieto Sánchez and Mª Pilar Orozco Sáenz of Spain described a secondary school student workshop conducted in Algeciras. The students made and used quadrants while learning how sailors employed them for navigation by the Sun and stars. Students also had the opportunity to explain their work to the general public at a local science fair.

These articles that follow are both enlightening and inspirational in their descriptions of history and with the many examples of how quadrants and sundials can be constructed to fascinate students with this type of astronomy. You will enjoy them very much as you read.

Traveling and navigate using astronomy

Rosa M. Ros, Beatriz García, Eder Viñuales and Ricardo Moreno

NASE

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.

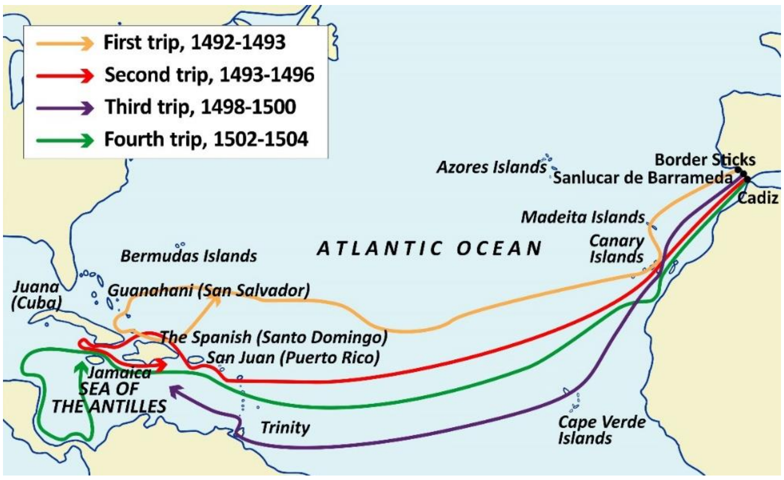


Figure 2. The four voyages of Columbus. They cross the Atlantic Ocean.
On the first voyage Columbus moves between the parallels of the Canary Islands 29ºN and San Salvador 25ºN

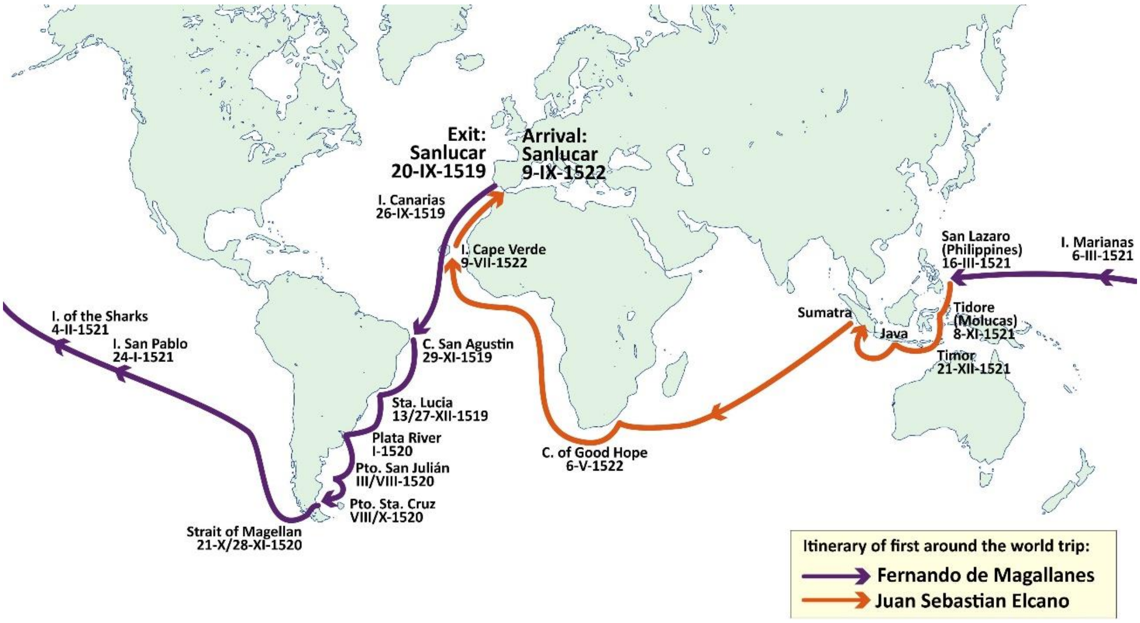


Figure 3: First circumnavigation of the world by Magellan and Elcano. In addition to the Atlantic Ocean and the Indian Ocean, they must cross the Pacific Ocean between the parallels of the Strait of Magellan (53ºS) and the parallel of the Philippines (14ºN).

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).

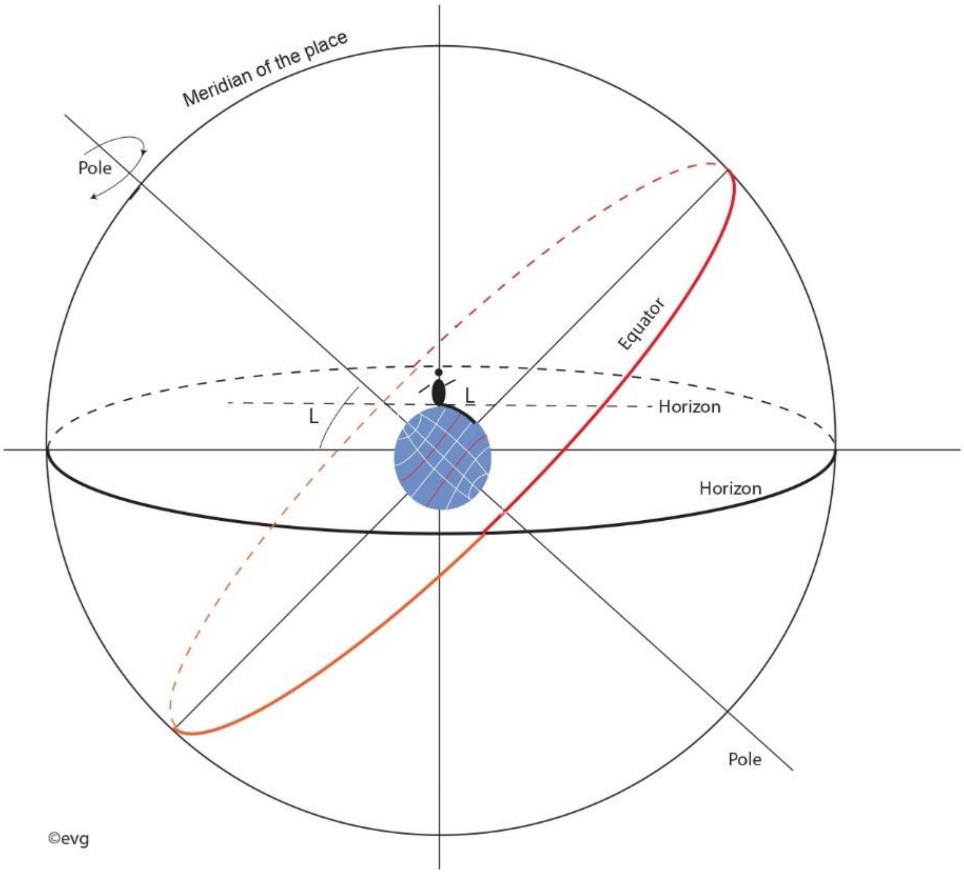


Figure 4. The latitude coincides with the altitude of the polar and the colatitude is the height of the equator at solar noon on the day of the equinox.

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.

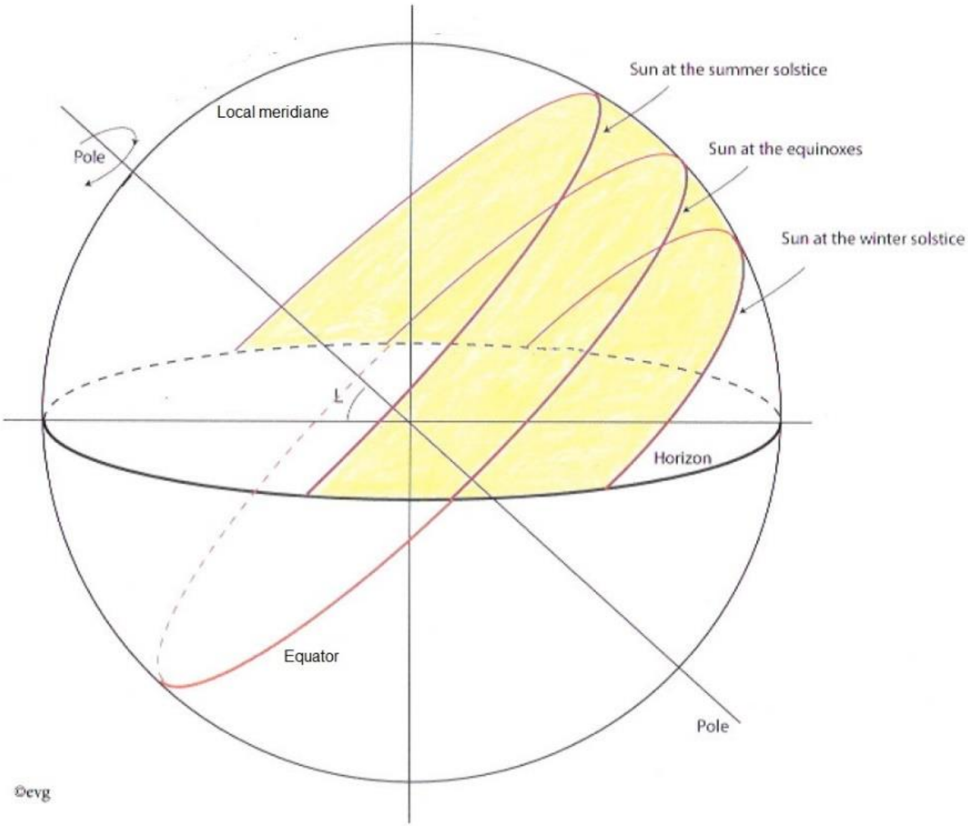
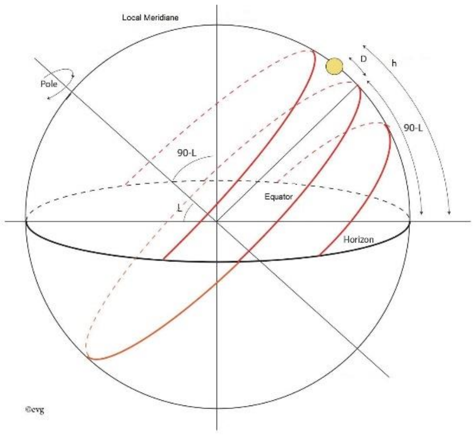


Figure 5. The Sun moves parallel to the equator where the Sun's declination varies from +23.5 degrees above to -23.5 degrees below the equator, giving rise to the two solstices.

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.



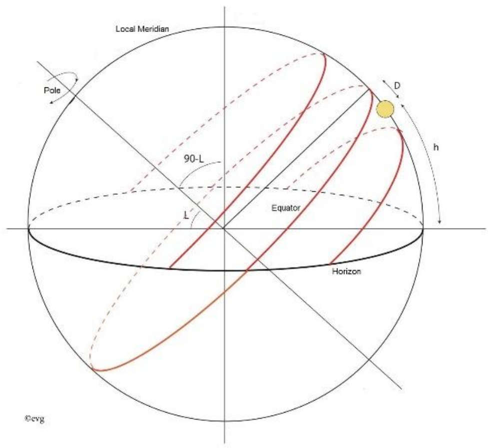


Figure 6. In spring or summer the Sun moves in parallel above the equator and its height is h-|D|=90-|L|.
Figure 7. The Sun moves in parallel below the equator and its height verifies h+|D|=90-|L|.

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

	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.

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.

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).

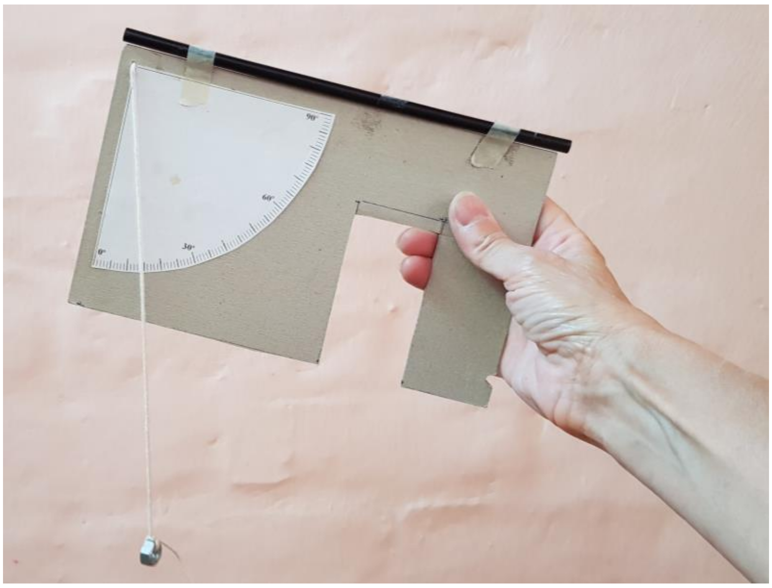


Figure 8. NASE quadrant finished

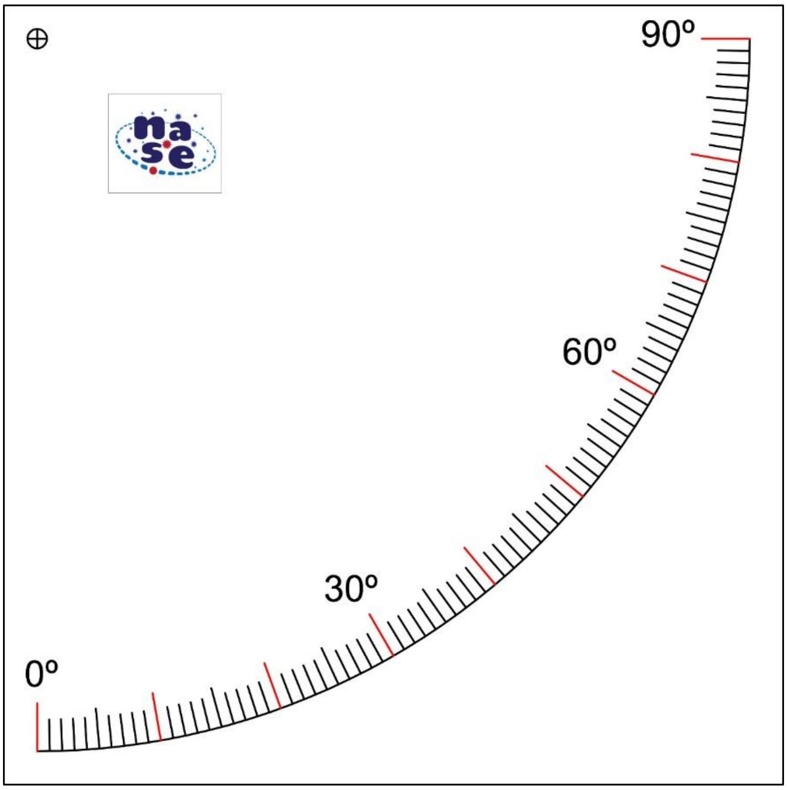


Figure 9: Graduated quadrant to glue on the cardboard.

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).

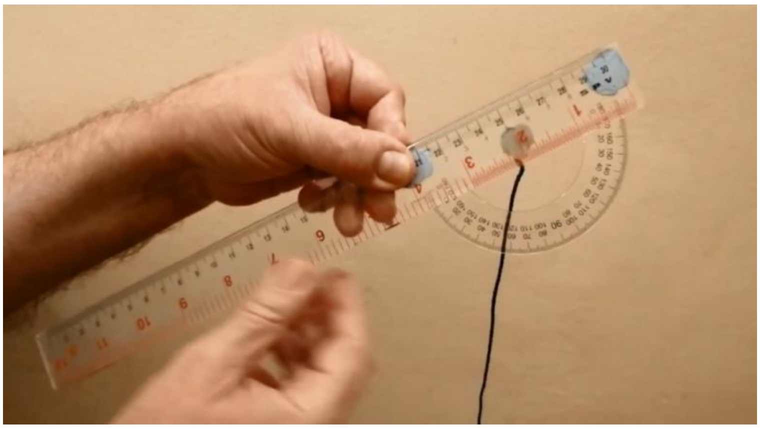


Figure 10: Quadrat with rule and protractor

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.

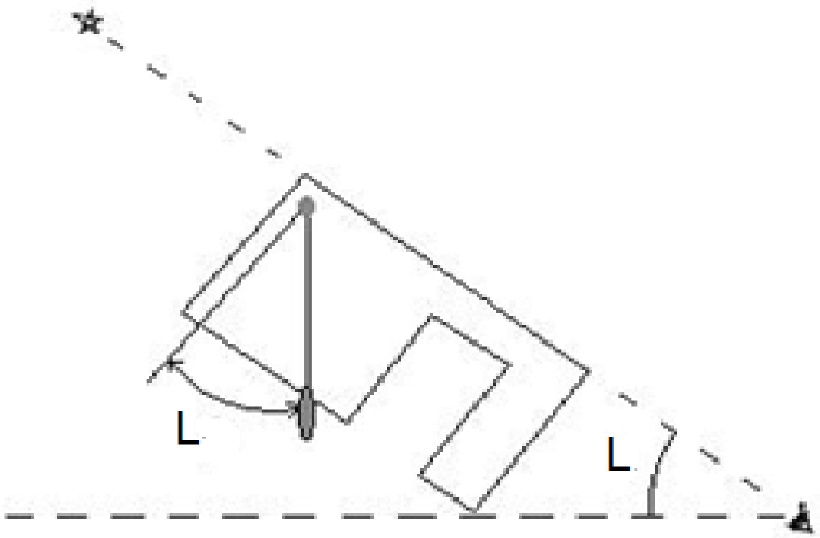


Figure 11: El ángulo que se lee en el cuadrante coincide con la altura del objeto sobre el horizonte.

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.

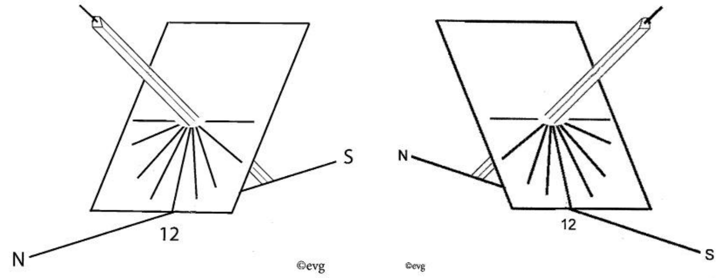


Figure 13. Orientation of an equatorial sundial in the northern hemisphere (left) and in the southern hemisphere (

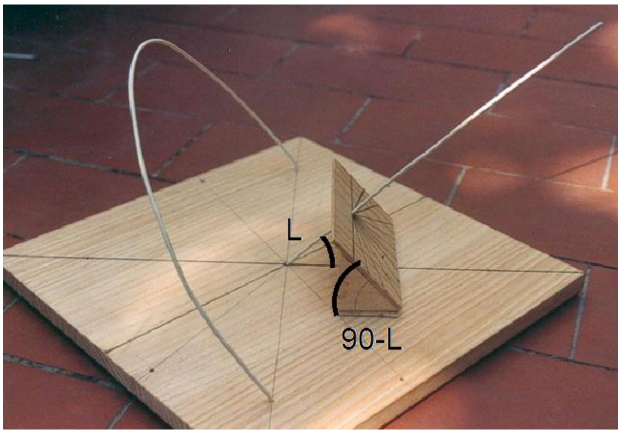


Figure 14: An equatorial clock has the stylus in the direction of the earth's axis of rotation and the plane must be parallel to the equator. Thus the angle of the pole height is the latitude of the place L, and the inclination of the plane (perpendicular to the stylus) is the colatitude of the place.

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).

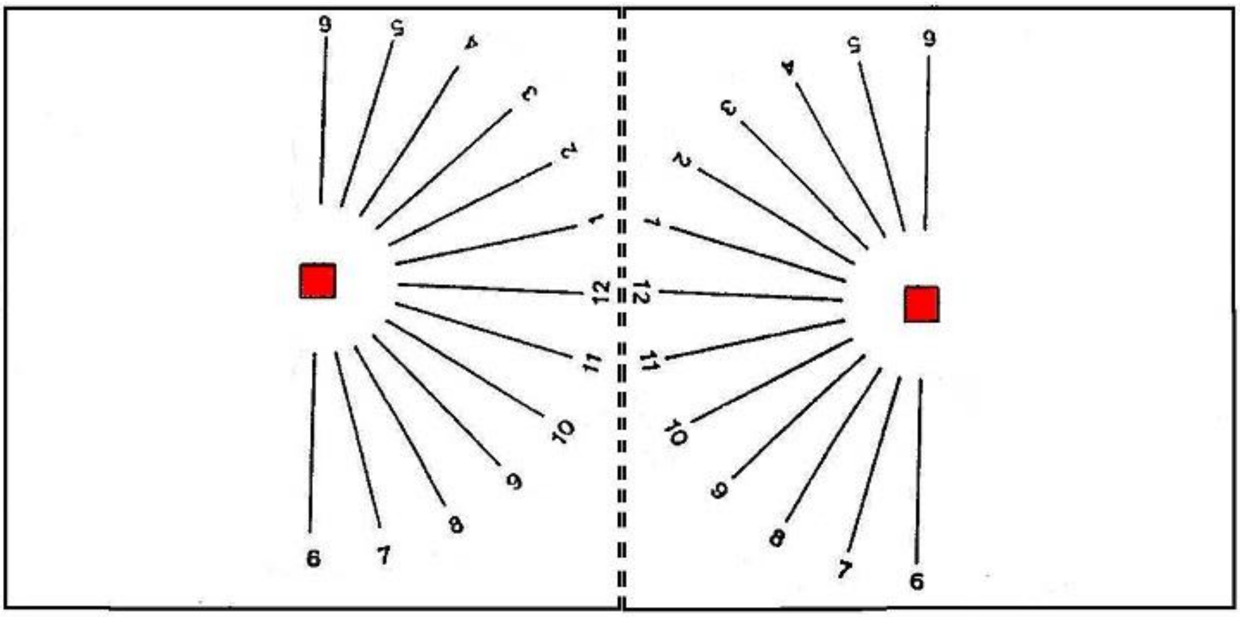


Figure 15. Plane of the ecuatorial sundial

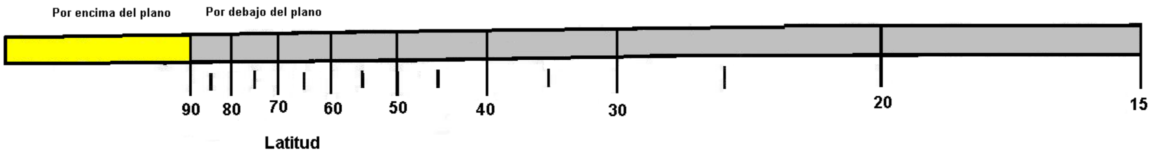


Figure 16. Reference to cut the gnomon according to the latitude of the place

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

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Silk Road

Medieval Astronomical Observatories along the Silk Road

Carlos Dorce
Universitat de Barcelona

The Silk Road is one of longest and the most famous commercial routes which has ever existed. From China to the Mediterranean Sea, a lot of traders traveled making money in the markets of the cities which spanning over almost 8.000 kilometers, eased political and economic interactions between different kingdoms and empires. The first commercial activity began in the second century BCE with the Chinese production of silk textiles which were very appreciated in the Roman Empire. From East to West, the Parthian Empire in Central Asia supplied the needed bridge to connect both territories and soon all markets began to be full of other products as porcelain, honey, wine, tea or perfumes. Therefore, it is not accidental to notice that some of the most important and booming Asian cities and kingdoms flourished along this commercial network along the history. The frame of the Silk Road allowed that cities like Damascus, Baghdad, Nishapur, Samarkand or Kashgar to play an important role in the political, religious and cultural development which let a great scientific and mathematical activity to also take place.

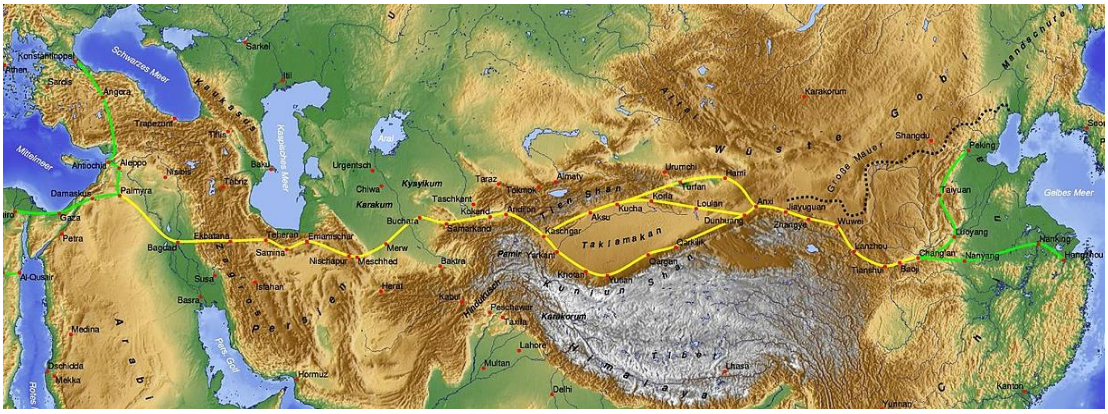

Fig. 1: map of the main routes of the Silk Road

It is obvious that all these traders who traveled from East to West or from West to East needed astronomical instruments to know the exact latitude of their locations. We can see in the map of the main routes of the Silk Road (fig. 1) that all the main cities are more or less lined up because the latitudes all of them are between 33º and 43º. To know the latitude of a place, it is necessary to determinate the exact altitude of the Sun at the midday and this determination can be made for example with an astrolabe. It is said that first astrolabes were made in Ancient Mesopotamia but the one of the first descriptions of this device was made by Hipparchus of Nicea (fl. 150 BC) and recorded by Ptolemy (fl. 150 AD) in his great *Almagest*. So, from Ancient Greek times it should be craftsmen skilled in making astrolabes to supply astronomers and astrologers the necessary device to compute planetary ephemerides. In the 4th century, Theon of Alexandria wrote a rigorous treatise about the construction and use of the astrolabe so the contents of the letters which Synesius of Cyrene sent to Theon's daughter, Hypatia (d. 412 AD), are not surprising: Synesius asked his teacher Hypatia for advice on the construction of one astrolabe, so this wonderful scientific woman not only knew how to use this kind of astronomical instrument but knew how to make it. In short, we can say that in the Alexandrian School the astronomical and mathematical bases of the astrolabe were perfectly established, and we cannot think that all this knowledge was not taken advantage of the wise men and women who were to succeed them.

The astronomical activity in the House of Wisdom of Baghdad:

One of the first documented astronomical activities in this long way was in Baghdad. During the reign of the Abbasid Caliph Al-Ma'mun (from 813 to 833 AD), Baghdad was the center of one of the most important intellectual, cultural and scientific activities of the Middle Ages. Al-Ma'mun founded the House of Wisdom, and a great public library became one of the focus of the well-known Islamic Golden Age. Al-Ma'mun also ordered the foundation of the Shammasiyyah Observatory, and the astronomical activity began in 828 AD. Sanad ibn ^{c}Ali (d. c. 864 AD) was the chosen person to build the worship houses in the periphery of Baghdad and also all the astronomical instruments of the observatory. Almost all the important scientific men of the first half of the 9th century worked in this institution, like Muhammad ibn Musa al-Khwarizmi (c. 780-c. 850 AD), al- 'Abbas ibn Sa^{c}id al-Jawhari (c. 800-c. 860 AD) or the outstanding Yahya ibn Abi Mansur (fl. 820 AD). Al-Khwarizmi whose book about *Algebra and Muqabala* changed the history of mathematics was also the author of the Arabic version of the Indian astronomical texts, compiling his famous *Zij al-Sindhind*. Yahya ibn Abi Mansur carried out astronomical observations in Shammasiyyah Observatory and also in Damascus from 823 to 833 AD, probably in the Qasiyun Observatory, and the result was the compilation of the *Zij al-Mumtahan* (*Tested Tables*) which were widely used by Islamic astronomers and astrologers in the following centuries. Qasiyun Observatory was also founded by al-Ma'mun in late 830 AD and ^{c}Abd al-Malik al-Mawrudhi was ordered to prepare new astronomical and more exact instruments to replace previous ones. Both observatories declined with al-Ma'mun's death in 833 AD and other astronomical activities appeared out of these institutions.

All the references to both institutions say that Ptolemaic astronomical instruments were made for Shammasiyyah and Qasiyun Observatories. For example, the Persian astronomer Habash al-Hasib (c. 775-c. 870 AD) and the historian Ibn Khaldun (1332-1406) speak of an armillary sphere for Shammasiyyah although we do not have much information about it. It seems that it was owned and used by Yahya ibn Abi Mansur and its scale contained divisions for each ten minutes. It was constructed by Ibn Khalaf al-

Marwrudhi who also constructed an astrolabe. The great Persian astronomer, historian and mathematician al-Biruni (973-1048 AD) speaks of a mural quadrant made of marble in Qasiyun whose radius was about 5 meters long. A There also was a 5 meters long gnomon made of iron which was standing up vertically. Another important improvement carried out in Qasiyun was the invention of an azimuthal quadrant for the measurement of azimuths and elevations. Therefore, we can see that important scientific innovations were made in Baghdad and Damascus with the works of the most outstanding astronomers in those times and although both observatories were linked to al-Ma'mun's life, they are a particularly important reference in History of Medieval Astronomy.

In the second half of 9^{th} century, Baghdad still was the capital of the Caliphate and the court continued to attract scientists from all corners of the kingdom. For example, al-Khwarizmi continued his studies and wrote some astronomical and mathematical treatises after al-Ma'mun's death. Another interesting example is the case of Persian Banu Musa Brothers: Muhammad (d. 873 AD), Ahmad and al-Hasan. His father Musa ibn Shakir was astrologer in al-Ma'mun's court and after his death, al-Ma'mun took care of them. The three brothers enrolled in the House of Wisdom and studied under Yahya ibn Abi Mansur and after al-Ma'mun's death they became good astronomers and also became patrons of translators and scientists. Al-Biruni quotes their astronomical observations from 858 to 869 AD and the Egyptian Ibn Yunus (c. 950-1009 AD) mentions six of their observations. Some of these observations were made from their house near a bridge on the Tigris River close the city gate Bab al-Taq in Baghdad, like a determination of the latitude of the city.

Al-Dinawari (c. 815-c. 895 AD) was also a famous physician and astronomer whose scientific activity took place in this second half of 9^{th} century. He lived in Dinawar and Isfahan and wrote and astronomical treatise with observations made in 849-850. He had a private observatory in Dinawar in which he carried out an important astronomical activity to compile his *Zij*, although we do not have any information of the instruments used by him.

The construction of astrolabes:

Abu ^{c}Abd Allah Muhammad ibn Jabir ibn Sinan al-Raqqi al-Harrani al-Sabi al-Battani (c. 858-929 AD) was one of the most outstanding astronomers of the first half of the 10^{th} century. He had a private observatory in Raqqa where he made observations from 877 to 918 AD. Among the instruments used by him was a gnomon divided into 12 parts, an armillary sphere, a mural quadrant, parallactic rulers (the diameter of one of them measured 5 meters long), astrolabes and horizontal and vertical sun clocks. It seems that al-Battani used astrolabes only for measurements which did not require a very exact value and he was a particularly good designer of this king of instrument. However, most craftsmen workshops capable of making astrolabes were centered in Baghdad. For example, Muhammad ibn ^{c}Abd Allah Nastulus was a prolific 10^{th} century astrolabist whose some of his astrolabes are in the list of the oldest surviving ones in our days. One of them is preserved in the Kuwait Museum of Islamic Art and it has a single plate for latitudes 33º and 36º. The value 33º was standard for Baghdad among the instrument makers (the latitude of Baghdad is 33º 21') but as a portable instrument it could also be used in Damascus, whose latitude is 33º 31'), and the plate for latitude 36º would be useful in Tyre (35º 11'), Rayy (35º 36'), Nishapur (36º 12') and Mashhad (36º 18'), all these cities located along the Silk Road not very far from Baghdad. The throne of the astrolabe bears the inscription "made by Nastulus in the year 315H" (927/928 AD) and the alidade is missing. Its diameter measures 17,3 centimeters, only 4 more than the second Nastulus known astrolabe, of which only the mater is extant. It was probably made in 925 AD, and it is exhibited in the Museum of Islamic Art in Cairo. The third (figure 2) is also "made by Nastulus" and its diameter measures 7,6 centimeters. The rim of the mater is divided clockwise for each 5º and subdivided for each 1º and labelled for each 5º up to 360º. It has a small notch at the bottom to accommodate the two plates which serve latitudes 31º/32º and 33º/34º (figure 3), respectively.

Fig. 2: Nastulus' third astrolabe

Fig. 3: Nastulus' plate for Baghdad

Now a lot of astrolabe makers could be named but as the purpose of this article is not to make an exhaustive list of them, we just want to mention the 10^{th} century Muslim woman Maryam al-’Ijliya, also known as Maryam al-Asturlabiyya. She was daughter of another astrolabe maker named al-’Ijliyy and she learnt her job working in her father’s workshop. She was employed by the Emir Sayf al-Dawla of Aleppo, who reigned from 944 to 967 AD. Nothing else is known about her life, but if Maryam stood out in a basically male world, it is because her mathematical talent was unquestionable. She is without any doubt one of the first Muslim known women scientists in history.
Coming back to Baghdad, we also find Abu al-Wafa Muhammad ibn Ahmad al-Buzjani (940-997 AD) making observations for the determination of the obliquity of the ecliptic, which he determined to be 23º 37’, the same value obtained by al-Biruni. He worked in the new observatory ordered by the emir Sharaf al-Dawla in Baghdad. Among the astronomical instrument made for the observatory, there was a 6.5 meters quadrant and a large quadrant of about 10 meters diameter.

Before we continue with our review, we must answer the question: why the use of astrolabes is so important for travelling across the Silk Road? As we can see in figure 1, the main route of the Silk Road seems to follow terrestrial parallels between 33º and 43º. If we imagine a medieval trader going from East to West or from West to East, how could he know if he was in a wrong way? In Medieval Age the longitude of a place could not be determined and the only possible clue that this trader could have in mind is his ubication in latitude. For example, if he wanted to go from Damascus to Baghdad, he did not have to move from a latitude around 33º. Then, how the astrolabe could be useful?

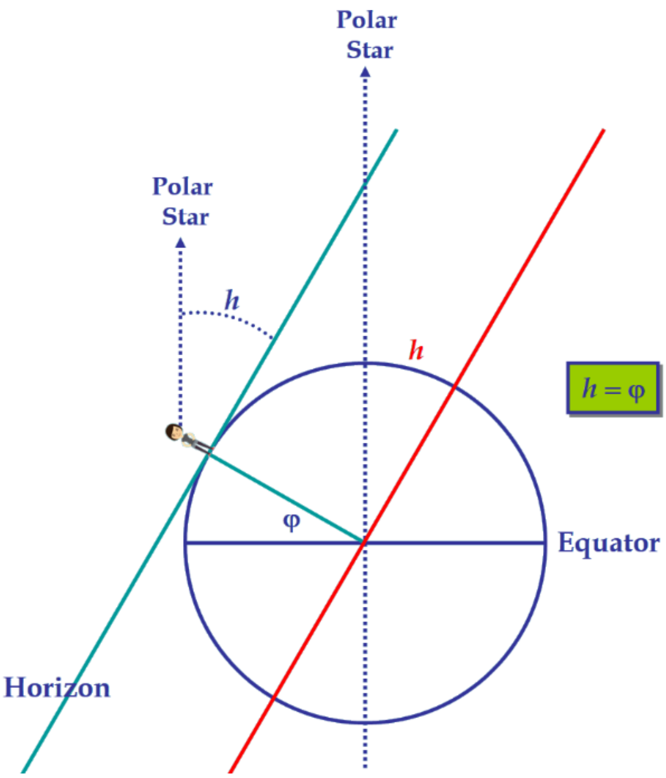

Fig. 4: Determination of the latitude of a place

Let us suppose that the trader was in any point of the Earth in which the Equator perpendicular to the axis to the Polar Star is drawn. Then, the horizon is the blue line and if he looked at the Polar Star, he would be able to determine the altitude h of the Polar Star. Thus, he could notice that this angle h is equal to the latitude φ of the place where he was taking the observation so the latitude of the place could be determined. This trader had to have an astrolabe to determine this altitude h looking through the two holes of the alidade. Furthermore, the spider and the mater served to locate the fixed stars in the sky so that he was also able to determine the different hours of the night. Therefore, it is difficult to imagine any traveler merchant or business without an astrolabe among his belongings.

Three observatories up to the 13th century: Malikshah, Maragha and Gaocheng:

In the 11th century, the Saljuq sultan Malikshah (1072-1092 AD) ordered to build a new observatory as part of his idea of setting up a madrasa system as the school higher education in his realm. The location of this new institution is not certain, and it has been speculated with the cities of Merv, Rayy and Nishapur, although nowadays it is though that Isfahan was the chosen town. Among the list of astronomers who worked there, the name of Omar Khayyam (1048-1131 AD) is probably the most important. He was an important astronomer who collaborate in the Persian calendar reform and was the first mathematician to solve geometrically the cubic equation. Khayyam noticed that the cubic equation could be solved by the intersection of two conic sections. A circle and a parabola, two parabolas, a hyperbola and a parabola, two hyperbolas, … Nowadays, we do not have any problem in considering a cubic equation in the form $x^3 + px^2 + qx + r = 0$ but only positive numbers existed in Medieval times so that if $x, p, q, r > 0$, then an equation could have solution if each term of the equation had one or two monomials: $x^3 = r,\ x^3 + qx = px^2,\ x^3 + r = px^2 + qx,\ x^3 = px^2 + r,\ \ldots$ Khayyam determined a particular geometrical solution for each case. Khayyam also compiled the so called *Zij Malikshah* which probably contained the result of a lengthy observational program although it could be that it only contained astronomical tables for the Sun and the Moon.

Undoubtedly, Malikshah Observatory was the most important astronomical institution of the 11th century but one century and a half later two important astronomers flourished thanks to the foundation of the Maragha Observatory, at the north of the Silk Road: Nasir al-Din al-Tusi (1201-1274 AD) and Muhyi al-Din al-Maghribi (d. c. 1283). The construction of Maragha Observatory started in April-May 1259 upon a hill which lies along the meridian together with some wheels and devices to get the water to the buildings on the top of the gill, a mosque and the residence of the prince and patron Hulagu Khan. The observatory building was described as “huge”, with a high tower, a “marvel” and a “treat to the eye”. A dome and a wonderful library were also built which were mentioned by a lot of astronomers, historians and travelers who visited Maragha. On the top of this dome there was a hole through which the rays of the Sun entered inside so that astronomers could determine the mean motion of the Sun, the altitude of the Sun, and some visitors described the walls inside the building depicted with illustrations of the zodiac, the phases of the Moon and representations of the celestial spheres with deferents and epicycles. It is also said that there were several celestial and terrestrial globes and maps. Among these instruments, we have news of a terrestrial globe made of paper pulp and a metallic celestial globe constructed by Muhammad ibn Muayyad al-Din al-^{c}Urdi in 1279. In fact, al-^{c}Urdi started to make instruments for the observatory in 1261 and he specifically elaborated a list of all the instruments which had to be made for Maragha and sure that most of them were constructed. The first is a mural quadrant with a radius of about 4.3 meters graduated down to the minutes. It was equipped with an alidades which helped to determine the obliquity of the ecliptic and the latitude of Maragha. An armillary sphere with an alidade and five rings was also described. Its radius of the meridian ring was about 1.6 meters long. Al-^{c}Urdi also thought in a solstitial armilla consisting of a circle with 2.5 meters diameter, a similar equinoctial armilla, an azimuth ring, a parallactic ruler, a sine and versed sine instrument and the "perfect instrument", which was like the parallactic ruler, but it was not fixed in the meridian and could be revolved around a vertical axis.

In Maragha Observatory, several astronomical treatises and *zijes* were compiled, like al-Tusi's *Ilkhani Zij* (1271) and Muhyi al-Din al-Maghribi's *Zij*. Muhyi al-Din was a prolific astronomer and wrote works on the construction and use of the astrolabe, two *zijes* more and three commentaries on Ptolemy's *Almagest*. However, Nasir al-Din al-Tusi was probably the most eminent astronomer since the influential work of Nicolaus Copernicus (1473-1543 AD). His astronomical tables for the motion of the planets were the most accurate ever compiled and the *Ilkhani Zij* became a fundamental work of for other future astrologers and astronomers.

Fig. 5: Gaocheng Observatory

Finally, a third important observatory of the 13th century was built in 1276 in the Chinese town of Gaocheng. Hulagu Khan's brother, Kublai Khan, has been expanded his Mongol Empire and setting up his power in the new conquered cities, he had noticed the need of a calendar reform which people could see as the best example of the political benefits of the new regime in comparison with the old one. Then, Kublai Khan opened a new special bureau whose aim was to carry out the specific research to elaborate the new calendar and to list all the necessary proposals to set it up in society. Guo Shoujing (1231-1316 AD) and Wang Xun (1235-1281) were asked to lead this new project. Both astronomers knew that the success in their assignment was linked to have more accurate observational data and Guo decided to make a new set of seventeen new astronomical instruments. Only four of them were portable while the rest were set up in the new observatory founded by Kublai in his capital Dadu (Beijing) in 1279. However, three years before, Guo and Wang designed a new building for the observatory in Gaocheng, at the end of the Silk Road. The main building was almost 13 meters high and a shighi was annexed to it. This shigui was a more than 31 meters long and 0.5 meters wide north faced ruler to measure the sky. Guo was able to determine the altitude of the Sun with a precision of 2 millimeters on the ruler and all these data were used for the new calendar of 1281 (the length of the tropical year was determined to be 365 days 5 hours 49 minutes and 20 seconds, a value consistent with the tropical year for the Gregorian calendar obtained three centuries later).

Ulugh Beg Observatory in Samarkand:

In 15th century, the most influential astronomical focus moved to Samarkand with the Timurid sultan Ulugh Beg (1394–1447 AD), who reigned from 1447 to 1449. When he was a child, he visited the remains of the Maragha Observatory and as a very young prince he was the main patron of the idea that Samarkand should become the most important stopover on the Silk Road. In late 1410's, he ordered to build a big madrasa which was intended to be the most prominent intellectual center in those times and therefore he invited a lot of very important astronomers and mathematicians to work there. In late 1420's, a new observatory was built, and it was provided with the most accurate instruments ever made. For example, the giant *Fakhri* sextant had a radio of about 36 meters so that the altitude of the Sun and the stars above the horizon could be determined with a precision of 1 sexagesimal second. Of course, other astronomical instruments were made for this observatory as, for example, a lot of astrolabes, a clepsydra and a very big sundial covered with external walls in which a colored fresco depicting the zodiac was painted on them. The observatory building had three floors which reached more than 45 meters high, and the upper terrace was the place where the astronomers worked

.

All the observational data obtained in Samarkand was used to compile the so-called Ulugh Beg's *Zij-i Sultani* (1437). It was written in Persian, and it listed around one thousand stars. This star list was the first complete catalogue since Ptolemaic times (2nd century AD) improving the latitudes and longitudes of the catalogue of the *Almagest*. Without any doubt, the merit of this new catalog was the use of the great quadrant of Samarkand, and it seems that Ulugh Beg himself was the director and guide of all the observations, assisted by great astronomers such as Ali Qushji (1403-1474 AD) and Jamshid al-Kashi (c.1380-1429 AD). Al-Kashi also compiled his *Khaqani Zij* based upon the tables of Nasir al-Din al-Tusi's *Ilkhani Zij* in Samarkand although he recognized that his work was completed thanks to Ulugh Beg's support. The trigonometric tables of the *Khaqani Zij* were the most accurate so far, giving values for the sine function to four sexagesimal places for each minute of arc.

Fig. 6: The extant great sextant in Samarkand Observatory

Conclusion:

The astronomical activity in the Middle Ages across the Silk Road was linked to all the wonderful cities and great empires which existed from the 9th to the 15th centuries. There were of course more examples of astronomical activity near this main terrestrial way of the Silk Road. For example, al-Khujandi made observations in Baghdad in 994 AD with a very big 60 degrees quadrant invented by him, al-Badi' al-Asturlabi (fl. c. 1130) was famous in the same city for designing an astrolabe which could be used in all latitudes, ^{c}Abd al-Rahman al-Khazini (fl. 1135 AD) computed planetary longitudes for the latitude of Merv, or Ibn al-Shatir (1304-1375 AD) made much work on astronomical instruments for his own observatory, making an azimuthal quadrant. Great observatories were built in some of these cities and kings, sultans and emirs of all ages were proud of them as a symbol of their power. Therefore, we can say that not only the main way of the Silk Road was one of the most productive Medieval commercial routes but many of the cities across the way had a lot of political, commercial and cultural power and became cultural focus with important markets, madrasas and observatories. They were attended by wise men who found the right place to work, and astronomers and astrologers were able to carry out all their observational activity thanks to the patronage of these great emirs who changed history.

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CHINA

Determining Local Latitude in Beijing Planetarium

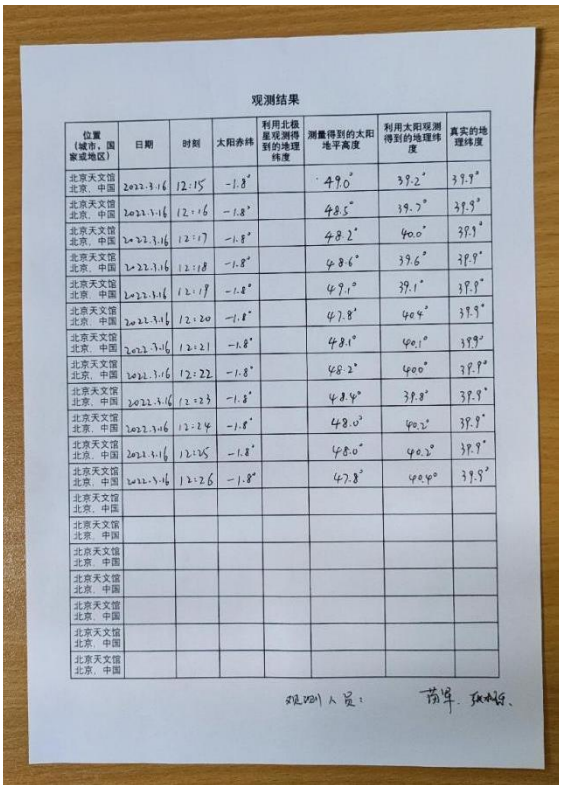
Dongni Chen
Beijing Planetarium

Experiment carried out in Beijing Planetarium by Dr. Dongni Chen; Mr. Jun Miao and Mr. Fengyue Zhang on March 16th 2022.

Fig. 1: Mr. Miao is testing the altitude of the Sun

Following a few simple instructions, which can be found in NASE website (www.naseprogram.org),we found it is possible to determine the latitude of Beijing in a similar way to how Columbus, Magellan or Elcano were able to do it centuries ago on his trips across the Atlantic and the Pacific. The data are listed in Figure 3. We are sure that students in primary school are capable of doing this with great fun.

Fig2: The sundial made by Beijing Planetarium



观测结果

位置（城市，国家或地区）	日期	时刻	太阳赤纬	利用北极星观测得到的地理纬度	测量得到的太阳地平高度	利用太阳观测得到的地理纬度	真实的地理纬度
北京天文馆 北京，中国	2022.3.16	12:15	-1.8°		49.0°	39.2°	39.9°
北京天文馆 北京，中国	2022.3.16	12:16	-1.8°		48.5°	39.7°	39.9°
北京天文馆 北京，中国	2022.3.16	12:17	-1.8°		48.2°	40.0°	39.9°
北京天文馆 北京，中国	2022.3.16	12:18	-1.8°		48.6°	39.6°	39.9°
北京天文馆 北京，中国	2022.3.16	12:19	-1.8°		49.1°	39.1°	39.9°
北京天文馆 北京，中国	2022.3.16	12:20	-1.8°		47.8°	40.4°	39.9°
北京天文馆 北京，中国	2022.3.16	12:21	-1.8°		48.1°	40.1°	39.9°
北京天文馆 北京，中国	2022.3.16	12:22	-1.8°		48.2°	40.0°	39.9°
北京天文馆 北京，中国	2022.3.16	12:23	-1.8°		48.4°	39.8°	39.9°
北京天文馆 北京，中国	2022.3.16	12:24	-1.8°		48.0°	40.2°	39.9°
北京天文馆 北京，中国	2022.3.16	12:25	-1.8°		48.0°	40.2°	39.9°
北京天文馆 北京，中国	2022.3.16	12:26	-1.8°		47.8°	40.4°	39.9°
北京天文馆 北京，中国							
北京天文馆 北京，中国							
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观测人员： [illegible]

Fig3: The table of our data

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MONGOLIA

Mapping the route of the cultural exchange that occurred along the Silk Road

Tsolmon Renchin and Altangerel Balgan
University of Mongolia

In 2022 NASE program proposes to return to its origins, inviting everyone to participate in the project "silk road" and navigate its latitudes because Mongolia is located between latitudes among Silk Road network.

As history tells The Mongol Empire plays a significant role and influence in the history of the Silk Roads. The Mongolian empire dates to the 13th and 14th centuries, having reached its highest peak in expansion after Genghis Khan’s successor Ögedei Khan took power in 1229. He made the Mongol Empire the largest contiguous land empire in history. This massive geographical reach allowed the Empire to offer the Silk Roads more secure and organized trade throughout its land. This allowed the land routes to flourish. Around the 1350s, the empire began to collapse. Finally, once it did, the trade routes of the Silk Roads lost their security, and trade interest shifted to maritime routes. As a result of this important political and security role, the Mongols were heavily engaged in the Silk Roads network. Mongolians have a history of being nomadic people, including many that engaged in trading along the Silk Roads. The main cities along the Silk Roads were Karakorum and Ulaanbaatar, Mongolia’s capital today. Ulaanbaatar is especially important to demonstrate Mongolia’s inclusion in the Silk Roads network. It was considered a very important place for Buddhism, holding the status of second-most sanctimonious, behind Lhasa. One would find a large Buddhist temple to mark the presence of a Buddhist community, a religion that was brought to Mongolia by the exchange of thoughts, ideas, and beliefs as a result of the Silk Roads (https://en.unesco.org/). From this, it can be seen that Mongolia was a member of the silk road network before the 16th century. There are still happening activities for Silk Road in Mongolia . For instance, there was The International Silk Road Conference on “Nomadic Tourism and Sustainable Cities” was held in Ulaanbaatar, Mongolia in October 2016. The aim of the conference was to explore the nomadic culture and tourism opportunities along the world’s renowned Silk Road, develop a new tourism brand product, and raise awareness of the necessity to conserve and protect nomadic heritage. During the conference, numerous interesting presentations were made regarding the conservation and protection of the environmental, historical, and cultural heritage of Silk Road nations and delegates exchanged know-how on the sustainable development of tourism.(https://en.unesco.org/silkroad/content/international-silk-road-conference-nomadic-tourism-and-sustainable-cities) There are many educational activities on silk road networks in the World.

NASE is a program for post-graduates. The main objective of NASE is to educate new generations of teachers and re-educate the current ones. The topics of the NASE course are as follows: position astronomy, solar system, exoplanets, spectrography, photometry, spectroscopy, determination of absolute magnitudes, the potency of stars, nucleosynthesis, star evolution, and cosmology. The main goal is to set up in each country a local group of NASE members who carry on teaching “the basic NASE course” every year and create new courses by using NASE materials. (http://sac.csic.es/astrosecundaria/en/Who-we-are.php).NASE is initiating a wonderful educational project that allow people to return to the Silk road and make measurements of Latitude for traveling and navigating.

Fig. 1: During class for navigation.

Fig. 2: Outreach activity for public.

Fig. 3: Lectures on project involvement for school teachers.

Mongolian school teachers and students are involved in this NASE project and started to navigate latitudes for the silk road. They will learn how the Silk Road helped global exchanges.The Project will allow them to review civilizations. Students will understand about the Silk Road network. They can make a discussion about the ancient trading routes They will have an opportunity to map the route and discuss the importance of the cultural exchange that occurred along the Silk Road and how global exchange continues in their región today.

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- http://sac.csic.es/astrosecundaria/en/

IRAN
Silk Road and Local Latitude

**Parham Eisvandi, Mahdi Rokni, Rahimeh Foroughi,
Fatemeh Salimi, Samaneh Tafazolinia, Siavash Eisvandi,
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Iranian Teachers Astronomy Union - ITAU

Silk Road runs through the sea and land and from east to west through Iran. Traders in ancient Iran used some astronomical tools to navigate day and night.

Fig. 1: Ancient astronomical instruments

In NASE courses teachers make simple but practical tools it is possible to determine the latitude of the place where they are in a similar way than ancient went, on their road.

In a meeting before taking action for the arrangements and doing experiments with the students, the teachers expressed their ideas for the better and more attractive experiments, some of which we failed to do due to unpredictable events. But to perform experiments simultaneously and at different points, we encountered different arrangements and challenges. One of them the holiday of Nowruz and after the reopening of the schools in the Pandemic Covid 19 is the right time to carry out the project.

Fig. 2: Preparing the observation instruments

Fig. 3: Obtaining the altitude of the Sun at solar noon

The cloudy weather in spring, the dust, and wind were among the other challenges that delayed the timing of the experiment.

These experiments were performed in the south of Iran, in Bushehr province, in high heat. The situation was difficult for the students, but they still performed the experiments with enthusiasm, interest and excitement. The teachers met again and presented various ideas at that meeting, which they could put together at a time appropriate to the students.

Fig. 4: Prepared with all the instruments.

References

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

Journey arround the world by Fernand Magallan and Juan Sebastián Elcano

Latitude determination at the time of the Magellan-Elcano expedition

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The Magellan-Elcano expedition, carried out between 1519 and 1522, completed the first circumnavigation of the Earth and was the longest and one of the most eventful expeditions of those carried out during the time of the Portuguese and Spanish maritime expansion in the 15th and 16th centuries. As a result of this expedition, a truly global maritime trade was inaugurated, connecting the main geographical inhabited areas of the planet, constituting the definitive demonstration of the roundness of the Earth. Astronomy was an essential and strategic element in the European maritime expansion as a tool in determining the position of ships and the new territories discovered, as well as in determining sailing directions.

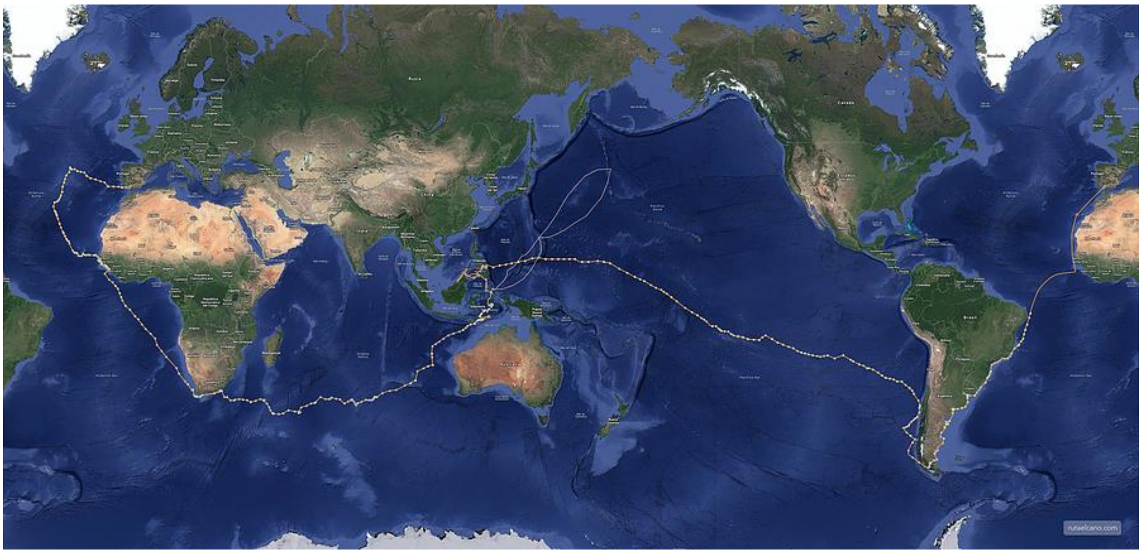

Fig. 1: Route of the Magellan-Elcano Expedition. Obtained from http://www.rutaelcano.com.

The Magellan-Elcano expedition, financed by the Kingdom of Spain, left Seville on August 10, 1519, was initially led by the Portuguese navigator Fernão de Magalhães, who died in combat in the Philippines on April 27, 1521. The Spanish sailor Juan Sebastián Elcano who returned to Seville three years later, on September 8, 1522 led the return. The objective of the expedition was commercial, to open an alternative route to the Spice Islands (the current Moluccas Islands) that allowed the Spanish to reach these territories without crossing the area of Portuguese influence delimited by the Treaty of

Tordesillas of 1494. Initially, the expedition was made up of 5 ships of between 75 and 120 tons and about 243 crewmen, but only one of the ships returned, the Victoria, with 18 men on board. During the expedition there were 127 deaths, 52% of the original crew.

There are several fundamental activities to be carried out during ocean navigation, among them the determination of the ship's position at all times, the maintenance of its course, and the estimation of the distance travelled. In European ships at the time of the Magellan-Elcano expedition, the person in charge of these activities was the pilot, the third in the hierarchy of the crew after the captain and chief officer. Being a highly technical position, it required training and experience, so they had to study mathematics, astronomy and cosmography and learn the use of navigational instruments.

In the initial crew of the Magellan-Elcano expedition there were six pilots, of whom only one survived returning to Spain with the ship San Antonio, which abandoned the fleet in the Strait of Magellan and, therefore, did not complete the circumnavigation. Among the list of 18 survivors who returned in the Victoria, only Francisco Albo appeared as a pilot, who held the position of boatswain of another ship (Trinidad) at the time of the departure of the fleet. Albo wrote a logbook of part of the trip, from the coast of Brazil to the return to Spain, where he detailed the latitude measurements as well as geographical, climatic and economic details of the different places where the expedition sailed.

To locate a point on the earth's surface we must provide two coordinates: latitude and longitude. At the beginning of the 16th century it was only possible to determine latitude with some precision. It was necessary to wait until well into the 18th century to be able to determine longitude during sea voyages, when mechanical chronometers were sufficiently precise and stable.

Determination of latitude in European ships of the 16th century

Latitude could be obtained in two ways, the first by measuring the altitude of the Pole Star (Polaris) above the horizon, and the second by measuring the altitude of the Sun, also above the horizon, as it passes through the local meridian. Polaris is a relatively bright star located very close to the north celestial pole that will only be observable while we are in the northern hemisphere. In that area of the Earth, the latitude will coincide with the angle that the north celestial pole makes with the horizon. At the beginning of the 16th century, Polaris was about 3.5º from the pole (now it is less than 1º) so, if one wanted to calculate the latitude accurately, one had to correct the altitude of the pole from this deviation, which is variable and depends on the time of day when one takes the measurement. As we know, the Earth rotates on its axis and the stars (including Polaris) describe a circular path around the celestial pole with a period of about 24 hours.

The correction to be applied to the measured altitude of Polaris to determine latitude was determined using a set of rules known as the "The Regiment of the North Star". These were based on estimating the difference in altitude between Polaris and the pole by observing the relative position of the stars called "Guardians of the Polar". The most used one was Kochab, the brightest star of Ursa Minor, constellation of which Polaris is also a part. The area of the sky around the north celestial pole was mentally divided into eight sectors of equal size separated by eight radii centred on the pole (Figure 2) and it was estimated on which of these radii the line connecting Kochab with Polaris was located (which varied throughout the night) and a correction was added or subtracted that could vary between 0.5º and 3.5º. To make the application of the "regiment" more graphic, the position of Kochab was imagined with respect to the figure of a man centred on the pole and with extended arms. According to the position of Polaris with respect to the head, the feet or the left or right arm, the value and sign of the correction were chosen. Latitude was then calculated by applying the relationship: latitude = altitude of Polaris + correction.

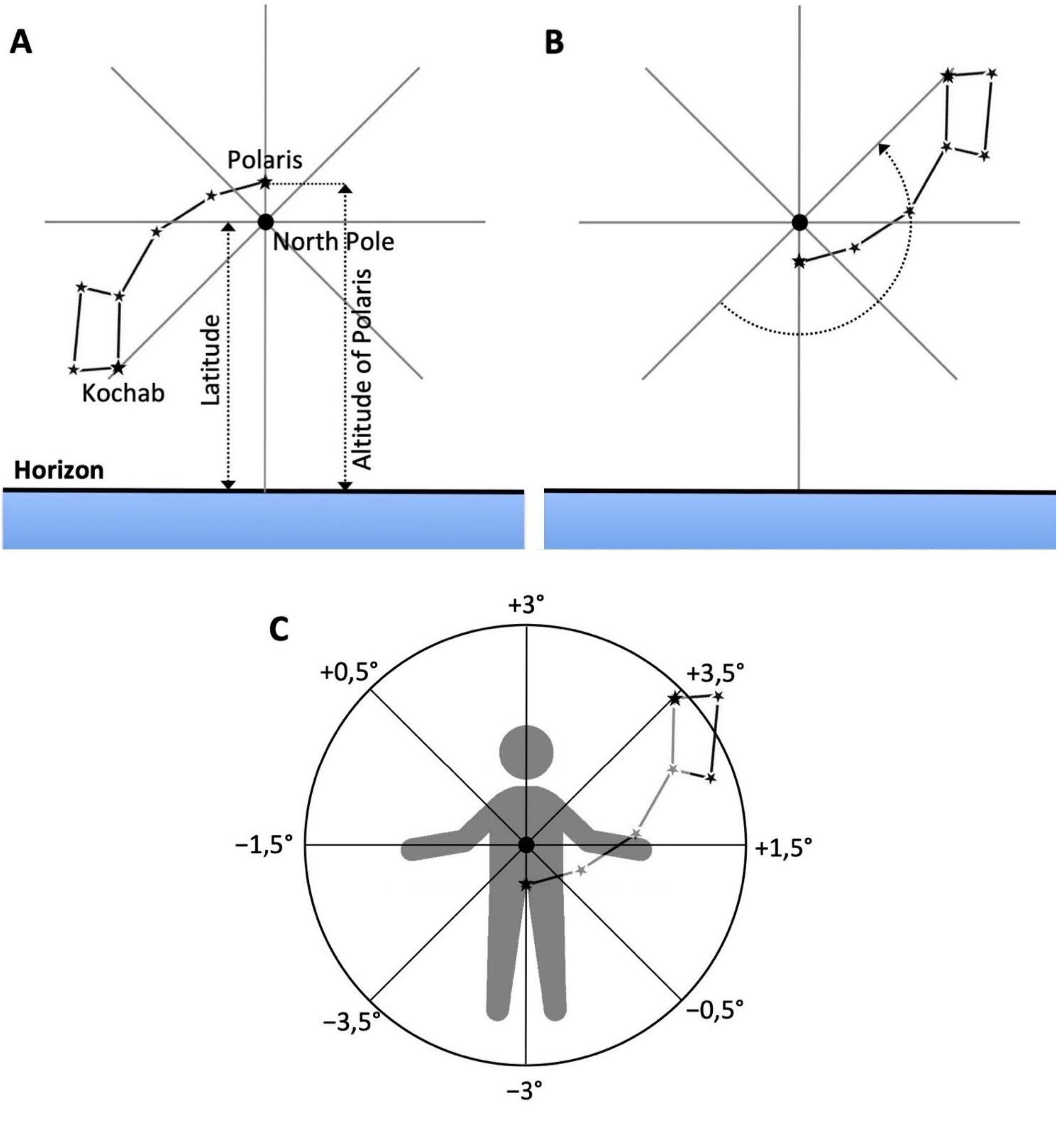

Fig. 2: Graphical description of the “The Regiment of the North Star”, used to estimate the necessary correction to obtain the latitude from the altitude of Polaris according to the relative position of Kochab

and Polaris (both in the Ursa Minor constellation), changing according to the moment of the night in which it was observed. Adapted from Pereira (2002: his figures 21, 2b and 3).

The determination of latitude by means of the altitude of Polaris could only be done at night and from the northern hemisphere. The method based on the measurement of the altitude of the Sun did not have these limitations. The principle is quite simple because, as already said, latitude corresponds to the altitude of the celestial pole with respect to the horizon but, by symmetry, it also coincides with the angle between the zenith and the celestial equator measured along the meridian (see Figure 3). As during the day we cannot determine where neither the pole nor the equator is, we can solve this problem using daily tables of the position of the Sun. At the time of the Magellan-Elcano expedition, the *Alfonsine tables* were used, which were part of the *Books of wisdom of astronomy of King Alfonso X of Castile,* which provided the daily solar declination for a period of 4 years.

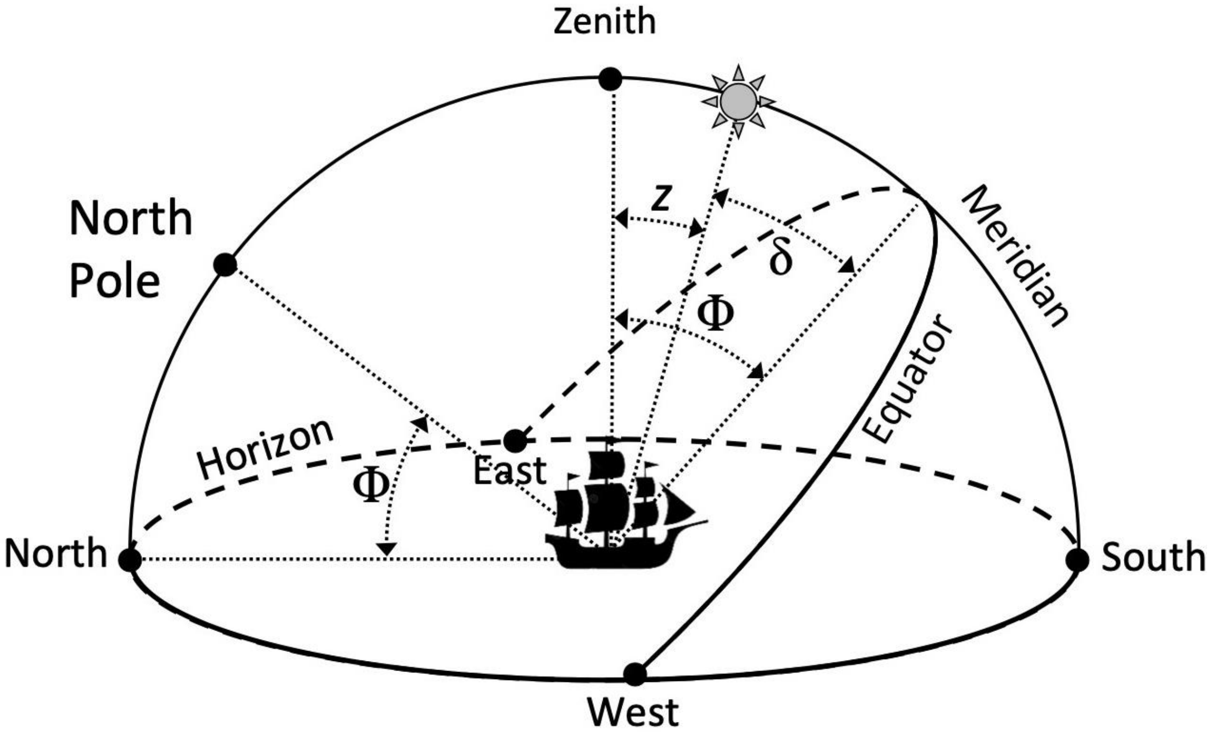

Fig. 3: Geometric relationship between solar declination (δ), zenith distance (z) of the Sun and latitude (Φ) of a vessel sailing in the northern hemisphere.

Once the solar declination (δ) on the day of observation was obtained from the tables, the altitude of the Sun (h) (or its complementary angle, the zenith distance: $z = 90° - h$) was measured along the meridian, the latitude (ϕ) could be calculated by applying the relationship: $\phi = \delta + 90° - h$ in the arrangement shown in Figure 3. Now, depending on the time of year and hemisphere in which the ship was located, the relative position of the Equator, the Sun and the ship could be different, so the signs that should be used to combine the different angles would also be different. In the so-called "The Regiment of the Sun" a series of rules were collected with which the pilots could calculate the latitude in each particular arrangement.

Instruments for determining latitude

In 16th century Europe, several instruments were available to measure the altitude of the stars during navigation and, therefore, determine latitude. The first of them was the nautical quadrant, used at least since 1461 according to the references of the Portuguese navigator Diogo Gomes (Pereira, 2000: 7). Although it was already in use on land since the time of the Greek astronomer Ptolemy, its design is based on portable quadrants introduced in Europe by Arab astronomers during the 13th century. It consists of a metal plate in the shape of a quarter of a circle that has a graduated arc, and from whose centre hangs a plumb bob that indicates the vertical. One of the straight sides of the quadrant has two sights (small plates with holes) with which a star or the Sun is pointed. The intersection of the plumb bob with the graduated arc provides the altitude of the star above the horizon. A graphical description of this instrument and its application is shown in Figure 4. Stabilizing the quadrant during navigation was difficult, especially during night observations, so other instruments soon replaced it. Pereira (2000: 49) carried out a statistical study of the precision of this instrument from measurements obtained by several observers using modern replicas of the quadrant from Portuguese navy ships, obtaining latitude determinations with average errors of 17 minutes of arc (0.28°), corresponding approximately to an error of about 29 km in the position of the ship along the observer's meridian.

The nautical astrolabe was already known from the end of the 15th century. The first description of its structure and use appeared in 1551, in *Arte de Navegar*, a work by the Spanish cosmographer Martín Cortés de Albacar. This instrument is based on a metal graduated circle that hangs from a ring held by hand, so the vertical axis of the instrument defined the perpendicular to the horizon. The measurement system was based on a metal alidade that rotated around the centre of the disc and had two sights to point towards a star or the Sun. According to Pereira (2000: 10-12), the astrolabe was more stable than the quadrant due to its greater weight and was more comfortable for night observations. With this instrument, Pereira (2000: 10-12) obtains average errors in the determination of latitudes of about 12.4 and 18 minutes of arc (0.21° and 0.3°) in day and night observations, respectively, which correspond to errors of between 21 and 31 km in the position.

The third instrument dedicated to measuring altitudes was the Jacob’s staff, which appeared in the first half of the 16th century. Its design is very simple and could only be used to measure stars when the horizon was visible, that is, at sunset or on moonlit nights. It consisted of a graduated stick (main staff) about a meter long on which another shorter perpendicular stick (transom or transversal, see Figure 4) slid. To determine altitudes, the end of the stick was placed in front of the eye and the transom was slid until its lower part coincided with the horizon and the upper part with the star to be measured. In his measurements with modern replicas of the Jacob’s staff, Pereira

(2000: 17-25) obtains average errors of the latitude of the order of 5 minutes of arc (0.08°), more precise determinations than with the quadrant or the astrolabe. Those errors translate to uncertainties of only 9-10 km in position.

The annotations made by the pilot Francisco Albo in his logbook during the passage of the Strait of Magellan indicate an error of 20 minutes of arc (0.33°) in his determinations of latitude, which translates into an uncertainty of about 35 km in position. As we can see, an error similar to that obtained by Pereira (2000) from current measurements obtained with a modern replicas of quadrants or astrolabes. These three instruments described were used until the 18th century, when reflection instruments such as the octant and the sextant replaced them.

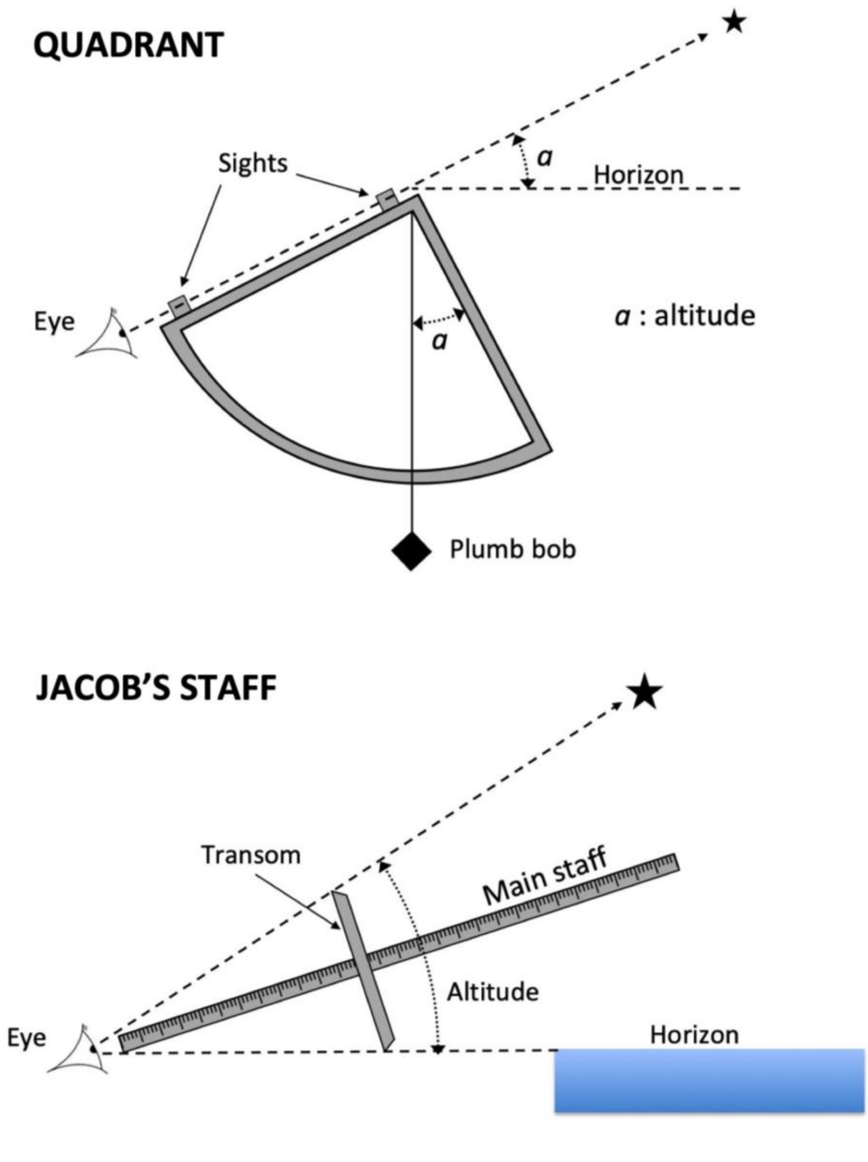

Fig. 4: Structure and operation of the nautical quadrant and the Jacob's staff, instruments used by European pilots at the beginning of the 16th century to determine the altitude of a star or the Sun above the horizon.

Discovering the southern skies

The Portuguese and Spanish pilots who guided the ships of the maritime expansion of the 15th and 16th centuries had to face the problem of losing sight of Polaris as they approached the Equator and entered the waters of the southern hemisphere. Magellan's fleet did so in November 1519, sailing between West Africa and Brazil. The main chronicler of the expedition, the Italian Antonio Pigafetta, comments that: "When we had passed the equinoctial line, approaching the Antarctic pole, we lost sight of the Polar Star" (Pigafetta, 2012: 14). Since then, pilots could only use the Sun to determine latitude. About the southern sky, Pigafetta tells us: "The Antarctic pole does not have the same constellations as the Arctic..." (Pigafetta, 2012: 37), so they had to learn to locate and distinguish new constellations. On the other hand, in the southern sky there is no reference star analogous to Polaris, in fact the area around the south celestial pole lacks bright stars. The sighting of the striking constellation of the Southern Cross is described as follows: «Finding ourselves in the middle of the sea, we discovered to the west five very bright stars placed exactly in the shape of a cross» (Pigafetta, 2012: 37), but it is quite away (about 25º) from the pole, so it is not easy to use it to determine southern latitudes. Finally, Pigafetta also describes the presence of two small nebulous objects not far from the south celestial pole: "... seeing in it two groups of small nebulous stars that look like little clouds, a short distance from each other." (Pigafetta, 2012: 37). The chronicler refers to what will be known much later as the Magellanic Clouds (the Large and Small Magellanic Clouds). Two dwarf irregular satellite galaxies of our Milky Way located 160,000 and 200,000 light years from the Sun.

Traditional stellar navigation in Oceania

Among the many important achievements of the Magellan-Elcano expedition, it is worth highlighting the discovery and navigation of what they called the Pacific Ocean for Western civilization. After sailing the eastern coast of South America, they discover the passage between the Atlantic and Pacific oceans, which will later be known as the Strait of Magellan. It took them 36 days to explore and traverse it, abandoning it on November 28, 1520. After 100 days without touching land, they crossed thousands of kilometres of a completely new ocean unknown to Europeans. During those days, the crew of the expedition saw only two uninhabited islands without being able to land on them, which is why they called them *Unfortunate islands*. The first possibly corresponds to the Puka Puka atoll, in the Tuamotu Archipelago (French Polynesia). The second has been identified with present-day Flint, in the Republic of Kiribati.

On March 6, 1521, when the conditions in the three surviving ships of the expedition were already desperate, they sighted two high islands, Guam and Rota, initially called the Islands of the Lateen Sails because of the type of canoe that its inhabitants handled with skill, the Chamorro people. Although they soon came to be called the Islands, of the Thieves because the Chamorro amazed at the metal tools available to the Europeans, stole everything that was within their reach. Finally, the archipelago will end up being known as the Mariana Islands, in honour of the second wife of the King of Spain Philip IV, Mariana of Austria, who in 1668 financed the evangelization and conquest of the islands under the direction of the Jesuit Diego Luis de San Vítores. These islands constituted the first European enclave in Oceania, where the first church was built and the first school on the continent was founded. They were under Spanish control until 1899, when they were sold to Germany, except for the largest and most populous, Guam, which was occupied by the United States in 1898, during the Spanish-American War.

The three-day stay of the Magellan-Elcano expedition in the Mariana Islands marked the first direct contact of Europeans with an Oceanian culture. At that time, most of the Pacific islands were inhabited (all if we only consider the largest ones). Their colonization was carried out through maritime expeditions that reached the different archipelagos from west to east, originating in Southeast Asia and islands such as Taiwan or the Philippines. Melanesia and Micronesia began to be populated around 3000 BC, and the outermost islands of Polynesia, such as Hawaii, New Zealand or Rapa Nui, ended up being occupied around 1000 AD. The Europeans and the Oceanians who met in the early 16th century shared the ability of navigation and the use of the stars to move across the ocean, albeit in different ways.

Most of the Pacific archipelagos are located around the Equator, between the tropics of Cancer and Capricorn, that is, their latitude (positive or negative) is usually small. This fact means that the movement of a star on the celestial sphere describes a path almost perpendicular to the horizon, so its ascending (to the east) or descending (to the west) position can be used as a reliable indicator of sailing direction for several hours. At higher latitudes, such as those in Europe, this is not the case, since the trajectories of the stars are oblique with respect to the horizon and do not indicate a fixed course. This property of the stars at low latitudes was a fundamental element for the pre-European navigators of Micronesia and Polynesia.

Traditional navigation is still in use in some atolls of the Caroline Islands (Federated States of Micronesia) such as Satawal or Puluwat and has been studied by various authors such as Goodenough (1953), Gladwin (1970) or Lewis (1994). In the atolls, the Micronesian pilots, the navigators, are important members of the community and learn their techniques for years in the "canoe house", where the study of the position and movement of the stars and other objects in the sky is treated as a fundamental branch of the art of navigation.

Carolinian navigators use the stellar or sidereal compass (Figure 5) to define sailing directions between islands. The compass is represented as a circumference with 32 points, which correspond to the places on the horizon where the rising, setting or culmination of 15 bright stars or relevant asterisms of the sky occurs. In this compass we find the Pleiades, the Southern Cross, Ursa Majoris or the Orion’s Belt, and also bright stars such as Aldebaran, Altair, Antares or Vega. The 32 points of the stellar compass cover the entire horizon symmetrically about the north-south axis, although they are not evenly spaced.

During their learning period, Carolinian navigators memorize the groups of stars that, as they rise or set, mark the course towards each of the islands they know and with which they are in contact, as well as all the information on winds and marine currents that have been collecting for generations. We can say that Carolinian navigators have a complete knowledge of the sky at all times, since they are not only capable of following the course by pointing the bow of their canoes towards a guide star, but also, when the star cannot be seen due to the presence of clouds, they can use another one that is visible keeping it fixed with respect to any structure of the canoe and with the appropriate angle in relation to the desired sailing direction.

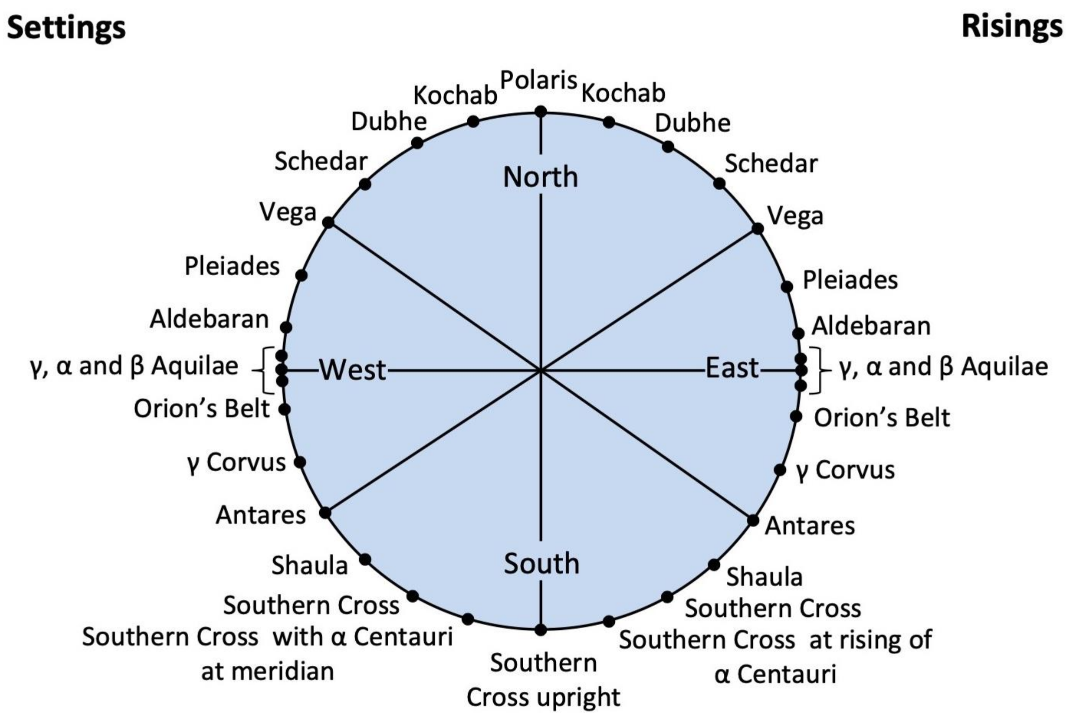

Fig. 5: 32-point sidereal compass based on the rising, setting and culminating bright stars or asterisms used by traditional navigators of the Caroline Islands. Adapted from Goodenough (1953: his figure 2).

Carolinian navigators also used the concept of zenith star (Lewis, 1994: 287-289), which corresponds to the star (or stars) that culminates in the zenith of a certain island (depending on its latitude), which was verified by observing the position of the star in relation to the top of the mast of the canoe. This concept was also applied to know the situation of the boat, especially during long trips.

Other secondary indicators of the sailing direction are also used in traditional Pacific navigation. The points of sunrise or sunset are also used but, as their position varies throughout the year, they are calibrated with stellar observations during the night before or after. Since the arrival of the Europeans, the magnetic compass is also used, but mainly during the day or when it is cloudy, although it is also calibrated with stellar observations. Another much more subtle technique is the estimation of the sailing direction with respect to the swell, waves of low frequency and small amplitude that usually have a constant direction in certain geographical areas and times of the year (Lewis 1994: 130).

Traditional navigation techniques have experienced a renaissance in Oceania in the last 50 years, especially in Hawaii, mainly promoted by the Polynesian Voyaging Society, dedicated to the research and dissemination of these techniques. In 1975 they built a large double-hulled canoe following ancient Polynesian methods: Hokule'a ("Star of Joy", Hawaiian name for the star Arcturus). On its first voyage it sailed from Hawaii to Tahiti, covering 4,200 km in just over a month, using only traditional techniques and no modern instruments. The new Hawaiian navigators had to learn the techniques from the masters of the Caroline atolls, such as Mau Piailug, from the island of Satawal or Hipour, from Puluwat. Between 1976 and 2009, Hokule'a made several ocean voyages of thousands of kilometres departing from Hawaii and visiting Samoa, the Cook Islands, New Zealand and the coasts of Japan, Canada or the United States. In 2014, the Hokule'a and its sister canoe Hikianalia (Hawaiian name for the star Spica) set out on a three-year voyage around the world. Nowadays, traditional navigation has become an element of fraternization and cultural reaffirmation between the inhabitants of the different islands of Polynesia and Micronesia, a relationship that once again extends along oceanic sailing routes guided by the stars.

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BENIN

Obtaining Latitude in Benin

Pide Aristide Ahanhanzo

Secondary General Education College of Akpassa

We prepared the primary students of the public school Médédjonou Sème Tchakou and the secondary school students of Secondary General Education College of Akpassa for several days. We started preparing for the experiment on March 8, 12, 19 and 20 in order that students understand very well the full process.

Fig. 1: Preparing the experiment with the sundial and the quadrant.

To do this, we built the sundial and the quadrant carried out several tests with the students so that they understood their use.

Before taking the altitude of the Sun at noon, it is necessary to determine said instant. First of all, we check that the time of our watch or mobile coincides with that of the equatorial clock that gives the solar time. So we can proceed to calculate the altitude of the Sun at usual noon.

Fig. 2: Rehearsing with the quadrant

Fig. 3: Using the quadrant to determine the height of the Sun.

Fig. 4: The determination of the altitude of the Sun at noon in March 2022

To determine the local latitude on March 19th, 2022 at noon the altitude of the Sun was 81º and the declination of the Sun was D = -1º. The measurements were taken on March 19th, 2022, therefore in winter

Altitude (H) of the Sun = 81º
Declination D = - 1º

The latitude (L) verify $L = 90 - H - |D| = 90 - 81 - 1 = 8°$

Benin's latitude is between 6ºN and 9ºN, so the result is reasonable.

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TOGO

Design of an equatorial sundial and a simple dial to determine the latitude

Doh Koffi Addor

ONG SG2D, **S**cience **G**éologique pour un **D**éveloppement **D**urable

Introduction

In order to participate in the 2nd Brigdes between Cultures-Latitude for traveling and navigate project, a project that allows the design of an equatorial sundial and a simple sundial in order to calculate the Latitude of places and to link with the history of travel and navigation, the teachers of Togo member of the NGO SG2D (Geological Science for Sustainable Development), proceeded to the construction of the equatorial sundial and a simple sundial and the position according to the North-South direction using a compass.

The construction of the equatorial and simple sundial as well as the determination of the latitude was done in three successive stages: Construction stage, latitude determination stage and presentation stage of the sundial to the students and the secondary school teachers.

Construction stage

The stage of the construction of the equatorial sundial in Togo has been radiant because Togo is located near the equator and thus the table of the sundial tends to be vertical. The positioning of the sundial rod in relation to the table is another difficulty since it must tend to the horizontal (see fig 1).

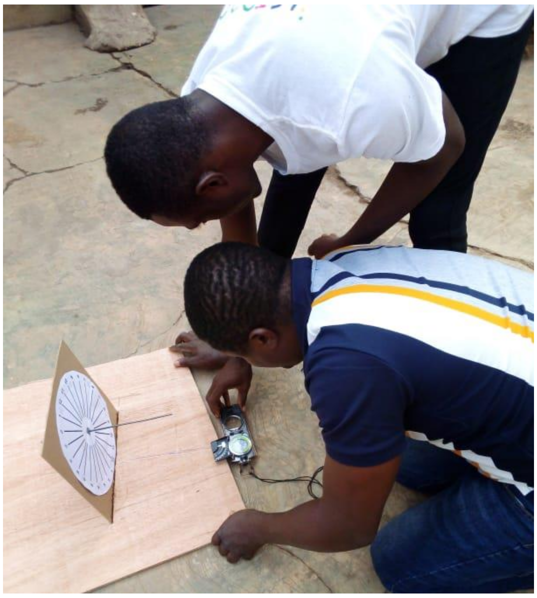

Fig. 1: Positioning of the equatorial sundial according to the North-South direction

We used a glue to stabilize the table respecting the normal angle and in the same way we stabilized the rod which must project its shadow on the table to allow to determine the latitude by using the simple dial.

Step of the determination of the latitude

In order to be able to calculate the latitude of the place, we used a simple dial which allows us to determine the height (the angle) of the sun when the sundial indicates the solar noon (see figure 2).

It was both a rough and complicated experiment since we had to position the simple sundial well pointed towards the Sun and have a projection (a round point) on the palm of the hand (not to look at the Sun with the naked eye). But, on the other hand, it is also a fantastic experience once you manage to get the height of the Sun.

Fig 2: Determining the height of the Sun with a simple dial

Determination of the latitude (L) of the location
The measurements were taken on March 21, 2022, thus in spring

Height (H) of the Sun = 84
Declination D = -00 01 45

La latitude (L)
L= 90 – H + | D |
L=90 – 84 + 00 01 45
L= 6° 01' 45'' ou L= 6,03

Stage of presentation of the sundial to the pupils and their teachers

After the conception of the sundial and the simple dial, we had made a demonstration of presentation of these magnificent tools to the pupils and the teachers during our astronomical tour "TOGO UNDER THE STARS" in the schools of Togo from North to South. The students and their teachers were really happy to discover these tools which allow not only to determine the latitude of the place but also and especially to determine the exact time to the minute. The advantage is that our country Togo is close to the equator and the solar time is almost equal to the exact time. This impressed the students and their teachers. This really brought them closer to history and ancient culture and they were all happy. They were not only happy but very interested in figuring it out for themselves.

Fig3: Presentation of the sundial to the students and their teachers.

Conclusion

We thank infinitely NASE for this beautiful and magnificent opportunity that it gives us to be able to take part in this beautiful project in order to be able not only to make discover these splendid tools to the Togolese (the students, the pupils and their teachers) but also and especially to be able to teach them to calculate the Latitude and also to be able to teach them to determine the time the equal one starting from the Sun which is present at all times at home. This could bring them closer to the ancient culture. In the coming days, we will work first with some teachers, then with primary and secondary school students (first and second cycle) and also with the students of the University of Lomé and we will present the reports to NASE at each step.

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INDONESIA

Fun Activities to Introduce Navigation and Geographical Coordinate Determination Using the Sun to ITERA Students

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Introduction

Indonesia is an archipelago country that has a long history in the maritime world. The existence of this historical fact shows that the ancestors of the Indonesians were very adept at determining position at sea when sailing. Our ancestors have long used the stars and other celestial events to navigate between islands. There were sea faring kingdoms to sail across Nusantara seas, as like Srivijaya and Majapahit, long ago before the European came to Indonesia at 17th century. [1]

Nowadays, not every Indonesian know about how to navigate or determine location using the sky, especially the young generation. In ITERA, we tried to have some sample of young students to be introduced about ocean and navigation, and determine the position and our coordinate on the globe, using DIY Quadrant and Sundial provided by NASE.

Fig. 1: Briefing and Introduction to quadrant, sundial, compass, and globe.

The Activities and Experiments

Before starting the activities, our team made a rundown of activities, how students can receive explanations about this in a sequential and easy-to-understand manner.

In general, the rundown of activities is as follows:
1) A description of the history of navigation, and the tools used for navigation, explain how Compass, Quadrant, and Sundial works.
2) Give an example of making Quadrant and Sundial.
3) Making Quadrant and Sundial all together.
4) Try using Quadrant and Sundial
5) Regather participants to reflect on activities and also present experimental results
We thought that the best time to do these activities is started at 3 hours before the noon. Because we can do the Quadrant experiment to determine latitude using sun at noon.

The first activity is Briefing and Explanation. In this section, we tried to explain about several things:
1) About geographic coordinates by using a globe.
2) About the history of using the sky as a navigational aid.
3) About the history of navigation tools like quadrant, sextant, compass.
3) How sundial works
4) How to determine position or geographic coordinates with quadrant, as well as sundials or other chronometers.

In this section, in this section we conduct some dialogues and questions and answers about their knowledge of navigation using the sky. Only one of them said that when they were young, they were taught by their parents about several ways to use the constellations to determine the direction of north and south. Such as using the constellation Crux or we are familiar with the term “Gubuk Penceng” to point to the south, or using the rising or setting point of the Orion belt to indicate the direction of the East or West. After explaining the quadrant works, many of the students have just learned that we can determine the location above the earth's surface using the sun. They also revealed that they have just understood the relationship between geographic coordinates and the shape of the sky horizon seen at night in this section discussion. In this section we also find some of students never use a field compass and not understand about compass magnetic declination.

Fig. 2: The Students are making foldable sundial

The second section is giving an example of making Quadrant and Sundial. In this section, we need the instructor to give an easy explanation about how to make the

Quadrant and Sundial. We think the maximum ideal ratio of instructor to participant is about 1:20.

The third section is making the foldable sundial and quadrant. NASE sundial design is very easy to make, but we have to modify several things to work with low latitude zone as like in Indonesia. We need some tools and materials: 1) Printed template, 2) Unused pen or anything looks like stick figure, 3) Strong paper glue, and 4) Cutter or scissor. Students the participants were very enthusiastic about cutting, folding, and gluing. They find it was very fun and easy to do.

Next is making the quadrant. The tools and material used are very easy to find as like: 1) Printed quadrant template, 2) Unused cardboard, 3) Unused pen, 4) Double tape, 5) Some small string, 6) Some small weights, 7) cutter or scissor. Some of student cleverly use on site unused objects to become the string and weight.

Fig3: Students Making and trying the Quadrant

The last section is trying to use the sundial and quadrant. Unfortunately, we couldn’t do it in the first meeting because we have a bad weather with thick clouds at noon. But the team give students to do it at home. Several did it and reported it back. They used the quadrant to try determine sun declination and try to determine altitude of several stars at night. They think it’s very hard to do at night if not train well.

Results and Thought about Experiments

We have introduced the history of navigation done by several civilization to students, and they found it very interesting, specially by utilization simple tools of quadrant and sundial to do navigation and how our Indonesian culture is used to be using sky as navigation. Several students found the activities are fun and easy to do, even at home.

Geographical coordinate determination using quadrant and sundial is possible to be done by the students, although we failed to do it because the cloud, students can still gain new knowledge with this activity.

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The four journeys of Cristobal Columbus

Columbus and his navigational instruments

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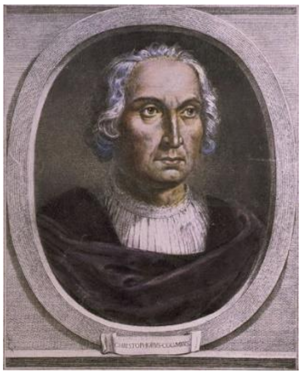
Introduction

Christopher Columbus, would try again with the kings of Spain (Isabel and Fernando), the convenience of opening a new route to the West (through the Atlantic Ocean), after having failed before the ruling authorities of Italy and Portugal.

Thanks to his stubbornness and better theoretical/practical plot preparation, he managed to convince and reject traveling to the East, along the Silk Road, due to the danger it entailed at the time.



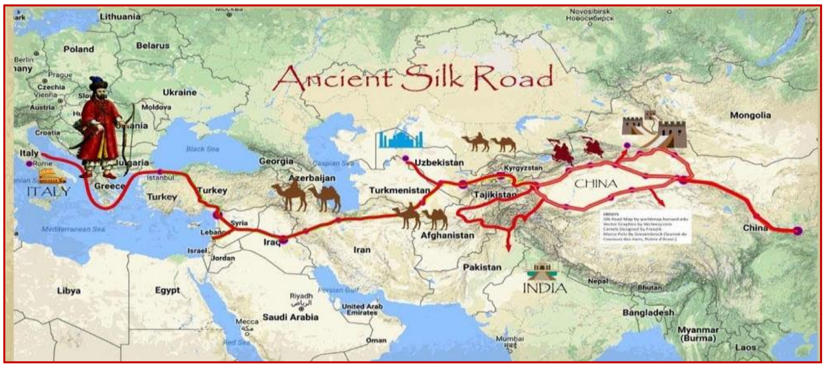


Fig. 1: Christopher Columbus (1451 -1506). Fig.2: Map of the Silk Road opened by Marco Polo (1254 - 1324). Source Wikipedia.

The Silk Road was controlled by soldiers of the Ottoman Empire (Asia Minor) descendants/heirs of Genghis Khan, where merchants had to pay a tribute in money or merchandise for crossing their territories and they did not guarantee your safety and the rest of merchandise.

On the other hand, the southern route had already been taken over by the kingdom of Portugal, which soon realized that the silk route had to be avoided, so they decided to do so by traveling by sea, bordering the African continent. It was believed to have a longer range, but it was safer. At that time, Portugal had very good navigators such as Enrique the Navigator, who in 1426 conquered the islands of the Azores, later Bartolomé Diaz in 1488 managed to double the Cape of Good Hope and in 1497 Vasco de Gama arrived in India

Fig. 3: Map of the African continent. Source Wikipedia

Commercial need to open a new route to the West

The arguments put forward by Columbus to try to convince the Catholic kings and the commission of scientific specialists made up of astronomers, geographers, military men from the navy, shipowners of caravels and ships, religious scholars (doctors of the church) and Spanish businessmen, gave the go-ahead. to Colon of his proposal to sail in a WEST direction,go-ahead. to Colon of his proposal to sail in a WEST direction.

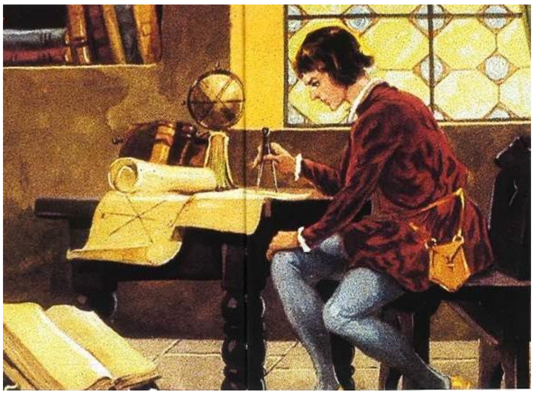


Fig. 4: Illustration of Columbus preparing his project for his defense. Source Wikipedia. Fig. 5: Woodcut after an oil painting by Wenzel Von Brozik. XIX century. Columbus explaining his project to the scientific authorities and doctors of the Church.

Let us remember that in Spain at that time its coffers were at a minimum, due to the wear and tear of the war of the reconquest that lasted almost eight centuries and, it barely had the liquidity to undertake such a project.

Once the need to open a new trade route to the west was approved, the first trip would be financed thanks to the contribution of a businessman from the court who donated 1,200,000 maravedís, which marked the start of the first trip.

Christopher Columbus and his crew were aware that they would possibly never return from this adventure and it could be a journey of no return, but even so, on August 3, 1492, Columbus fulfilled his wishes and cast off the moorings from the port of Palos de la Frontera (Huelva), with a very high personal ego, capable of making history as a great conqueror.

Fig. 6: Replica of Columbus's ship. Source Wikipedia

Previous cartographic considerations

Columbus took for good the cartography, geography and astronomy that were known at that time, carried out by the great Greek and Alexandrian sages. However, in some books and documents Columbus is still blamed for making various errors, but I believe that it is not fair, but rather that those errors are due to other specialists on whom the preparation of his trip was based, such as: astronomers, geographers and cartographers of recognized prestige.

From the 5th century B.C. calculations had been made on the measurement of the radius of the Earth, among which we highlight Pythagoras, Anaxagoras, Hipparchus of Nicaea, Eratosthenes of Alexandria, Posidonius of Apamea, Claudius Ptolemy, etc.

Today, we know and know the precision of the calculation that Eratosthenes made in the third century BC. on the measurement of the great equinoctial circle, resulting in the Earth having an approximate value of 40,000 km of circle with a relative error of less than 1%. However, the great circle of Posidonius of Apamea 1st century BC. it was a much lower value than that of Eratosthenes, possibly due to several causes, for example: not using the same values in the measurements of stadium patterns, since each country had different measurements, another cause could be the methods used, Eratosthenes used the shadow method with the gnomon applying it in two different places Siena and Alexandria for the same day (summer solstice). However, Posidonius used a novel method consisting of observing the same star on the same date and time from different places Rhodes and Alexandria, with an astrolabe, obtaining a value of the maximum circle of the earth of 29,000 km, being 11,000 km less than that of Eratosthenes).

- **A success of Columbus considering the smaller Earth**

Columbus was interested in the fact that it was the smallest Earth and, like all the cartography of his time, they had been based on Claudius Ptolemy's map (2nd century

AD) where the greatest circle considered was the one calculated by Posidonius of Apamea (mathematician , cartographer and astronomer), so he considered it valid.

Fig. 7: Map of Claudius Ptolemy 2nd century Source book of the history of cartography

This Ptolemy map was the reference base for other later cartographers, such as Toscanelli in the year 1474.

Also, Columbus as a basis would argue to convince the scientific commission that the Earth was narrower at the equator than at the meridian of the poles, believing that the earth was pear-shaped and not apple-shaped, with which being narrower they would reach the Indian lands sooner, which meant loading the caravels with less supplies.

I am curious [after 100 years Giovanni Cassini (1625 – 1712), a French cartographer and astronomer, also believed that the earth was pear-shaped, while Isaac Newton (1642 – 1727), an English physicist, mathematician and astronomer, believed that it was an apple ; the discussion ended, with the realization of an expedition to determine the true shape of the Earth, and for this, two expeditions had to be undertaken, in order to measure a meridian degree at different latitudes, on the one hand, the expedition Cassini, where the Spaniard Jorge Juan was, were in Peru and the other expedition led by Newton went to Lapland.

<<Newton was right>> The earth is shaped like an apple, as a result of these expeditions the international metric system was created)] I close my curiosity.

Columbus would also count on the collaboration of his Italian friend, the Florentine cartographer Toscanelli, to refute that the route to the West was possible and shorter, considering that in approximately 45 days he would reach the Indies.

- **The Map of the cartographer Toscanelli that conditioned Columbus**

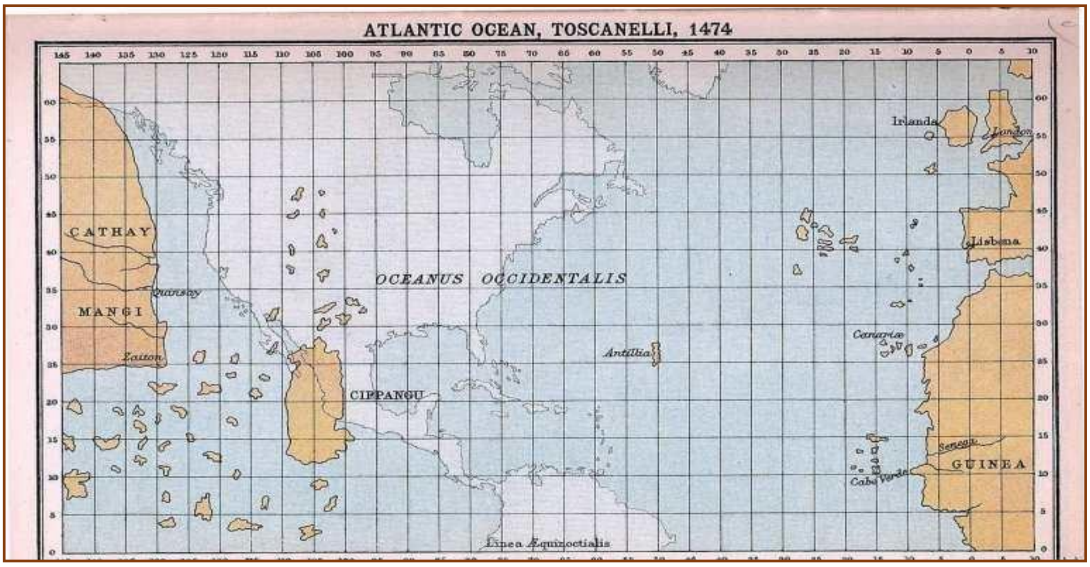


Fig. 8: Map created by the Florentine Paolo dal Pozzo Toscanelli (1397 -1482)

In this Toscanelli map, we see that the current American continent has been superimposed on the original Toscanelli map. In Toscanelli's time, other maps (of unknown author) were also made, where the islands of the Indies appear with the idea that if they traveled west they would find them.

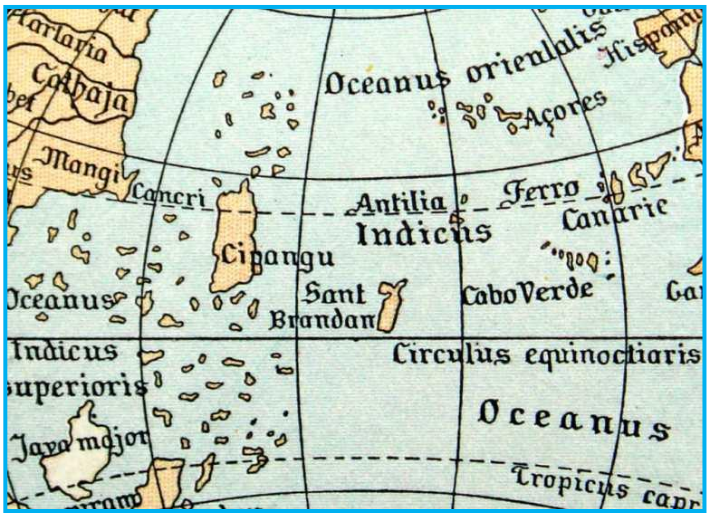


Fig. 9: Illustrative map of unknown origin made in the 20th century. Source Wikipedia

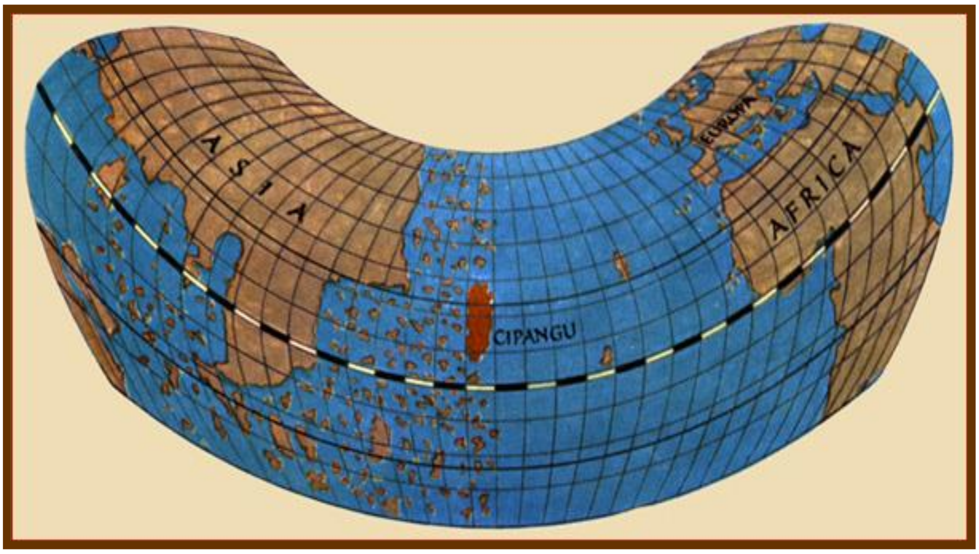


Fig.10: Illustrative map of the late fifteenth century where the American continent does not appear

These two maps reflect the ideas prior to Columbus' voyage, where the location of Hispania (northeast of the map) is clearly seen and in the center above the equinoctial line (which was then the great circle of the Earth that divided the Earth in two hemispheres, is the island of Cipangu (current Japan) and below Cipangu is the archipelago of spices that I wanted so much to find

Another of the persistent argumentative force of Christopher Columbus was the economic importance that it would have, if he managed to reach the Indies, opening a new commercial route for all of Europe since there was a strong demand for these exotic products such as: cloves, cinnamon, essences of varied oils, to be used in medicine, beauty, cosmetics, food preservation and gastronomy, etc.

Fig.11: Panel of exotic spices for Europe. Source Wikipedia

Instrumentation used by Columbus: Latitude and Longitude. To determine the geographical coordinates of a point on the high seas.

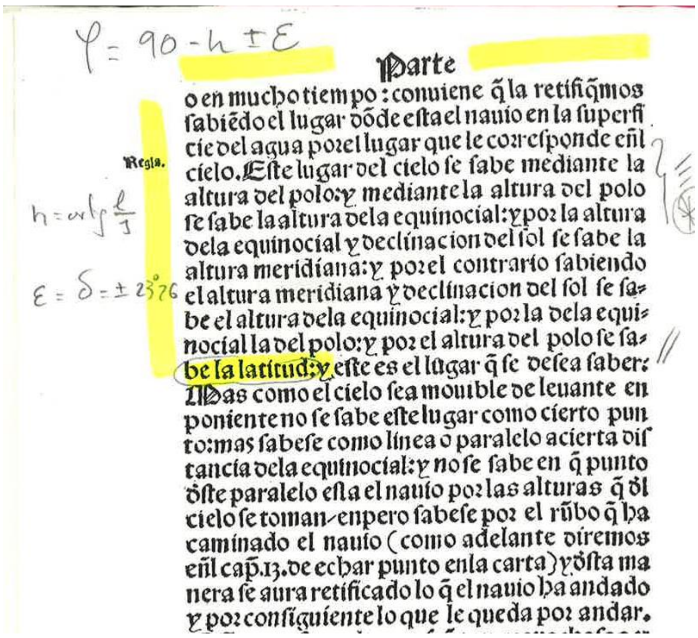
It was essential to know the sea and the art of navigating, as well as to know the stars in the sky, since high-altitude navigation had to be carried out, abandoning cabotage or dead reckoning (without losing sight of the coast), so the captains / admirals had to have some knowledge of the celestial vault and its brightest stars (according to each season of the year), in addition to knowing the sea currents and trade winds and knowing all the instruments on board that were carried to determine the latitude and length.

Columbus knew that the earth was spherical, according to his lived experiences. He knew that, if he kept approximately the same value of the latitude of a parallel, close to the equator from which he started, without leaving it and sailing towards the West, he would go around the world unless he ran into some terrestrial obstacle, which he did. , discovering a new continent without knowing it.

Years later, two other great Spanish admirals such as Juan Sebastián el Cano (1476 - 1526) and Fernando de Magallanes (1480 -1521) were the first to circumnavigate the Earth, that is, to go around the world bordering the continents and saving the lands. they were and returning to the starting latitude. In the facsimile book of the "brief compendium of the sphere and the art of navigating" he comments on the mathematical expression for calculating latitude, simply substituting in the expression:

$$\textbf{Local Latitude} = 90^{o} - h + - \varepsilon$$

obtained from the spherical trigonometry of the triangle formed by (Sun – Zenith – Pole), according to the fundamental formulas for the resolution of spherical Bessel triangles, we can always obtain any of its terms, but now the latitude is of interest.


φ = 90 - h ± ε

Parte

Regla.

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cie del agua por el lugar que le corresponde eñl
cielo. Eſte lugar del cielo ſe ſabe mediante la
altura del polo: y mediante la altura del polo
ſe ſabe la altura dela equinocial: y por la altura
dela equinocial y declinacion del ſol ſe ſabe la
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el altura meridiana y declinacion del ſol ſe ſa-
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dẽſte paralelo eſta el nauio por las alturas q̃ dl
cielo ſe toman, enpero ſabeſe por el rũbo q̃ ha
caminado el nauio (como adelante diremos
eñl cap. 13. de echar punto enla carta) y dẽſta ma
nera ſe aura retificado lo q̃ el nauio ha andado
y por conſiguiente lo que le queda por andar.

Fig.12: Chapter of art of navigation of the facsimile of Martin Cortes published in 1551

Substituting the values, we will have

h = altitude of the Sun taken at noon above the plane of the horizon, obtained mainly with the instruments of the quadrant and the astrolabe

ε = is the value of the obliquity of the ecliptic that varies between the values + - 23º 26' (depending on the date you are on)

We will be able to obtain the latitude of the place and, at night, it would be checked with the height of the polar

- **Charting the point**

With the daily data provided with the various specific instruments for the determination of latitude and longitude, plus the course of the course and distance traveled, the point was drawn on a new chart and this was compared with the official reference chart that they had, this operation was called "charting the point". This operation of charting the point was not so simple and it was necessary to know and take into account the leagues traveled or nautical miles or kilometers traveled each day, as well as the course marked with its variations.

Instruments for determining latitude

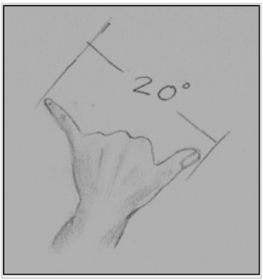
Next, a series of instruments and methods are described that served seamen to carry out high-seas navigation during the 14th and 15th centuries and later, being replaced by other instruments that improved their precision, with greater safety for sight and better materials in their manufacture, for example, sextants.

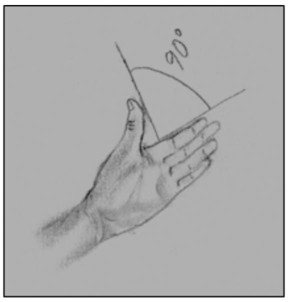
- **The hand and its application graduations in heaven and earth**

An instrument that is not mentioned in the books that Columbus and his officers surely used was the use of their hands and the relationship of the sky with the existing degrees according to the angle. The precision was not very good, but it was quite close to the data obtained with other more precise instruments.

***The method of the hands serves as a first rough approximation for the calculation of latitude, but it is very useful and gives confidence.*

Here we have some graphics of the author that according to the position of the hand would be equivalent to the corresponding degrees, we always have to stretch the hand to the maximum and level the part of the hand below with our view, then here it would be 0º and if we place the desired angle for example 15º where it ends we will obtain the angular value.





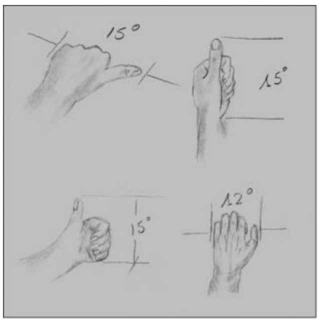


Fig.13: Graphs of the hands with their angular values. Own elaboration

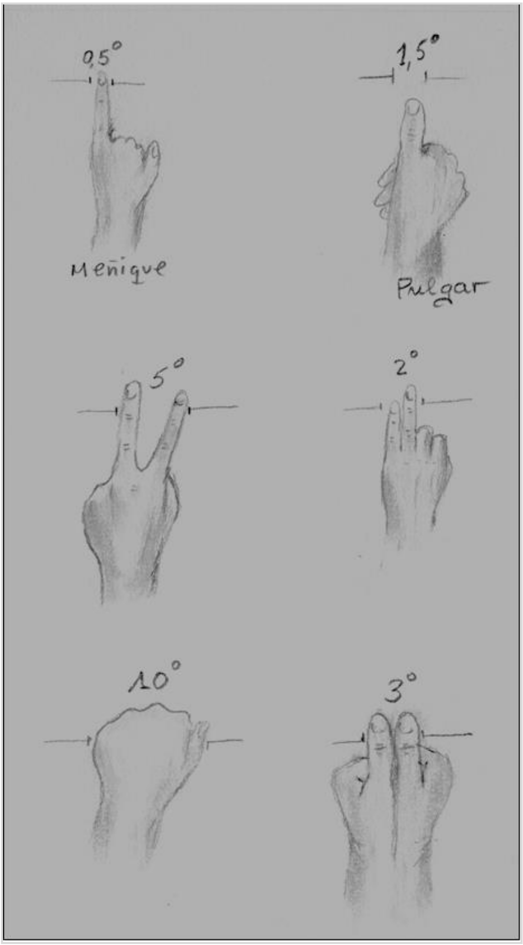


Fig. 14: Graphs of the hands with their angular values. Own elaboration, extracted from the book of Sancho's clock by the author himself

We can also express it in times since if 360º is 24 hours, 15º is one hour, this being a very useful measure. Recall that it takes the Earth one hour to traverse a land use. It is applicable to any part of the world for the determination of latitude. Another example was determining the height of the Pole at night, which, as we well know, has the same angular value as the latitude where one lives.

So we can know the latitude of the place at all times. This procedure could also be done with any very bright star. Columbus and his officers knew it and used it

- **The short and long crossbow**

The short crossbow was used anciently by the Egyptians on the ground to know the arrival of the seasons. Later the Arabs raised it to the heavens to measure the heights of the stars and the sun. The practical foundation of the crossbows consists of knowing the angular relationship between the distance traveled by the smaller crossbar over the larger graduated crossbar, both perpendicular and, according to the position in which the horizon is flush below and the star (Sun) above. we can know the altitude (h) of the object above the horizon. It was widely used by the Arabs in the middle latitudes, which is why all fifteenth-century sailors always carried it on board.

Fig.15: The image on the left is from the time of Columbus and the image on the right is the author himself in a demonstration in Tavira (Portugal) of EAAE conferences to determine the height with the short crossbow and the method of leveling below the horizon and above the sun running the angular crossbar to obtain the value of (h) height of the object in question.

But, when the Portuguese were in latitudes close to the equator, the short crossbar was not worth it, they created the long crossbar, they had to add more larger and longer crosspieces to be able to level the sun when it was near the zenith. The inaccuracy was notable because they only managed to appreciate half a degree by dead reckoning and it was necessary to use both hands, with the assessment of the movement of the ship and look at the Sun.

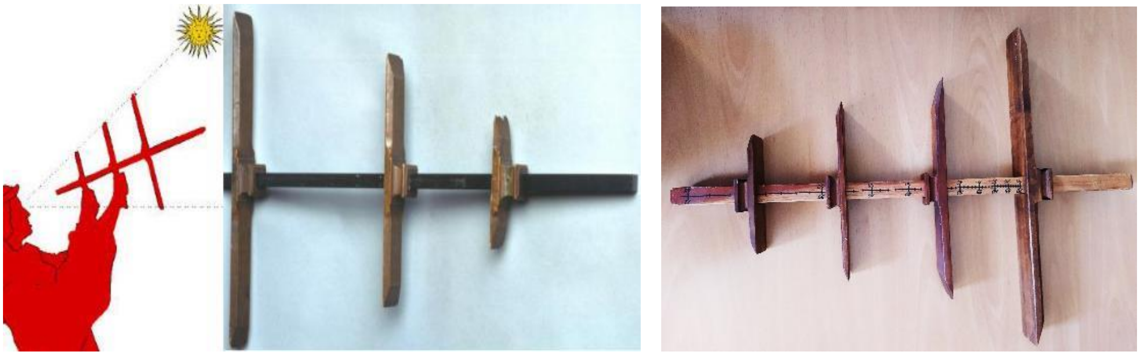


Fig.16: Ballestillas larga/ecuatorial o equinoccial creada por los portugueses. Fuente Wikipedia

- **The Karmal**

It was an improvement on the crossbow in that better stability could be achieved between the hands, but it was similar to the hands-on method. It was made up of two wooden arms held in the center by a graduated semicircle. It is a very practical and intuitive instrument for teaching and can be measured with the opening of the desired angle between the horizon and the star (Sun), also to know the height of a building

Fig.17: Karmal Very simple instrument for determining latitude. Own source

Commentary on the three instruments described

These three instruments described above lacked precision, in addition, the officer in charge of handling the vision had serious problems since having to collimate or forcefully point to the sun during the day, over time, the retina would be seriously damaged, so they remained without sight in one eye called one-eyed (case of pirates).

- **The Quadrant**

Another instrument highly appreciated and inseparable by Columbus was the quadrant (the fourth part of 360º, that is, 90º, which on the limbo was divided into degrees and minutes. It was made of wood, versatile, fast and easy to use by Columbus' officers. On the center of the quadrant, suspended a plumb line that marked the degrees and minutes of the height of the star or the Sun at noon This quadrant contained two pinnules with a hole in them, which served for the light to pass between the two holes and when they were coincident, the height of the Sun was determined; it reached an accuracy of half a degree and also, and very importantly, it was not necessary to look at the Sun

Fig.18a

Fig.18b

Fig.18c

Fig.18d

Fig.18e

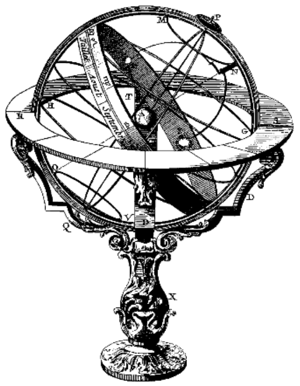
Fig.18f

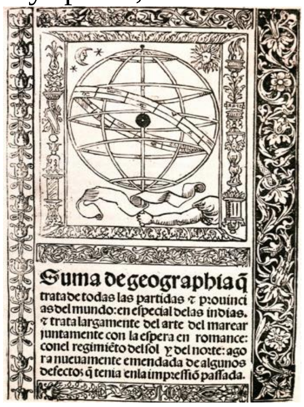
Fig.18: We have six images of quadrants a) it is made of wood with brass reinforcement, b) brass quadrant c) Graph of construction of the quadrant that appears in the book "El saber de astronomia" by

Alfonso X the wise (1221 -1284), d) wooden dial with the hours of light and darkness according to the time, e) sailor is using WRONG the dial should not be looked at with the eyes through the pinnules (hole), f) detail of the dial with the two pinnules and their holes. Source Wikipedia

• The armillary sphere

Columbus knew about the armillary sphere, even if he did not take it on board





Suma de geographia q̃
trata de todas las partidas ⁊ prouinci
as del mundo: en especial de las indias.
⁊ trata largamente del arte del marear
juntamente con la espera en romance:
con el regimiẽto del sol y del norte: ago
ra nuevamente emendada de algunos
defectos q̃ tenia en la impressiõ passada.

Fig.19: Esfera armilar a la izquierda y a la derecha la portada del libro Suma de Geographia de Martín Fernández Enciso. Sevilla, 1519. MN. Fig.20: Ilustración de la Esfera armilar de la época que además contiene el astrolabio y el cuadrante. Fuente. Wikipedia

In this work, Suma de Geographia, contains the first description of the lands of the New World, and especially of its coasts. It includes a navigation treatise and some solar declination tables, which any tall navigator always carried on board, to find out the value of the ecliptic obliquity (ε).

****Cervantine curiosity**, about the knowledge that was had of the instruments, in the 16th century. In chapter XXIX of the second part of the book by D. Miguel de Cervantes in "**Don Quixote de la Mancha**" (Don Quixote speaks)... Make Sancho the inquiries that I have told you, and don't worry about another, because you don't know what Whatever they say, you do not know what colors, lines, parallels, zodiacs, ecliptics, poles, solstices, equinoxes, planets, signs, points, measurements are, of which the celestial and terrestrial spheres are composed; that if you knew all these things, or saw part of them, clearly what parallels we have cut, what signs we have seen and what images we have left behind and are leaving now.

• El nocturlabio or sancho's watch = the polo man

*This instrument has been used to determine the time at night, very important both on land and at sea.

The night lip fell into disuse due to conceptual errors in its construction and lack of updating, and it was also difficult to apply. If we look at one of the faces of the dial instrument, the well-known image of the **man from the pole** appears, where Columbus knew him and used him to know the hours at night and to change **the guards** of his crew. If we look at the circumpolar constellations and specifically the little bear and the extreme stars known as the guards (**Pherkad and Kochab**), especially **Kochab**, depending on the position of this star at the time of the beginning of the nautical twilight, we could know what time will dawn.

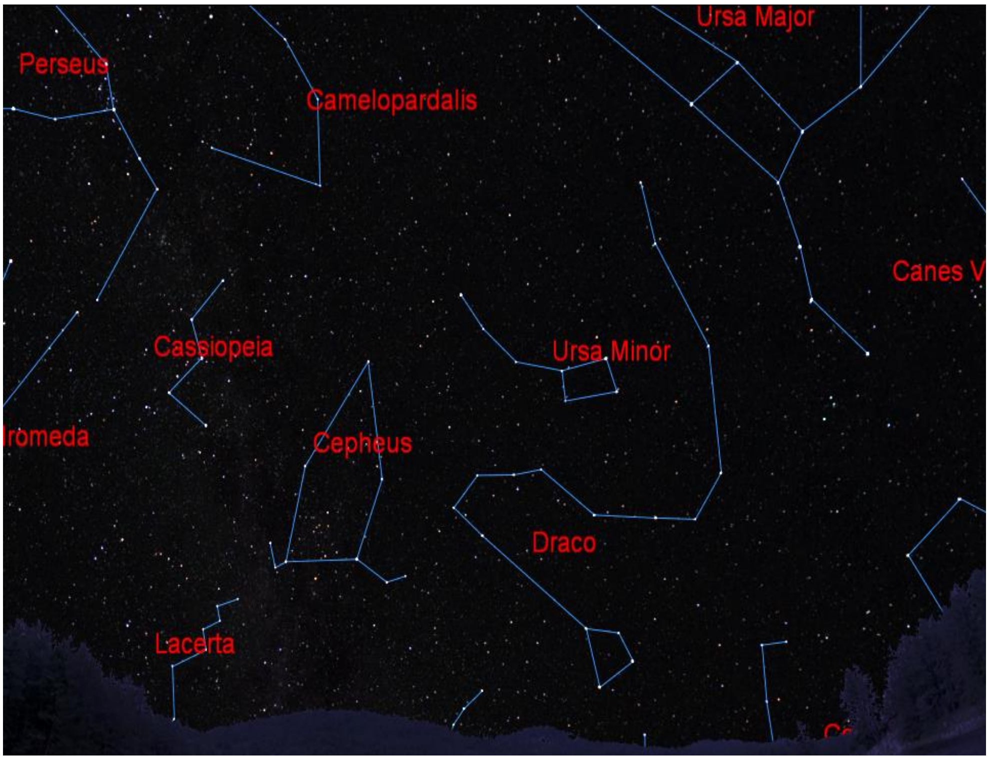


Fig.21: Northern hemisphere circumpolar constellation map. Source Stelarium.org

It is very interesting and rewarding to teach the hours at night, we can also know the day, the month and the season of the year in which you are. It is necessary to know the duration of each of the three twilights: civil, nautical and astronomical conditioned to the latitude of the observer.

Next, we have several images that represent the man from the pole looking towards us, although Columbus used him from the back like the one (Fig. 22b): markers of the head-foot and arm axes, as well as the bisectors between the respective quadrants equivalent to 3 hours of heaven.

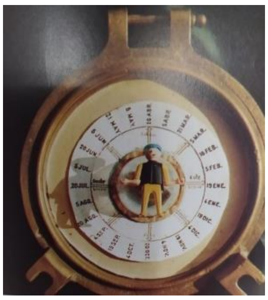


Fig.22a: Pole Man

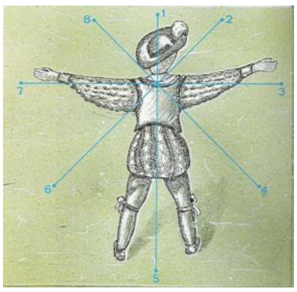


Fig.22b: Columbus Pole Man

Fig.22c: Ursa Minor Constellation

Fig.22d: Fixed brass calendar

Fig.22e: Dial with polar man

Fig.22f: Sancho clock

These six images of the pole man are based on the movement of rotation on the axis of the world.

In the fifteenth century and earlier they already knew this method where they imagined a man on a cross looking at us with his arms outstretched as if they were the Cartesian axes (X, and Y), where the "x-axis was represented by the left arm and right arm and the y-axis was represented by the head and feet.

The 15th and 16th century cosmographers and navigating pilots of the high seas were aware of the relationship “**that, for any meridian, each degree that rises or falls in height from the pole or from the sun would be equivalent to 16 leagues and 2/3 of leagues**”. In other navigation treaties appears the equivalence of 1st degree = 5,555Km and was equal to 17.5 Castilian leagues

In Columbus' logbook, on February 3, he makes the following entries... Today, going astern with the flat sea I will have traveled about 29 leagues and I thought I saw the North Star very high as in Cabo de San Vicente (Portugal), but I couldn't take height with the astrolabe or with the quadrant because of the waves.

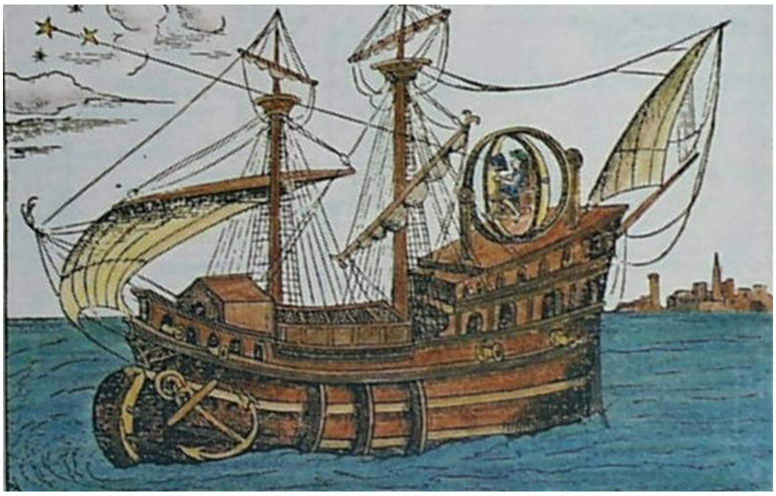


Fig.23: Representative illustration of a ship with a security compartment where the officer on duty would sit to collect data from the stars or the sun. The instrument you have is a quadrant.

**The value of a Castilian league was 5,555 km. Although, for example, in France it was 4.5 km, depending on the country the measurement could range from 4.5 to 7 km. We have an example in the image (Fig.24) of a French cartography where two scales appear, the French and the Spanish, and their equivalence of common leagues of 20 to a degree in Spain and 25 common leagues to a degree in France.

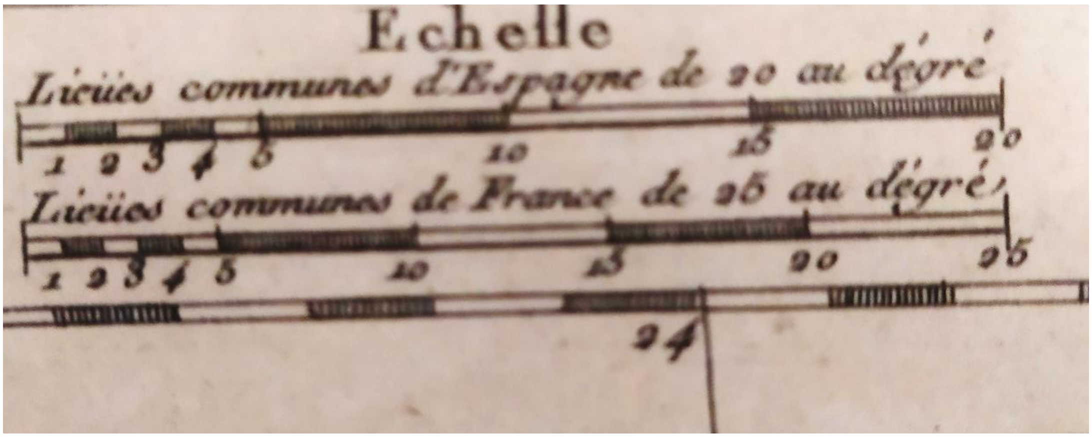


Fig.24: Image of the French and Spanish scales regarding the leagues and their equivalence to a degree reflected in a French map of the 16th century. Source History of cartography

- **Astrolabe (a jewel of medieval astronomy)**

Fig.25: Three images of astrolabes of the time used in the 15^{th}, 16^{th} centuries

These three types of astrolabes, are of Arabic/Spanish origin, were very heavy and used to be made of brass. It was an instrument widely used by Arab astronomers before the creation of the Toledo school of translators in the 13th century. Later it would go on to be spread throughout Europe and America.

The Arabian astrolabe is described in detail about its construction and handling in the book of "Astronomy Knowledge" of the King of Castile Alfonso X "The Wise" (1221 - 1284). The quadrant is also described in detail.

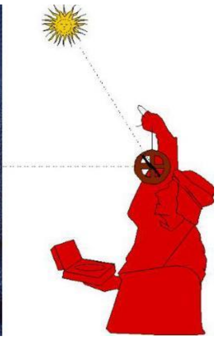
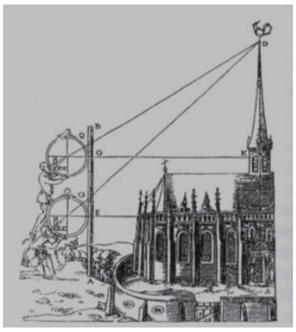





Fig. 26 a Fig. 26 b Fig. 26 c Fig. 26 d

Fig. 26: Images of the astrolabe applications and accuracy of the astrolabe in the 15^{th}, 16^{th} centuries

The astrolabe is a very complex and difficult to use instrument that had quite a bit of angular precision and giant astrolabes could also be used to check the vertical, in the great monuments or Gothic cathedrals such as Figure 26 c.

It was a true traveling observatory, since an entire astronomy treatise was engraved on it. It was mainly composed of two circles, one fixed and the other rotating (spider), where it contained reference stars according to the seasons, it also had their azimuths, on the outside (limbo of the astrolabe) it had the sexagesimal graduation divided into degrees its precision reached the minutes and seconds by dead reckoning.

** Azimuth is the angle of the location horizon from true north to the desired star lowered to the horizon

**Another Cervantine curiosity that demonstrates the knowledge that Miguel de Cervantes had about the instruments that allowed him to know the leagues traveled and what he still had to go when he traveled to Barcelona, and had such a funny adventure when he navigated the Ebro river.

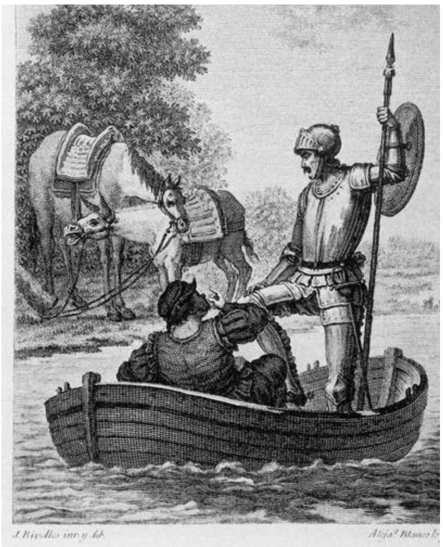


Fig. 27: Illustration by Gustave Doré (1832 – 1883) in the book of Don Quixote

Chapter XXIX (second part)

<<From the famous adventure of the enchanted ship>>
Don Quixote speaks... in a short space we will go out to the dilated sea? But we must already have left and walked at least seven or eight hundred leagues; and if I had an astrolabe here with which to take the height of the pole, I would tell you how far we have walked: although either I know little or we have already passed or will soon pass the equinoctial line, which divides and cuts the two opposite poles equally distance.
-And when we get to that wood your grace says - asked Sancho - how far will we have walked?
- A lot - replied don Quixote - because of the three hundred and sixty degrees that the globe contains of water and of the earth, according to the computation of Ptolemy, who was the greatest known cosmographer, we will have walked halfway, reaching the line what I said

The astrolabe fell into disuse for several reasons, one of which was its complexity, and the failure to update the Gregorian calendar reform that was officially launched on October 15, 1582 in Spain, but not in other countries.
Today, it is still used in a light and comfortable version in astronomy, because part of it is represented on a celestial planisphere, obviously conditioned to the latitude of the place and the date of the observer, taking in part the astronomical information that the ancient astrolabe had.

- **Cosmography in Spain in the 15th and 16th centuries**

Cosmography was a specific training, intended for future navigators (sea captains) that they had to take before embarking on the Americas. The subjects (subjects) dealt with the knowledge of the celestial vault, referential stars according to the seasons, calculation of latitudes, speed of the ship, determination of courses, knowledge of astronomical ephemerides, algebra, interpretation of nautical charts, drawing of a new portolan, as well as its custody, it was also important to know and handle all the instruments that would be used in maritime navigation, etc.

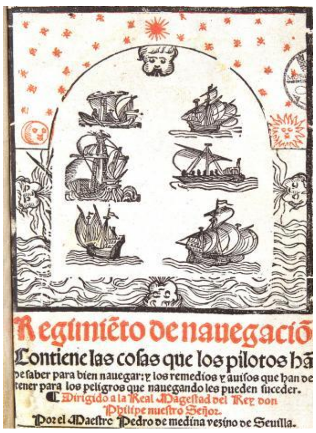


Fig. 28: Cover image of the Navigation Regiment. Peter of Medina. Seville, 1563

The regiment was a type of practical navigation treaty for use by future pilots. The recommendations and rules were prohibited from being disseminated, as they were considered state secrets.

The first school of cosmography was located in the contracting house of Seville in 1503, promoted by Isabel la Católica for the control of merchandise and control of people who came and went from the new world. The first director of the school was the Florentine Américo Vespucio (1454 – 1512), assistant to Columbus, he was named after the continent of America, due to an error by the cartographer Waldseemuller (1510), later Juan de la Cosa would succeed him (another aide to Columbus).

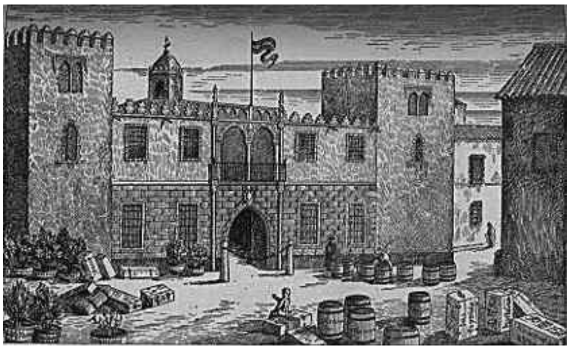


Fig.29*:* Main facade of the contracting house in Seville. Source Wikipedia XVI century

Determination of angles in the 15th and 16th centuries at sea

- **The tide needle (compass)**

It is a very valuable instrument, invented by Chinese military astronomers who called it "Luo Pan" (Fig. 30ª] in the 10th century BC. Later in the 14th century, the merchant explorer of the Silk Road, Marco Polo, brought it Genoa (Fig.30b) soon realized the potential of the instrument and adapted it for navigation (Fig.30c).It is a very important instrument for plotting courses and portolan mapping, even today it is still used on Earth Sea and Air.

Fig.30 a Fig.30 b Fig.30 c

Fig. 30, a, b, c: Three instruments dedicated to obtaining angles (courses) at sea or on land, being 30 c, the one used at sea called the tide needle

The tide needle was protected against the water from the waves and the wind, it had an appendix (little box) on one side of the compass, inside which there was a wick that lit up at night to see the course well and not go out. by wind or wate

- **The rose of the winds**

The compass rose was copied from the Chinese Luo Pan and was used to trace the different directions, taking advantage of the automatic orientation of the needle towards the magnetic pole. By definition it is said that the angle between the magnetic needle and the desired direction is the course and is expressed in sexagensimal degrees. This instrument was and continues to be very useful for determining magnetic North (NM) and we could also know the angular difference between NM and true North (NV) called magnetic declination; this declination can be to the West or to the East of true North (NV) which is the one that marks the axis of the world (near the Polar), but as it is known today the declination varies according to the time and place.

- **Los portolans**

The portolans, were some nautical charts that were made in high-seas navigation, with the instruments and skill of tracing the angle or course that it provided, the tide needle and knowing the distance or leagues traveled, from the last demarcation to the new point, then the cartographer proceeded to chart the new point on the portolan.

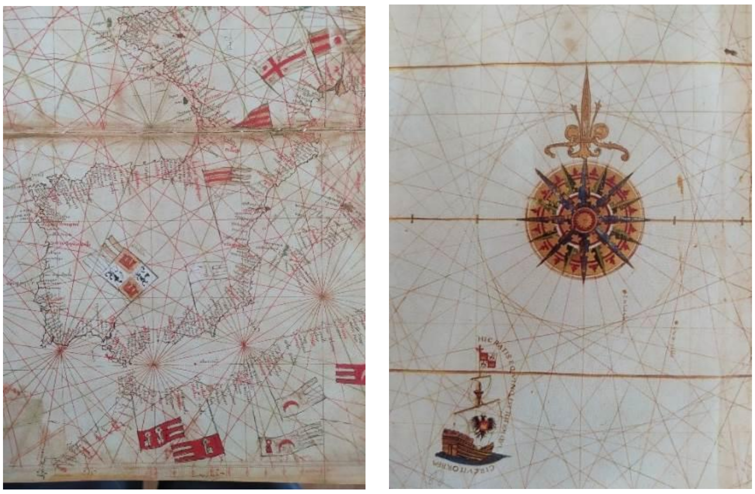
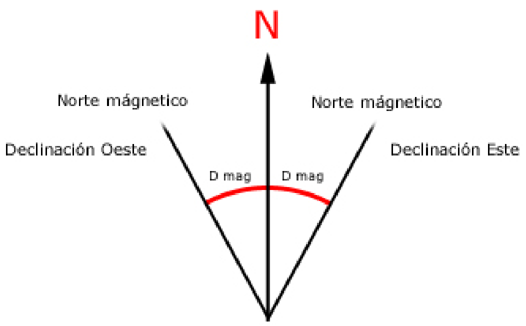


Fig.31: Spanish compass rose copied from the French of the 16th century, Fig.32: Two images of nautical charts (portolans) of the 15th and 16th centuries

- **Colón constata por primera vez, un fenómeno extraño**

A surprising event happened to Columbus that he knew how to cunningly keep his crew from alarming them more than they already were. He verified with his eyes on the tide needle that at a given moment it was marking the direction of the northwest and shortly after it happened to mark the northeast without him knowing it he had crossed the agona line (line of magnetic declination of zero value), writing in his logbook …. It is as if I had crossed a mountain while I was going up it marked the northwest and when I came down the mountain it marked the northeast, just like a pear….

This is what he comments on September 13 in the logbook of Columbus, made by Fray Bartolomé de las Casas….That day with his night, going to his road, which was the West, they walked thirty-three leagues (Colón always said a number fewer leagues traveled so as not to further alarm the crew), the currents were contrary. On that day, at the beginning of the night, the needles were northwest and the next morning they were not...



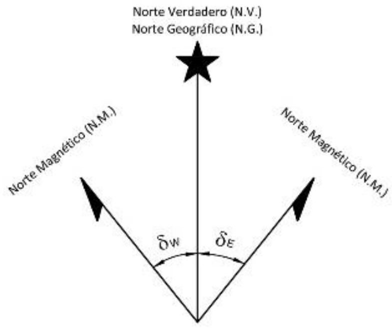


Fig. 33 a Fig. 33 b

Fig.33: Two images of the secular movement of the poles and the passage of the agony line (0º) by the University of Alicante in September 2016

Fig.34: Portuguese nautical chart depicting the line of demarcation

This zero line (agona) that unites the magnetic poles, was decisive in ending the disputes between the crown of Portugal and the crown of Castile, since this change of the needle was used approximately to locate a new line called demarcation that would serve to know and know which lands were for the Portuguese and which for the

Spanish, that is why in the treaty of Tordesillas (Valladolid) of June 7, 1494, both kingdoms signed the agreement to respect said demarcation line drawn imaginarily from North to South, located 370 leagues to the west of the Portuguese islands of Cape Verde, decreeing that all the lands that surpassed said line would be for the crown of Castile and the lands prior to it would be for the crown of Portugal. That is why Brazil kept it to conquer Portugal and the rest for Spain

Fig.35: Nautical chart of the admiral and cartographer Juan de la Cosa where the demarcation line is highlighted

• Variation of the magnetic field

Today, it is known that the tide needles (the compass), both on land, sea or air, vary according to the intensity of the lines of force of the magnetic field that surrounds the Earth. These lines of forces are divided into positive and negative intensity values called isogonal lines, with a zero line dividing the field.

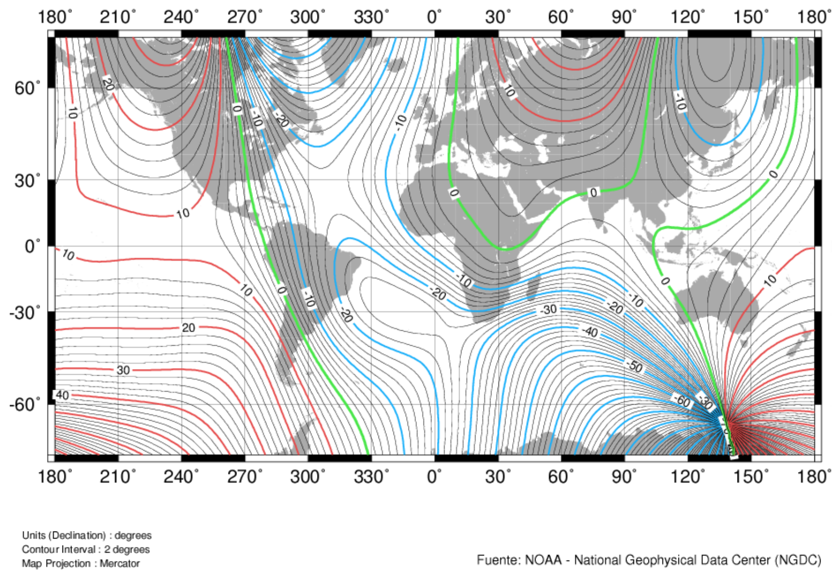


Fig.36: Geophysical map of the isogons of the Earth for a given date. NOAA Source

The magnetic field lines are moving and for an observer in a specific location they will have a value and how they are changing, it may be that one day the agony line (0º) will pass over your head. The values of the lines of force depend on the geographical coordinates and on the date. It is possible that someone is interested in this topic or just out of curiosity, I suggest copying the link and observing the movement of the agony line (0º) from 1590 to 1990.

The zero line (agona) passed over the University of Alicante in September 2016, in a few days, the magnetic meridian that contains the magnetic North (NM) coincided with the superior celestial meridian that contains the true North (NV) being in those instants, its zero declination.

- **Magnetic workshop**

You can do a small workshop and know when the zero line will pass through our vertical location, if we know today's declination of the place and the minutes that the declination increases or decreases per year with respect to the NV, we will be able to know when they are coincident.

Christopher Columbus experienced this phenomenon himself, observing and noting the change in direction of the tide needles, and this is how Bartolomé de las Casas writes it in the logbook saying… that the stars are not wrong, although sometimes the needles dizzy maybe yes.

As a result of having knowledge of this phenomenon, the study of the magnetic field and its properties begins, a discipline that studies Geophysics

- **Instruments for determining longitude**

The instruments that were used for the determination of the longitude * (angle that exists between the reference meridian and the local meridian), were three: **hourglass, vial and nautical slider or gondola**.

For sailors on the high seas, it was a real ordeal to determine longitude accurately, until in the 18th century it was solved by the idea of J. Harrison's precision clock-5, meanwhile, there was a feeling of uncertainty generated by the instruments and methods used, producing true catastrophes and shipwrecks, producing numerous human losses and assets of the armed forces of their respective countries.

In addition, at that time, there was no uniform standard measurement, even in the same country there were different measurement values between leagues, stadiums, or feet, etc. and the measurement of time the same thing happened with hourglasses or vials, they also varied according to the internal grain, humidity, temperature, pressure and, they could not be contrasted with a standard hourglass

- **Hourglass**

The hourglass consisted of two glass cones joined by their narrow part and was protected by two wooden bases and wooden protection rods.

The hourglass normally used in navigation was 30 minutes because they were adjusted to the comfort of simple calculation, but there were many sizes and precisions, later it would begin to be completely protected, which was called a bulb.

Fig. 37: 30 minute protected hourglass. Source Wikipedia Fig.38: Vial. Wikipedia Sourcea

- **The vial**

Over the years, even centuries, the hourglass improved in terms of the uniformity of the grains of sand, the wear of the glass inside, and it was protected from the weather (humidity, temperature, pressure, etc.), which is why sometimes it appears with this aspect called bulb that was protected from the outside.

It was a very important element in navigation and, sometimes, its length was fixed with several vials of different granulometry, marking the duration of the journey from departure to arrival.

- **Nautical log or basket**

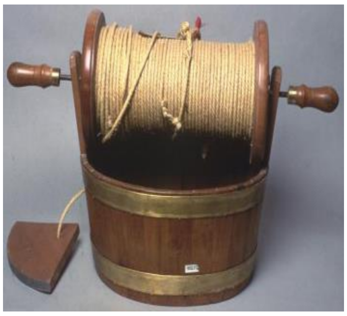


Fig. 39: Nautical slide. Source Wikipedia, Fig.40: Self-made pod, Fig.41: Starting the operation with the three instruments Source Wikipedia

The nautical log was used to determine the speed of the ship and the speed was expressed in knots or miles per hour.

It was a rope that contained a series of marks, called knots placed at a certain distance, eg. the measure of a common elbow, which was the distance between knot to knot of 0.418 m and was released in the opposite direction to the marked course. The rope was wound on a reel or roller at one end and at the other it was attached to a wooden triangle that floated and from which hung a counterweight that was dropped when the operation began.

The method of obtaining the speed consisted of several sailors specialized in this task, being placed in the bow or stern of the ship and each one was in charge of a task, one with the hourglass and the other with the nautical log and the other that ran the gondola well. When the hourglass of 30 minutes was finished, then the knots that had been released were counted, obtaining the distance traveled, then if we know the total distance that they have come out of the slider in a given time of 30 minutes we will be able to know the speed of the ship (expressed in knots or nautical miles).

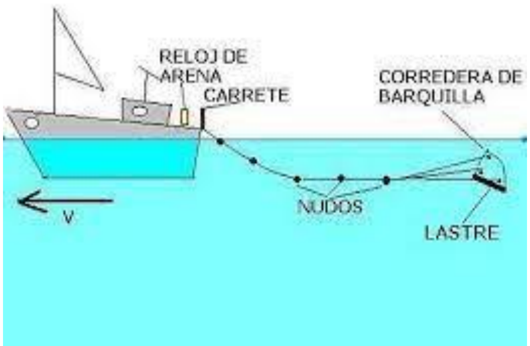


Fig.42: Two images of the method used to calculate the speed. Source Wikipedia

Example. If we know the equivalent of a common elbow that in Castile was worth 1.5 feet or 24 fingers, that is, 0.418 m, and if 120 knots had been released, that would be equivalent to a distance of 50.16 m and in a time of 30 minutes; we can get an idea of the speed that a ship could have, then it could be expressed in miles per minute or kilometers per hour.

We remember that a **nautical mile** is 1852 m; Since a mile is the meridian arc that contains a minute, and a **knot** is the speed that corresponds to traveling a nautical mile for an hour, it is usually expressed as 1M = 1,852 Km/hour.

This problem of inaccuracy in time for the measurement of the longitude coordinate could not be properly resolved until the 18th century, by the English watchmaker John Harrison (1693 -1776), winning the contest for this purpose.

Fig.43: Reloj cronómetro de precisión de J. Harrison versión 5. Fuente Wikipedia

• Columbus stars, eclipses and observatories for latitude and longitude

Columbus knew the instruments for calculating latitude perfectly, but he never put into practice a system for determining longitude as did the great Chinese navigators such as the explorer admiral Zheng He (1371 - 1433), who under the orders of the emperor Zhu Di of the Ming dynasty sailed the seas off South China in the early 14th century building some excellent cartographic maps.

Thanks to the numerous data provided by sea voyages, they would use latitude by comparing observatories, one fixed in Beijing and another on land or sea wherever they were, and by measuring the heights of the same stars observed from different places, they could determine the latitude and longitude just like Posidonius of Apamea did.

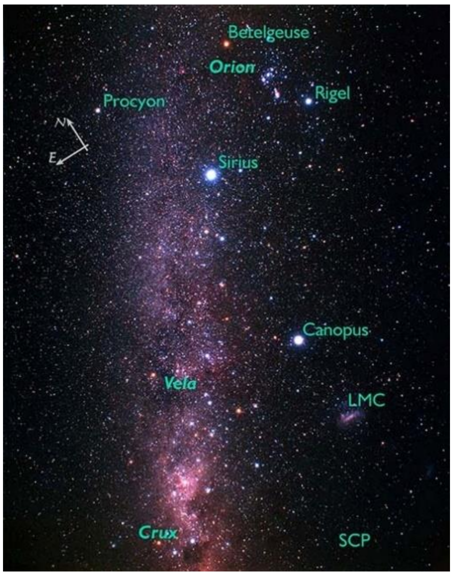


Fig. 44: Southern hemisphere reference stars to determine latitude. Source Wikipedia

The most used visible stars from the southern hemisphere were sirius del (can major) and canopus (from the constellation of Carinae, second star in brightness after sirius).

In addition, they determined the length, by differences in times that produced the inputs of umbra and penumbra contacts in eclipses of either the moon or the sun, since they had a good calendar and knew when they were going to occur, then they transformed the times into degrees so that the cartographer on duty drew up the map with precision.

Fig.45: Two images of eclipses one of the Chinese and the other image is of Bartholomew (brother of Columbus) using for another purpose. Source Wikipedia

While the Chinese used eclipses to make their nautical charts, Columbus' brother, Bartholomew, would use the arrival of a lunar eclipse to deceive and frighten the natives, making them fill the caravels with food, threatening that if they did not, the moon would turn very red and bring misfortunes and illnesses to the town.

• The return of Columbus and the cartography of the new continent

On October 12, 1492, Columbus arrived in his Indians (realizing his dream), although in reality he had reached the island of Guayami (which they named the island of Salvador), Columbus had discovered a new continent that would later be called America.

But, not only Columbus opened a new trade route to the West and without danger, but also, he had to return to Spain and tell the kings Catholics, of such a feat and the riches that those islands and countries contained. It is known that other navigators, such as the Turkish cartographer Admiral Piri Reis (1465 -1553), had already visited those lands, but only Columbus returned to tell about it and with a lot of information about the new open route.

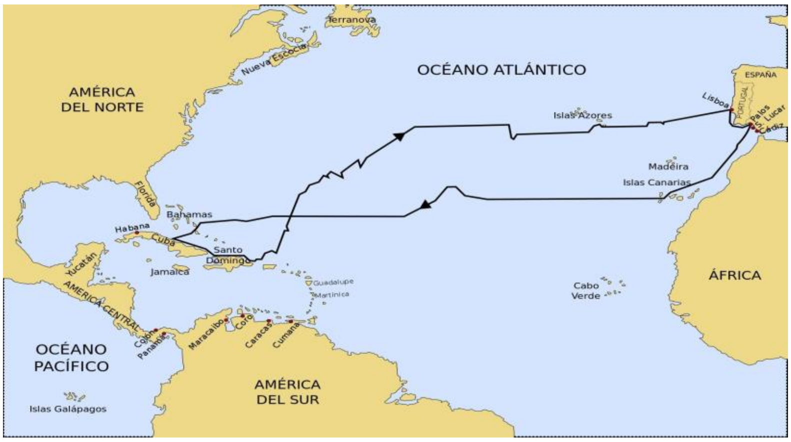


Fig.46: 20th century map of routes to and from the American continent. Source Wikipedia

Fig.47: Nautical chart (portolano) drawn up by C. Colón. Fountain National Library of Paris

With the discovery of the Indies, Columbus achieved a new commercial renaissance for Spain, Europe and therefore, for the rest of the world, which would gradually imbue them with a certain Renaissance social/economic enthusiasm, generating advances in many disciplines such as maritime navigation, war weapons, naval shipyards, improvement of specialists in astronomy, cartography and topography, use of methods and techniques of astronomical instruments, construction of observatories in various countries, in the cultural transmission of languages with various cultures, in scientific development, anthropological, religious (evangelization) in commercial exchanges of hundreds and hundreds of agricultural, livestock, botanical products, creating numerous bridges of cultural diversity, very enriching and rewarding to this day**.**

Fig. 48: Nautical chart (Portolan) drawn up by Juan de la Cosa. Fountain National Naval Museum of Madrid

The nautical chart of Juan de la Cosa. It is the first time that the American continent appears

PD. AUTHOR: It is currently easy to obtain geographic coordinates (latitude and longitude) or analytical coordinates (UTM- (X, Y,) by using the different existing platforms (GPS, GLONASS, BeiDou, GALILEO) of artificial cartographic satellites, but in the twentieth century XV and XVI with the instruments available already described, it was not so easy in the elaboration of nautical charts, or terrestrial maps, my admiration to all!

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NICARAGUA

Measurement of latitude during the vernal equinox and passage of the Sun through the zenith.

Ligia Areas Zavala and Ricardo Canales Salinas
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Introduction

As part of the "Latitude to travel and navigate" project that aims to calculate the latitude where the participants are. In Nicaragua, the calculation of the latitude was carried out during the spring equinox, with the participation of the students of the Guardabarranco Public School located in the city of Managua and first-year students, Renewable Energy career of the UNAN-Managua university. In the same way, the latitude was determined during the passage of the sun at the zenith with students of the Renewable Energy career.

Calculation of the latitude during the vernal equinox

The experiment was carried out on Monday, March 21, 2022, with a workshop where the students were explained how the seasons occur and the calculation of the latitude of the participants' places. The experiment took place in the Reptile Farm Auditorium, UNAN-Managua.

It should be noted that March 20 was the spring equinox and for this reason the declination is null, consequently, the formula to use is simpler, L = 90-h. The details of the activity are detailed below:

Professor's name: Lic. Félix Antonio Navarro, Dra. Ligia Areas and Dr. Ricardo Canales Salinas.
City and country: Managua, Nicaragua
Actual latitude: 12.10391 degrees
Day, month, hour = 21st, March, 12:00 solar time.
Solar declination: |D| = 00 01´ 45´´ = 0.0292 degrees

Obtained latitude: ≈ 12 degrees
Day, month, time = 21st, March, 11:49 a.m.

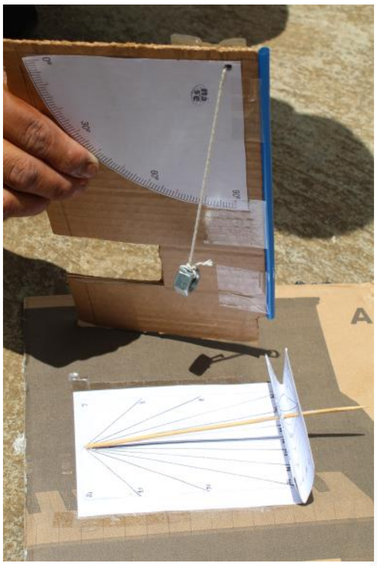

Fig. 1: Measurement of the altitude of the Sun at the vernal equinox.

Figure 1 shows the height of the Sun (h) at its highest point, obtaining an altitude of 78º, with the sundial indicating solar noon. The declination (|D|) is equivalent to 0.0292º on March 21st. Being the latitude (L) equivalent to

$$L= 90^{\circ} - h - |D| = 90^{\circ} - 78^{\circ} + 0.0292 = 12.0292^{\circ} \approx 12^{\circ}$$

Passage of the Sun through the zenith

The passage through the zenith is a very special day in those countries where it is possible and for this reason the experiment is carried out on this occasion. It is evident that on this day the altitude of the Sun is 90º, to the measured solar time.

The experimentation was carried out on Thursday, April 21st, 2022, when the sun passed through the zenith in Nicaragua, with a workshop where the students were given a lecture on Position Astronomy and measurement of the height of the Sun at its highest point. It took place at the Rubén Dario University Campus, UNAN-Managua.

Below is the activity data

Professor Name: Dr Hugo Otoniel Munguia, Dra. Ligia Areas Zavala and Dr. Ricardo Canales.
City and country: Managua, Nicaragua
Real Latitude: 12.01 degrees
Day, month, hour = Abril 21st, 12:00 solar time
Solar Declination: |D| = 11 37 53 degrees = 11.63 degrees

Obtained Latitude: 11.63 degrees ≈ 12º
Day, month, hour = Abril 21st, 11:44 am

Fig 2: Measurement of the altitude of the Sun during the passage of the Sun through the zenith. It was found that the altitude of the passage through the zenith at solar noon was 90º.

Figure 2 shows the altitude of the Sun (h) as it passes through the zenith, obtaining an altitude of 90º, with the sundial indicating noon alone. In the lower left part of figure 2 you can see the gnome that does not show a shadow. When the Sun passes through the zenith its declination (D) is equivalent to the latitude of the observer.

Being the latitude (L) equivalent to: $L = 90^{o} - h + D = 90^{o} - 90^{o} + 11.63^{o} \approx 12^{o}$

Participants

Figures 3 and 4 show the participants during of the first experiment on March 21st

Fig. 3: Guardabarranco Public School Students

Fig. 4: Renewable Energy career students from UNAN-Managua

Figure 5 illustrates several examples of the students of the Renewable Energy career at UNAN-Managua developing the experiment of measuring the height of the Sun during its passage through the zenith. On this occasion, interest was shown in the topic addressed and execution of the corresponding measurements, the theory was verified with practice. Teachers collaborated with this activity by giving part of their class hours.

Fig. 5: Students making the observations during the passage through the zenith in UNAN-Managua on April 21st

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GUATEMALA
Determination of the local Latitude

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Universidad San Carlos de Guatemala

The NASE course has been developed in Guatemala since 2012 at different times of the year, but in this time of pandemic we have done it in June. Due to that for March 2022 we could not carry out the activity with them.

Fig. 1: Latitude determination using the polar star is 18º

However, throughout all the editions of NASE in Guatemala we have had the support of our physics students and thanks to them we have been able to carry out the activity and here I share some photographs of that work.

Fig. 2: The determination of the altitude of the Sun at noon on March 13 is 72º

The work was done remotely as we are still working through virtual classes due to the pandemic. For this, instructions were given so that they could do the activity at home, then some additional virtual meetings to clarify doubts until finally the vast majority of them carried out the activity satisfactorily.

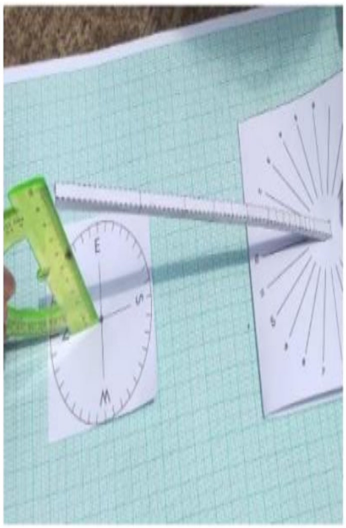

Fig. 1: Preparing the sundial

To determine the local latitude on March 13, 2022, the measurement of the altitude of the Sun taken was 72º and the declination of the Sun was D = -3º. The measurements were taken on March 13, 2022, therefore in winter

Altitude (H) of the sun = 72º
Declination D = - 3º

The latitude (L) verify $L = 90 - H - |D| = 90 - 72 - 3 = 15°$

The latitude of Guatemala is between 13ºN and 18º N depending on the area of the country

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PANAMA

Astronomical importance of the fourth voyage of Columbus and his passage through Panama

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Specialized Superior Technical Institute (ITSE),

Introduction

In this last transoceanic expedition of Christopher Columbus, he sailed between the parallels of the Canary Islands (29ºN) and San Salvador (25ºN) and the height of the polar served him to determine his latitude in the northern hemisphere. Arriving for the first time to tour the Central American coast of Honduras, Nicaragua, Costa Rica and Panama, as well as some small Caribbean islands. The purpose of going to the "West" was one more attempt to find a maritime passage through the west towards Asia in order to get ahead of their Portuguese rivals and conquer the riches that Europe knew from the Indian Ocean.

Columbus astronomical knowledge

On a political level, Columbus' career was declining. Almost a month before leaving for his fourth voyage, he lost all the privileges he had acquired in 1492 as the sole governor of the territories he discovered and was dismissed from the government of Spain. The Kings did not grant him permission to reach Hispaniola with the excuse that he would not waste time and would dedicate himself to finding gold and other valuable supplies. Columbus was instructed to go another way "that pleased God" and that if he thought it necessary he could go back through Hispaniola to stop a bit and report what was happening or what was needed in those places. However, on a scientific level, this trip helped him demonstrate his knowledge of astronomy and meteorology. Based of course on your previous travel experiences. This is demonstrated on June 15, 1502, when being in the Caribbean Sea he could perceive the symptoms that a hurricane was approaching. This was one of the occasions of this trip in which his knowledge and observations led him to draw scientifically based conclusions. In addition to identifying the hurricane, Columbus knew where it was going, which allowed him to take the opposite direction and avoid being devastated by the hurricane that devastated the Spanish Island and killed hundreds of people.

Christopher Columbus in each of his trips changes his trajectory with the desire to find the route to reach Asia, on the other side of the planet. On his third voyage he entered the southern hemisphere and became convinced that he must return to more northerly latitudes. Columbus was convinced that the discovered lands were not united, but that there must be a maritime passage to reach the spice islands directly. All of Christopher Columbus's voyages followed different paths, but they were very similar with respect to the shape of the path. When sailing in the sea without references, Christopher Columbus tried to stay on the same parallel only with the help of a quadrant that allowed him to determine the height of the Pole Star in order to follow the same parallel.

The Central American natives described "an immense channel of water inland" that Columbus considered could be a viable step to find the route to Asia. Just off the shores of the Ngäbe-Buglé Shire they followed a channel inland thinking they would find a way out, but were unsuccessful. Then the Indians told them of a nine-day overland route through the mountains that led to a different ocean. Columbus began the route, practically in the same area where the Panama Canal would be built in the 20th century, but decided not to continue along it, considering that it was too risky to intern his men in that jungle and mountainous territory and because he wanted to find a strictly maritime route. Had he continued, he would have become the first European to sight the Pacific Ocean. Columbus was convinced that the sea passage he needed should be between Veraguas and Nombre de Dios, belonging to Panamanian territory. As he traveled south along the coast of Central America, he began to see that the Indians looked more and more like those he had seen on his third voyage, in which he had reached the shores of what we now know as Venezuela. Furthermore, these natives had told him that there was no sea passage. On December 5, 1502, after covering practically the entire Central American coast and with an exhausted crew, he abandoned the search for the western passage and headed for Veraguas, in present-day Panama, because the aborigines had told him that there was abundant gold.

Fig. 1: Fourth voyage of Columbus in which he reaches Panama

The story told by Diego Méndez, the scribe of the fourth voyage of Columbus, relates that just being at the mouth of the Belén River, between the provinces of Colón and Veraguas, the natives of the place, led by Cacique Quibian, tried to burn the ships and kill the Spanish Under the pretext that they were preparing for a war with the province of Cobravá Aurira, which is what is known today as Calovébora. This caused the wear and tear of the crew who used persuasive strategies to emerge victorious and leave the natives dumbfounded when Diego Méndez's partner, Escobar, cuts Méndez's hair using scissors, a comb and a mirror. This was enough to "tame" them and ask them to bring him something to eat.

In June 1503, Christopher Columbus lost two ships (there were four in total) because they were gradually being corroded from their foundations thanks to the joker, which is a species of mollusk that causes damage to submerged boats and wooden structures. On June 25, to avoid his death and sinking to the bottom of the ocean, Columbus ordered his men to dock on the nearest island, which turned out to be the north coast of Jamaica Island, where they would await rescue from his great friend. Diego Mendez.

Originally, the locals, the Arawak indigenous people, warmly welcomed the team impressed by these strange aliens, happy enough to provide them with shelter and food. Above all, because they were experiencing difficulties. So, they gave them food, fresh water, just about anything they asked for. They were fascinated by the shiny trinkets and loud whistles they would receive in exchange for corn, fish, and lodging. However, soon everything changed. Six months later, part of the team rebelled and began looting and killing the indigenous people. In response, the locals stopped supplying the people of Colón with food.

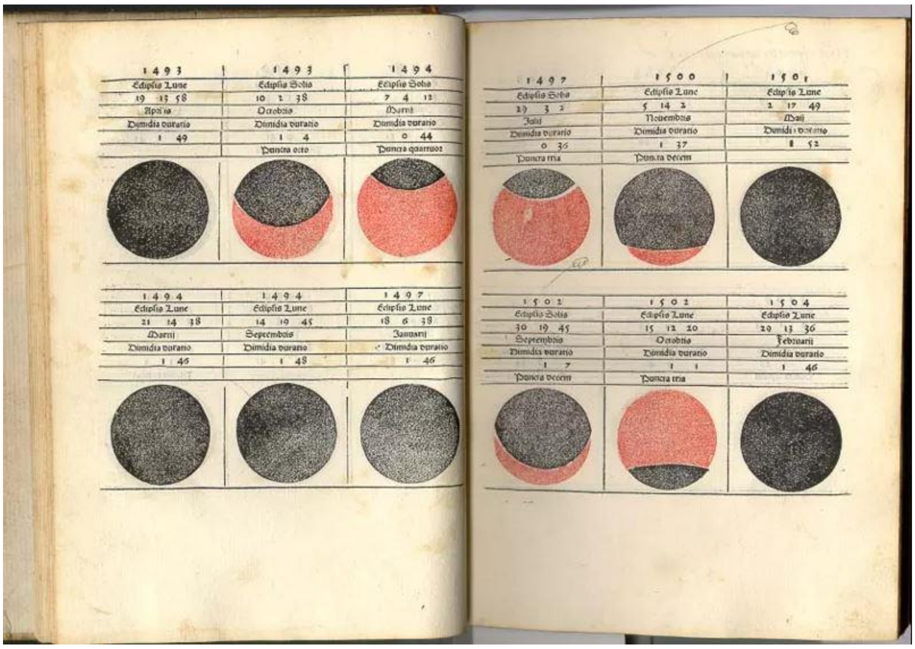

Fig. 2: These two pages from the Regiomontanus almanac describe the eclipses of the Sun and Moon. In the lower right corner, the lunar eclipse of February 29, 1504 used by Christopher Columbus is indicated.

While the great explorer spent time going through his astronomical tables to calculate when his rescue would arrive, he found two special volumes that almost all explorers used to navigate the high seas, including Vasco da Gama during his expeditions: Abraham Zacuto's Perpetual Almanac and Ephemerides, a recent volume of astronomical maps compiled and published by Johann Müller, a prominent German astronomer and mathematician who later became famous by his Latin name Regiomontanus. These books contained astronomical tables, covering the period 1475-1506. It was an indispensable aid for cartographers, navigators and astronomers.

Months passed and Columbus remembered the persuasion strategies used in his previous voyages and especially months before in Panama, led by his friend Diego Méndez. This time, based on astronomical knowledge of precise information from the books he possessed about the Sun, Moon, and planets, as well as their position and detailed instructions for navigating the stars, the famous explorer found a forecast of a total lunar eclipse that it was just around the corner, February 29, 1504, just the extra day of that leap year.

Considering that the tribe that recently expelled them would not have taken such an event for granted, Columbus thought of a solution and asked permission to meet with the natives and try his last resort. At the scheduled meeting, he said that God would show a clear sign in the next few hours, after which he would cast his wrath on them for not helping him and his people. Then the Moon, just as he predicted, immediately turned red in the sky.

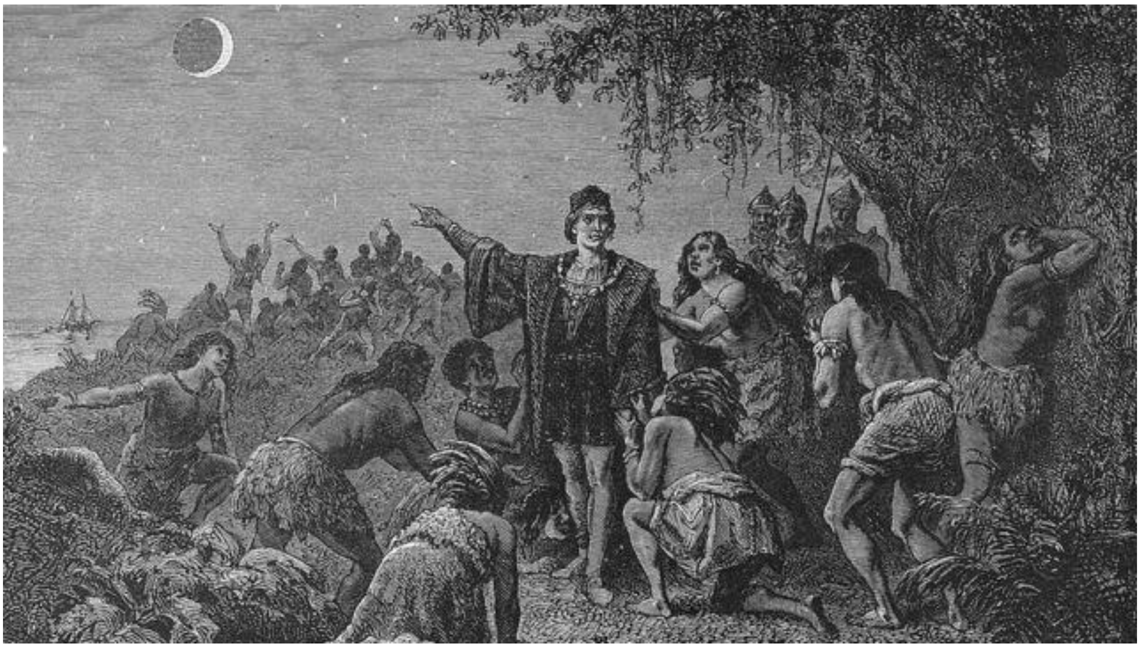

Fig. 3: Christopher Columbus during the eclipse of February 29, 1504.

The natives fled far and wide to search for supplies, begging him to restore the Moon. Columbus told them to wait based on the Regiomontan writings, he knew how long it would take for the Moon to lose that reddish hue of refracted light and recover. And as it was about to happen, he returned to shore and informed them that their God agreed to return to the Moon as long as they would keep him and his people safe. The next day they kept their word until June 29, 1504, when a Spanish ship finally arrived to rescue Columbus and his stranded men.

On his fourth voyage, Christopher Columbus continued to use ingenious instruments and methods to navigate, for example, to determine the height of the Sun, record tables of its declination and always follow the same direction that they never lost sight of. He applied astronomical observations to correct course errors. Christopher Columbus during his trip observed the variations between the distances of the Sun from the Moon and other planets, as well as those of their eclipses and conjunctions. With all this information he was able to deduce a system based on the observations of great travelers who were his predecessors. And the repetition of his trips or scientific expeditions, which promoted part of the human knowledge obtained thanks to the ephemerides of Regiomontano. This precise information about the expected dates of many eclipses also contained explicit information about their duration and timing. When the Sun, Earth and Moon are aligned it is visible from almost half the globe and this event saved the lives of him and his crew. In addition, he provided facts and observations on which much scientific knowledge was based, the truth of which lies in the testimony of the writers who have been actors or witnesses of the events they refer to.

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SPAIN

Looking to improve observations

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Introduction

Our team is formed by seven 3rd Year Secondary School students. We started our observations in March and since then we have developed several aspects: we have introduced changes in the method for taking data and registers; we have improved the observation instrument because the latitude calculated was incorrect when compared with the real one, we have increased the theoretical knowledge and we have made some nocturnal observations. It has to be said that lately, we have noticed an increment in the motivation of our students, they are more implicated with the project, for instance, they collect data during the weekends, in the evenings and even during family holydays they have continued to collect data.

Fig. 1: 3rd Year secondary school group.

Making of the observation instruments

Following a theoretical session, students made their own instruments. They tried to build them using different elements: a printed quadrant showing the angles, a protractor (more precise) or even a "*gun*" quadrant or a ruler.

Fig 2. Making their instruments

Fig 3. First instruments

First daily observations and first mistakes.

During the first observations, we noticed that there was a significant difference between our calculations and real value of the latitude.

The measurements were imprecise. As shown in figure 4, when calculating the angles, any insignificant variation was converted into a major variation with respect to the true values.

Fig. 4: Instrument errors

Modifications in the instrument for observation

Besides the changes in the instrument, we decided to fix the device to a stand so as to improve the reading of the degrees.

Fig. 5: Improvements in the situation of the observation instrument

Upgrading calculations. Making an Excel document

We decided to collect data daily, as far as the weather was favourable. To organise the register, we created an Excel document.

	A	B	C	D	E	F
1	Latitud real Coordenadas decimales: 36,1336 Coordenadas GD: 36,1333o N Coordenadas GMS: 36o 7´59,7´´					
2						
3						
4		h	D	L		
5	01/04/2022; 12:00	55	4	39		
6		50	4	44		
7		55	4	39		
8		40	4	54		
9		55	4	39		
10		45	4	49		
11		50	4	44		
12						
13	01/04/2022; 14:00	50	4	44		
14		53	4	41		
15		58	4	36		
16		39	4	55		
17		58	4	36	36º 16' 57''	

Registros | Hoja3 | Cuadrante

Fig. 6: Registers of observations

Workshop with Sebastián Cardenete and Carlos Durán, "*Sailing under the stars in Magallanes times*".

During the celebration of Algeciras science fair," Diverciencia", we had the opportunity to participate in a workshop given by Sebastián Cardenete and Carlos Durán, in which they explain how sailors were able to navigate with the help of the Sun and the stars. During this workshop, our students had the chance to increase their knowledge on the subject and solve some questions.

Fig. 7: In the workshop *"Sailing with the stars in the time of Magellan"*

Dissemination in "Diverciencia"

From 4th to 6th May the science fair "*Diverciencia*" was held in Algeciras so we had the possibility to explain our project to the general public.

Fig. 8: Diverciencia, Algeciras

Nocturnal observations

In order to make the nocturnal observations, we had to show our students how to find the Polar star.

First of all, it is necessary to locate the Ursa Major constellation. Based on the last two stars of the constellation (represented in Fig. 10), an imaginary line, with a length five times bigger than the distance between both stars, has to be drawn to reach the Polar star.

To can make sure that we have reached our star if it is placed in a smaller constellation, the Ursa Minor.

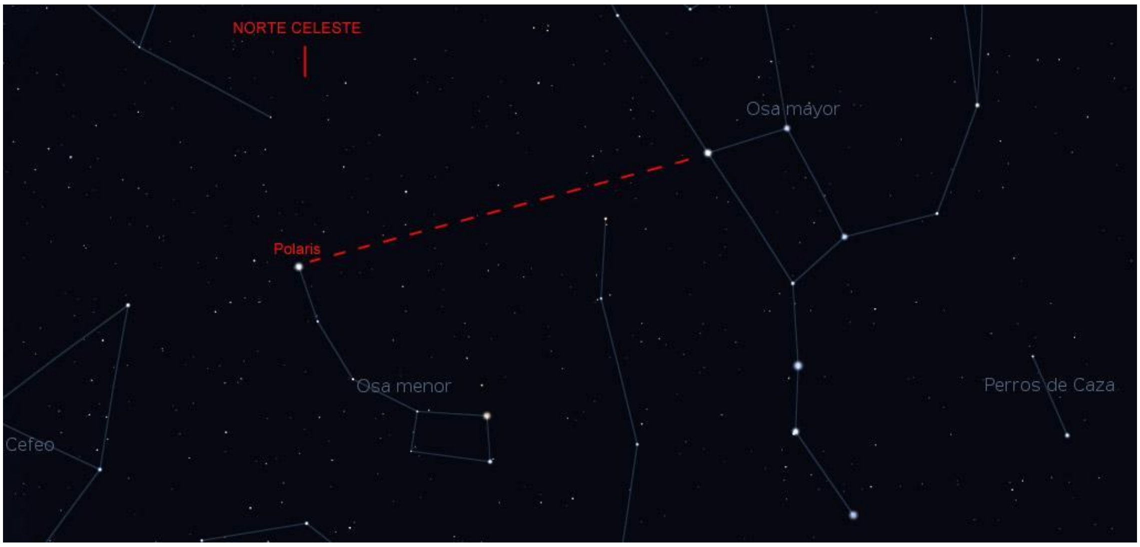

Fig. 9: Locating the Polar star

Similarly, by using the application “*SkyView*” with their smart phones, it is also possible to find the Polar star.

Fig. 10 and 11: Initial nocturnal registrations

“*Searching for the source of the Nile*”. Making observations during a trip to Egypt.

At Easter, one of our students seized the opportunity to collect some date during a family holyday. She made some measurements along the Nile.

10-04-2022 12:18 El Cairo
31º 41' 55''

14-04-2022 12:10 El Cairo
30º 09' 56''

11-04-2022 12:00 Assuán
24º 04' 08''

15-04-2022 12:21 El Cairo
30º 31' 34''

12-04-2022 11:55 Lúxor
26º 26' 12''

13-04-2022 12:09 Lúxor
26º 48' 08''

Fig. 11: Observations in the Nile

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