SPACE awareness

NAVIGATION THROUGH THE AGES

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OVERVIEW

- A. Basics: directions, coordinates, the North star
- B. Ancient times: celestial navigation
- C. Middle Ages and Islamic heritage
- E. Age of exploration: 15th century in Europe
- F. Modern times: the sextant
- F. Links with school science
- Galileo Satellite System

1. What is it or what it represents?
2. What is its use? (what is it used for)
3. When the object was discovered/developed? (When did it appear first?)
4. Was or is useful in nowadays?
5. May you put it on the timeline on the wall?

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01

HISTORY OF NAVIGATION

The basics

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1

Salle des Taureux” in Lascaux Cave in France's Dordogne River Valley. Prehistoric painting

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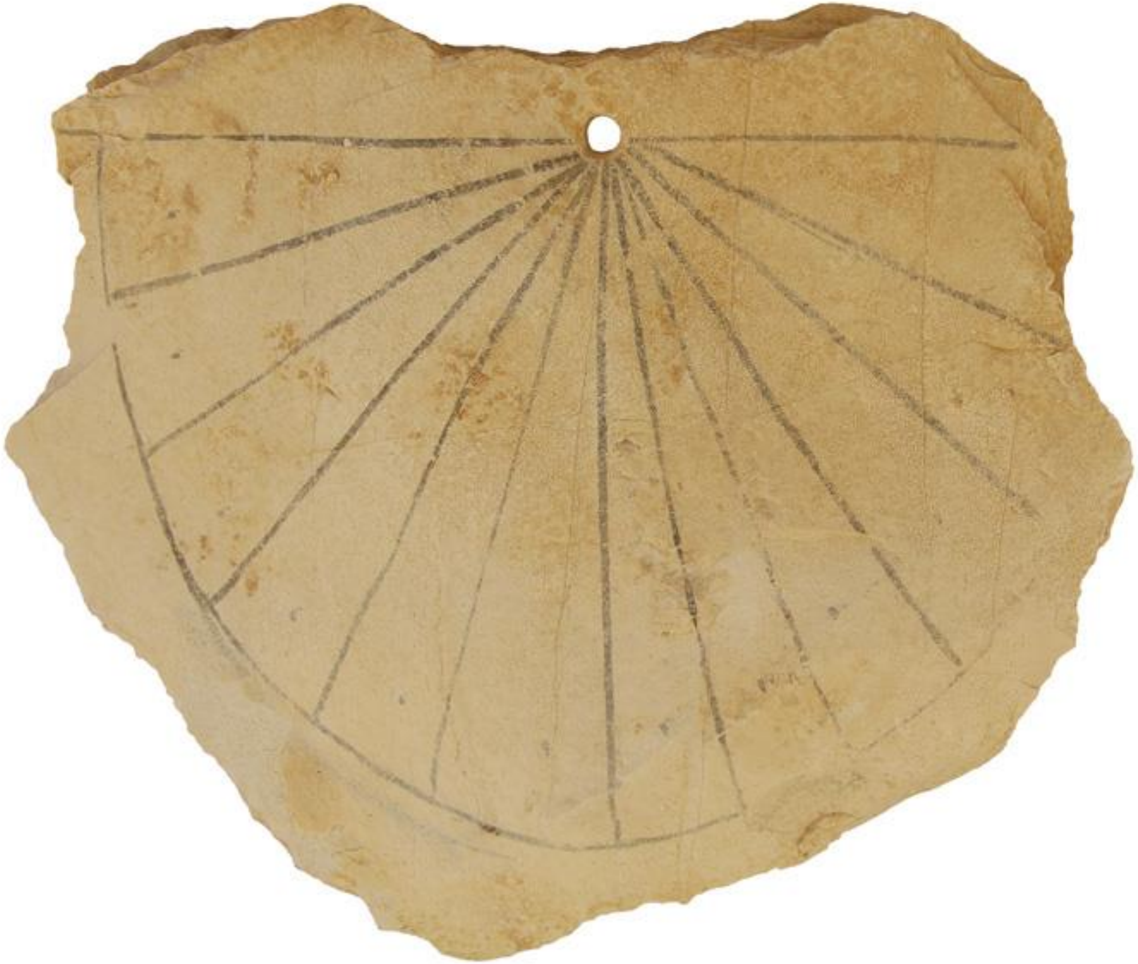
2

Constellations are imaginary patterns that farmers, poets, navigators, or astronomers invented to easily identify stars.

There are 88 constellations, adopted by the International Astronomical Union

Orion is a constellation that has the shape of a man and is made of 7 main stars. It has been observed and drawn since prehistoric times. The name ‘Orion’ derives from Greek mythology. Orion was a gigantic, supernaturally strong hunter of ancient times.

3



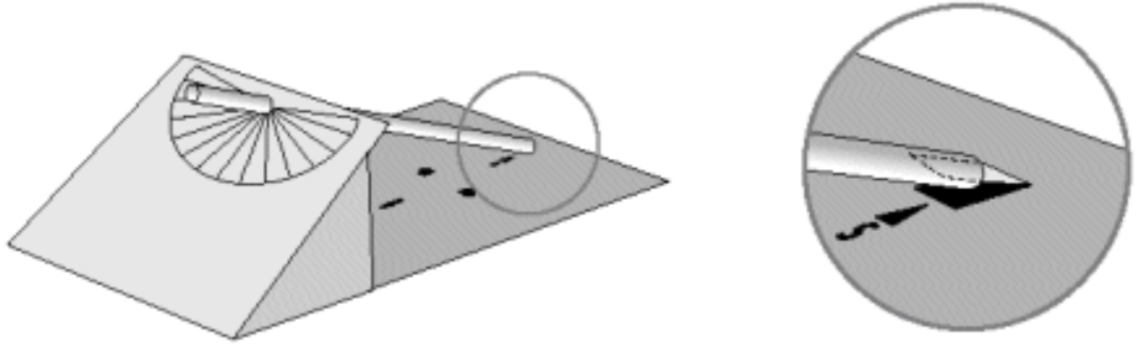
A sundial dating to the 13th century B.C.
and considered one of the oldest Egyptian sundials

4

Experiment

The Sun is at its highest in the sky at midday. At sunrise and sunset your shadow is longer. Now you can make a clock which will tell you what time of day it is.

- Cut out your sundial from the card and fold it as shown in the diagram.
- Cut out a U-shape along the top and sides of the rectangle and fold it along the dotted line.
- Cut out the black dot of the clock face so that you can fit a straw through it.
- Glue the grey flaps of the card to the bottom of the sundial and push the straw through the hole.
- Slope the straw so that the bottom fits around the raised piece of card that you cut out.



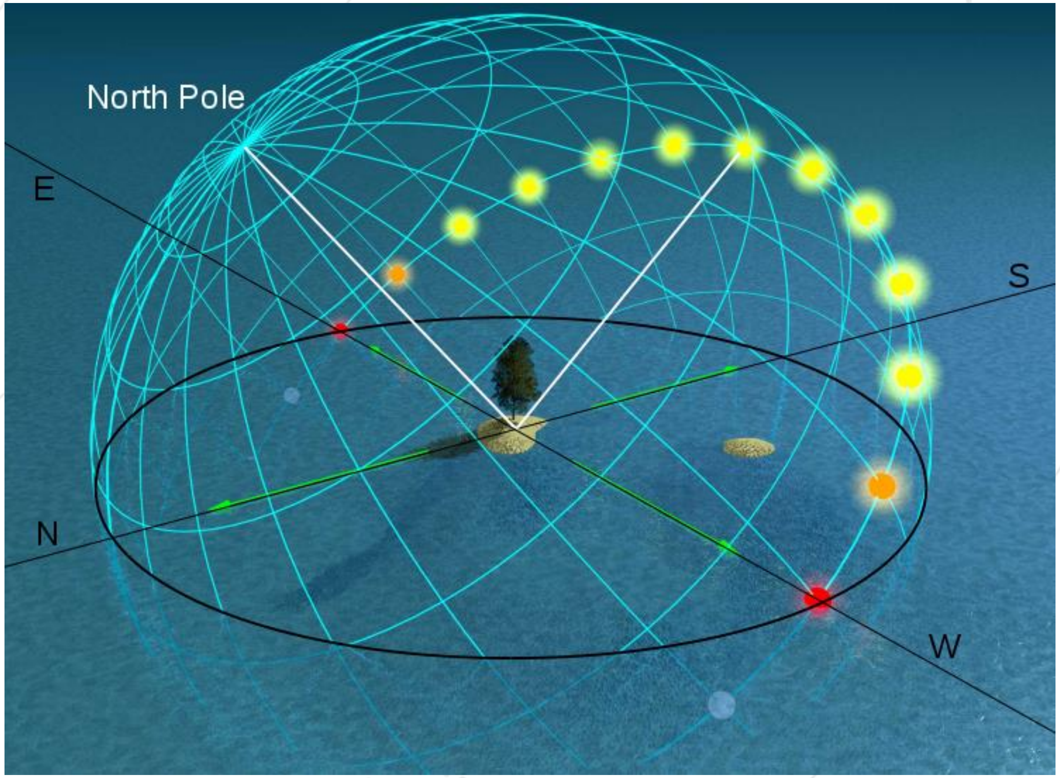
- Place your sundial in a sunlit spot in the fresh air, on the window or on the balcony.

- Using your compass, line up your sundial with the cardinal points marked on the card.

Your sundial is now working. The shadow of the straw shows approximate noon time on the clock face. In spring and summer the shadow of the straw falls on the outer face, in autumn and winter the shadow falls on the inner face.

THE BASIS: CARDINAL DIRECTIONS

- Astronomical processes like days and night were monitored from prehistoric times



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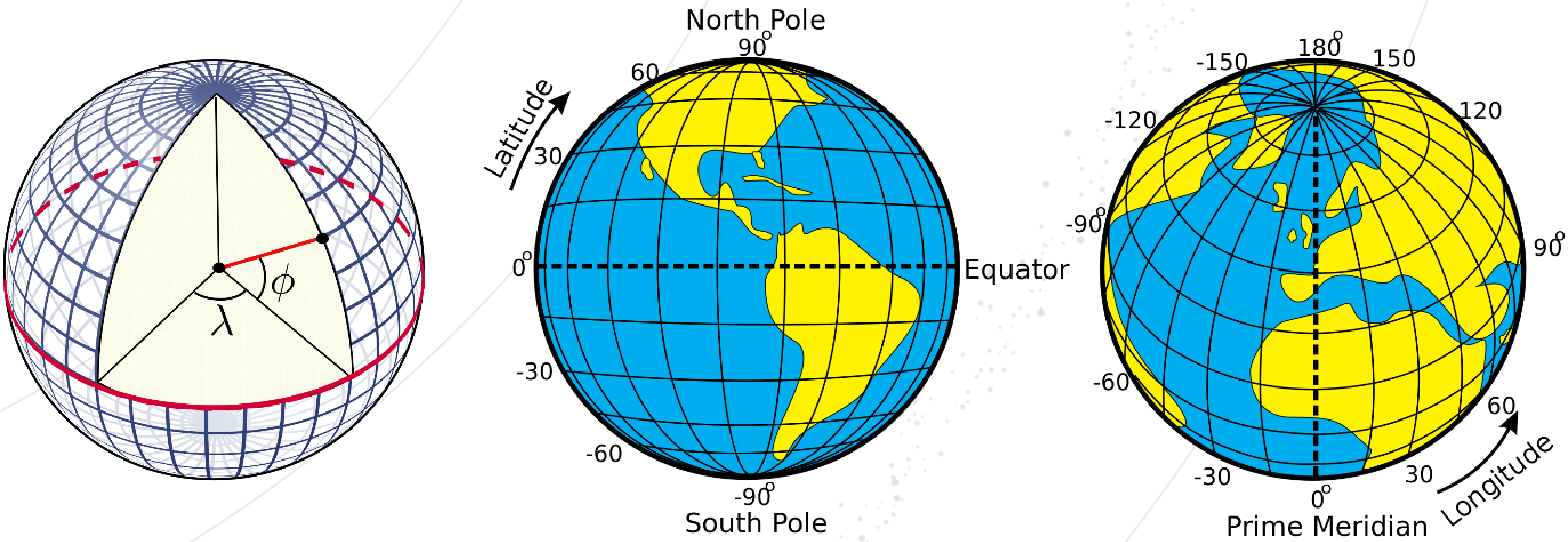
Chinese Magnetic compass

The first compasses in ancient Han dynasty (206 BC-220 AD) China were made of lodestone, a naturally magnetized ore of iron. The compass was later used for navigation during the Song Dynasty of the 11th century.

THE BASIS: LATITUDE AND LONGITUDE



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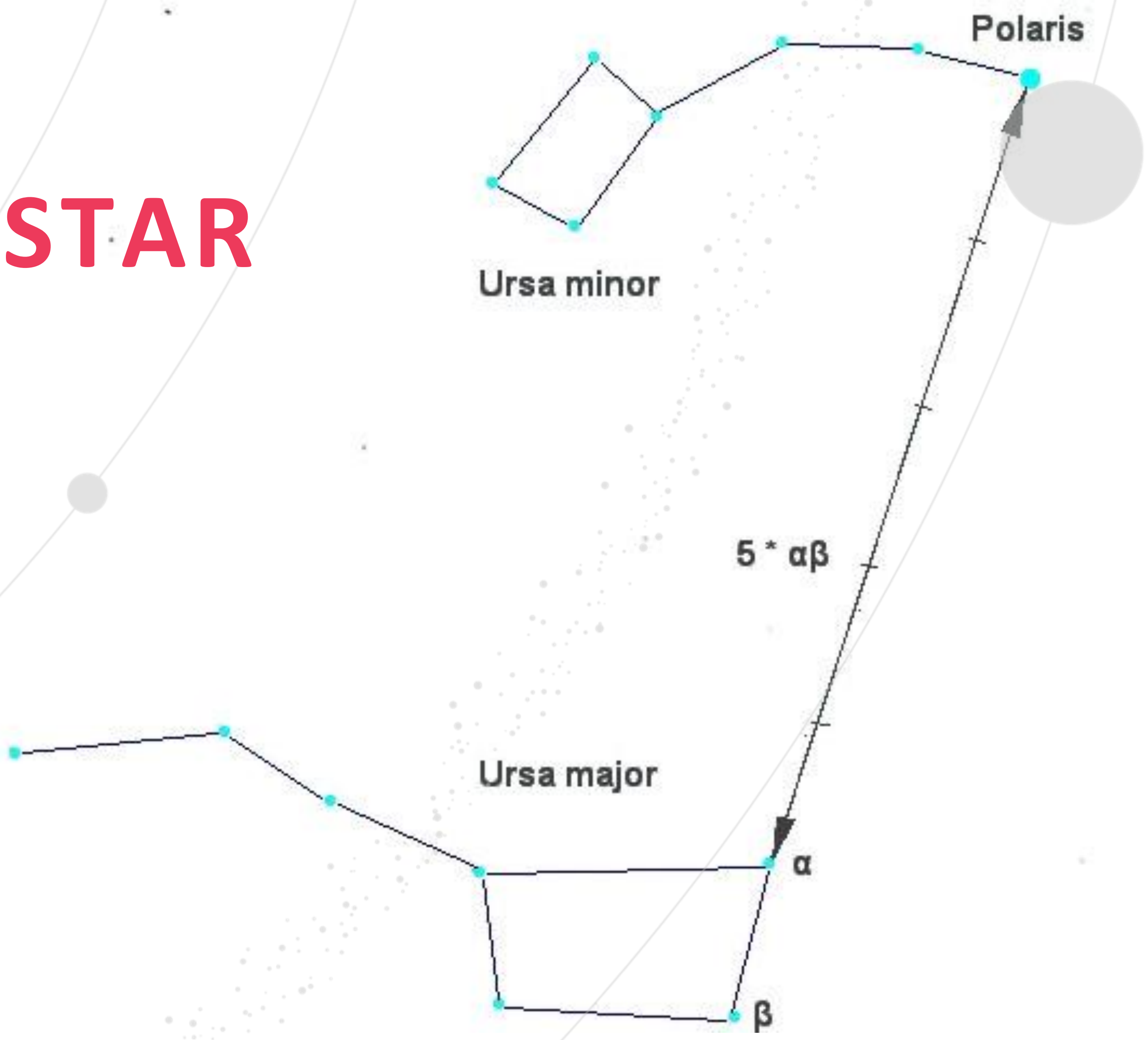
THE BASIS: THE NORTH STAR



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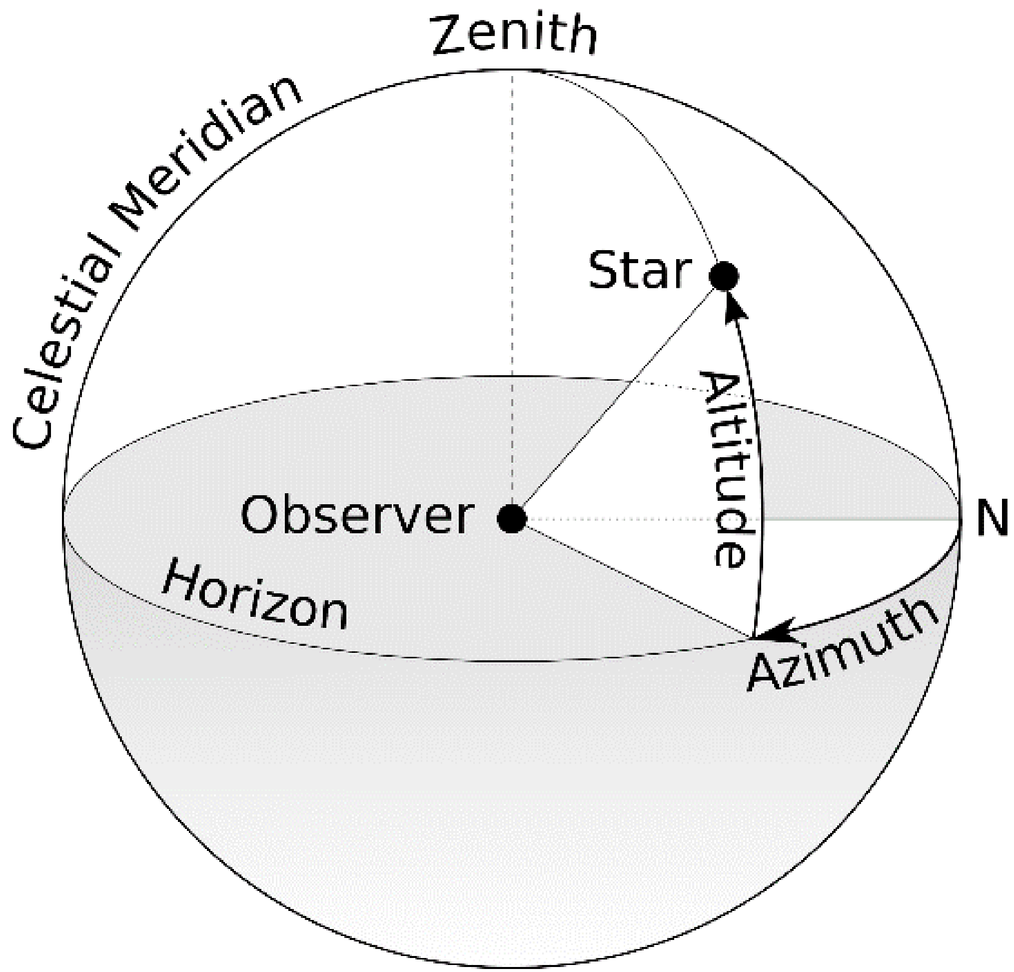

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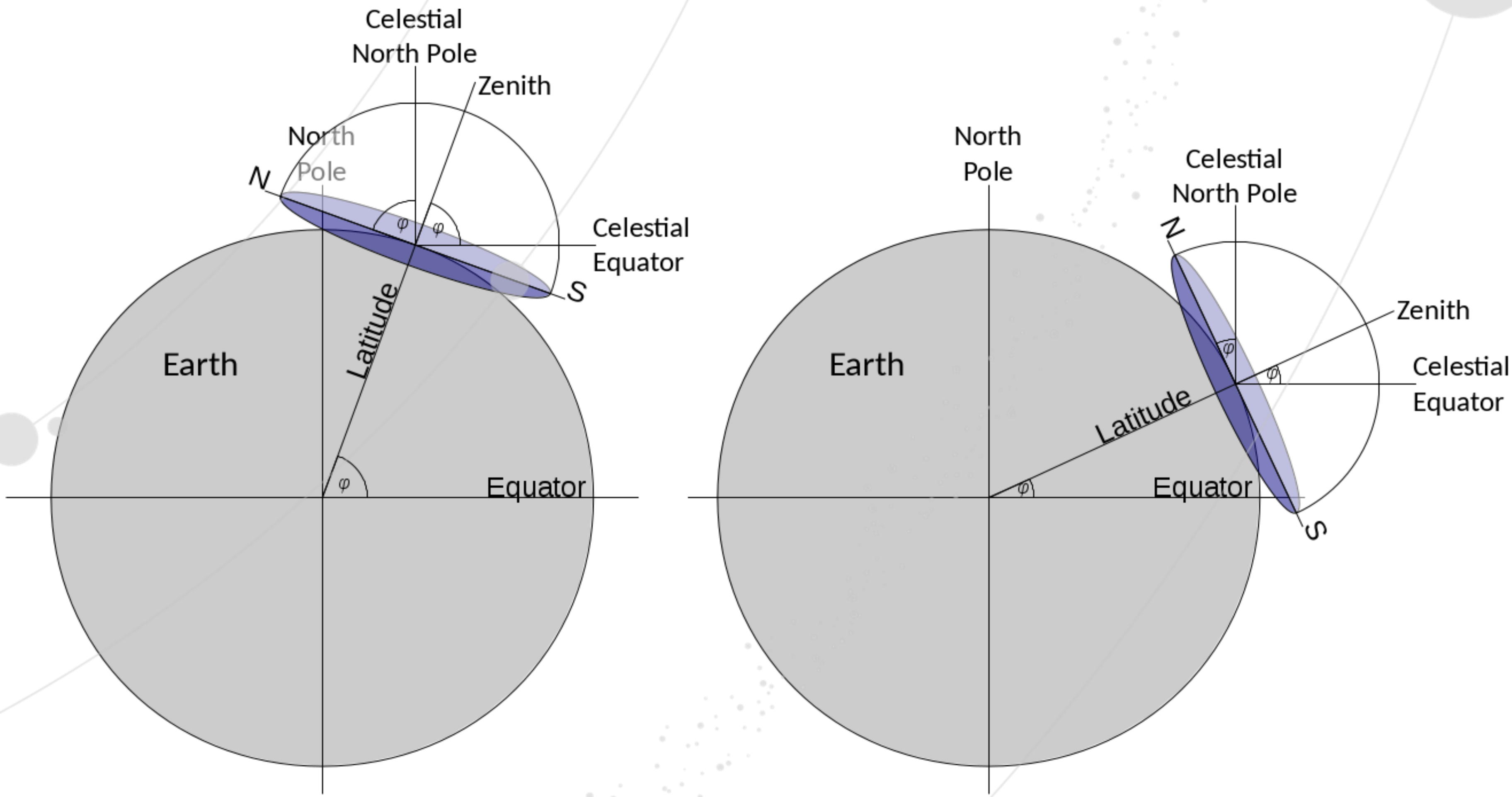

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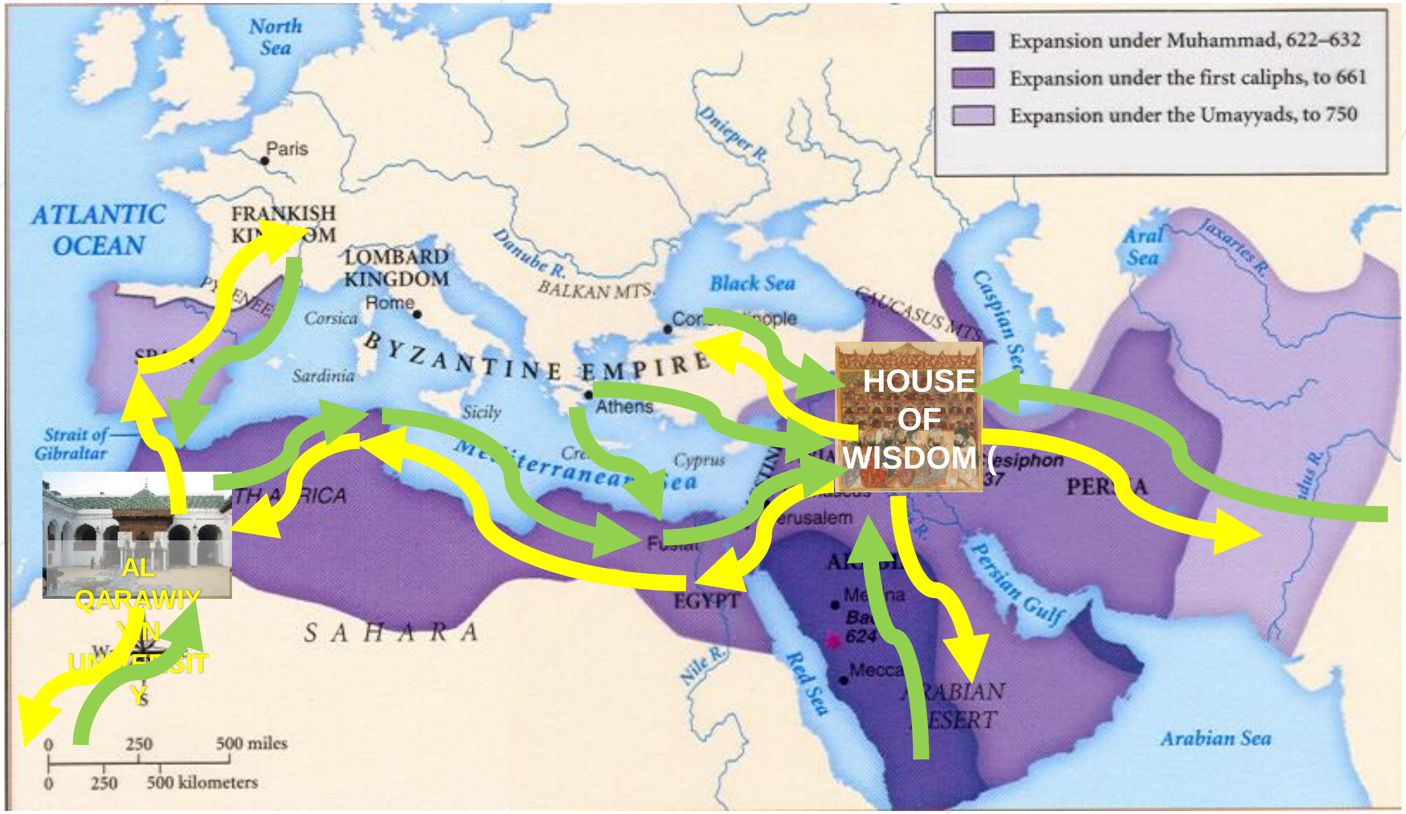
02

HISTORY OF NAVIGATION

Middle ages and Islamic heritage

THE ISLAMIC GOLDEN AGES

- Between the 8th and 13th century



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THE ISLAMIC GOLDEN AGES

Religion placed values on education and emphasized the importance of acquiring knowledge

- Special venues created
- Scientific knowledge collected and translated from other civilizations including Greece
- Knowledge and instruments developed or improved

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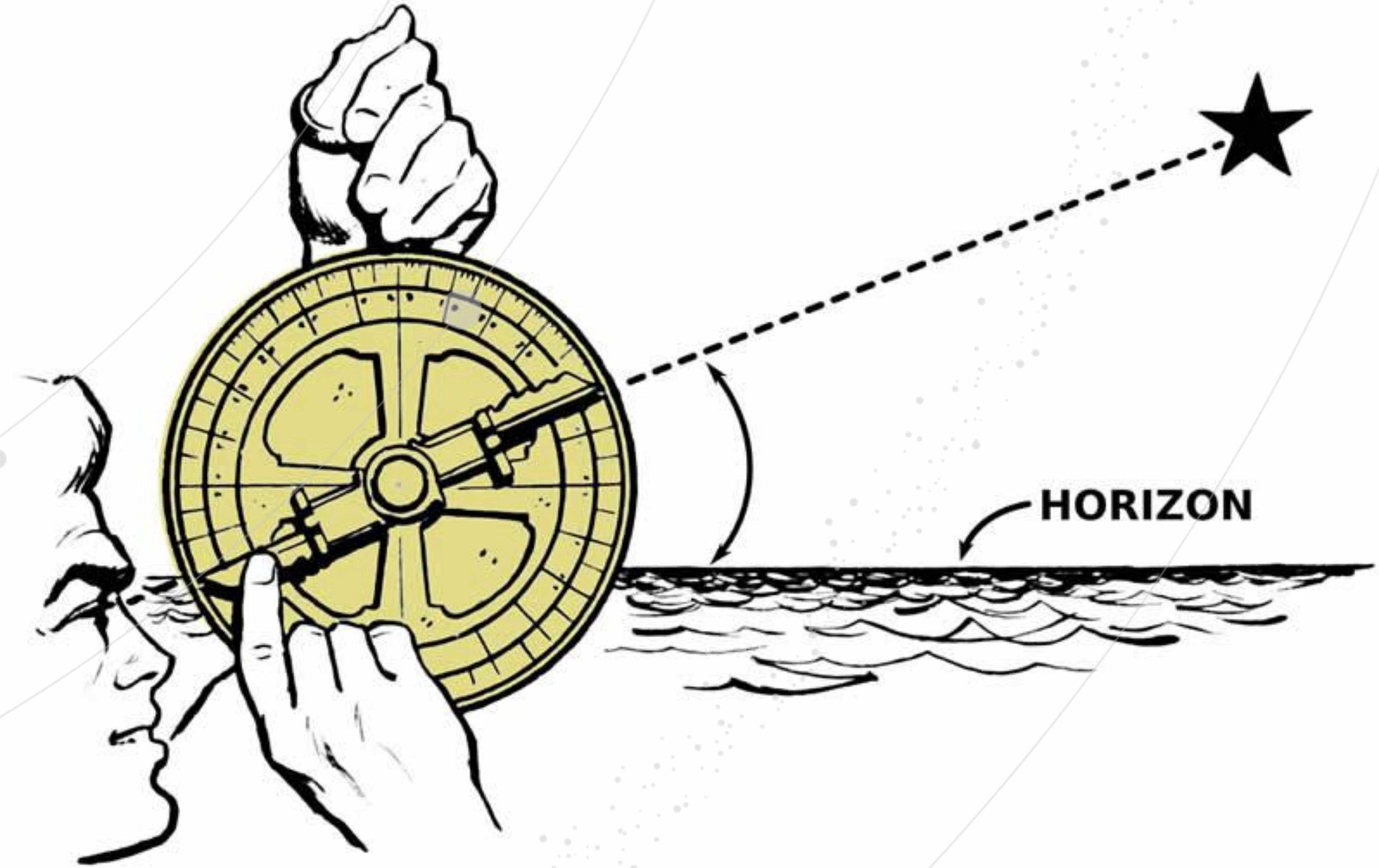
THE ASTROLABE

- Was born in Greece
- Was fully developed during the 8th century in the Islamic world
- Was transmitted to Europe by Spain and Portugal and used by the greatest explorers in the 15th century

THE ASTROLABE

THE ASTROLABE



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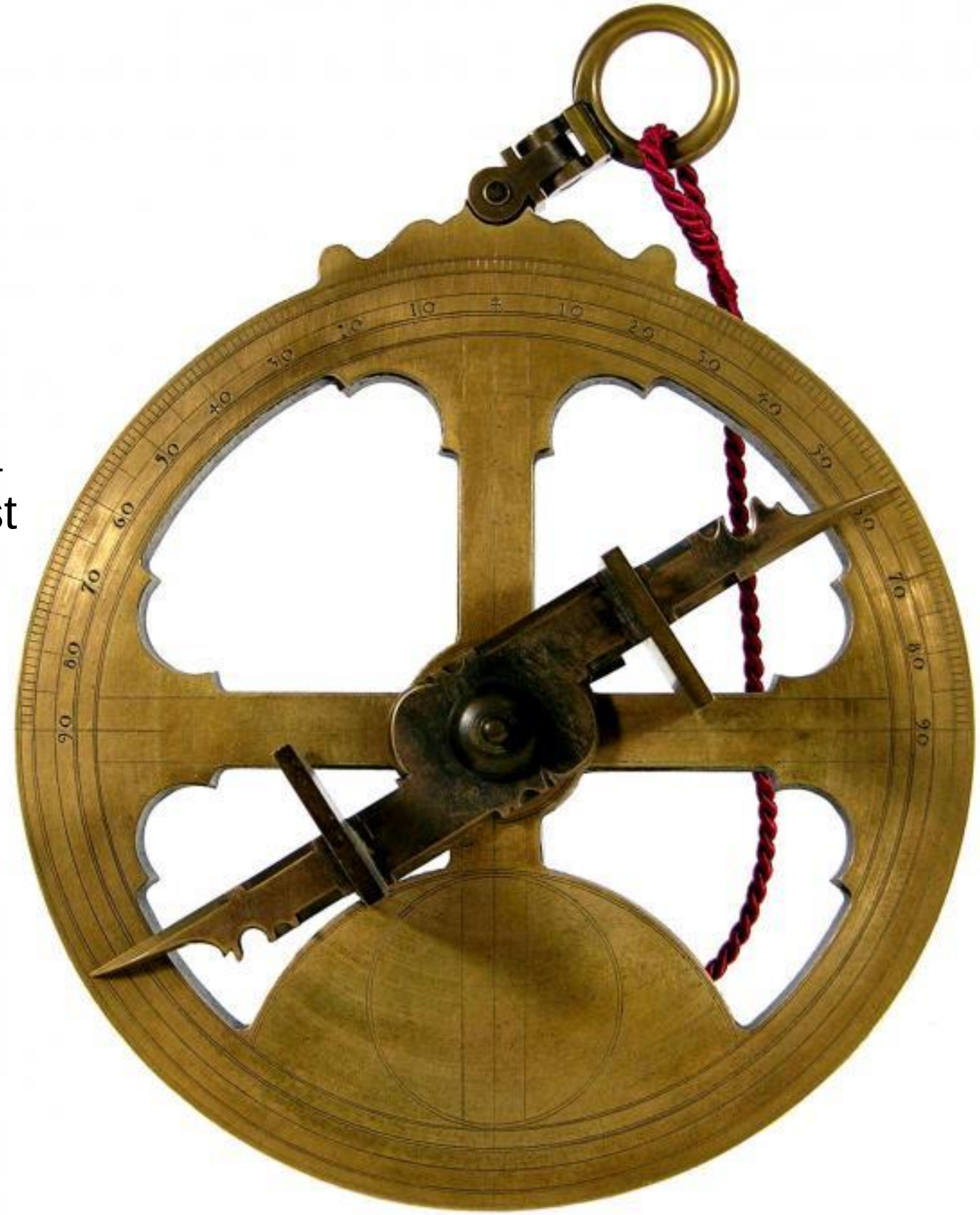
The mariner's astrolabe

developed during the 15th century out of the astronomical astrolabe and its earliest recorded use at sea dates from 1481 when it was used in a voyage by Diogo d'Azambuja down the west coast of Africa.



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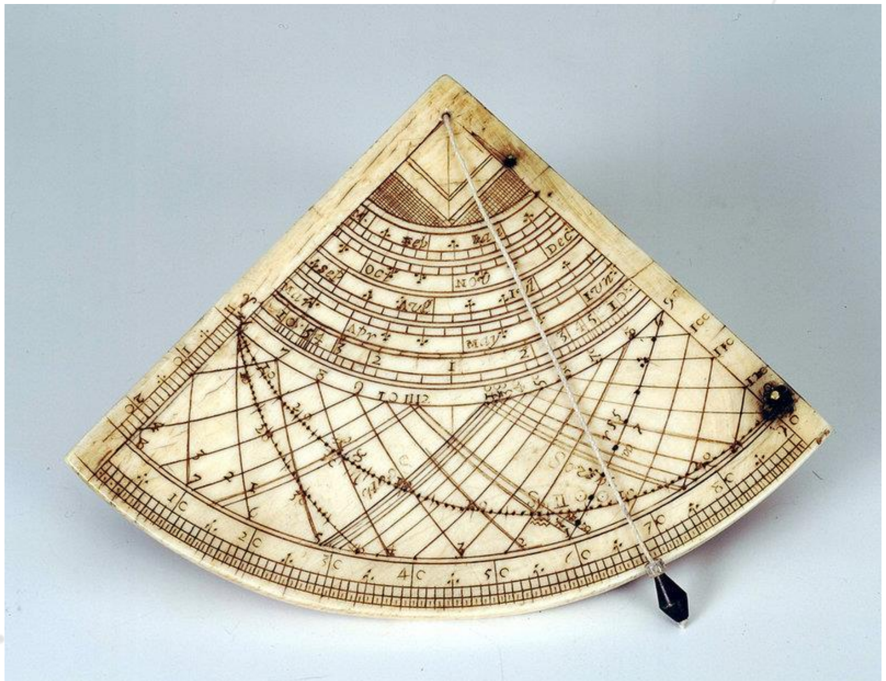
A DIFFERENT ASTROLABE: THE QUADRANT

- Measure angles up to 90°
- Proposed by Ptolemy in Greece
- Further developed by the Muslims



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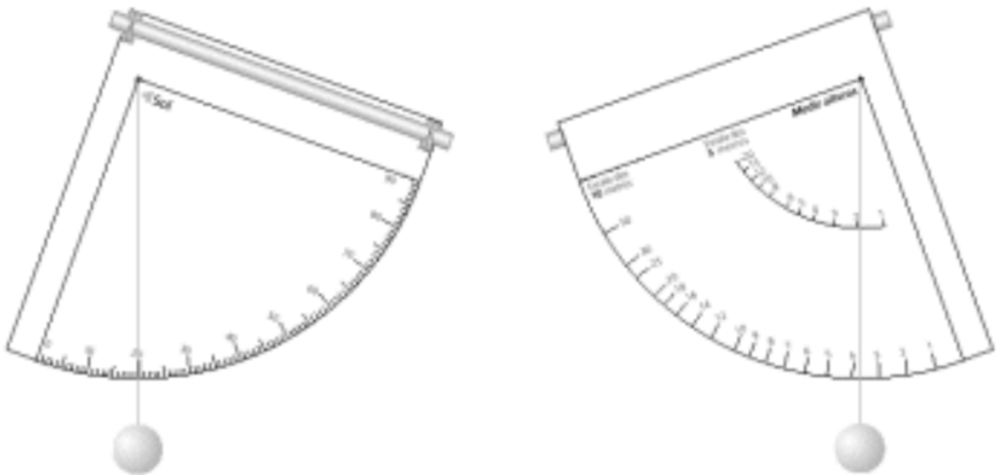
For marine navigation, the earliest quadrants were found around 1460.

Experiment

- Cut out the card quadrant and the four black dots on the flaps.
- Fold the flaps over and insert a straw through the holes.
- Use a needle to put a thread through the hole on the quadrant. Tie the two ends so that the quadrant hangs on the loop.
- Tie a weight onto the thread so that it hangs down.

Your quadrant should look like this:



Be very careful when you are using your quadrant - you should never look at the Sun through the straw because you could damage your eyes.

- Now you can use your quadrant to measure the angle of the Sun above the horizon. Hold your quadrant in one hand and turn the straw towards the Sun. Put your other hand on the outer end of the straw and tilt the quadrant until you can see a bright spot on the palm of your hand. Read the number where the thread lies and you will find out the angle of the Sun above the horizon. Early in the morning this angle is smaller and at midday it is larger. If you do the experiment with your protractor, you will see that the measurements given by both the quadrant and the protractor are the same.

latitude = 90° - measured altitude + declination.

Ask someone to show you the North Star and the Little Dipper.

From now on, you will always be able to tell which direction is north at night, even without a compass.

Experiment

- Look for the North Star on a starry night. Don't forget that it is found in the north. If you can't find it, ask someone to help you. After you find it, point the straw on your quadrant towards the North Star, look up through the straw and line it up with the North Star. Read the angle that the thread shows on your quadrant scale.

- The angle that you have just taken tells you your position on Earth and is called the latitude of your location. Write this latitude down so that you don't forget it.

Latitude of my location:____________________________________

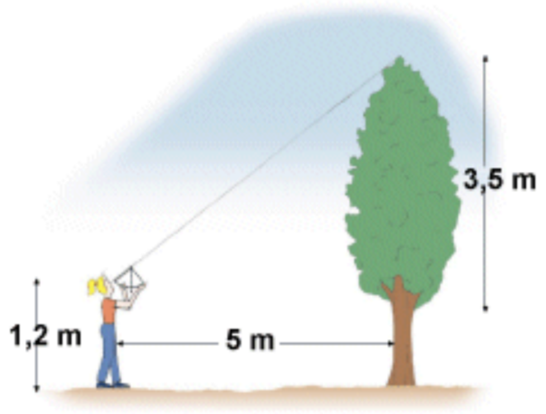
We can also use the quadrant to measure the height of a tree in a park.

On one side of your quadrant, there is a scale in degrees just like the protractor. This scale measures a deviation or an angle above the horizon. On the other side, the scale gives you the height of an object.

To find out the height of a tree, follow these instructions:

- Choose the tree you want to measure. Stand five metres - five large steps - away from it in a straight line in any direction and then turn to face the tree.
- Hold up your quadrant and look at the top of the tree through the straw. The thread shows a number on the five metre scale on the quadrant.
  This figure is the height of the tree from your eye level.
- To find out the height of the tree, measure the distance from your eyes to the ground and add this to the number you read on the quadrant. E.g. if you read 3.5m. on the quadrant and you are 1.20m. tall, the height of the tree is 3.5 + 1.20 = 4.70m. On the other side of the quadrant, you can see the angle from which you are looking at the tree. The higher the tree, the greater the angle.
- You can repeat this experiment with higher houses from a distance of 10 metres. In this case you must use the ten metre scale on your quadrant to find out the height.

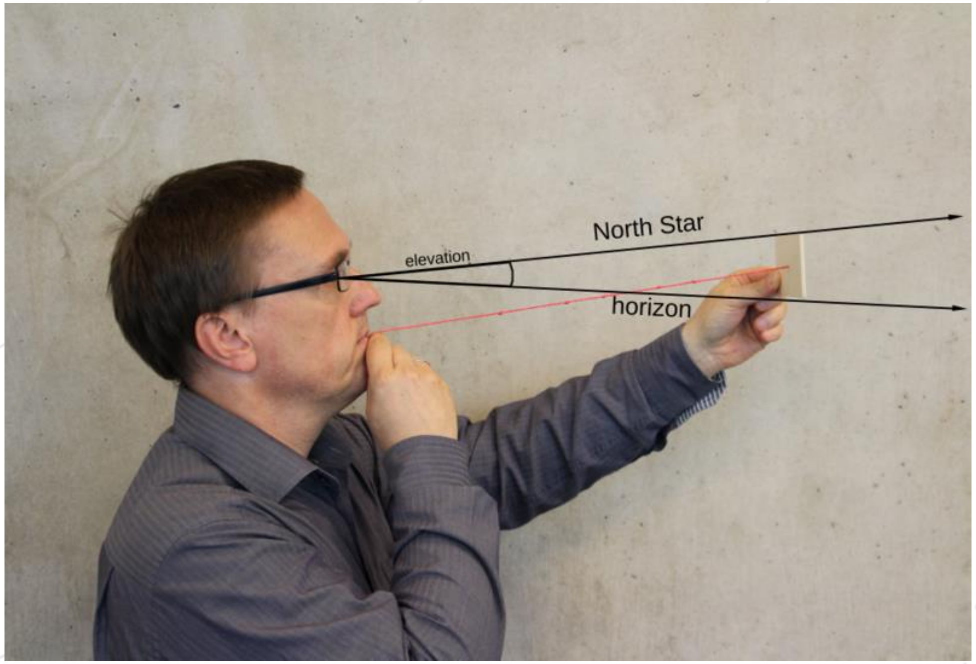
- You can repeat this experiment with higher houses from a distance of 10 metres. In this case you must use the ten metre scale on your quadrant to find out the height.

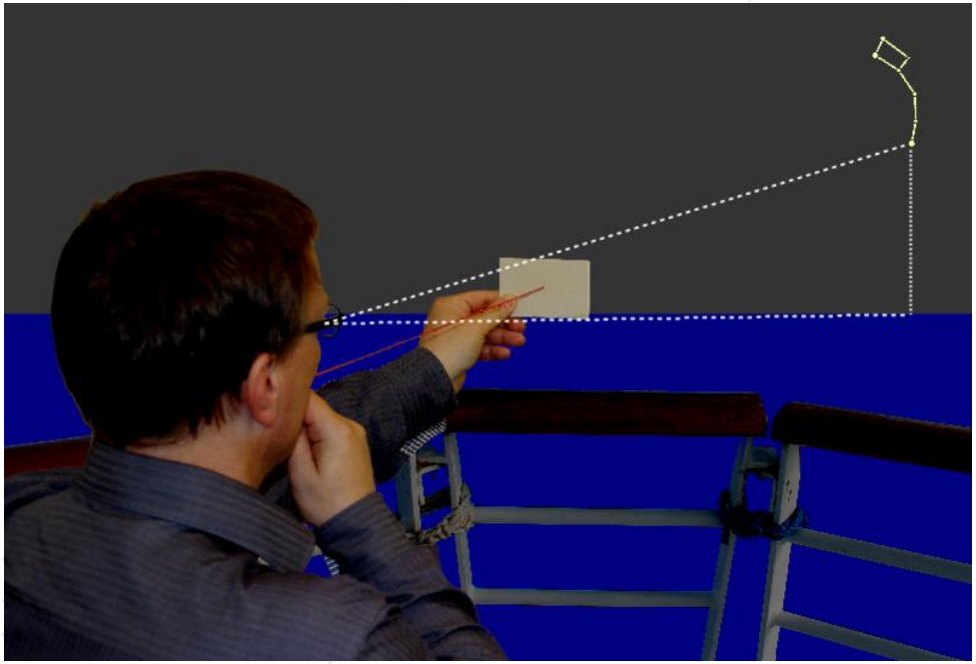


latitude = 90° - measured altitude + declination.

THE KAMAL

Developed in the 9th century





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03

HISTORY OF NAVIGATION

Age of exploration: 15th century in Europe

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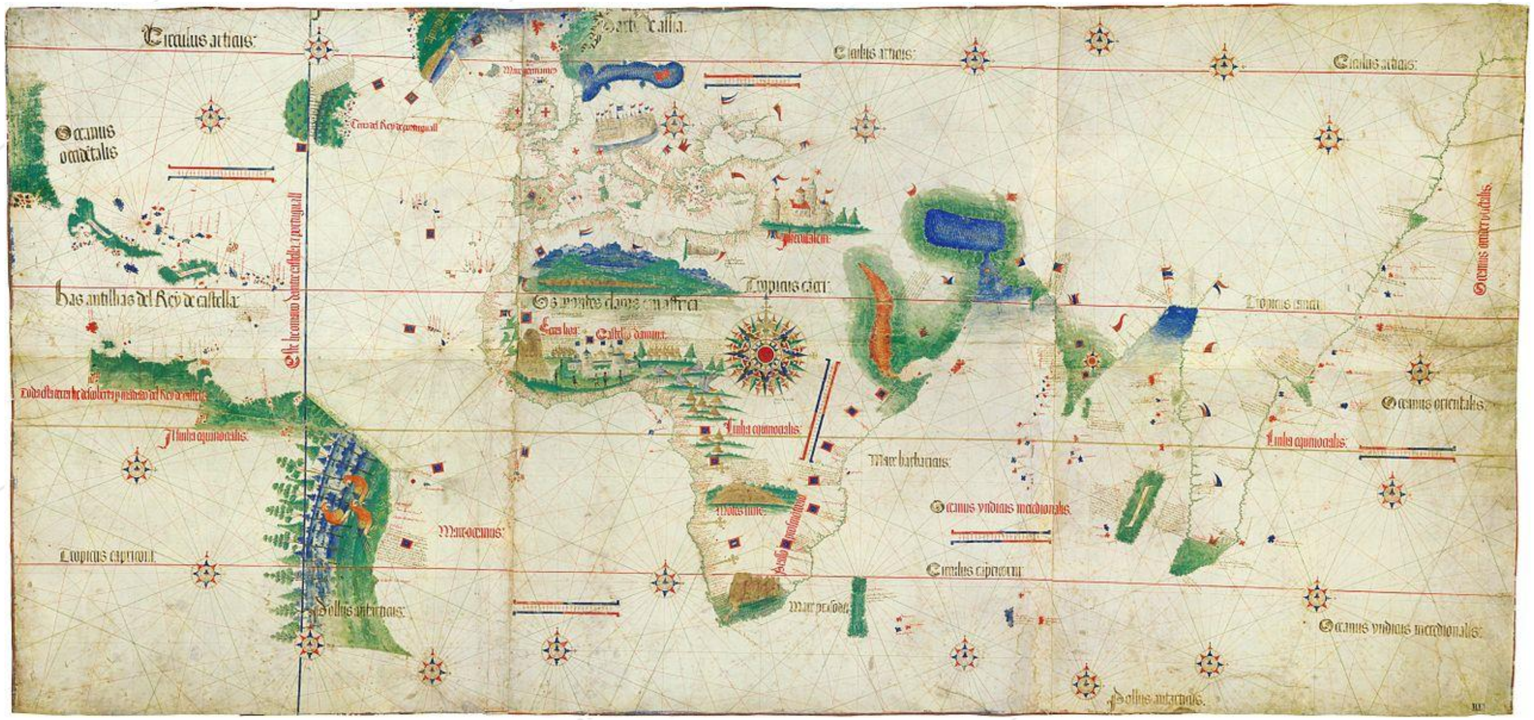
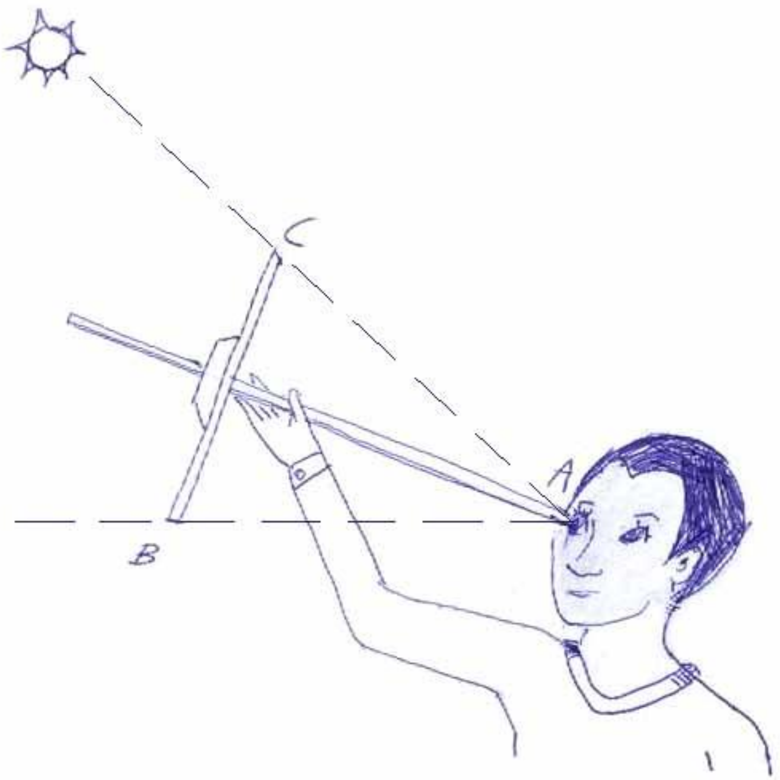
EXPLORATIONS AND COMMERCE

- 15th century in Europe
- Fastened the progress of navigation systems



THE INSTRUMENTS USED

- A method to correct for the altitude of Polaris
- The compass
- A cross-staff or astrolabe
- Rudimentary nautical charts
- Ancient tools were improved



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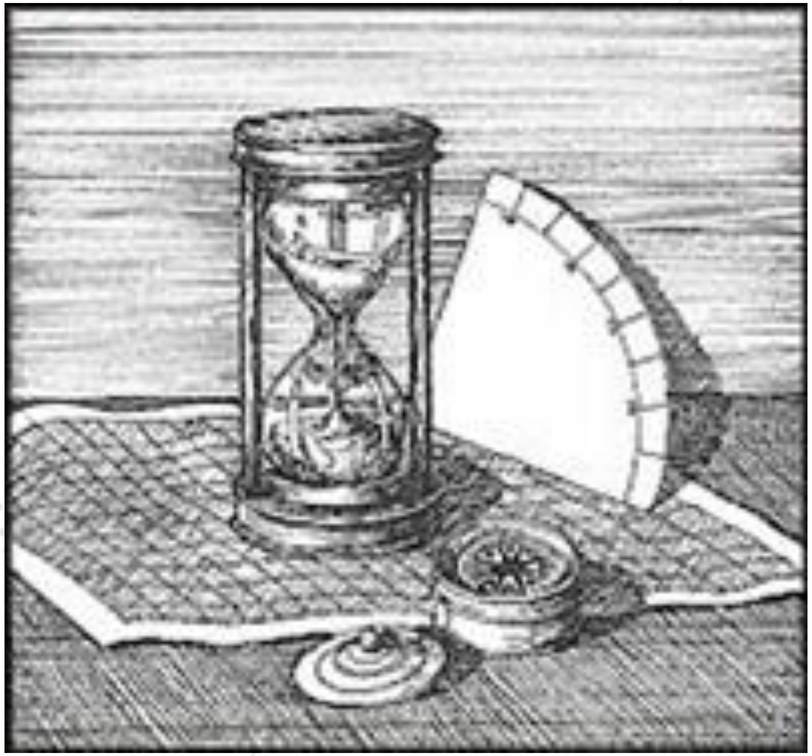
baculus Jacob
1342 (Levi ben Gerson [1288-1344])
was introduced at sea by the Portuguese
around 1515.

TIME KEEPING IMPORTANCE

- Accurate time-keeping necessary to determine longitude
- The use of hourglass was frequent for navigators
- Magellan used 18 hourglasses on each ship!
- A sundial can also be used



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HISTORY OF NAVIGATION

Modern times: the sextant

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A COMMISSION FOR NAVIGATION

- In 1714 the British created the Commissioners for the discovery of longitude at sea until 1828
- Offered grants and rewards for the solution of navigational problems until 1828
- Between 1737 and 1828, the commissioners disbursed some £101,000!

THE MARINE CHRONOMETER

- Invented by John Harrison, winner from the Commission in 1714
- A reliable clock that keeps the time of a reference place
- Challenge to design a clock not affected by variations

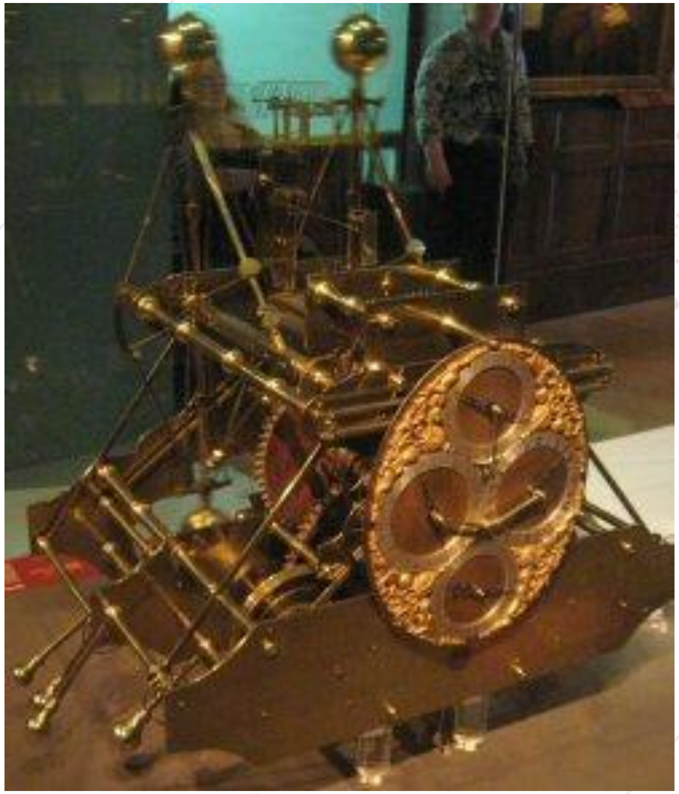
  in temperature, pressure or humidity, remained accurate over long time

  intervals, resisted corrosion in salt air, and able to function on board a

  constantly-moving ship.

THE MARINE CHRONOMETER

- First version of Harrison's clock



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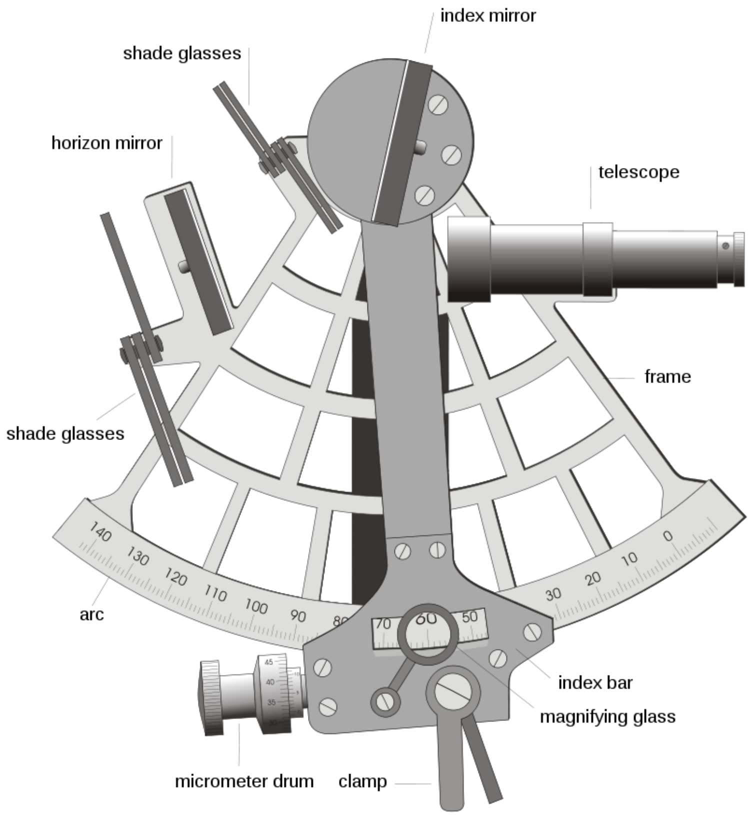
THE FIRST SEXTANT

- Invented in 1757 by John Bird
- Determine the angle between an astronomical object and the horizon



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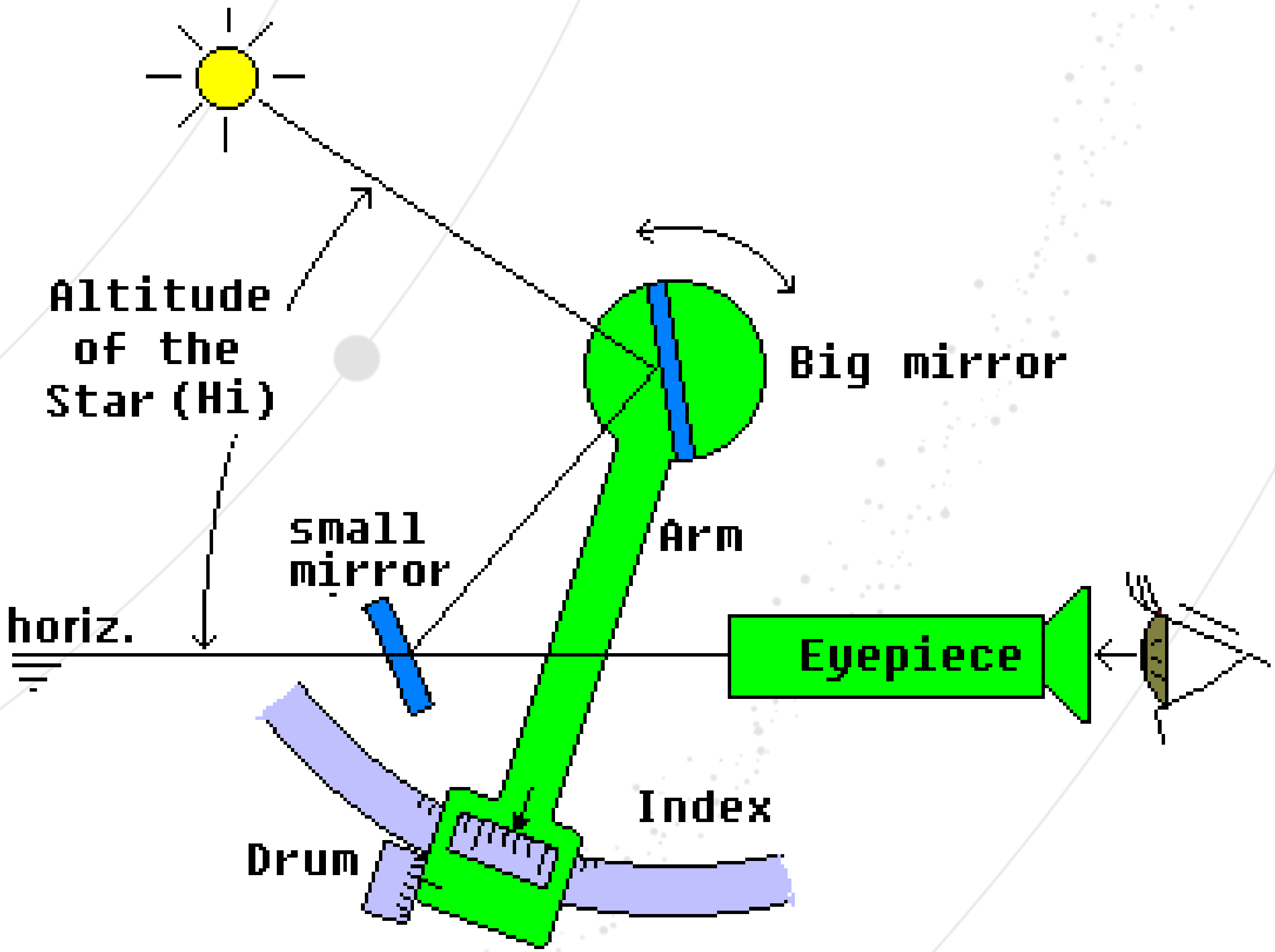
THE SEXTANT


Altitude
of the
Star (Hi)
Big mirror
Arm
small
mirror
horiz.
Eyepiece
Index
Drum

PRACTICAL NAVIGATION

Practical celestial navigation usually requires:

- a marine chronometer to measure **time**,
- a sextant to measure the **angles**,
- an almanac giving schedules of the **coordinates of celestial objects,**
- a set of sight reduction tables to help perform the height and azimuth computations,
- a **chart** of the region.

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HISTORY OF NAVIGATION

Links with school science

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LINKS WITH SCHOOL SCIENCE

Main activity topics:

(Primary, 6-12 years old)

- Basic concepts, Latitude, Longitude

(Secondary, 12-18 years old)

- Basic concepts, Latitude, Longitude
- Coordinate Systems

Secondary activity topics:

(Primary, 6-12 years old)

- Coordinate Systems
- Instruments

(Secondary, 12-18 years old)

- Celestial navigation
- Constellations
- Instruments
- Satellite navigation

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LINKS WITH SCHOOL SCIENCE

- **Geographic** information, cartography, topography, coordinate systems...
- **Mathematics** processess, methods, applications, measure angles...
- The contribution of **civilization**, their **history**, and culture
- The stars, constellations, how and why we can use them
- **Technologies** and **physics**: telescopes, and instruments, measuring space and time
- **Etc**...

SPACE AWARENESS ACTIVITIES

- Many Space Awareness activities allows you to introduce nagation instruments to your students

- Try one of them!

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CURRENT SCIENCE OF NAVIGATION

The Galileo mission

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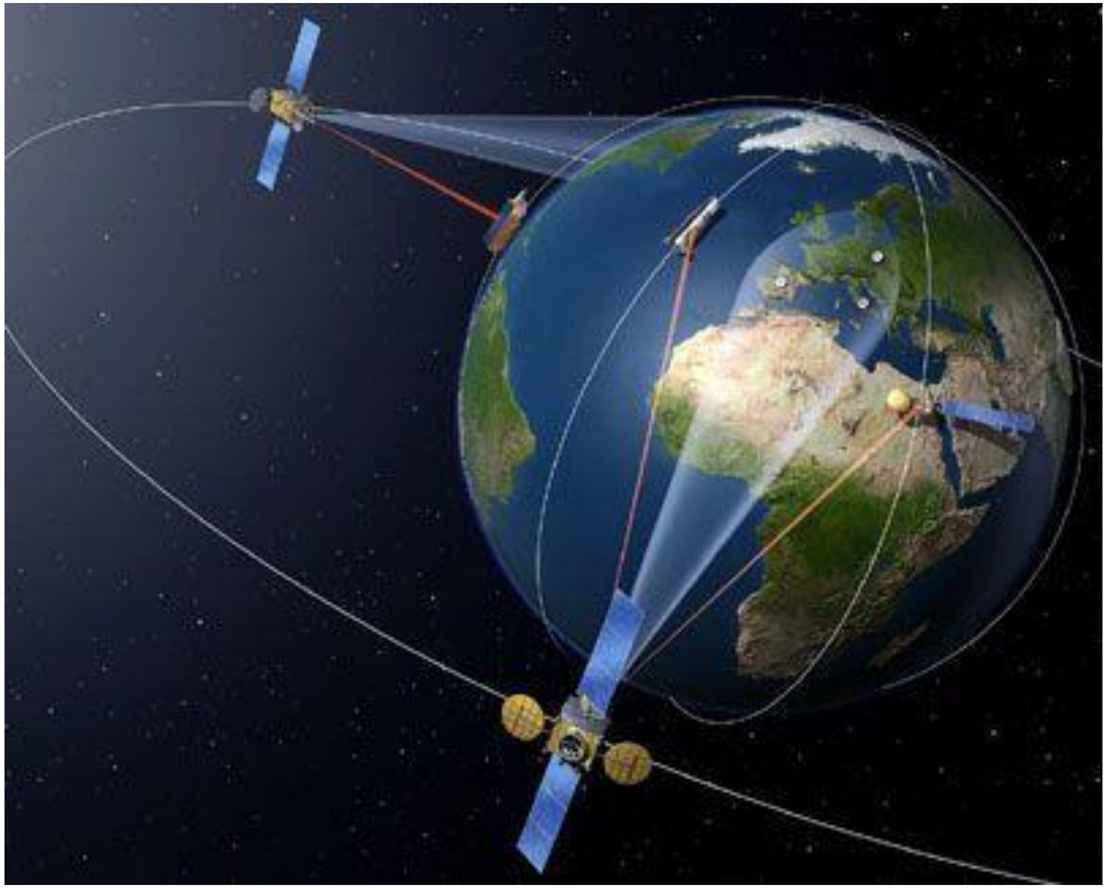

GPS AND GALILEO

Global Navigation Satellite System (GNSS)

- Worldwide system for positioning and navigation
- Since 2000
- 32 satellites including 24 operational
- 6 orbital planes
- Controlled by the USA, initially military project started in 1960s (Transit)

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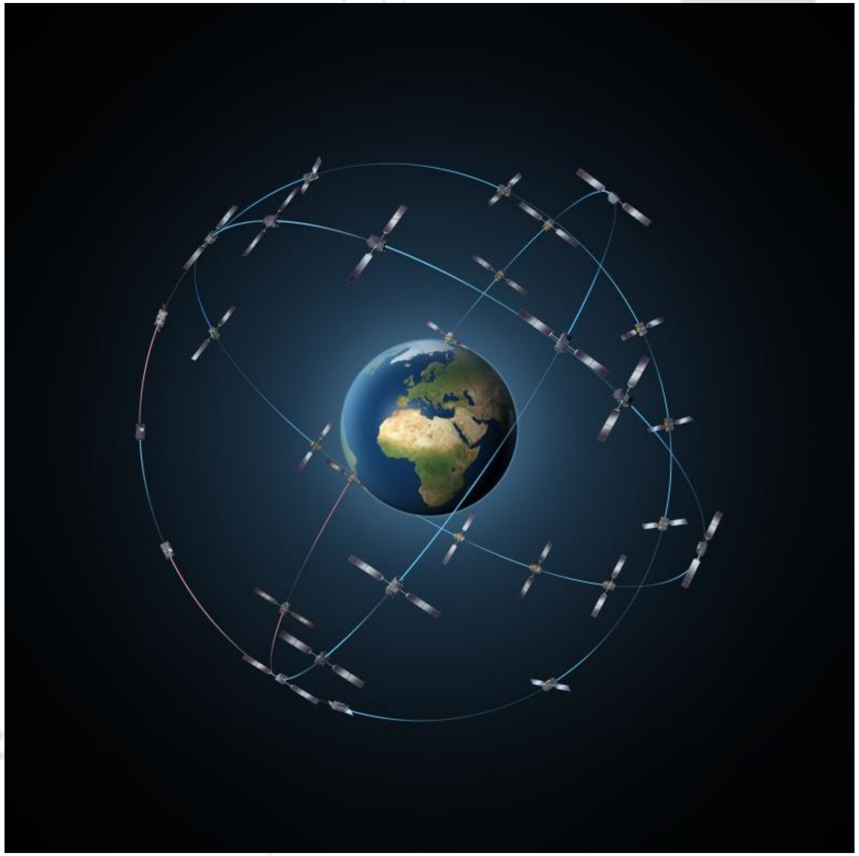
GPS AND GALILEO

Galileo, the EU project

- 30 satellites launched between 2005 and 2019
- Full operations for 2020
- EU dependent system
- Reduce the chances of signal failure



GALILEO SERVICES

- **Open Service** The signal will be accessible by the general public free of charge, providing improved global positioning.
- **Public Regulated Service** Two encrypted signals with controlled access for specific users such as governmental bodies.
- **Search and Rescue Service** Galileo will contribute to the international Cospas–Sarsat international system for search and rescue.
- **Safety-of-Life Service** Already available for aviation to the ICAO standard thanks to EGNOS. The system will be extended to augment Galileo as well, thus further improving service performance.
- **Commercial Service** Galileo will provide a signal for high data throughput and highly accurate authenticated data.

GALILEO APPLICATIONS

- Internet better accuracy and availability
- Location services devices
- Transport efficiency, security
- Emergency, security and humanitarian services

stolen property, missing persons, civilian protection and humanitarian operations, coastguards and border control, faster rescue, boat or airplane crash

- Science, environment, weather

support research in meteorology, geology, atmospheric measurements, climate change space weather, earthquakes' predictor events, movement of animal populations

- And also: agriculture, fisheries, civil engineering…

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MEASURING TIME

The basis of satellite navigation is to measure the distance between a receiver and a satellite

= travel time of a radio signal from the satellite to the receiver

TURNING TIME INTO DISTANCE

- Time difference between satellite and receiver is calculated
- Precise distance the signal has travelled from the satellite to reach the receiver is deducted

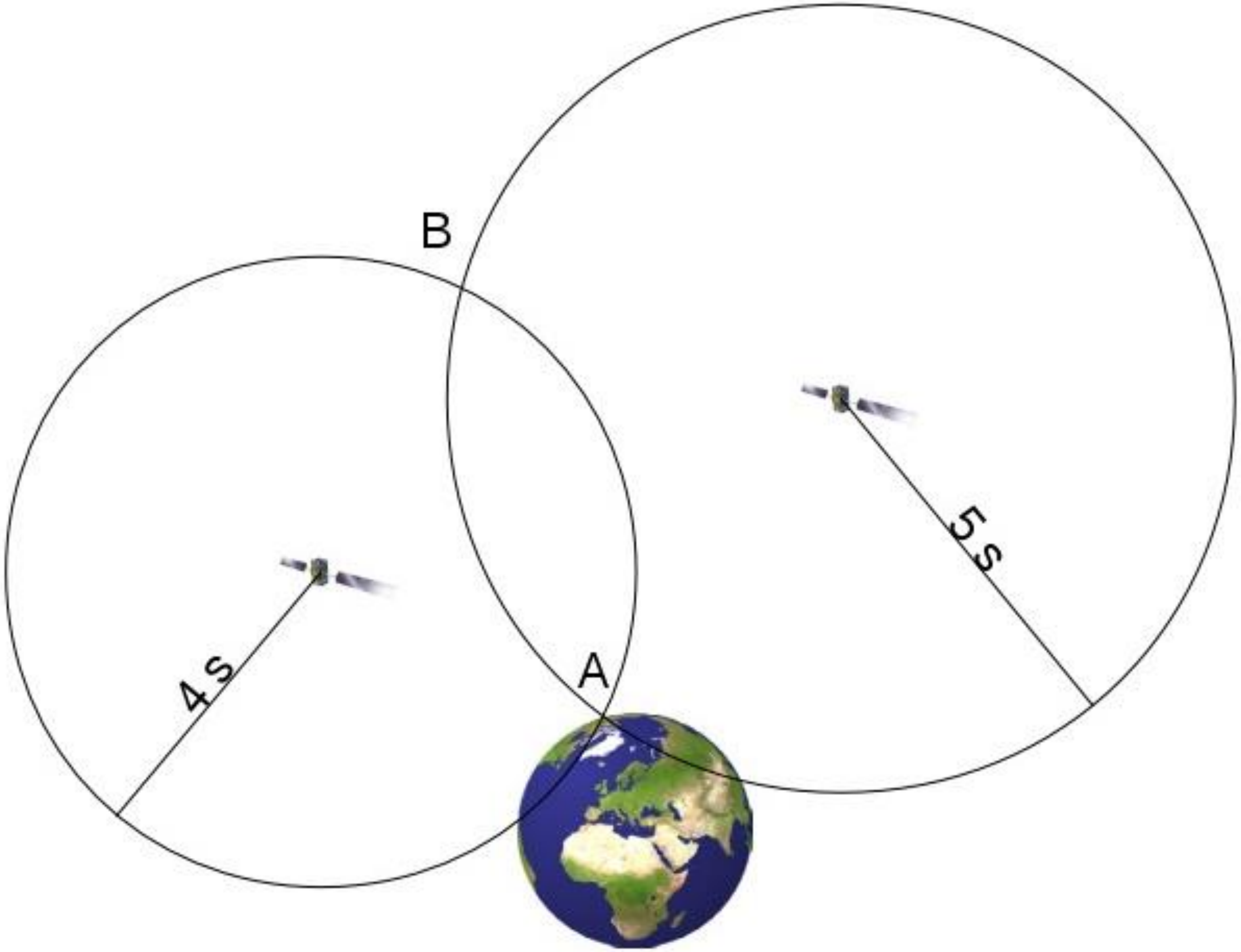
It is like counting the seconds after lightning flash before hearing the thunder to estimate how far is the storm!

SATELLITE NAVIGATION

4 satellites for one location

- 2 satellites tell you that you are situated somewhere on the circle where two spheres intersect
- A third satellite fixes your position at one of the 2 points where the circle intersects the third sphere
- In practice, a fourth satellite is needed to synchronise your receiver's clock with a common time standard and resolves the position ambiguity that occurs with only 3 satellites.

FINDING YOUR PLACE



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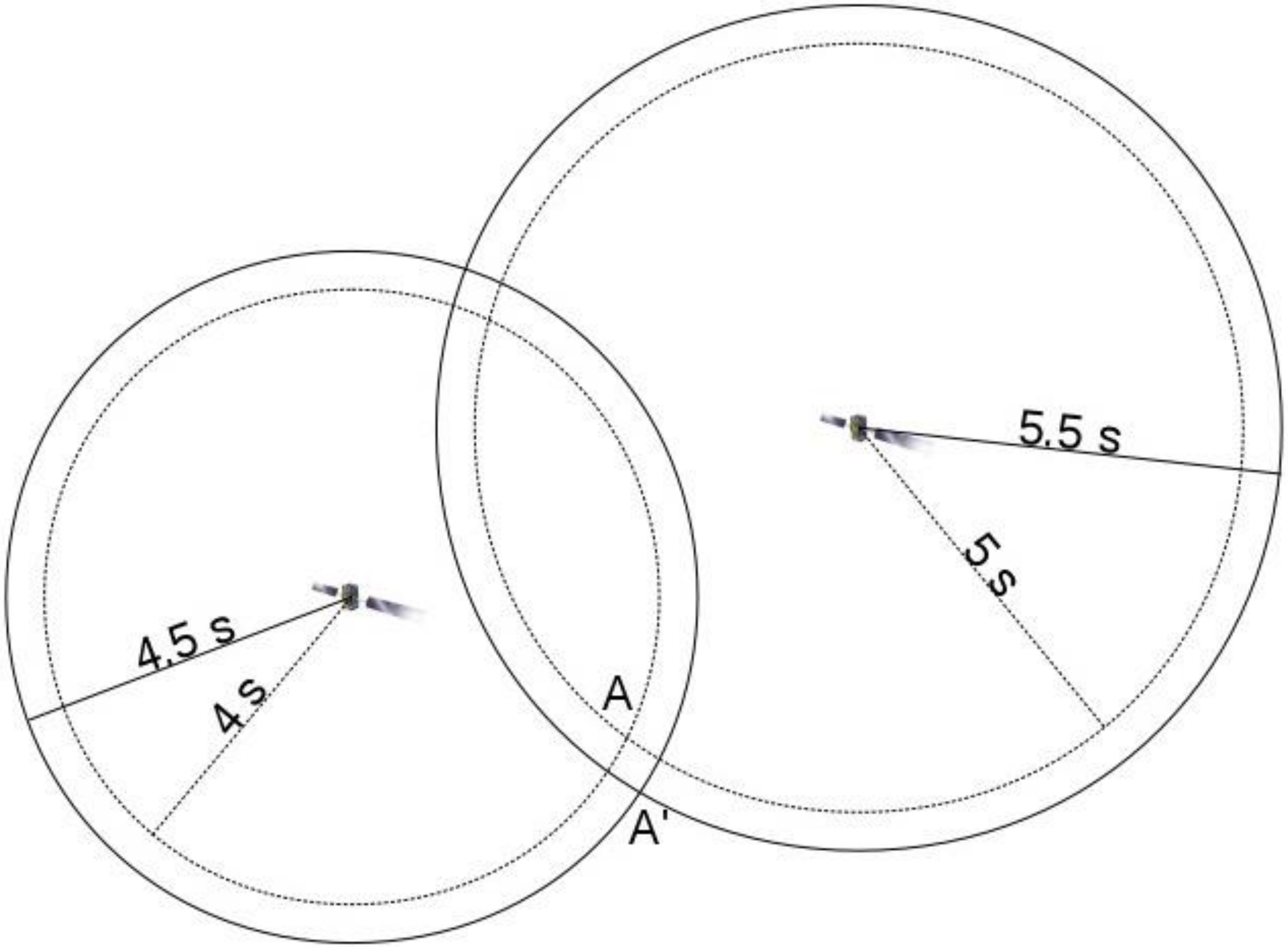

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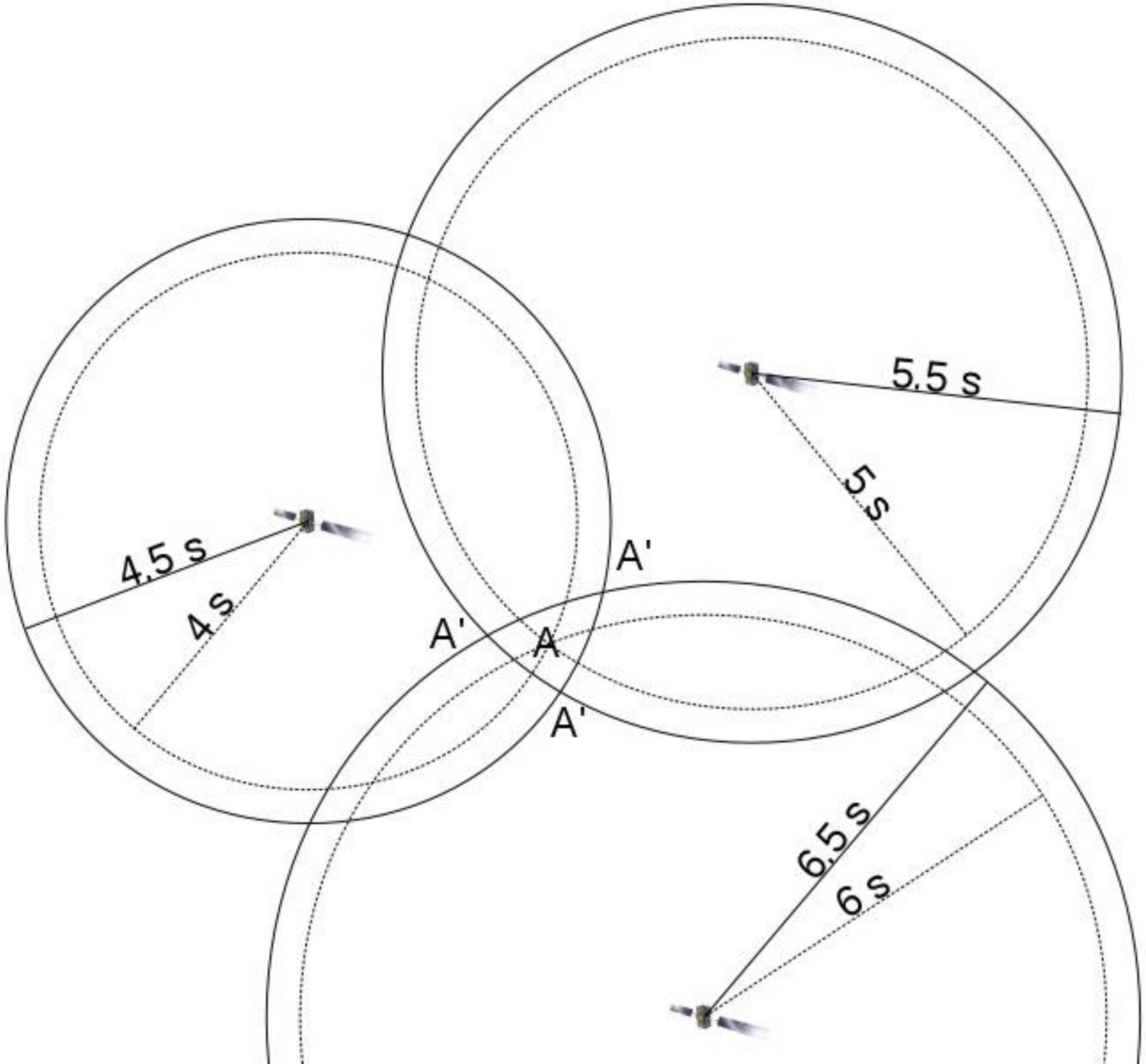
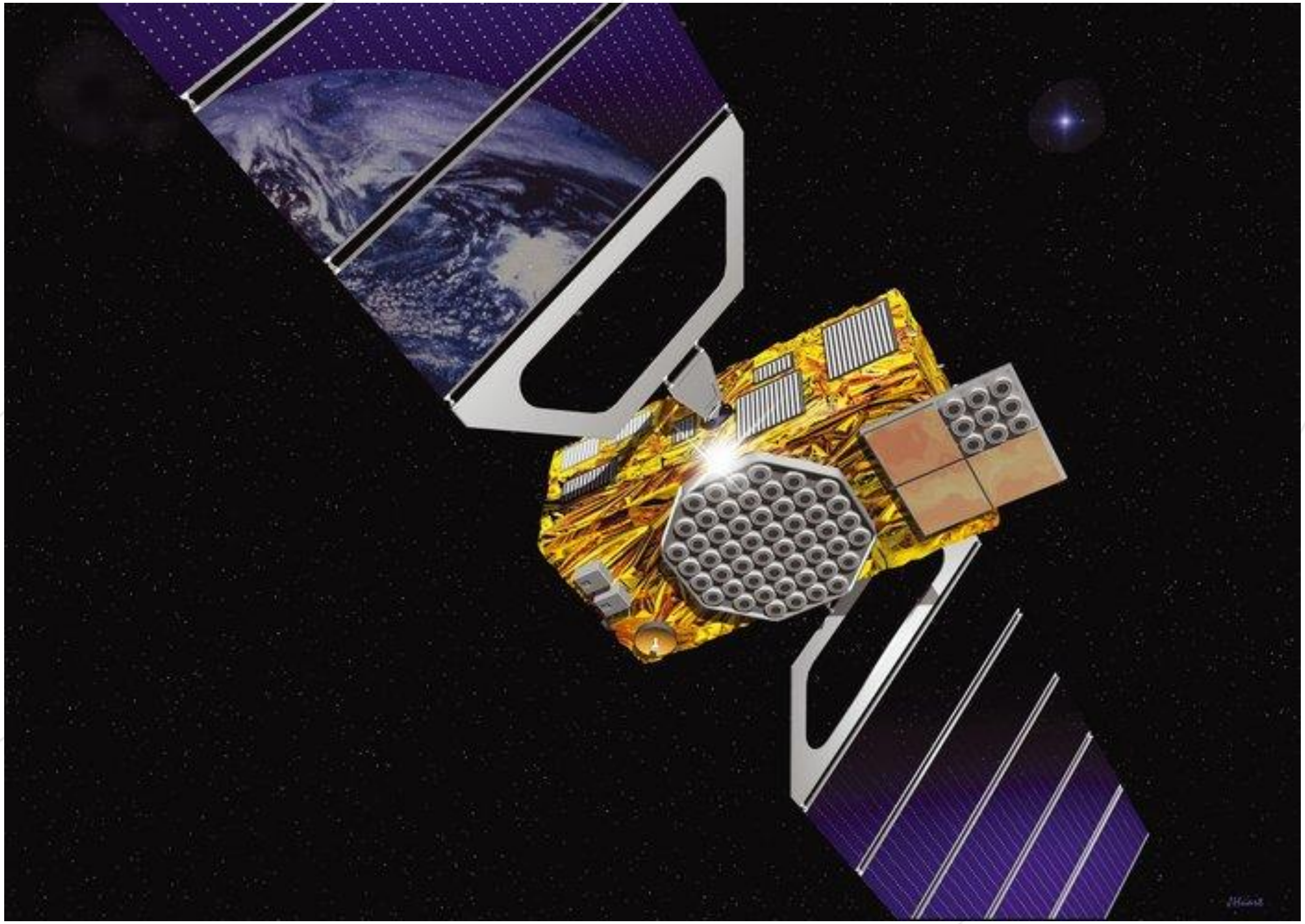


GALILEO SATELLITES



SATELLITE ANATOMY

- **Antennas transmitting and receiving** the navigation signals
- **Search and Rescue antenna** for distress signals
- **C-band antenna** to receive mission data including data to synchronise the onboard clocks with a ground-based clock and integrity data
- **S-band antennas** receiving commands to control the satellite and operate the payload, measure the satellite’s altitude to a few metres accuracy.
- **Infrared Earth sensors and visible light Sun sensors** to keep the satellite pointed at Earth.
- **Laser retroreflector** to measure the satellite altitude
- **Space radiators** to maintain onboard electronics within their operational temperature range.

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SATELLITE ANATOMY

- **Passive hydrogen maser clock**: the master clock on the satellite
- **Rubidium clock**: smaller atomic clock based on a different technology, ensuring redundancy to the masers
- **Clock monitoring and control unit**: the interface between the four clocks and the navigation signal generator unit
- **Navigation signal generator unit** generates the signals using the input from the clock and navigation and integrity data
- **Gyroscopes** to measure the rotation of the satellite
- **Reaction wheels** to control the rotation of the satellite
- **Magnetotorquers** modifies the speed of rotation
- **Power conditioning and distribution unit** regulates and controls power from the solar array and batteries
- **Onboard computer** controls the satellite platform and payload.

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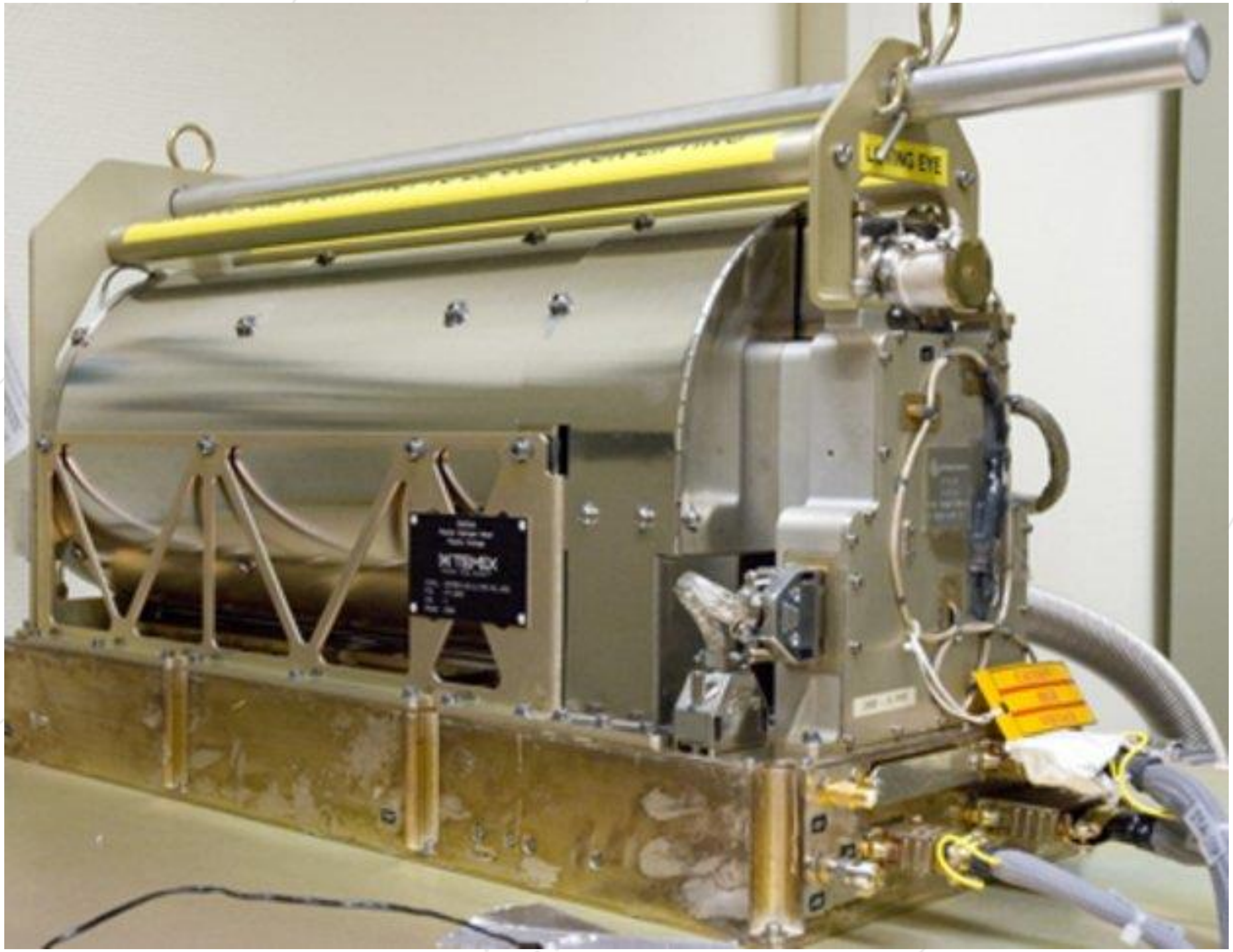
THE CLOCK AT THE CENTRE



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AND ON THE GROUND?

Ground stations check:

- Satellite’s position and identify any orbital drift
- Satellite’s clock
- Quality and reliability of each individual signal

07

CURRENT SCIENCE OF NAVIGATION

Relation to school subject and education

GALILEO LINKS TO EDUCATION

- Galileo is a **current European space mission** that will be on full deployment in 2020
- An opportunity to **link current science to school science**
- Introduce a **current mission,** its **international components**, its diversity and amount of **linked careers**

GALILEO LINKS TO EDUCATION

How? Some examples on how to link to current science

- Follow-up the Space Awareness webinars programme to meet scientists working on the mission
- Follow-up sentinels launches and ESA events to share the excitement of current science with students
- Use citizen science projects to participate to research on related subjects
- Use the opportunity to introduce space careers to students

SOME LINKS WITH SCHOOL

- **Inquiry** based methods: the engineering and scientific process
- **Mathematics** processes, methods, and applications
- **Geographic** information, cartography
- **Physics**: measuring space and time, orbits, launches…
- **Technologies**: rockets, satellites, clocks, signals…
- **History** of navigation, evolution of technics and space sciences
- **Languages** and **cultures**: international endeavor and cooperation
- Science **careers**, **etc**..

HANDS-ON!

- Let’s map the Earth / Where on Earth am I?

Thank you!

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Núcleo Interactivo de Astronomia