Navigation

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Navigation

Navigation is a field of study that focuses on the process of monitoring and controlling the movement of a craft or vehicle from one place to another. (Wikipedia)

Navigation includes:

- Determination of position (Where am I?)
- Orienteering (Where is the North?).

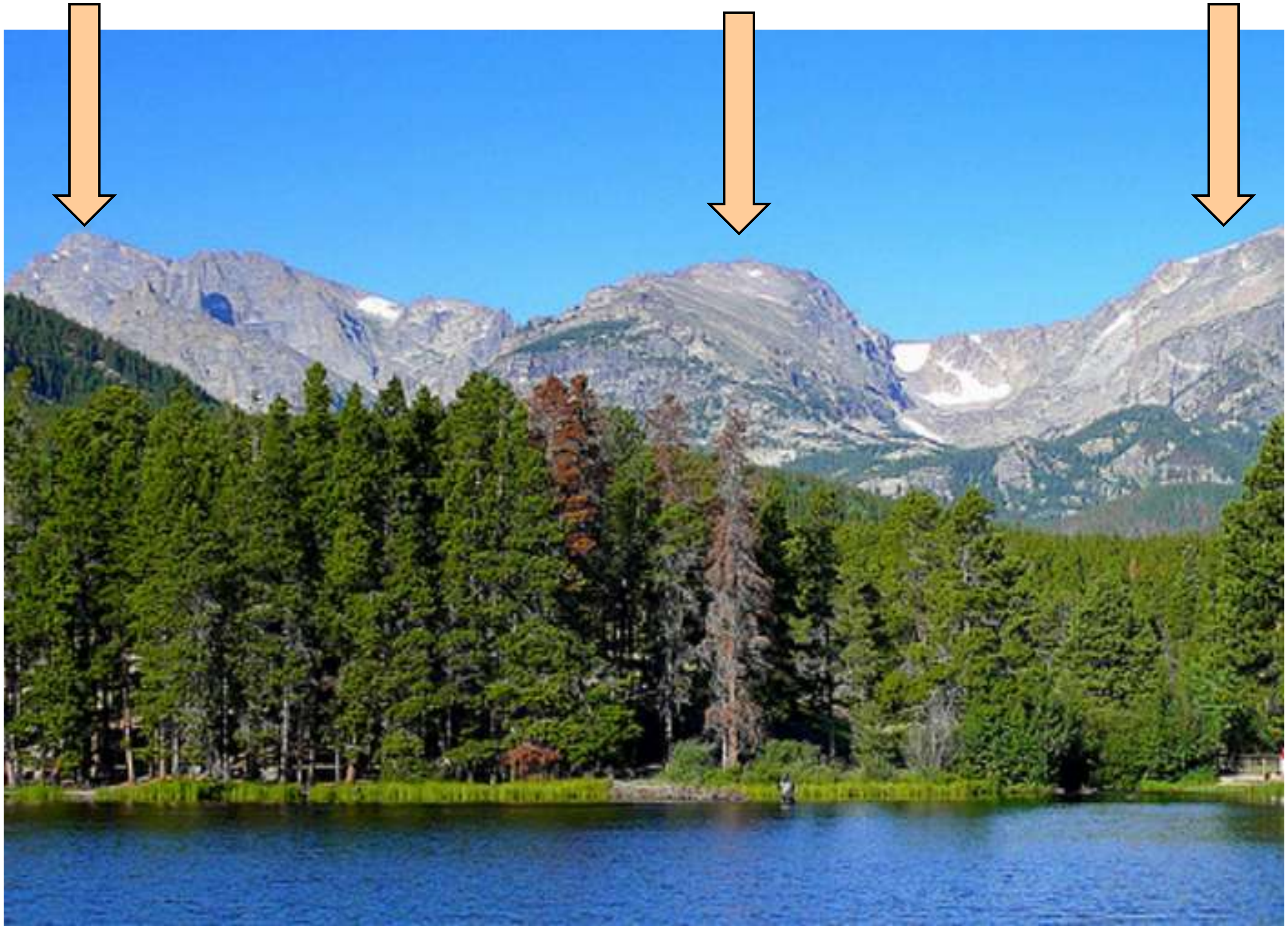
Where am I? Where is the North?

Once upon a time (6000 years ago)…

Orientation by local features

Pioneers returning from their journeys provided travel instructions for those who wished to repeat their journeys. They wrote descriptions of their routes and made charts or maps pointing out landmarks and hazards such as rivers, and mountains on land or shoals and rocks at sea. Mapmarkers devised a global coordinate system, using a grid of latitude and longitude circles, by which the position of any place on the earth could be defined.

Orientation by local features



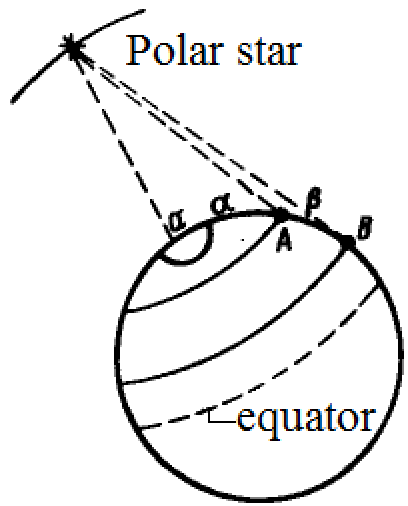
In darkness…pharos(lighthouse)

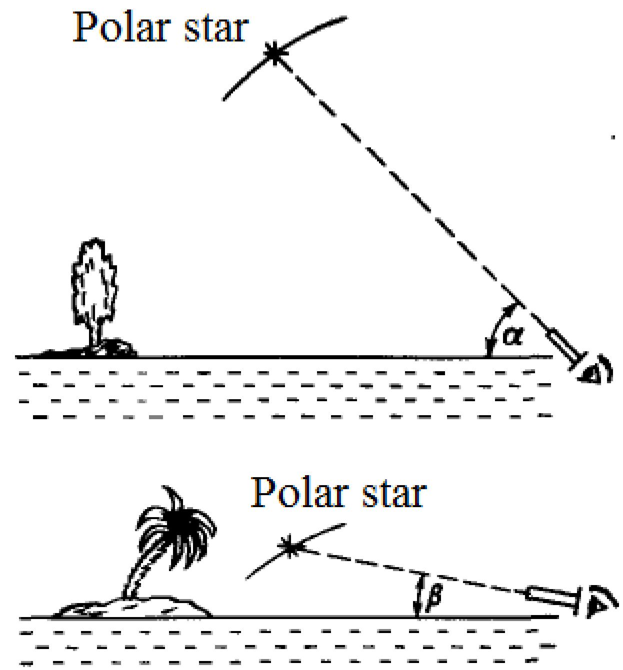




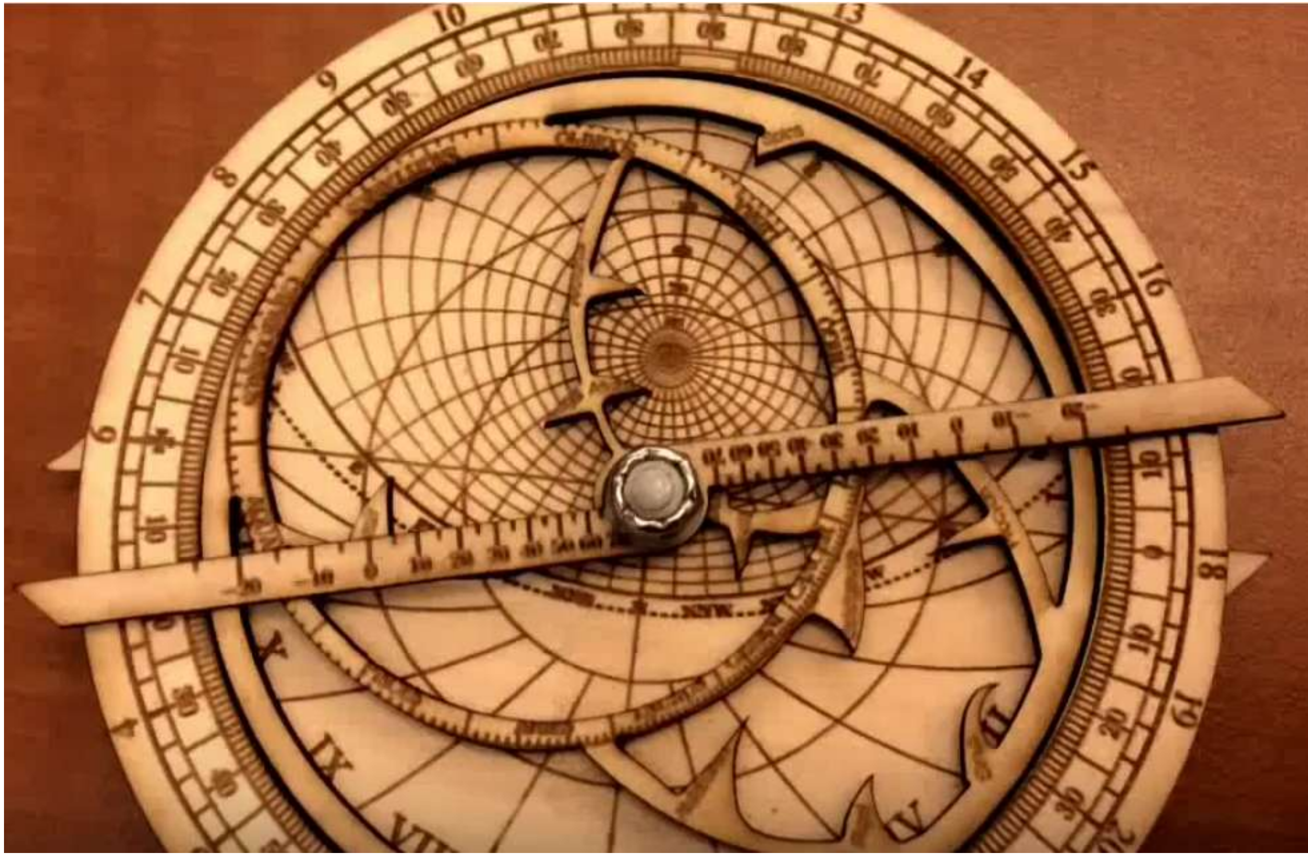

Stars

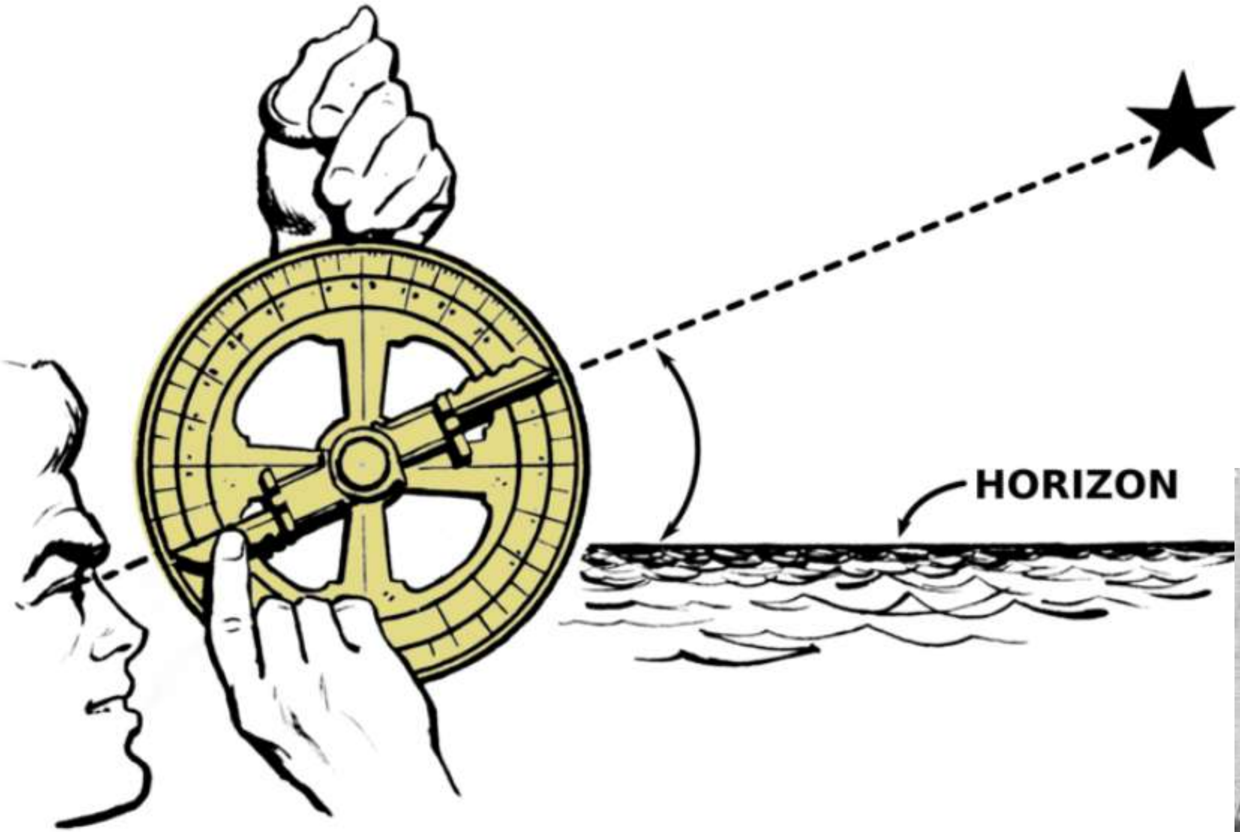
Determining latitude was relatively easy because it could be calculated from the altitude of the sun at noon or Polar star in the night.





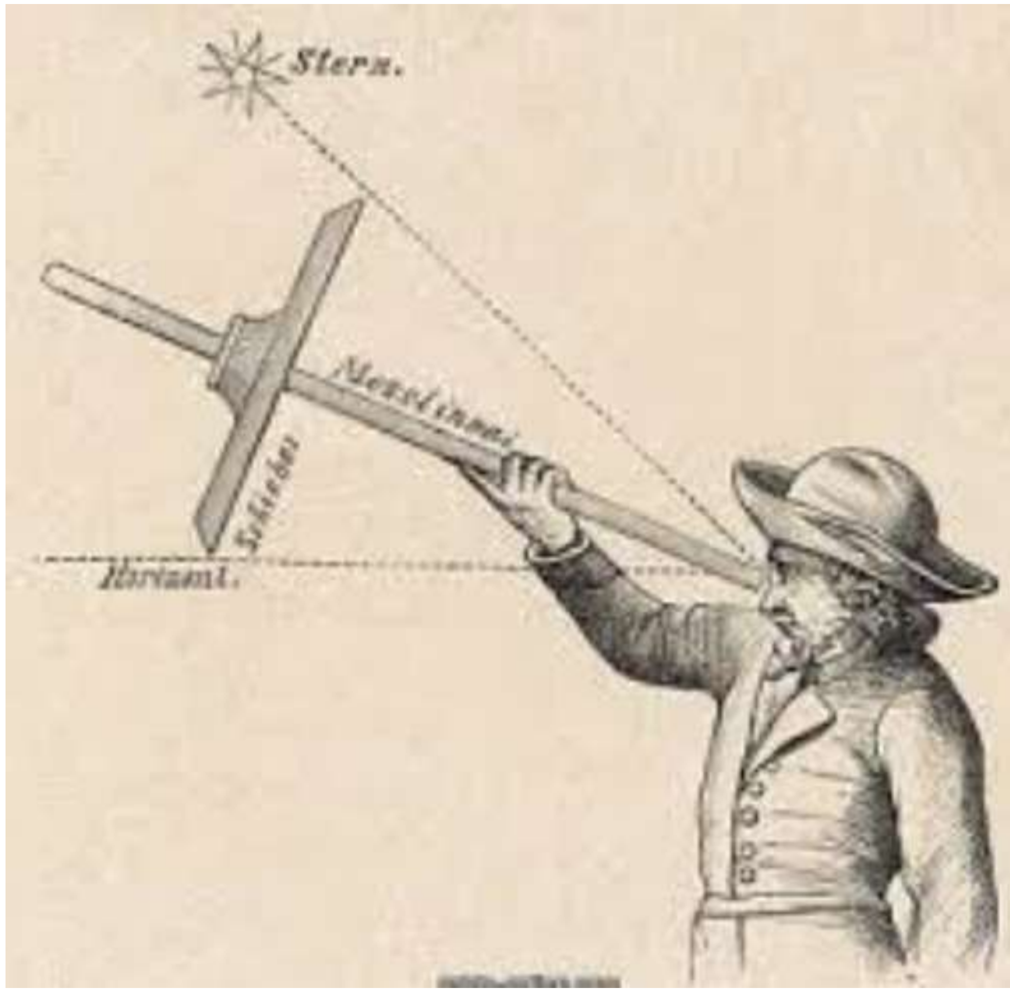
Predicting sunrise and sunset with astrolabium



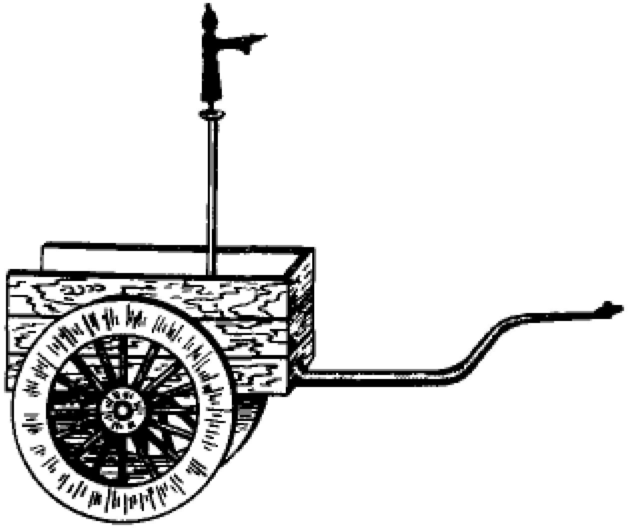


Inventor Claudius Ptolemaeus
c. AD 100 – c. 170

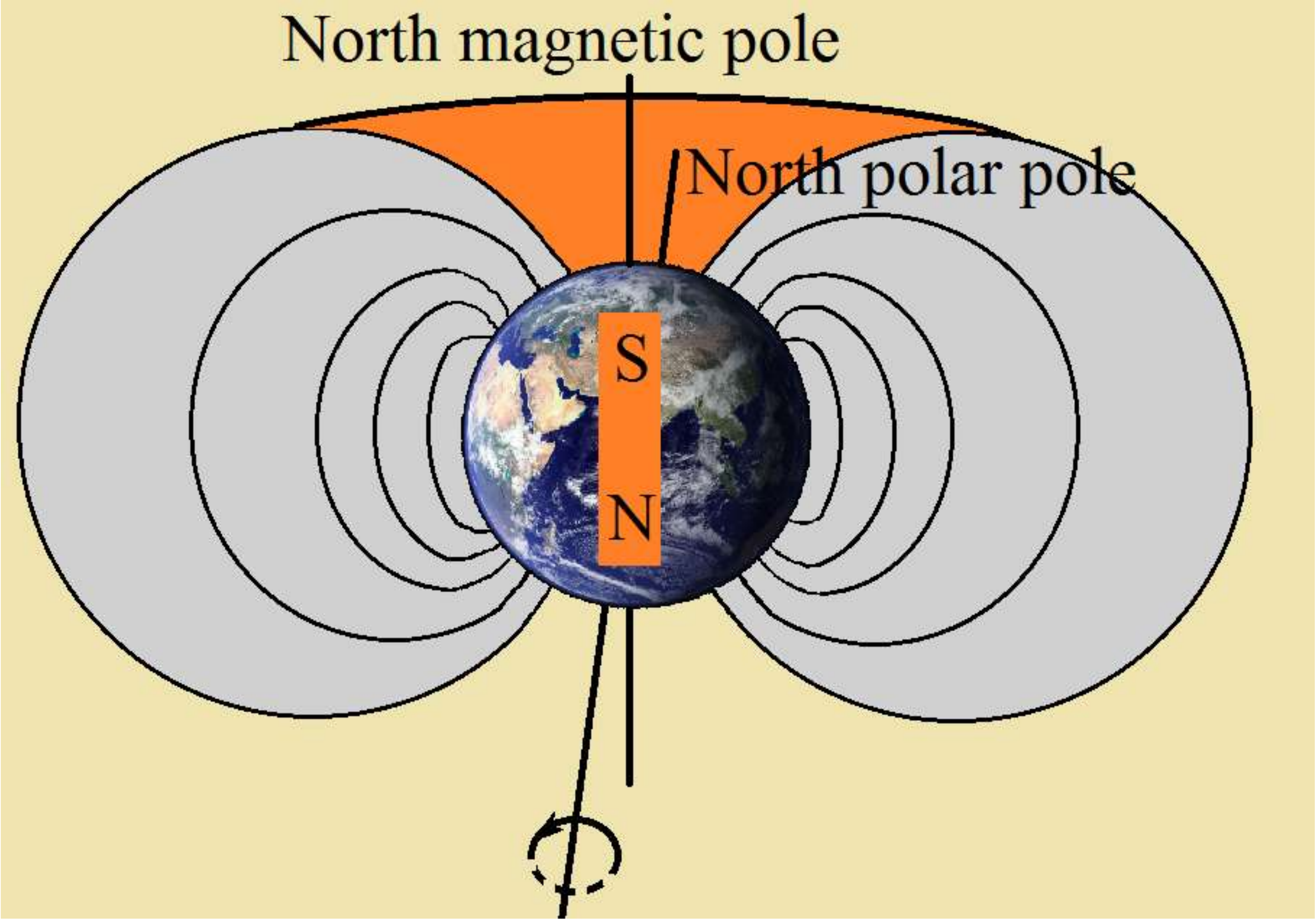
Ballastella



Compass



Chinise chariot with lodestone figure, pointing to the North


North magnetic pole
North polar pole
S
N

Finding the longitude

Finding an accurate and reliable method of determining longitude took centuries of study, and involved some of the greatest scientific minds in human history. Time equals longitude. Finding apparent local time is relatively easy. The problem, ultimately, was how to determine the time at a distant reference point while on a ship. In 1612, having determined the orbital periods of Jupiter's four brightest satellites, Galileo proposed that with sufficiently accurate knowledge of their orbits one could use their positions as a universal clock, which would make possible the determination of longitude.But these observation were complicated to be done on ship.

Summary

Until now we learnt how to orientate using local features, how to find sunrise and sunset (the position latitude), how to point North magnetic Pole and North Pole. But we could not estimate yet our longitude. To measure the longitude we have to measure by accurate hronometer the difference between the local time of the previous place and current local one.

In July 1714 the British Parliament passed the Longitude Act and this established a Board of Longitude which offered a £20,000 prize for the person who could invent a means of calculating longitude.

Time, hronometer, pendulum

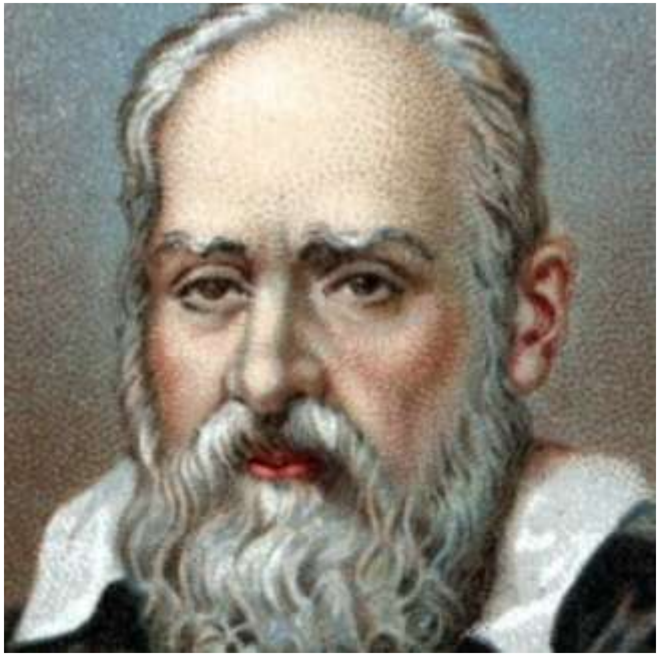
-Mechanical watches with gears were invented XI-XII c., but their precision was poor. They were moved by large weigths at the beginning and since XV c. by springs.

- The sandglasses at that time were more precise hronometers.

Pendulum

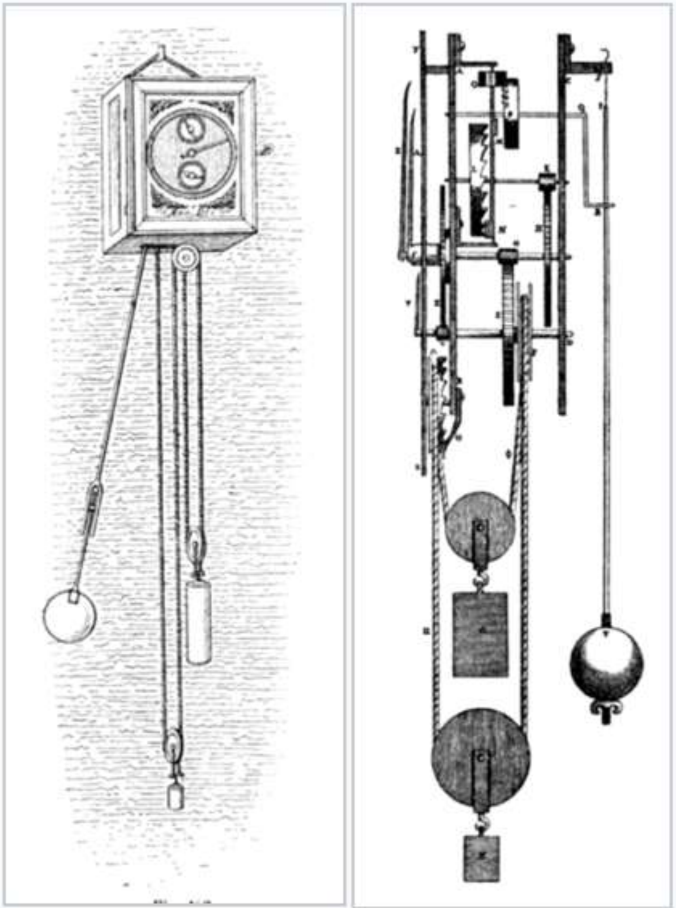
A pendulum is an object hung from a fixed point that swings back and forth under the action of gravity. The swing continues moving back and forth without any extra outside help until friction (between the air and the swing and between the chains and the attachment points) slows it down and eventually stops it. The period of the pendulum depends on the force of gravity, as well as the length of the pendulum. It doesn't depend on weight **and** ***on the arc of swing*****.**

Pendulum cont.



Galileo Galilei made aforementioned notable discovery about the pendulum around 1602. Later, this crusial discovery would lead Galileo to conclusion to use the regular motion of pendulums for timekeeping and the development of his idea for a pendulum clock.

Pendulum clock



The first pendulum clock

In 1656 the Dutch scientist Christiaan Huygens built the first pendulum clock. This was a great improvement over existing mechanical clocks; their best accuracy was increased from around 15 minutes deviation a day to around 15 seconds a day. Drawback - even small change of temperature leads to a change of pendulum length and period.

Pendulum clock

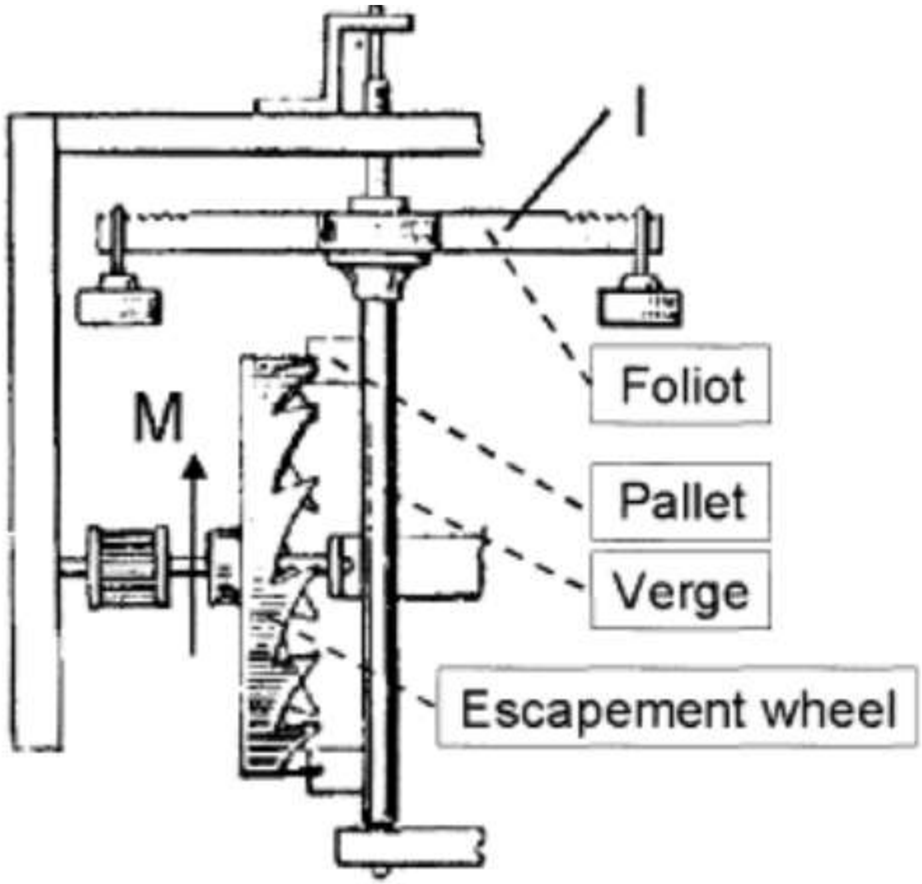
Spring driven pendulum clock, designed by Huygens, built by instrument maker Salomon Coster (1657),[98] and copy of the *Horologium Oscillatorium*,[99] Museum Boerhaave, Leiden

$$T = 2\pi\sqrt{\frac{l}{g}}$$

In 1673 Huygens published Horologium Oscillatorium sive de motu pendulorum. Huygens was the first to derive the formula for the period of an ideal mathematical pendulum. He later used spiral springs and balancing wheel in more conventional watches, made for him by Thuret in Paris from around 1675.

Balance wheel with verge escapement

Foliot with verge escapement. The escapement wheel is driven by a constant moment of force M, the foliot has a moment of inertia I, determined by the mass of the weights and their distance to the verge[1]



After XVII c. …

- ***More ships were made of Steel and Iron***
- ***They have their own magnetic field that can effect changes in the ship's magnetic compass***
- ***Determined by angle in which the Keel is laid during initial construction***
- ***Equipment – electric/electronic can also cause deviation***
- ***The ships became with higher speed and more maneuverable, compass is sensitive to accelerations***

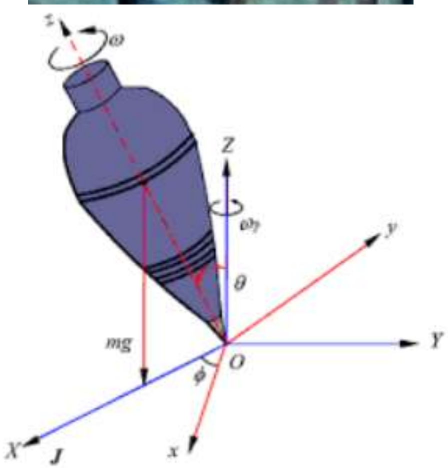
Spinning top




A spinning top is a toy designed to spin rapidly on the ground, the motion of which causes it to remain precisely balanced on its tip because of its rotational inertia. Such toys have existed since antiquity.

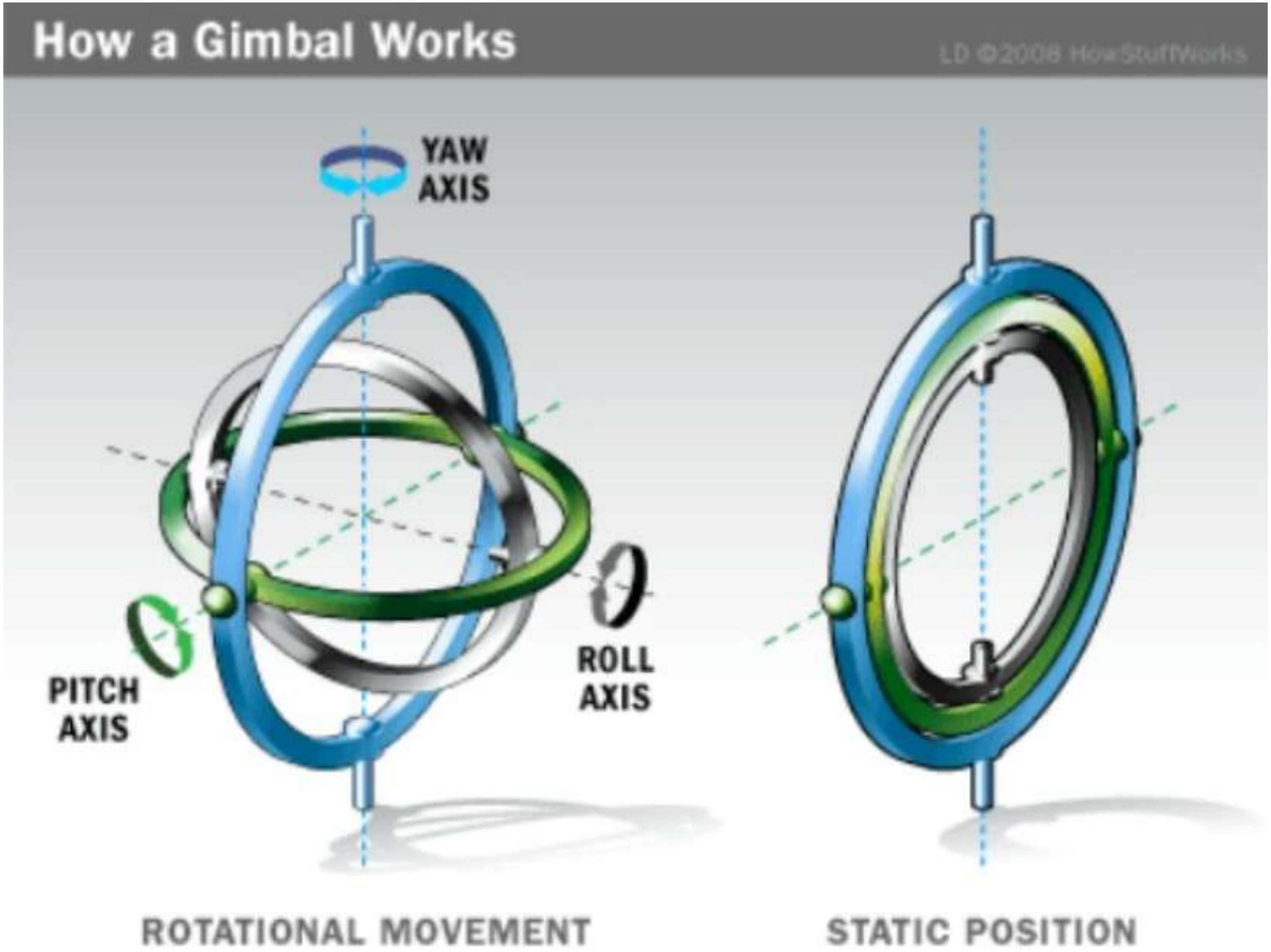
Spinning top

Euler was one of the most eminent mathematicians of the 18th century. Spinning top effect was theoretically investigated by Euler in 1765, in the book "Теория движения твердых тел"



Gimbal

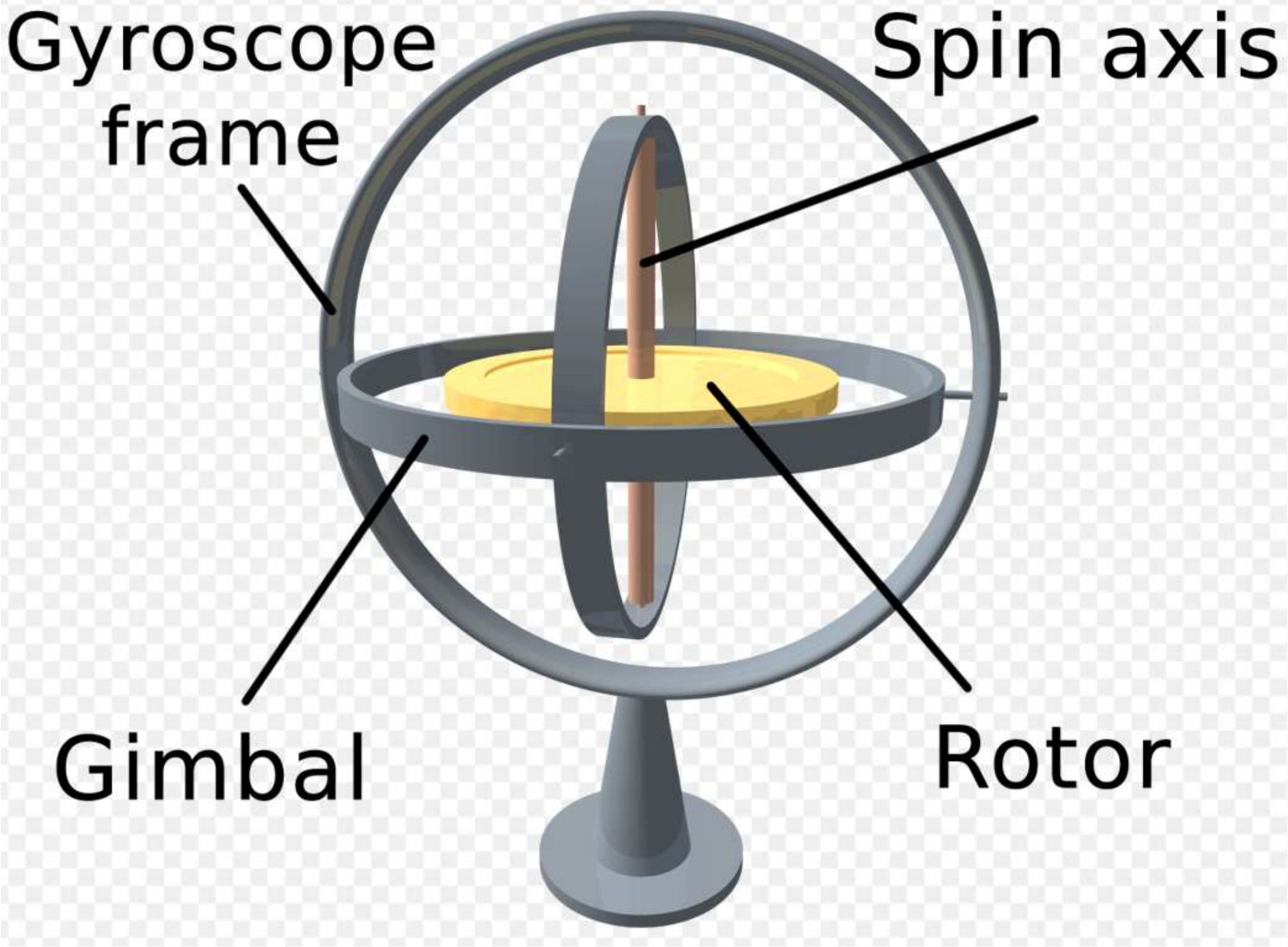
Gerolamo Cardano (1501 – 1576, Pavia, Italy) partially invented and described several mechanical devices. One of them is the combination lock - a gimbal consisting of three concentric rings allowing a supported compass or gyroscope to rotate freely. The most famost remains Cardan shaft with universal joints. It allows the transmission of rotary motion at various angles and is used in vehicles to this day.


How a Gimbal Works
LD ©2008 HowStuffWorks
YAW
AXIS
PITCH
AXIS
ROLL
AXIS
ROTATIONAL MOVEMENT
STATIC POSITION

Leon Foucault Gyroscope

Gyroscope invented by Léon Foucault *in 1852*

A gyroscope is a spinning wheel or disc in which the axis of rotation is free to assume any orientation by itself. L. Foucault first conceived of the gyro as an inertial reference in 1851. In 1890, one other event was to set the stage for the practical application of the gyrocompass; the development of the first electrically driven gyroscope by G.M. Hopkins.


Gyroscope frame
Spin axis
Gimbal
Rotor

Foucault's theory

Every free rotating body, when subjected to some other or new turning force, tends to set its axis of rotation parallel to the new axis of rotation by the shortest path, so that the two rotations take place in the same direction.

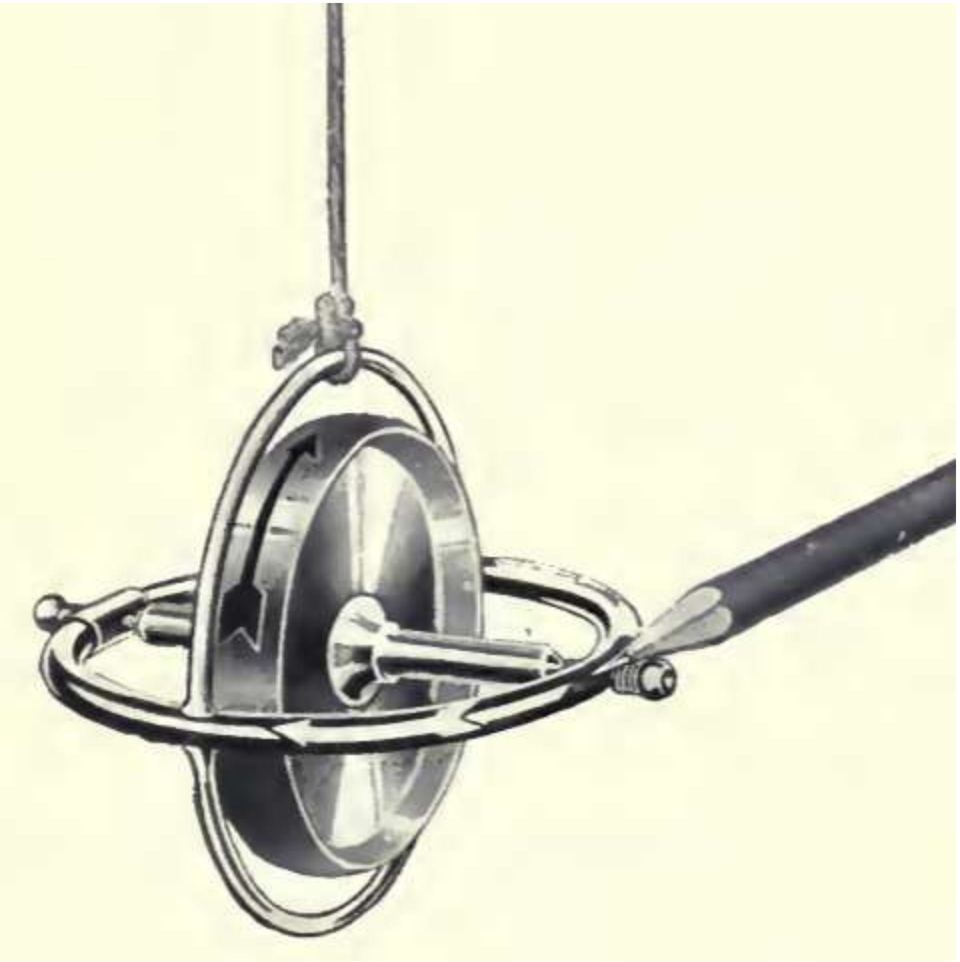
Foucault's theory

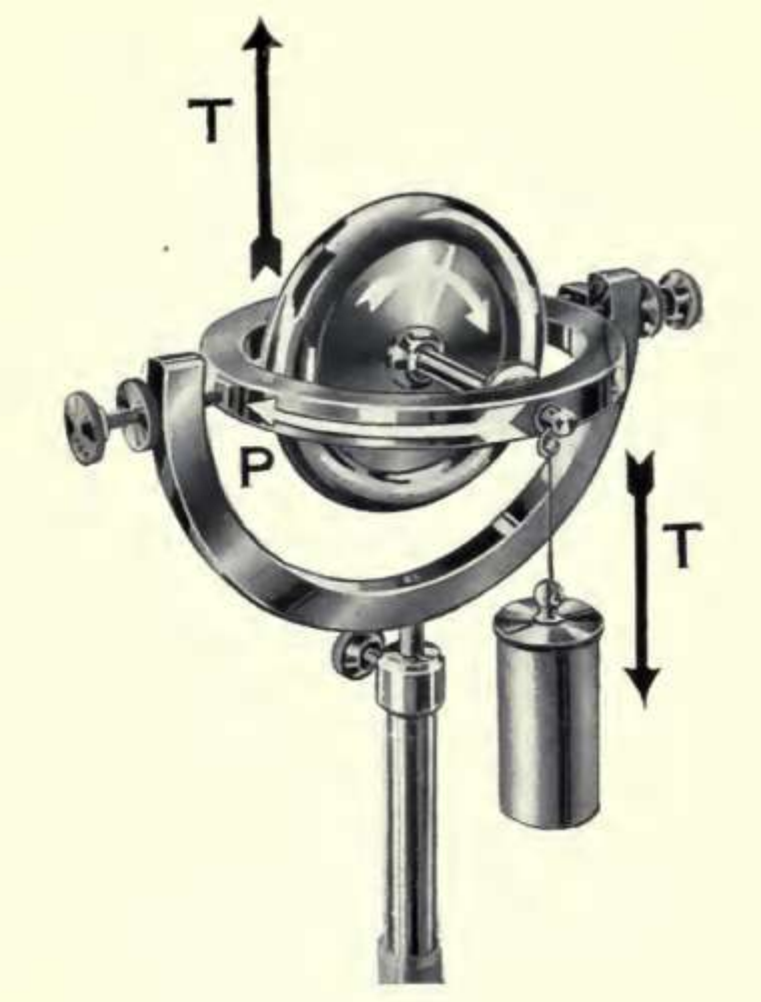
The first low he laid states that any Gyrostat possessing three degree of freedom and unaffected by the force of gravity, must indicate the rotation of the earth in a manner, similar to that demonstrated by the pendulum in his celebrated work. The Gyro would continue with its plane of rotation fixed in space, while the earth turned round under the Gyrostat.

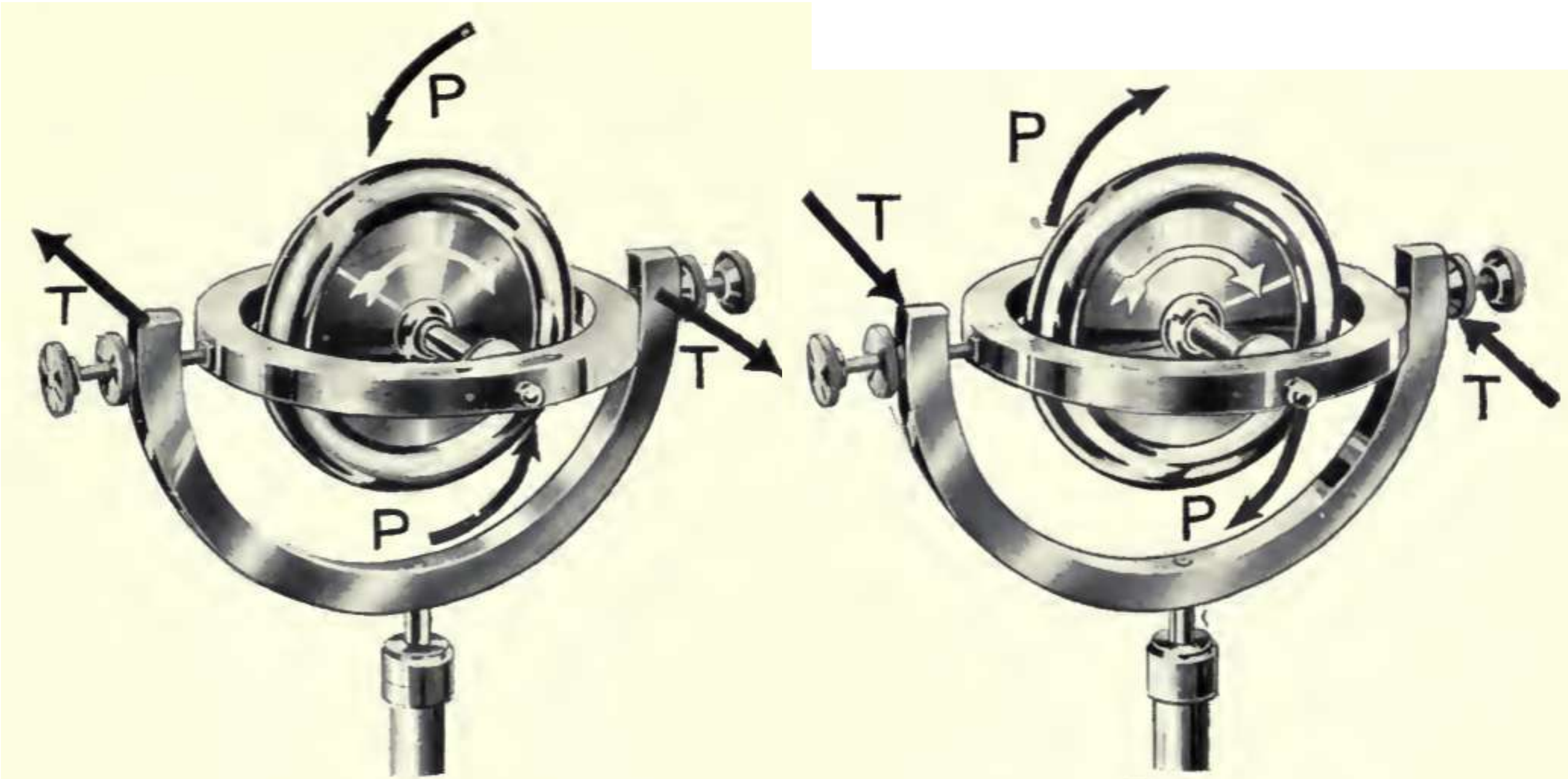
Foucault's theory

He further arrived at the conclusion that any Gyro with only two degree of freedom, free to move in two planes only, will at any place on the earth's surface, other than two poles, tend to set itself with its axis of rotation parallel to the axis of the earth itself, by reason of relative rotations of the two bodies.

Spinning top in a gimbal






P
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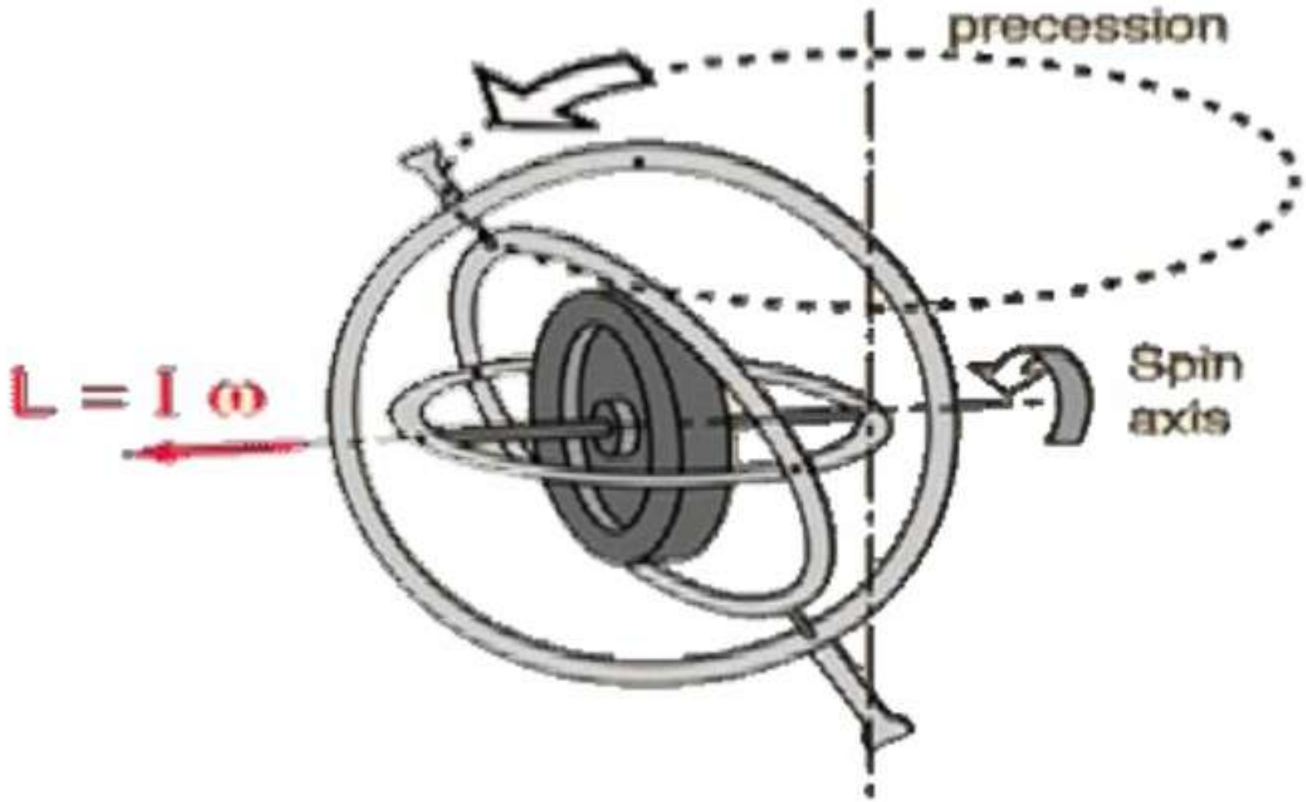
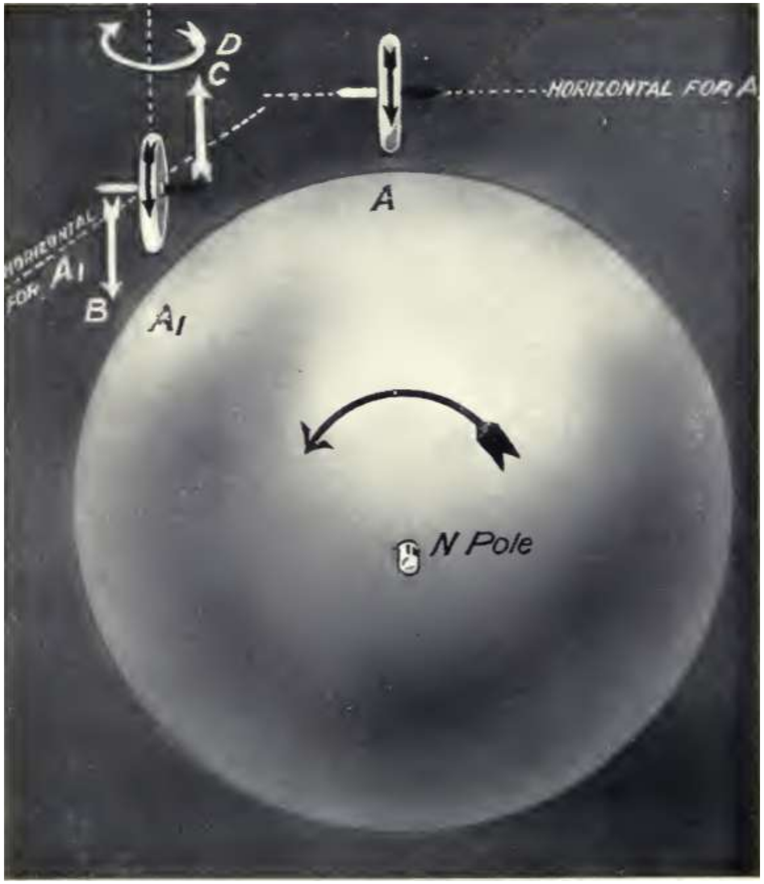
P

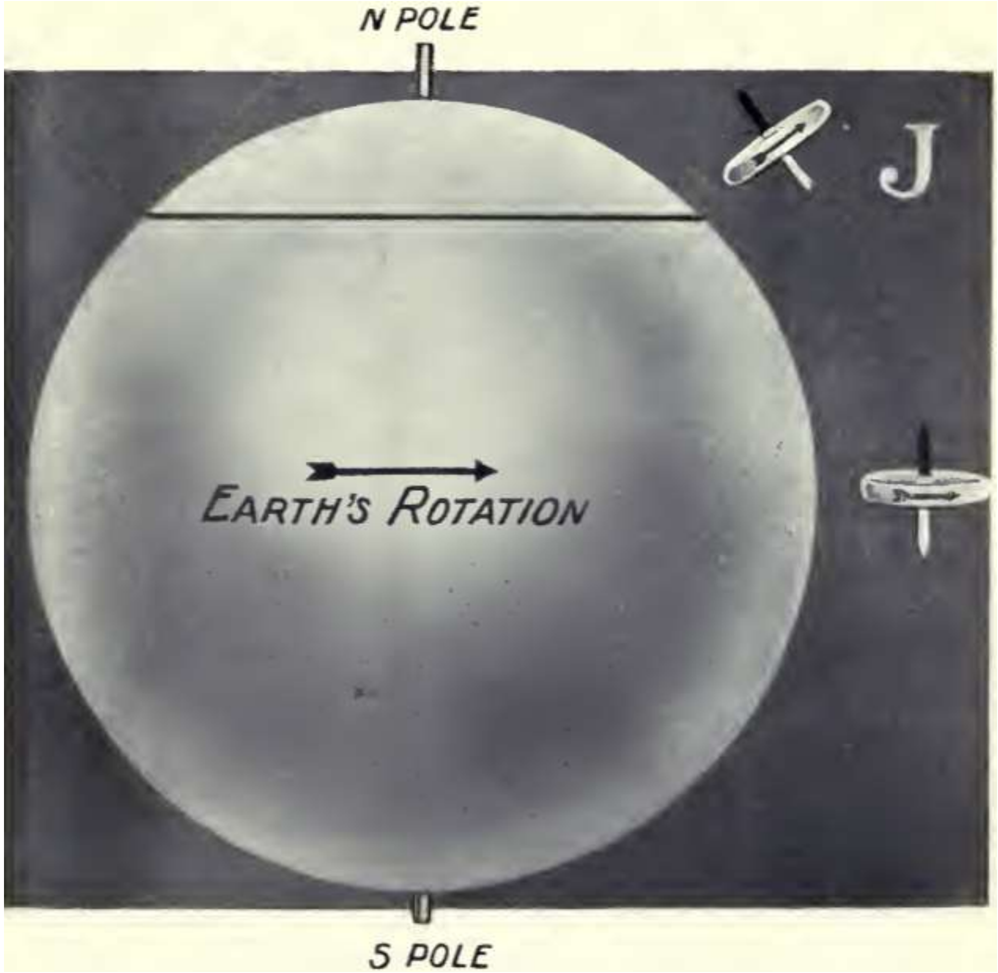
Advantages/disadvantages of Gyrocompass

+	-
Seeks geographic true nort instead of magnetic.	*Loses orientation as Earth rotates unless torque is applied in opposite rotation*
Cheap, self-contained, simple, not easily damage	*Gimbal lock occur when two axis align parallel to each other*
Can be used near the earth's magnetic poles, where magnetic compass is useless	*Require a constant source of electrical power and is sensitive to power fluctuations*
Unaffected by surrounding metals	*Requires periodic maintenance by qualified technicians*
Gyrocompasses need no magnetic corrections	*Excessive weight and space requirement*

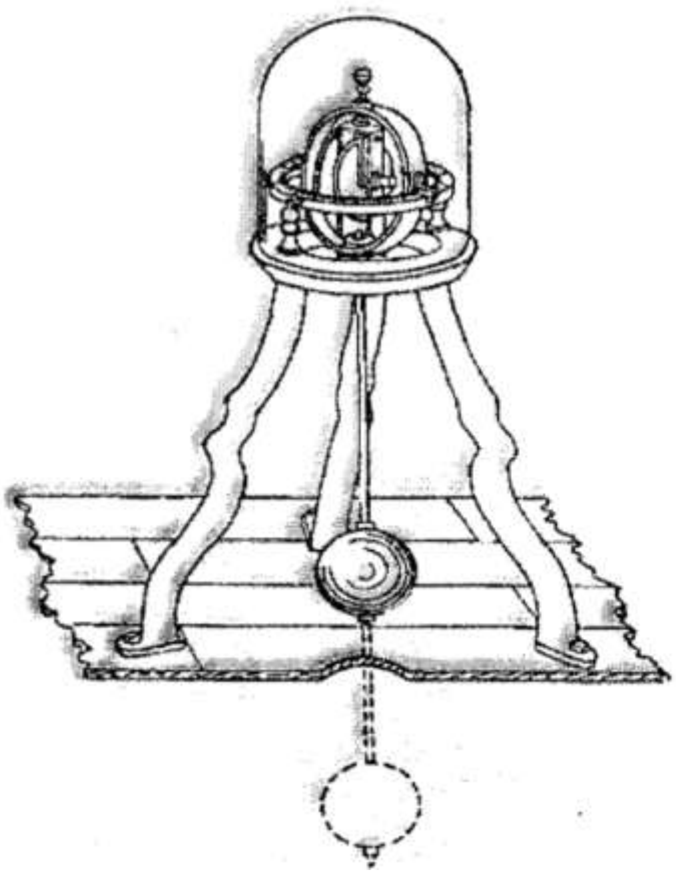
$$\mathbf{L} = \mathbf{r} \times m\mathbf{v}$$



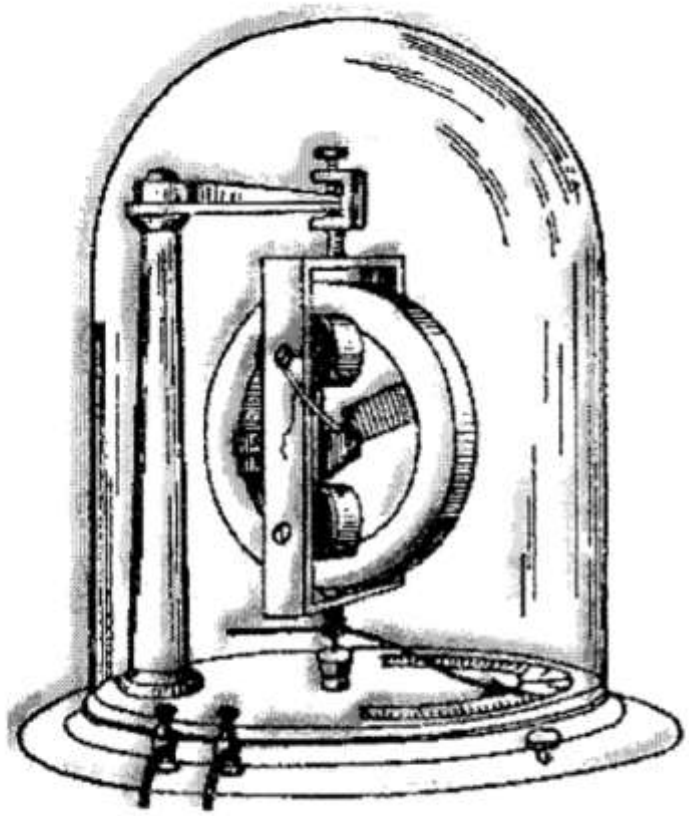

D
C
HORIZONTAL FOR A
A
HORIZONTAL FOR A1
B
A1
N Pole


N POLE
J
EARTH'S ROTATION
S POLE

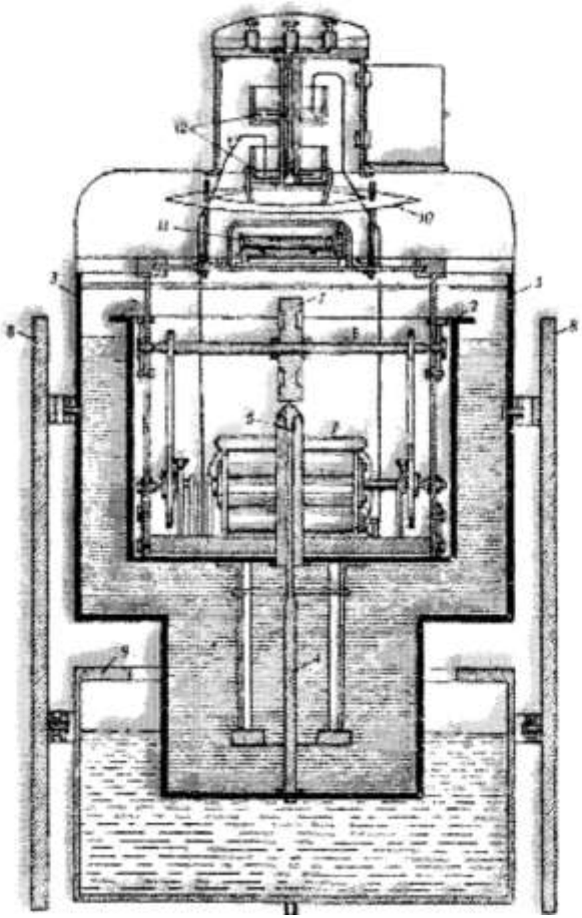
Trouve's gyrocompass 1865



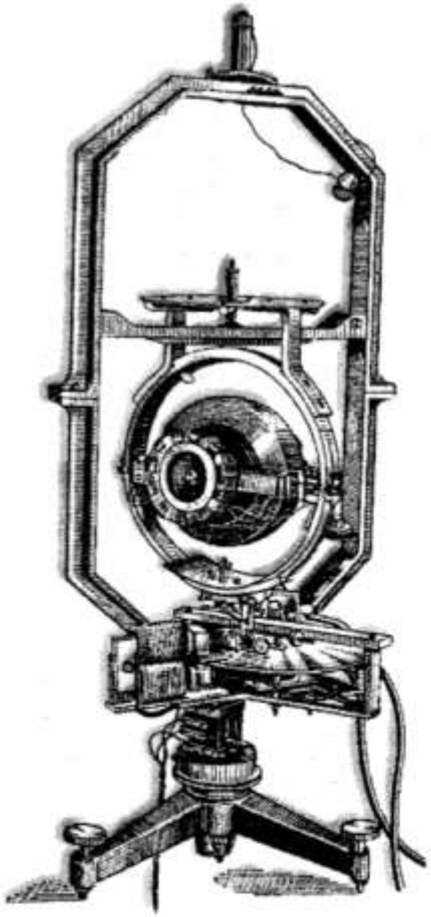
Hopkins Gyro 1878 (electric)



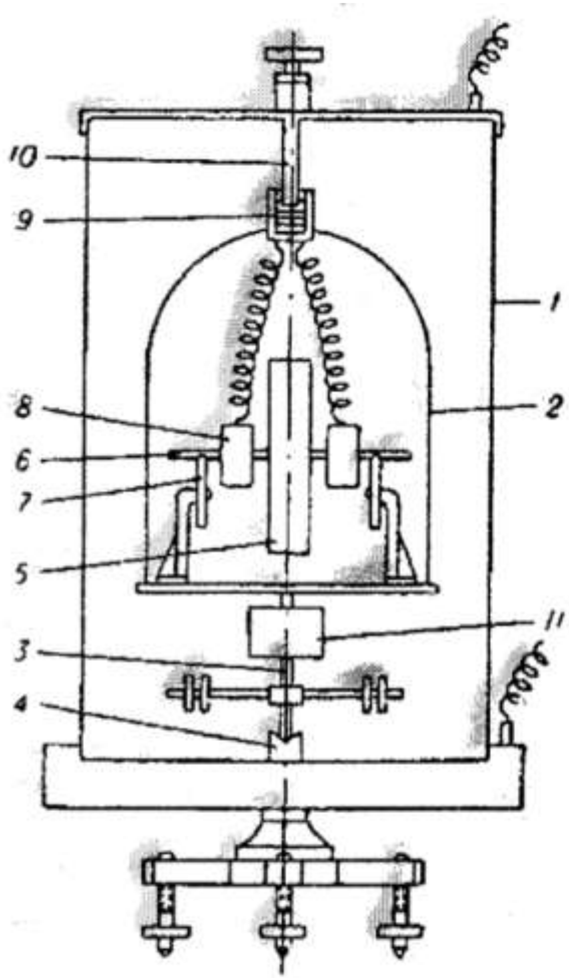
Van De Bos patented gyrocompass - 1888



Bruger gyrocompass - 1912



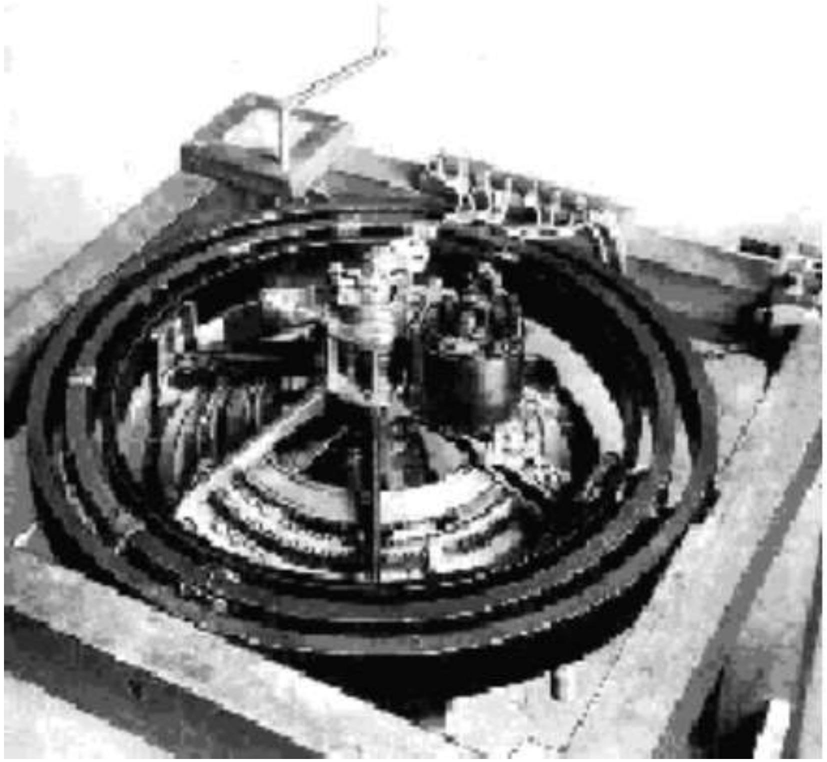
Gyrocompass Martinsen

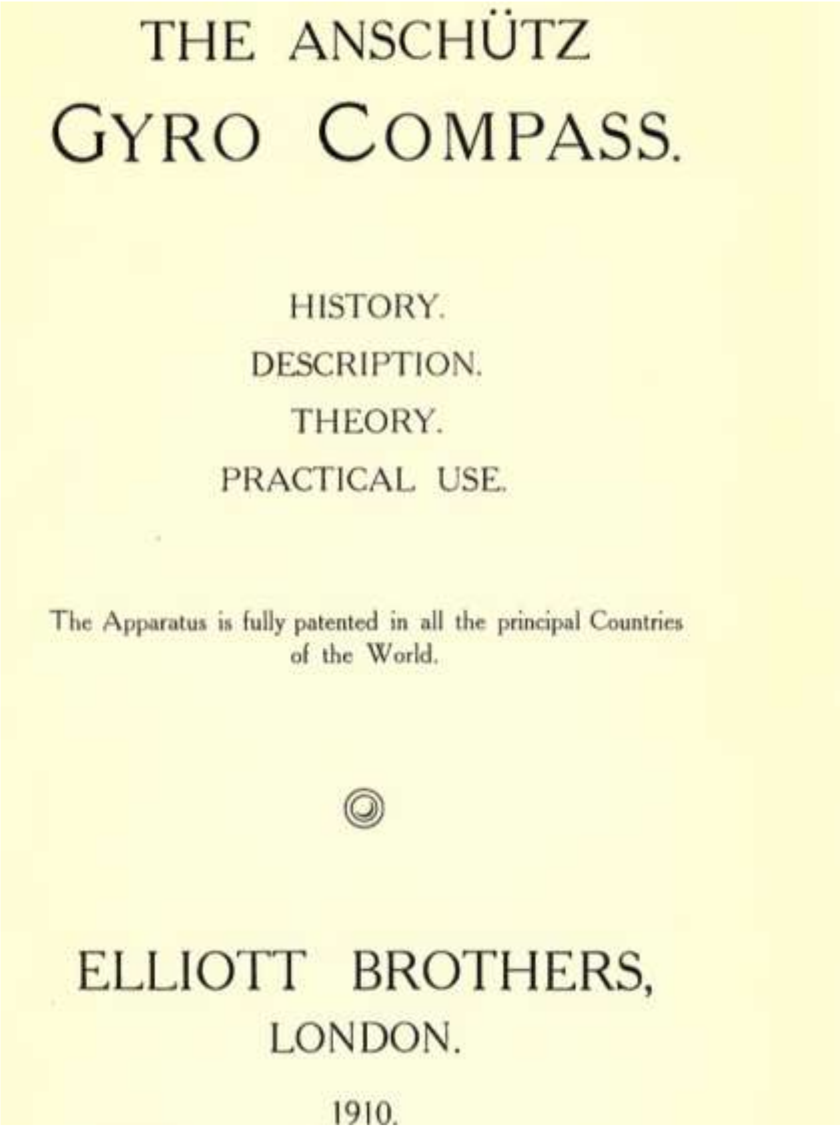


Gyrocompass (first 10-th of XX c.)

Two companies produced gyrocompasses:

Anshutz **Sperry**




THE ANSCHÜTZ
GYRO COMPASS.

HISTORY.
DESCRIPTION.
THEORY.
PRACTICAL USE.

The Apparatus is fully patented in all the principal Countries of the World.

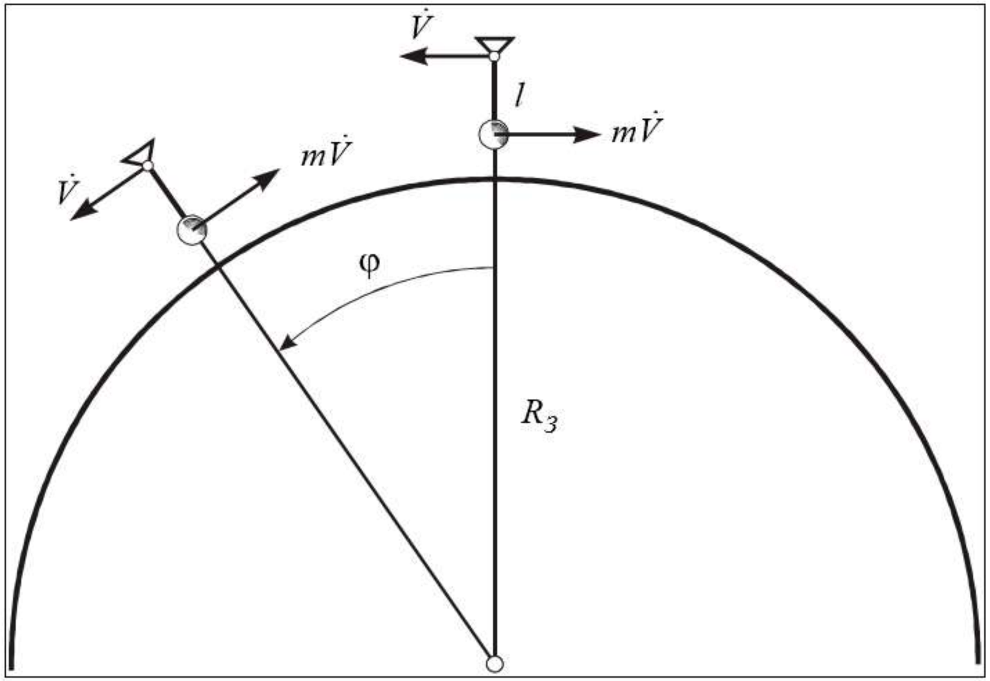
ELLIOTT BROTHERS,
LONDON.
1910.

Sperry gyrocompass was produced in 1914 following in many details Anschutz's patent. A lawsuit was filed in the court agains Sperry. The court apointed as expert Einstein. The company Anschutz received compensation of 300000 DM.

Shuller theorem

Dr. Maximilian Schuler (a German scientist active during the early 1900's time period) reasoned condition when a pendulum would remain vertical under random horizontal acceleration of the suspension point.

Shuller theorem



$$J\ddot{\alpha} = m\dot{V}l\,,$$

$$\ddot{\alpha} = \frac{m\dot{V}l}{J}\,.$$

$$\ddot{\varphi} = \frac{\dot{V}}{R}\,,$$

but $\ddot{\alpha} = \ddot{\varphi}\,.$

then $\frac{ml}{J} = \frac{1}{R}\,.$

$$T = 2\pi\sqrt{\frac{J}{mgl}} = 2\pi\sqrt{\frac{R}{g}} = 2\cdot\pi\cdot\sqrt{\frac{6371\cdot 10^3}{9{,}81}} \approx 5064\text{s}$$

INERTIAL NAVIGATION SYSTEMS

INS are completely self-contained navigation system capable of providing navigation without reference to external information sources.

- The most complex and expensive flightdeck navigation system currently in use.

- Developed for the military – accurate dead-reckoning system, reliable, not susceptible to signal jamming or erroneous signal transmission.

- Extremely simple in concept, extremely complicated in execution.

-Still the navigation system of choice for many operations.

Dead reckoning

Dead reckoning (also ded for deduced reckoning or DR) is the process of calculating one's current position by using a previously determined position, or fix, and advancing that position based upon known or estimated speeds over elapsed time and course. The mathematical term is path integration. The main drawback – accumulation of errors.

INERTIAL NAVIGATION SYSTEMS

- Starts from a known point, estimates next position based on speed, direction and time.
- Uses acceleration and rotation velocity (changes in speed & direction) in place of speed itself.
- Movement is detected by accelerometers mounted on a stable platform (Stabilized gyroscopically, gimbal INS).
-Accelerometers are like pendulums but more sophisticated, using sliding shutters with frictionless bearings. Now MEMS realized accelerometers can detect velocity changes up to 1,000 times greater than g.

INERTIAL NAVIGATION SYSTEMS

- The most critical element is platform stability.

- Gyros are of primary importance.

- Accelerometer technology fairly static; advances now are mostly in gyro technology, especially Ring Laser Gyros.

INERTIAL NAVIGATION SYSTEMS

Inertial navigation systems were originally developed for rockets. American rocketry pioneer Robert Goddard experimented with rudimentary gyroscopic systems. Inertial guidance using gyroscopes saw its first use in a ballistic missile after Germany's defeat in World War I. This method of guidance was referred to as "black box" navigation, as it could operate without any input from its surroundings (such as from radio or the stars). Black box navigation was considered superior over other methods because it was not subject to outside influence. Real implementation of INS realized Wernher von Braun. He designed V2 guidance systems combined two gyroscopes and a lateral accelerometer with a simple analog computer to adjust the azimuth for the rocket in flight.

INERTIAL NAVIGATION SYSTEMS

Analog computer signals were used to drive four graphite rudders in the rocket exhaust for flight control. The GN&C (Guidance, Navigation, and Control) system for V2 provided many innovations as an integrated platform with closed loop guidance. The systems entered more widespread use with the advent of spacecraft, guided missiles, and commercial airliners. Radio guidance was also an option at the time, but it was feared that radio could be jammed.

INERTIAL NAVIGATION SYSTEMS

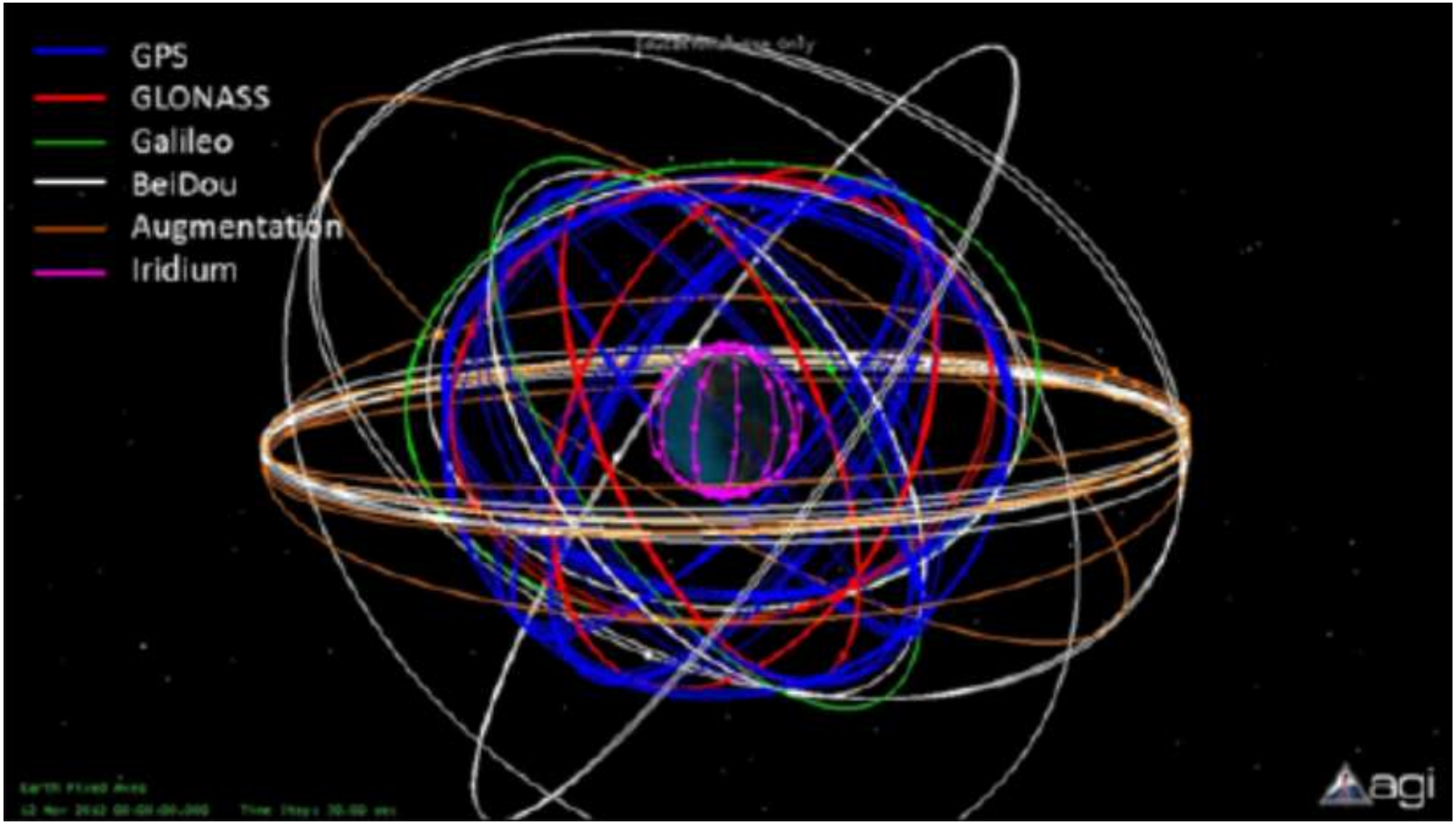
Germany did not pursue the gyroscope by chance. The Treaty of Versailles attempted to limit Germany's ability to rearm itself after World War I. The effect, instead, was to focus Germany's resources into technological innovation in order to compensate for these limitations. Germany, still working within the confines of the treaty, had to develop lightweight and accurate munitions instead of simply manufacturing great quantities. The eventual result was the V-2 rocket. While it was not very accurate, it used gyroscopes for guidance and was effective in its goal: striking anywhere in Greater London.

Simultaneously the development of black box inertial guidance systems was organized in the United States. The most influential individual during this period was Charles Stark Draper from MIT Instrumentation Laboratory. He had just become famous for his work on an extremely successful gyroscopic gun sight used by the Navy. His success made him a strong supporter of black box navigation using his gyroscopes. The possibility of using the gyroscope was met with severe opposition, however, as it seemed like an unrealistic goal. Even Einstein stated that "the effects of linear acceleration inside the box were indistinguishable from the effects of Earth's gravitational field", making black box navigation impossible.

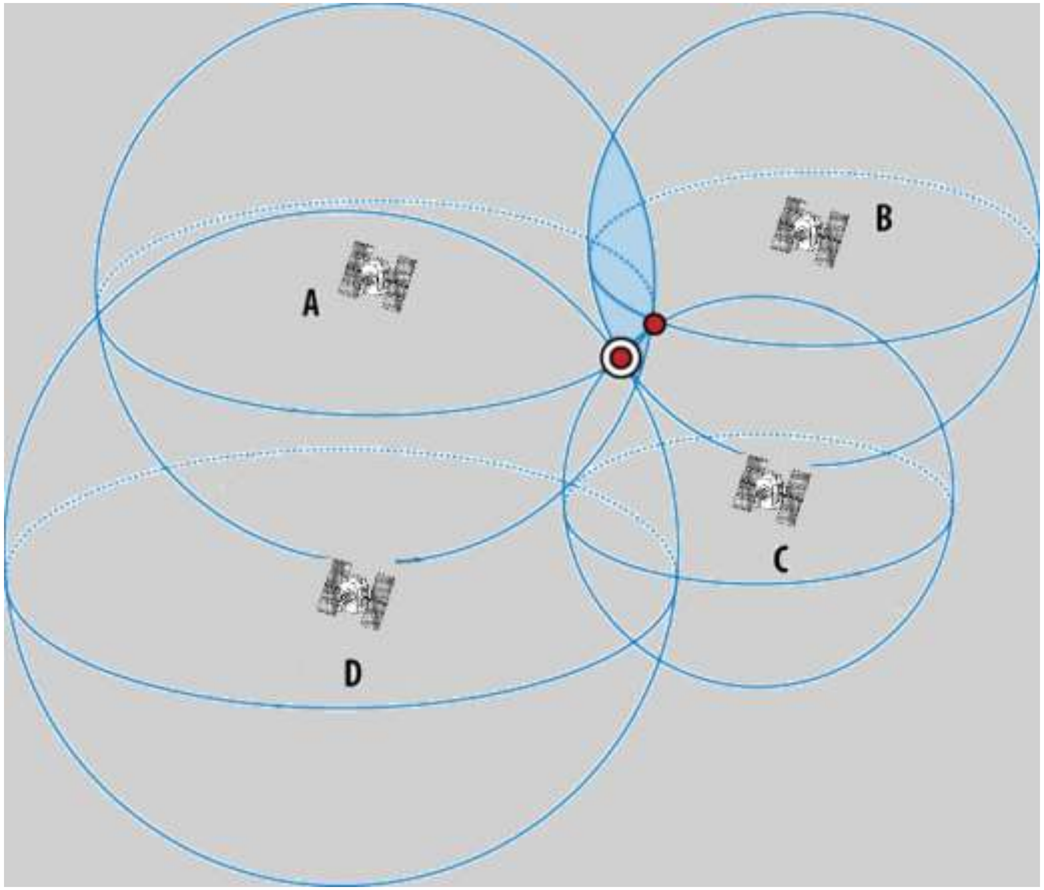
Global Navigation Satellite Systems

GNSS is a technology for outdoor navigation. The most popular example is GPS, which is a constellation of satellites that transmit encoded radio frequency (RF) signals. By means of trilateration, ground receivers can calculate their position using the travel time of the satellites's signals and information about their current location, this being included in the transmitted signal.

The GPS satellite constellation



The concept of position fixing by trilateration



Ariane's aerodynamic fairing is jettisoned and the four Galileo satellites "see" space for the first time.

Summary
General Classification of Positioning Techniques

- **Techniques Using Relative Measurements (Known as dead reckoning - DR);**

- **Techniques Using Absolute Measurements (Known as Reference-based Systems)**

DR Techniques

- **Odometry**

  The odometry data is obtained by using sensors that measure the rotation of the wheel axes and the steer axes (e.g. high resolution encoders).

- **Inertial Navigation**

  Inertial navigation systems employ inertial sensors (gyroscopes and accelerometers) which measure the rotation rates and the specific forces from which acceleration can be obtained. They are autonomous, self-contained; i.e. they don’t need external references.

Reference-based Systems

- Electronic Compasses
- Active Beacons
- Global Navigation Satellite Systems
- Landmark Navigation
- Map-Based Positioning (Or Model Matching)

Electronic Compasses

Compass is a device which provides heading measurements relative to the Earth's magnetic north by observing the direction of the local magnetic field. To convert the compass heading into an actual north heading, the declination angle, which is the angle between geographic and magnetic north, has to be considered. The declination angle is position dependent, so it is necessary to know the position of the compass in order to calculate the heading relative to geographic north.

Active Beacons

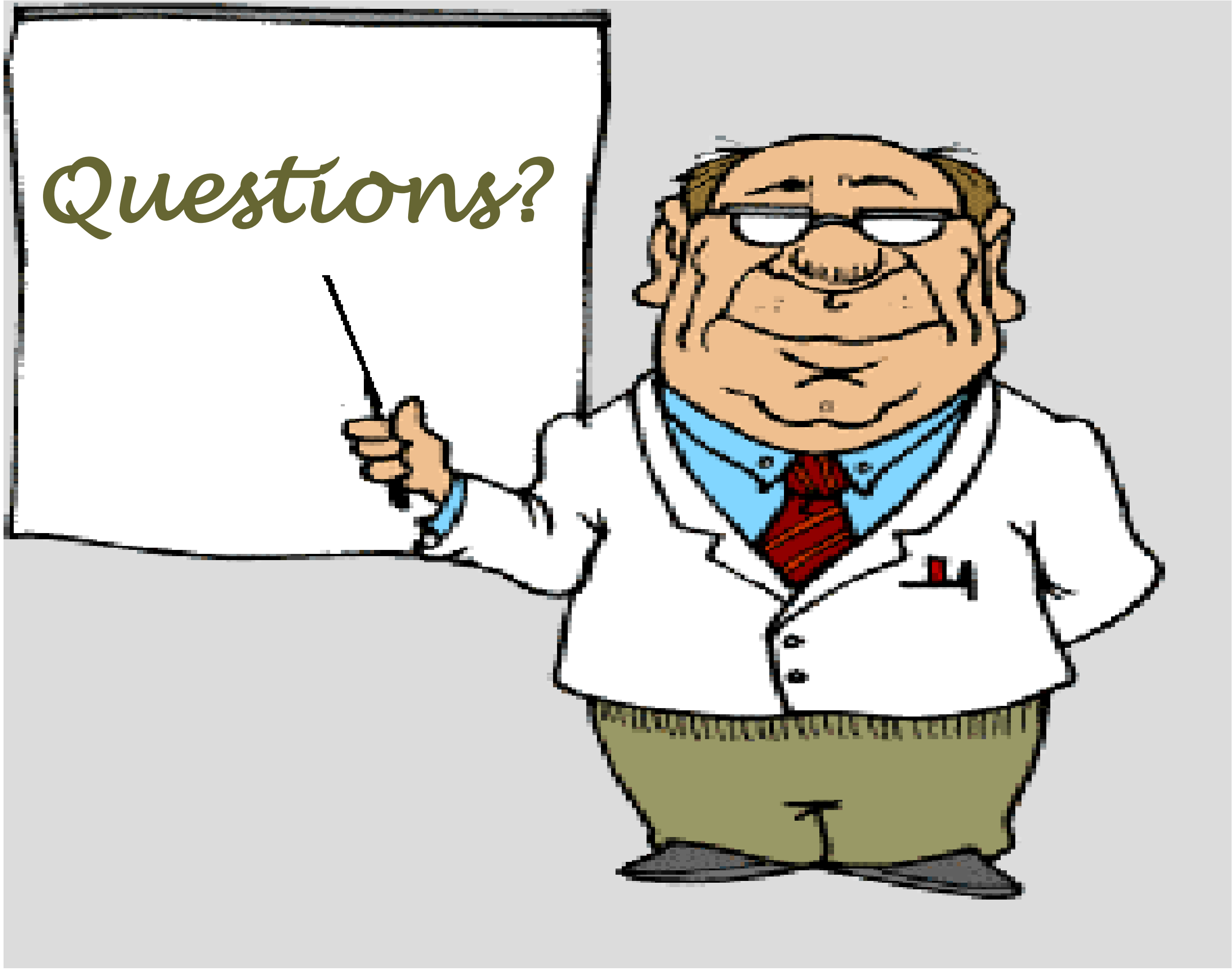
Several positioning algorithms can be used with different active beacon systems, such as the trilateration-based algorithm, the triangulation-based algorithms, and the fingerprinting algorithms. Trilateration is the calculation of a vehicle's position based on distance measurements relative to a known beacon using, for example, time-of-flight information. Triangulation is the calculation of a vehicle's position and possibly its orientation based on the angles at which beacons are seen relative to the moving platform's longitudinal axis. Fingerprinting is template matching technique.

Landmark Navigation

This approach can be used when the moving platform is moving in well known environment. Landmarks are distinct objects or features that can be detected and distinguished by appropriate sensors on a vehicle. They can be either natural or artificial. Artificial landmarks are objects added to the environment specifically for positioning and navigation, whereas natural ones are already present in the environment. Each landmark must have a fixed position. The vehicle preserves a database of landmarks and their locations.

Map-Based Positioning

This approach can be used if the platform is moving in a specific mapped environment. In this approach, the moving platform uses its sensors to perceive its local environment, and this perception is then compared to a map previously stored in its memory. If a match is found, then the vehicle can calculate its position and orientation in this specific environment. Cameras and laser range finders are examples of sensors that can be used with this type of positioning.


Questions?