Chapter III

Astronomy

ASTRONOMY

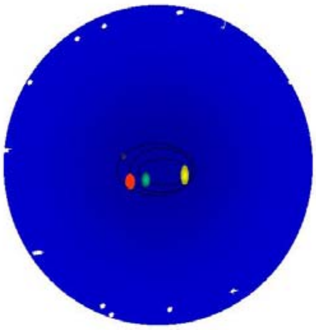
In previous chapters we learned how to perform the nautical computations in an abstract space in which co-ordinates' systems seemed to be arbitrary defined. In this chapter we will examine the surrounding universe in order to understand:

- The properties on which the co-ordinates' systems are defined
- The behaviour of EAP of the celestial bodies
- How to watch the sky
- The data given in the nautical almanac
- Inherent phenomena and properties such as seasons, tropics and the polar circles

In order to have a view on celestial motions we will describe them first in the ***heliocentric universe*** and then we will transpose these motions to the ***geocentric universe*** as we observe these bodies from earth.

THE HELIOCENTRIC UNIVERSE

Simplified description of the sky



For our needs it is sufficient to represent the sky as a hollow sphere which has the sun in its centre and an infinite radius. That is the heliocentric universe.

The stars are all situated on the inner surface of the sphere and are fixed in their position, hence the pattern formed by the stars remains identical at any moment. As the pattern is constant we are able to group the stars in constellations. The celestial sphere is also totally immobile in particular there is no spinning around the sun.

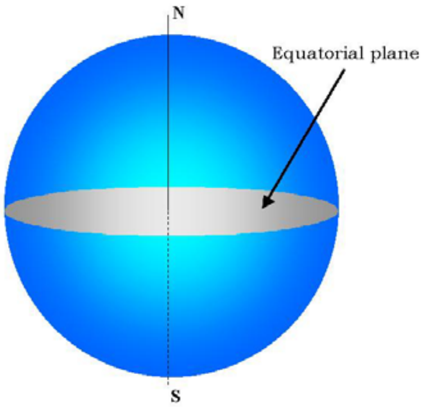
On a finite distance of the sun we have the planets turning around the sun in their respective orbits. The motion of a planet around the sun is called the ***revolution*** of the planet. ***The Laws of Kepler*** (1) govern this motion.

In addition to the revolution each planet executes a spinning motion about its own axis which is called the ***rotation*** of the planet. It is the terrestrial revolution that causes the apparent movement of the sun and the stars in our sky.

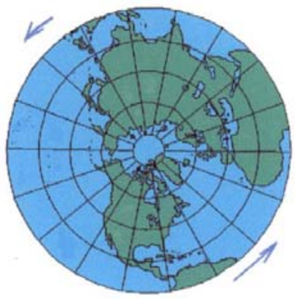
(1) In the appendix the Laws of Kepler are given

THE MOTIONS OF THE EARTH

The rotation of the Earth

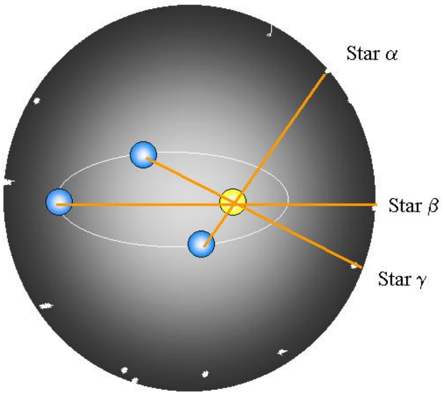


The axis of rotation intersects the earth's surface in the North and South Poles. The plane through the centre of the earth and perpendicular to the axis is the ***Equatorial plane***. The axis of rotation is the unique physical element we need to construct the terrestrial co-ordinates' system. The direction of rotation is identical to the one of revolution. This direction is anti-clockwise when the earth is seen from above the North Pole.



Because of this the sun and stars rise in the east and set in the west whatever the location on earth. The moment of the day when the sun culminates, i.e. reaches its highest point in the sky is the real noon, this moment depends of our location on earth. The elapsed time between two successive culminations of the sun is a ***Solar day***. The elapsed time between two successive culminations of a particular star is a ***Sidereal day***.

Revolution of the Earth around the Sun



From the laws of Kepler we know that the orbit of the earth is an ellipse with the sun in one of its focuses. This ellipse lies in a plane called the ***ecliptic***. The figure above represents the cross-section of the celestial sphere with the ecliptic.

Each position of the earth on the ellipse corresponds to a particular moment of the year. We immediately see that each position on the ellipse corresponds to a unique alignment of the sun and earth with a particular constellation situated in the ecliptic. These constellations are known as the signs of the Zodiac in astrology. The revolution is complete when we see the same alignment again. The time this takes is called a ***sidereal year***. In practice ***the point Aries*** is taken as a reference, about we will say more in the next paragraph.

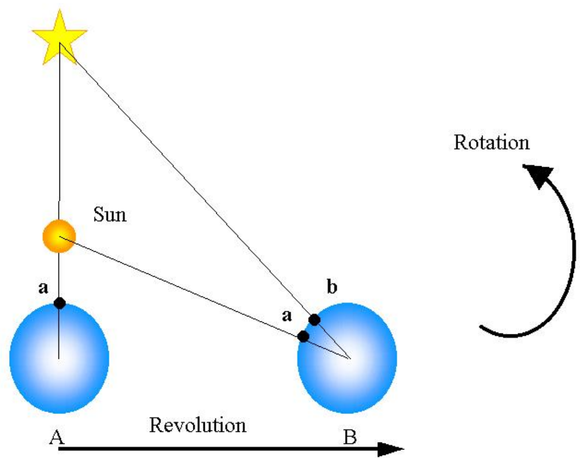
We will never observe directly these alignments because the sun blinds us, because of this the constellations in and near the ecliptic are only visible at some particular periods of the year.

We remark also that the distance between the earth and the sun is not constant, because of this the diameter of the sun seams smaller in July than in January.

Difference between Solar and Sidereal time

All planets whose sense of rotation is identical to the sense of revolution have a Sidereal day which is shorter than their Solar day. If rotation and revolution are opposite to each other then the solar day is shorter than the sidereal day. In both cases the Sidereal day corresponds more accurately than the Solar day to a rotation of 360° of the planet.

Illustration



On the picture above a fraction of the earth's orbit is represented. In position **A** the sun and a particular star are culminating in point **a**. After a Solar day the Sun will culminate again in point **a** while the Earth will have moved to point **B** on the orbit. We see that this takes a rotation of more than 360°. The star however has already culminated in point **b**.

This shows that a Sidereal day is shorter than a Solar day and approximately corresponds to a rotation of 360° because the star is much farther from earth than the sun.

Mean Solar Time

According to Kepler laws the speed of revolution is not constant. An effect of this is that Solar days are not constant. Therefore ***Mean Solar Time*** was introduced. This corresponds to a fictive sun. Our watches are referenced to it. The difference between them is the equation of time ε.

The geometry of the terrestrial Orbit

In order to construct the Equatorial co-ordinates system, which we use to describe the EAP we need to know some geometrical properties of the terrestrial orbit. In parallel we will see some consequences of these properties such as the seasons.

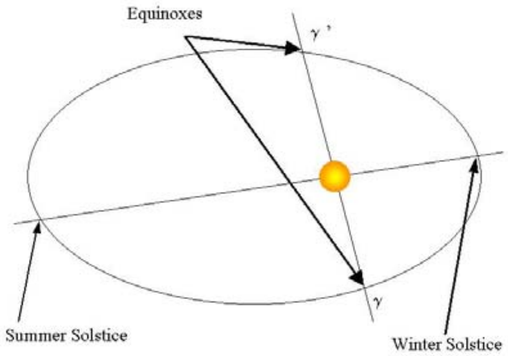


fig.1

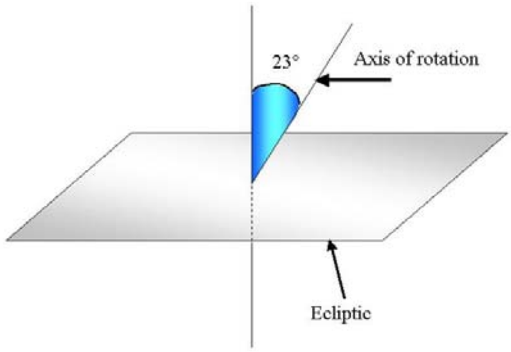
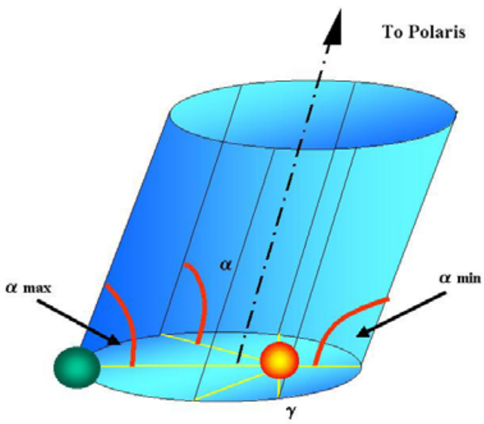


fig.2

As said previously the shape of the orbit is an ellipse lying in the ecliptic with the Sun in of one of its focuses as shown on fig.1. On fig.2 we represent the angle which the axis of rotation makes with the perpendicular on the ecliptic, this angle is invariable in every direction of space. On fig. 3. we have drawn the yearly movement of the axis along its elliptic path. We see that the axis describes an oblique cylinder in space with an elliptical cross-section. These parallel lines intersect at infinity at their northern part at the Polar star. That is why the EAP of Polaris coincides constantly with the North Pole.



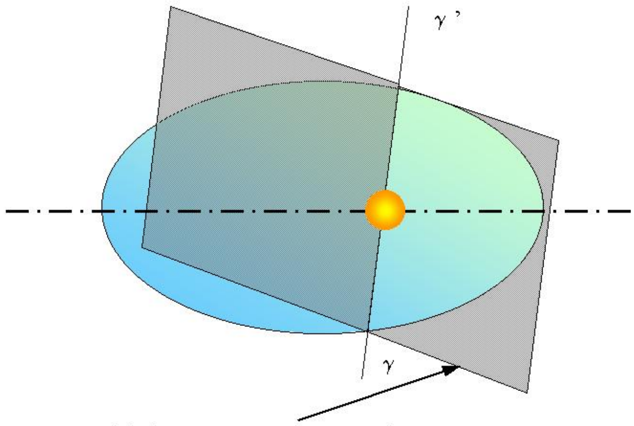
In addition we connect the points of the orbit with the sun. These connection lines define the EAP of the sun. We see that the angle α between the respective connection line and the axis is <u>not</u> constant through the year and varies between 90°-23° and 90°+23°. The points where this occurs are respectively the summer and winter solstices. The points where α is 90° are the equinoxes.

The declination of the Sun

The declination of the Sun, δ, is the angle that the connection line between the Earth and the Sun makes with the Equatorial plane. This angle is complementary to α as the Equatorial plane is perpendicular on the axis of rotation by definition. As α varies between 90°-23° and 90°+ 23° then δ will vary between 23°N and 23°S. The declination of the sun is tabulated in the Nautical Almanac for every hour.

The Equinoxes and the solstices

The Equinoxes are the points on the orbit where the declination of the Sun is 0°. The Spring and Autumn equinoxes are respectively reached at the 21 of march and the 22 of September. The spring equinox is always designed as ***Point Aries*** *γ*. The winter and summer solstices are the points where the declination is maximum respectively 23 ° S and 23° N at the 21 of December and the 21 of June.



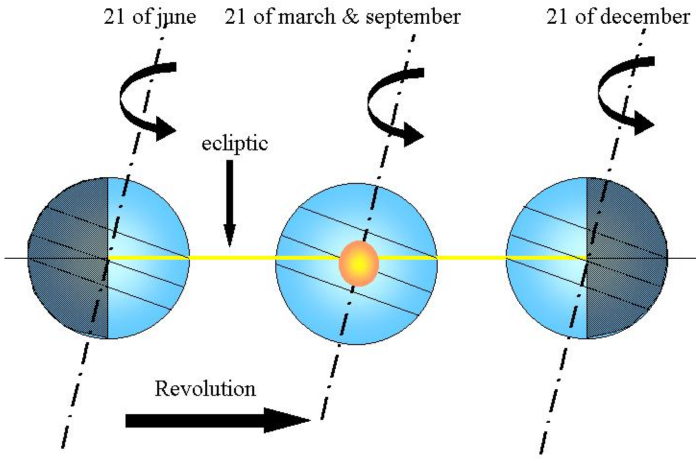
Equatorial plane at 21 march & sptember

Geometrical place of γγ '

At the equinoxes d is equal to 0° hence the connection line must lie at the same time in the ecliptic and the equatorial plane. The particular connection line is the intersection between the ecliptic and the plane through the Sun which is parallel to the direction of the equatorial plane. This connection line intersects the orbit in γ and γ' and is called the line of the equinoxes. The line which is perpendicular on the line of the equinoxes intersects the orbit in the solstices.

CONSEQUENCES OF THE ORBITS GEOMETRY

The tropics and the seasons



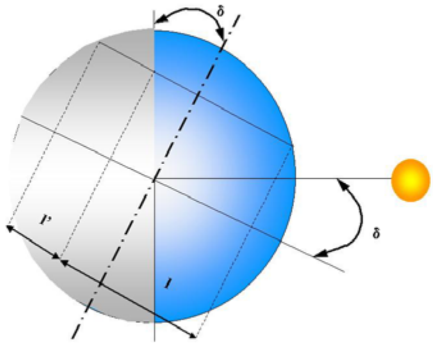
On the picture we represented a perpendicular cross-section of the ecliptic. We see that on June 21and December 21 the EAP of the sun reaches respectively its most northern (23° N) and most southern (23° S) position.

The parallel circles on which these maximums occur are respectively the ***tropic of Cancer*** and the ***tropic of Capricorn***. The area between these parallels is the tropical zone of earth. In this area the sun crosses each parallel twice a year, when this occurs there is no shadow at noon, i.e. the sun culminates at 90° above the horizon. On its limits i.e., the tropic of Cancer and Capricorn this occurs once a year. On the equator this occurs on the 21 of march and September. In non tropical zones this never occurs.

The periods when the declination of the Sun is North are the northern spring and summer, when the declination is south are the northern autumn and winter. As the EAP is always situated in the tropical zone we will always see the sun at noon in the south from the non-tropical zones of the northern hemisphere and north from non tropical zones of the southern hemisphere.

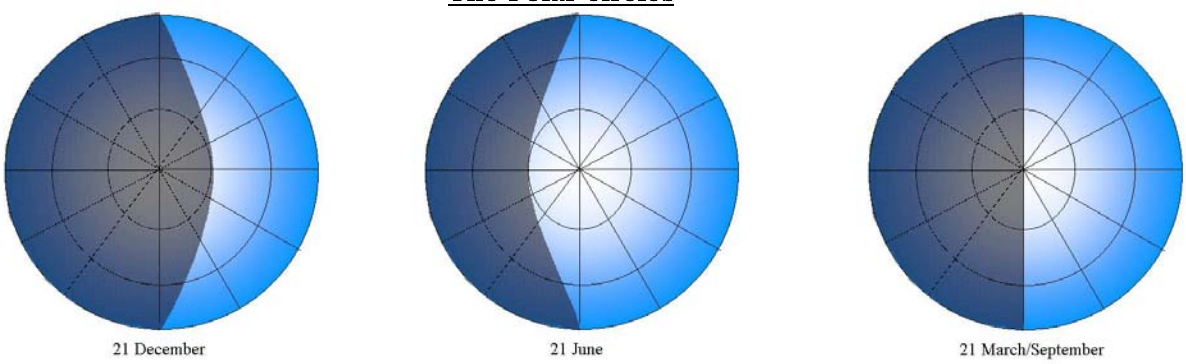
In both hemispheres the sun will rise in the east and set in the west but when we are looking facing the sun in the northern hemisphere the sun will turn clockwise and in the southern hemisphere anti-clockwise in non-tropical zones. In the tropical zone this varies with the time of the year.

The length of the days



On the figure the shade side represents the earth's side where it is night. As the earth rotates we will have alternatively day & night on each longitude of each parallel. The border line between daylight and night is a variable plane which goes through the centre of the earth. This plane makes an angle equal to δ with the axis of rotation as the respective legs of the angles are perpendicular to each other. The length of the day & night on a particular latitude is proportional to the respective arc lengths l and l', as δ varies throughout the year so will l/l' and hence will daylight/night do. On the equator however the proportion l/l' remains always equal to one, so we always have days and night of 12 hours.

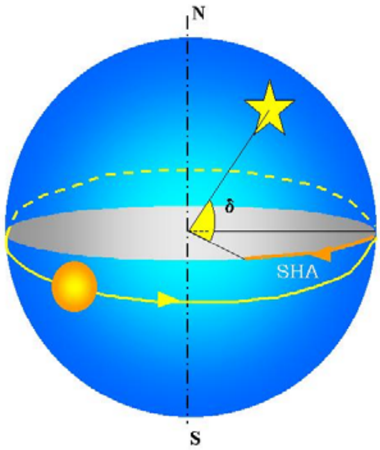
The Polar circles



On the picture we have a view from the Earth from above the North Pole. On the 21 of June the shade angle will be 23°, which corresponds to a latitude of 90°-23°=67° hence they are complementary to the latitude of the tropics. The latitude at 67°N and 67°S are respectively the ***Northern and Southern Polar circles***. Areas enclosed between the Pole and polar circle will not cross the daylight side for at least one day per year. On the poles themselves day and night last 6 months

THE GEOCENTRIC UNIVERSE

In the geocentric universe we observe from the centre of the earth standing on the equatorial plane. We project the celestial bodies on a sphere with infinite radius in order to obtain a view of the universe. The centre of the sphere is the centre of the earth. The equatorial co-ordinates system we saw previously uses the **GHA** and δ as co-ordinates **GHA** is actually a derived value of **SHA** so the basic co-ordinates for the equatorial co-ordinates system are in fact δ and **SHA**. It is obvious that the values of **SHA**, **GHA** and δ are independent of the chosen radius.



Relation between SHA and GHA

The **SHA** as the **GHA** is measured clockwise by the observer but starting from point Aries (γ) instead of the Greenwich Meridian. As both are clockwise we find the **GHA** of the celestial body by adding its **SHA** to the **GHA** γ.

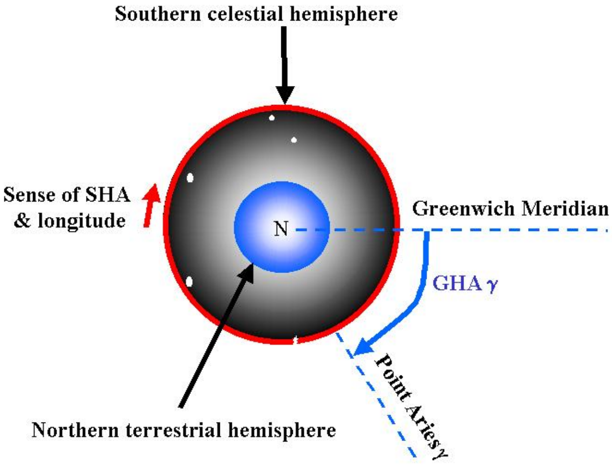
Apparent celestial motions

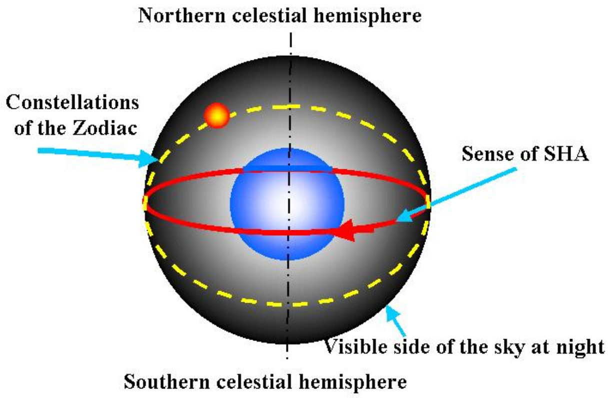
The movement of the earth in space causes the apparent movement of the sun and stars when we are watching space from earth.

As the distance between the earth and the stars is much greater than the mean radius of the terrestrial orbit we can consider that the displacement due to the revolution of the earth relatively to the stars is nearly zero! That means that δ and SHA of a star will nearly be constant during the year. Their **GHA** however will constantly vary due to earth rotation. Another consequence is that a star chart using **SHA** is valued the whole year. The much nearer sun however will have a yearly motion to the left as we are overtaking the sun by the right as the revolution is anti-clockwise. The planets will seem to roam between the stars of the ecliptic, as their orbits are near to the ecliptic.

Watching the sky in function of the season

As the sky depends on the hour of the night we must turn the celestial sphere over an angle **SHA** γ about the earth's axis while the earth remains immobile. This is shown on Fig 1. We omitted the Northern Celestial Hemisphere in order to show the relation between The **SHA** and the longitude scale on the Star charts, as these charts work with inner views.





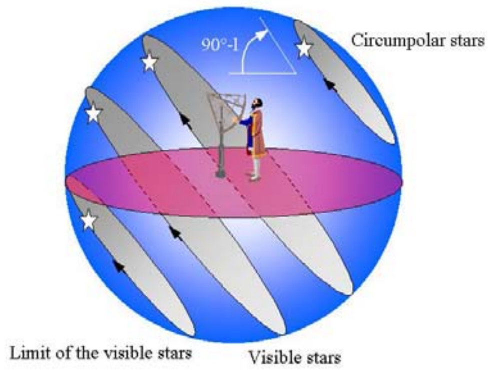
We determine the visible part of the sky at night by putting the sun in the sign of the Zodiac of the month, for example in may we put in on Taurus. Only the stars on the side of the sphere opposite to the sun are visible at night. This is shown on fig.2

In fact we imagine that the celestial sphere makes a turn of 360° about the earth's axis. This representation enables us to know which area of the sky is above which area of the earth in function of time (**SHA**) and season (the place of the sun in the Zodiac). Be aware however that in this view we observe the sky from the centre of the earth.

About ancient navigation

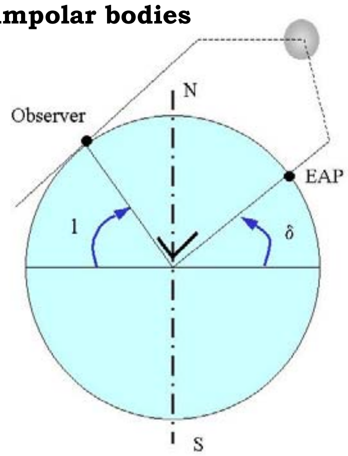
As the declination of the stars remains quite steady during the year, so elementary tables were sufficient. Each increase or decrease in height at the meridional passage of a star is equal to the change in latitude at any time of the year. The change in longitude on the contrary had to be estimated by the covered distance in western or eastern direction.

Watching the sky from the Earth's surface

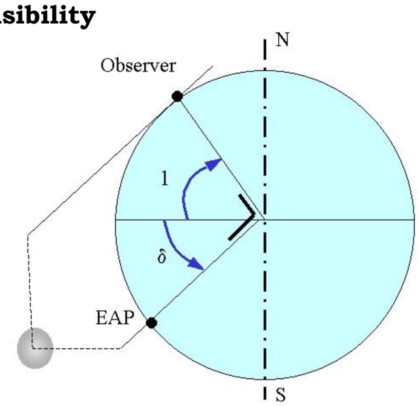


All the celestial bodies seen from the earth's surface execute parallel circular trajectories above our heads. Each trajectory intersects the surface with an angle equal to the co-latitude of the place of observation. The position of each intersection line depends on the declination of the celestial body. The figure above tells us also that some stars never disappear under the horizon and that some cross the horizon and some always remain under the horizon, i.e. the circumpolar, the visible non-circumpolar and invisible stars. For example we cannot see Polaris from the South Pole. The following demonstrations are based on the properties of connection lines.

Limit of circumpolar bodies



Limit of visibility



The stars at the limit of circumpolarity touch the horizon at the lowest part of their trajectory in the sky. The stars at the limit of circumpolarity satisfy the condition:

δ=90-l, where δ and l belong to the same hemisphere

The stars at the limit of visibility just touch the horizon at their meridional passage. The stars at the limit of visibility satisfy the condition:

δ=90-l, where δ and l belong to opposite hemispheres

The Star Charts

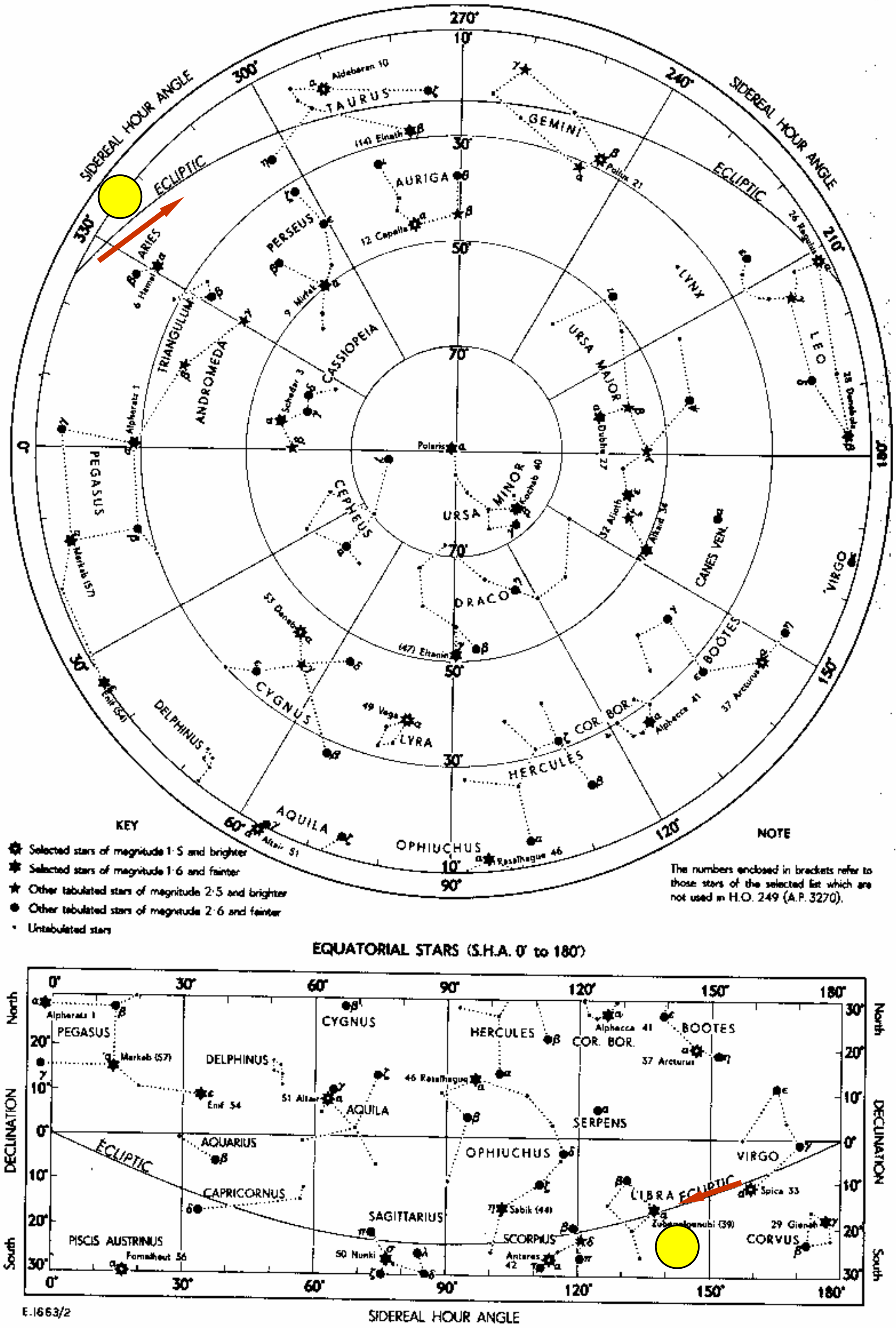
On the next pages we have star charts which are a plane representation of the inner side of the celestial sphere. The equatorial sectors are lost by the projection so they have been developed as rectangles under their respective hemispheres. The ecliptic becomes a great circle of the celestial sphere; this circle intersects the equatorial plane at the points where SHA is 0° and 180°. We also see the maximum declinations at 23°N and 23°S. In addition the direction of the yearly movement of the sun is drawn on it. The opposite orientation of SHA and the movement of the sun in both views is due to the fact that we are looking under the inner northern hemisphere and above the inner southern hemisphere.

General remark:

Do not confuse the constellation of Aries with Point Aries.

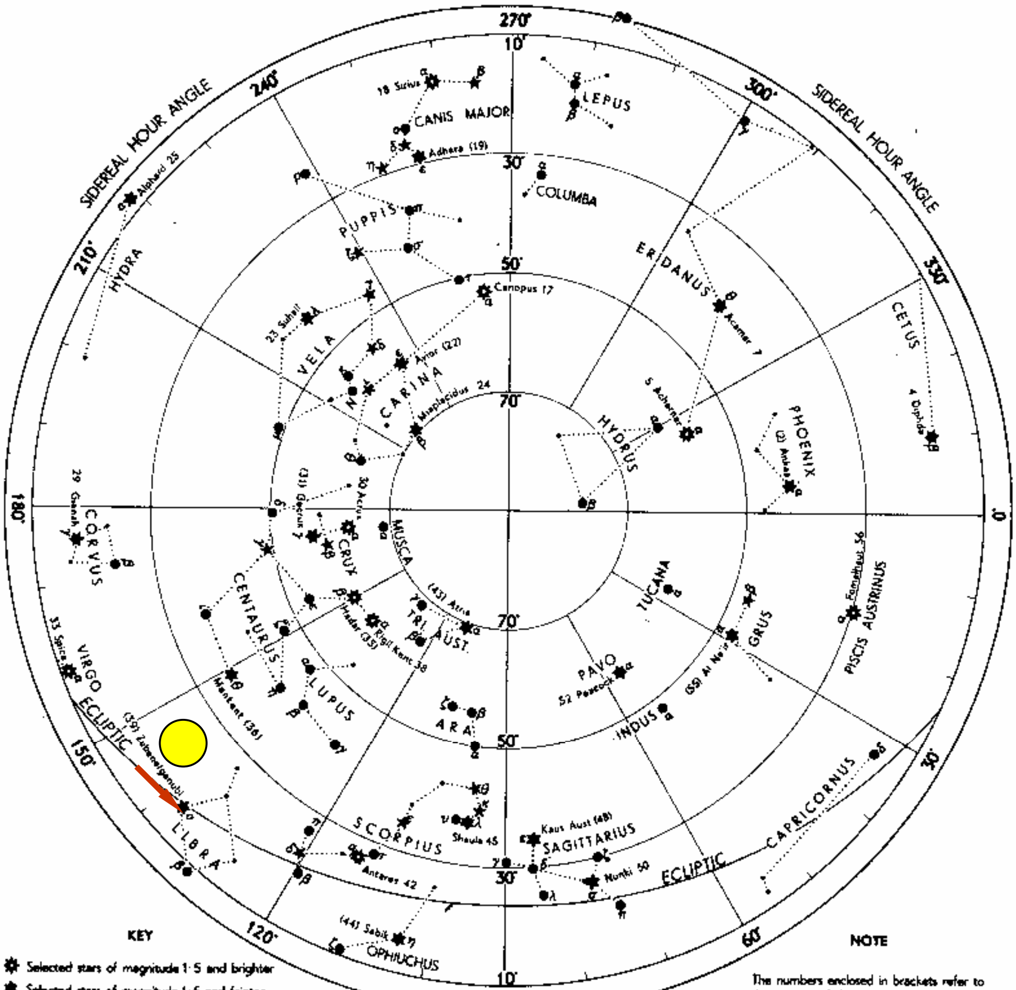
STAR CHARTS

NORTHERN STARS



STAR CHARTS

SOUTHERN STARS



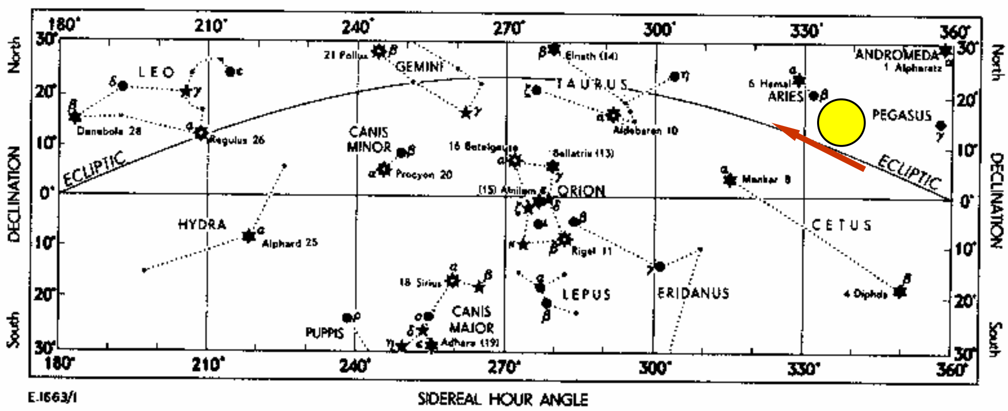
KEY

- Selected stars of magnitude 1·5 and brighter
- Selected stars of magnitude 1·6 and fainter
- Other tabulated stars of magnitude 2·5 and brighter
- Other tabulated stars of magnitude 2·6 and fainter
- Untabulated stars

NOTE

The numbers enclosed in brackets refer to those stars of the selected list which are not used in H.O. 249 (A.P. 3270).

EQUATORIAL STARS (S.H.A. 180° to 360°)



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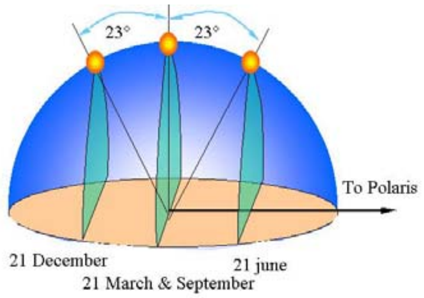
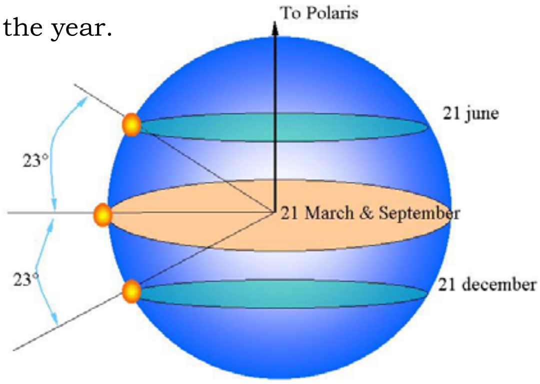
The apparent motion of the Sun
As Seen from the earth's surface

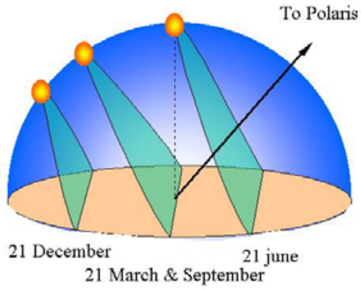
The pictures are valid for any celestial body in the sky. On the pictures below the sun is shown as its declination varies considerably during the year.



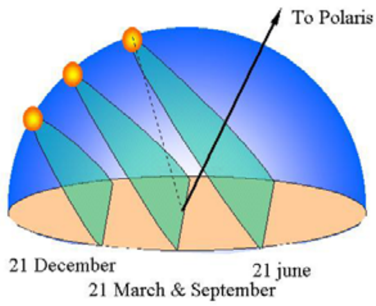
At the equator



At the North Pole



At 53° north



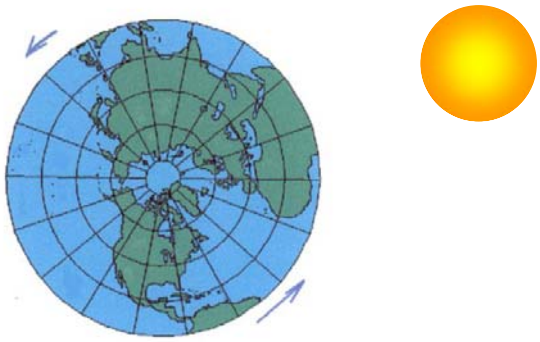
At the tropic of Cancer

On each picture the plane of the daily sun's motion is drawn, the angle this plane makes with the earth's surface is equal to the co-latitude. The location of the line of intersection however depends on the value δ at that moment of the year. This is also the case for any celestial body.

We remark that the height of the sun at noon is equal to the co-latitude minus the declination ($h=90-l-\delta$), hence at noon on the equinoxes this is exactly equal to the co-latitude from which we can immediately compute the latitude.

A trip around the world

If we travel around the world we respectively loose or win a day when we perform this trip in western or in eastern direction. The crew of Fernão de Magalhães experienced this, on their return from their trip of two years around the world in western direction in 1522. According to their carefully kept logbook they arrived on the 24 of august at the Cabo Verde islands but for the inhabitants of the islands it was already the 25 of august 1522. What did happen?

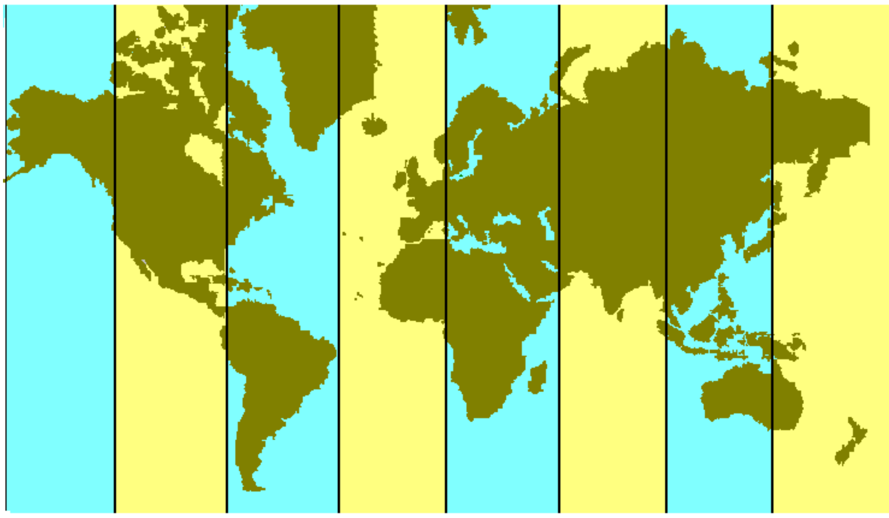


The earth is nothing else then a device spinning about its own axis at a constant number of turns. The beginning and ending of a turn are marked by a sunrise.

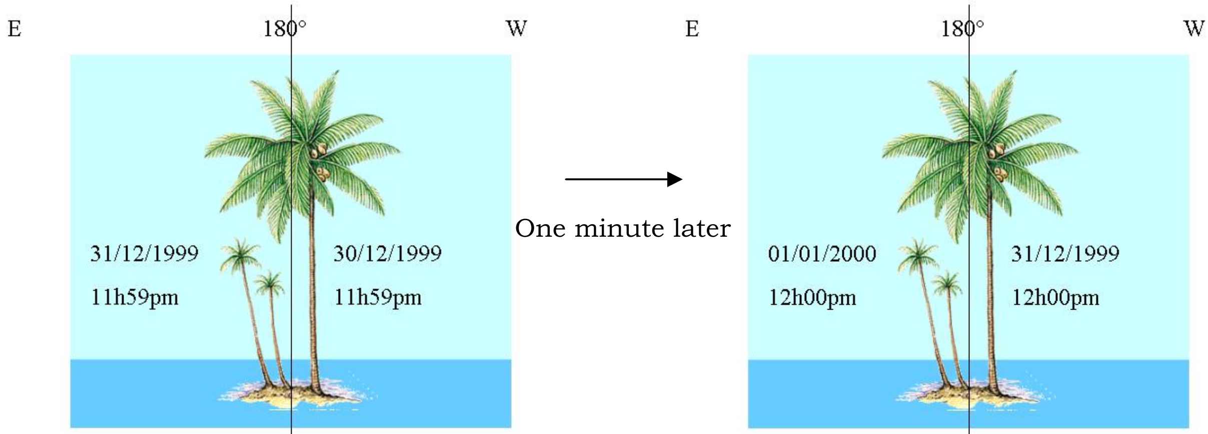
If we remain at the same place our number of turns in space is equal to that of the earth. Once we start turning around the earth's axis we respectively increase or decrease our number of turns in space by moving in the same sense or opposite sense.

So by one trip around the world we increase or decrease our number of turns by one unit. As a turn is equal to one day we missed or won a day by missing or winning a sunrise.

[The time zones and the date change line]



Due to the terrestrial rotation of 360° in 24 hours the earth is divided in 24 time zones of 360°/24=15° width in longitude. The time zones are referenced relatively to Greenwich. The time at Greenwich is known as the Greenwich Mean Time or GMT. The time zones vary from GMT+0 to GMT+12 and GMT-0 to GMT-12 for respectively East and West of Greenwich.



At the antipodes of Greenwich at the 180° meridian we have the date change line. If we cross the date change line we change time zone but the hour of the day remains the same while the day on the calendar has to be decreased by one day if going west, increased if going east. This is not the same as winning or loosing a day by a trip around the world as we did not miss or win physically a Sunrise.

The Times

For us tree kinds of times are important:

Greenwich Mean Time or GMT

This is the time indicated by the Chronometer (1). The Nautical Almanac uses GMT as argument for the daily tabulation of the EAP. GMT is the same at each moment anywhere on Earth. GMT refers to the mean solar time of a fictive Sun at Greenwich.

Local Mean Time or LMT

This time only differs by a multiple of hours of GMT. This time differs from west to east. We use this time in our daily life.

Universal Time or UT

UT is identical to GMT. But the name is used to avoid confusion when a summer time is kept at Greenwich.

Local Apparent Time or LAT

This is the **GHA** expressed in time units increased by an amount ε. At 12.00pm apparent local time the real Sun crosses the local meridian. The amount ε is tabulated daily in the Nautical Almanac.

(**1**) John Harisson constructed the first usable Marine chronometer in 1730 for which he was rewarded in 1759. James Cook took a replica with him during his second voyage in the Pacific Oœan in 1772.