Practical Observational Astronomy

Lecture 1

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based on lectures by Arkadiusz Olech

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Work plan

Three lectures with short introduction to the observational astronomy.

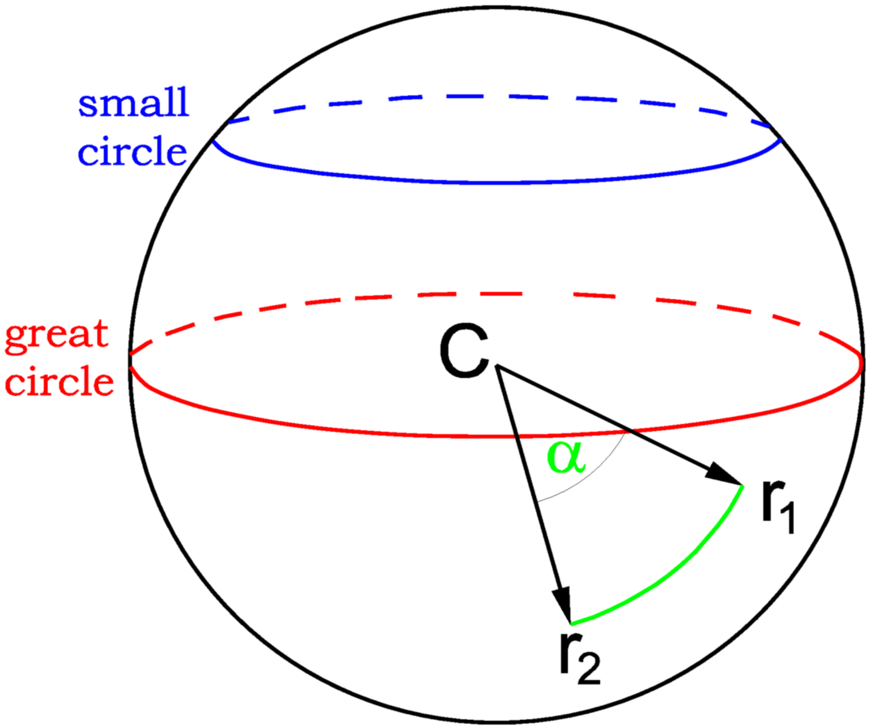
Two lectures with introduction to CCD data reduction, photometry and spectroscopy.

Observing practice using the telescope located on the roof of CAMK.

Each team spends ~3 nights at the telescope.

To pass the subject you have to obtain the light curve (time vs magnitude) of the observed star.

The celestial sphere and coordinate systems



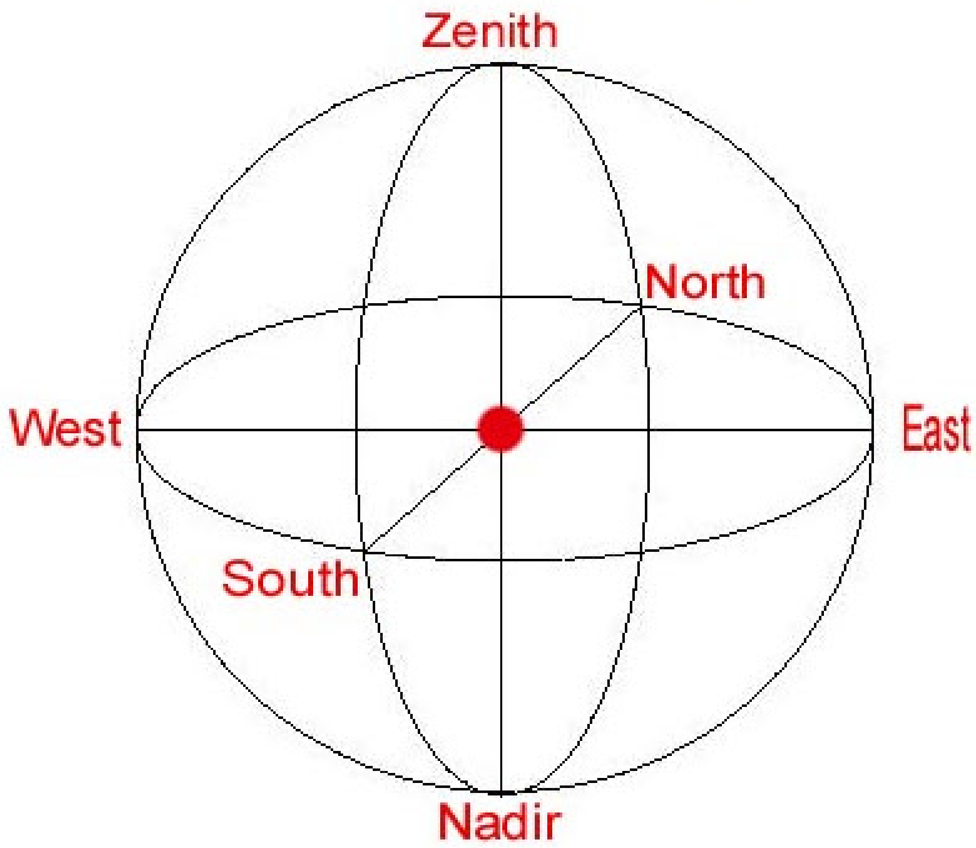
Celestial sphere (sfera niebieska) – imaginary sphere of arbitrary large radius concentric with Earth (the observer).

Great circle (koło wielkie) - intersection of the sphere and a plane which passes through the center point of the sphere.

Small circle (małe koło) - a circle on a sphere other than a great circle.

Angular distance (odległość kątowa) - size of the angle between the two directions originating from the observer and pointing towards these two objects.

The celestial sphere and coordinate systems

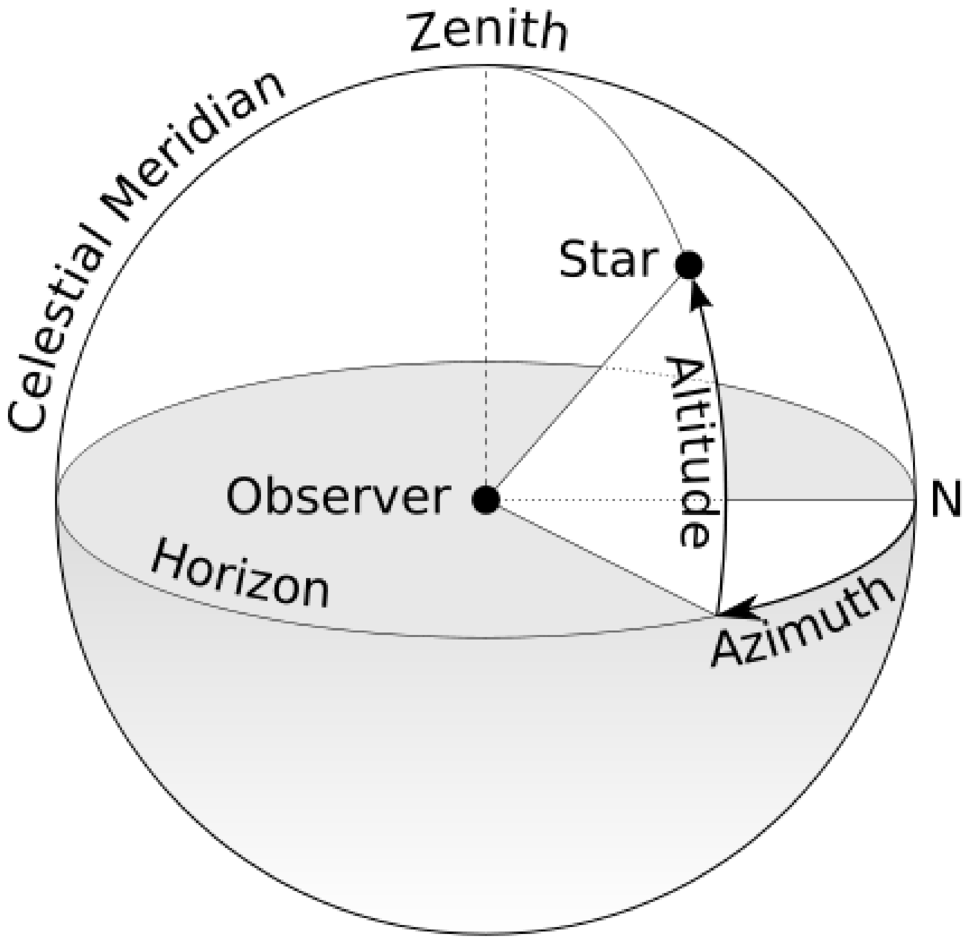


Zenith (zenit) – zenith refers to an imaginary point directly "above" a particular location, on the imaginary celestial sphere.

Nadir (nadir) – nadir is the direction pointing directly below a particular location. The direction opposite of the nadir is the zenith.

Horizon (horyzont) – great circle perpendicular to zenith-nadir line.

The celestial sphere and coordinate systems



Horizontal coordinate system (układ horyzontalny) - is a celestial coordinate system that uses the observer's local horizon as the fundamental plane. It is expressed in terms of altitude (or elevation) angle and azimuth.

Altitude or elevation (wysokość nad horyzontem) - angle between the object and the observer's local horizon.

h → [-90 deg, +90 deg]

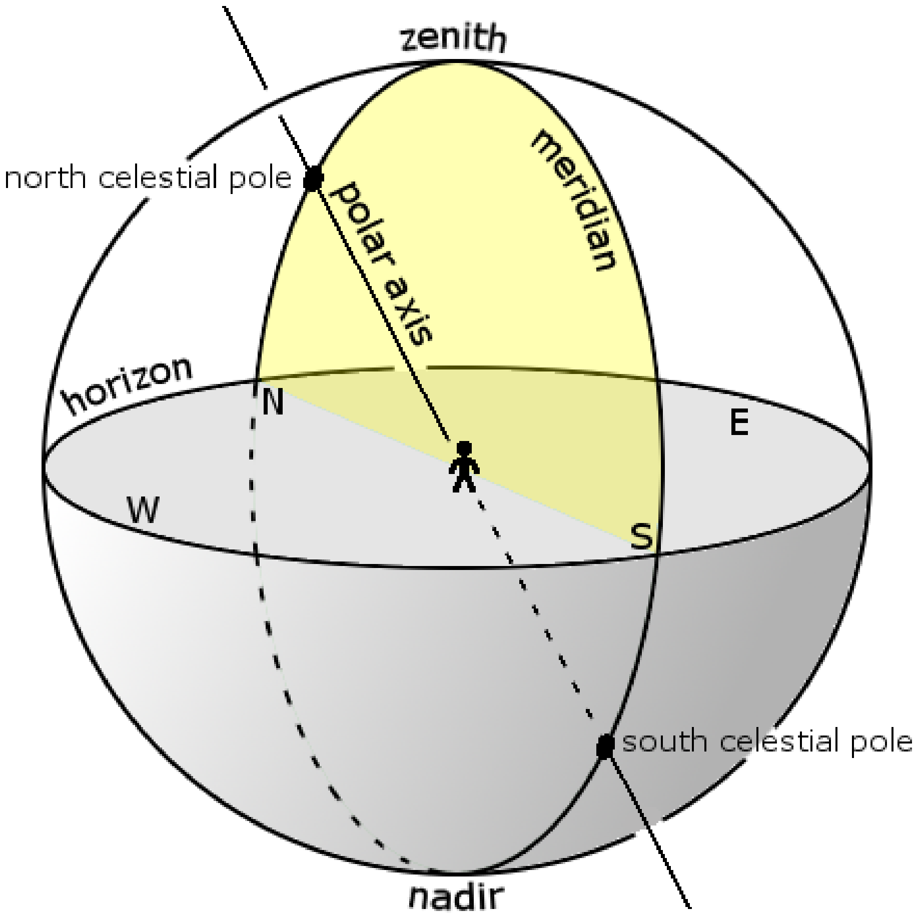
Zenith distance (odległość zenitalna) – angular distance from the zenith, *z = 90-h*

Azimuth (azymut) - angle of the object around the horizon, usually measured from the north increasing towards the east.

Az → [0 deg, +360 deg]

h, Az → time dependent due to the rotation of the Earth (celestial sphere)

The celestial sphere and coordinate systems



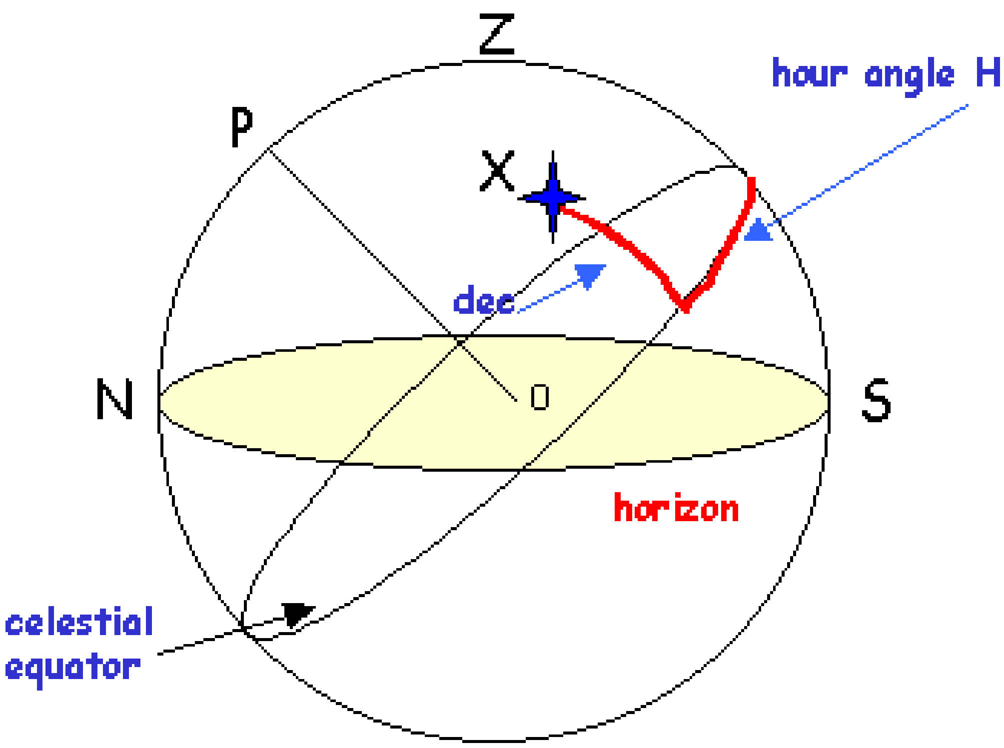
North and South celestial poles (północny i południowy biegun niebieski) – two imaginary points where the Earth's axis of rotation, indefinitely extended, intersects the celestial sphere.

Meridian (południk lokalny) – great circle containing both poles, zenith and nadir.

Celestial equator (równik niebieski) – projection of the Earth's equator onto the celestial sphere i.e. great circle perpendicular to polar axis.

Altitude of the visible pole is your geographical latitude.

The celestial sphere and coordinate systems



Equatorial coordinate system I (układ równikowy I) - is a celestial coordinate system that uses the celestial equator as the fundamental plane. It is expressed in terms of declination and hour angle.

Declination (deklinacja) - angular distance of an object from the celestial equator, positive to the North, negative to the South.

Decl. or $\delta \rightarrow$ *[-90 deg, +90 deg]*

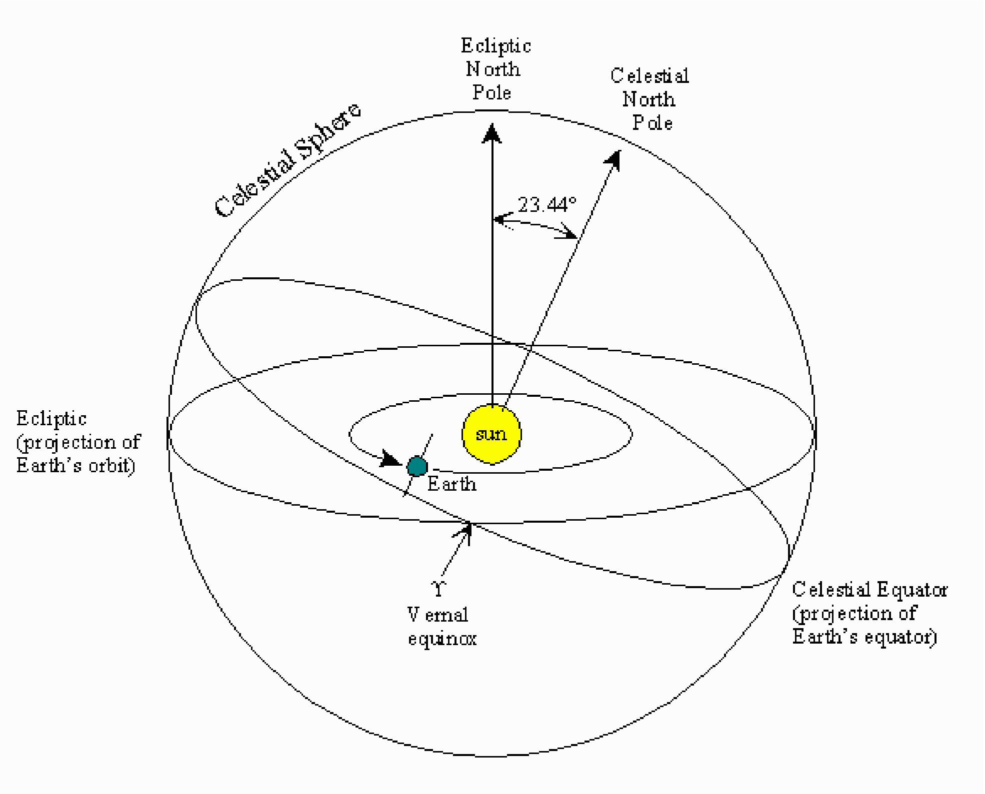
Hour angle (kąt godzinny) – angle between meridian and great circle containg poles and the object measured from meridian to the West.

HA or $t \rightarrow$ *[0 hours, 24 hours]*

HA or $t \rightarrow$ *[0 deg, +360 deg]*

t – time dependent due to rotation of the Earth (celestial sphere)

The celestial sphere and coordinate systems



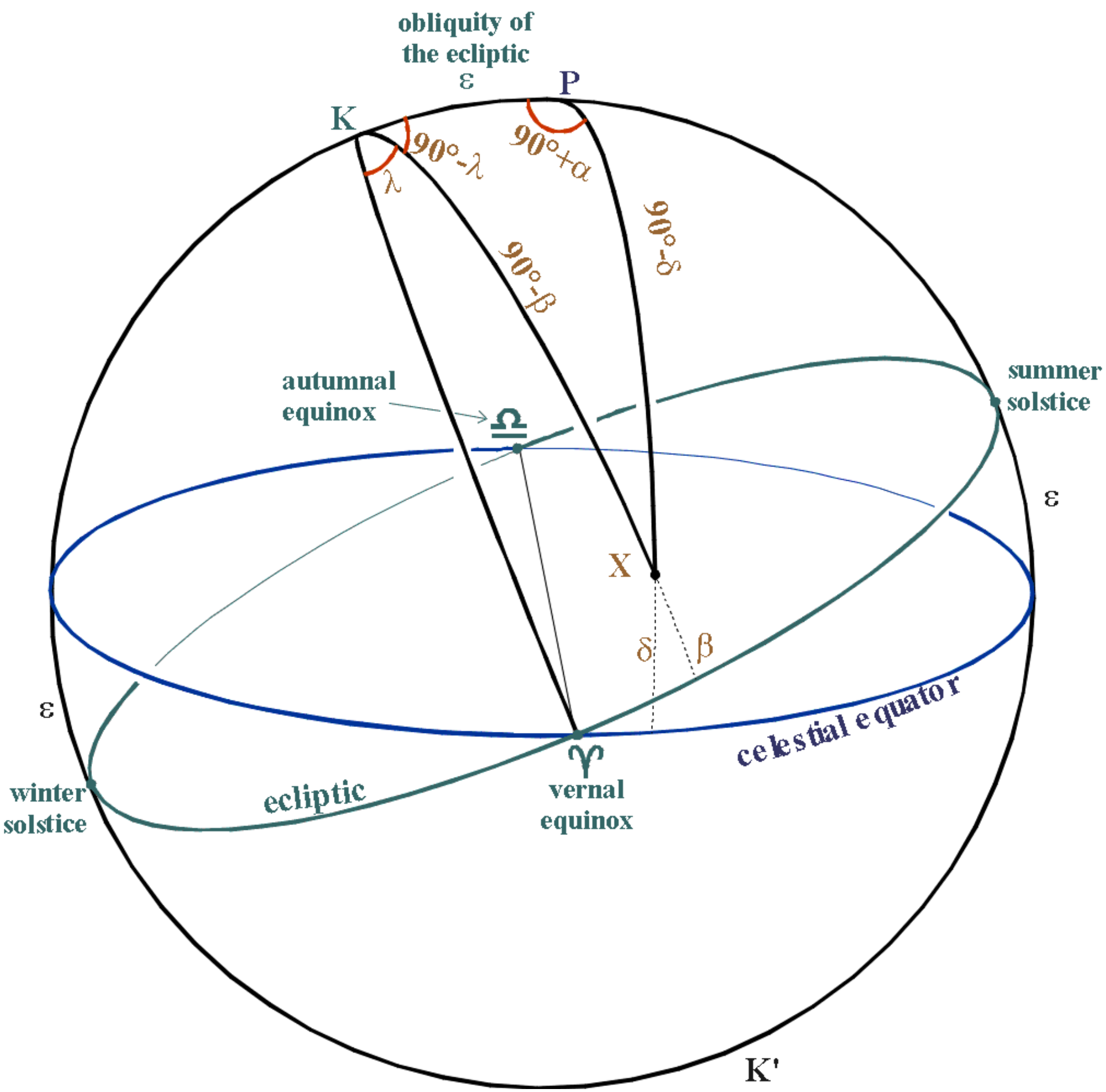
Ecliptic (ekliptka) - apparent path of the Sun on the celestial sphere.

Vernal point (punkt równononocy) – crossing of the ecliptic and celectial equator.

Spring vernal point, first point of Aries (punkt równonocy wiosennej, punkt Barana) – the point where Sun crosses the celestial equator from South to North.

Autumn vernal point, first point of Libra (punkt równonocy jesiennej, punkt Wagi) – the point where Sun crosses the celestial equator from North to South.

The celestial sphere and coordinate systems

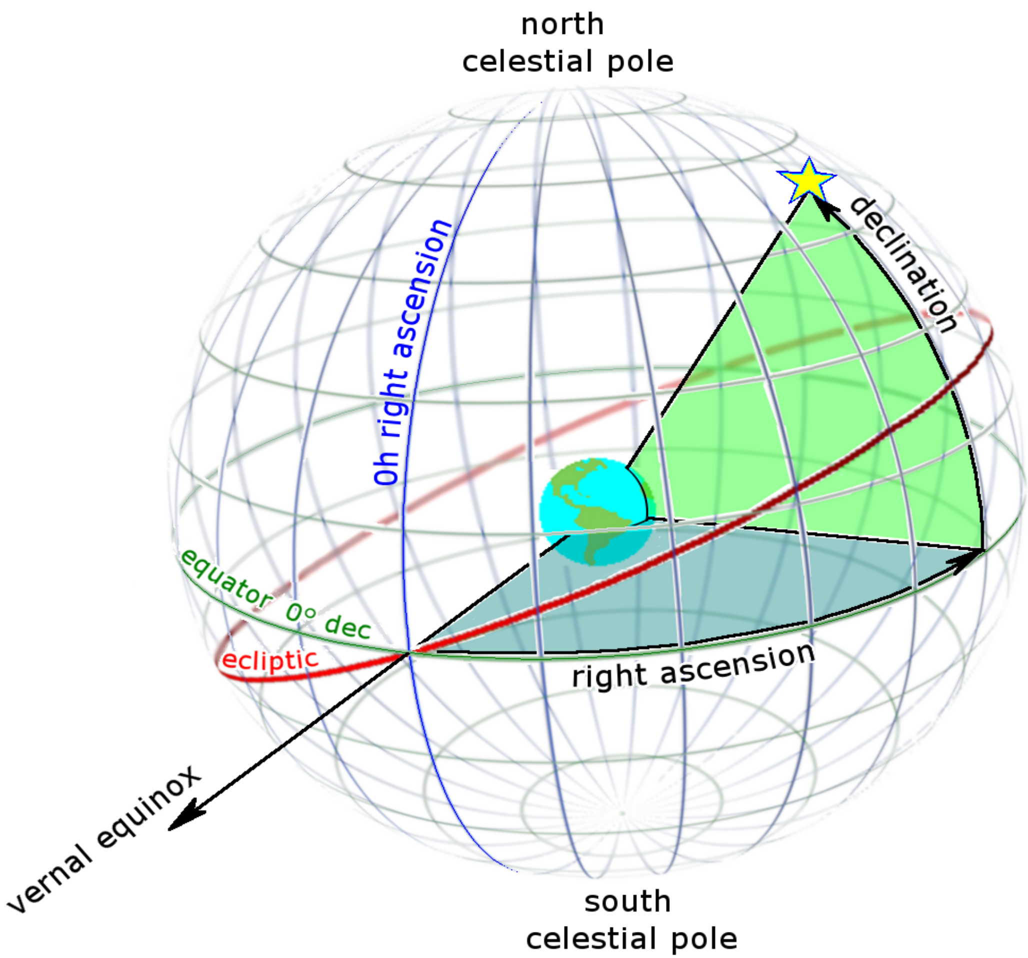


Angle between celestial equator and ecliptic ε = 23.44 deg.

Summer Solstice (punkt przesilenia letniego) – moment of maximum inclination of Earth's rotation axis towards the Sun (northern hemisphere). Maximum declination of the Sun equal to ε.

Winter Solstice (punkt przesilenia letniego) – moment of maximum inclination of Earth's rotation axis towards the Sun (southern hemisphere). Minimum declination of the Sun equal to -ε.

The celestial sphere and coordinate systems



Equatorial coordinate system II (układ równikowy II, równonocny) - is a celestial coordinate system that uses the celestial equator as the fundamental plane. It is expressed in terms of declination and right ascension.

Declination (deklinacja) - angular distance of an object from the celestial equator, positive to the North, negative to the South.

Decl. or $\delta \rightarrow [-90 \text{ deg}, +90 \text{ deg}]$

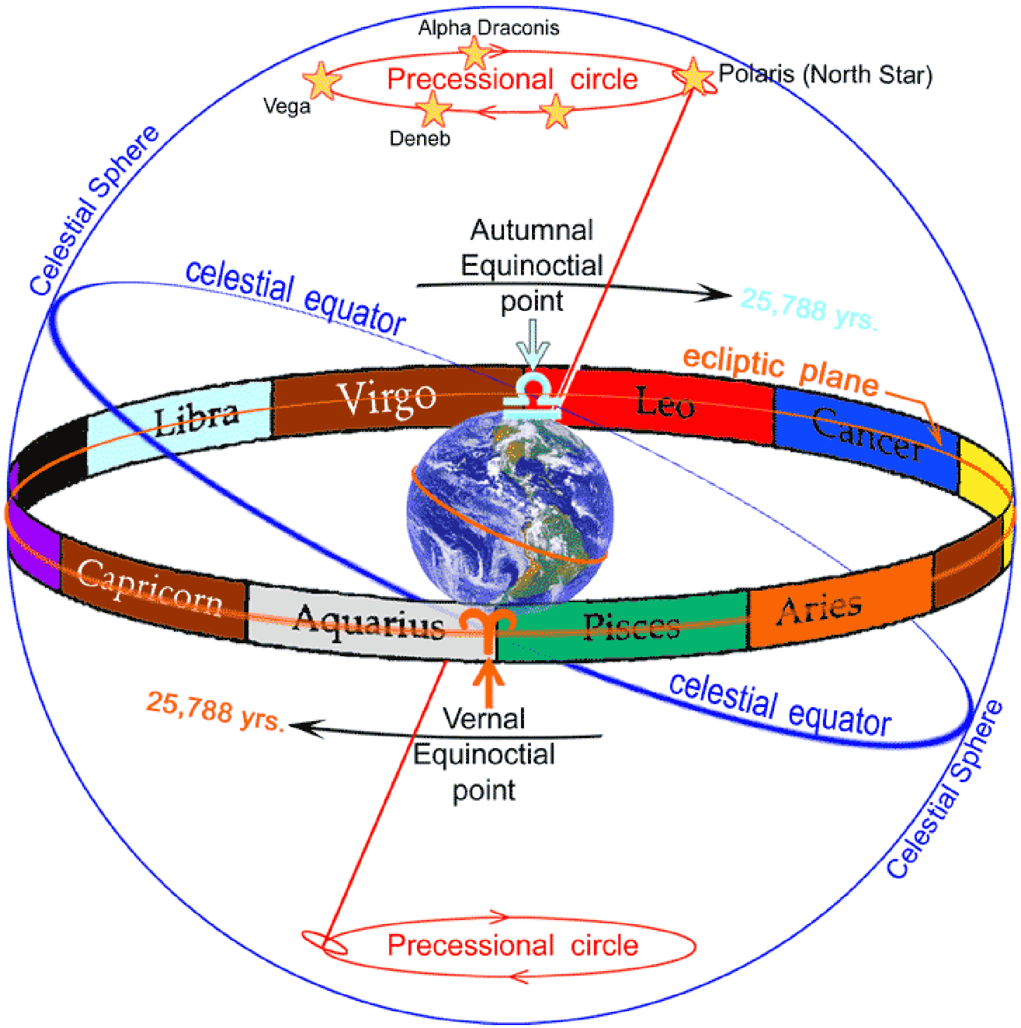
Righ ascension (rektascencja) – angle between vernal point (Aries) and great circle containing the object and poles measured eastward.

RA or $\alpha \rightarrow [0 \text{ hours}, 24 \text{ hours}]$

RA or $\alpha \rightarrow [0 \text{ deg}, +360 \text{ deg}]$

(α,δ) - time independent due to rotation of the Earth (celestial sphere)

The celestial sphere and coordinate systems



(α,δ) - time independent due to rotation of the Earth (celestial sphere) ...

... but still time dependent due to the precession effect.

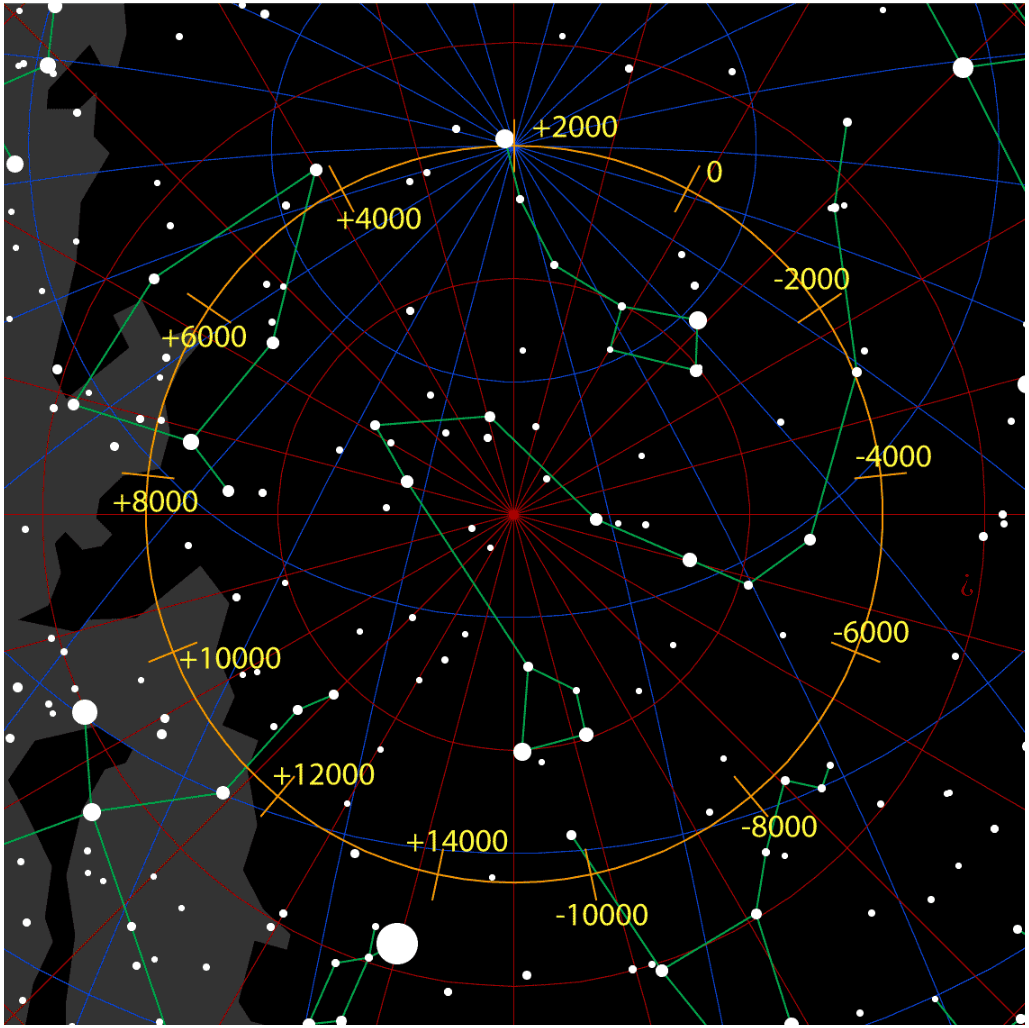
Precession (precesja) - gravity-induced, slow, and continuous change in the orientation of an rotational axis.

Precession of the Earth's rotation axis changes the location of the Vernal point which is zero point for equatorial coordinate system. Period of precession is ~26000 yr.

Vernal point moves 50.29" per year.

Currently it is located in Pisces constellation, close to the border with Aquarius constellation.

The celestial sphere and coordinate systems



Precession of the Earth's rotation axis changes also the polar star.

This means that Polaris not always is... Polaris.

Exact equatorial coordinates need epoch:

$$(\alpha 2000, \delta 2000)$$

Corrections for precession:

$$\Delta\alpha = \frac{m + n \sin\alpha \tan\delta}{15}$$
$$\Delta\delta = n \cos\alpha$$

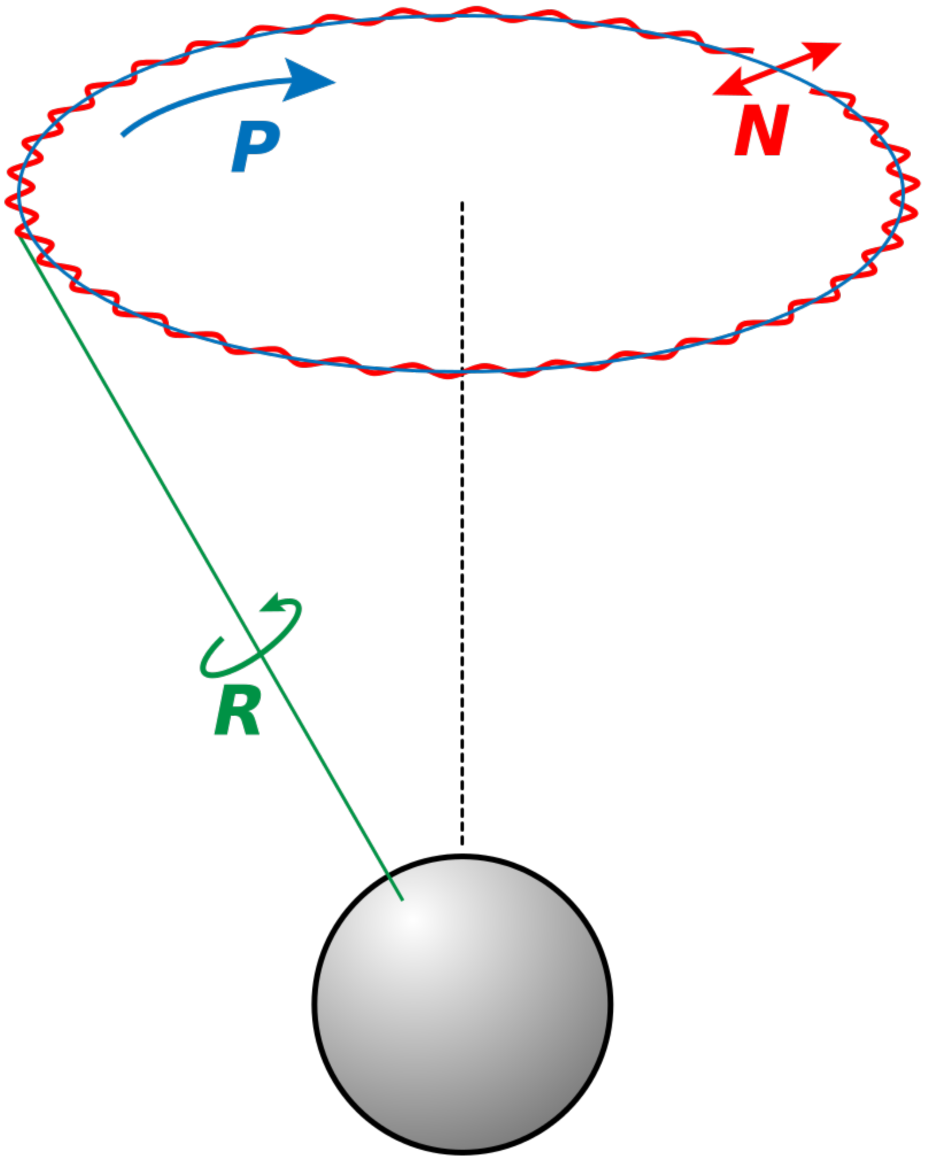
$\Delta\alpha$ [seconds of time],

$\Delta\delta$ [arc seconds]

$$m = 46.1244 + 0.000279\, t$$
$$n = 20.0431 - 0.000085\, t$$

t number of years that have elapsed since 2000.0

The celestial sphere and coordinate systems



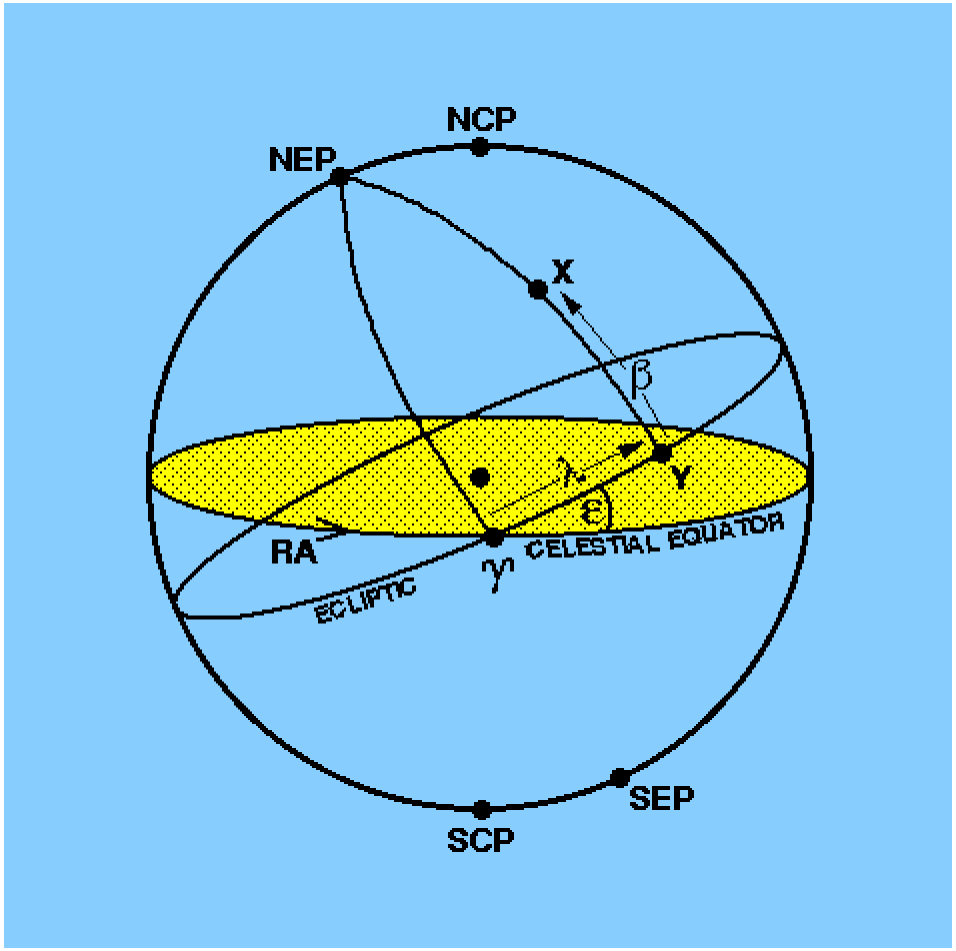
Not only precession...

Nutation (nutacja) - is a rocking, swaying, or nodding motion in the axis of rotation of the body.

The nutation of a planet happens because of gravitational attraction of other bodies that cause the precession of the equinoxes.

The largest component of Earth's nutation has a period of 18.6 years.

The celestial sphere and coordinate systems



Ecliptic coordinate system (układ ekliptyczny) - is a celestial coordinate system that uses the ecliptic as the fundamental plane. It is expressed in terms of ecliptic longitude and latitude.

Ecliptic latitude (szerokość ekliptyczna) - angular distance of an object from the ecliptic, positive to the north, negative to the south.

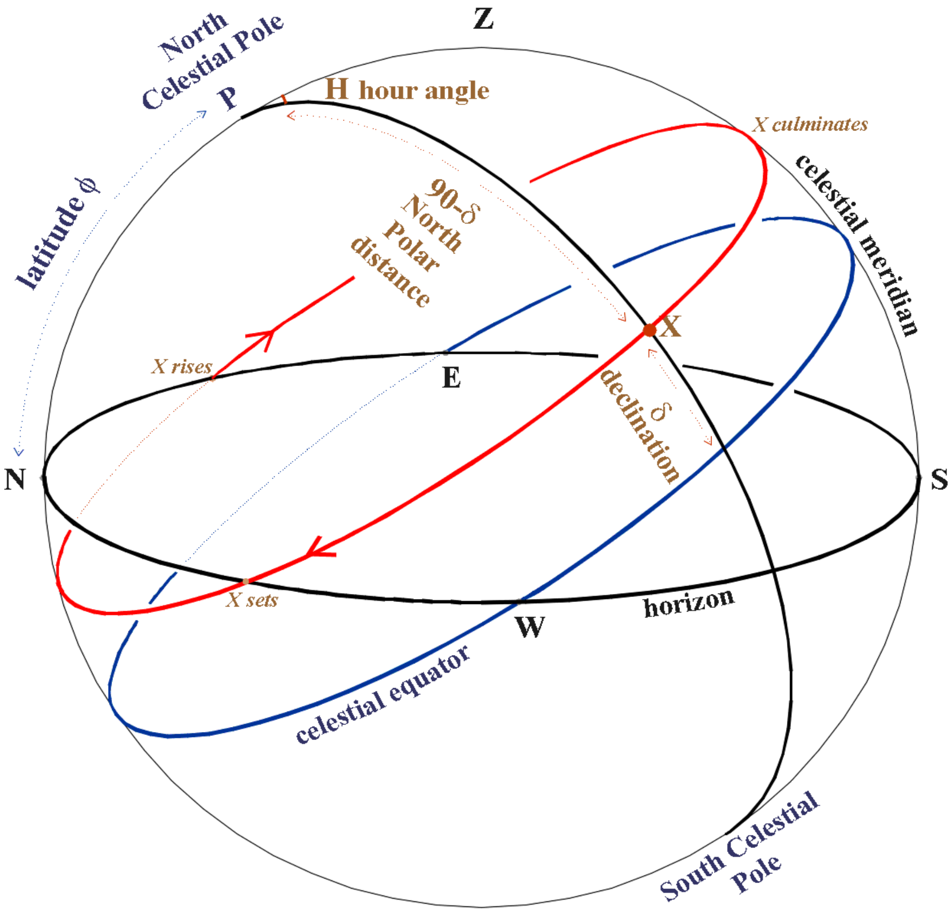
β → [-90 deg, +90 deg]

Ecliptic longitude (długość eklipticzna) – angle between vernal point (Aries) and great circle containing the object and ecliptic poles measured along the ecliptic.

λ → *[0 deg, +360 deg]*

It can be centered in the Sun → heliocentric ecliptic coordinate system *(l,b)*

The celestial sphere and coordinate systems



Culmination (górowanie, dołowanie) - of an object is its transit over an observer's meridian.

During one day, an astronomical object crosses the meridian twice: once at its upper culmination, when it is at its highest point as seen from the earth, and once at its lower culmination, its lowest point.

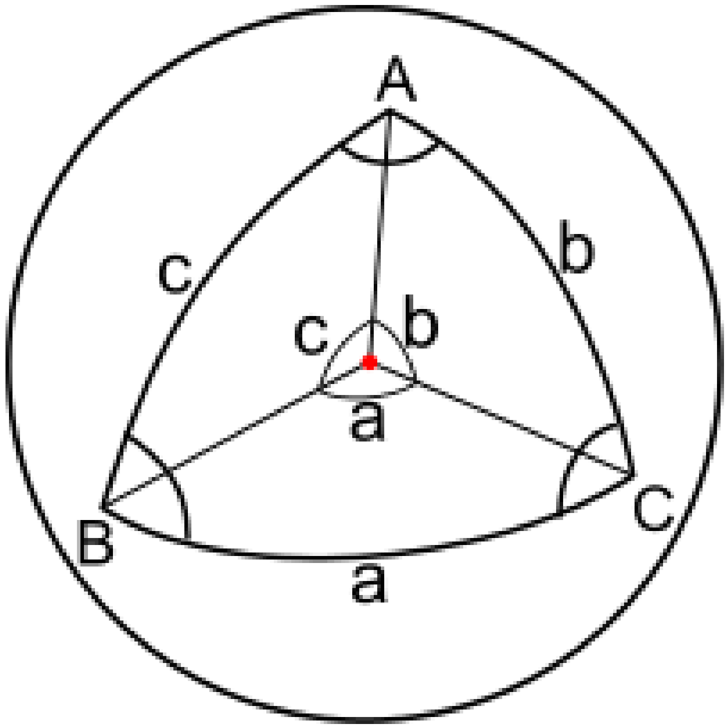
Exercise 1

For given geographical latitude φ calculate the ranges of declination for objects which are:

a) Circumpolar
b) Can be visible from this location
c) Can not be visible from this location
d) Can be observed in the zenith
e) Can be observed at altitude h>30 deg.

Use geographical latitude of Warsaw for calculations (φ = 52 deg).

Basic rules of spherical trigonometry



For spherical triangle ABC we have:

1) sine rule

$$\frac{\sin a}{\sin A}=\frac{\sin b}{\sin B}=\frac{\sin c}{\sin C}$$

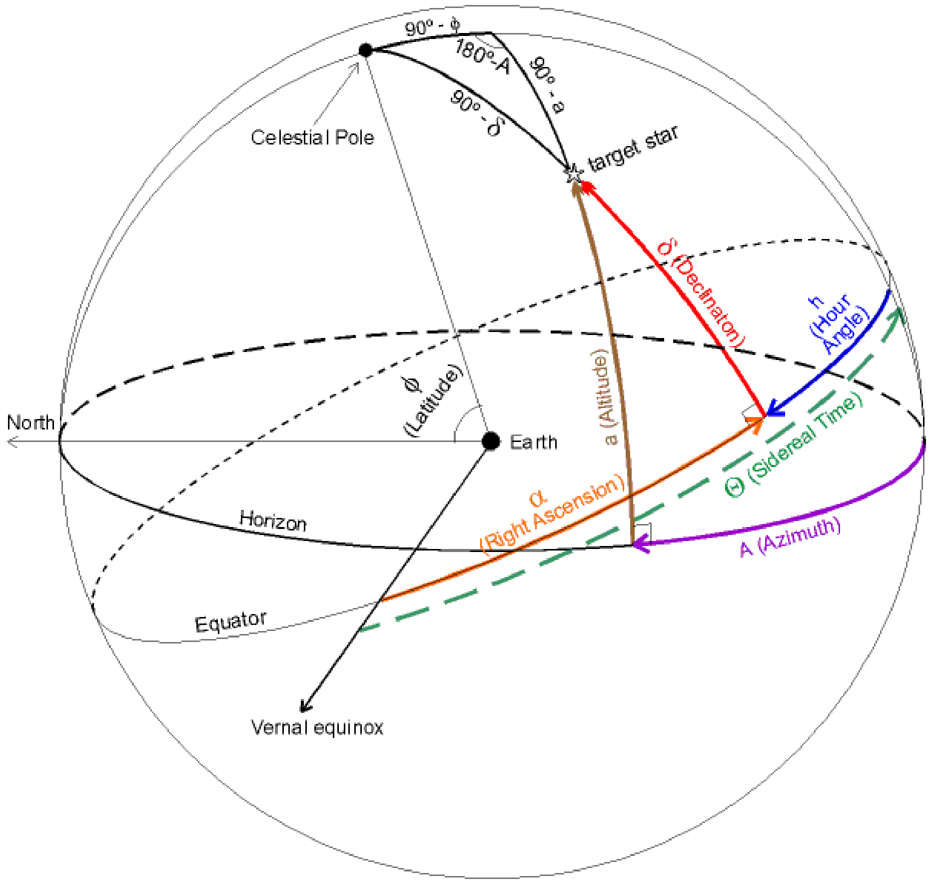
2) cosine rule

$$\cos a=\cos b\cos c+\sin b\sin c\cos A$$
$$\cos b=\cos c\cos a+\sin c\sin a\cos B$$
$$\cos c=\cos a\cos b+\sin a\sin b\cos C$$

Exercise 2

For stars A and B with given equatorial coordinates compute their angular distance.

Time



Sideral time (czas gwiazdowy) – time connected with the rotation of the celestial sphere.

Simply speaking it is hour angle of the first point of Aries.

Period of time between two upper culminations of the first point of Aries is **sideral day**.

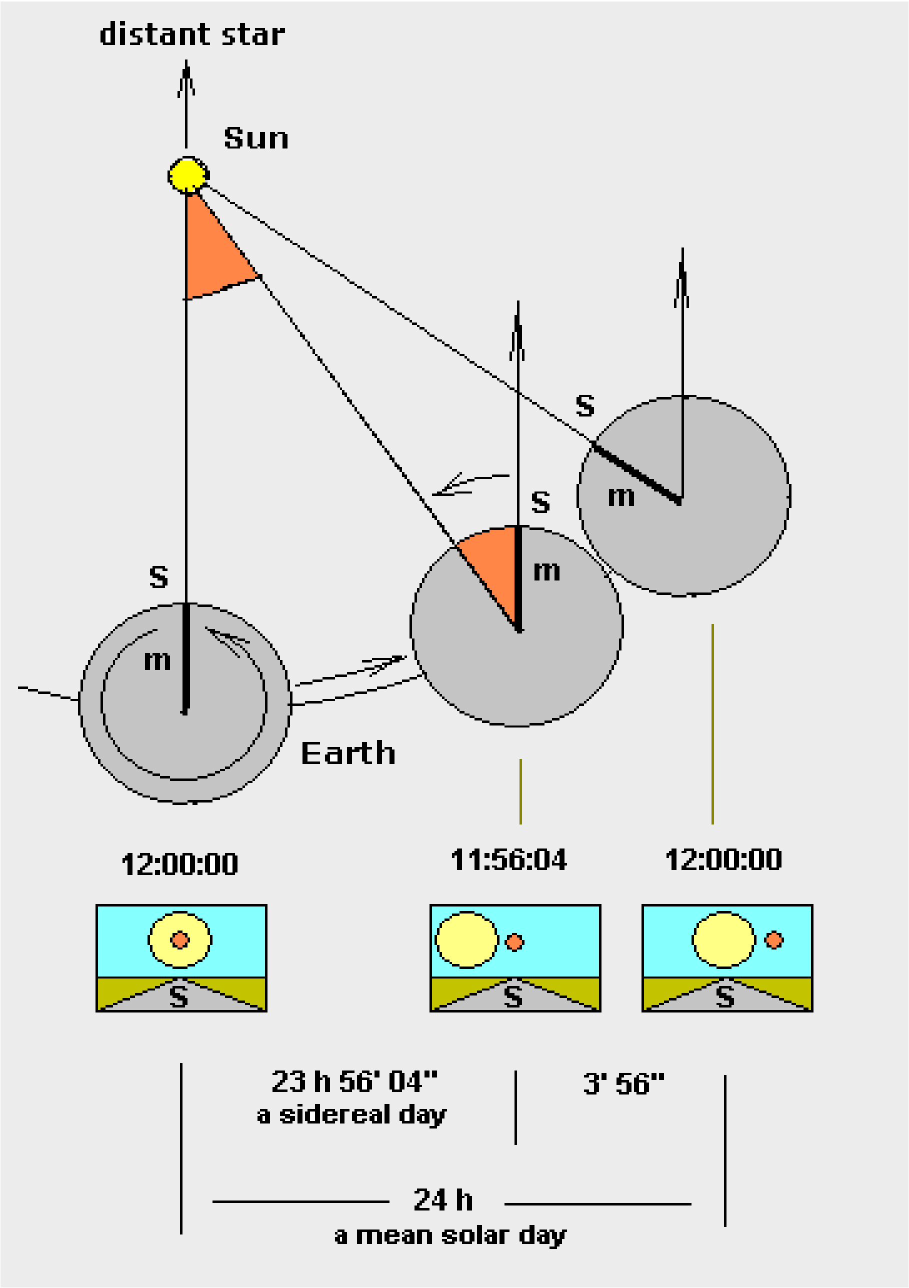
For any object in the celestial sphere:

Hour angle of vernal point = α + *hour angle*

For upper culmination hour angle=0

Sideral time = α *of the star in upper culmination.*

Time



Sideral day is equal to is 23h 56m 4.0916s (23.9344699 hours). See the picture.

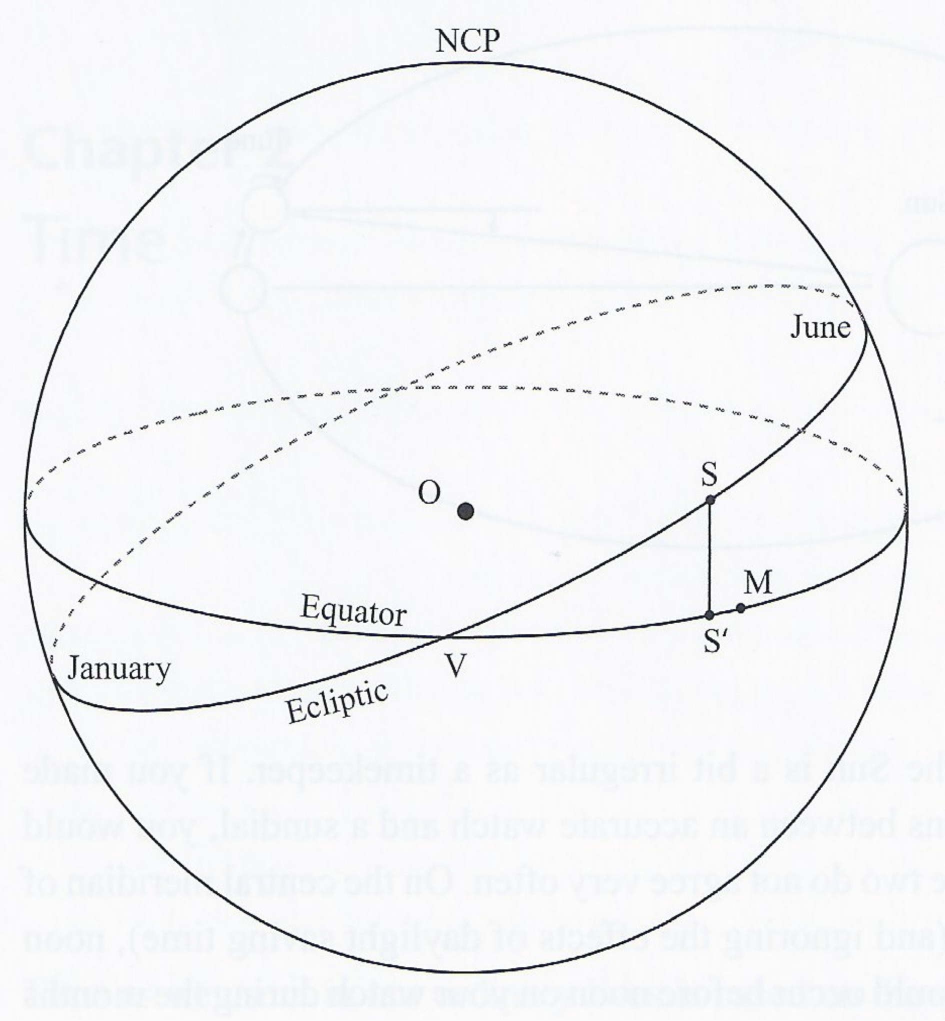
Our time is connected with movement of the Sun.

It is convinient to measure the time with the hour angle of the Sun → **solar time (czas słoneczny).**

Apparent solar time (czas prawdziwy słoneczny) - the apparent Sun is the true sun as seen by an observer on Earth. Apparent solar time or true solar time is based on the apparent motion of the actual Sun. It is based on the **apparent solar day (prawdziwa dobra słoneczna)**, the interval between two successive returns of the Sun to the local meridian.

Apparent solar time can be measured by a **sundial (zegar słoneczny)**.

Time



Apparent solar time is not uniform time.

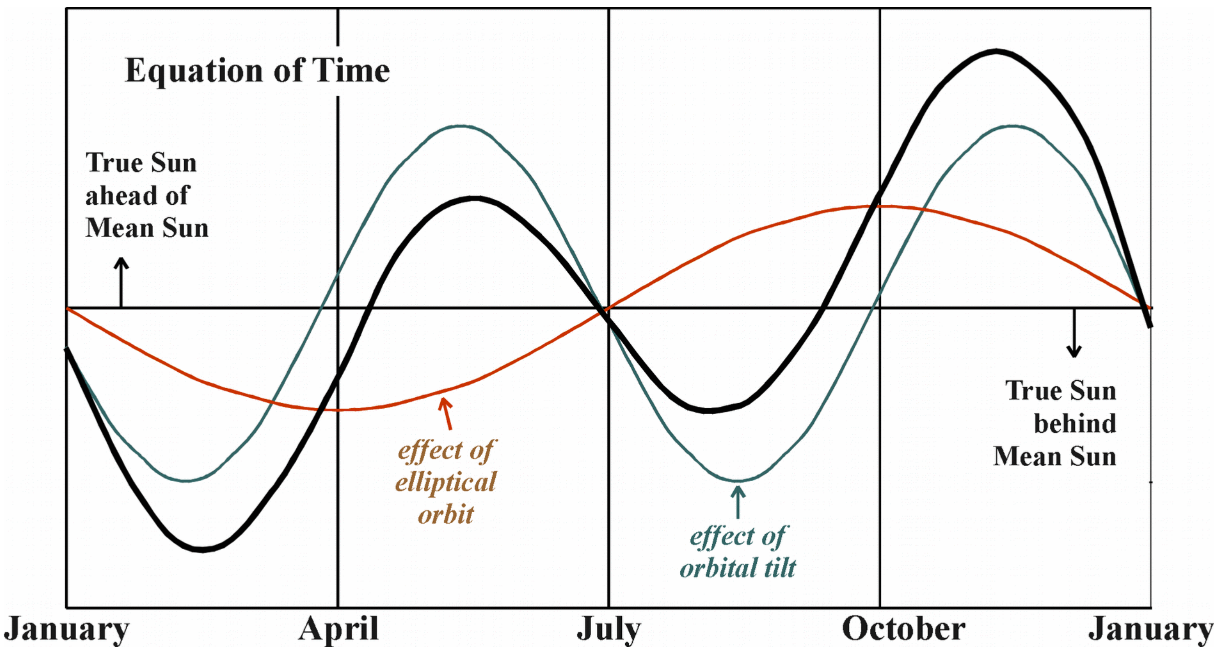
The length of an apparent solar day varies through the year due to the:

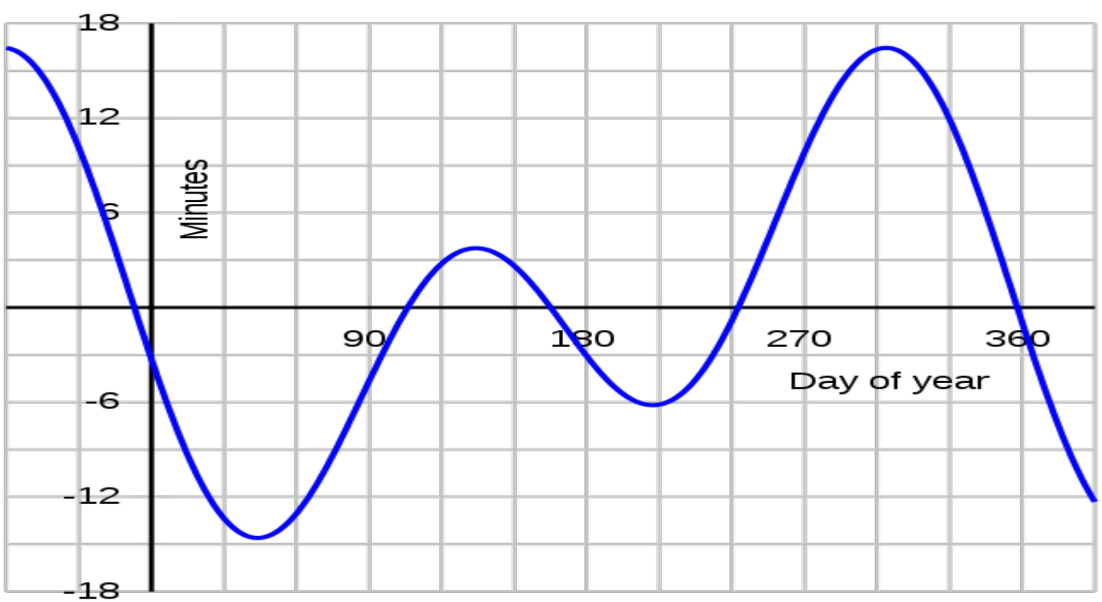
1. Earth's orbit is an ellipse, not a circle, so the Earth moves faster when it is nearest the Sun (perihelion) and slower when it is farthest from the Sun (aphelion).

2. True Sun moves along the ecliptic which is inclined to the celestial equator. The projection of the position of the Sun onto celestial equator causes non uniform movement along the equator.

The true Sun projected to S' is lagging behing the mean Sun at M. Angles VOS and VOM are the same.

Time





We need uniform time with a clock running at a constant rate...

We introduce imaginary "mean Sun" that moves along the celestial equator at a constant rate that matches the real Sun's average rate over the year.

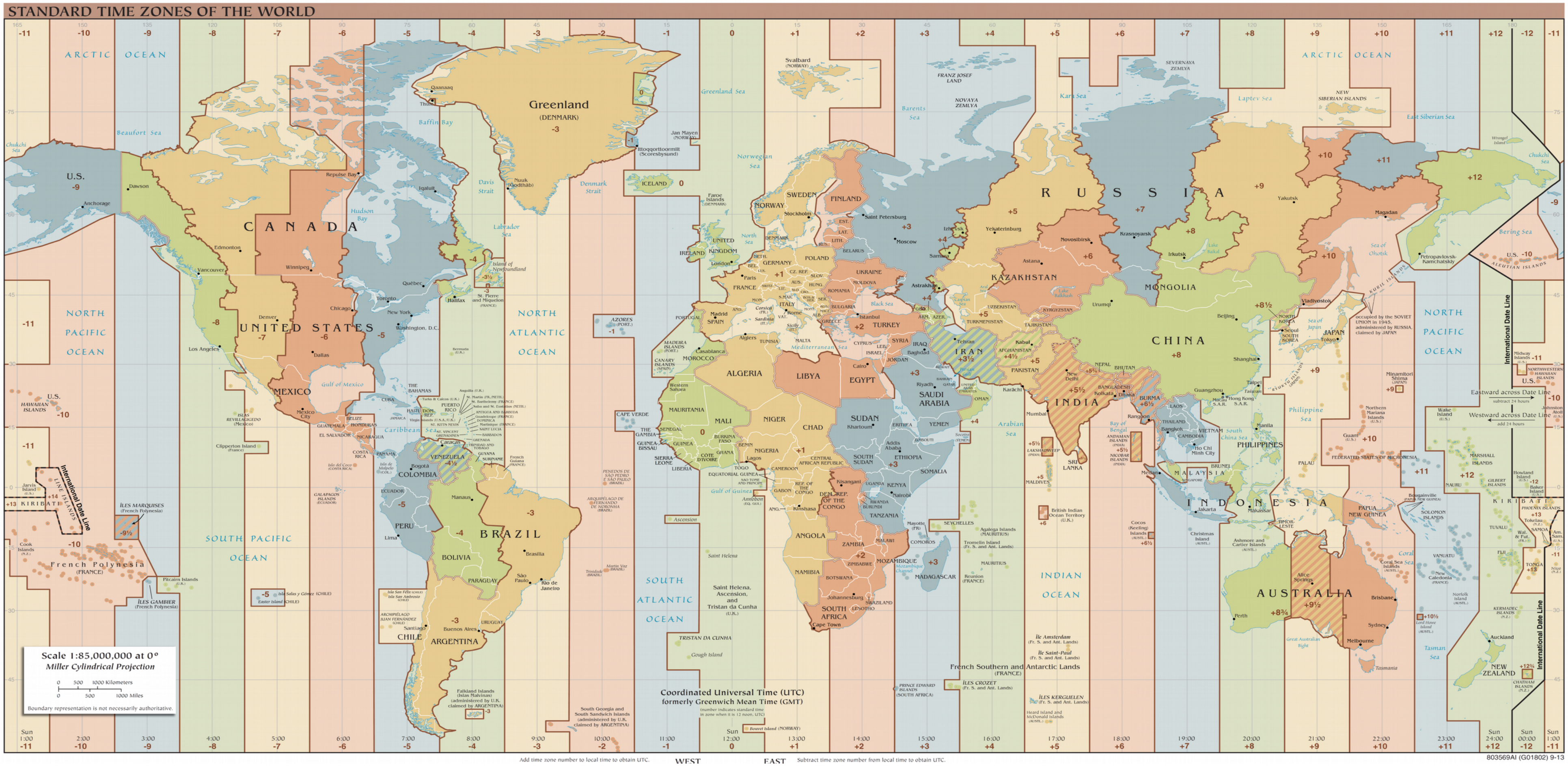
Mean solar time (czas średni słoneczny) is then the hour angle of the mean Sun plus 12 hours.

Equation of time is the difference between apparent and mean solar time.

It is zero around April 15, June 12, September 1 and December 24 (close to equinoxes and solistices).

Maxium +16m 28s around Nov 2.

Time zones



Mean and true solar time is valid for an observer only along specific longitude.

24 zones (each 15 deg) created with so called **standard time**.

In 1884 the meridian of Greenwich was chosen as meridian of 0 deg longitude with mean solar time at this location called **Greenwich Mean Time (GMT)** or **Universal Time (UT)**.

Dynamical time

Earth rotation period is not constant and is increasing in a slow but irregular manner affecting the clock connected with mean solar time.

In 1984 **Terrestial Dynamical Time (TDT)** was introduced:

$$TDT = UT + DT$$

Where DT is an empirically determined correction published in astromical calendars.
For 2019 DT is +69 sec.

Terrestial Dynamical Time is reffered to the Earth. There is also **Barycentric Dynamical Time (TDB)** which is reffering to the center of the Solar System.

Julian Day

Continous numeration of days since January 1, 4713 BC. Each day is considered to start at noon rather than midnight.

$$JD = 2451544.5 + 365 * (Y - 2000) + N + L$$

where *Y* is the year, *N* is the day of the year, and *L* is number of leap days since January 1, 2001.

Due to the orbital motion of the Earth the light of the star can reach an observer as much as 16m 55s earlier on later depending of the Earth position on the orbit and star position.

The shift depends on the ecliptical coordinates of the star. Thus **Heliocentric Julian Day (HJD)** is introduced.

$$HJD = JD - \frac{r}{c} \cdot [sin(\delta) \cdot sin(\delta_{\odot}) + cos(\delta) \cdot cos(\delta_{\odot}) \cdot cos(\alpha - \alpha_{\odot})]$$

$$HJD = JD - \frac{r}{c} \cdot cos(\beta) \cdot cos(\lambda - \lambda_{\odot})$$

Where *r* is Sun-Earth distance and *c* is speed of light.

Barrycentric Julian Day (BJD) refers to the center of the Solar System instead of the center of the Sun. Te difference bewteen the HJD and BJD is up to +\- 4 sec.

Julian and Gregorian Calendars

Julian calendar introduced in 46 BC: twelve months with 365 days, every 4 years leap year with one day added. Mean year equal to 365.25 days.

Not very good approximation of the **tropical year** (which is equinox to equinox interval with precession taken into account) which is 365.242190 days.

With passing centuries vernal equinox was occurring earlier and earlier → in XVI century around March 11.

In 1582 pope Gregory XIII switched the date from Thursday, October 4, 1582 to Friday, October 15, 1582 bringing the vernal equinox again to around March 21. The following changes to the calendar were made:

- every fourh year is the leap year,
- except for century years (eg. 1700, 1800, 1900),
- unless it is divisible by 400 (eg. 1600, 2000)

In this case the mean lenght of the year was (400*365+[100-3])/400 = 365.2425 days.

Later one more modification → no leap year in years divisible by 4000. The mean length of the year is then 365.24225 days very close to tropical year.

Now it takes 17000 years to change the date of the vernal equinox by one day.