Coordinate Systems
&
Time

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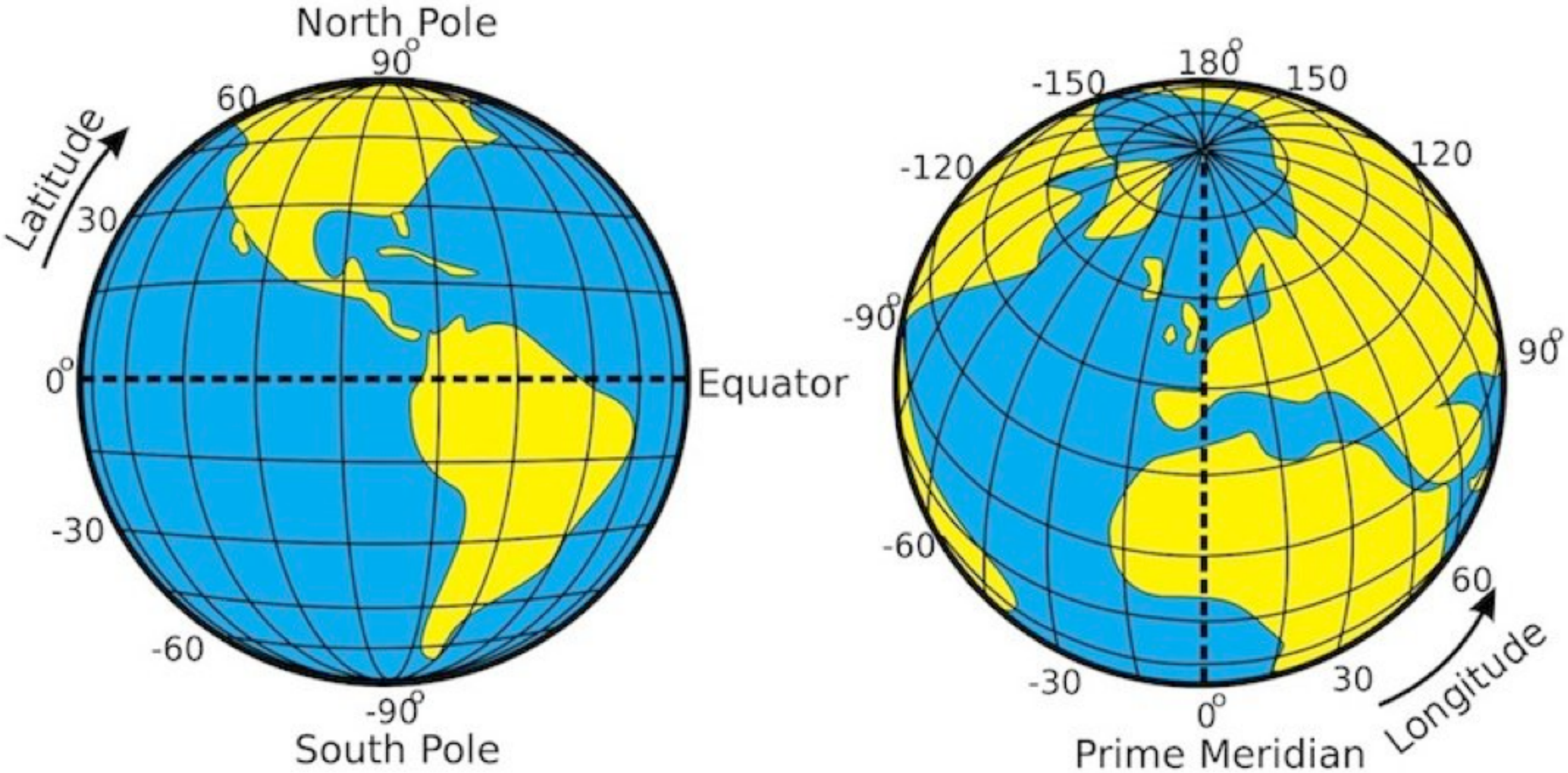
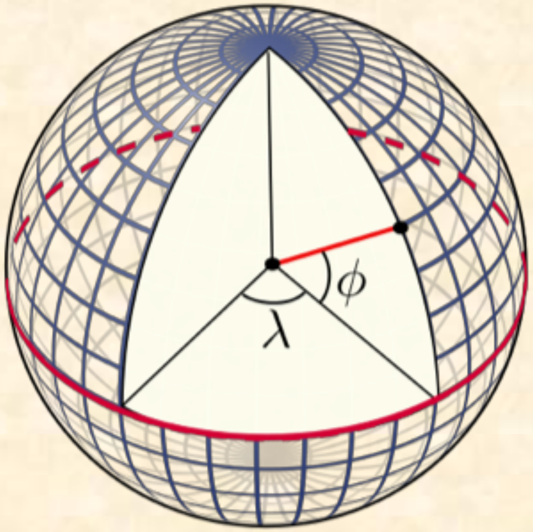
Geographic coordinate system



Geographic coordinates (Earth)



- Latitudes [φ] and longitudes [λ].
- Equator and meridians.

- Metsähovi Radio Observatory, Finland:
  Lat.: N 60° 13' 2.9''
  Long.: E 24° 23' 43.1''
- APEX telescope, Chile:
  Lat.: S 23° 00' 20.8''
  Long.: W 67° 45' 33.0''

- Degrees, arcminutes, arcseconds
  (minutes of arc, 1/60 degree;
  seconds of arc, 1/60 arcmin).

Earth’s rotation

- Different times of the day (direction of the Sun).
- Visibility of stars (day/night).
    - N.b.: radio astronomical observations can be made in the daylight, even though the objects are not optically visible because of sunlight!

Earth on its orbit

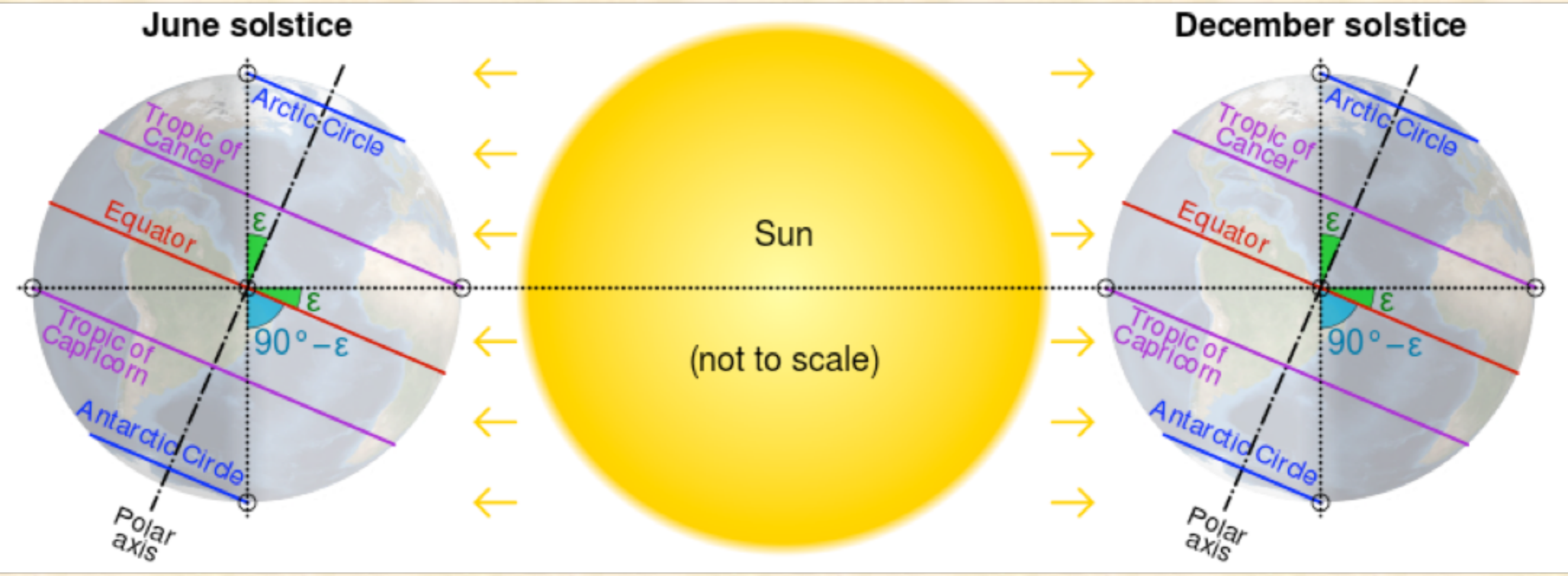
- Visibility of stars
  (different constellations/objects
  during different seasons)

Because sunlight blocks their visibility

- Visibility of the Sun north/south, seasons
- Tropics (t. of Cancer/Capricorn).
- Polar circles.
- Equinoxes and solstices.

Because of the tilted axis of the Earth

Sun and Earth

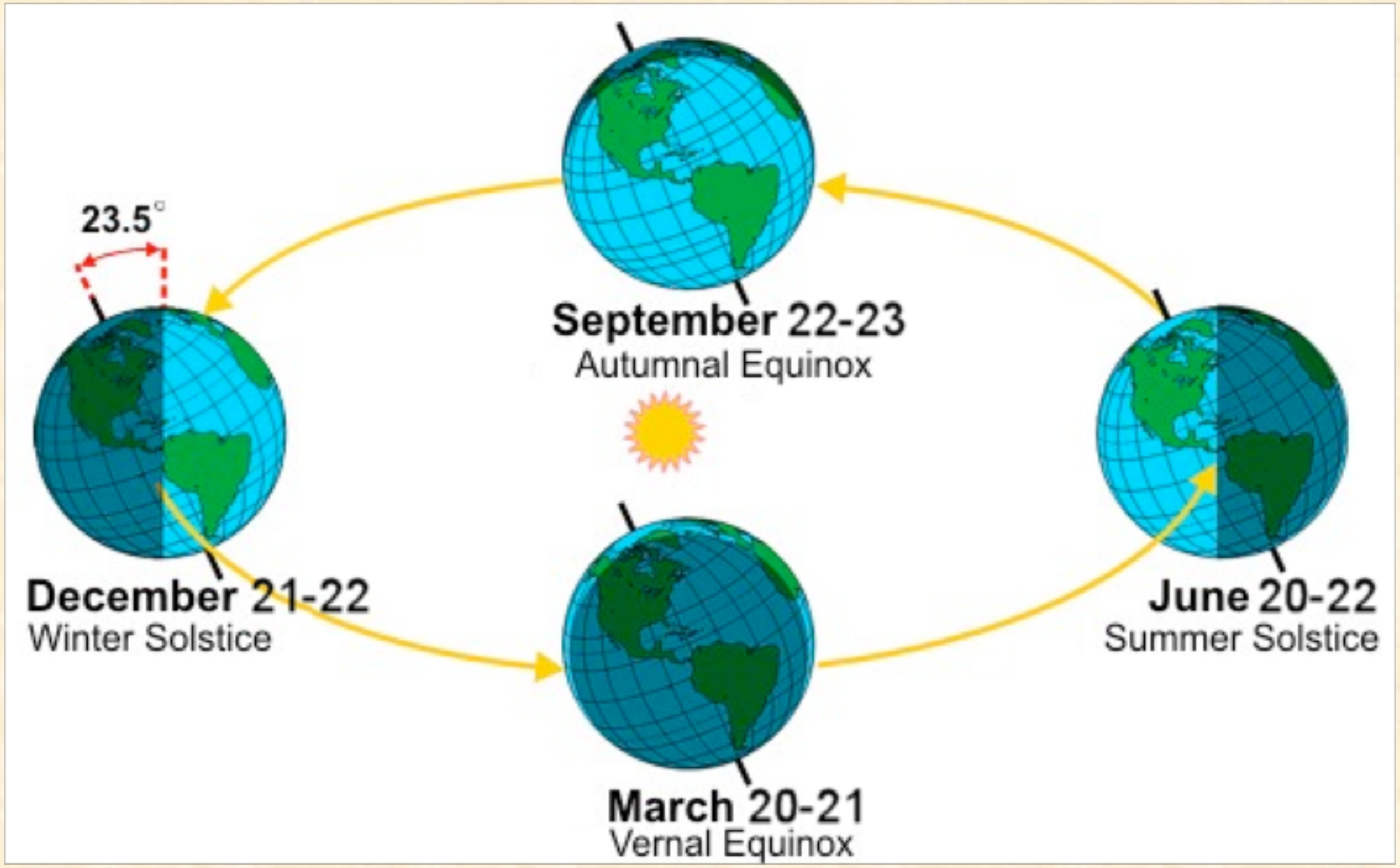


Obliquity of the ecliptic = Earth's axial tilt = ε=23.4°

Tropics and polar circles

- Tropic of Cancer, the Northern Tropic (N 23°26′13.9″)
- Tropic of Capricorn, the Southern Tropic (S 23°26′13.9″)
  - The most northern/southern circles of latitude on the Earth at which the Sun may appear directly overhead.
    This occurs once per year, at the time of the Northern/Southern solstice.
  - Latitude = the axial tilt of the Earth [ε].
- Arctic Circle, the Northern Polar Circle (N 66°33′46.1″)
- Antarctic Circle, the Southern Polar Circle (S 66°33′46.1″)
  - Every year at least one 24-h period when the sun is continuously above the horizon, and at least one 24-h period when the sun is continuously below the horizon.
  - Latitude: 90 degrees minus the axial tilt of the Earth [ε].

Sun and Earth (2)



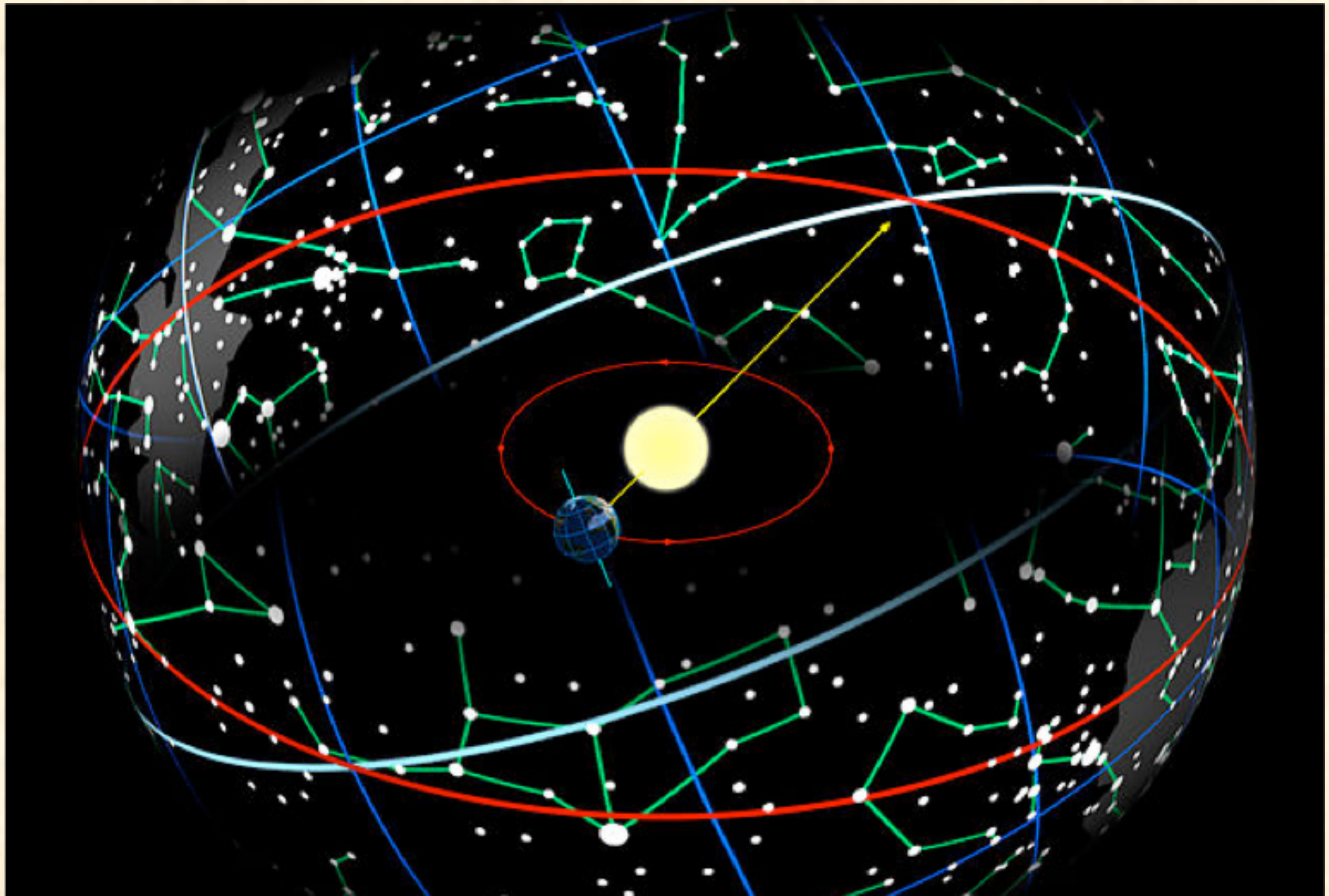
Sun-Earth distance 147-152 million km. (Smallest during northern winter!)

Obliquity of the ecliptic, ε

- Earth’s axial tilt
  - i.e. the angle between the ecliptic (= Earth's orbital plane) and the celestial equator on the celestial sphere.
  - Ca. 23.4°. Small changes due to planetary perturbations affecting the ecliptic.
  - Fixed direction → seasons.

Ecliptic

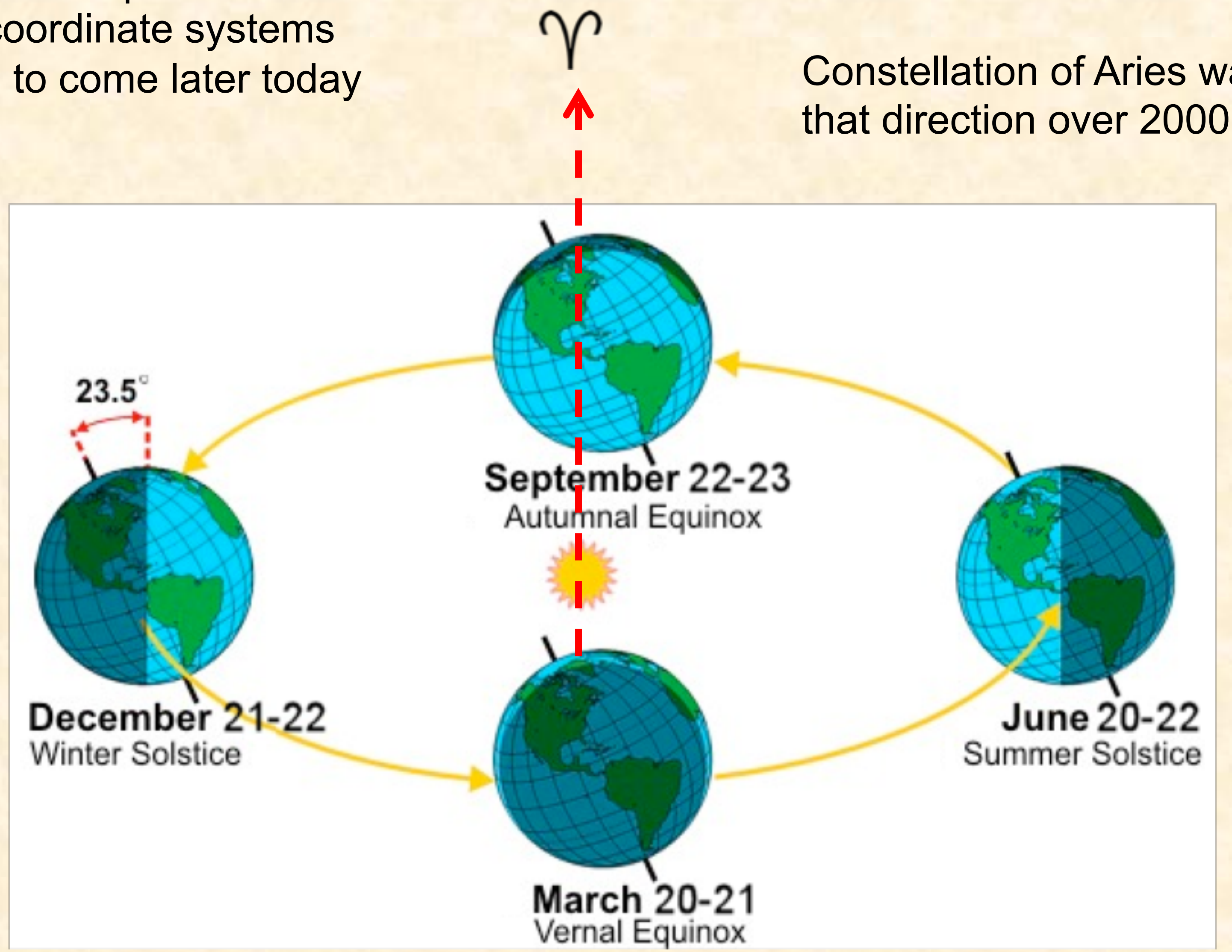
- Sun’s apparent path in the sky.
  - Planets are approximately in the same plane.
- Zodiac = constellations along the ecliptic.



First point of Aries ♈

Zero point of equatorial and ecliptic coordinate systems
→ slides to come later today

Constellation of Aries was in that direction over 2000 yrs ago!



Quiz!

What would happen if the rotation axis of the Earth would be turned exactly perpendicular to the Earth's orbit?

A. All days would have equal length.
B. There would be no prominent seasons.
C. The ecliptic would be in the equatorial plane.
D. The definition of Polar Circles would become obsolete.

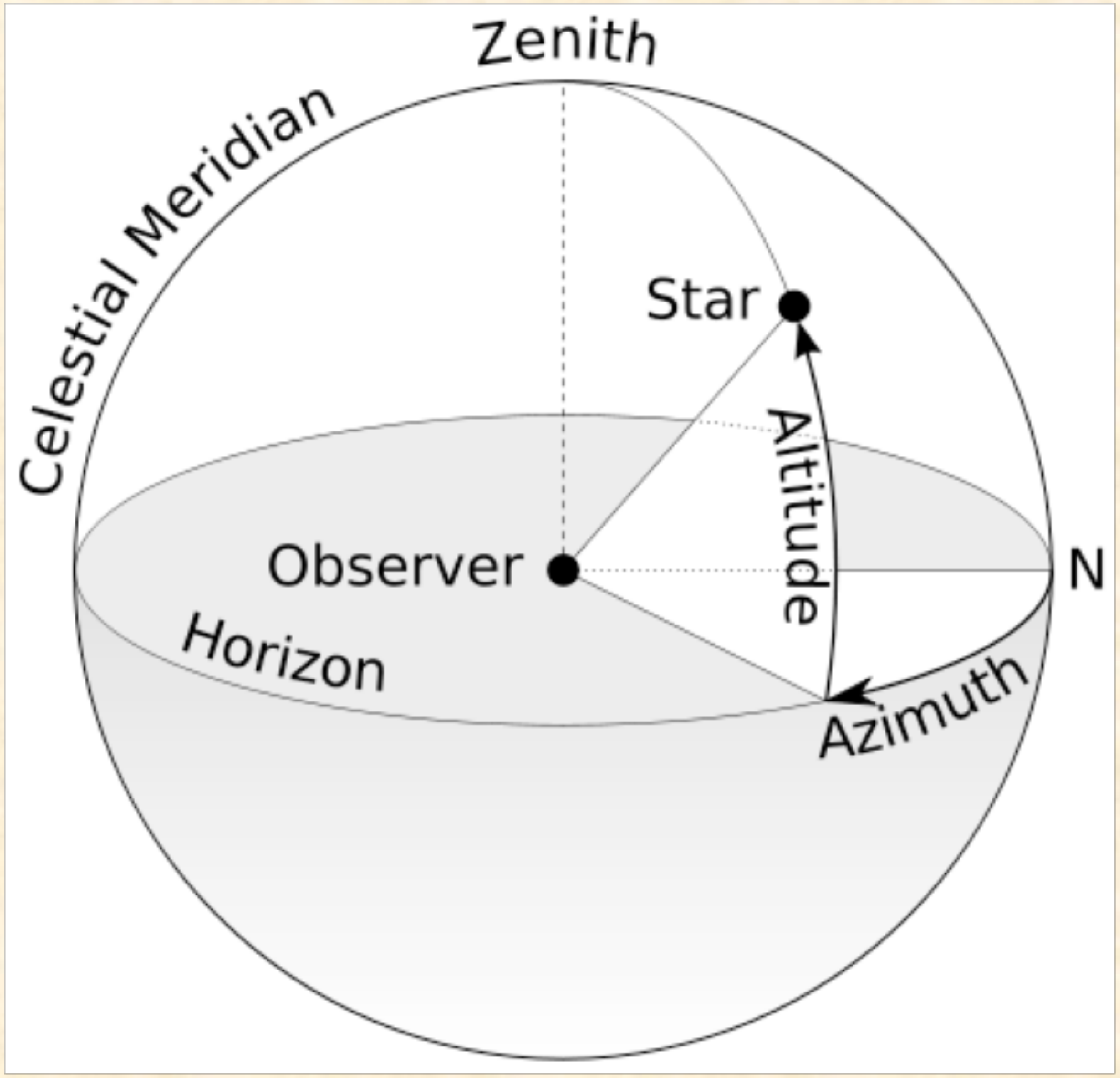
Coordinate systems (1)

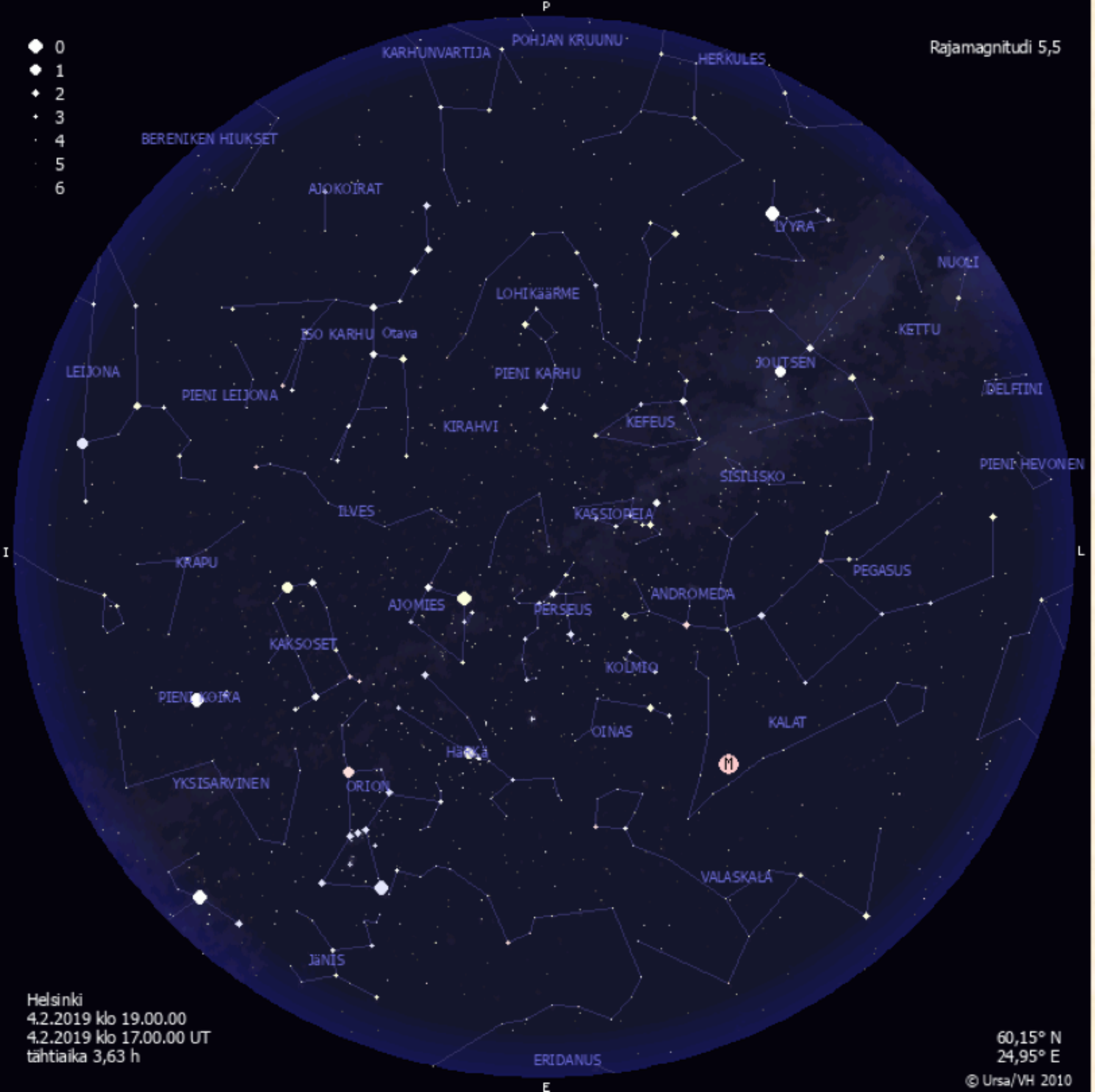
- Horizontal system
  - Elevation = altitude [a].
  - Azimuth [A].

Horizontal system

elevation, altitude =
angle from
horizon

azimuth =
vertical angle
from a fixed point,
often N,
Metsähovi S



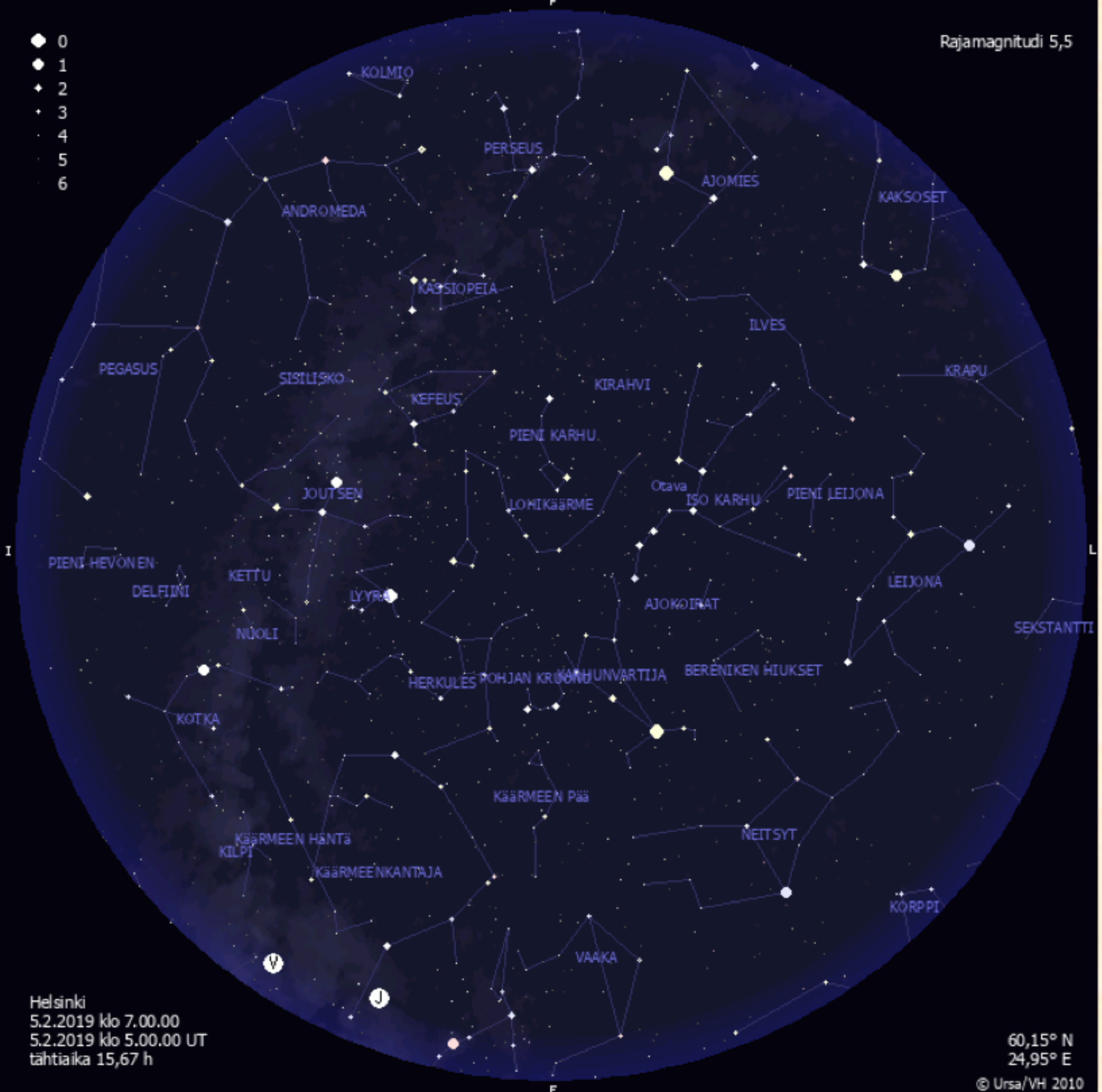


Local time 19 today.

Sidereal time 3.63 h

Local time 23 today.

Sidereal time 7.65 h



Local time 7 tomorrow.

Sidereal time 15.67 h

Local time 8:20 tomorrow.

Sidereal time 17.00 h

Compare to:

May 4th,
03:34 local time

Sidereal time 17.00 h like in previous slide!

Stars exactly in the same direction, positions of planets change more rapidly.

Quiz!

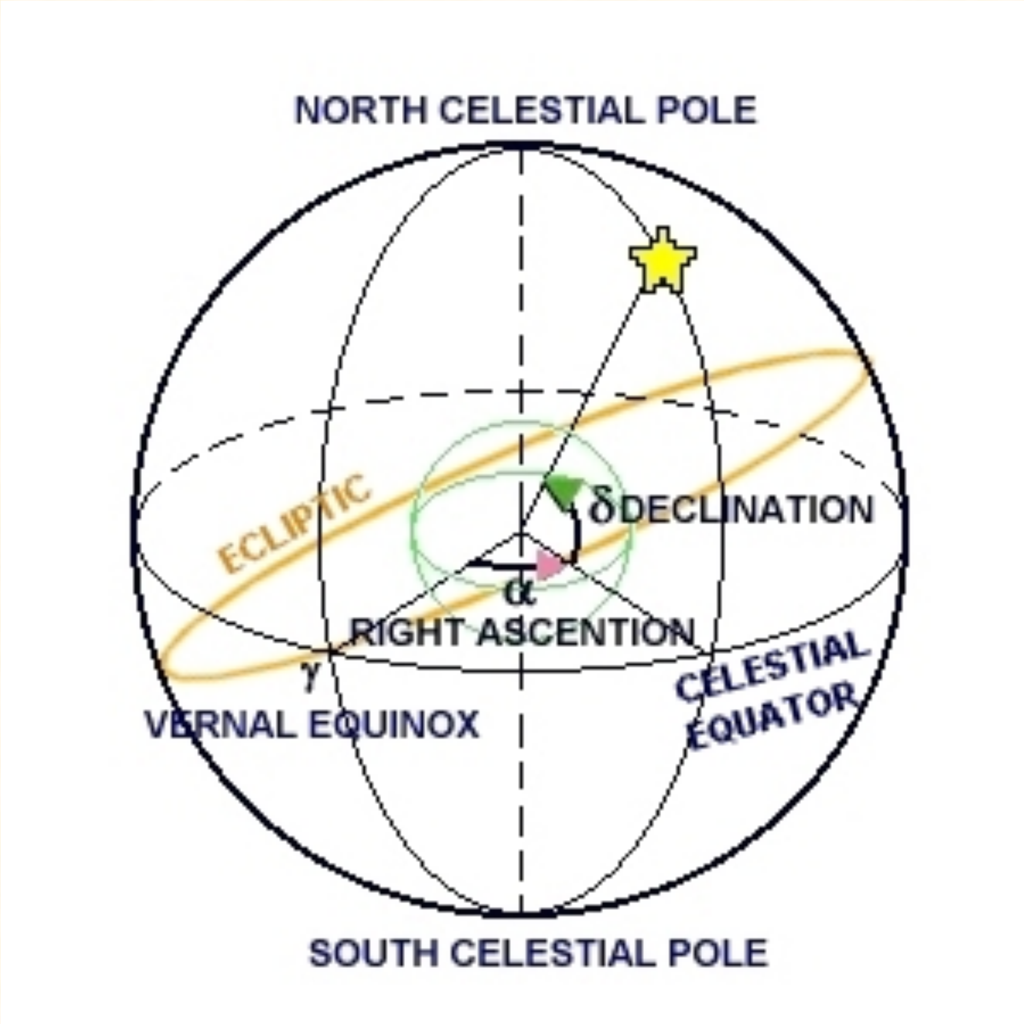
Which one(s) is true:

A. The same stars can always be seen in the same constellation.
B. The same planets can always be seen in the same constellation.
C. Within one full year, all constellations can be seen from Finland.
D. For an observer in Finland, some stars never set.

Coordinate systems (2)

- Equatorial system
  - Right ascension [RA; α].
  - Declination [Dec; δ].
  - Hour angle [h].
  - Sidereal time [LST; Θ].
  - Culmination(s).
  - Circumpolar.
  - Times of rise and set.

Equatorial system



ecliptic = the apparent path that the Sun traces out in the sky during the year. Rotational axis of the Earth is not perpendicular to its orbital plane → the equatorial plane is not parallel to the ecliptic plane, but makes an angle of about 23° 26'

declination = the angle of an object above or below the celestial equator. Degrees.

right ascension = the angle of an object east of the Vernal Equinox point (= apparent location of the center of the Sun at the moment of the vernal equinox). Hours.

hour angle = angular distance between the object and the observer's meridian. When calculating geography/time-dependent information, right ascension is converted into hour angle as an intermediate step. Hours.

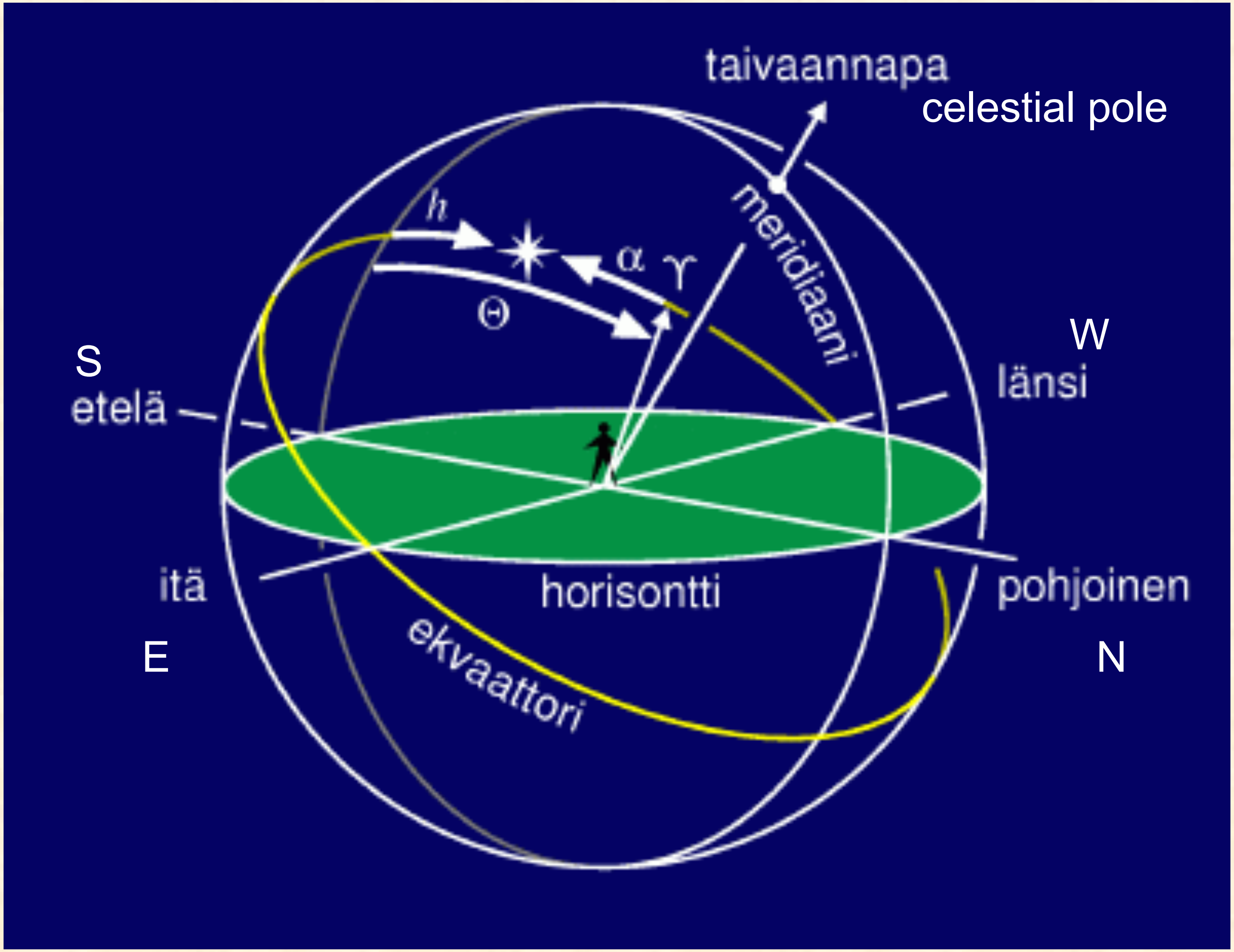
Note:

1^{o} (degrees) = 60’ (minutes of arc; arcminutes)
= 3600” (seconds of arc; arcseconds)

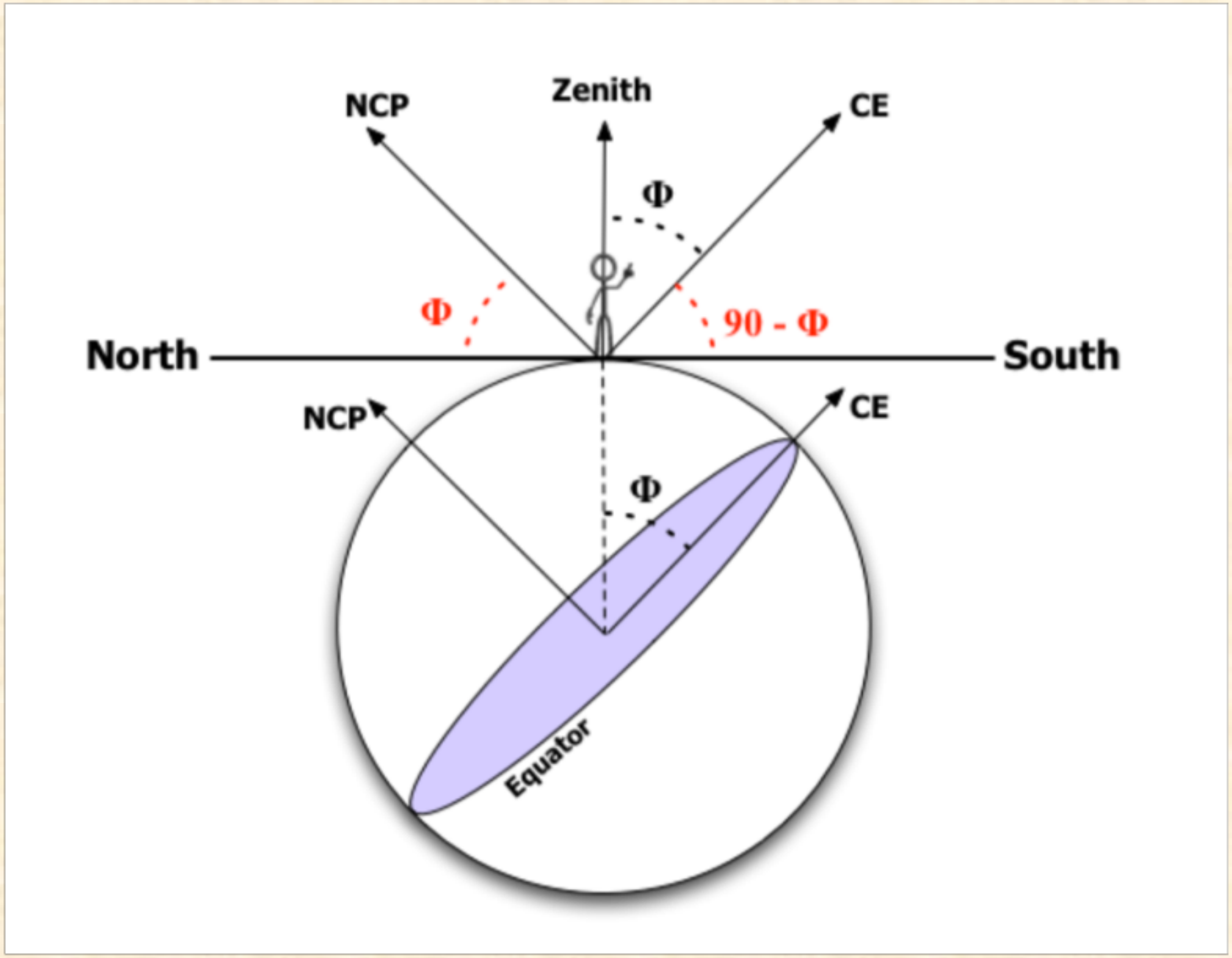
1^{h} (hours) = 60^{m} (minutes) = 3600^{s} (seconds)

$360^{o} = 24^{h}$

Declination in degrees, arc minutes, arcseconds.
RA & hour angle: hours, minutes, seconds.


taivaannapa
celestial pole
h
α
γ
Θ
meridiaani
S
etelä
W
länsi
itä
horisontti
pohjoinen
E
ekvaattori
N

The celestial sphere in the sky (for N hemisphere)



Important! **Only** at the north and south poles,
the celestial equator lies along the horizon.

Quiz!

You will be looking at the star Betelgeuze in the sky tonight, and again in two hours.

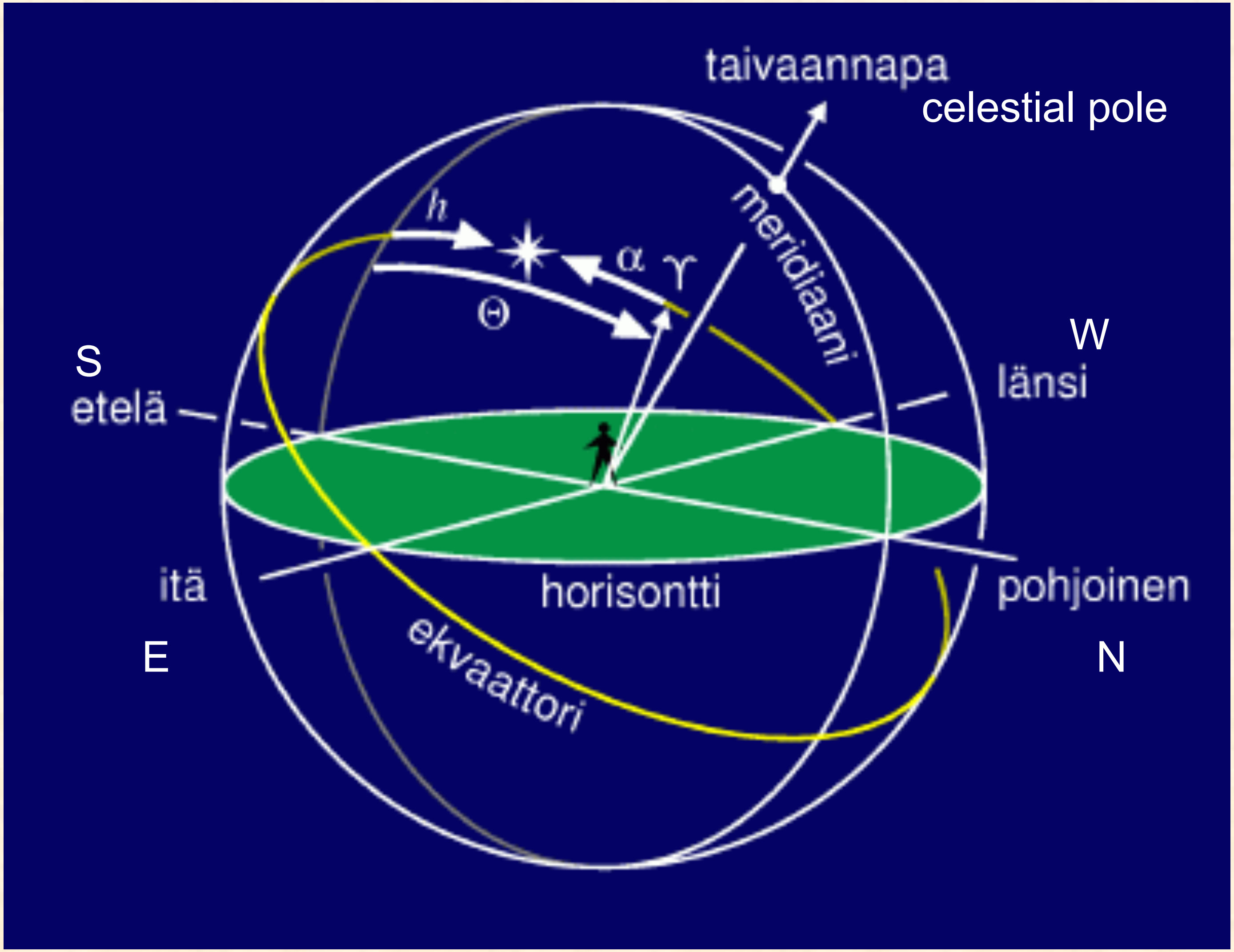
Which one(s) is true:

- **A.** Its azimuth will have changed in two hours.
- **B.** Its right ascension will have changed in two hours.
- **C.** It will be in another constellation in two hours.
- **D.** Its elevation will have changed in two hours.

Converting coordinates

- Star's position is unambiguously defined by right ascension & declination.
- To calculate the current position in the sky (where to look at or where to point your telescope), time and observer's latitude is also needed.
- Time information is converted from local time to the local sidereal time [LST; Θ].
  - LST: formally, the hour angle of the vernal equinox.
  - Time system according to which the same star is always in the same direction at the same time.
- Relationship between the LST, right ascension and hour angle is used in the formulae next page.
  - $\Theta = h + \alpha$

Revisiting this: pay attenion to the Θ



… Converting coordinates

- Horizontal to equatorial:

  $\sin h \cos \delta = \sin A \cos a$

  $\cos h \cos \delta = \cos A \cos a \sin \varphi + \sin a \cos \varphi$

  $\sin \delta = -\cos A \cos a \cos \varphi + \sin a \sin \varphi$

- Equatorial to horizontal:

  $\sin A \cos a = \sin h \cos \delta$

  $\cos A \cos a = \cos h \cos \delta \sin \varphi - \sin \delta \cos \varphi$

  $\sin a = \cos h \cos \delta \cos \varphi + \sin \delta \sin \varphi$

- Elevation and declination are between -90°,+90°, sine of the angle defines the angles unambiguously.
- Azimuth and right ascension are between 0,+360° (or 0h,24h); to define the right quadrant both sine and cosine must be calculated.
- Hour angle: time to/from passing the meridian, symmetric.

Times of rise and set

- $\cos h = -\tan \delta \tan \phi +$
  $\sin a / (\cos \delta \cos \phi)$
- Rise/set: a=0 —>
  $\cos h = -\tan \delta \tan \phi$
- Note: for observational purposes elevation of > 0 degrees is not enough! (Depends on location and type of observations; typically assume ca. 20 degrees.)
- For a certain moment in time, the hour angle can be calculated from the right ascension by using the sidereal time:
  $\Theta = h + \alpha$
- Circumpolar = objects that are always above the horizon
  - Northern hemisphere: $\delta > 90° - \phi$

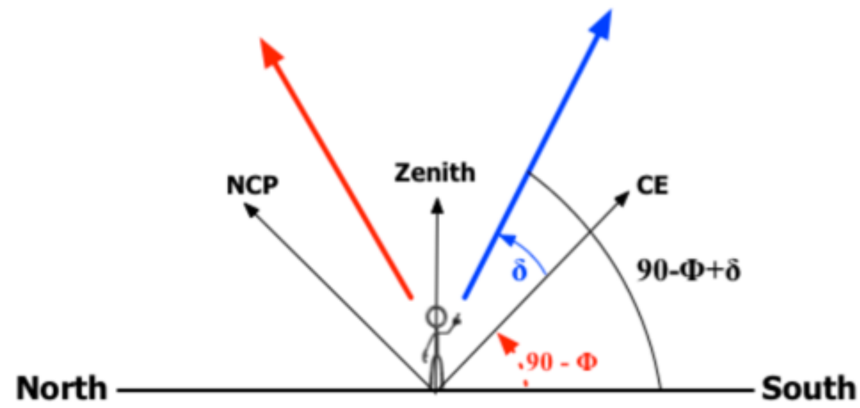
Culmination / transit

- In astronomy, the culmination of a planet, star, etc. is the elevation reached when the object transits over observer's meridian.
  During a sidereal day, an astronomical object will cross 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.

  $a_{max} = 90° - \varphi + \delta$
  when culmination occurs south of zenith
  $a_{max} = 90° + \varphi - \delta$
  when culmination occurs north of zenith

- Hour angle h: How many hours to/from culmination.

As shown here, the north celestial pole lies at an altitude of Φ above the horizon, and the celestial equator is 90° away. At it's highest point, the celestial equator attains an altitude of 90-Φ, as shown above. The declination of the star is measured from the celestial equator, and so the transit altitude of our star is given by 90-Φ+δ. The star will be due south when it transits. What about a star in the direction given by the red arrow? For this star, the formula 90-Φ+δ yields an altitude of more than 90°, but as we have seen, altitude ranges from 0° to 90°. Instead, we must use the formula 180-(90-Φ+δ), as shown in the diagram below. This star will be due north when it transits.



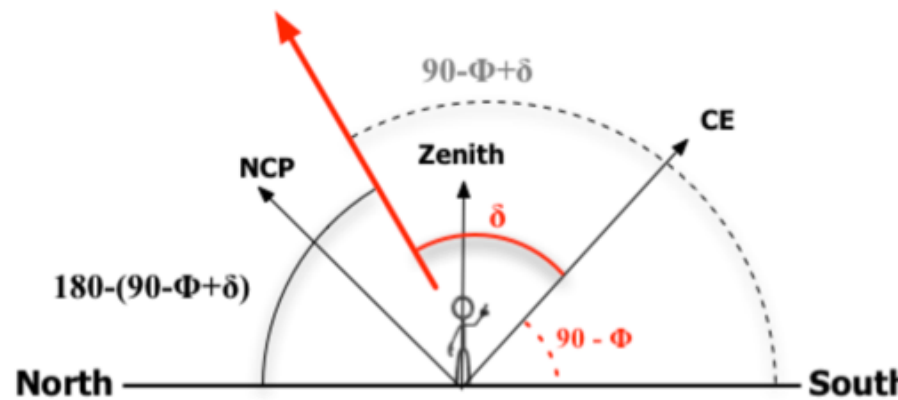


Image taken from:
`http://slittlefair.staff.shef.ac.uk/teaching/phy115/session1/`
(useful material!)

Homework – voluntary, **but do it**!

- Familiarise yourself with some skymap software or the Ursa stellar map – links will be provided in lecture material.
- Get to know some of the constellations that can be seen in the night sky at this time of the year, for example Orion, Cassiopeia (in Finnish "Kassiopeia") or Ursa Major ("Iso Karhu") or a famous part of it, Big Dipper ("Otava"), or some other constellation of your choice.
- Use sky map's tools to change the time, and pay attention to how the position of the constellation changes in the sky through the night. Check the situation also for some other months of the year!
- If the sky is clear during this week, try to find "your" constellation in the sky with the help of the sky map!

Voluntary homework, continued

- Using the sky map software, choose a location
  A) On the North/South Pole
  B) On the Equator
  Follow the paths of the stars trough the night, and at different times of the year.

  On the Equator location, pay special attention to how the stars behave in the directions North, West, South, East!

- **Having a basic understanding of these will enormously help you during the exercise session (and exam!)**

An easy-to-use sky map for Finland: http://www.ursa.fi/extra/tahtikartta/
You can enter the desired viewing date and time in the box below the map, or fast forward/backward.
Unfortunately the names of constellations etc. are here only available in Finnish :(

Lots of sky map apps are available for Anrdoid, iPhone, iPad etc. Look for SkyMap, for instance. Some of them (including SkyMap) allow you to point into a certain direction in the sky and use the device's sensors to identify the constellations visible in that direction!

Stellarium, http://www.stellarium.org/
A sophisticated free planetarium software available for most platforms.
It takes a while to familiarize yourself with all the various properties of this software, but it is a really powerful tool for astronomy enthusiasts! This may also be useful for checking the answers that you get for your calculations of the exercises.
To get started: Set the desired location in the location menu of the left side menus, and the desired date & time in the date & time window. Especially if you want to study locations of observatories elsewhere in the world, pay attention to the time zone -- the default is your computer's time zone, so it is advisable to change it to UTC time in order not to get confused.
In the search window you can give in the coordinates of your target source, and in the astronomical calculations window you can study for example its elevation vs. time plot.

Skymap.org: http://www.sky-map.org/
A web-based sky viewing application that lets you study individual objects in more detail. Not so practical for finding your way in the local night sky, though.

Coordinate systems (3)

- Star catalogs etc.
  - Epoch.
- Sun
  - Coordinates.

- Ecliptic coordinates.
- Galactic coordinates.

Will not be properly covered in this course

- Things that change coordinates.

Coordinates

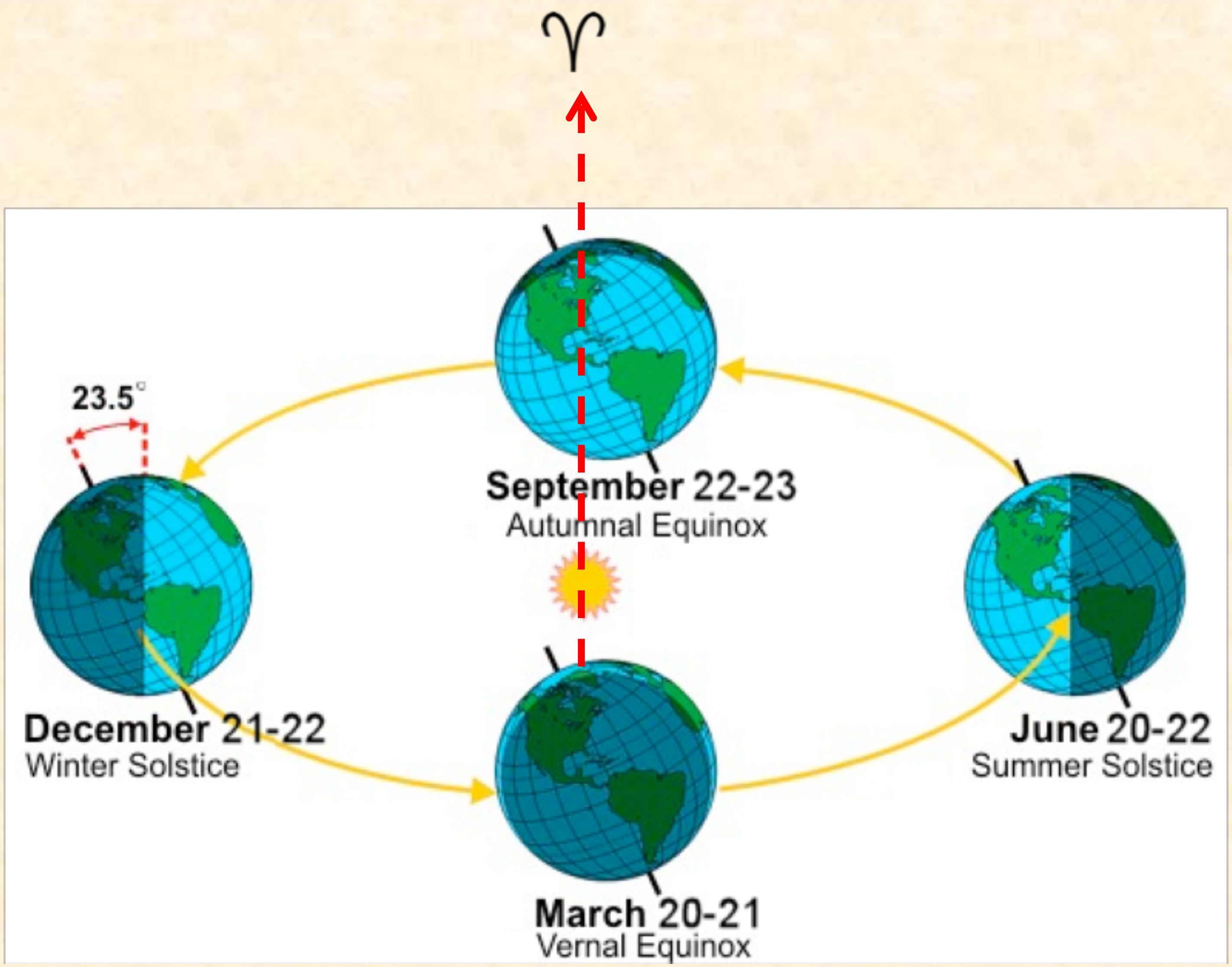
- Example of a source list:
  Epoch B1950.

0048-097	$00^h48^m09.99^s$	$-09°45'24.6''$
3C 120	$04^h30^m31.60^s$	$+05°14'59.5''$
2155-304	$21^h55^m58.30^s$	$-30°27'54.0''$
BL Lac	$22^h00^m39.40^s$	$+42°02'09.0''$

- RA: when the object culminates, in LST,
  Dec: defines the highest elevation (elevation of the culmination; see earlier slide).
  Observers usually think in the LST timeframe!
  (→ see slides later in this lecture)
- Coordinates must be converted to the present epoch for observations (see: causes for changes to coordinates).
  - For our course exercises it is enough to note that the effect is neglible for your calculations.

Coordinates of the Sun

- Declination
  - Range +- ε (= 23.4°)
  - Extremes at Summer (June) Solstice & Winter (December) Solstice.
  - 0° at Equinoxes.
- Right ascension
  - Zero point of equatorial coordinate system at Vernal Equinox (Spring Equinox).
  - Must also be a yearly cycle.
    → 6 h at Summer Solstice
    12 h at Autumn Equinox
    18 h at Winter Solstice.


♈
23.5°
September 22-23
Autumnal Equinox
December 21-22
Winter Solstice
June 20-22
Summer Solstice
March 20-21
Vernal Equinox

Coordinates of Solar System objects (planets)

- Orbit the Sun, ca. on the ecliptic plane
  → Move against the background stars.
  → RA and Dec are not constant.
- Each planet on its own orbit
  → changes in the coordinates are different for all planets.

“Useful to Know”

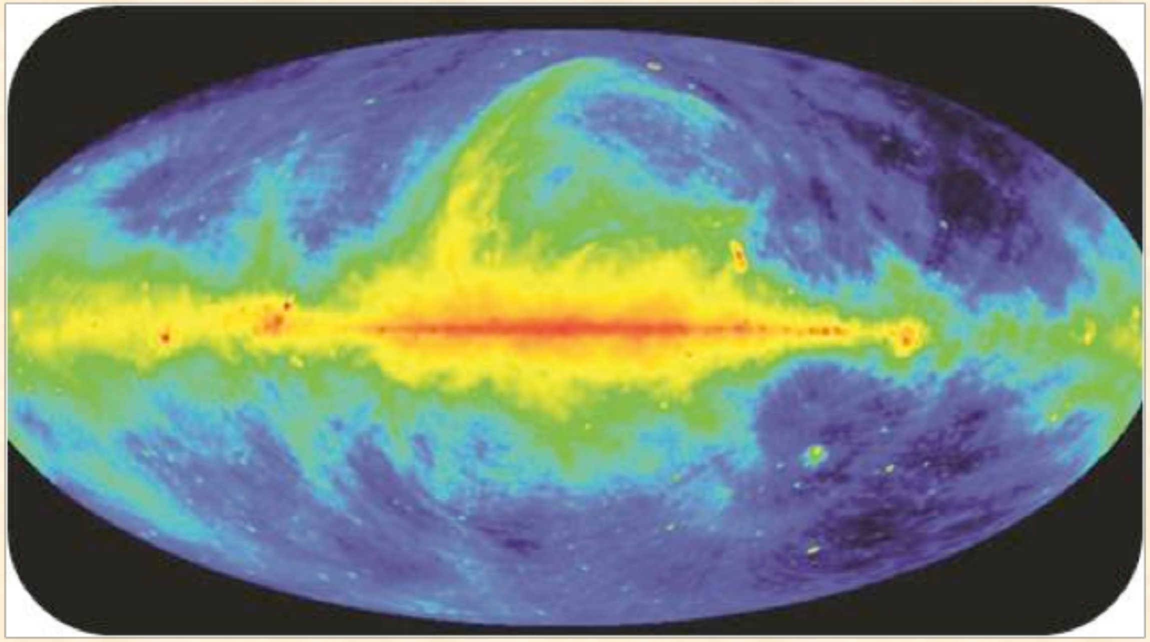
Ecliptic coordinates

- The ecliptic as the fundamental plane.
- Useful for planetary coordinates.
- Center: Sun → heliocentric
  Earth → geocentric
- Spherical coordinates longitude, latitude and distance.
- Rectangular coordinates through conversion.
  - Useful for orbital calculations.

“Useful to Know”

Galactic coordinates

- Center: Sun
- Fundamental plane: Galactic plane
- Galactic longitude, galactic latitude
- Natural use: galactic surveys etc.

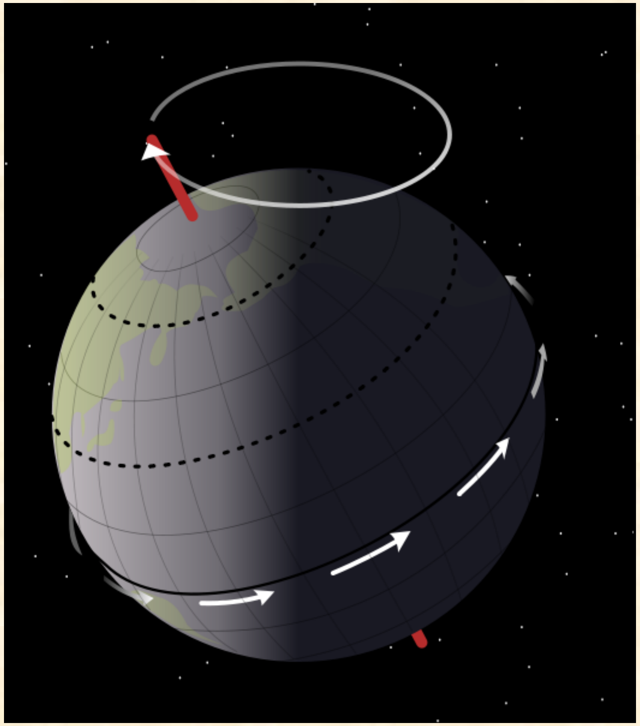


The sky seen at a radio frequency of 408 MHz. Credit: G. Haslam/MPIfR

Changes to celestial coordinates are caused by:

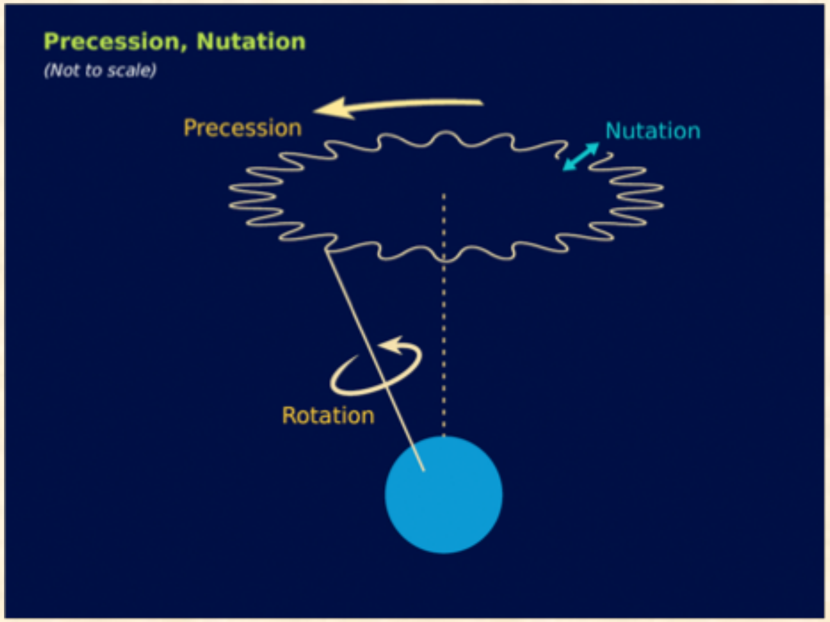
- Precession.
- Nutation.
- Parallax.
- Stellar aberration.
- Refraction.

Must be taken into account when pointing the telescope



Explanations

- Precession:
  Change in the orientation of the rotation axis of a rotating body. The Earth goes through one such complete precessional cycle in a period of ca. 26000 yrs.
- Nutation:
  The Moon's precessional cycle is 18.6 yrs, and the effect it causes to Earth's rotation is called nutation.



“Useful to Know”

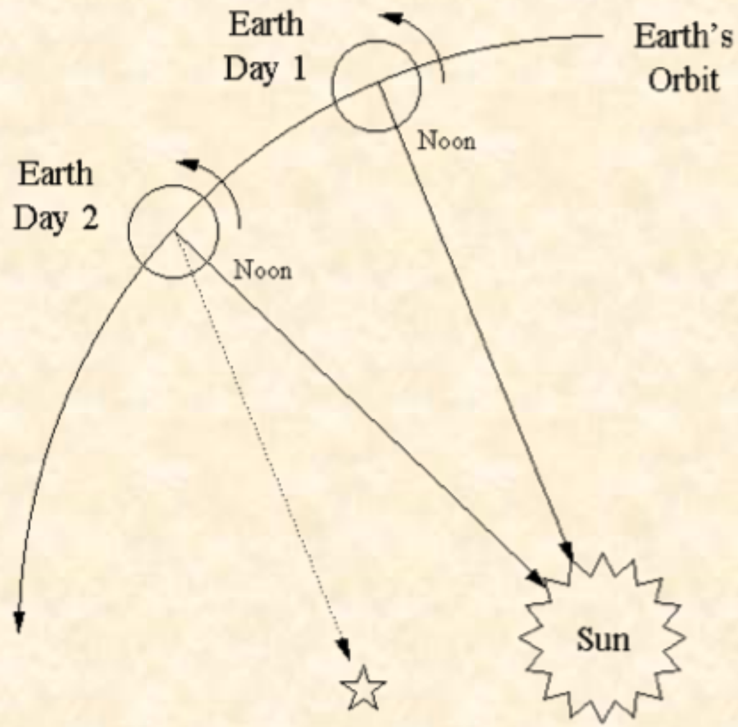
… Explanations

- Parallax:
  An apparent displacement or difference in the apparent position of an object viewed along two different lines of sight. Parallax created by the different orbital positions of the Earth causes nearby stars to appear to move relative to more distant stars.
- Stellar aberration.
  The apparent position of a star is displaced from its true position by an amount which depends solely upon the transverse component of the velocity of the observer with respect to the vector of the incoming beam of light. Independent of the distance between object and observer.
- Refraction.
  The angular displacement of astronomical objects from their true position due to the bending of rays in the Earth's atmosphere. (The refractive index varies according to the thickness of the airmass, temperature, pressure, etc.)

Solar time and sidereal time (1)

- Sidereal day = relative to stars.
- Synodic day = relative to the Sun.

$\Delta t = 3m56s$



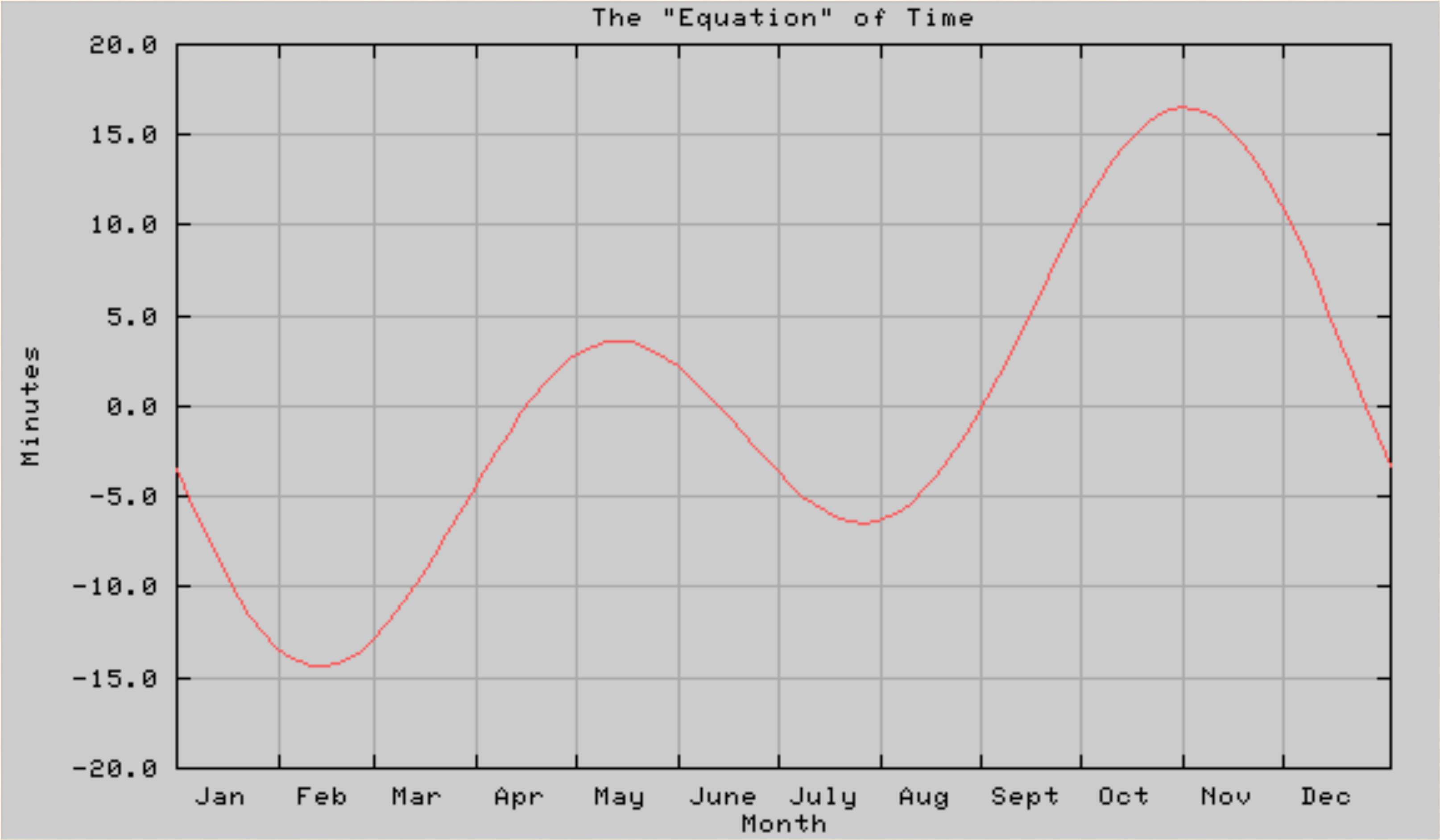
Solar time and sidereal time (2)

- Mean solar time ("conceptually the hour angle of the fictitious mean Sun"), apparent solar time.
- Standard time (for a region, country, etc.): Finland: meridian 30° E.
- Local time, local mean time, local apparent time (either for a region or a certain longitude).
- Daylight saving time (in the summer), DST.
- Equation of time.

- "It is XX o'clock..." / local time / standard time + DST

“Useful to Know”

Equation of Time



The **equation of time** is the difference between apparent solar time and mean solar time.

Time standards

- Universal Time UT[1], UT1[1], UT0[1].
  - Time standard based on Earth’s rotation.
- International Atomic Time TAI[2].
- Terrestrial dynamic time TDT[2].
- Barycentric dynamical time TDB[2].

“Useful to Know”

- **Coordinated Universal Time UTC**
  (“wrist watch” time, but always at Greenwich meridian)
  = time standard based on International Atomic Time (TAI) with leap seconds added at irregular intervals to compensate for the Earth's slowing rotation. Leap seconds are used to allow UTC to closely track UT1, which is mean solar time at the Greenwich Observatory,

[1] = Takes into account Earth's rotation; empirical and uneven.

[2] = Atomic clocks; is not relative to Earth's motion, even.

Julian Day

- Zero epoch 4712 BC.
- 1.2.2000 JD=2451545.0.
- Also Modified Julian Day, MJD.
- Note: Has nothing to do with the Julian calendar!

Calculation:
v=year, k=month, p=day; all divisions are INT(a/b)
Julian day at noon of the day v, k, p is:

$$JD = 367v-7(v+(k+9)/12)/4- 3((v+(k-9)/7)/100+1)/4+ 275k/9+p+1721029$$

Example1. January 1st, 2000, 12:00 UT: JD = 2451545.0.
Example2. June 19th, 1987, 12:00 UT: JD=2446966.0.

Estimating the sidereal time

- On vernal equinox (approx. 21.3.)
  $\Theta = T + 12h$.
  T = local solar time.
- Otherwise
  $\Theta = T + 12h + n*4min$.
  n = days since vernal equinox.
  - Note: A year's cycle;
    don't make the calculations unnecessarily complicated!

Estimating the sidereal time, example

- Example: What is the sidereal time in Helsinki on 15.4. 23:00?
  - "23:00" presumably "local time", using daylight saving time → 22 Finnish standard time.
  - T in Helsinki lags ca. 20 min Finnish standard time → 21h40min.
  - You can also include the effect of the equation of time: very small in April.
  - Ca. 10 + 15 days after Spring equinox.
- Thus:

$\Theta \approx$ 21h40min + 12h + 25*4min = 35h20min = 11h20min.