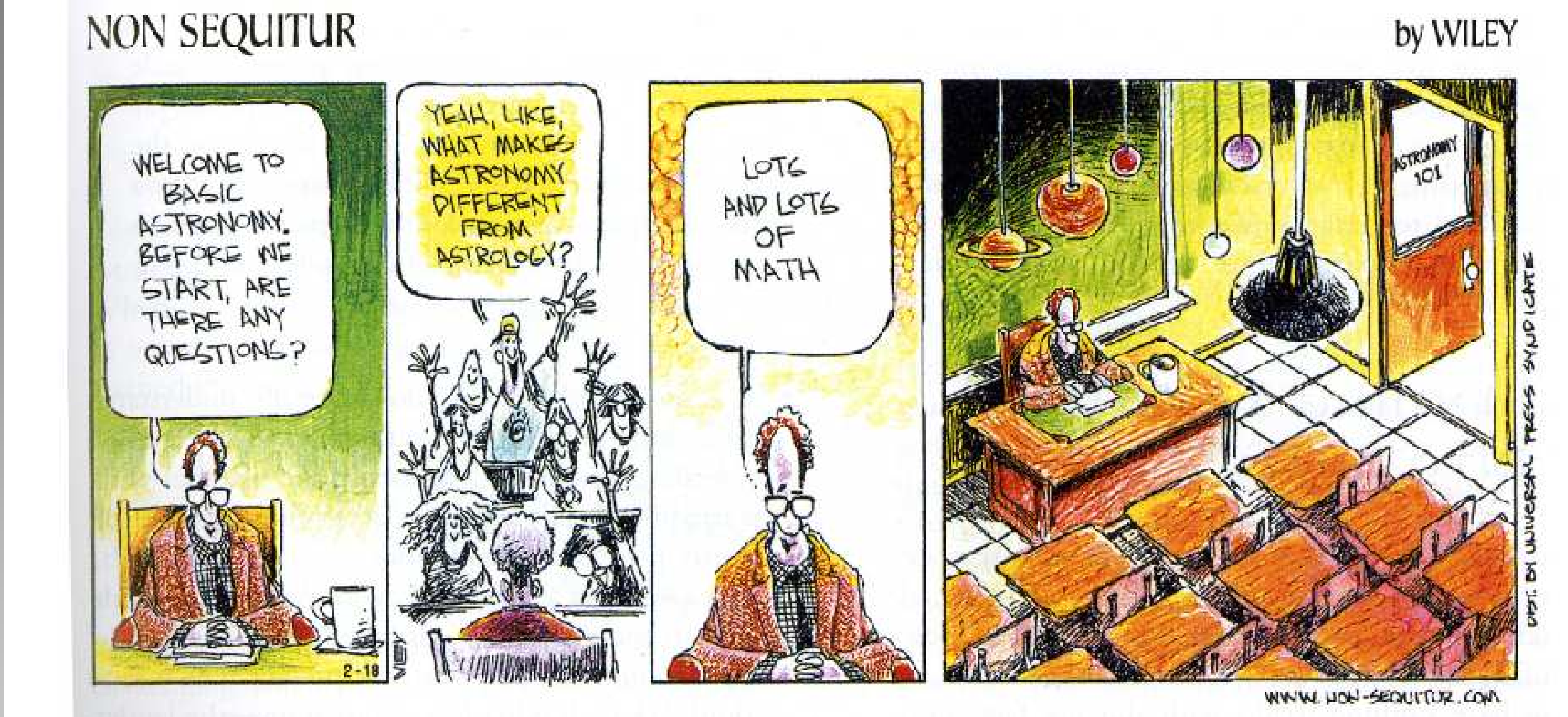
Observational Techniques in Optical/IR Astronomy

Basics I: Positional Astronomy



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Basics I: Positional Astronomy

Positional astronomy treats celestial objects (e.g. stars, planets, galaxies) as if they are on the surface of an imaginary sphere:

- ***The Celestial Sphere***
- ***From the perspective of their instantaneous positions, we can ignore their distances and assume (like the Greek's!), that they are 'painted' onto this sphere, as if the sky were really a solid surface.***
- ***Again, like the Greeks, we can pretend that the Earth, our observing 'platform', is fixed at the centre of the sphere, and that the sky or celestial sphere rotates about it.***
- ***For these purposes, we're quite happy assuming an Aristotlian (geocentric) universe!***

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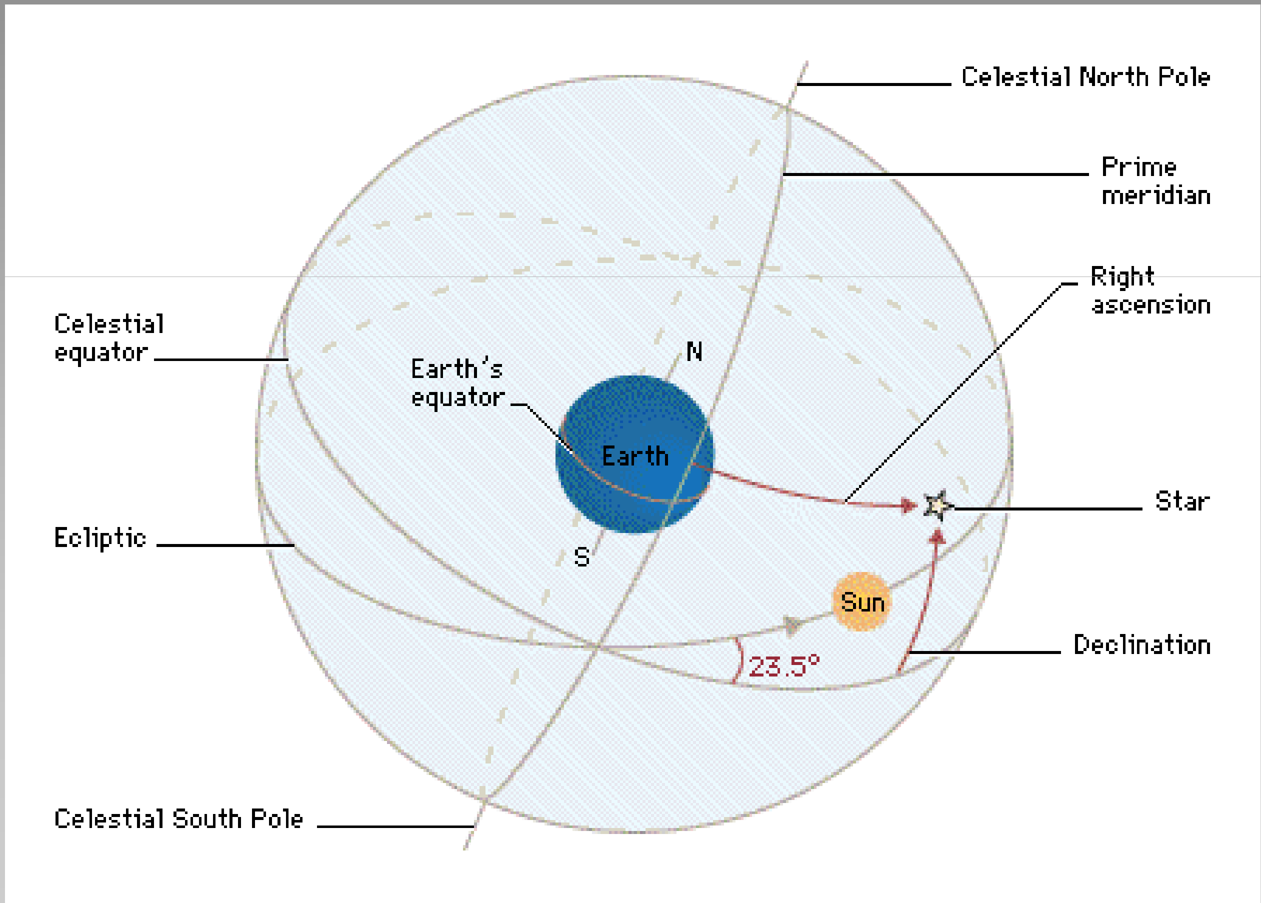
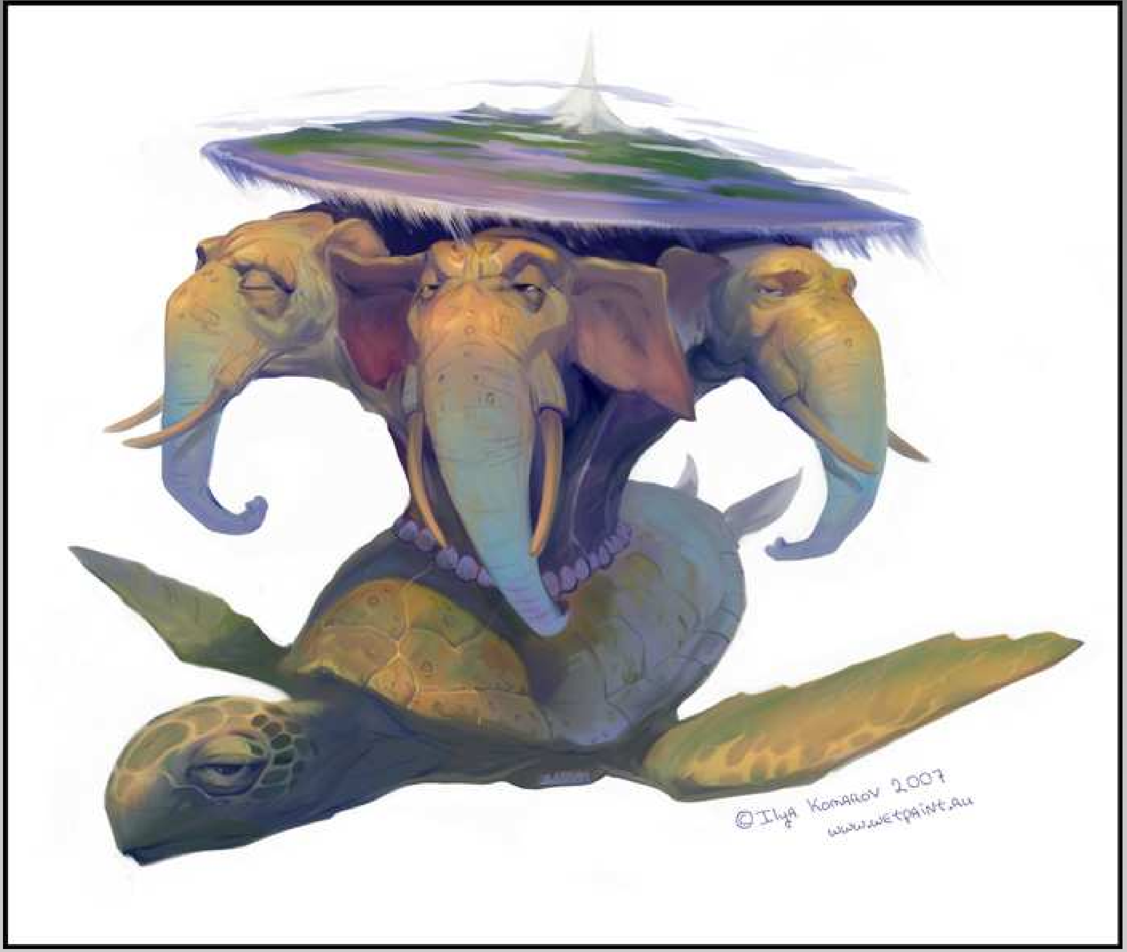
Basics I: Positional Astronomy

While this model of the Universe was eventually proven to be wrong (e.g. by Copernicus & Galileo), it serves as a useful mathematical mode when it comes to the basics of positional astronomy!



Basics I: Positional Astronomy

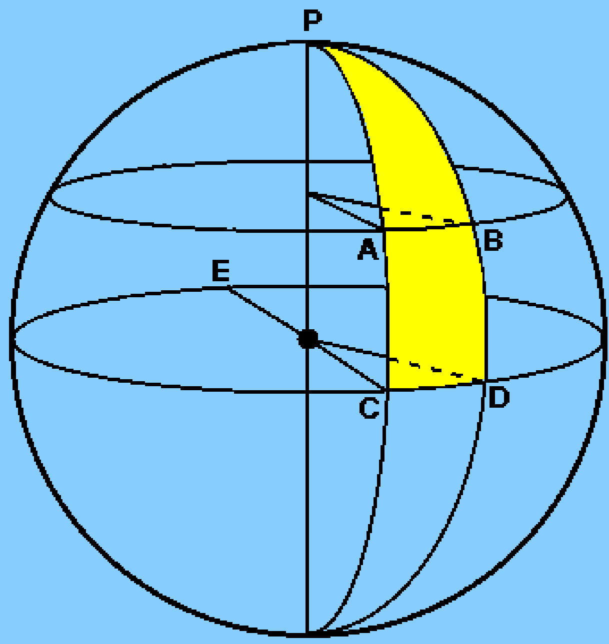
And its not as bad as some cosmologies (e.g. Terry Pratchett's "Diskworld")!



Spherical Trigonometry: the tool for positional astronomy

It is used to determine position of objects on *any* spherical surface

- The Earth (geodesy; surveying)
- The Sky or Celestial Sphere (positional astronomy)
- Use non-Euclidean geometry of *spherical triangles*
- Σ angles in a *spherical triangle is > 180º*

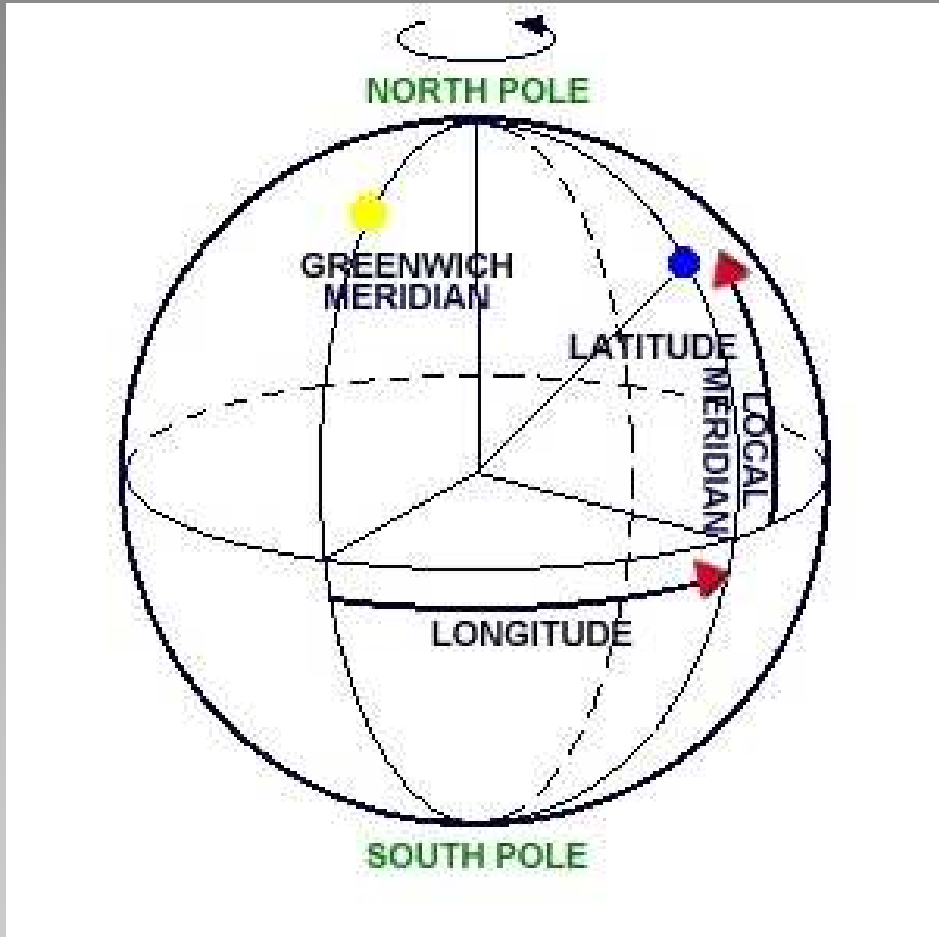


Definitions:

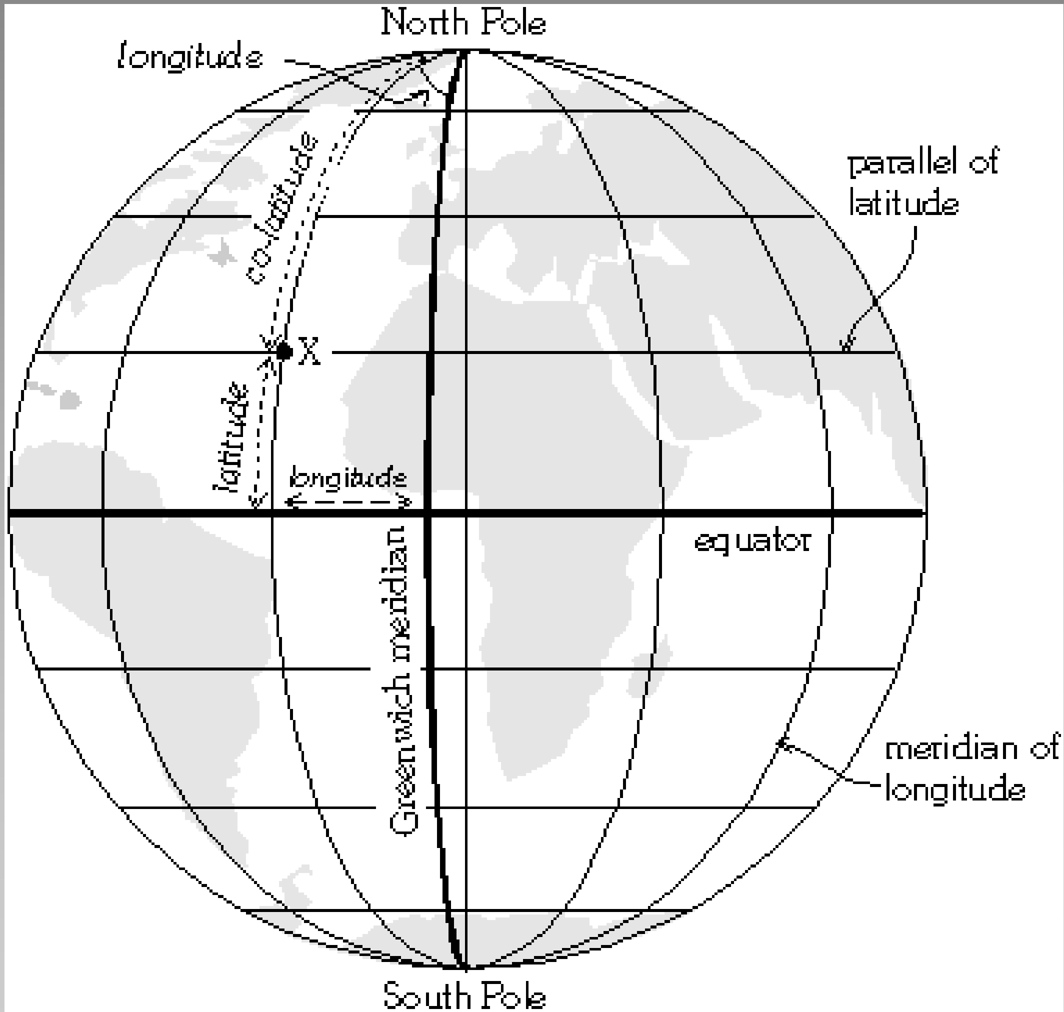
1. *Circle: any planar intersection (slice) of a sphere*
2. *Great Circle: planar section which passes through the centre of a sphere*
3. *Small circle: planar section NOT passing through the centre*
4. *An axis of a great circle is the diameter perpendicular to the plane of the circle*
5. *Poles are where an axis intersects a sphere*

Latitude & Longitude

- Coordinate system of the Earth
- Equator is the *fundamental plane*
- Axis of equatorial plane is the rotation axis of the Earth
- North & South poles are the poles of the equatorial plane
- Two coordinates are:
  - Latitude (measuring North-South)
    - » Small circles: parallels of latitude
  - Longitude (measuring East-West)
    - » Great circles: all pass through poles



Latitude & Longitude

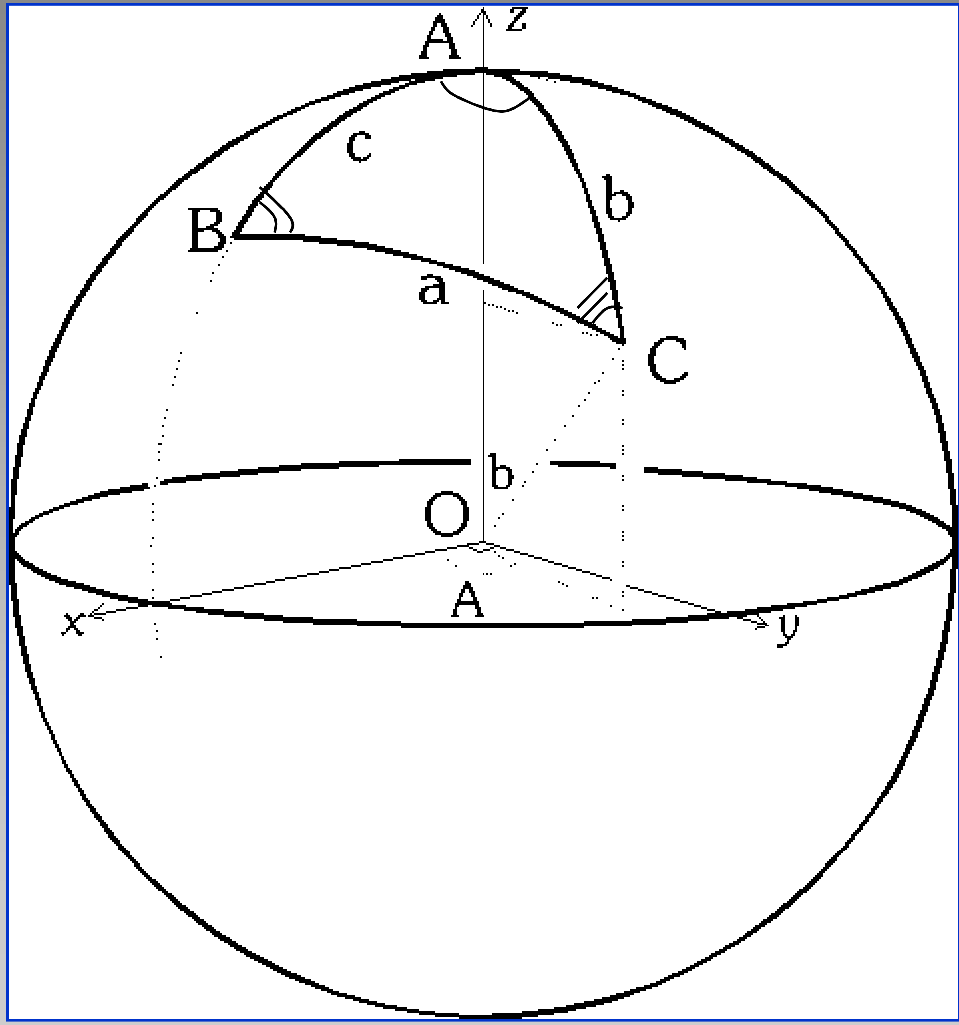


- **Definition of zero latitude is *physical* (i.e. great circle perpendicular to spin axis**
- **Definition of zero longitude is arbitrary, defined as great circle passing through Greenwich, London.**

Spherical Triangles

- **Spherical triangles are made up of arcs of great circles**
  - **If any of the arcs are NOT great circles, then it is NOT a spherical triangle, *even if it looks like a triangle on a spherical surface.***
- **Mathematically, a great circle, or segment of a great circle, is a *geodesic*: the shortest distance between two points on a sphere**
- **Unlike a planar triangle, the sum of the angles of a spherical triangle can vary:**

180º < sum of angles < 540º



Spherical Triangles

- **Spherical triangles are made up three sides and three angles, whose sum is generally > 180º**
- **Each *side* can also be expressed as an angle subtended at the centre of a sphere**
- **So all size measurements (3 sides; 3 angles) are expressed as angles**
- **Any three of the six measurements fully define a spherical triangle**
- **Two important formulae for determining angles of a spherical triangle:**
  - ***The Sine rule:***

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

  - ***The Cosine rule:***

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

The Sky

- Imagine the Earth is *flat* and the sky is a hemisphere centred on your position
- The ***celestial poles*** and ***celestial equator*** are imaginary projections onto the sky of the Earth's polar axis and equator

Definitions

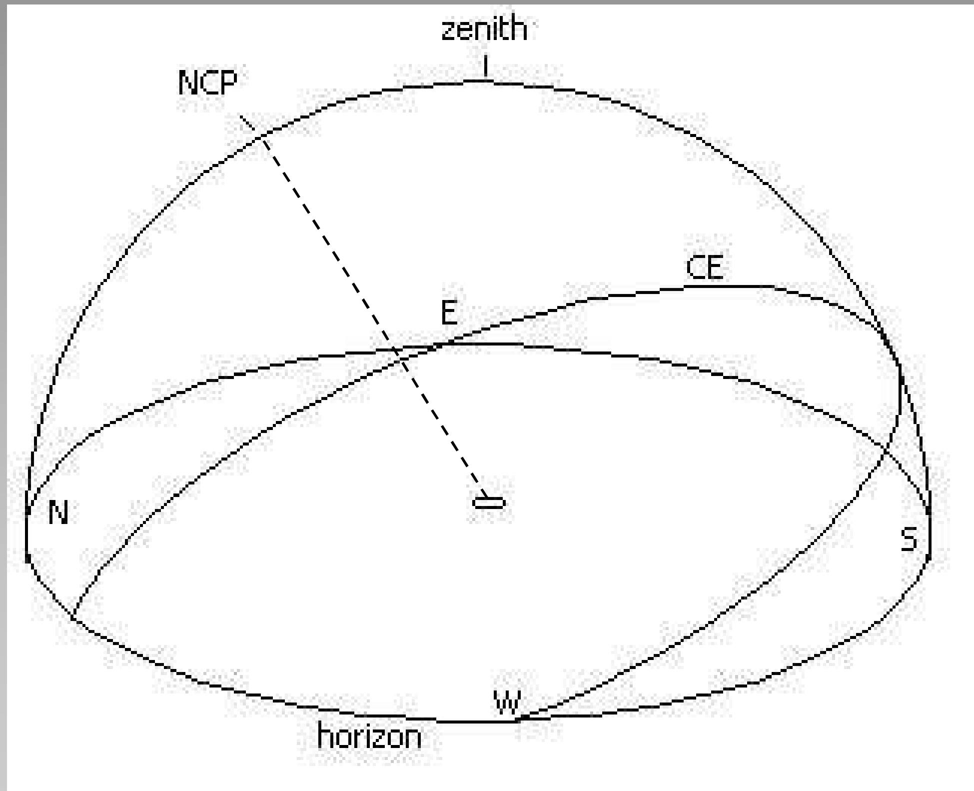
Cardinal points (4): intersections between meridian & horizon (N & S) and equator & horizon (E & W)

Zenith: intersection of the normal to Earth's surface and celestial sphere ('straight up')

Nadir: 'straight down'

Meridian: the great circle which passes through the poles, zenith & nadir

Note: if you are on of the Earth's poles, the equivalent celestial pole is at the zenith and the equator runs around the horizon



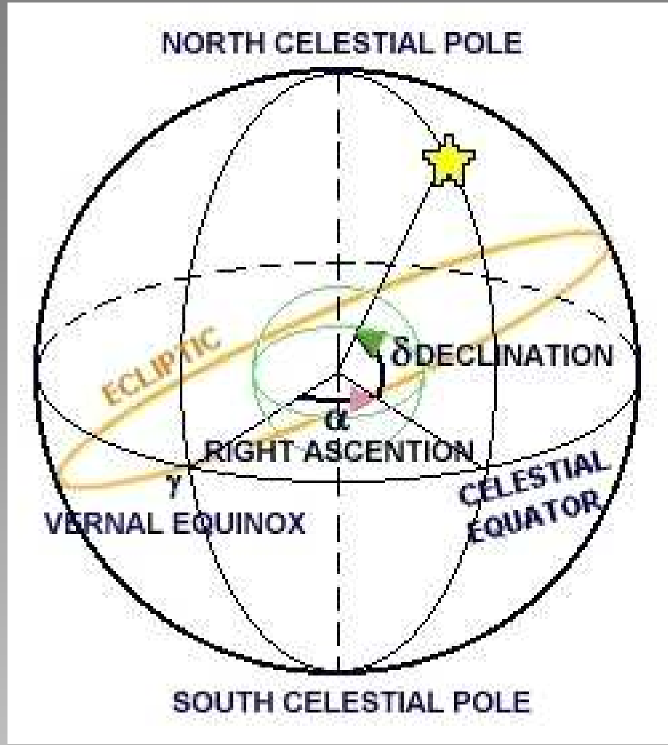
The Sky

Equatorial Coordinate System

- Fundamental circle/plane is the celestial equator
- The poles of this system are the north & south celestial poles (NCP & SCP)
- Objects measured by two coordinates, either:

  1. Hour Angle (H.A.) & Declination (*Dec* or δ) in the 'local equatorial system', or,

  2. Right Ascension (*R.A.* or α) & Declination in the 'general equatorial system')



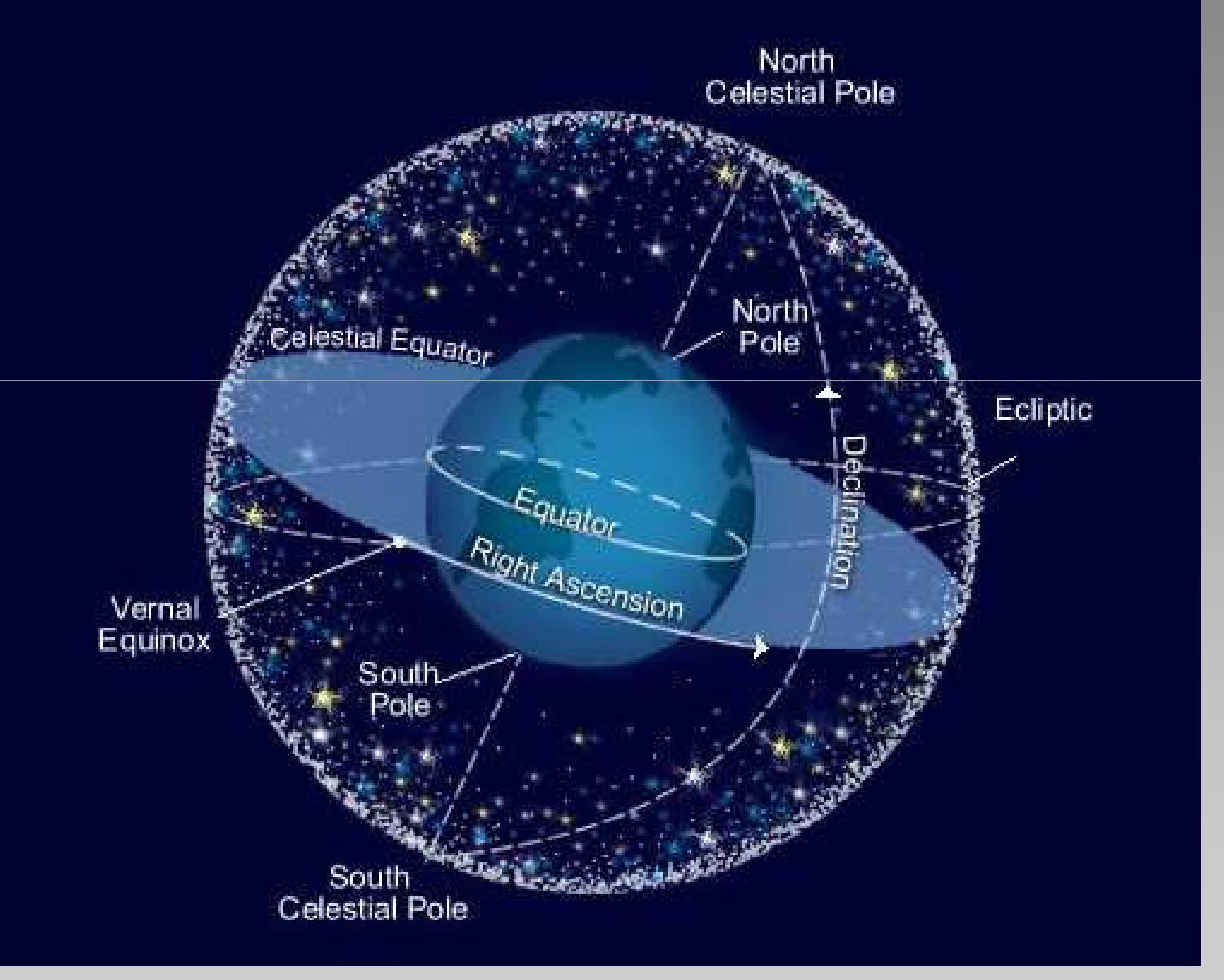
Definitions:

Declination (δ): *angular measure along a great circle from celestial equator to pole (0º to ±90º). [Like latitude on the Earth]*

Hour Angle (HA): *angular measure from the north to where a great circle passing through the object and the celestial poles intersects the equator. Measured in either hours west (+) or east (-) of the north part of the meridian, or sometimes in degree west of north (0º to 360º).*

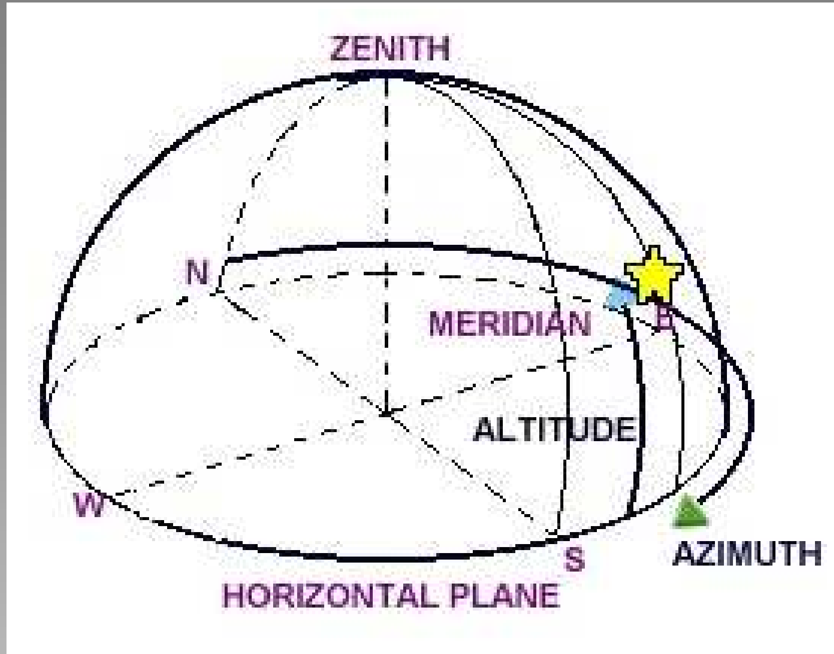
Right Ascension (α): *Like Hour Angle, but measured east from a point on the equator called the First Point of Aries (or Vernal Equinox or Spring Equinox), abbreviated as ♈ [like longitude on Earth]*

The Celestial Sphere & Equatorial Coordinates



Star Trails: Why?

The Sky



Altitude-Azimuth Coordinate System

- Also know as "alt-az" or horizontal system
- Fundamental circle is the horizon
- The poles of this system are the zenith & nadir
- Objects measured by two coordinates:

***Altitude* (or elevation): angular measure along great circle from horizon to zenith (0º to 90º)**

***Azimuth*: angular measure from North cardinal point along horizon to the where the altitude great circle intersects the horizon. Usually measured from North to East (0º to 360º), although there are other conventions sometimes used.**

Zenith distance is also sometimes used (e.g. when dealing with refraction in the atmosphere).

Zenith distanceº = (90 - altitudeº)

***Because celestial object move across the sky (rise in the east; set in the west) due to the Earth's rotation, Altitude & Azimuth generally both change with time (and position on the Earth).* [An exception, for altitude, would be where ?]**

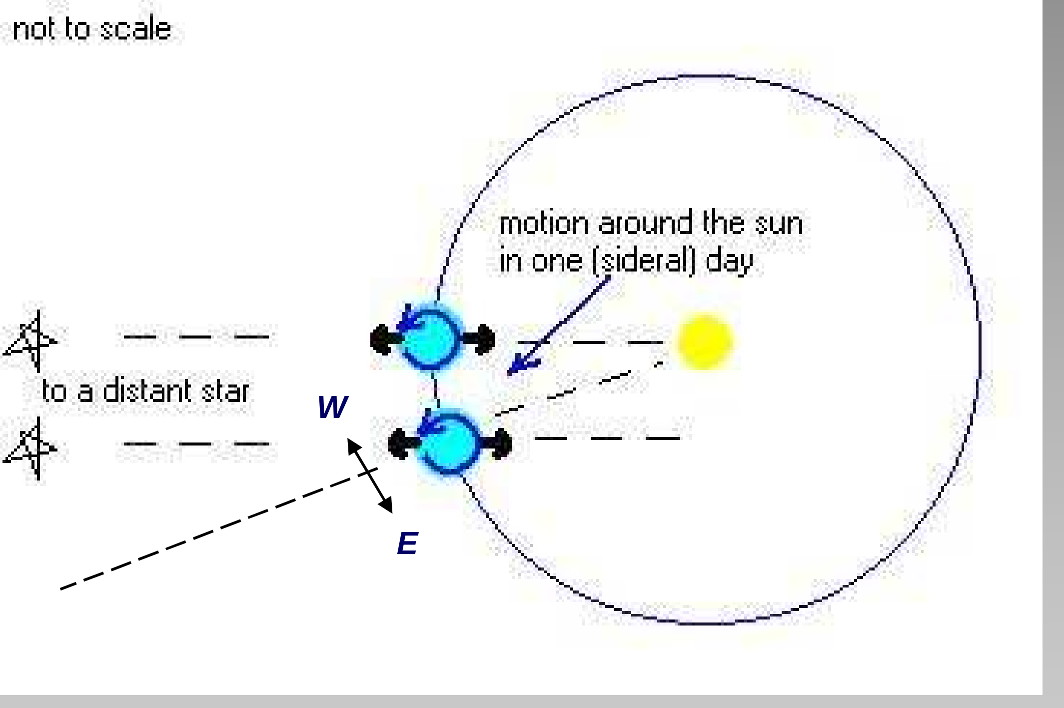
The Sky

General Observations

- **Due to Earth's rotation, objects appear to rise in the east and set in the west, excepting for those that are 'circumpolar' and *never* set.**
- **Objects appear to travel across the sky along small circles of *constant declination***
- **When an object passes its highest point in the sky, this occurs when it crosses the meridian and is called *culmination***
- **Declination and Right Ascension are essentially fixed for most objects, like latitude and longitude are fixed for geographical positions on Earth**
- **Exceptions to the above are for:**
  - **Precession and nutation (wobbling of Earth's spin axis)**
  - **Motion of nearby objects, e.g. solar system objects, or even nearby stars**
- **Hour Angle is dependent on observers location, since it refers to the local meridian**

Sidereal Time

Because the Earth rotates around the Sun (now we adopt Copernicus' theory!), the Sun appears to move with respect to the distant stars.



- **The mean solar day (defined by the time it takes the Sun to reappear at the same position on the sky) is ~4 minutes longer than the mean *sidereal* day, defined as when a star returns to the same position it was seen at the previous day.**

Sidereal Time

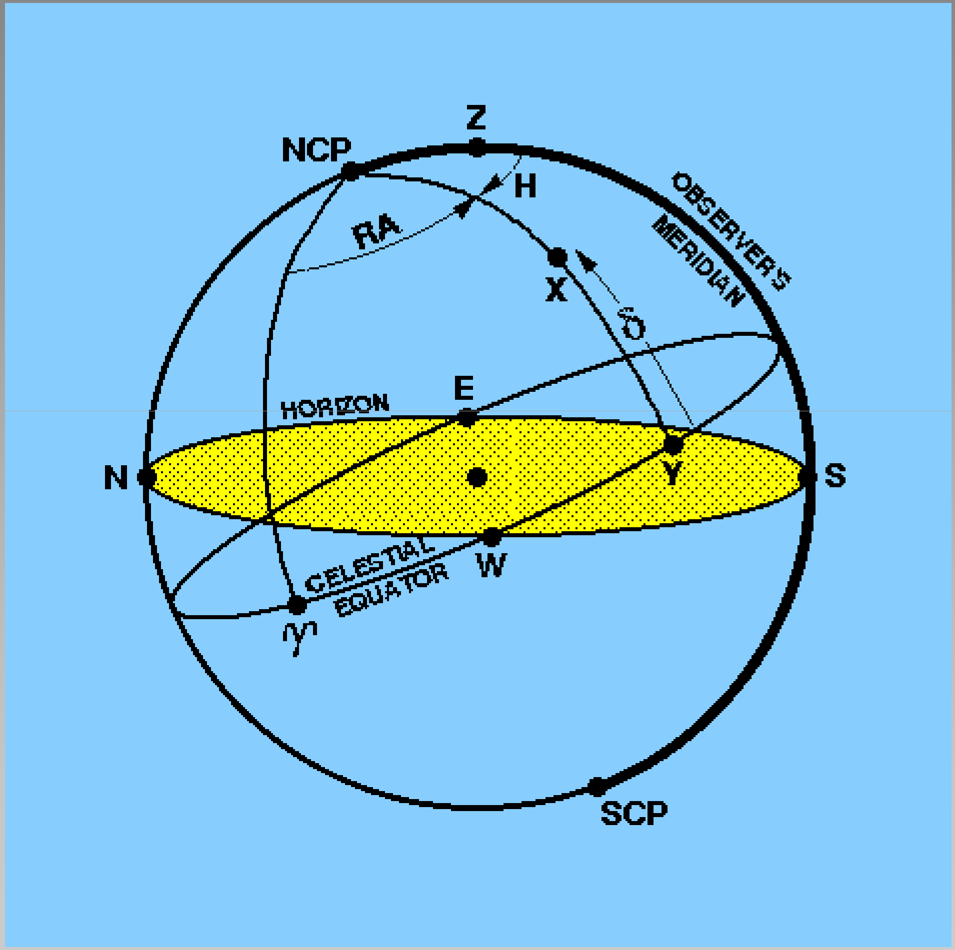
Because the Earth rotates around the Sun (now we *do* adopt Copernican theory!), **the Sun appears to move with respect to the distant stars.**

- **The length of a sidereal day is 23 hour 56 minutes 4.1 seconds**
- **This is *very close,* but *not exactly*, equal to the rotation period of the Earth as measured with respect to the stars**
  - **Because Sidereal Time is measured by the time it take the R.A. "zero point" – the First Point of Aries or Vernal Equinox – to make one rotation across the sky, *not* a star**
  - **Due to the precession of the Earth's axis, the position of the Vernal Equinox (where the Sun crosses the equator) drifts ~50 arcsec per year**
  - **A sidereal day is therefore 0.009 seconds shorter than the true rotation period of the Earth**
- **Another way of looking at this is that because of the motion of the Earth around the Sun, an extra Sidereal Day is produced each year.**
- **A normal year (from Earth's rotation) consists of ~365.25 Solar days and 366.25 Sidereal Days**
  - **1 Sidereal Day = 365.5/366.25 Solar Days = 0.9973 Solar Day = 0.9973 x 24 hours = 23 hours 56 mins 04 sec**
- **Relative to the stars, the Sun moves 360º in 365.25 days, or a bit less that a degree/day. In R.A., this is ~4 minutes a day (average).**

Sidereal Time, Right Ascension & Hour Angle

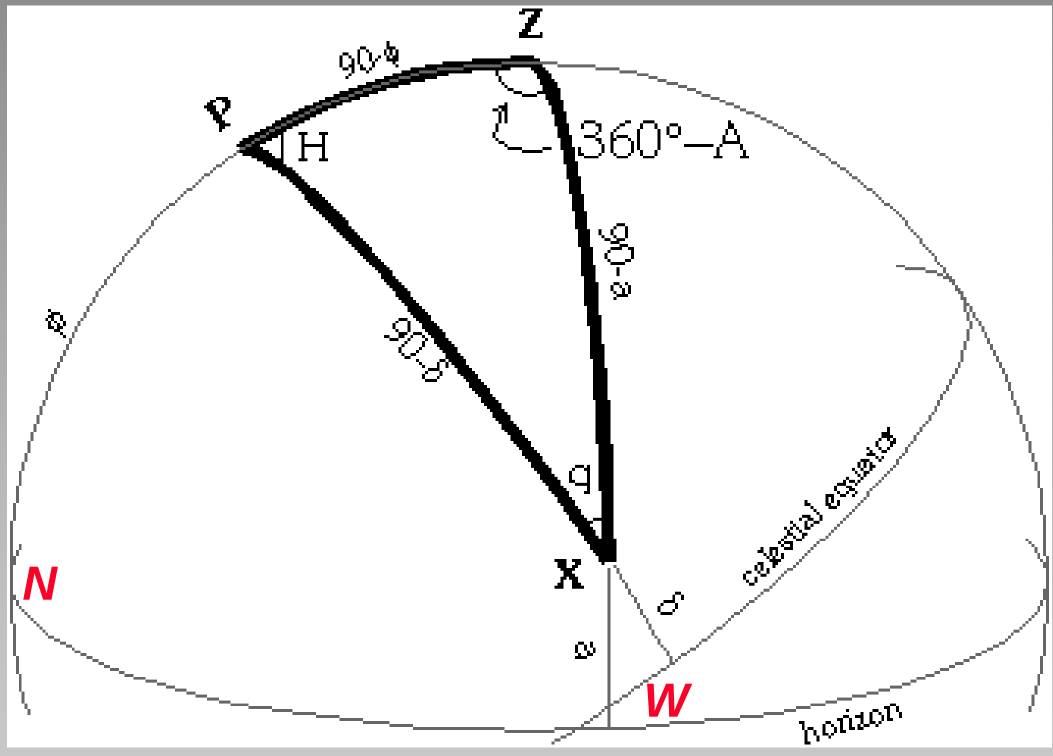
- Local Sidereal Time (LST): The instantaneous Hour Angle (H.A.) of the First Point of Aries (♈, whose R.A. = 0)
- LST depends on the longitude of the location, hence 'local'
- The start of a new sidereal day (0 hours 0 min 0 sec) is when ♈ crosses the meridian.
- ♈ is the 'zero point' of R.A. coordinate
- For a star on the meridian:

  LST = R.A. of star
- Once you have LST (e.g. from a clock or time tables) and R.A. (from a catalogue), you can locate an object in the sky from its H.A.



Coordinate Conversion

Lets consider Horizontal (or Alt-Az) and Equatorial systems.



- **φ = latitude; A = azimuth; a = altitude; H = Hour Angle; δ = Declination; q = parallactic angle**

Coordinate Conversion

Lets consider the spherical triangle formed between arbitrary object (X), the pole (P) and the zenith (Z):

- ***Using the cosine rule***

$\cos(90 - a) = \cos(90 - \delta)\cos(90 - \varphi) + \sin(90 - \delta)\sin(90 - \varphi)\cos H$

$\Rightarrow$

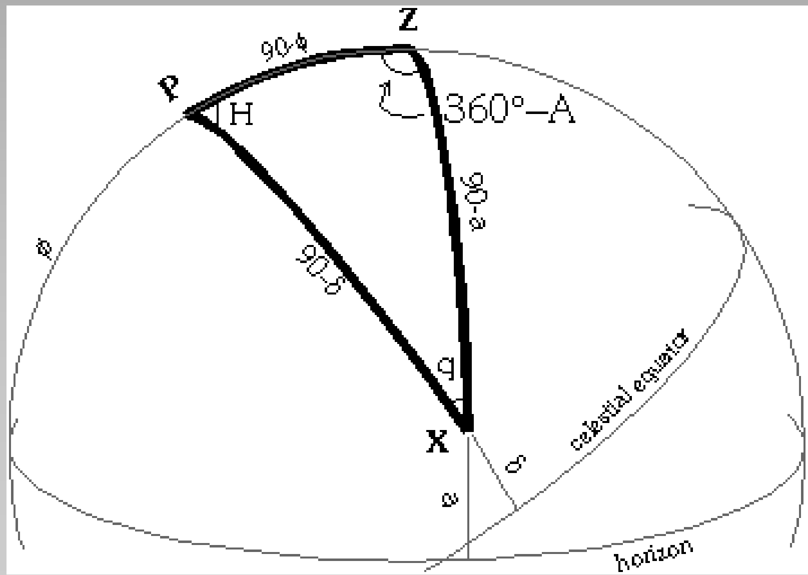
$\sin a = \sin\delta\sin\varphi + \cos\delta\cos\varphi\cos H$

- ***Using the sine rule***

$$\frac{\sin(360 - a)}{\sin(90 - \delta)} = \frac{\sin H}{\sin(90 - a)}$$

$\Rightarrow$

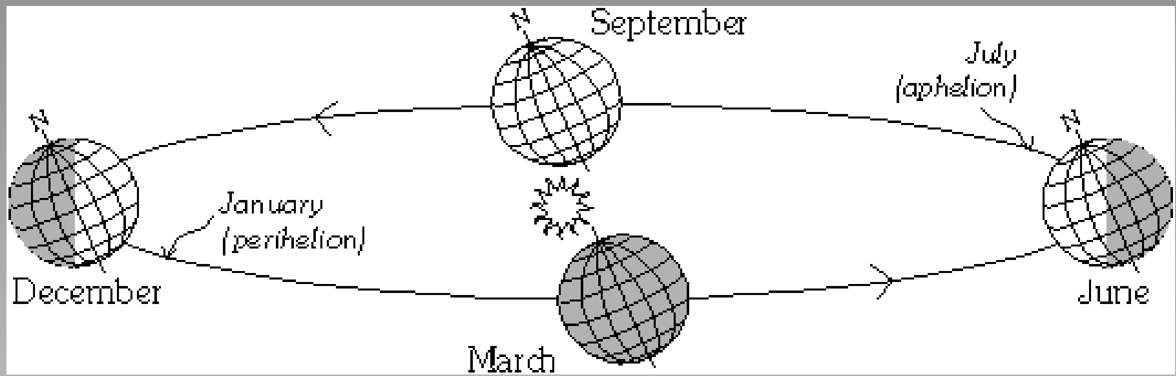
$$\sin A = -\frac{\sin H \cos\delta}{\cos a}$$



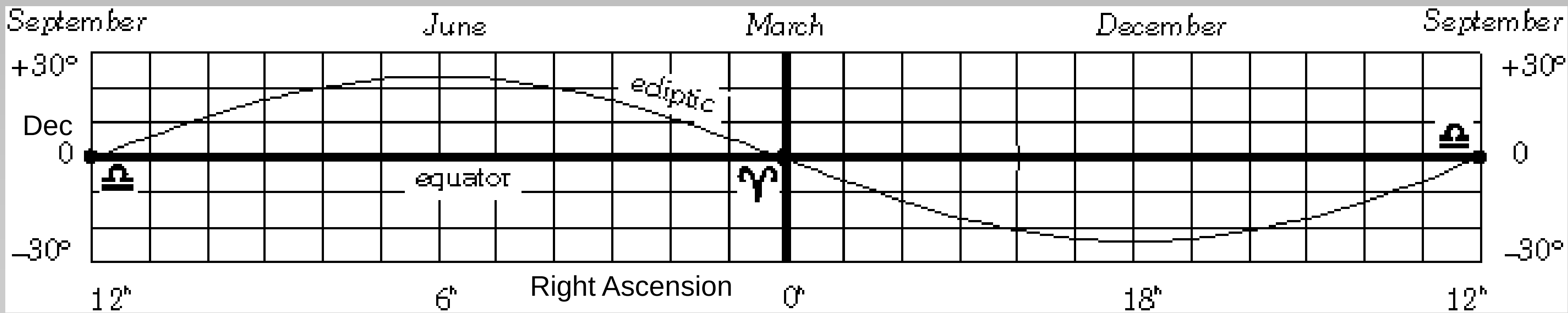
Similar expressions can be derived for the inverse transformations (H & δ from a & A or α & δ from LST, a & A)

Ecliptic Coordinates

- **Because of the tilt of Earth's axis by 23º 26', the Sun's path across the sky during the course of a year does not follow the equator**



- **Instead it follows a great circle called the *ecliptic***

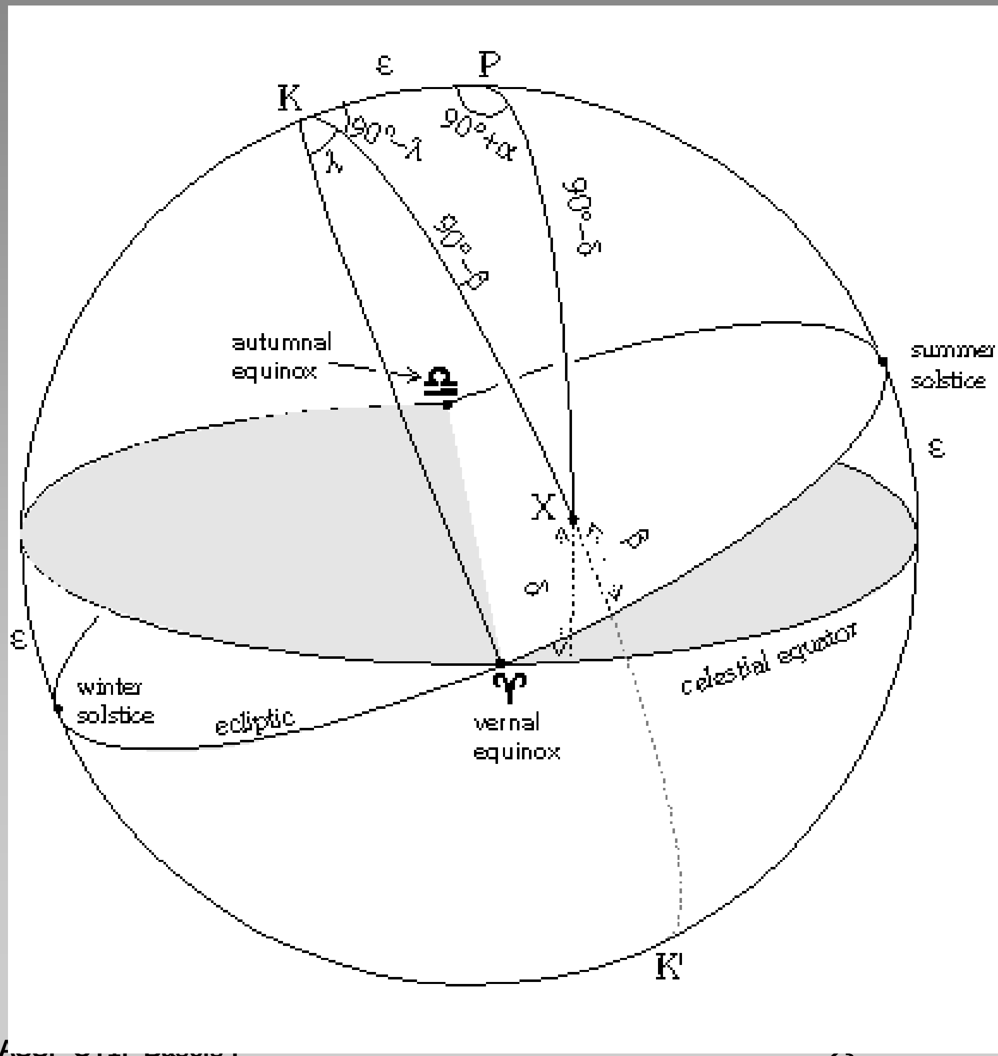


Ecliptic Coordinates

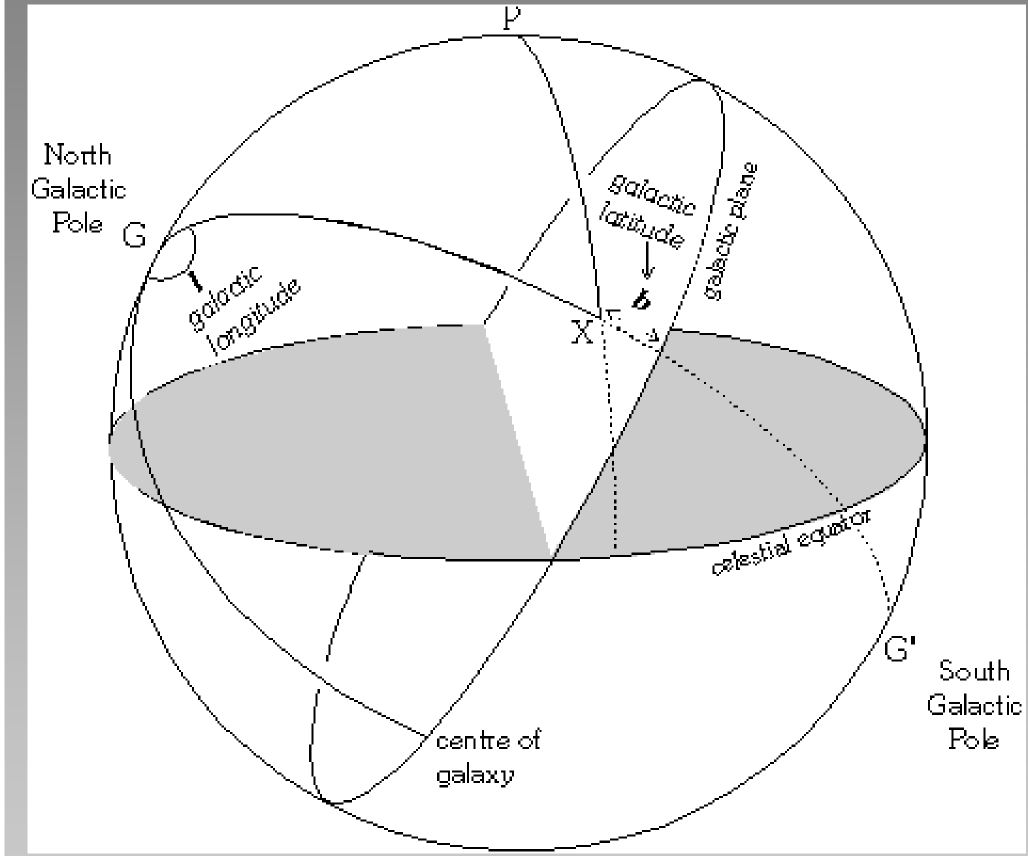
- The ecliptic is therefore the intersection of the Earth's orbital plane with the celestial sphere
- Since the Earth and the planets are confined to orbit in the same plane, then all the other planets also follow the ecliptic
- Ecliptic coordinate system has
  - Fundamental circle = ecliptic
  - Poles are the north and south ecliptic poles
  - Origin of the coordinate system is ♈ (First Point of Aries, or Vernal Equinox)
  - Coordinate are measured in terms of:
    - » ***ecliptic longitude*** (λ): measured east from ♈
    - » ***ecliptic latitude*** (β): measured from ecliptic to poles (-90º to +90º)
  - The ecliptic and equator intersect at the equinox ***nodes***
    - » "ascending node": when Sun moves from S to N at ♈ (λ = 0º, R.A. = 0 h)
    - » also known as ***Vernal*** or ***Spring Equinox***
    - » "descending node": when Sun moves from N to S at ♎ (λ = 180º, R.A. = 12 h)
    - » also know as ***Autumnal Equinox***
    - » At the equinoxes: length of day & night are equal

Ecliptic Coordinates

- Spherical trig (cosine & sine rules) can be used to convert from equatorial to ecliptic coord & vice versa



Galactic Coordinates



- Based on the plane of the Milky Way ("galactic plane")
- Coordinates are galactic longitude (l) & latitude (b)
- Similar to all the previous systems discussed
- Galactic centre is at $l = b = 0^{\circ}$

(R.A. = 17h 46m Dec = -28º 46')