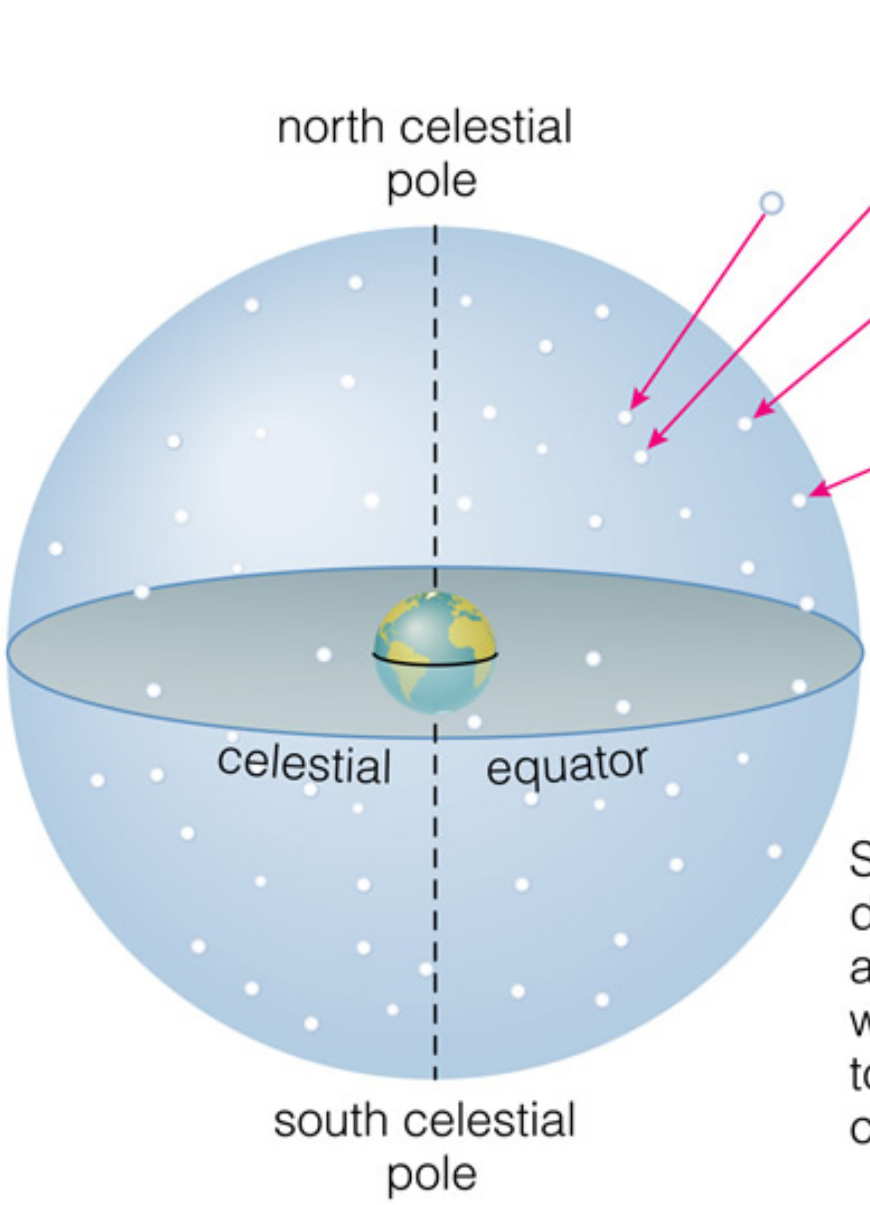
2. Descriptive Astronomy ("Astronomy Without a Telescope")

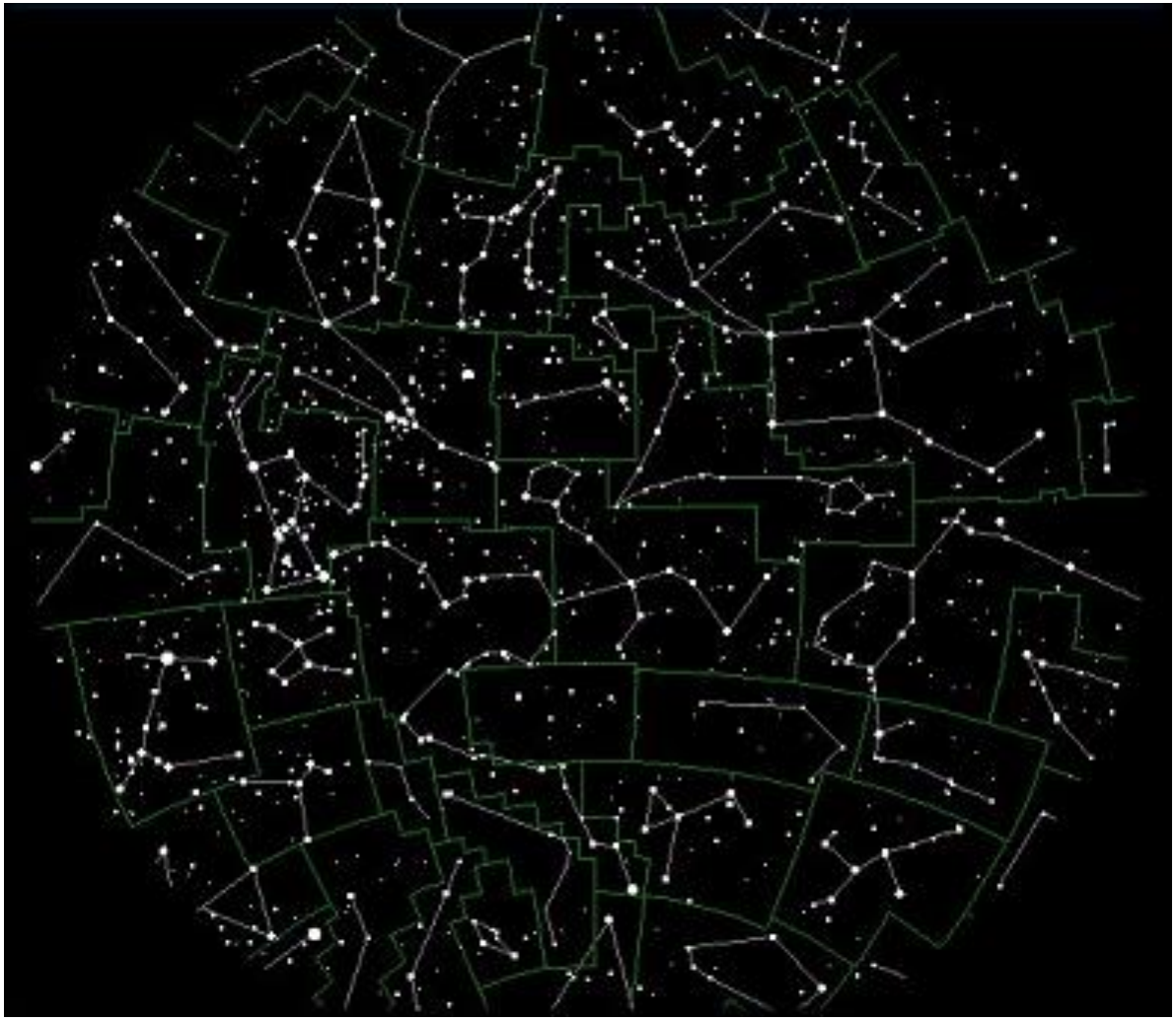
http://apod.nasa.gov/apod/astropix.html

- How do we locate stars in the heavens?
- What stars are visible from a given location?
- Where is the sun in the sky at any given time?
- Where are you on the Earth?



Stars actually lie at different distances; arrows indicate where they *appear* to be located on the celestial sphere.

An "asterism" is two stars that appear To be close in the sky but actually aren't



In 1930 the International Astronomical Union (IAU) ruled the heavens off into 88 legal, precise constellations. (52 N, 36 S)

Every star, galaxy, etc., is a member of one of these constellations.

Many stars are named according to their constellation and relative brightness (Bayer 1603).

Sirius

α – Centauri, α-Canis Majoris, α-Orionis

Betelgeuse

declination less than -53° not visible from SC

http://calgary.rasc.ca/constellation.htm - list

http://www.google.com/sky/

https://en.wikipedia.org/wiki/List_of_Messier_objects (1758 – 1782)

Biggest constellation – Hydra – the female water snake
1303 square degrees, but Ursa Major and Virgo almost as big.

Hydrus – the male water snake is much smaller – 2243 square degrees

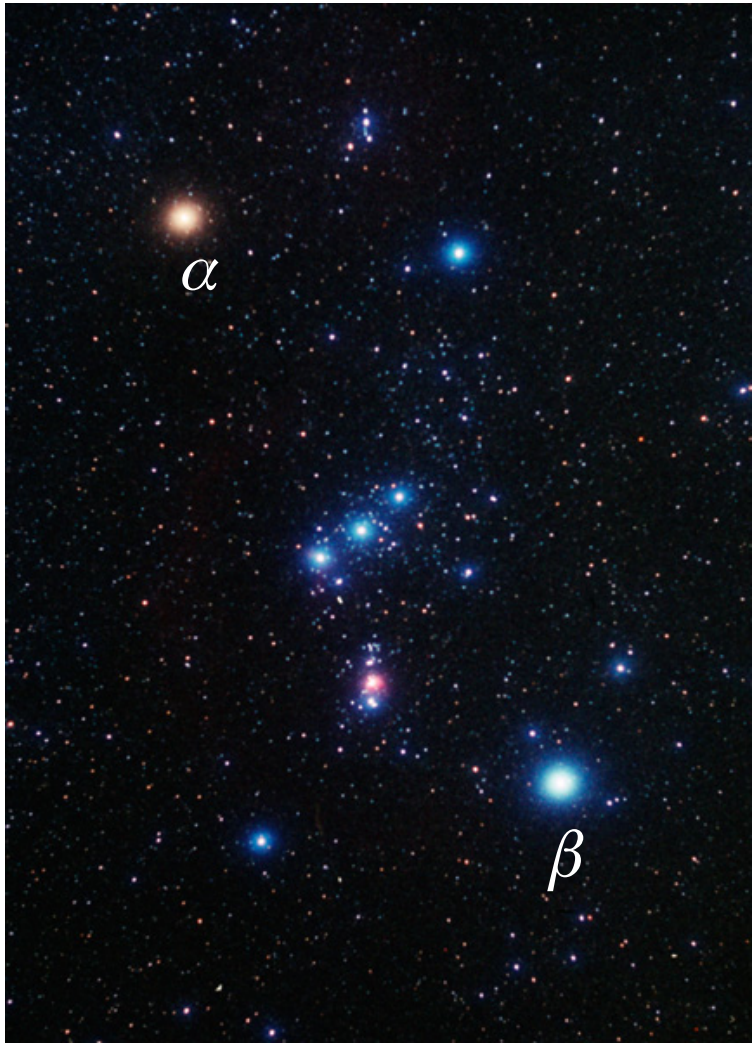
Smallest is Crux – the Southern Cross – 68 square degrees

Brief History

Some of the current constellations can be traced back to the inhabitants of the Euphrates valley, from whom they were handed down through the Greeks and Arabs. Few pictorial records of the ancient constellation figures have survived, but in the *Almagest* AD 150, Ptolemy catalogued the positions of 1,022 of the brightest stars both in terms of celestial latitude and longitude, and of their places in 48 constellations.

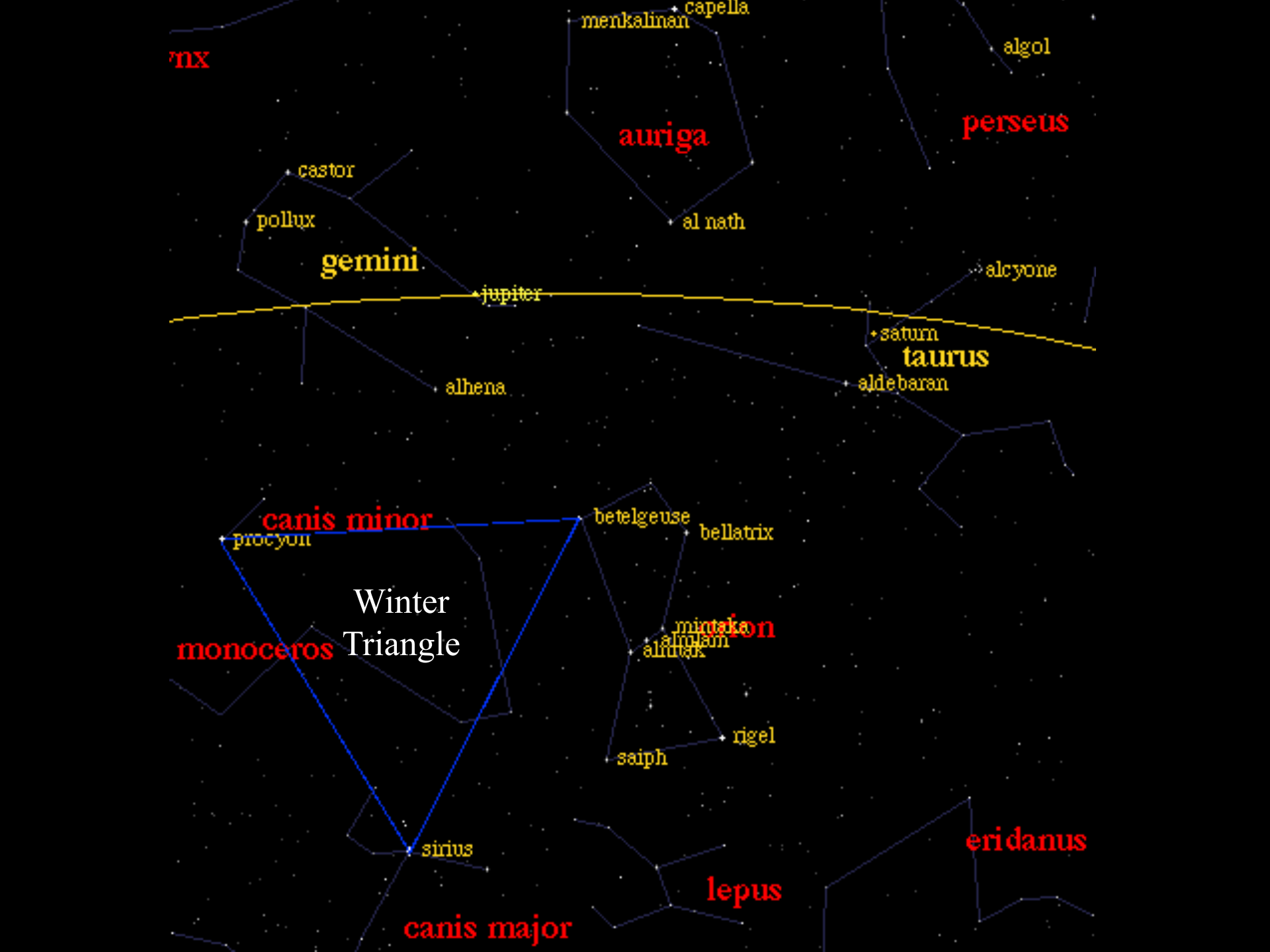
The Ptolemaic constellations left a blank area centered not on the present south pole but on a point which, because of precession, would have been the south pole *c.* 2800 BC, a fact that is consistent with the belief that the constellation system had its origin about 5,000 years ago.

E.g., ORION



Betelgeuse and Rigel are α– and β-Orionis

M42 = Orion nebula
M43 = DeMairan's nebula


capella
menkalinan
nx
algol
auriga
perseus
castor
pollux
al nath
gemini
alcyone
jupiter
saturn
taurus
alhena
aldebaran
canis minor
betelgeuse
procyon
bellatrix
Winter
Triangle
monoceros
rigel
saiph
sirius
eridanus
lepus
canis major

Sirius – brightest star in the sky – star of about twice the mass of the sun. Blue. Very luminous, very hot. A main sequence star (like the sun) but of Type A1

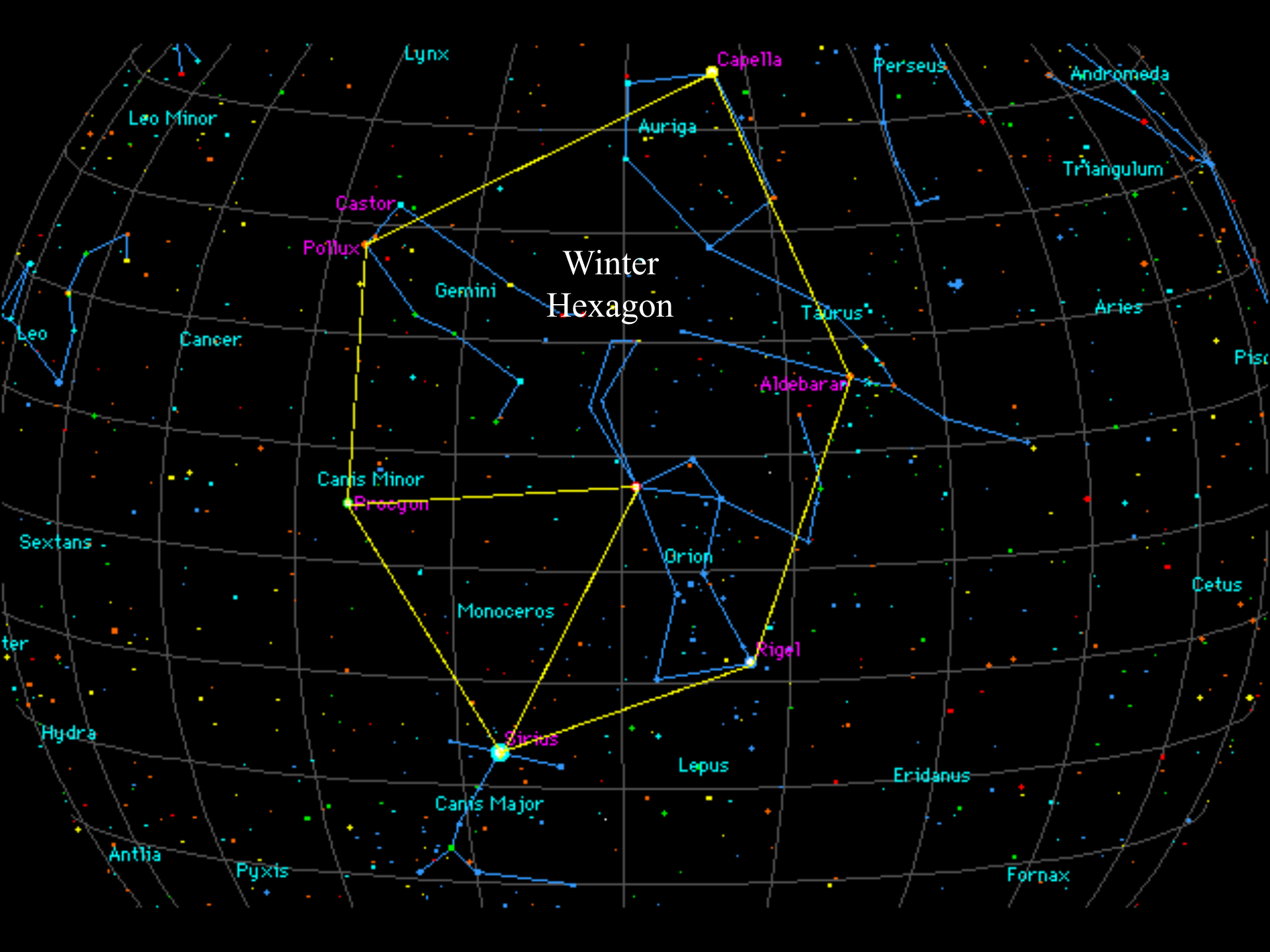
8.6 ly

Procyon – 8th brighest star. About 1.4 solar masses. Another main sequence star. Hotter and more luminous than the sun but not as luminous as Sirius. Type F5. May be close to finishing hydrogen burning as its luminosity is a bit high for its mass.

11.5 ly

Betelgeuse – 9th brightest star. 2nd brightest in Orion. Betelgeuse is a red supergiant. It is not fusing hydrogen in its center. It has left the main sequence. May vary in brightness over periods of years by as much as a factor of two. About 18 solar masses and around 10 million years old.

643 ly


Winter
Hexagon
Capella
Auriga
Perseus
Andromeda
Triangulum
Lynx
Leo Minor
Castor
Pollux
Gemini
Taurus
Aries
Leo
Cancer
Aldebaran
Canis Minor
Procyon
Sextans
Orion
Cetus
Monoceros
Rigel
Hydra
Sirius
Lepus
Eridanus
Canis Major
Antlia
Pyxis
Fornax

Orion Nebula: M-42

1600 light years away in the sword of Orion, easily visible to the naked eye. 85' x 60' across and part of a larger cloud spanning 20 degrees*. Diameter ~30 ly, Mass ~ 200,000 solar masses.

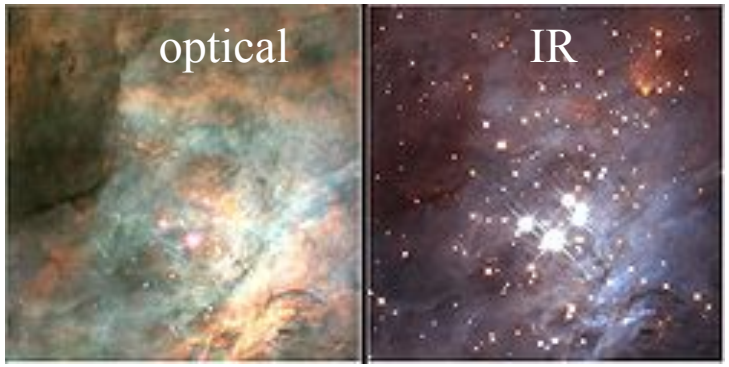
• *Your fist at arm's length is about 10 degrees*

Star Nursery

Betelgeuse - red supergiant, about 20 solar masses.
May have shrunk 15% in radius since 1993.
This probably does not indicate evolution at its center. 570 ly away. Variable star.
1000 times as luminous as the sun

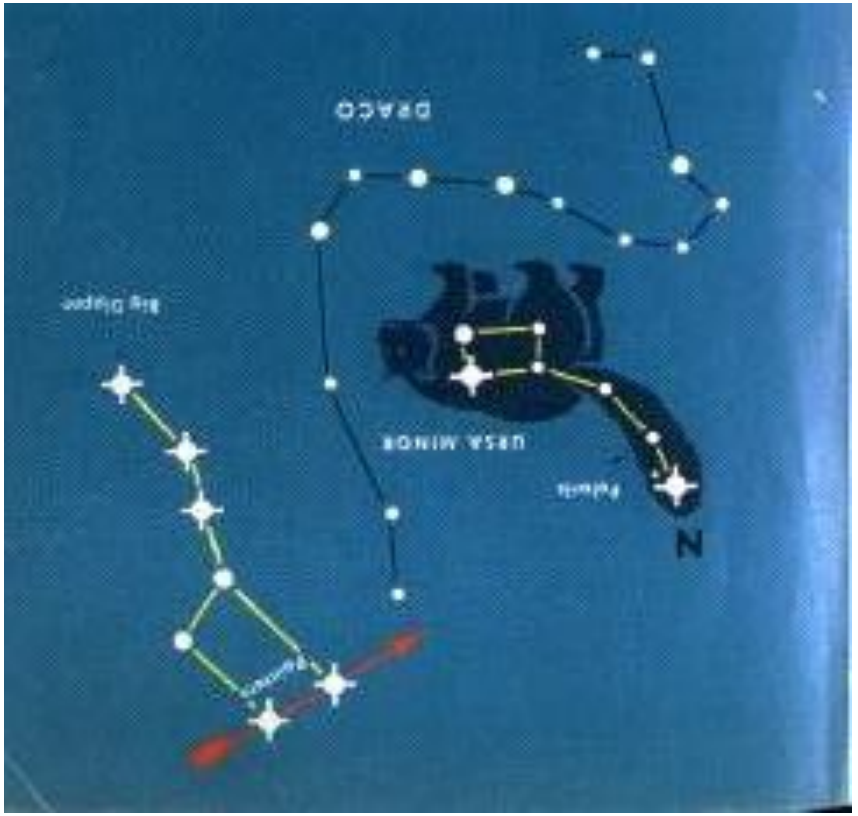
Rigel - brightest star in Orion by (a bit more than α-Orionis = Betelgeuse – a variable)
7th brightest star in the sky. 770 ly. Most luminous star in our region of galaxy.
A blue supergiant star, 17 solar masses.
Brightness varies by 3 to 30%
Triple star system. A is bright. B is a binary.

Trapezium - an open cluster of young stars which illuminate the Orion nebula. The 5 brightest are all over 15 solar masses. Three were discovered by Galileo in 1617.



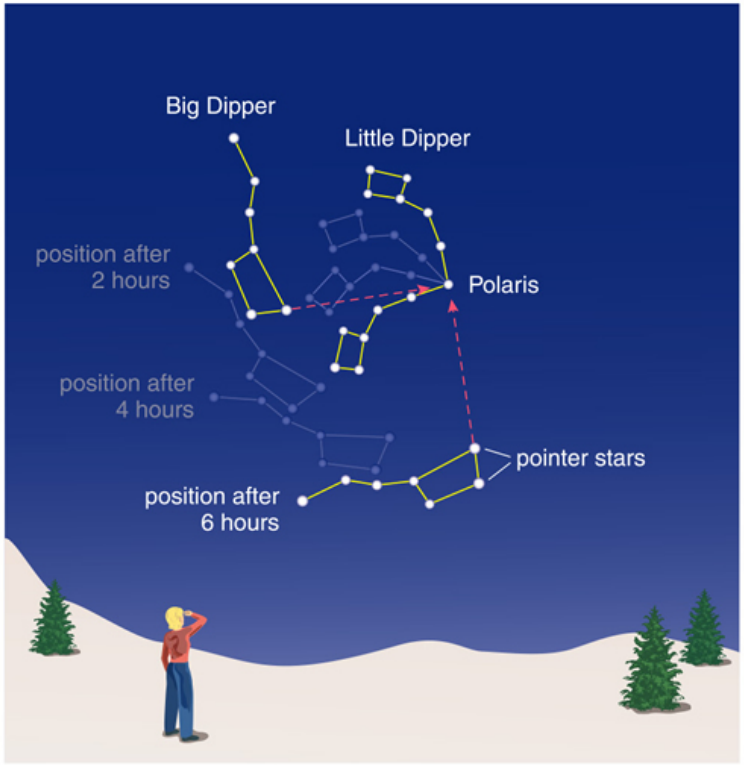
*Bayer (1603) designated the brightness of 1564 stars in his *Uranometria*

Finding the north star



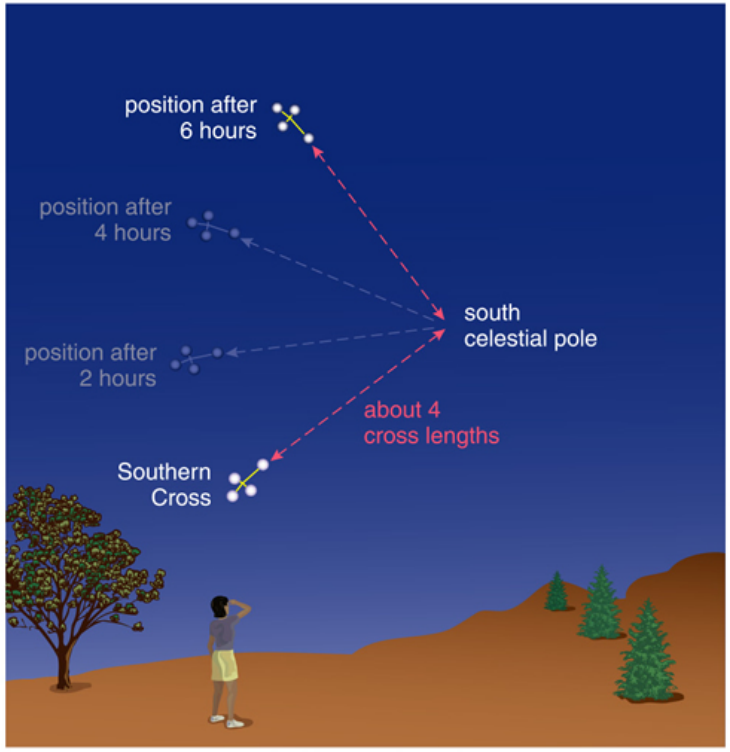
Your latitude is the angle above the northern horizon where you see Polaris. Polaris does not move.

Motions of stars in the sky



looking northward

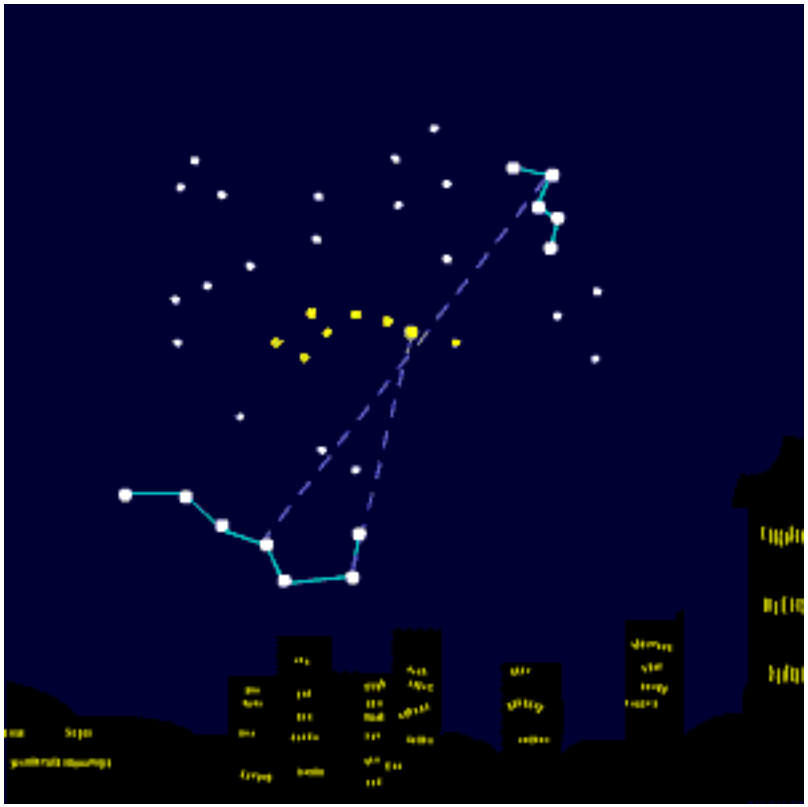
North



looking southward

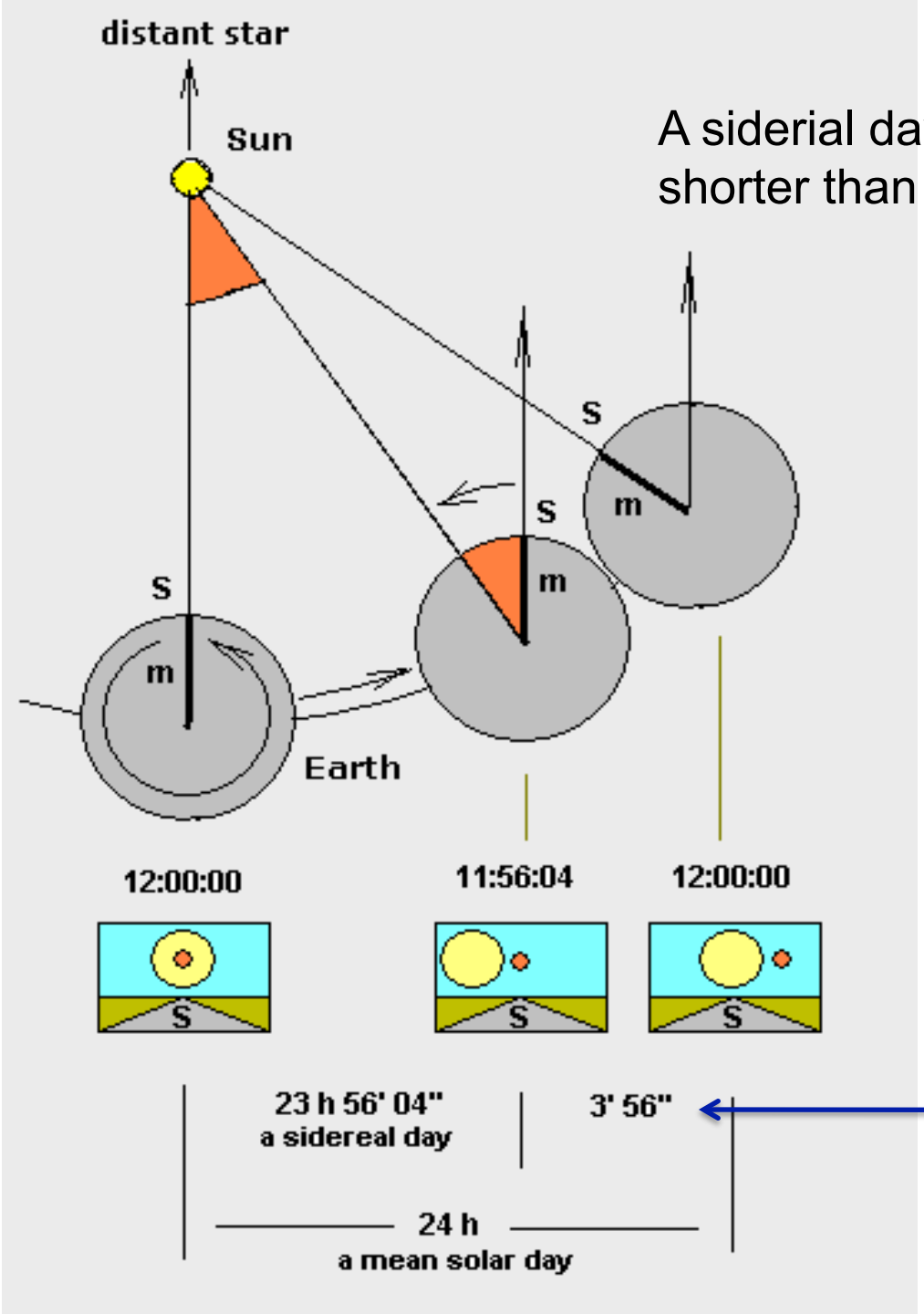
South

Polaris is 6 times the distance between the pointers away – i.e., ~30°.



Can tell time this way, but

a) 24 hr clock
b) sidereal time

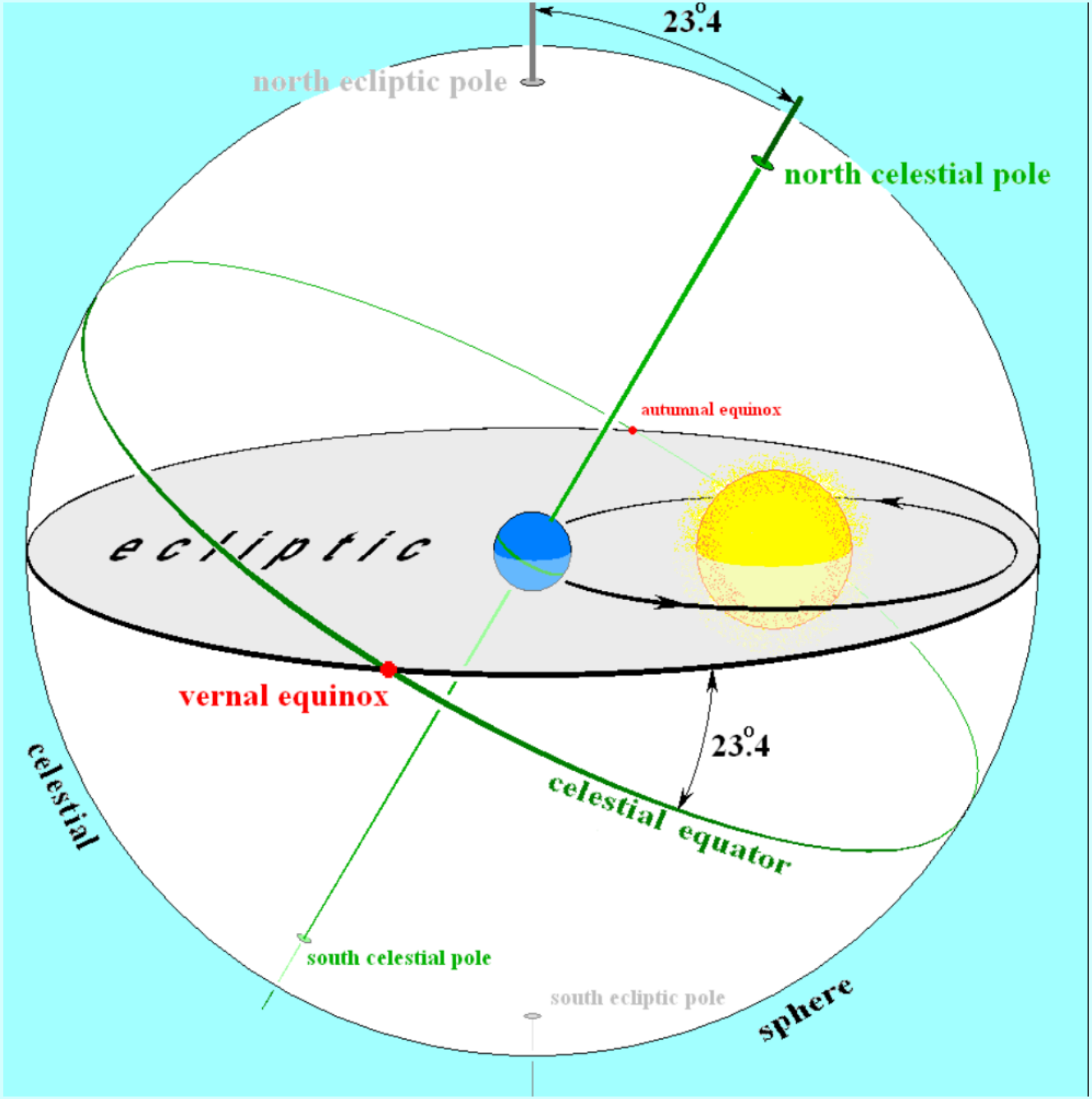


A siderial day is a bit shorter than a solar day

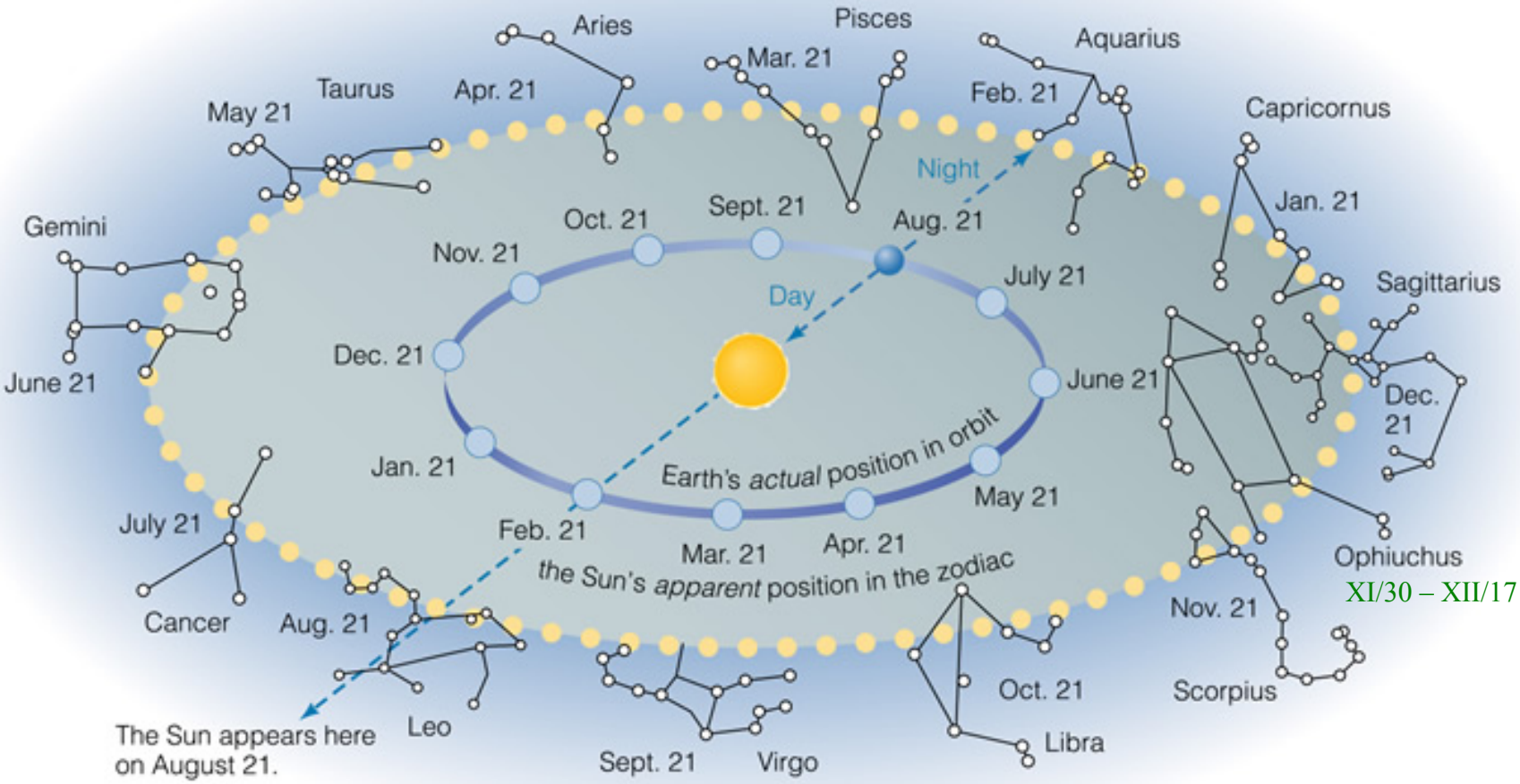
$$\frac{24\,\text{hr}}{365.25}$$

The apparent location of the sun in the sky as the earth goes round it defines a great circle in the heavens called the “ecliptic”.

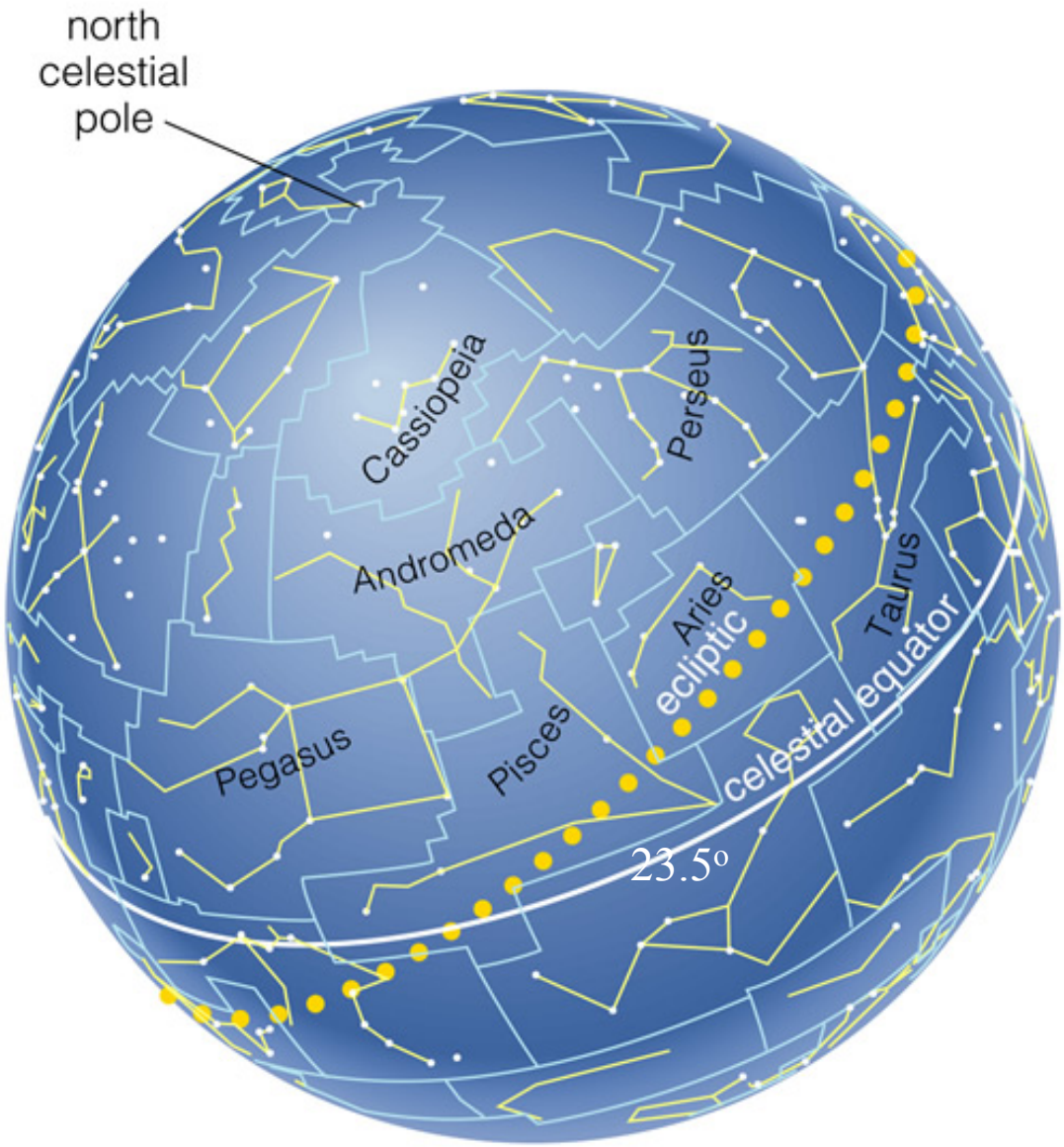
The projection of the earth’s equator in the sky gives another called the “celestial equator”. Because the Earth’s rotational axis is not perpendicular to the plane containing the earth’s orbit around the sun, the planes containing the two circles are not the same but are inclined to each other by 23.5^{o}.


23°.4
north ecliptic pole
north celestial pole
autumnal equinox
ecliptic
vernal equinox
23°.4
celestial equator
celestial sphere
south celestial pole
south ecliptic pole

The path of the sun in the sky



XI/30 – XII/17



Think of the earth as being at the center of this imaginary celestial sphere

The ecliptic is fixed in the sky because the earth's orbit doesn't change. The celestial equator moves over 1000's of years due to precession

Where the sun is

Astronomically speaking. The traditional signs of the zodiac are all 30 degrees in length and the sun spends roughly equal times in each. They are not equivalent to where the sun is. E.g., the zodiacal sign Aquarius (1/21– 2/19) roughly corresponds to Capricon below.

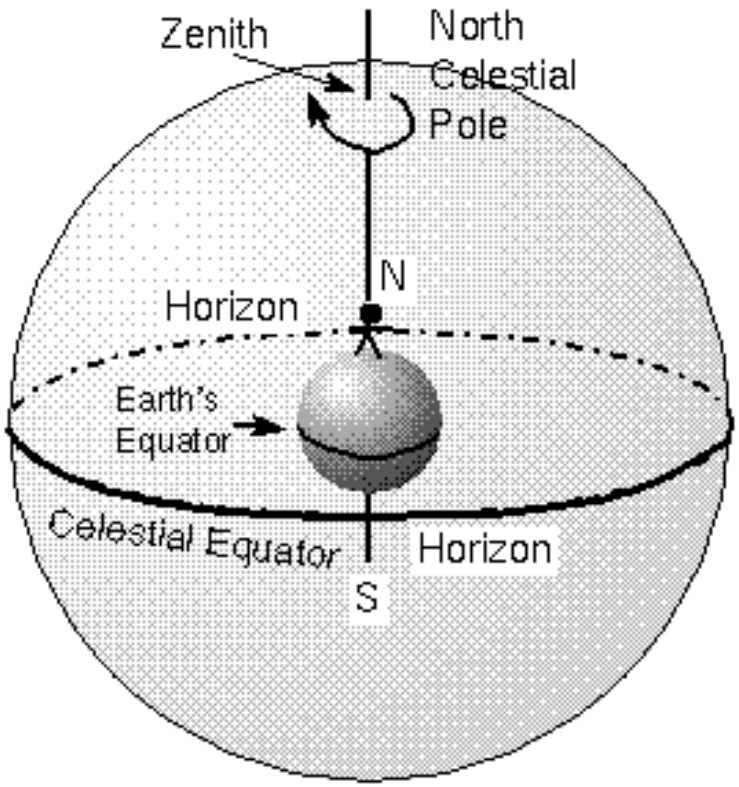
Pisces	The Fishes	March	12	to	April	18
Aries	The Ram	April	19	to	May	13
Taurus	The Bull	May	14	to	June	19
Gemini	The Twins	June	20	to	July	20
Cancer	The Crab	July	21	to	August	9
Leo	The Lion	August	10	to	September	15
Virgo	The Maiden	September	16	to	October	30
Libra	The Balance	October	31	to	November	22
Scorpius	The Scorpion	November	23	to	November	29
Ophiuchus**	Serpent-holder	November	30	to	December	17
Sagittarius	The Archer	December	18	to	January	18
Capricornus	The Goat	January	19	to	February	15
Aquarius	The Water-bearer	February	16	to	March	11

Because the planets and sun are all approximately in the same plane, the planets are also found in the constellations of the zodiac.

Name	Symbol	Tropical zodiac	Sidereal zodiac	Name	IAU boundaries[41]	Solar stay[41]	Brightest star
Aries	♈	21 March – 20 April	15 April – 15 May	Aries	19 April – 13 May	25 days	Hamal
Taurus	♉	21 April – 21 May	16 May – 15 June	Taurus	14 May – 19 June	37 days	Aldebaran
Gemini	♊	22 May – 21 June	16 June – 15 July	Gemini	20 June – 20 July	31 days	Pollux
Cancer	♋	22 June – 22 July	16 July – 15 August	Cancer	21 July – 9 August	20 days	Al Tarf
Leo	♌	23 July – 22 August	16 August – 15 September	Leo	10 August – 15 September	37 days	Regulus
Virgo	♍	23 August – 23 September	16 September – 15 October	Virgo	16 September – 30 October	45 days	Spica
Libra	♎	24 September – 23 October	16 October – 15 November	Libra	31 October – 22 November	23 days	Zubeneschamali
Scorpio	♏	24 October – 22 November	16 November – 15 December	Scorpius	23 November – 29 November	7 days	Antares
Ophiuchus	⛎	*n/a*		Ophiuchus	30 November – 17 December	18 days	Rasalhague
Sagittarius	♐	23 November – 21 December	16 December – 14 January	Sagittarius	18 December – 18 January	32 days	Kaus Australis
Capricorn	♑	22 December – 20 January	15 January – 14 February	Capricornus	19 January – 15 February	28 days	Deneb Algedi
Aquarius	♒	21 January – 19 February	15 February – 14 March	Aquarius	16 February – 11 March	24 days	Sadalsuud
Pisces	♓	20 February – 20 March	15 March – 14 April	Pisces	12 March – 18 April	38 days	Eta Piscium

Western astrology uses the tropical zodiac which is affixed to the vernal equinox. The siderial zodiac is fixed to the stellar background when the system started. Hindu astrology uses the siderial zodiac https://en.wikipedia.org/wiki/Zodiac - Constellations

How about the apparent motion of the stars in the sky?

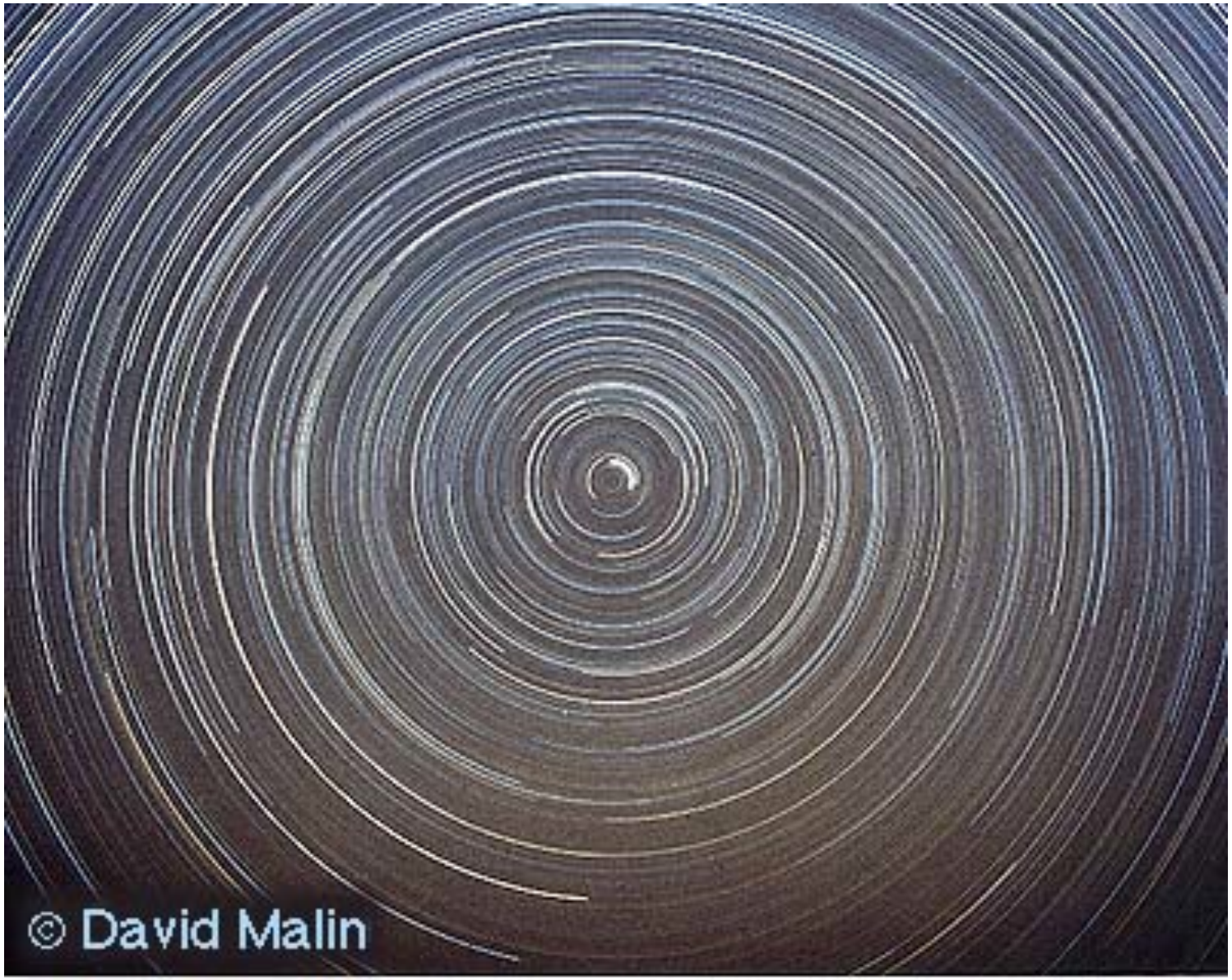


If you stood at the earth's north pole, your *zenith* would be the projection of the earth's rotational axis into the sky.

Your horizon would be the *celestial equator*.

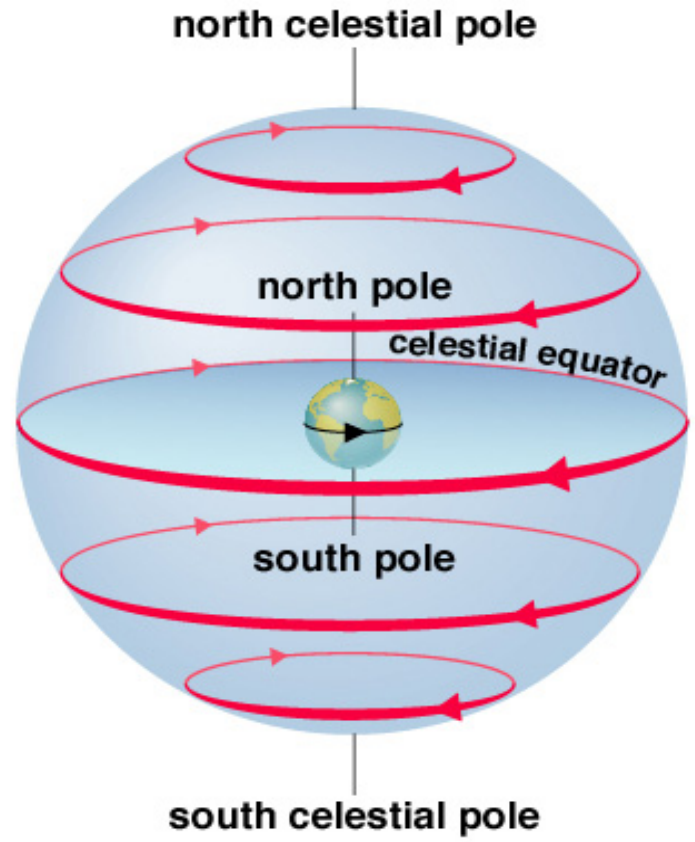
The stars would go round Polaris in a counter-clockwise direction

The celestial equator is the projection of the Earth's equator into the heavens.



8 hr time lapse photo

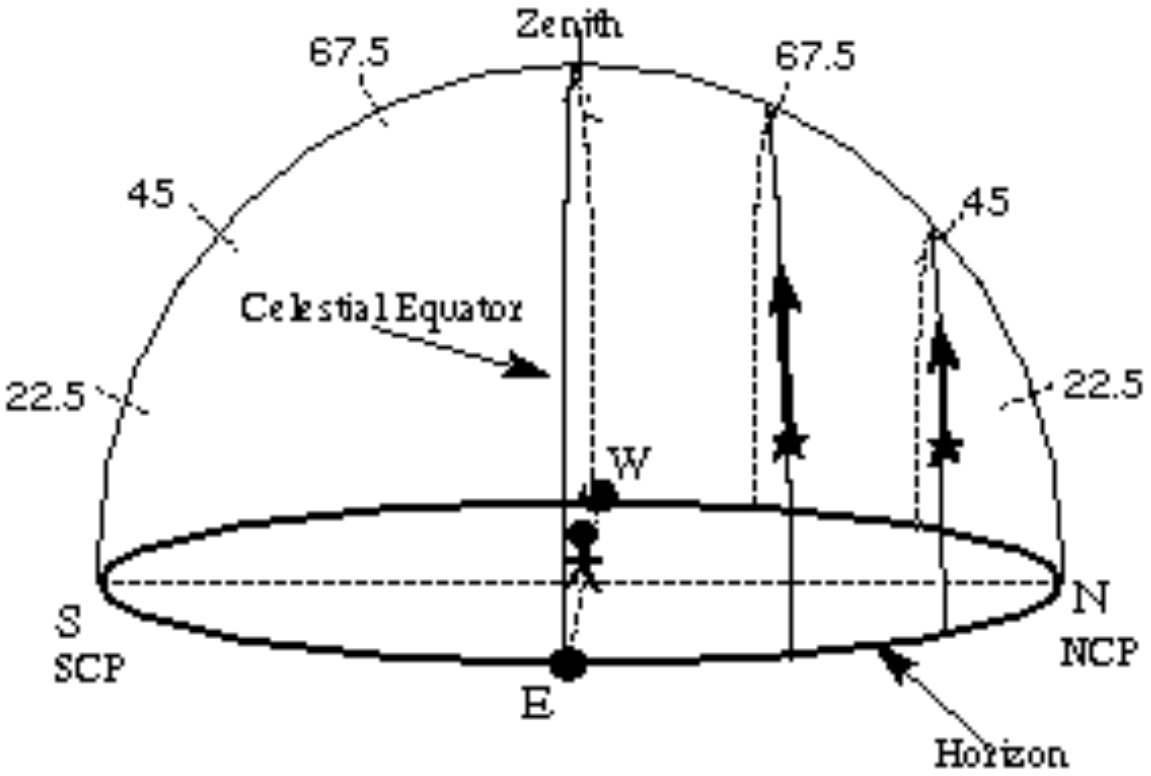
The Daily Motion



- As the Earth rotates, the sky appears to us to rotate in the opposite direction.
- The sky appears to rotate around the N (or S) celestial poles.
- If you are standing at the poles, nothing rises or sets.
- If you are standing at the equator, everything rises & sets 90^{o} to the horizon.

copied from Nick Strobel's "Astronomy notes". See his website.

At the equator, stars would all rise perpendicular to the horizon and set perpendicular to the horizon. Every day



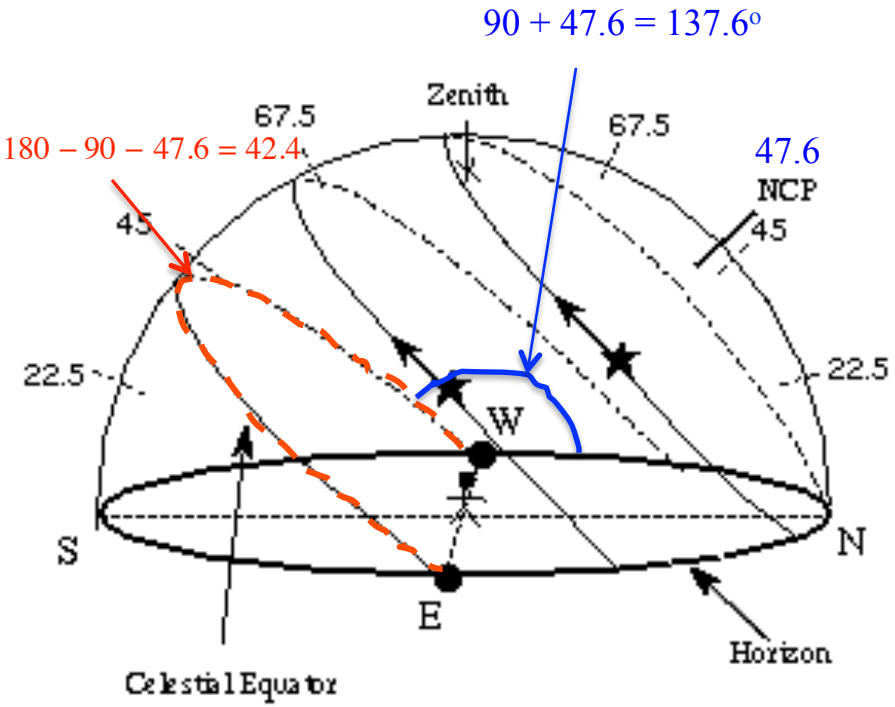
Stars motion at the Equator. Stars rotate parallel to the Celestial Equator, so they move perpendicular to the horizon here. All stars are visible for 12 hours. Both celestial poles are visible on the horizon.

Panoramic view of the African night from equatorial Kenya. The three hour long exposure was made on a clear, dark, mid November evening facing due west and covers just over 180 degrees along the horizon. So, the South Celestial Pole is at the center of the concentric arcs on the left and the North Celestial Pole is at the far right. The stars setting along the Celestial Equator leave the straight trails near the middle of the picture.

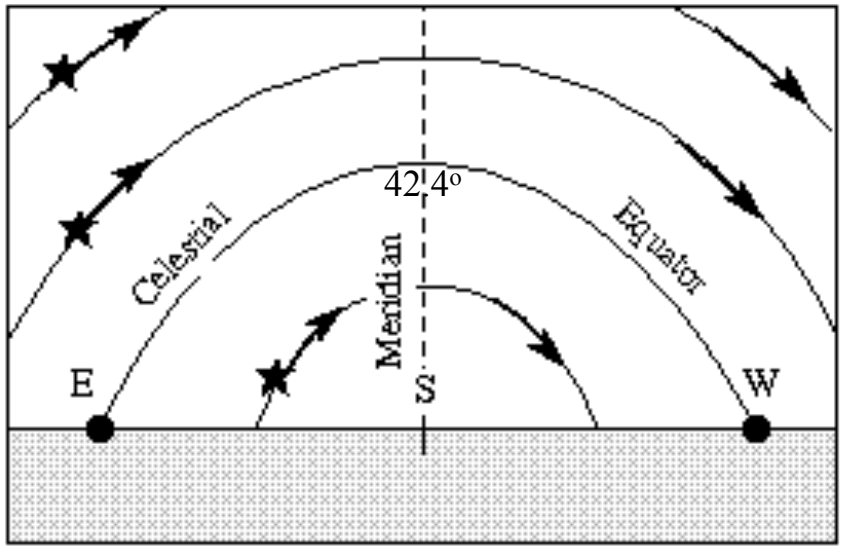
Leroy Zimmerman, Astronomy picture of the day November 15, 2002

Latitude of Seattle
= 47.6 degrees

At a lower latitude than the north pole



Stars motion at Seattle. Stars rotate parallel to the Celestial Equator, so they move at an angle with respect to the horizon here. Altitudes of 1/4, 1/2, and 3/4 the way up to the zenith are marked.



Your view from Seattle. Stars rise in the East half of the sky, reach maximum altitude when crossing the meridian (due South) and set in the West half of the sky. The Celestial Equator goes through due East and due West.

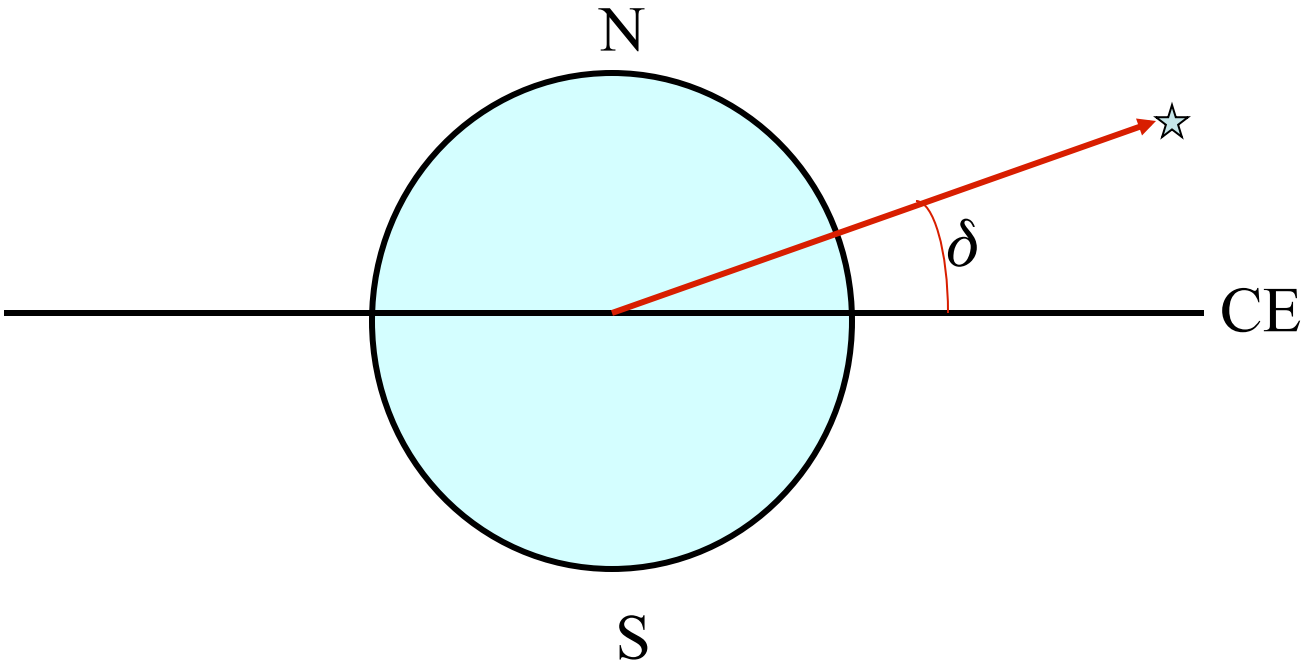
Stars within a certain angle of the north pole would go in circles around the pole and never set. Others have more complicated paths. Some near the south pole remain invisible. Only stars on the celestial equator would rise due east and set due west.

Stellar Coordinates

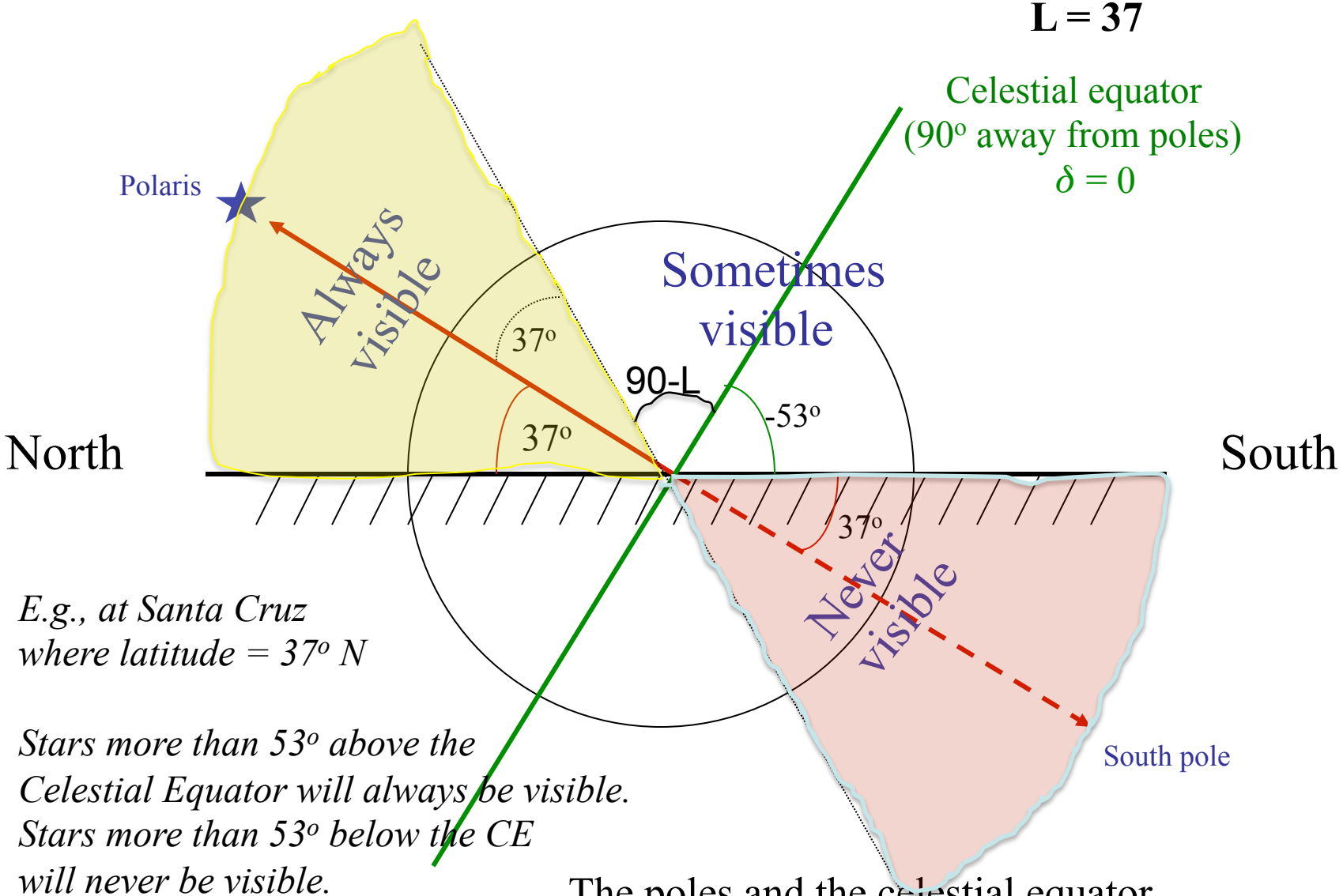
Right Ascension and Declination

- **Celestial Equator**
  Projection of the Earth's equator into the sky

- **Declination** $-90^o \leq \delta \leq +90^o$
  The angle to a star or other object in degrees, minutes, and seconds measured north or south of the Celestial Equator



What can be seen from a given location (e.g. Santa Cruz)?



E.g., at Santa Cruz where latitude = 37° N

Stars more than 53° above the Celestial Equator will always be visible. Stars more than 53° below the CE will never be visible.

actually latitude of SC is 36.792°`

The poles and the celestial equator remain fixed in the sky as the earth rotates

Stars will be "circumpolar", i.e., never set if their declination is

$$\delta \geq 90^o - L$$

L = latitude
L > 0

in the northern hemisphere and

$$\delta \leq -90^o - L \qquad L < 0$$

in the southern hemisphere. Note that L is negative in the southern hemisphere. At the south pole L = -90. At the north pole L = +90.

A star will rise above the horizon sometime in a 24 hour period if

Northern hemisphere $\delta > L - 90^o$

Southern hemisphere $\delta < L + 90^o$

e.g, north pole $\delta > 0$
south pole $\delta < 0$
equator $90 > \delta > -90$

Where δ is the declination of the star and L is your latitude.

$$90 \geq \delta \geq -90$$

$$90 \geq L \geq -90$$

L = -90 is the south pole. L = 90 is the north pole, 37 is Santa Cruz.

• What stars are visible from Santa Cruz (Latitude 37° N)?

Sometime each day: $\delta > 37^\circ - 90^\circ = -53^0$ L - 90

Never: $\delta < 37^\circ - 90^\circ = -53^0$

Always: $\delta > 90^\circ - 37^\circ = +53^\circ$ 90 - L

Examples:

Sirius - $\delta = -16^\circ\ 39'$

Polaris - $\delta \approx 90^\circ$

α-Centauri - $\delta = -60^\circ\ 38'$

• What stars are visible from the north pole?

All with $\delta > 0$ all the time

• What stars are visible from the equator?

All stars (including the sun) 12 hours per day

• What stars are above the horizon 12 hours per day everywhere?

Those on the Celestial Equator

Brightest Stars

Star	Name	M	RA	Dec
alpha CMa	Sirius	-1.46	06 45 8.9	-16 42 58
alpha Car	Canopus	-0.72	06 23 57.2	-52 41 44
alpha Cen	Rigil Kent	-0.01	14 39 36.2	-60 50 07
alpha Boo	Arcturus	-0.04	14 15 39.6	+19 10 57
alpha Lyr	Vega	0.03	18 36 56.2	+38 47 01
alpha Aur	Capella	0.08	05 16 41.3	+45 59 53
beta Ori	Rigel	0.12	05 14 32.2	-08 12 06
alpha CMi	Procyon	0.38	07 39 18.1	+05 13 30
alpha Eri	Archenar	0.46	01 37 42.9	-57 14 12
alpha Ori	Beteigeuse	0.50	05 55 10.3	+07 24 25
beta Cen	Hadar	0.61	14 03 49.4	-60 22 22
alpha Aql	Altair	0.77	19 50 46.9	+08 52.6
		0.77		
alpha Tau	Aldebaran	0.85	04 35 55.2	+16 30 33
alpha Vir	Spica	0.98	13 25 11.5	-11 09 41
alpha Sco	Antares	0.96	16 29 24.4	-26 25 25
beta Gem	Pollux	1.14	07 45 18.9	+28 01 34
alpha PsA	Fomalhaut	1.16	22 57 39.0	-29 37 20
alpha Cyg	Deneb	1.25	20 41 25.8	+45 16 49
beta Cru	Mimosa	1.25	12 47 43.3	-59 41 19

The Altitude of the Sun

Day	Solar Declination
~March 21	0
~June 21	23.5°
~September 21	0
~December 21	-23.5°

dates are approximate and vary from year to year

- The declination, δ, of the sun varies from -23.5° to +23.5°

  For regions above latitude 66.5° or below -66.5° there are times when the sun is not visible

- What is the highest the sun rises in Santa Cruz?

  $90° - 37° + 23.5° = 76.5°$ on June 21

  gives CE

- What is the lowest

  $90° - 37° - 23.5° = 29.5°$ on December 21

nb on equator just = inclination of ⊕ rotation axis

- When is the day 12 hours long everywhere

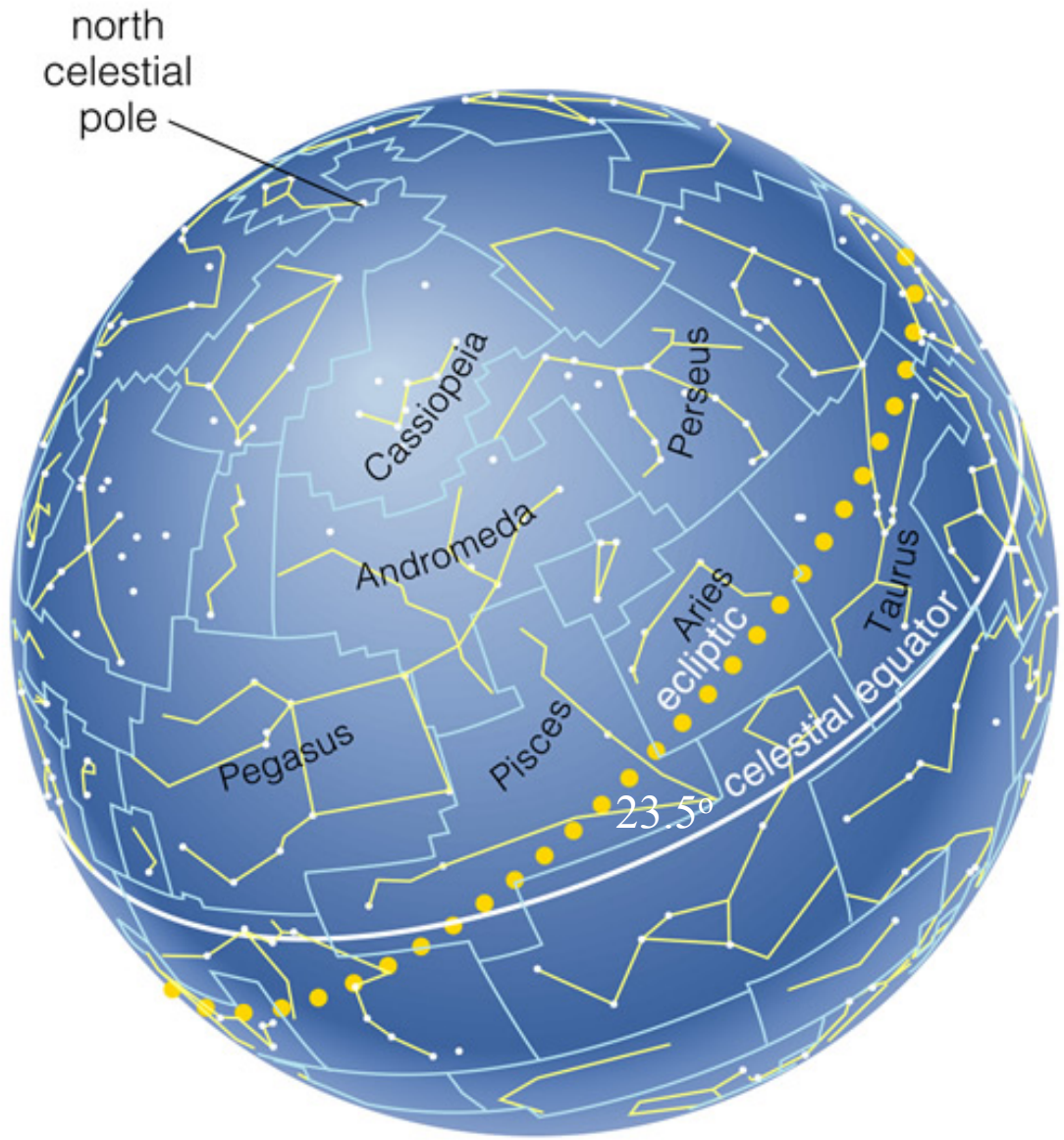
  When the sun is on the Celestial Equator, i.e., the two equinoxes

- Is the sun ever directly overhead in Santa Cruz?

  No

- How far south must one go?

To the "tropics" – latitudes below 23.5°



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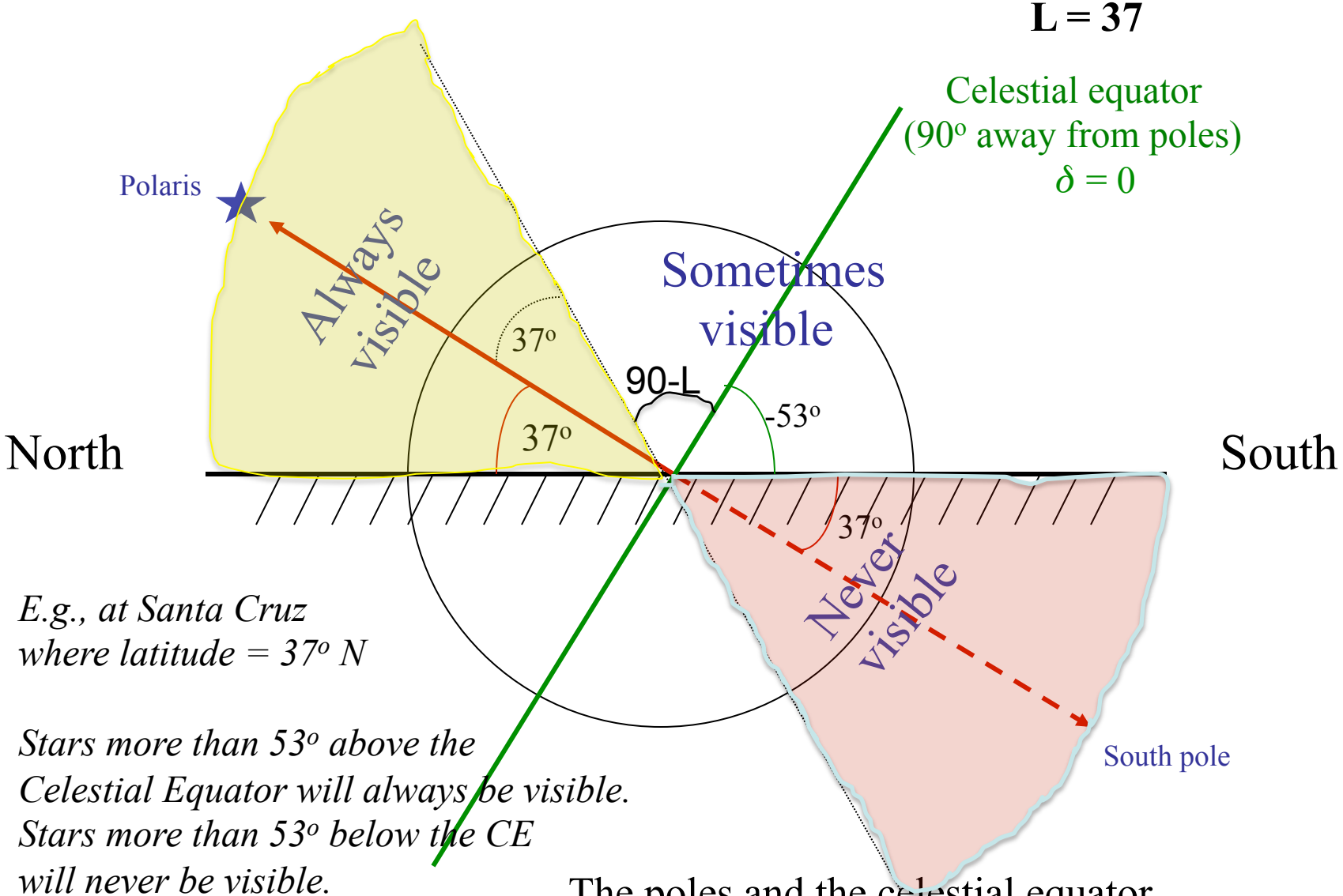

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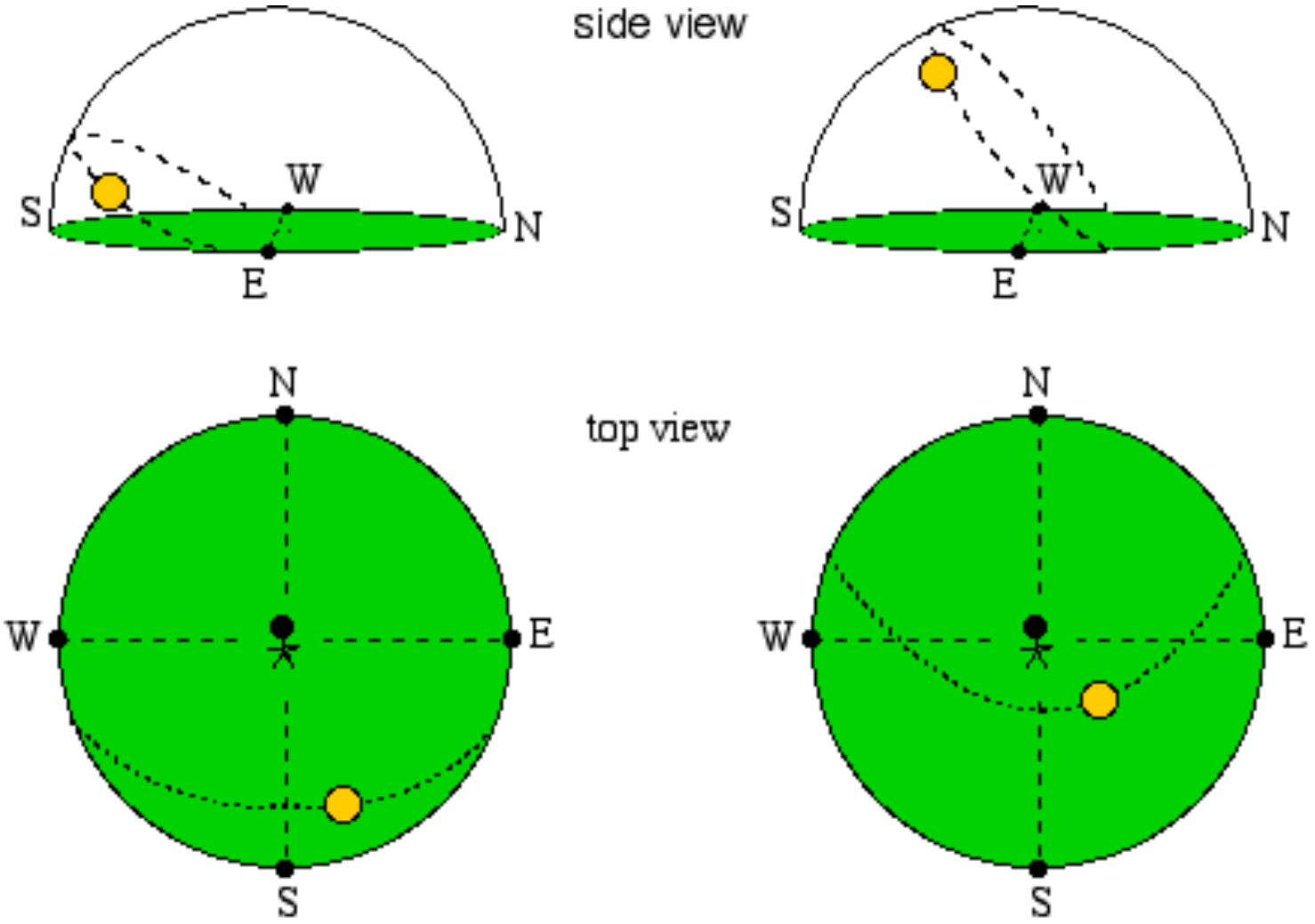


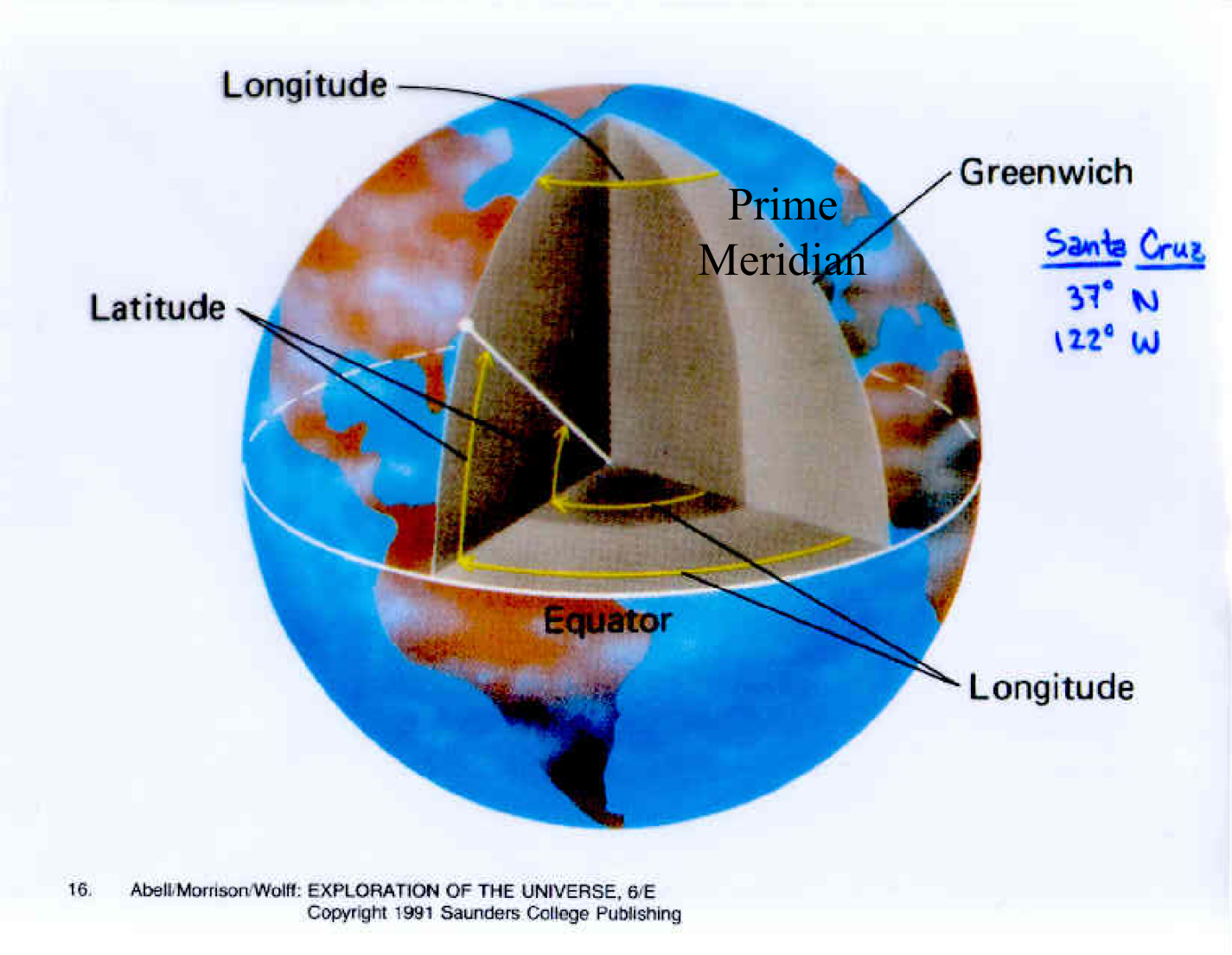
Fall + winter: short, low path.
Sunrise in southeast
Sunset in southwest

Spring + summer: long, high path
Sunrise in northeast
Sunset in northwest

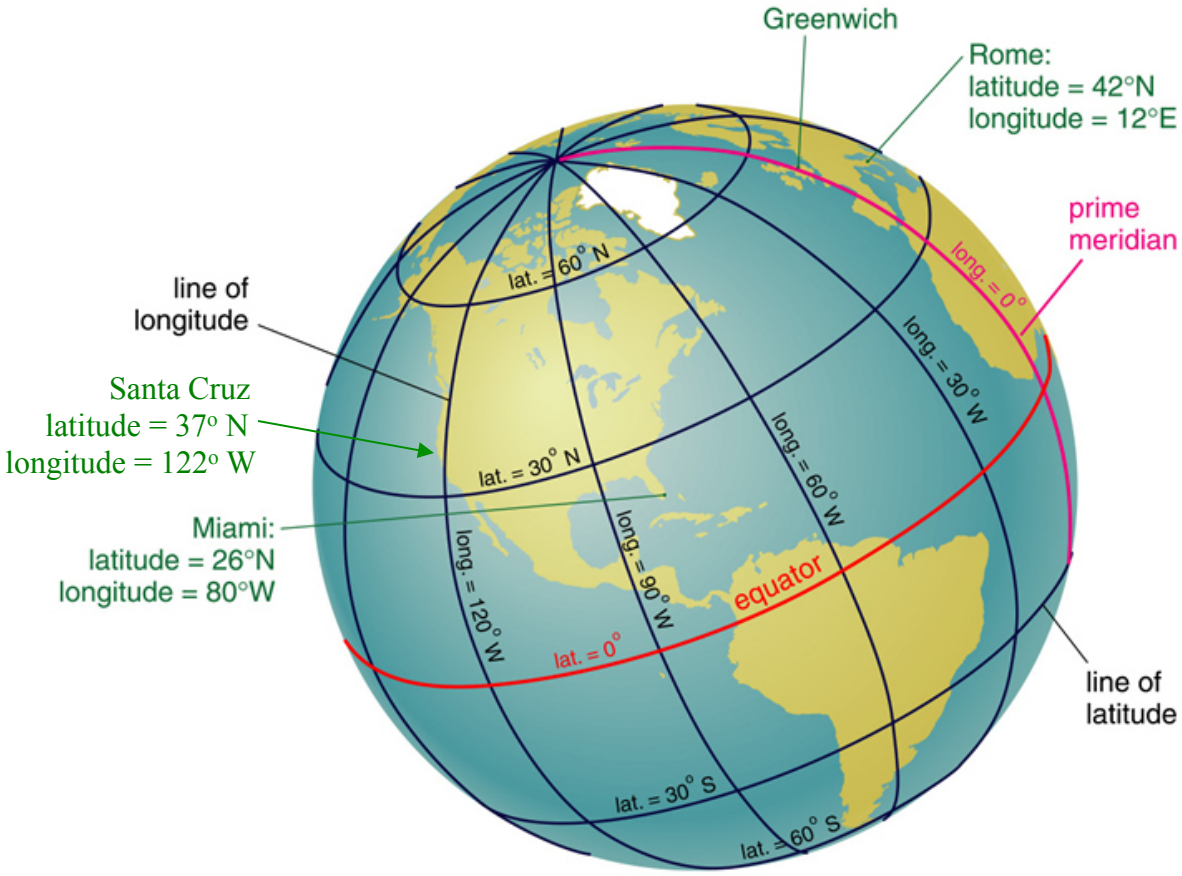
How do we assign a location to a star in the sky?

We could say so many degrees above the horizon
and so many degrees east or west from some point,
like the southern direction, but a little thought
shows that location would vary with location and time
on the Earth.

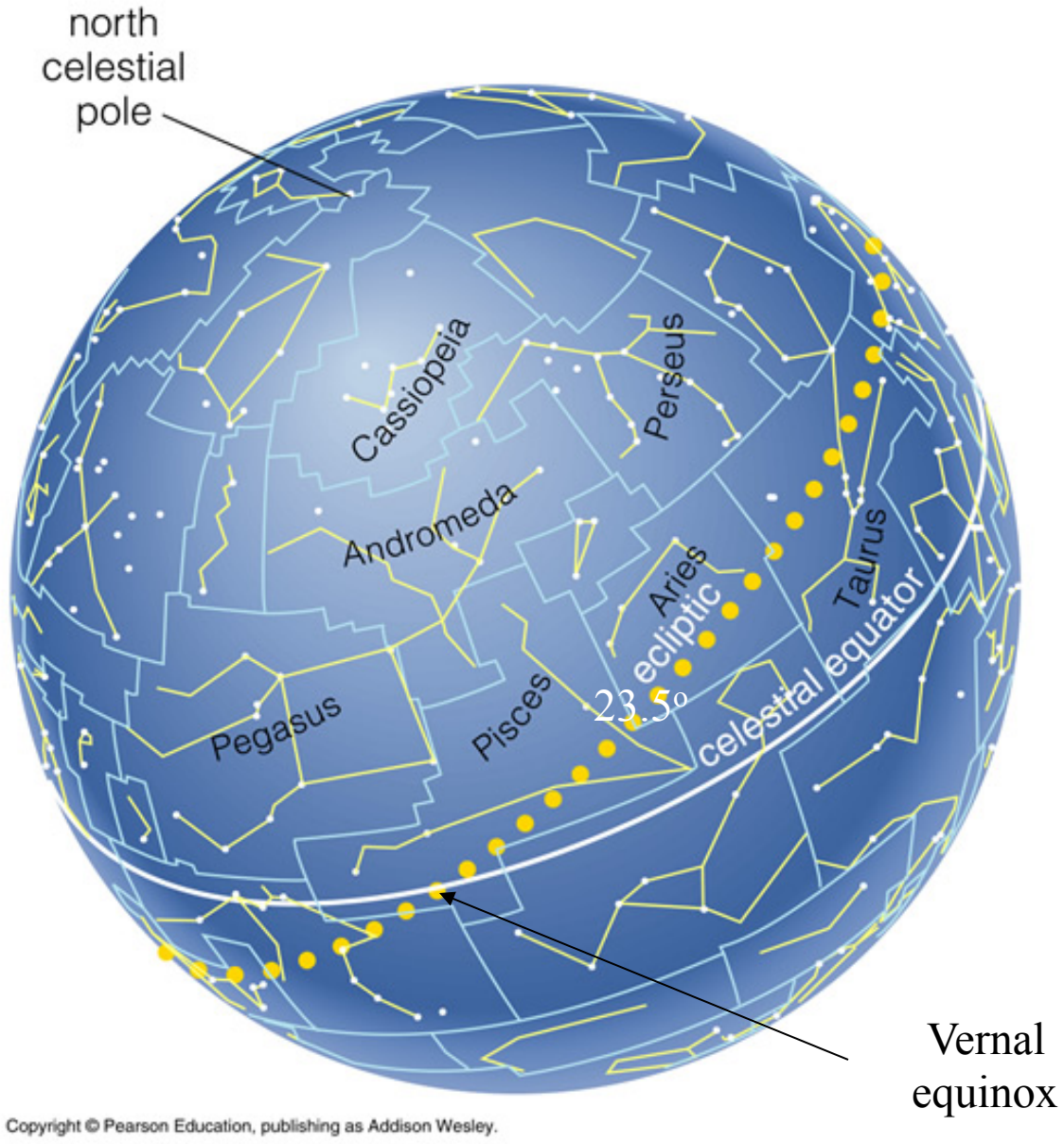
How we define our location on the Earth...



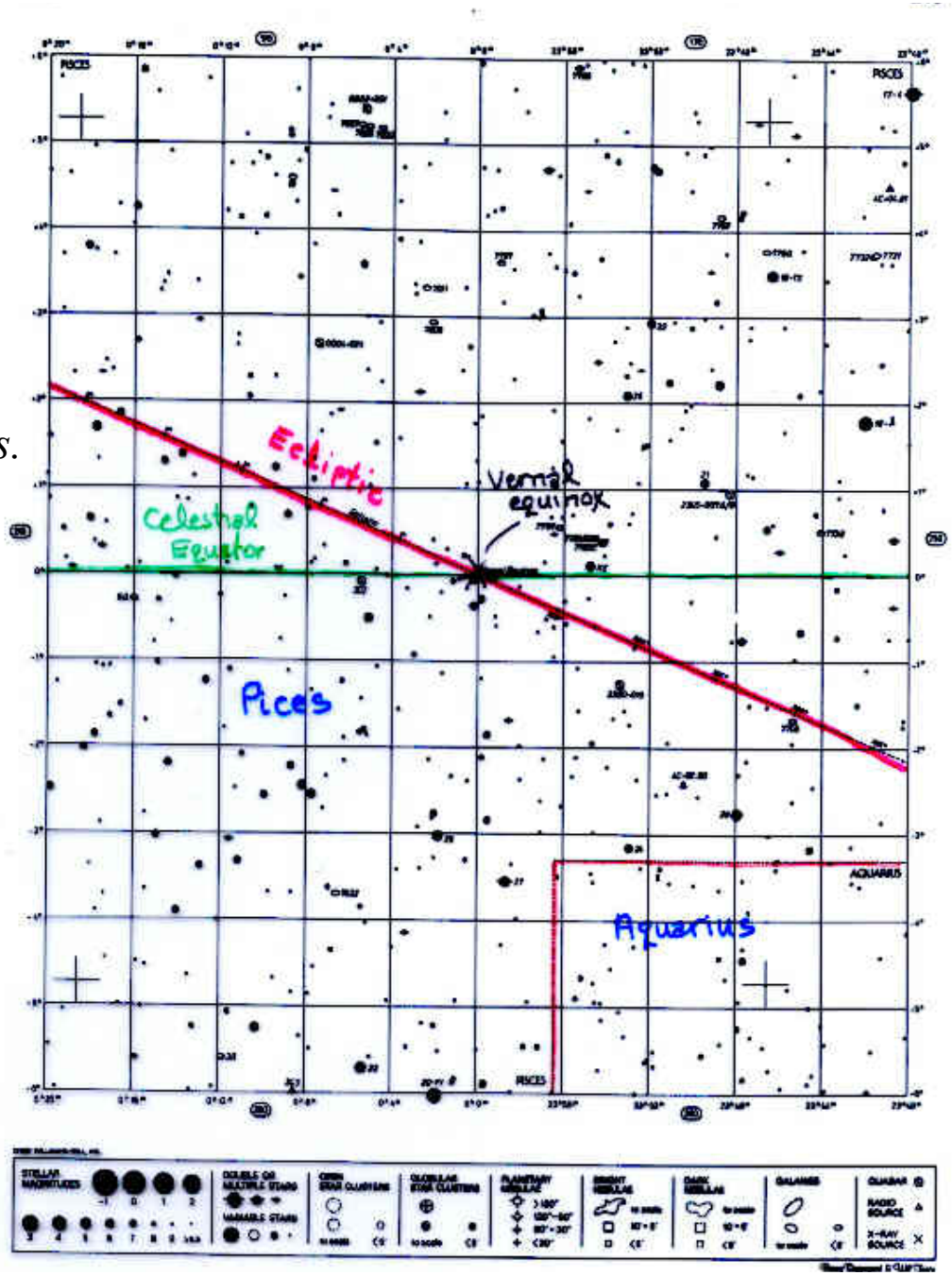
16. Abell/Morrison/Wolff: EXPLORATION OF THE UNIVERSE, 6/E



An important location in the sky, to astronomers, is the "Vernal Equinox", where the center of the sun crosses the CE.



The vernal equinox is in Pices. The autumnal equinox is in Virgo. Astrologers would say Libra (offset by the precession of the equinoxes).



UT date and time of equinoxes and solstices on Earth[1]								
event	equinox		solstice		equinox		solstice	
month	March		June		September		December	
year	day	time	day	time	day	time	day	time
2010	20	17:32	21	11:28	23	03:09	21	23:38
2011	20	23:21	21	17:16	23	09:04	22	05:30
2012	20	05:14	20	23:09	22	14:49	21	11:12
2013	20	11:02	21	05:04	22	20:44	21	17:11
2014	20	16:57	21	10:51	23	02:29	21	23:03
2015	20	22:45	21	16:38	23	08:20	22	04:48
2016	20	04:30	20	22:34	22	14:21	21	10:44
2017	20	10:28	21	04:24	22	20:02	21	16:28
2018	20	16:15	21	10:07	23	01:54	21	22:23
2019	20	21:58	21	15:54	23	07:50	22	04:19
2020	20	03:50	20	21:44	22	13:31	21	10:02

UT = Greenwich England

Stellar Coordinates

- **Celestial Equator**

  Projection of the Earth's equator into the sky

- **Declination**

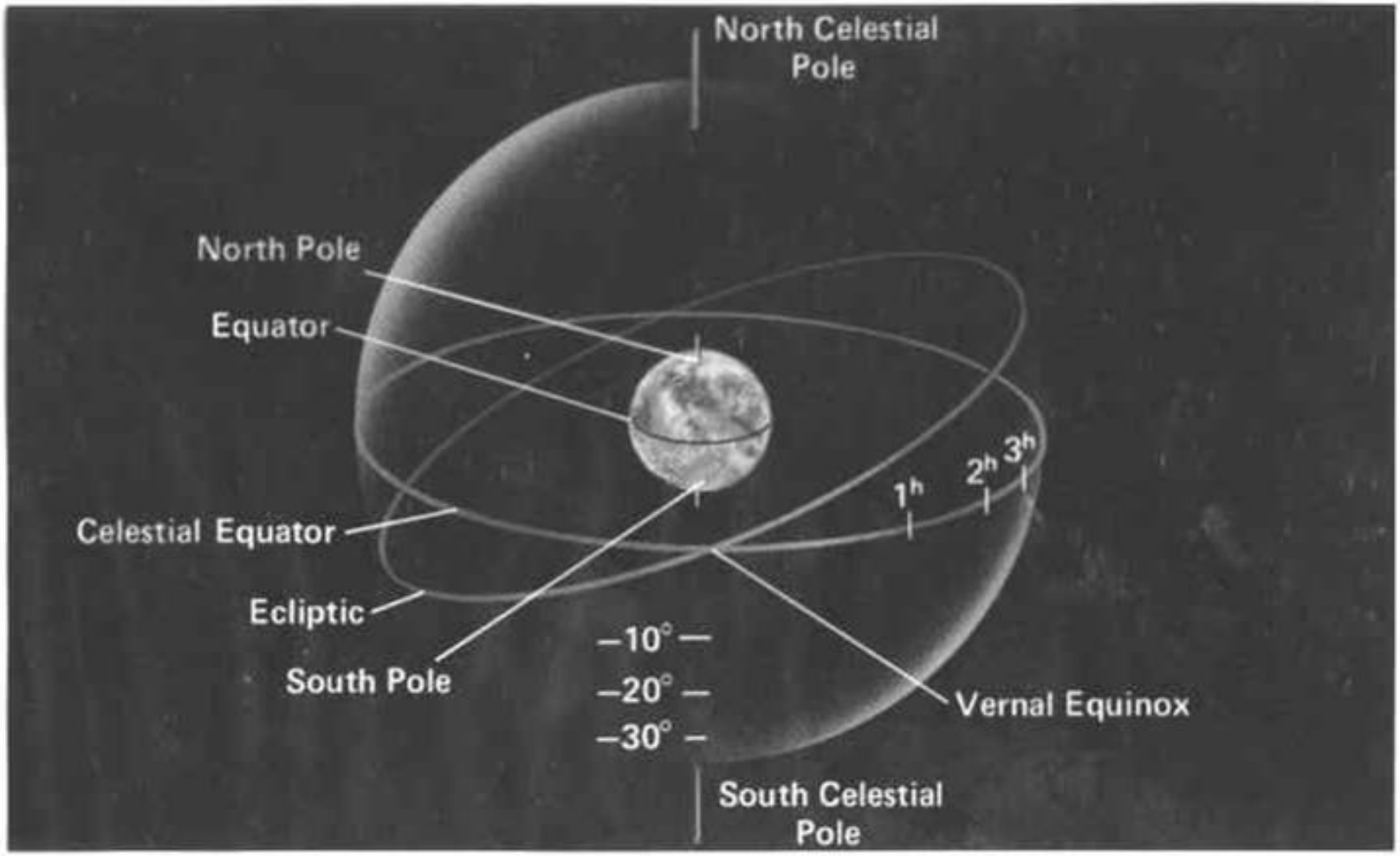
  The angle to a star or other object in degrees, minutes, and seconds measured north or south of the Celestial Equator

  $$-90^o \leq \delta \leq +90^o$$

- **Right Ascension**

  The angle measured *eastwards* from the Vernal equinox along the Celestial equator to the hour circle of the star. Measured in units of time (1 hour = 15 degrees; 1 minute of time = 15' of angle)

  $$0^h \leq \mathrm{RA} \leq 24^h$$



Measuring angles in units of time? A convention used in astronomy because of historical reasons.

Declination is measured in degrees (and minutes and seconds), but Right Ascension (RA) is measured in hours, minutes, and seconds…. sorry…

1 hr of RA = 15 degrees of ordinary angular measure (360/24)

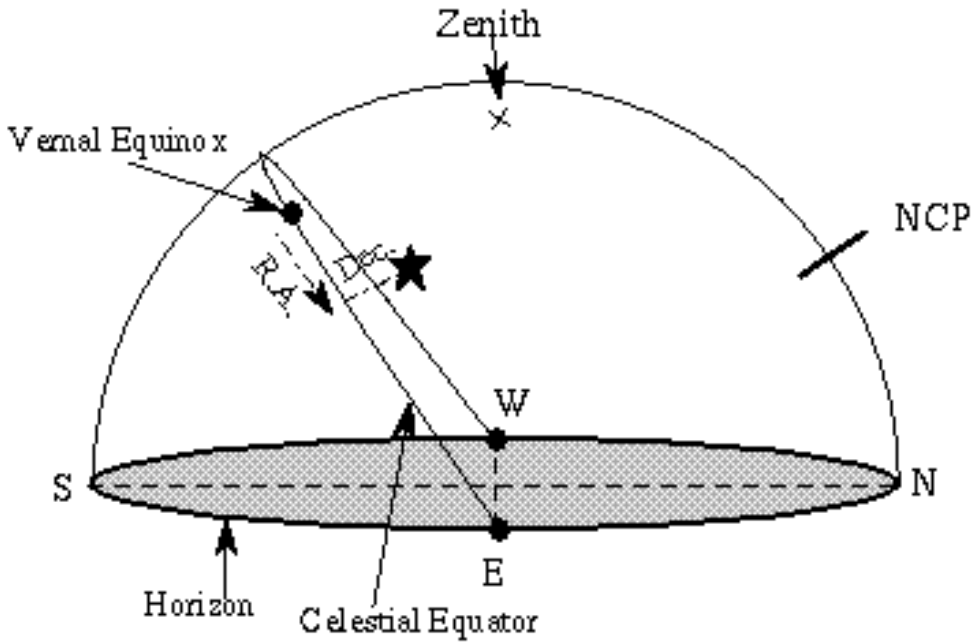
1 min of RA = 15/60 = ¼ degree = 15 arc min of angular measure

i.e., 15 degrees is one hour and one minute is 1/60 of that

1 sec of RA = 15/3600 = 1/240 degree = 15 arc sec

nb. 0 longitude on Earth is defined by Greenwich England.
0 right ascension in astronomy is defined by the vernal equinox in Pices

copied from Nick Strobel's "Astronomy notes". See his website.



A star's position in the equatorial coordinate system. The right ascension (R.A.)=1 hr 30 min and the declination (Dec.)=15°. The right ascension is measured in hours, minutes, and seconds in the easterly direction from the vernal equinox position on the celestial equator. The declination is measured in degrees above the celestial equator. The star's R.A. and Dec. does NOT change throughout the night—its equatorial coordinate position is fixed with respect to the stars. The star's position does depend on the location of the NCP and Celestial Equator in this system.

Brightest Stars

Star	Name	M	RA	Dec
alpha CMa	Sirius	-1.46	06 45 8.9	-16 42 58
alpha Car	Canopus	-0.72	06 23 57.2	-52 41 44
alpha Cen	Rigil Kent	-0.01	14 39 36.2	-60 50 07
alpha Boo	Arcturus	-0.04	14 15 39.6	+19 10 57
alpha Lyr	Vega	0.03	18 36 56.2	+38 47 01
alpha Aur	Capella	0.08	05 16 41.3	+45 59 53
beta Ori	Rigel	0.12	05 14 32.2	-08 12 06
alpha CMi	Procyon	0.38	07 39 18.1	+05 13 30
alpha Eri	Archenar	0.46	01 37 42.9	-57 14 12
alpha Ori	Beteigeuse	0.50	05 55 10.3	+07 24 25
beta Cen	Hadar	0.61	14 03 49.4	-60 22 22
alpha Aql	Altair	0.77	19 50 46.9	+08 52.6
		0.77		
alpha Tau	Aldebaran	0.85	04 35 55.2	+16 30 33
alpha Vir	Spica	0.98	13 25 11.5	-11 09 41
alpha Sco	Antares	0.96	16 29 24.4	-26 25 25
beta Gem	Pollux	1.14	07 45 18.9	+28 01 34
alpha PsA	Fomalhaut	1.16	22 57 39.0	-29 37 20
alpha Cyg	Deneb	1.25	20 41 25.8	+45 16 49
beta Cru	Mimosa	1.25	12 47 43.3	-59 41 19

http://www.google.com/sky/

Actual Coordinates of Polaris:

Declination = 89^{o} 15’ 51”

RA = 2^{h} 31^{m} 48.7^{s}

Examples

Sirius: $\delta = -16^o\ 43'$; RA = 6 hr 45.2 min

α-Centauri: $\delta = -60^o\ 50'$; RA = 14 hr 39.6 min

http://www.google.com/sky/

How many degrees is 14 hr 39.6 min?

1 hr = 15 degrees
1 min = 15'

14 hr*(15 ^{0}/hr) + 39.6 min (15'/min) = 210 ^{0} 594'

but 594'/60' per degree = 9^o with 54' left over

so 14 hr 39.6 min or RA is 219^o 54' East of the Vernal Equinox

This is also 360^o – 219^o 54' = 140^o 06' West of the Vernal Equinox

NAVIGATION

Your Celestial Meridian is the imaginary line through your zenith and north (or south pole) from horizon to horizon.

Your siderial time is equal to the right ascension of stars on your CM. At midnight siderial, the vernal equinox is on your CM

Your longitude is the difference between your local siderial time and the siderial time in Greenwich. (subtract Greenwich siderial time from your local siderial time).

To navigate in the old days your prime need was a good clock (if the sky was clear) and knowledge of the stars.

The **Longitude Prize** was a reward offered by the British government for a simple and practical method for the precise determination of a ships longitude. The prize was established through an act of Parliament (the Longitude Act) in 1714 and was administered by the Board of Longitude

Crude example

The longitude of New York is 74 degrees W.
We are 4 time zones west of New York
Each time zone is 15 degrees (360/24)
So we are roughly at longitude

$$74 + 15*4 = 134$$

Actually we are at 122 W, but this shows the idea.

E.g. RA of Betelgeuse is 05 h 55m 10.3053 s

Suppose Betelgeuse crosses your CM when the siderial time in Greenwich is midnight (0h 0 m)

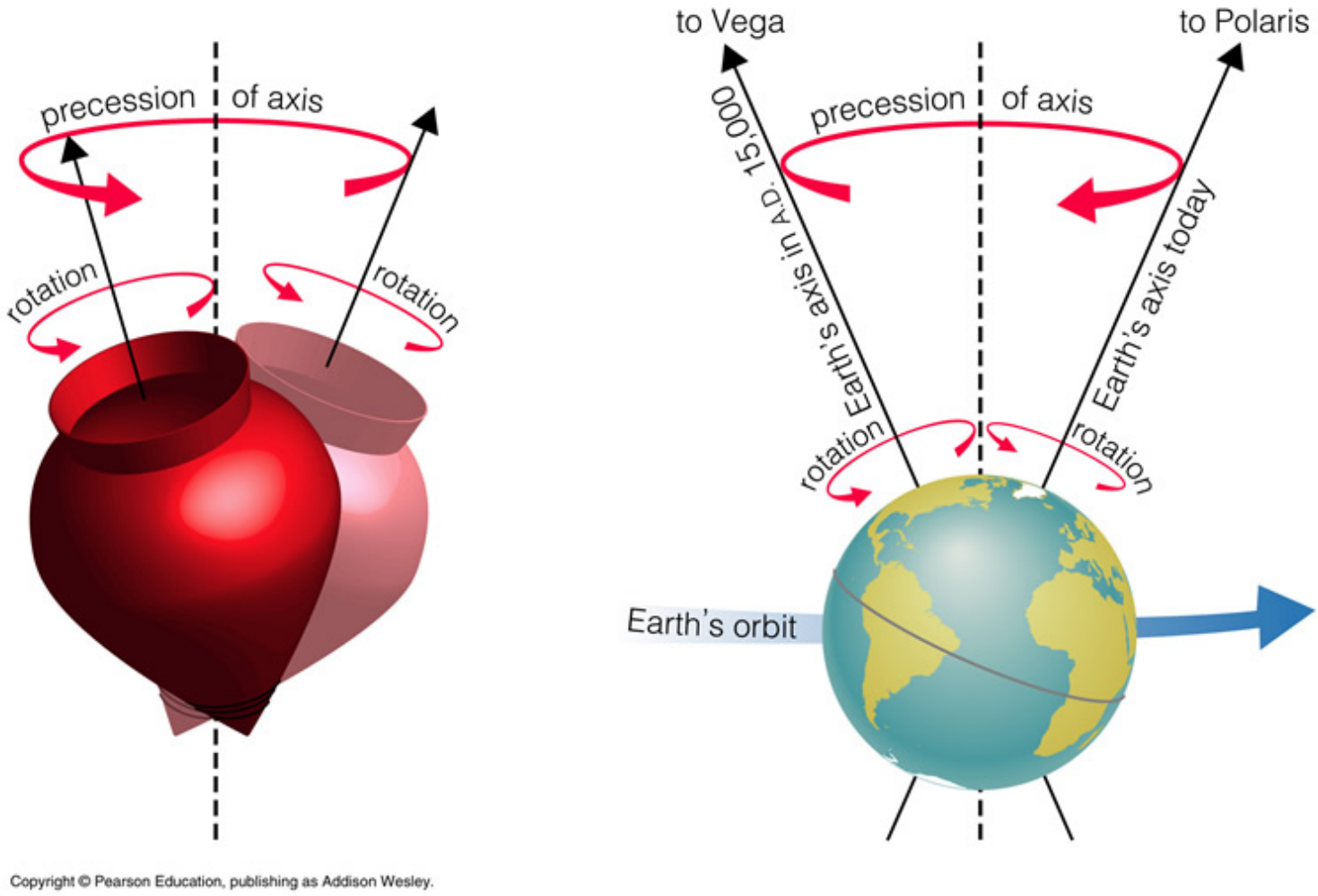
Your longitude is 5 h 55m … or 5.920 h or 88.79 degrees

You are 88.79 degrees east of Greenwich. Positive numbers are east (definitely not Santa Cruz; possibly India)

(Time is later as you go east, e.g., NY vs Santa Cruz)

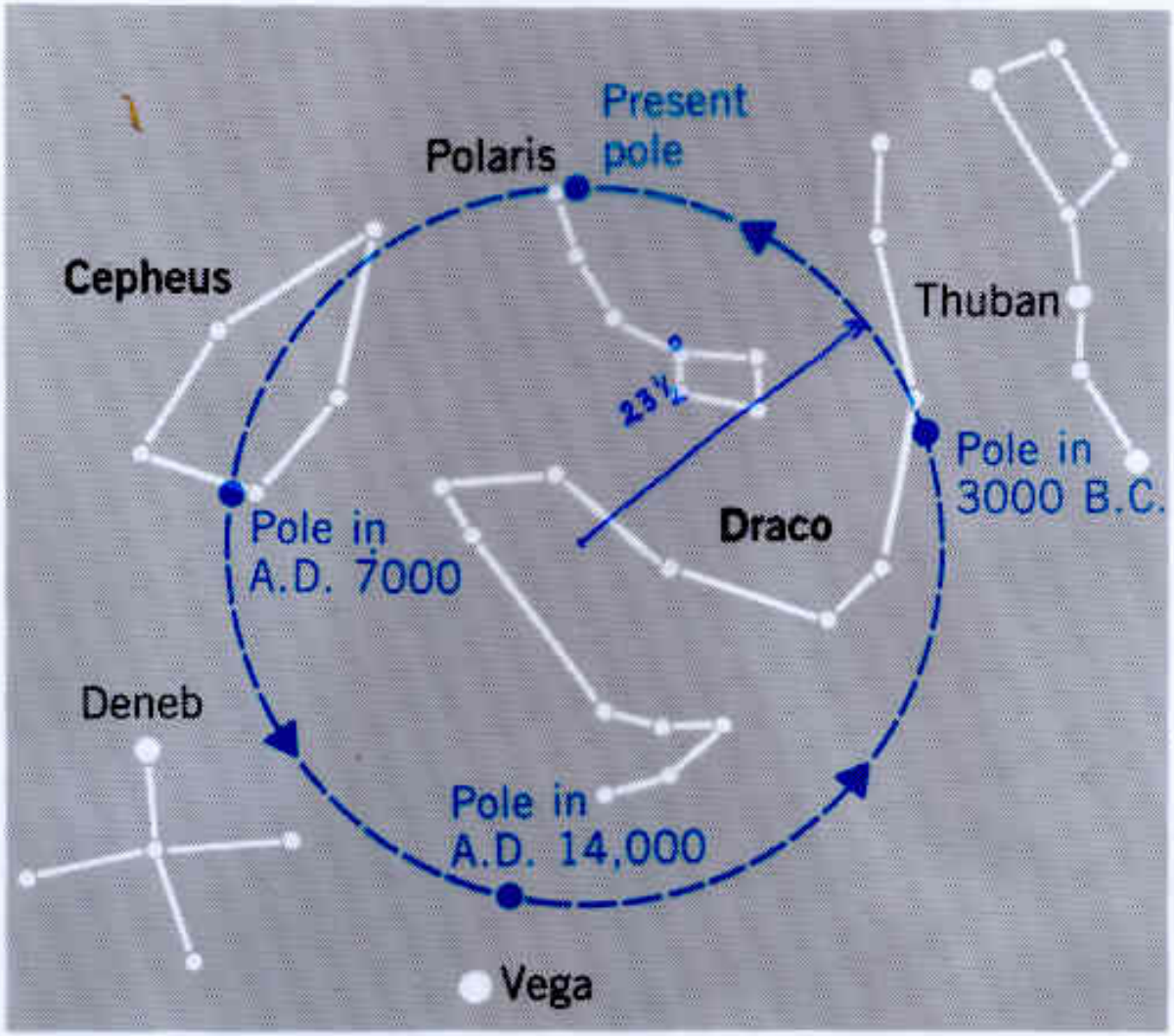
Aside, the vernal equinox is on your CM at "midnight" siderial time (not necessarily at night). Siderial time is defined as the "hour angle" of the vernal equinox.

Precession of the Equinoxes



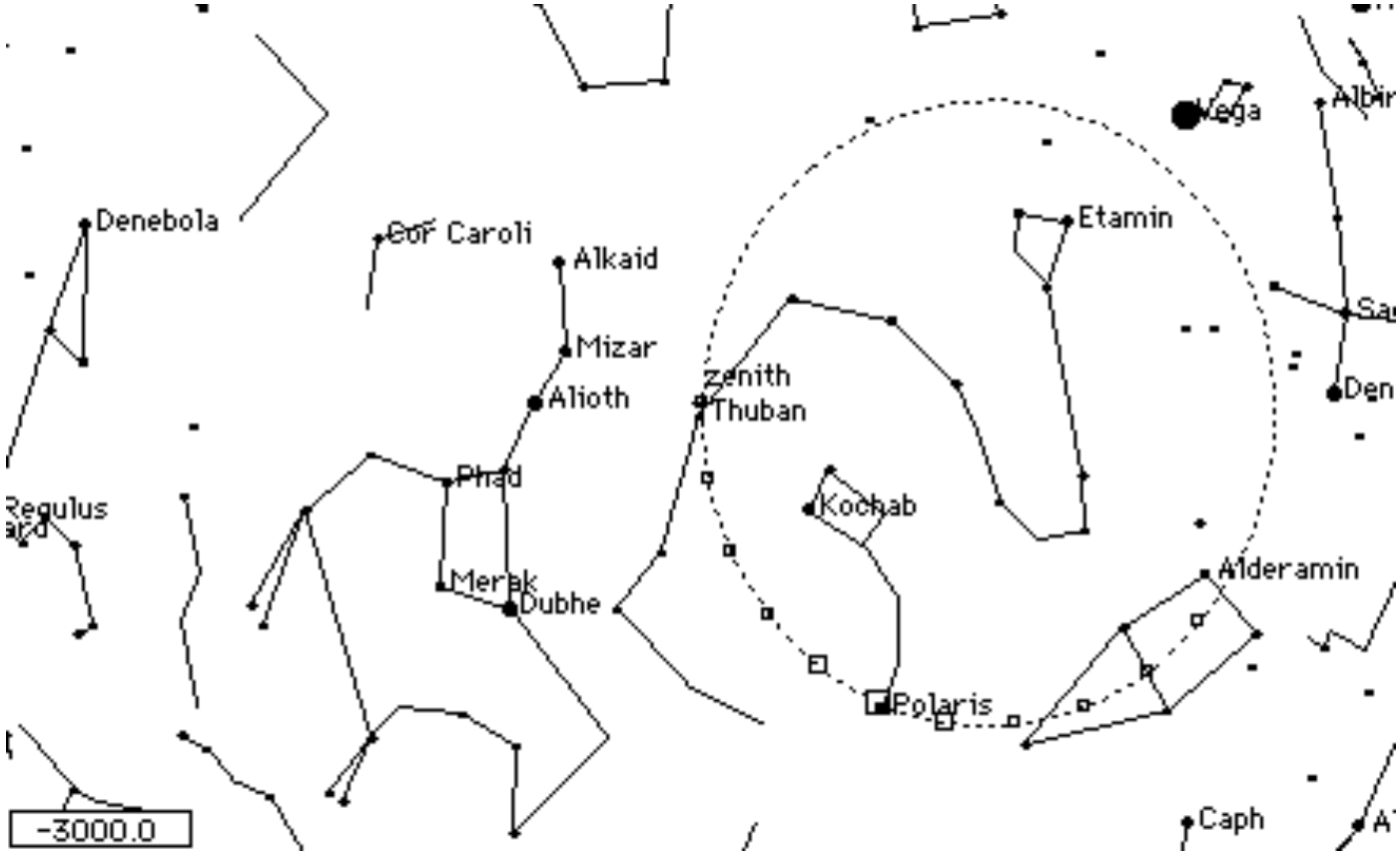
Due to the interaction of an earth that is not perfectly spherical with the gravitational pull of the sun and moon

1.38 degrees per century



Precession and the change of position of the north celestial pole with respect to the stars.

$\tau_p = 26{,}000$ yr.


Vega
Denebola
Etamin
Alkaid
Mizar
Alioth
Zenith
Thuban
Kochab
Phad
Merak
Dubhe
Alderamin
Polaris
-3000.0
Caph

As a result of this precession the projection of the earth's equator into the sky - the *celestial equator* - also moves and this causes an adjustment of the equinoxes. This in turn changes the coordinate system in which a star's location is measured. The vernal equinox drifts westward along the ecliptic about an arc minute per year (actually 50.35 arc seconds).

So when a star's coordinates are given (RA and δ), a date must also be given. Current tables use 2000 as a reference point.

Corrections to where to point a telescope are discussed at e.g.,

http://star-www.st-and.ac.uk/~fv/webnotes/chapt16.htm