PHY 517 / AST 443: Observational Techniques in Astronomy

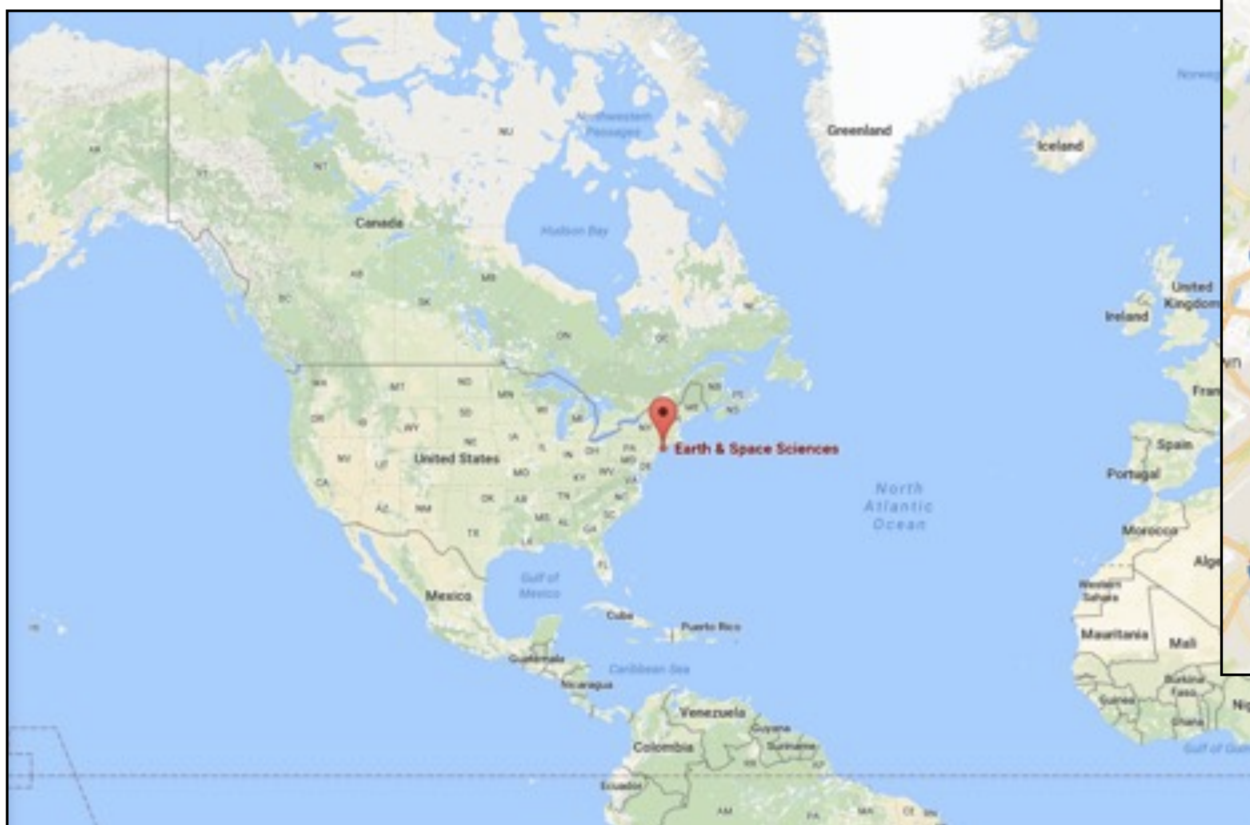
Lecture 1: How to find things in the Sky / Astronomical Coordinate Systems / Time

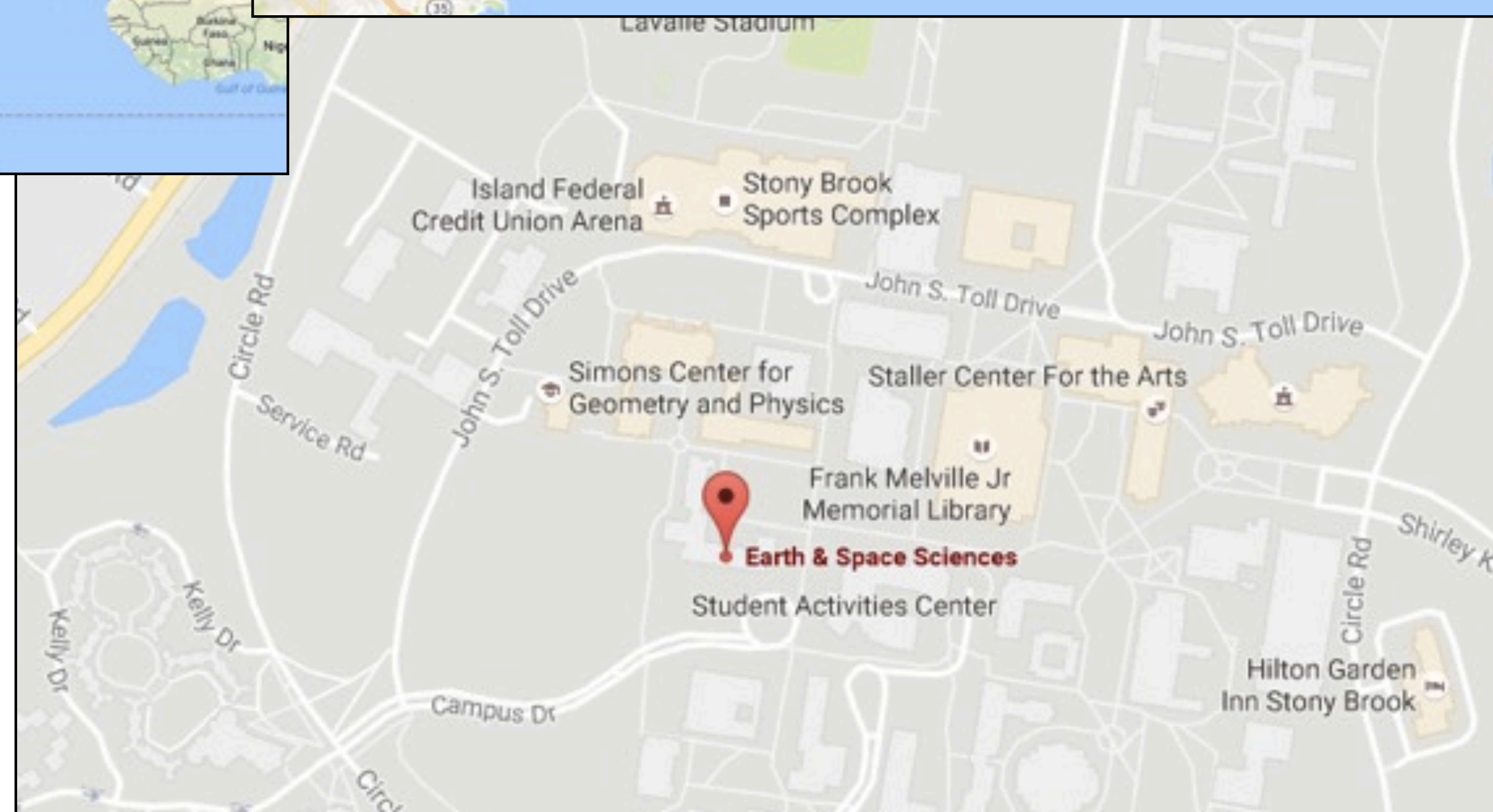
How do you find things in the Sky?

How do you find things on Earth?

How do you find things on Earth?

1. maps

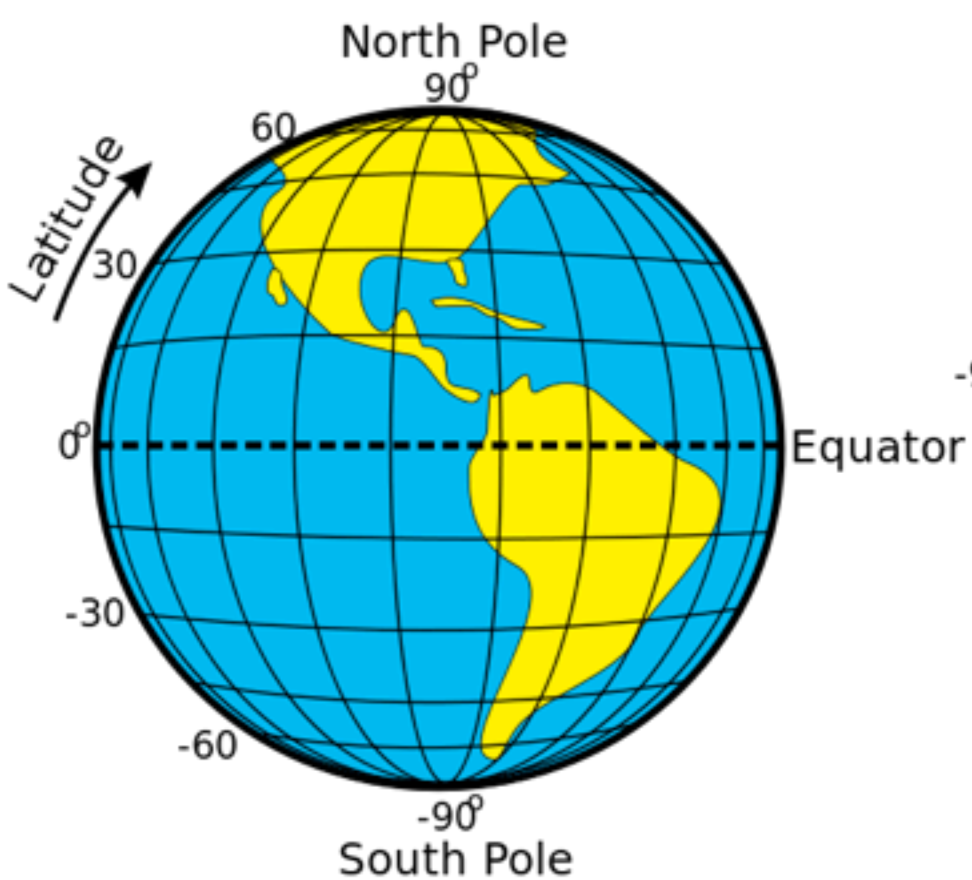


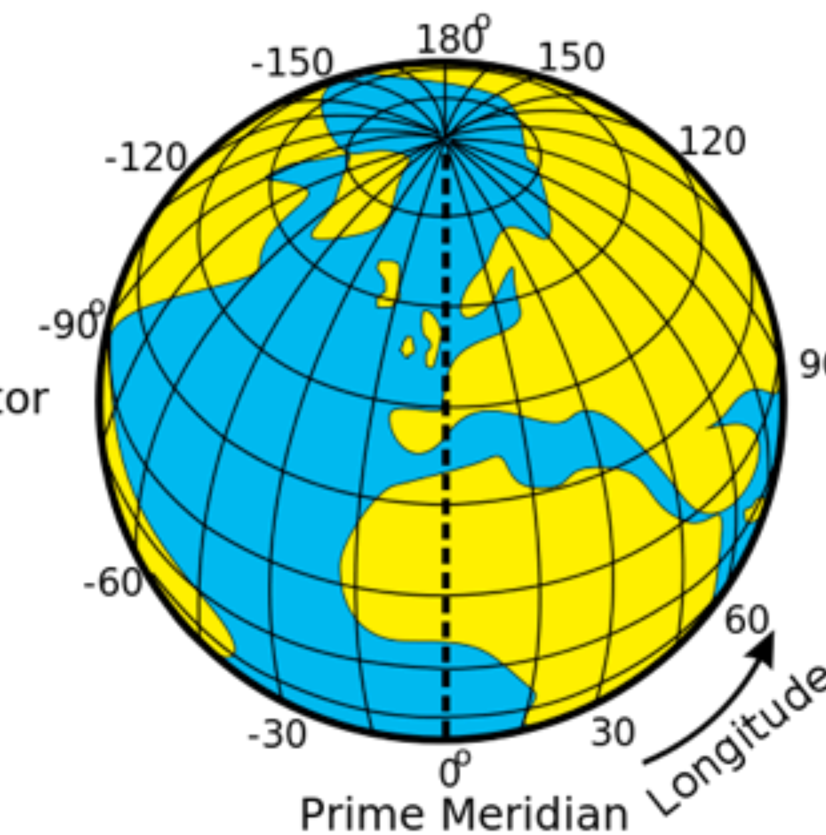


“pattern matching”

How do you find things on Earth?

2. latitude and longitude: 2 angular coordinates, related to Earth's rotation





Coordinates: 40.914224°N 73.11623°W

Stony Brook University

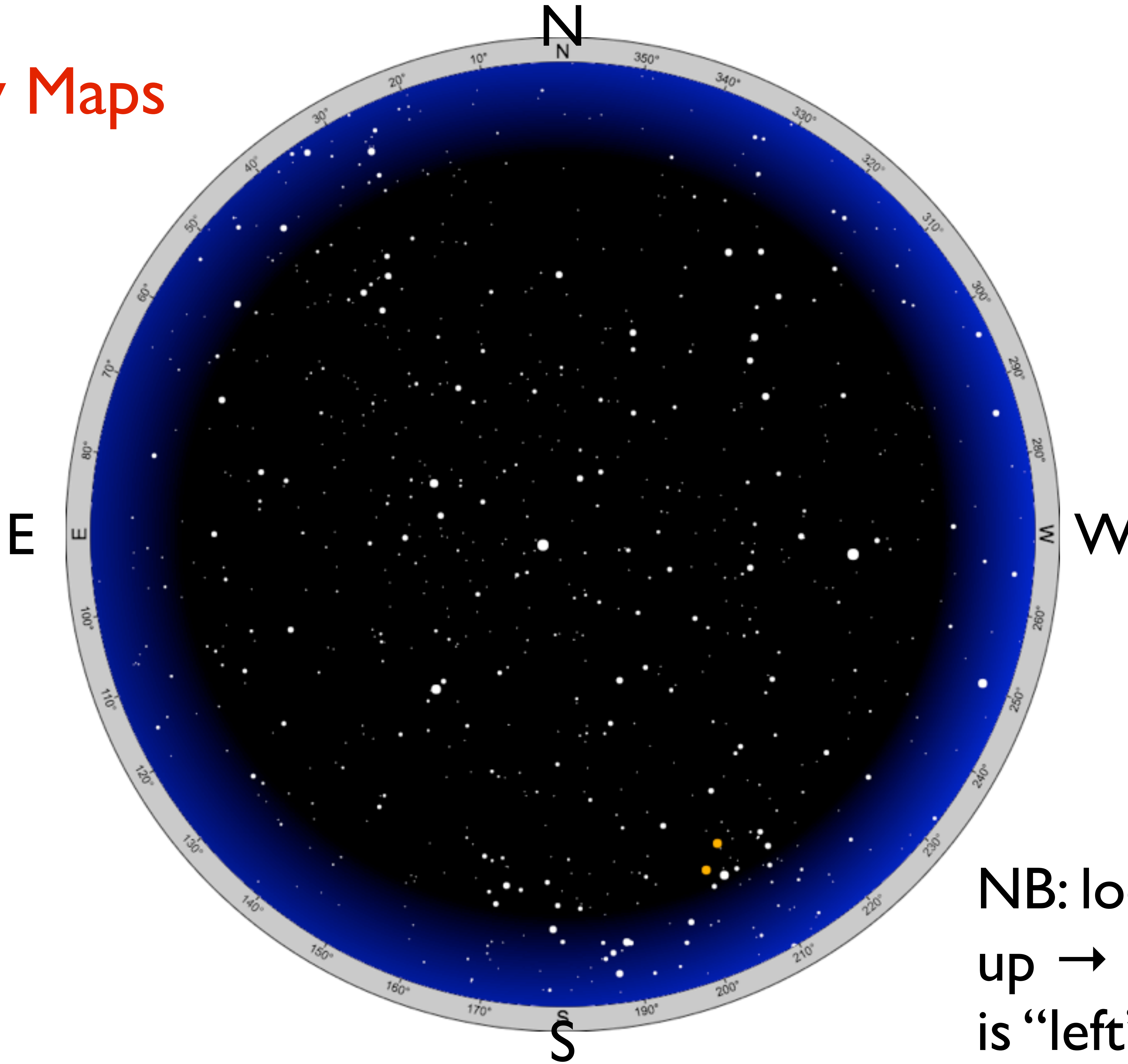
Former names	State University College on Long Island (1957–1962)
Type	• Public • Research university • Sea-grant • Space-grant
Established	1957
Endowment	$247.4 million (2015)[1]
President	Samuel L. Stanley
Provost	Dennis Assanis
Academic staff	2,471 (fall 2013)
Students	21,115 (West Campus)[2] 3,847 East Campus[2] 310 Southampton[2] 25,272 **Total**
Undergraduates	16,831 (2015 Fall)[2]
Postgraduates	8,441 (2015 Fall)
Location	Stony Brook, New York, U.S. 40.914224°N 73.11623°W

wikipedia

How do you find things on the Sky?

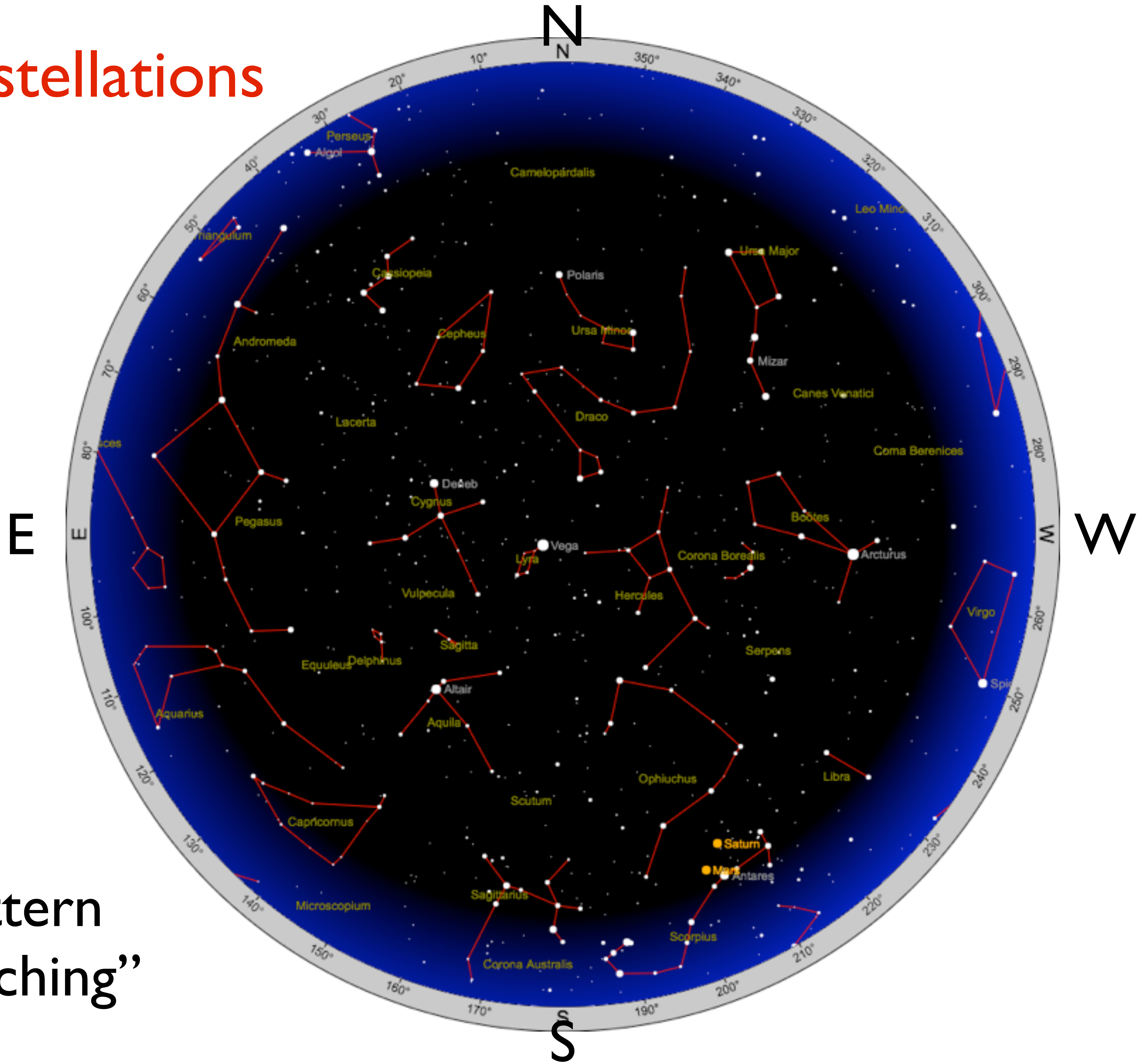
- similar to Earth:
    1. maps, “finding charts”, pattern matching
    2. angular coordinate systems

Sky Maps



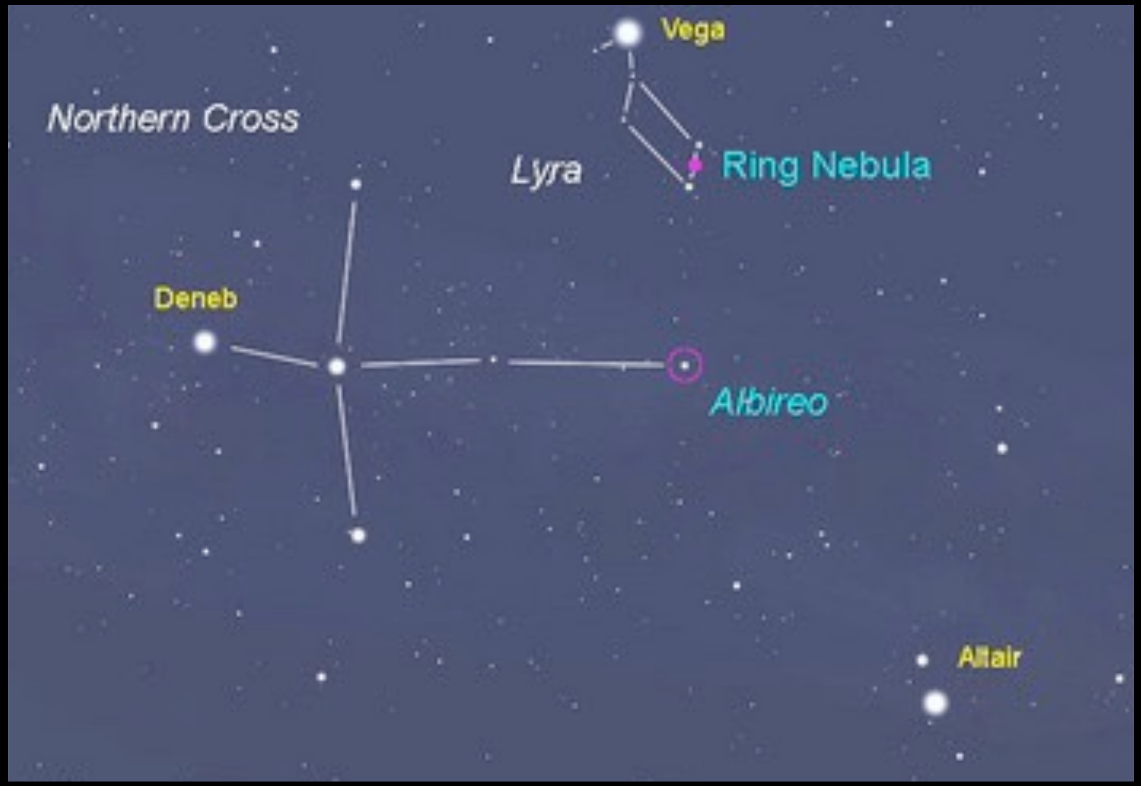
NB: looking up → East is “left”

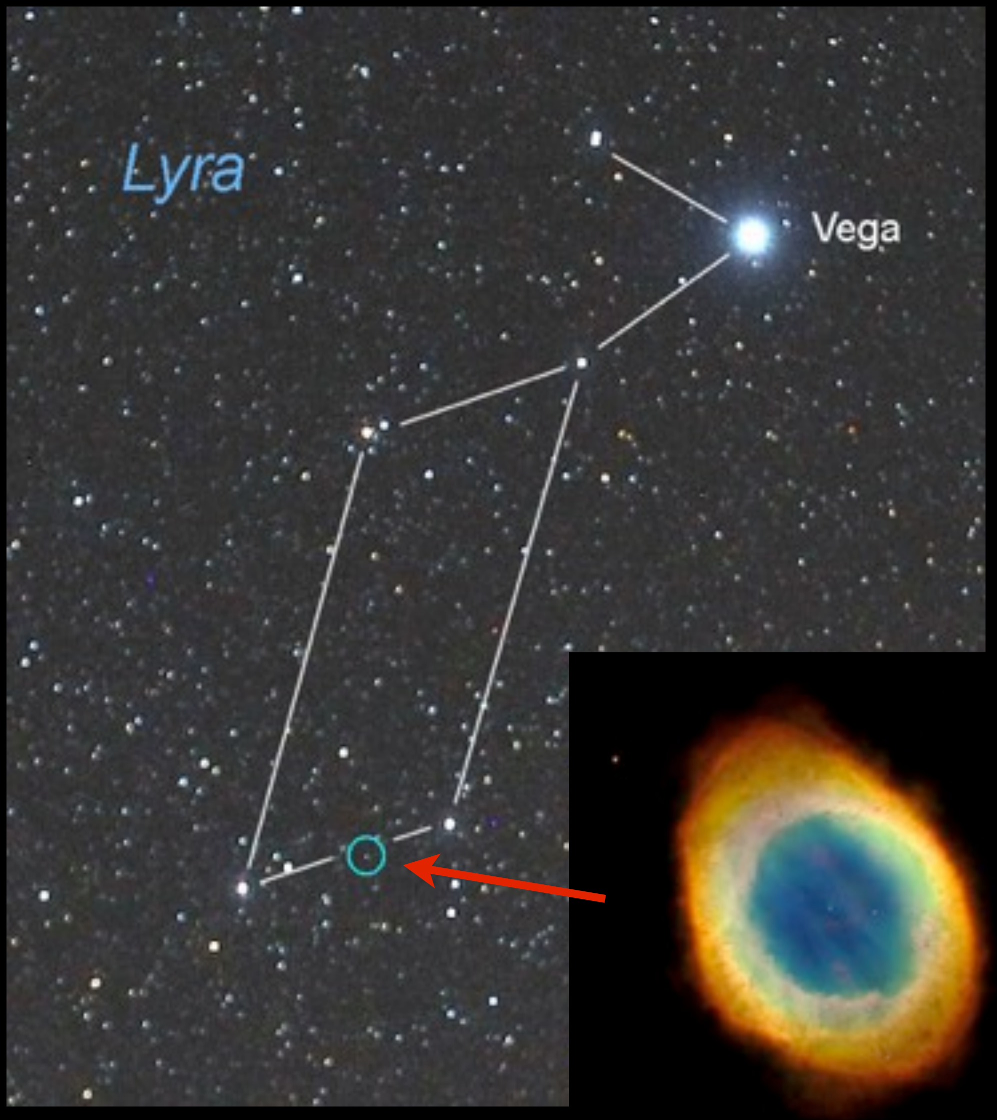
Constellations



“pattern matching”

How to find the Ring Nebula (M57)



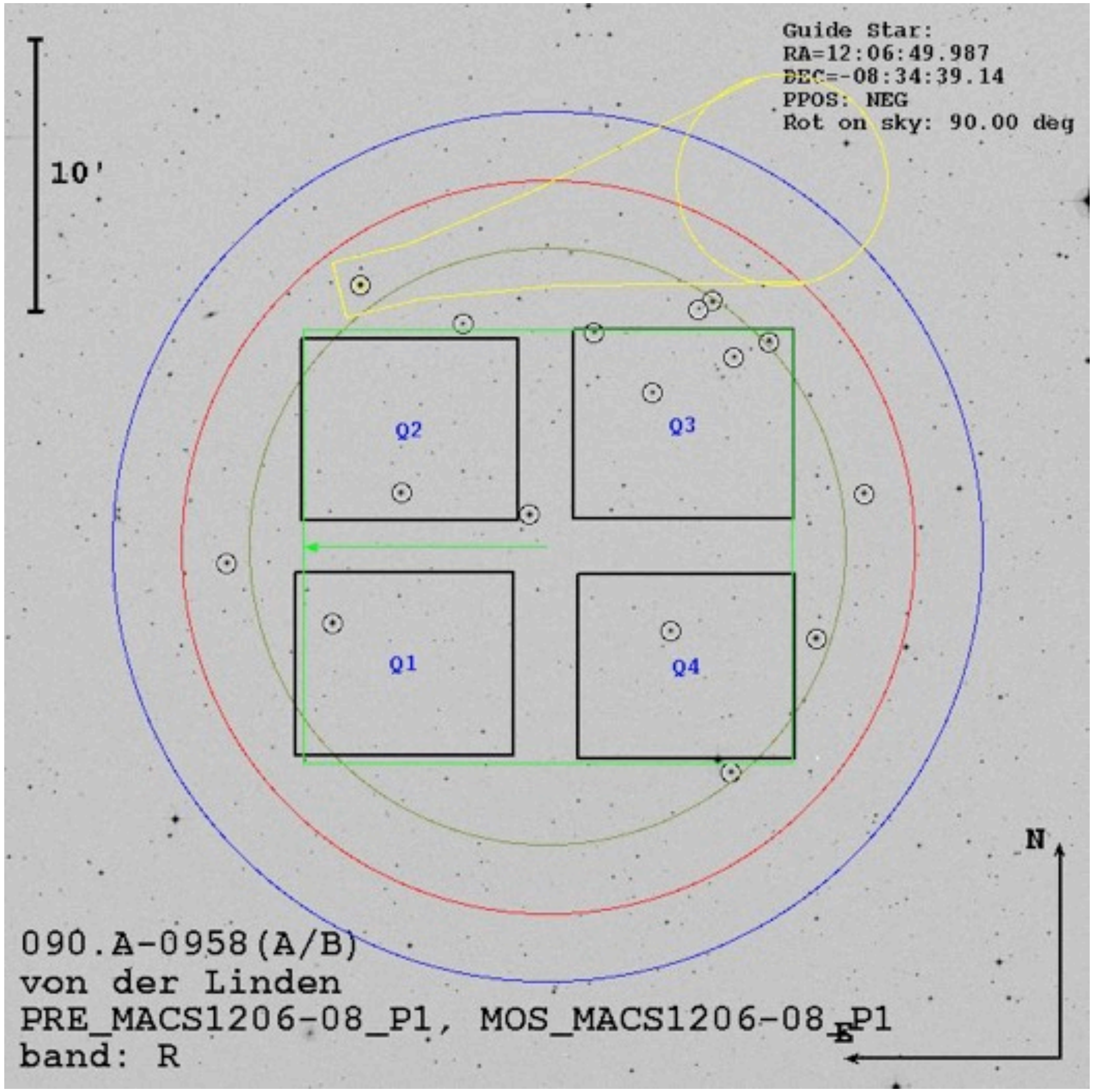


asterisms: easy-to-recognize star groupings
constellations: officially defined sky regions, based on historical asterims

Sky maps in professional astronomy

finding charts: big telescopes usually look at small sky regions; need to make sure you're looking at the right object!

include:
- scale
- direction
- identifiers / target
- instrument-specific features: field of view, guide star



Astronomical coordinate systems

Horizontal (or “Alt/Az”) Coordinate System

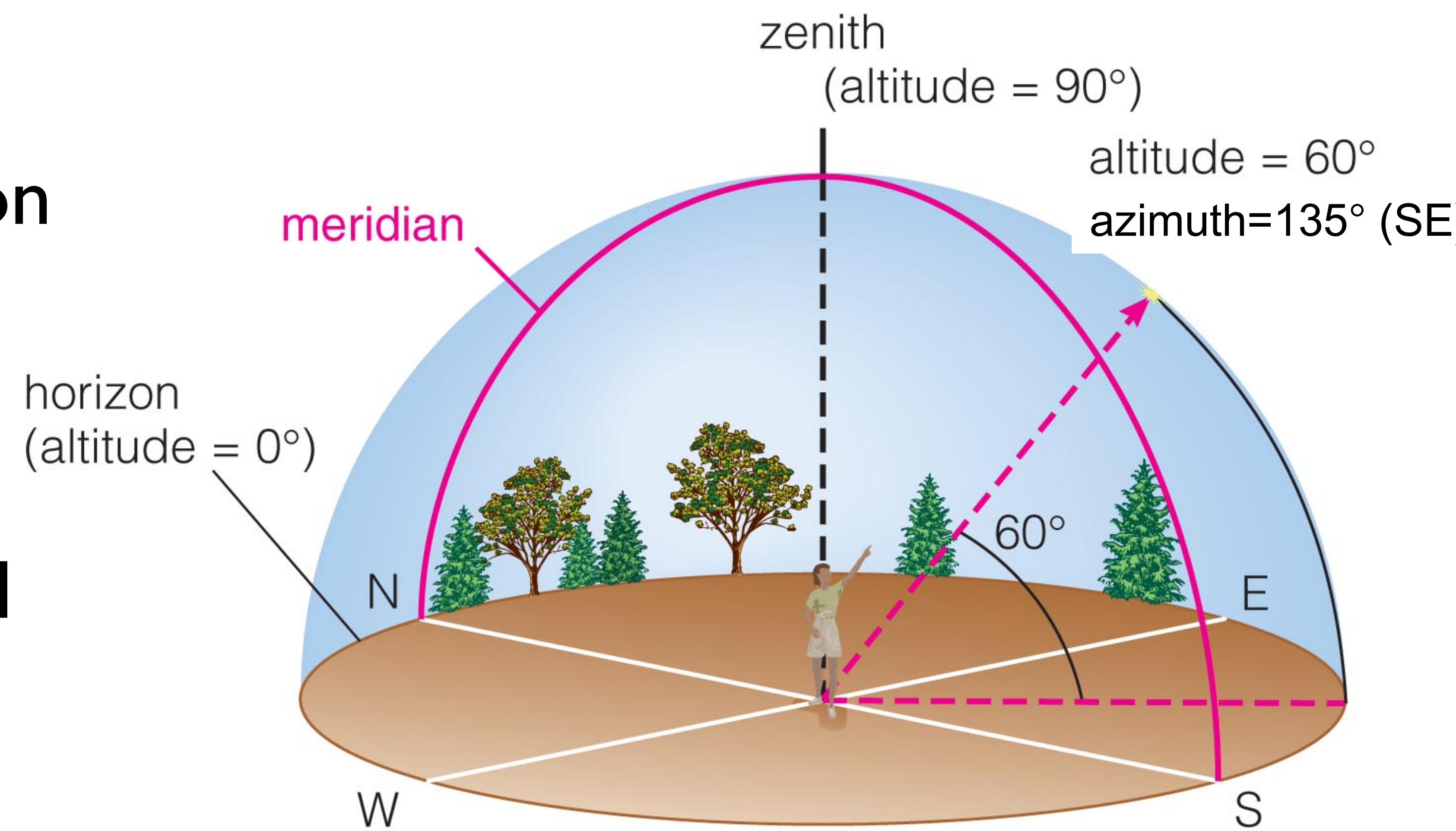
the sky above *a specific location*, *at a specific time*, is half a sphere - can be described with 2 (positive) angular coordinates

altitude: angular distance to the horizon

azimuth: angular distance from north

zenith: point overhead

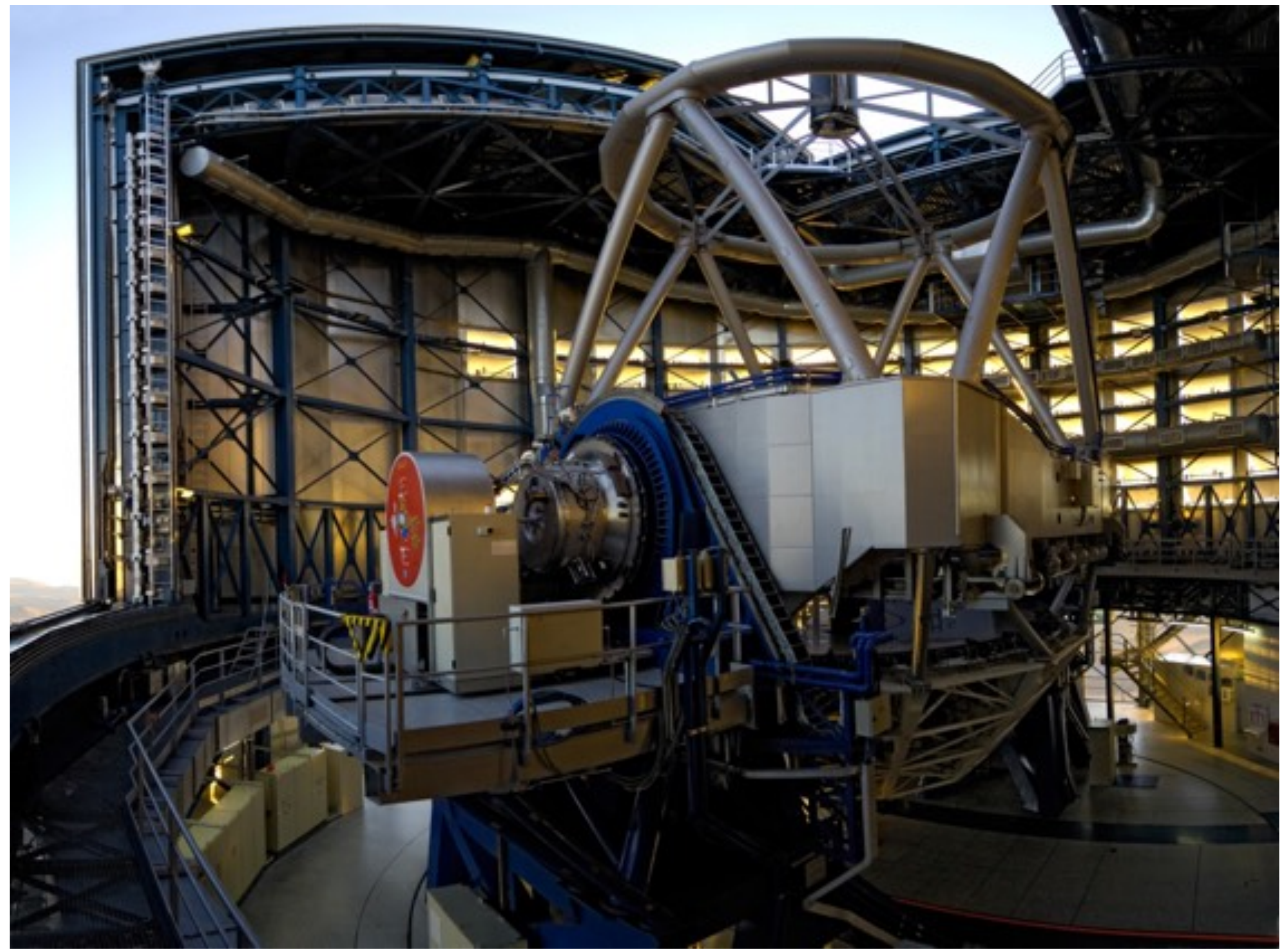
meridian: north-south line



Horizontal (or “Alt/Az”) Coordinate System

alt-az telescope mounts: simple, very stable

Dobsonian-style telescope (~8 inch)



Very Large Telescope (8 meters)

An Alt-Az telescope mount in action:

http://sguisard.astrosurf.com/Anim-astro/P21-P22/P21-P22.html

Horizontal (or "Alt/Az") Coordinate System

because of the rotation of the Earth: altitude and azimuth of a given object vary with time

in practice, we use "sky" coordinates to locate objects

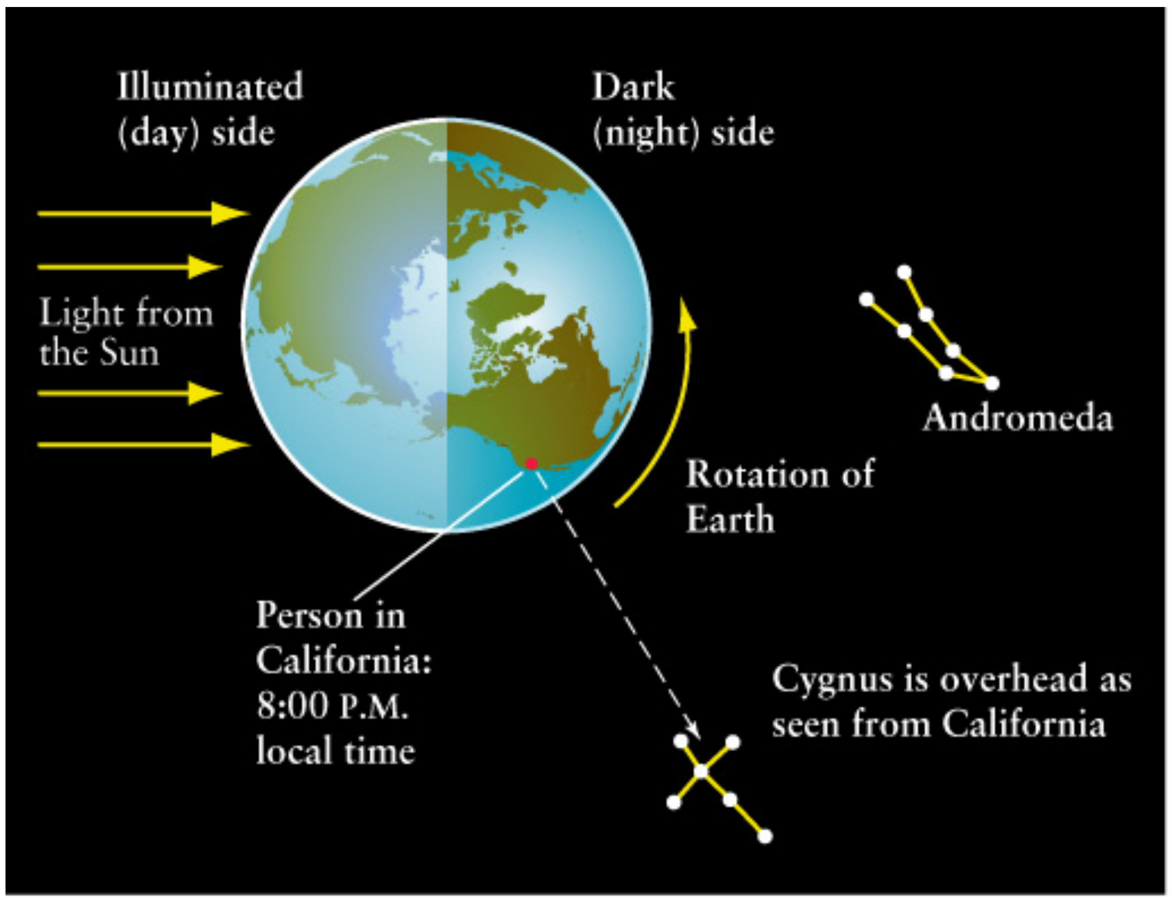
you need to (approximately) know the altitude and azimuth of your target independent of the telescope mount and how you plan to find the target

is my target "up" ? (altitude > 0°)

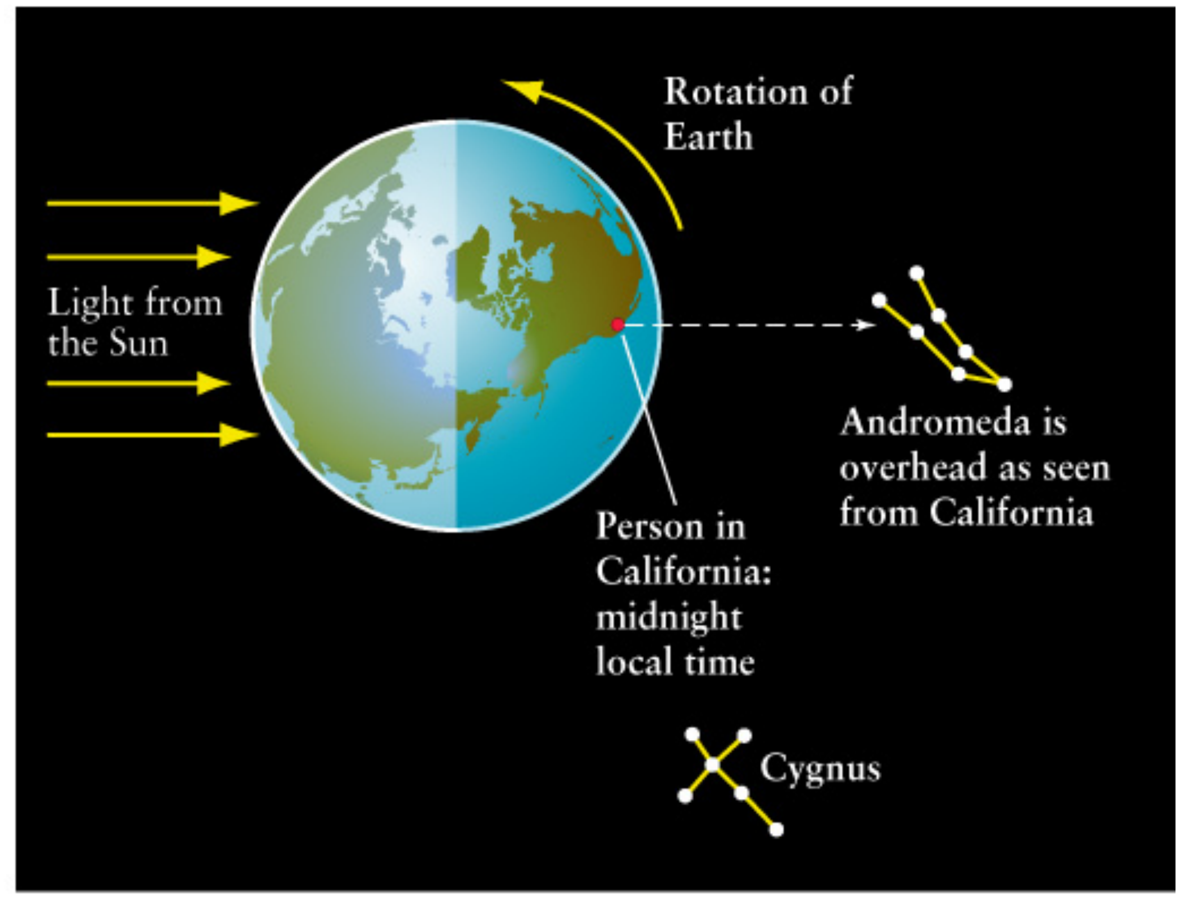
is my target "observable" ? (altitude > 30° / 40° / 50°)

Rotation of the Earth

looking down on the north pole, Earth rotates counter-clockwise



(a) Earth as seen from above the north pole



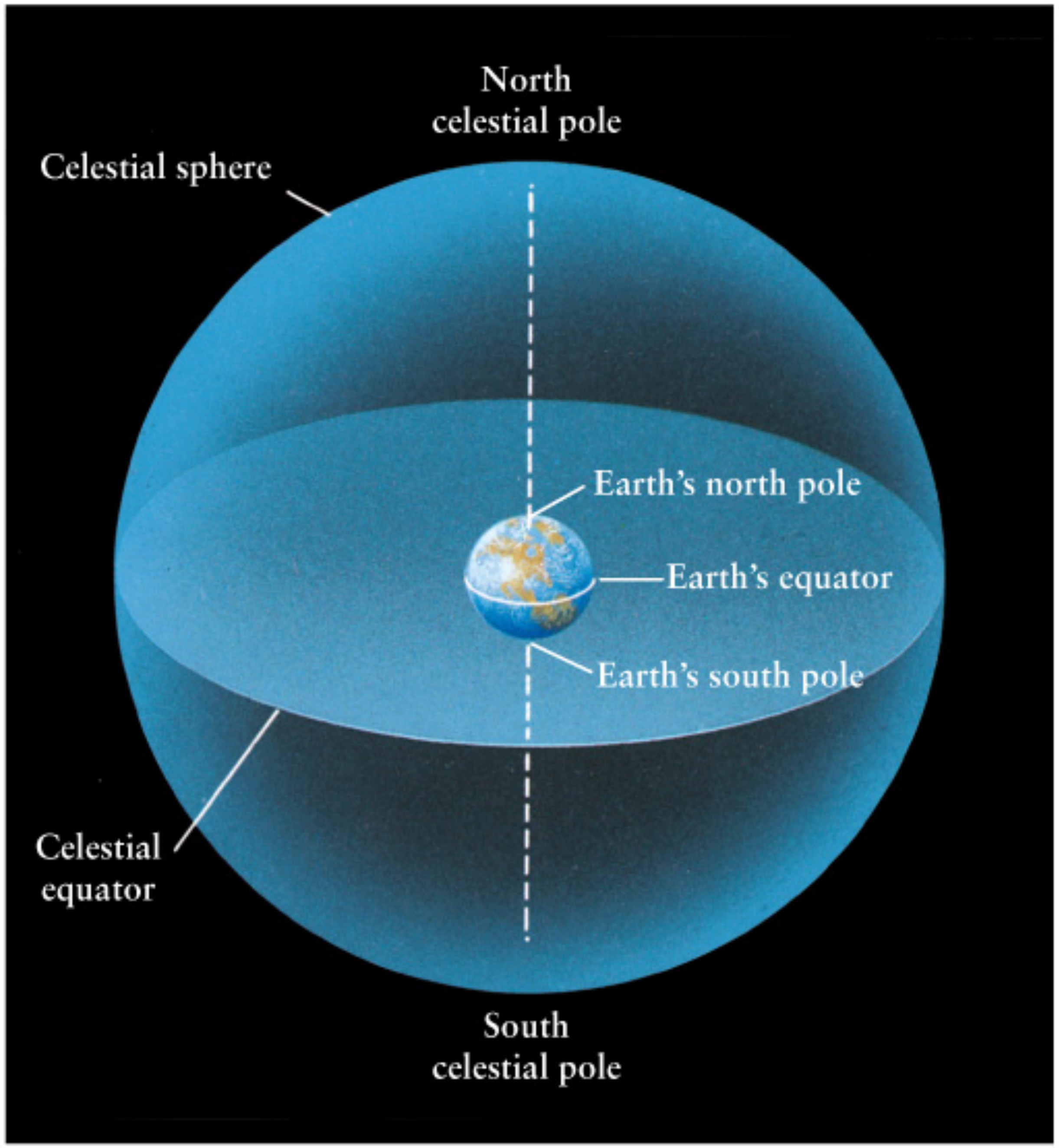
(b) 4 hours (one-sixth of a complete rotation) later

Andromeda is to the East; Cygnus is overhead

4 hrs later: Andromeda is overhead; Cygnus is to the West

the Sky appears to rotate East to West

Celestial Sphere

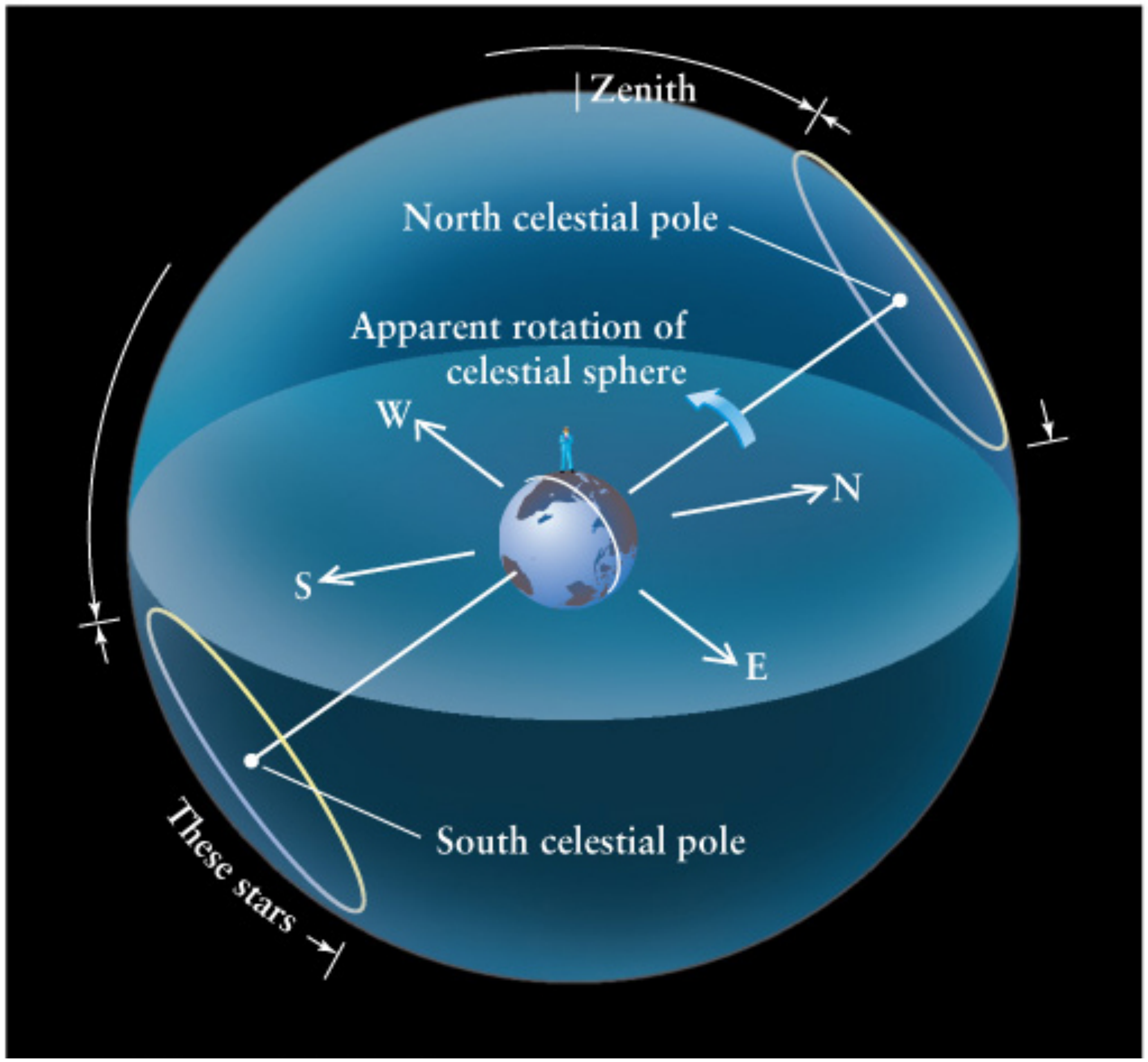


celestial sphere: describe objects by their position on a sphere centered on us

celestial north / south pole: projection of Earth's north / south pole

celestial equator: projection of Earth's equator

Apparent motion in the Sky

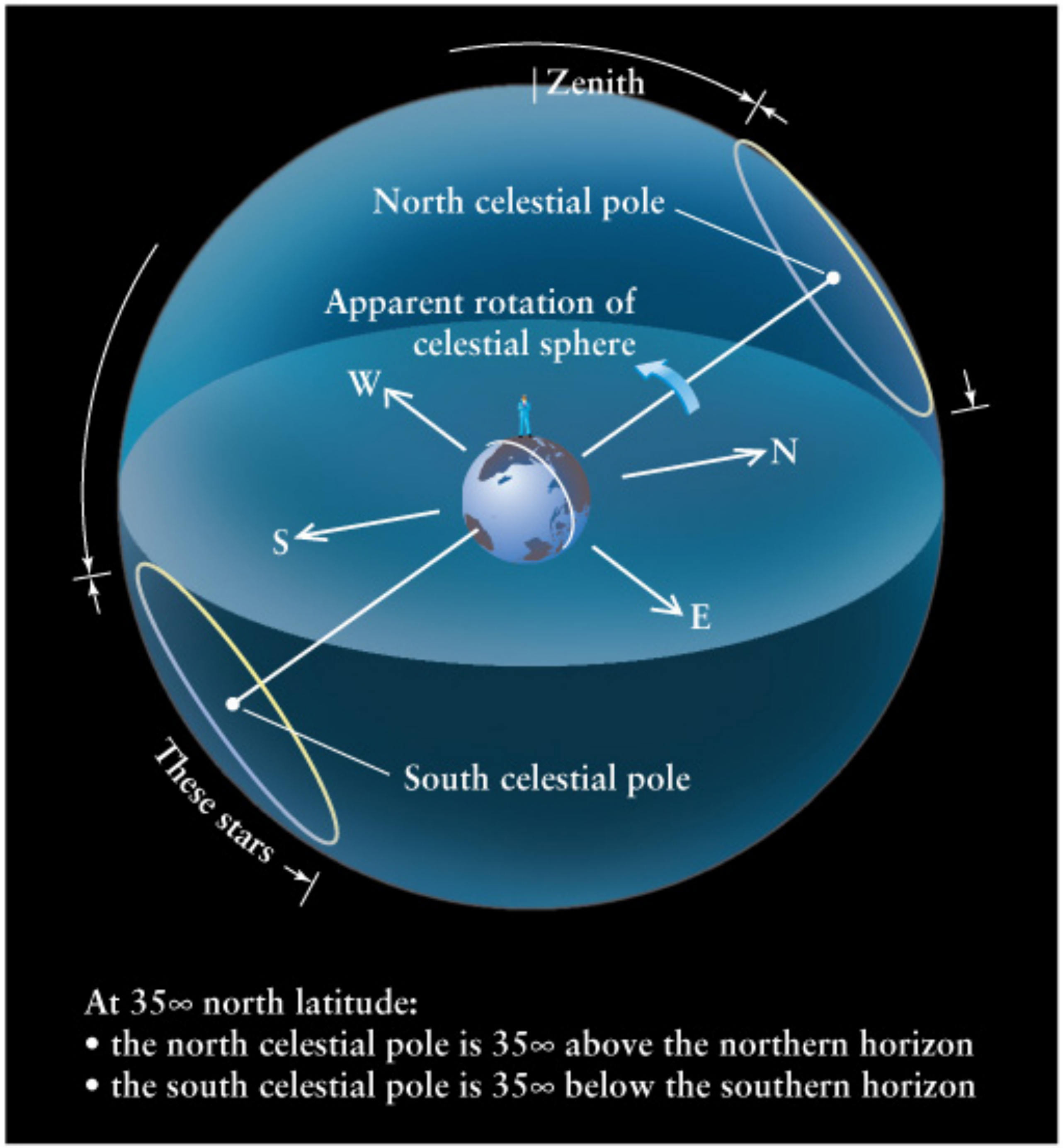


apparent sky motion depends on latitude of observer

e.g. SB is 41˚ north:

North Pole is at what altitude?

Apparent motion in the Sky



apparent sky motion depends on latitude of observer

e.g. SB is 41° north:

North Pole is at 41° altitude

objects within 41° of NP are always "up" - "circumpolar"

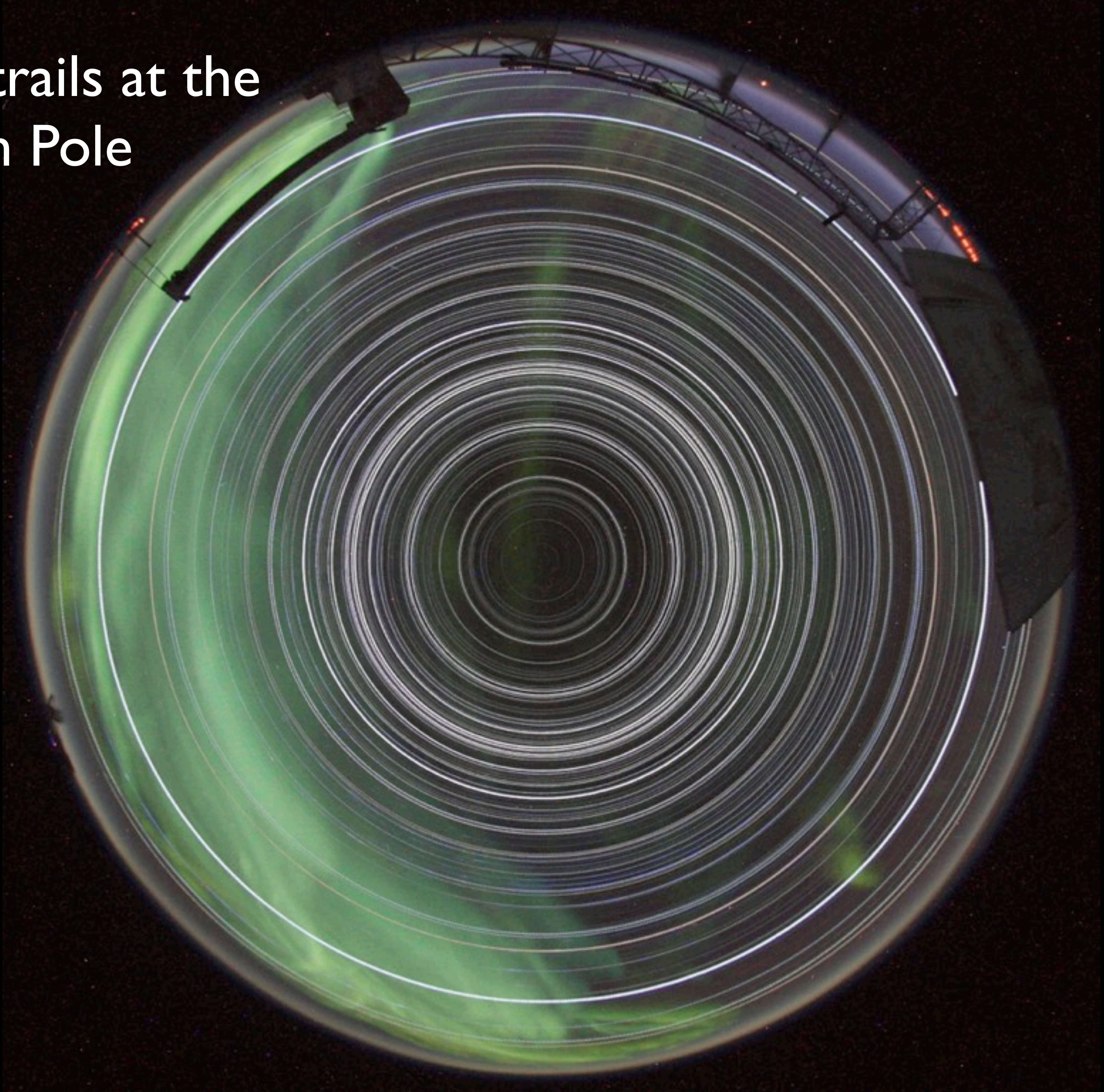
can never see objects within 41° of South Pole

all other objects rise in the East, set in the West

Star trails over CTIO, (c) Jose Delgado

Star trails at the equator

Star trails at the South Pole

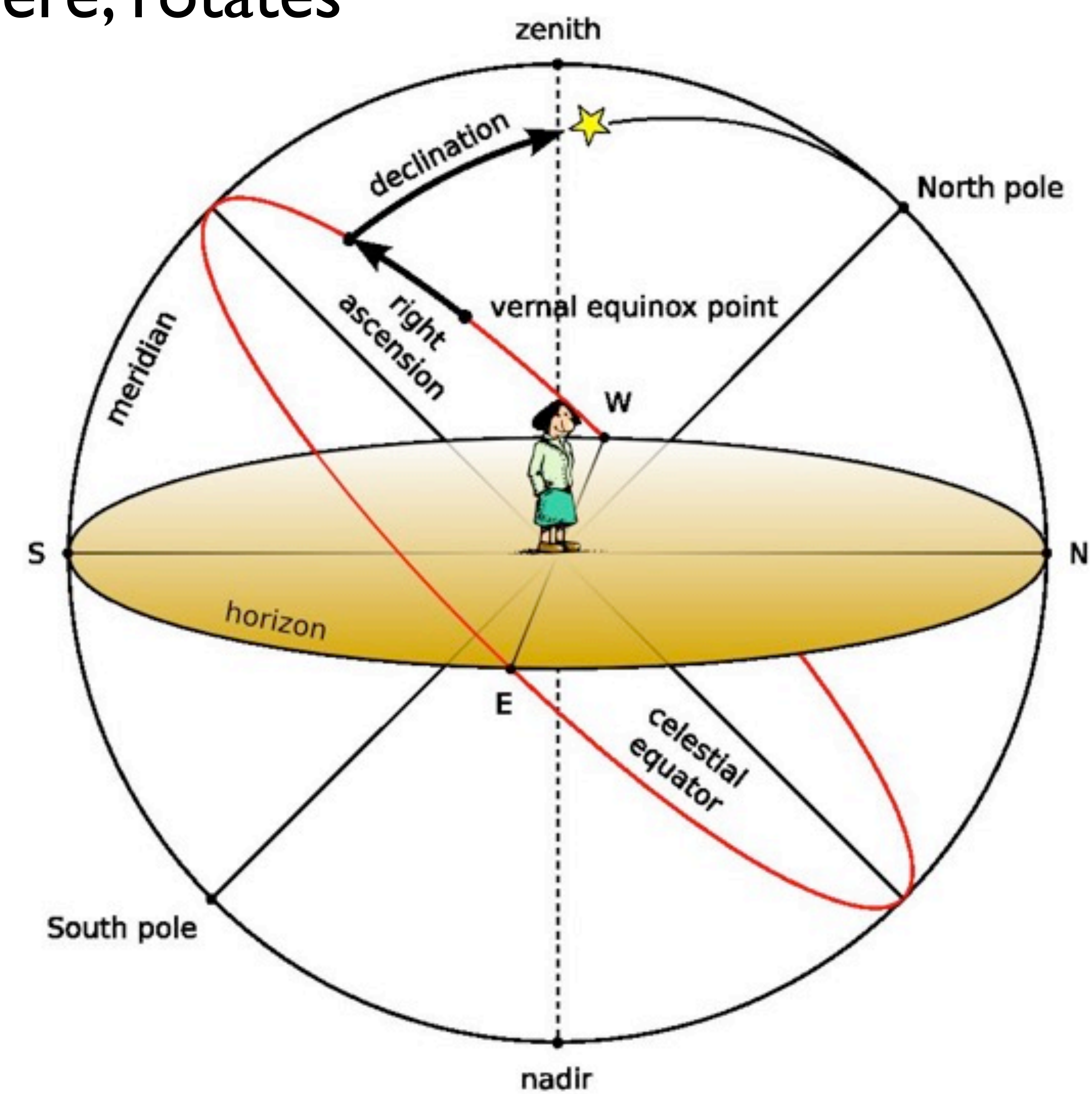


Equatorial (RA/Dec) Coordinate System

"fixed" to the celestial sphere, rotates with the sky

declination δ: angular distance from the celestial equator

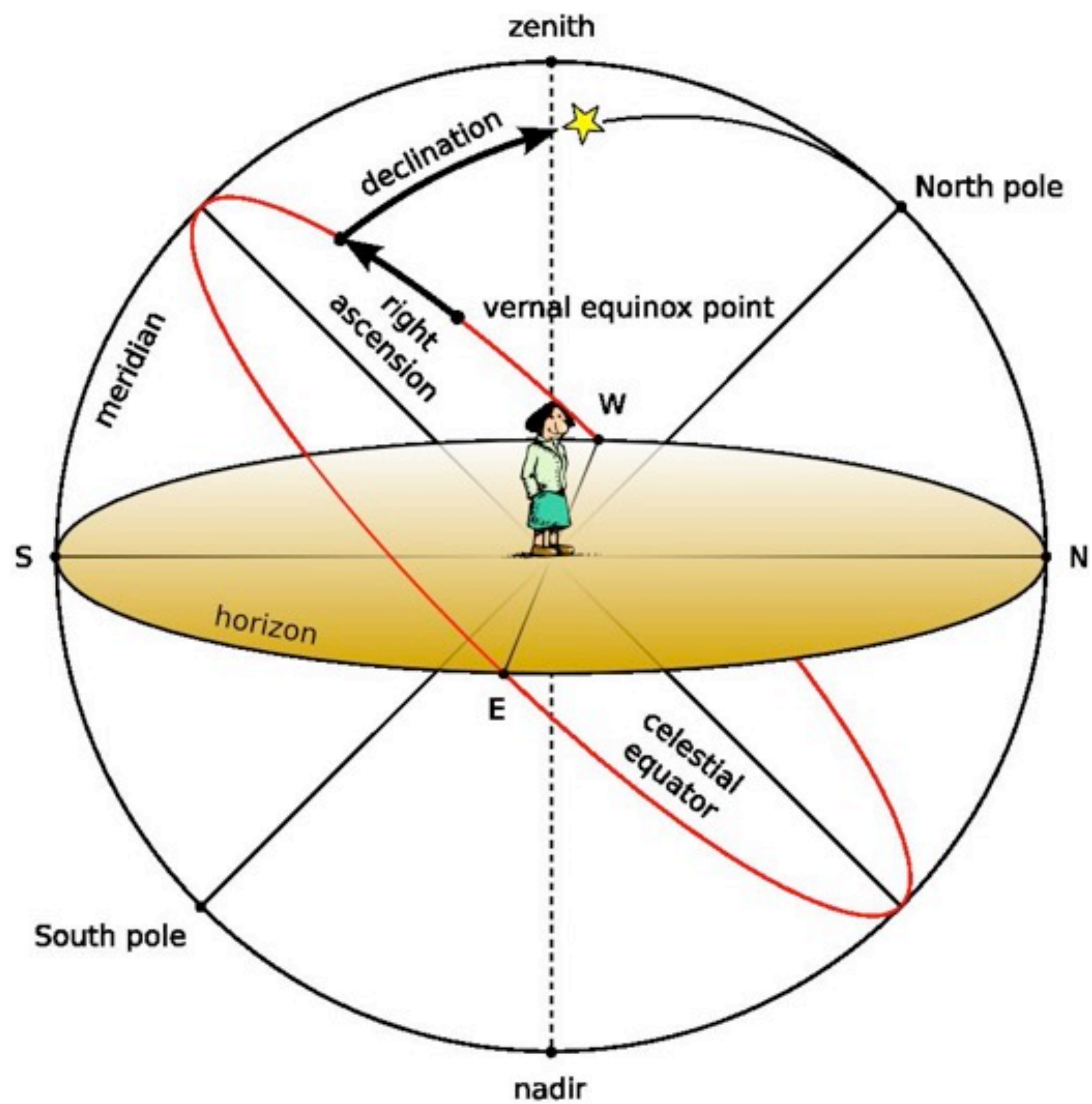
right ascension α: angular distance from vernal equinox (later; special point on equator)



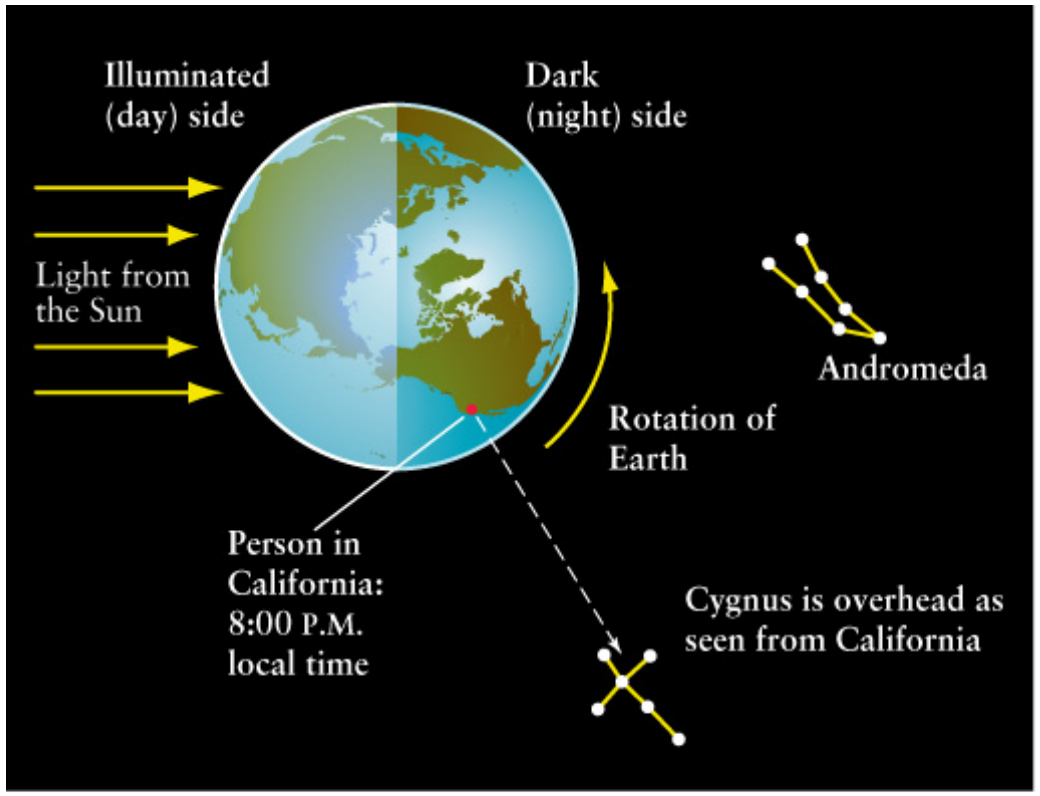
Equatorial (RA/Dec) Coordinate System

declination δ: measured in degrees, $-90^\circ \leq \delta \leq 90^\circ$ (like latitude)

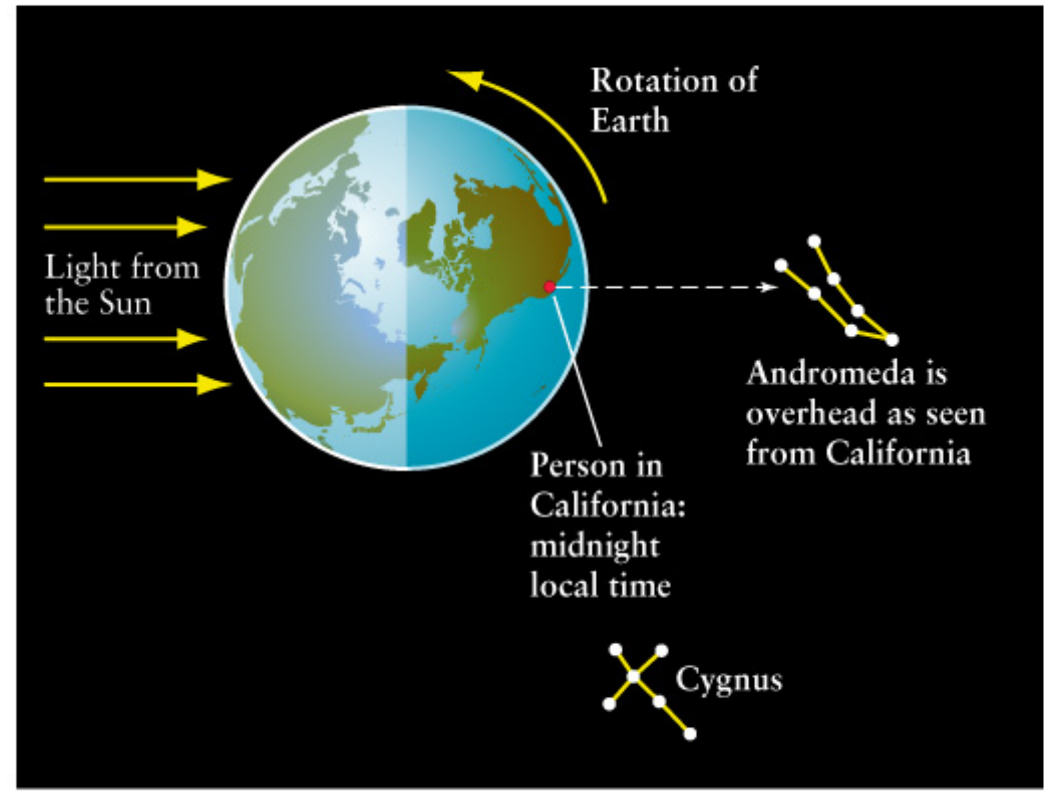
right ascension α: can also be measured in degrees ($0^\circ \leq \alpha < 360^\circ$), however:



Right ascension (RA)



(a) Earth as seen from above the north pole



(b) 4 hours (one-sixth of a complete rotation) later

a “natural” way to define right ascension is in units of time:

“distance” between two points is given by the time interval between each of them passes the meridian

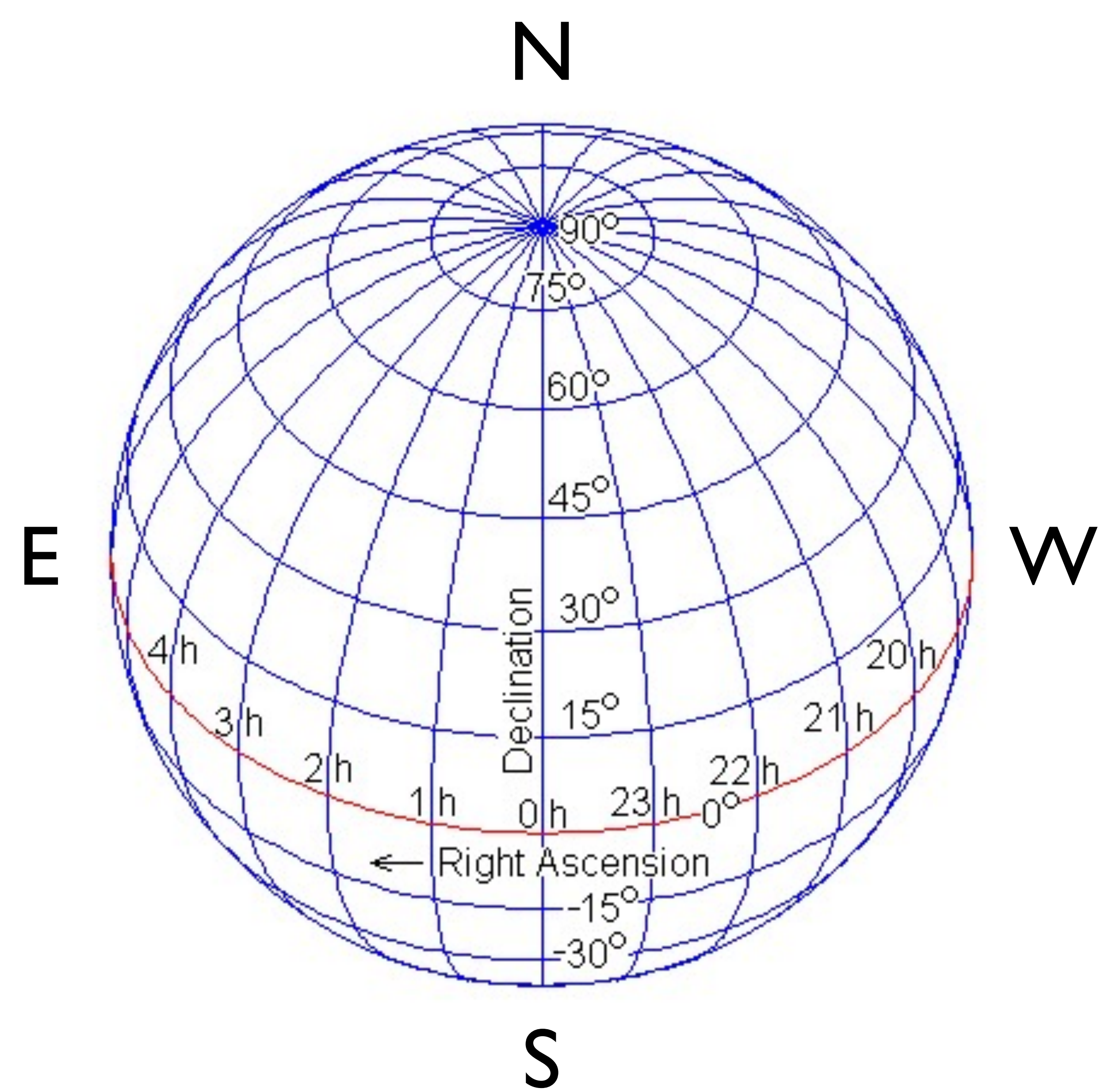
e.g.: reference point (0h) culminates (passes meridian) at midnight; all points that culminate 4 hours later have α = 4h

Right ascension (RA) + Local Sidereal Time (LST)

sky rotates East to West;
East is "left"

R.A. runs from right to left
in astronomical maps!

local sidereal time (LST): RA
of the objects currently
culminating (on meridian)



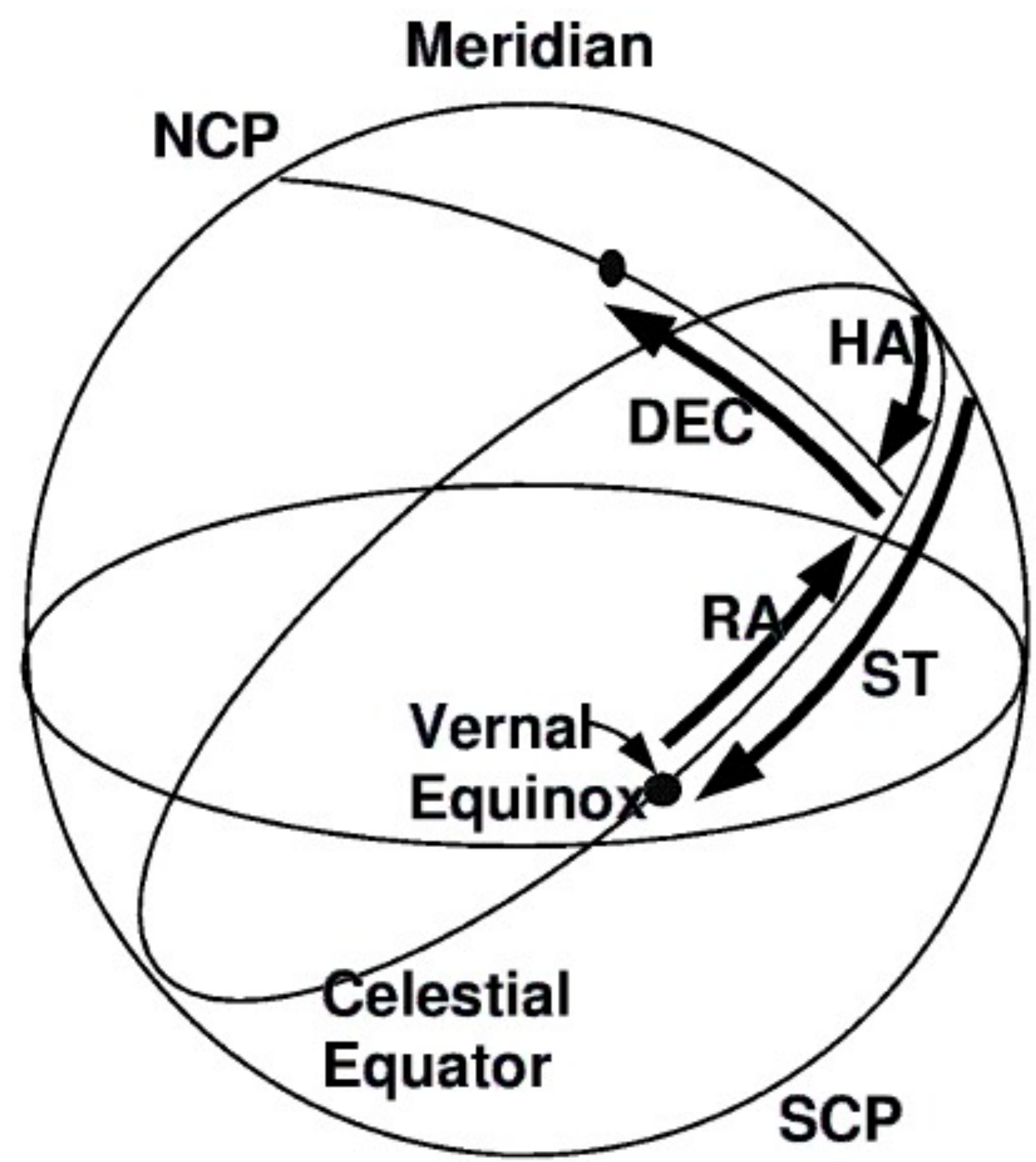
RA, LST, and Hour Angle

hour angle (HA): time that has passed since object culminated

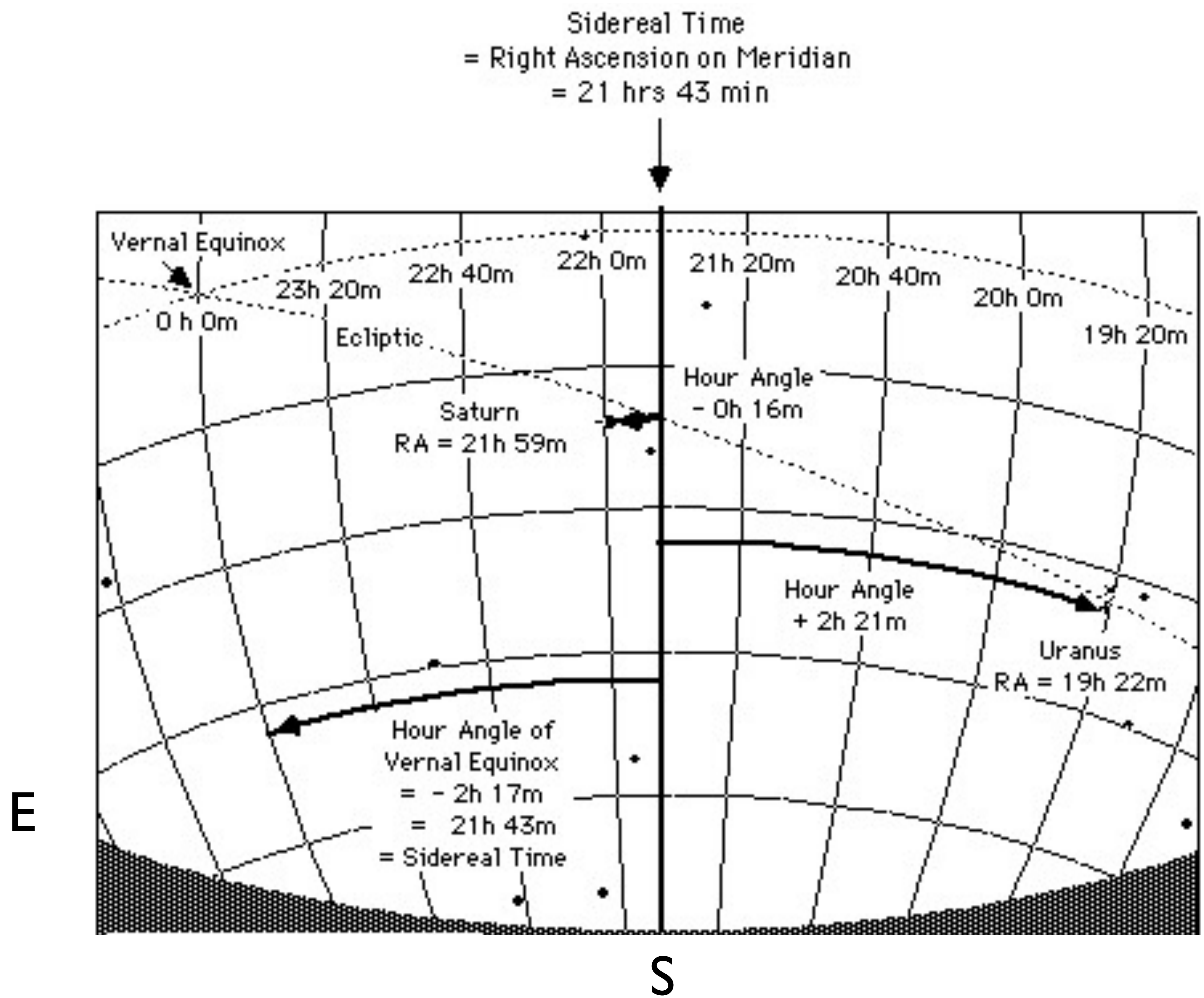
$HA = LST - \alpha_{object}$

HA > 0h: object has already culminated, it is "setting" and in the western half of the sky

HA < 0h: object is rising, is in the eastern half of the sky, will culminate in |HA| hours



Example



Sidereal Time =
Right Ascension +
Hour Angle

Saturn:
21h 59m RA +
(- 0h 16m) HA
= 21h 43m ST

Uranus:
19h 22m RA +
2h 21m HA
= 21h 43m ST

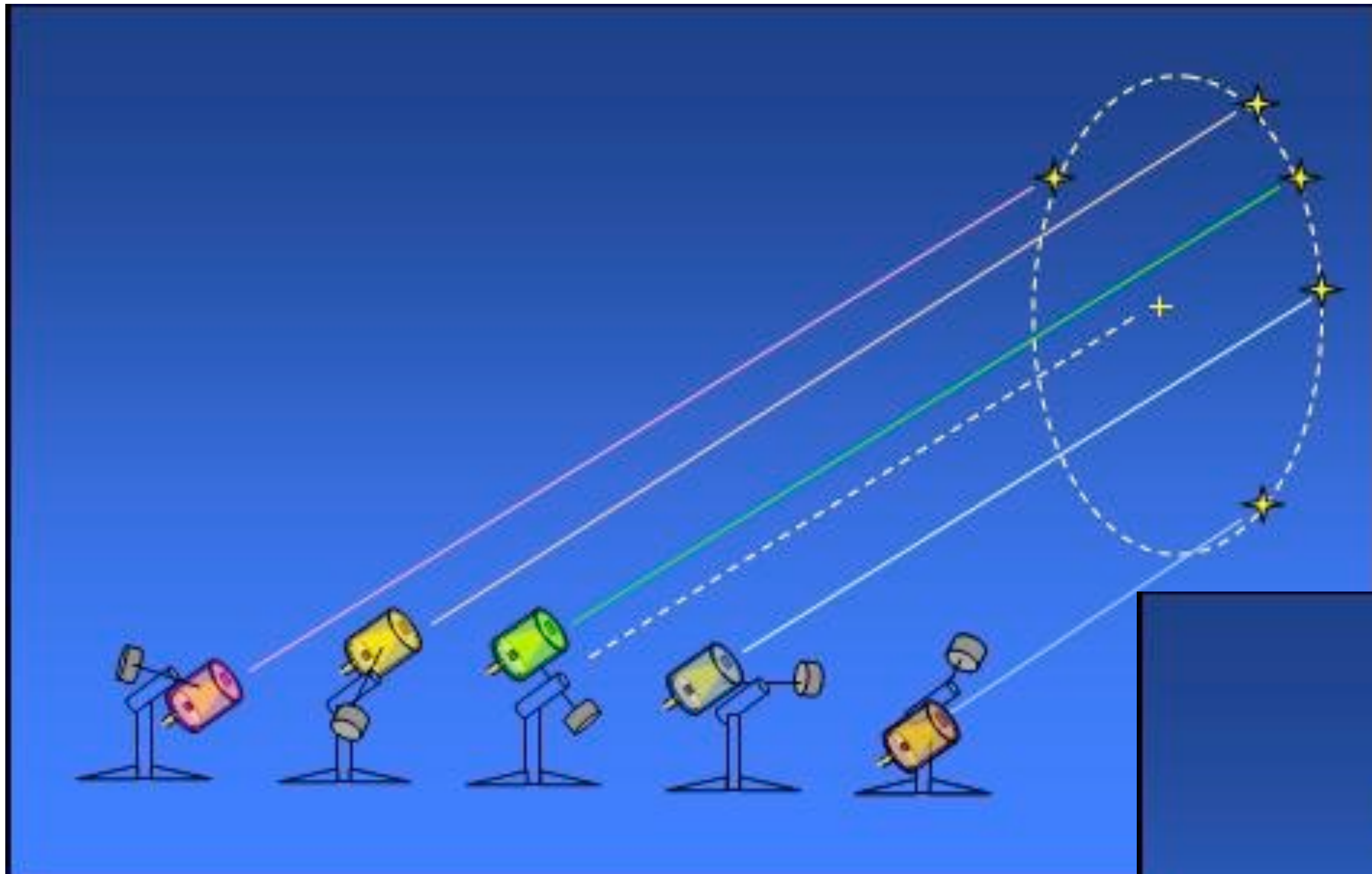
Equatorial telescope mounts

Alt/az mounts: need to track object in two axis, with variable speed

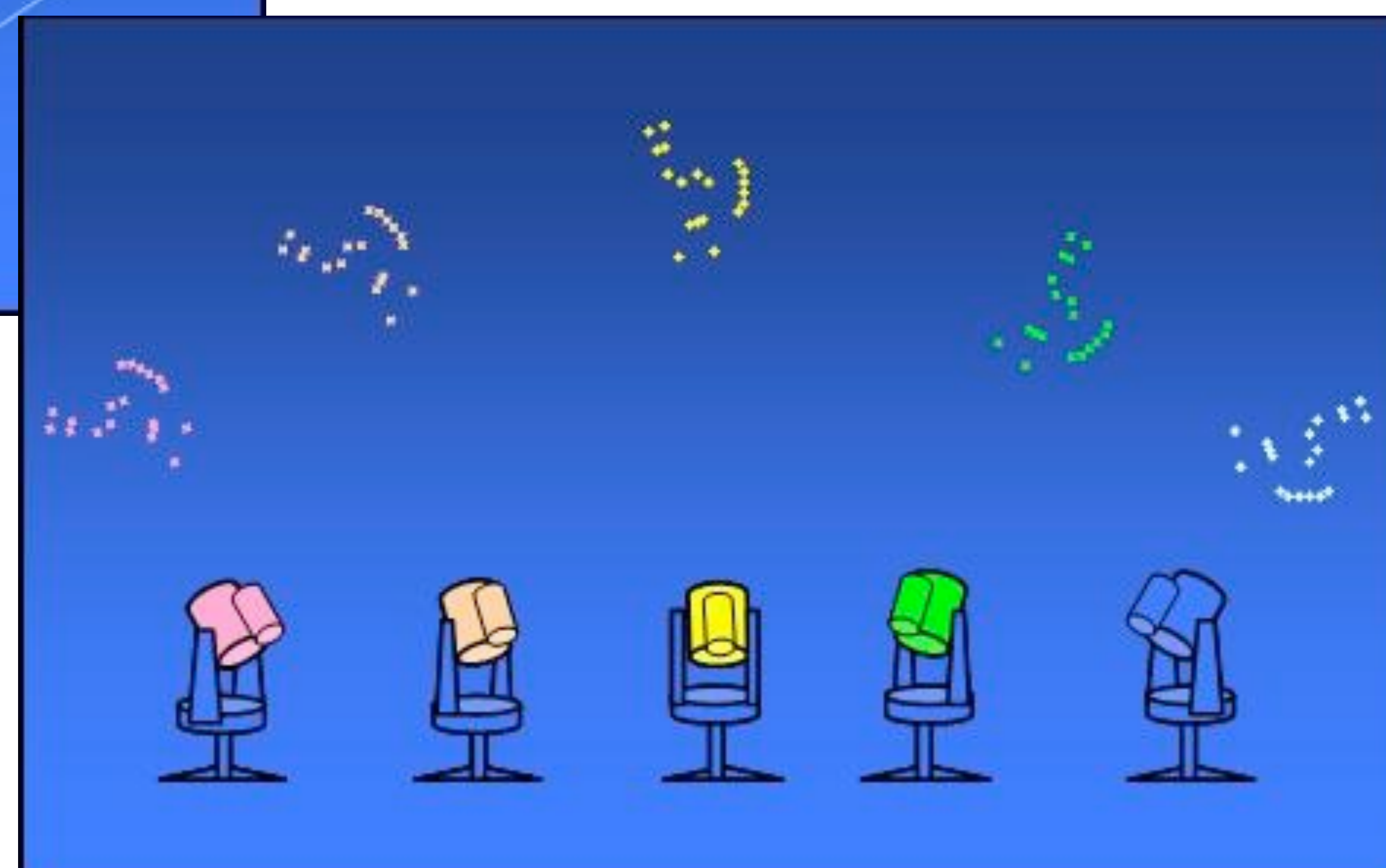
equatorial mount: one axis is parallel to Earth's rotation axis → need to track only in this axis, with constant speed

Equatorial telescope mounts

removes the need for a field de-rotator



alt/az mount

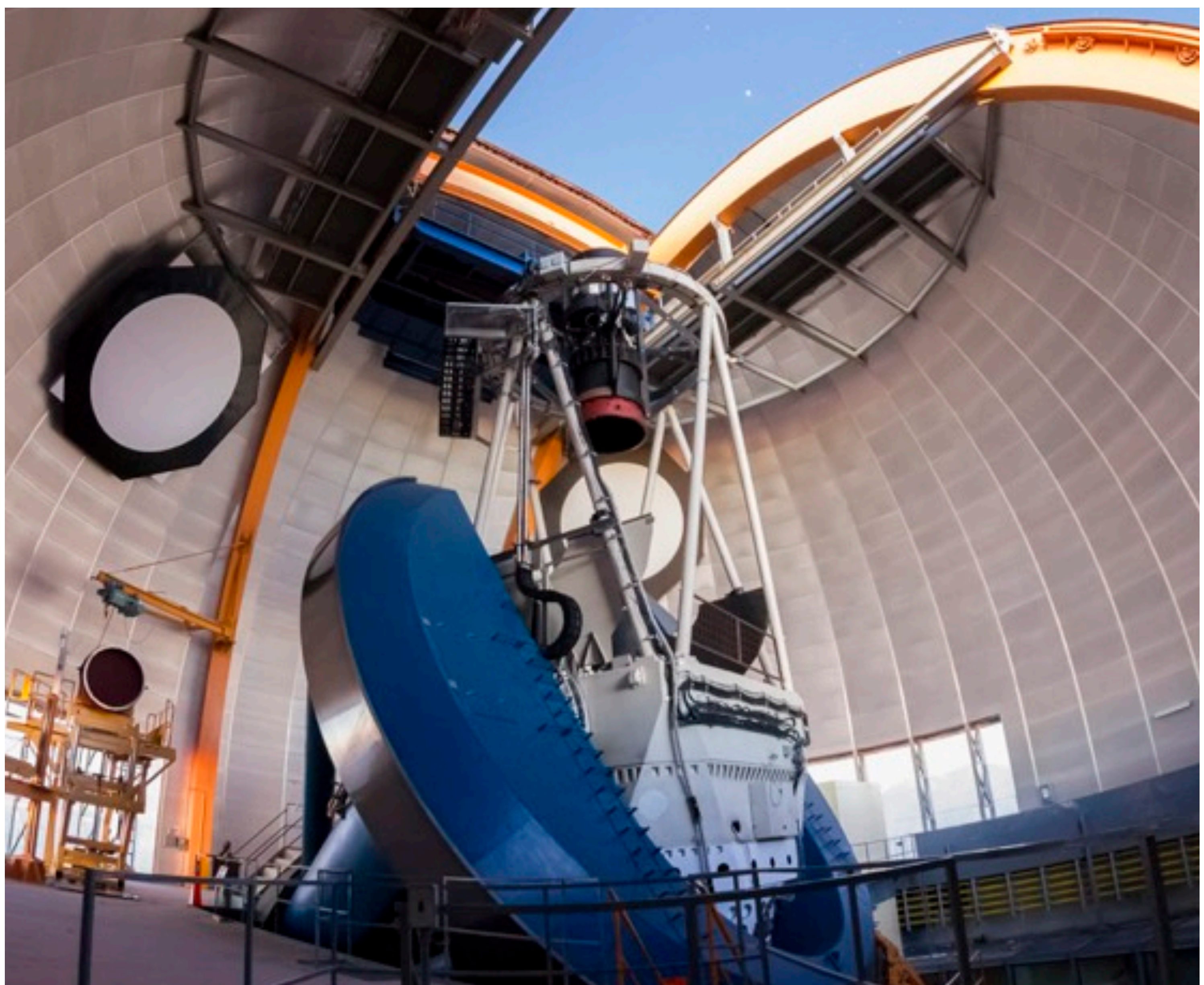


equ. mount

Equatorial telescope mounts

not feasible for the largest telescopes

found on some intermediate-class telescopes, e.g. 4m telescope on Kitt Peak and Cerro Tololo



R.A. and Dec - format

both can be expressed as degrees:

$$0^\circ \leq \alpha < 360^\circ$$
$$-90^\circ \leq \delta \leq +90^\circ$$

e.g. M31: $10.6847^\circ, +41.26875^\circ$

often expressed in sexagesimal system:

$$00^{\mathrm{h}}42^{\mathrm{m}}44.33^{\mathrm{s}}, +41^\circ 16'\, 07.5''$$
$$00:42:44.33, +41:16:07.5$$

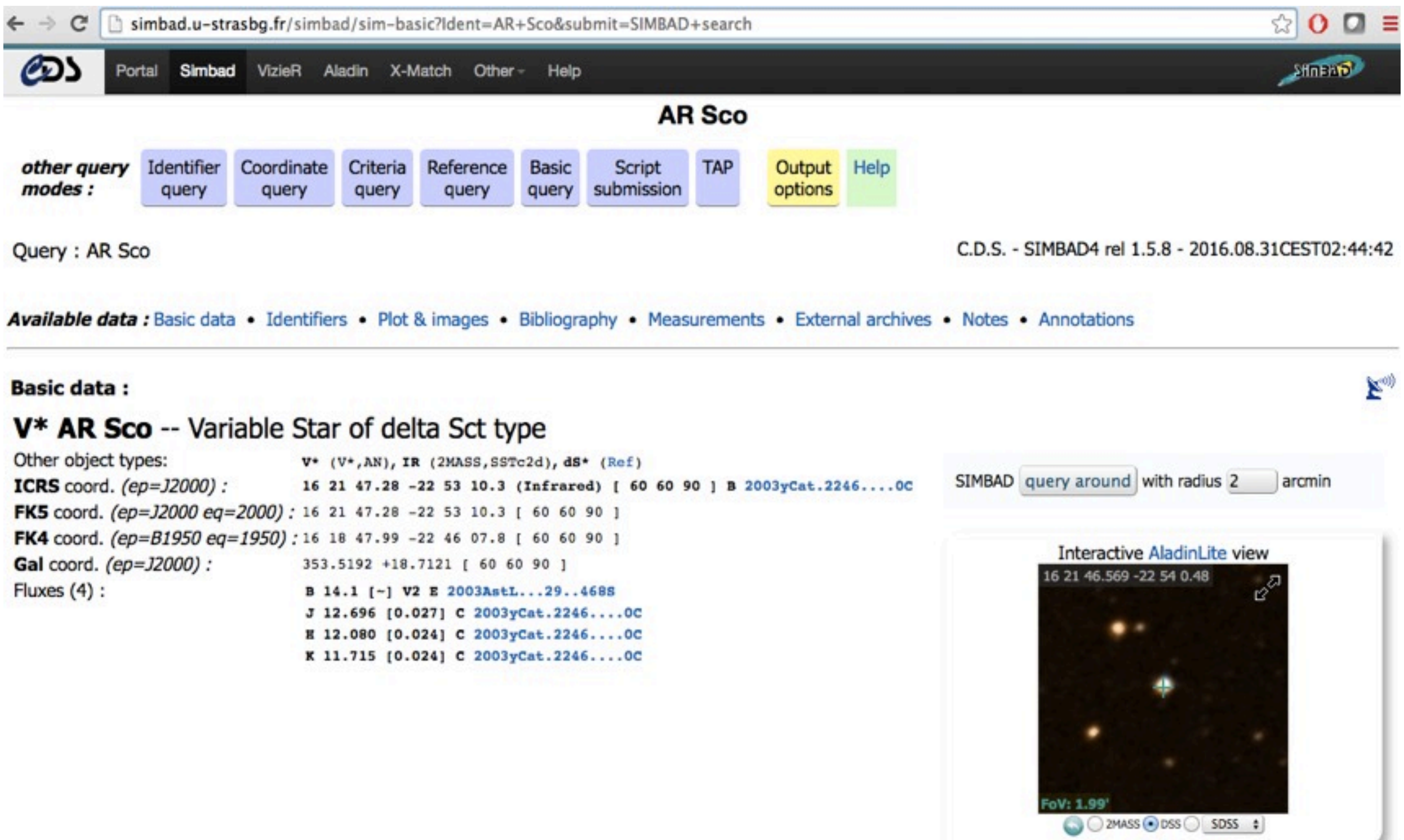
note:

$$24^{\mathrm{h}} = 360^\circ$$
$$1^{\mathrm{h}} = 15^\circ$$
$$1^{\mathrm{m}} = 15^\circ/60 = 0.25^\circ = 15'$$
$$1^{\mathrm{s}} = 15^\circ/3600 = 0.25' = 15''$$

Looking up coordinates / information

SIMBAD astronomical database:

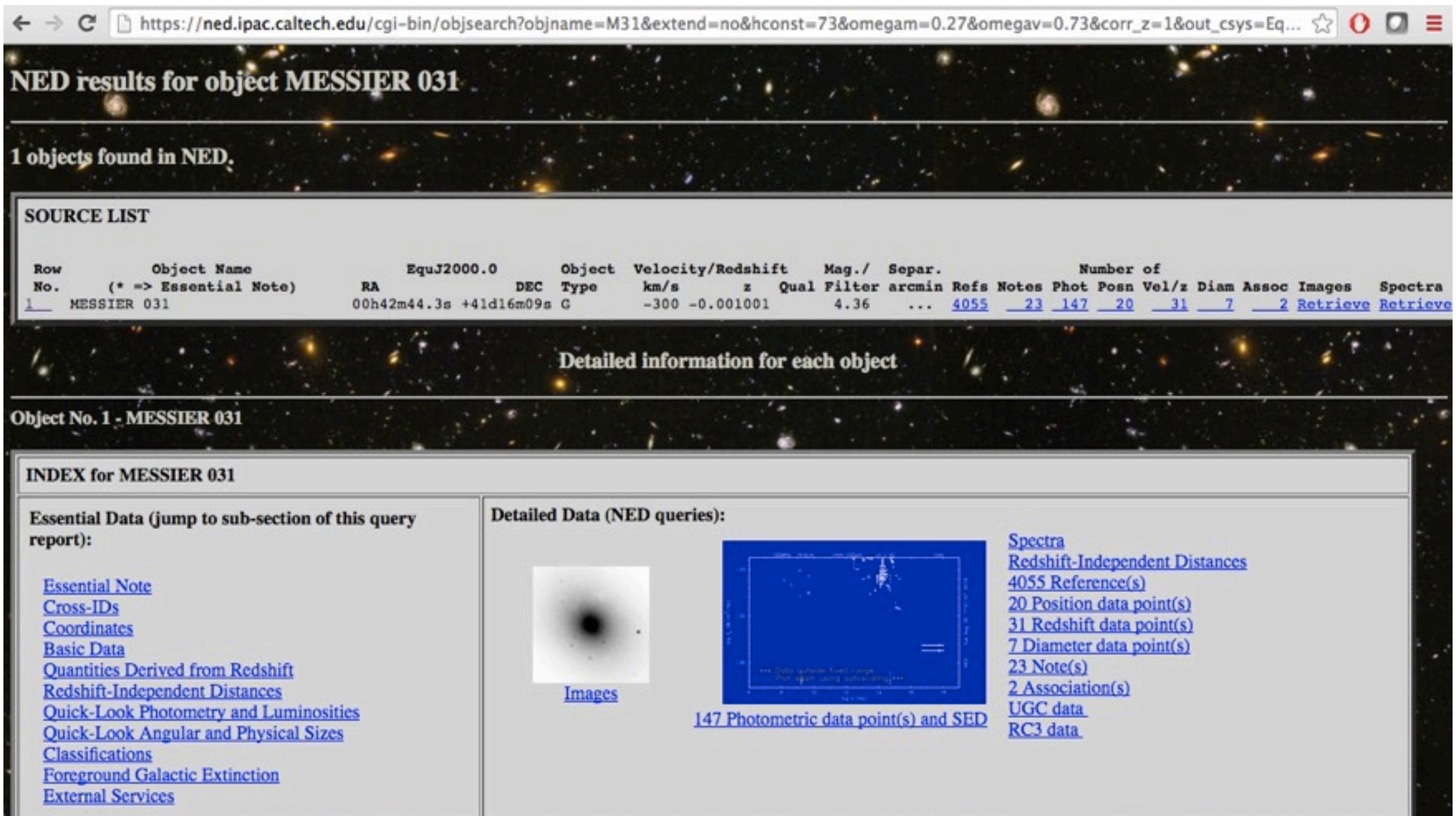
http://simbad.u-strasbg.fr/simbad/



Looking up coordinates / information

NASA/IPAC Extragalactic Database (NED)

https://ned.ipac.caltech.edu/



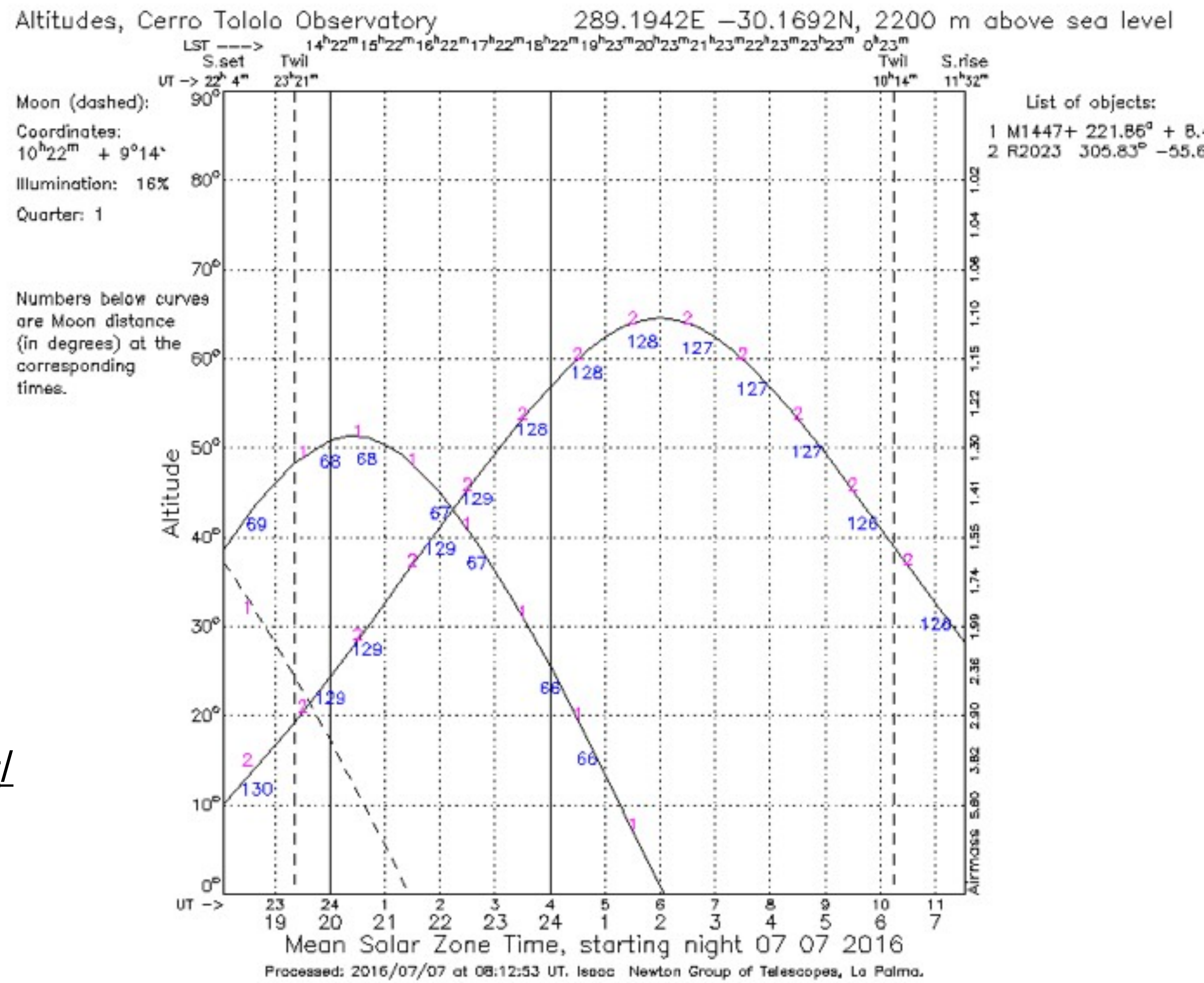
Object visibility tool

"StarAlt": http://catserver.ing.iac.es/staralt/

given input catalog of object positions, plots their altitude vs. time (+ a few other features)

also see

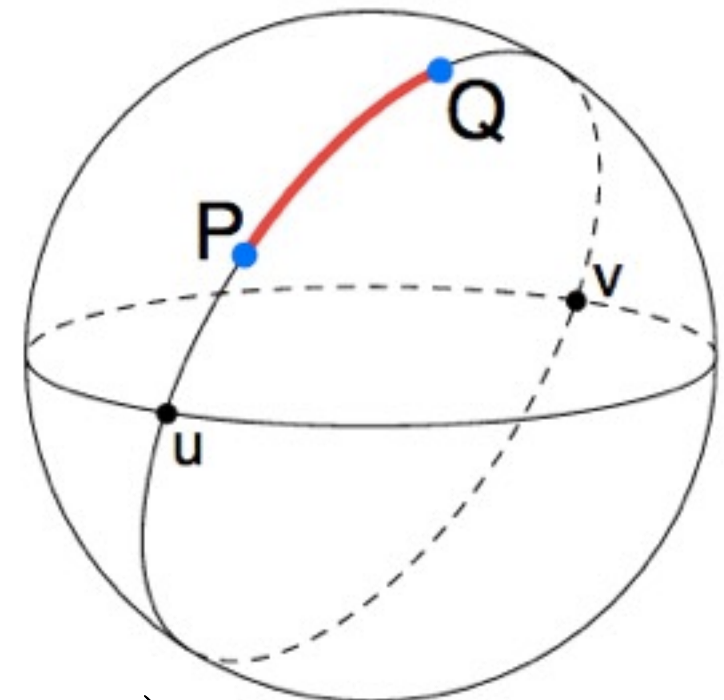
http://www.briancasey.org/artifacts/astro/airmass.cgi



Distance between two objects

two objects at (α_1,δ_1) and (α_2,δ_2) - how far apart are they?

- surface of a sphere is non-Euclidian
- e.g. sum of angles in a triangle is $>180^\circ$
- need to use spherical geometry



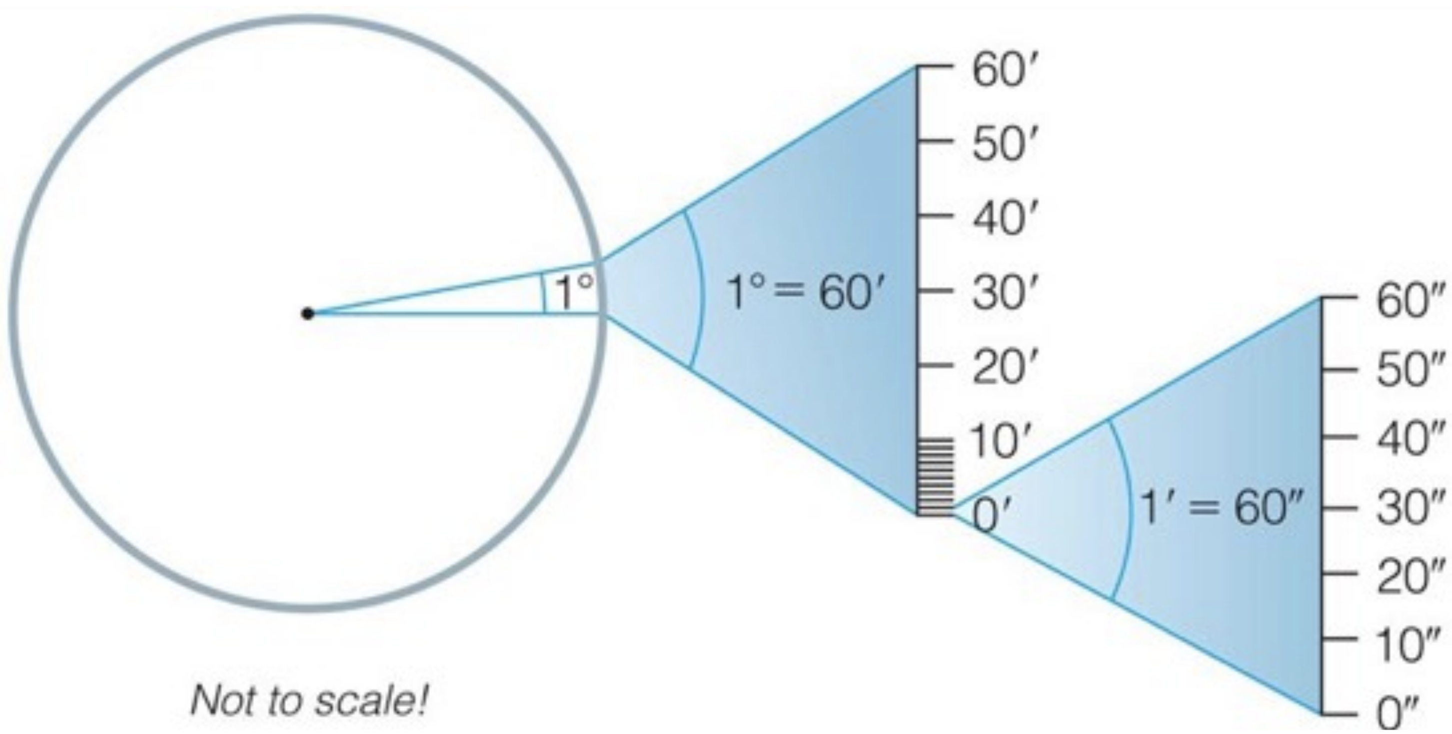
$$\cos(\gamma) = \cos(90^\circ - \delta_1)\cos(90^\circ - \delta_2) + \sin(90^\circ - \delta_1)\sin(90^\circ - \delta_2)\cos(\alpha_1 - \alpha_2)$$

for small distances, can use Euclidian approximation; HOWEVER, need to include $\cos(\delta)$

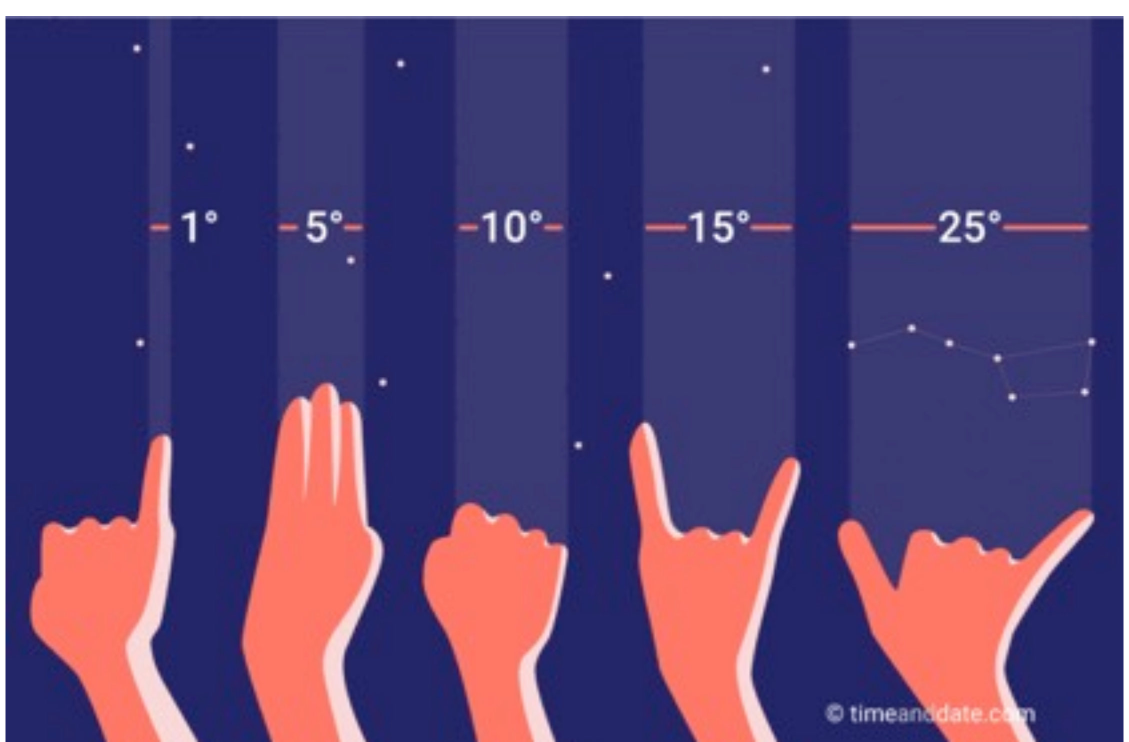
$$\gamma \simeq \sqrt{((\alpha_1 - \alpha_2)\cos(\delta_1))^2 + (\delta_1 - \delta_2)^2}$$

Lengths and distances on the Sky

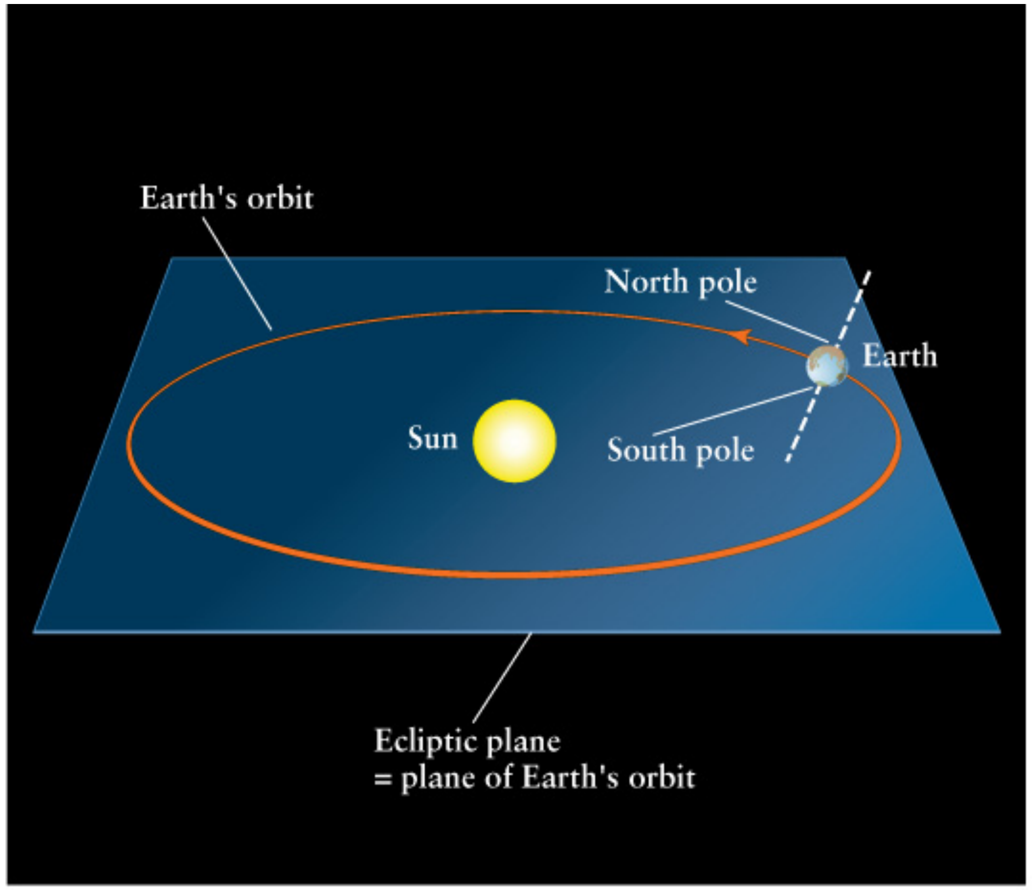
usually given in degrees (˚), arcminutes (‘), arcseconds (“)



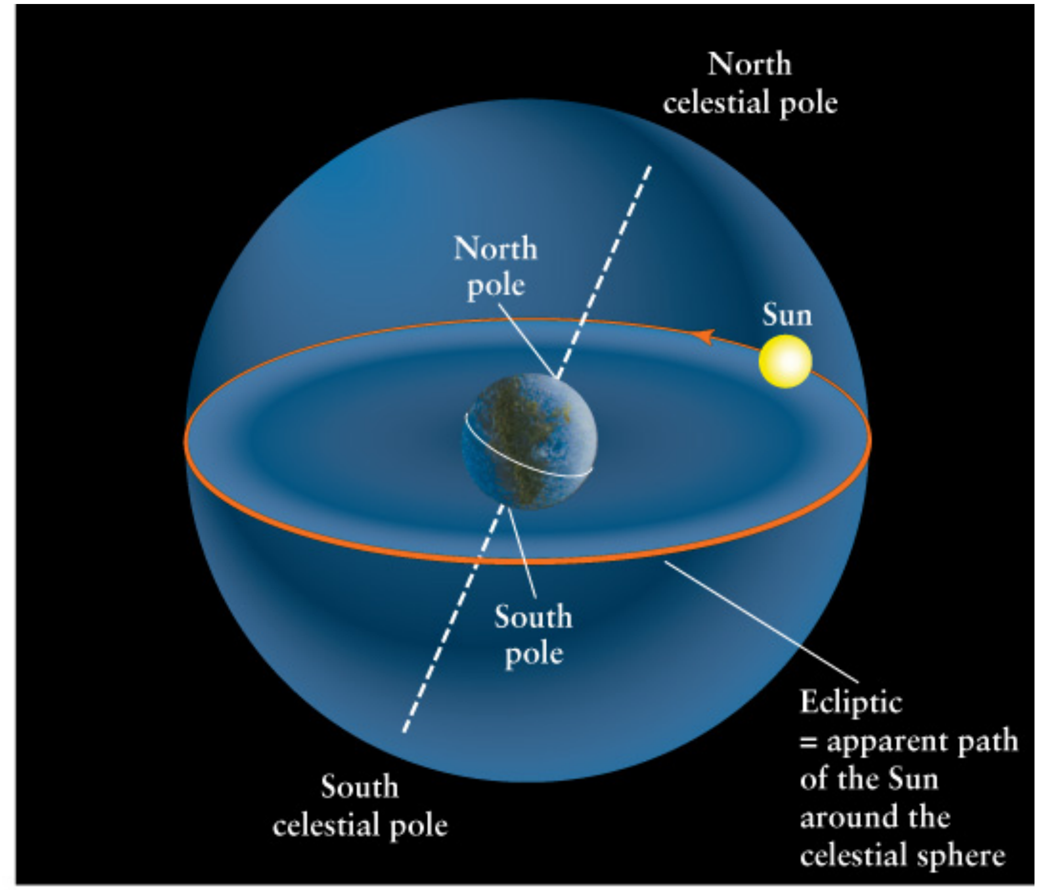
Moon: diameter is
~ 0.5˚ = 30’



Motion of the Sun in the Sky



(a) In reality Earth orbits the Sun once a year



(b) It appears from Earth that the Sun travels around the celestial sphere once a year

Earth’s motion around the Sun defines the ecliptic plane

its projection onto the Celestial Sphere is the ecliptic

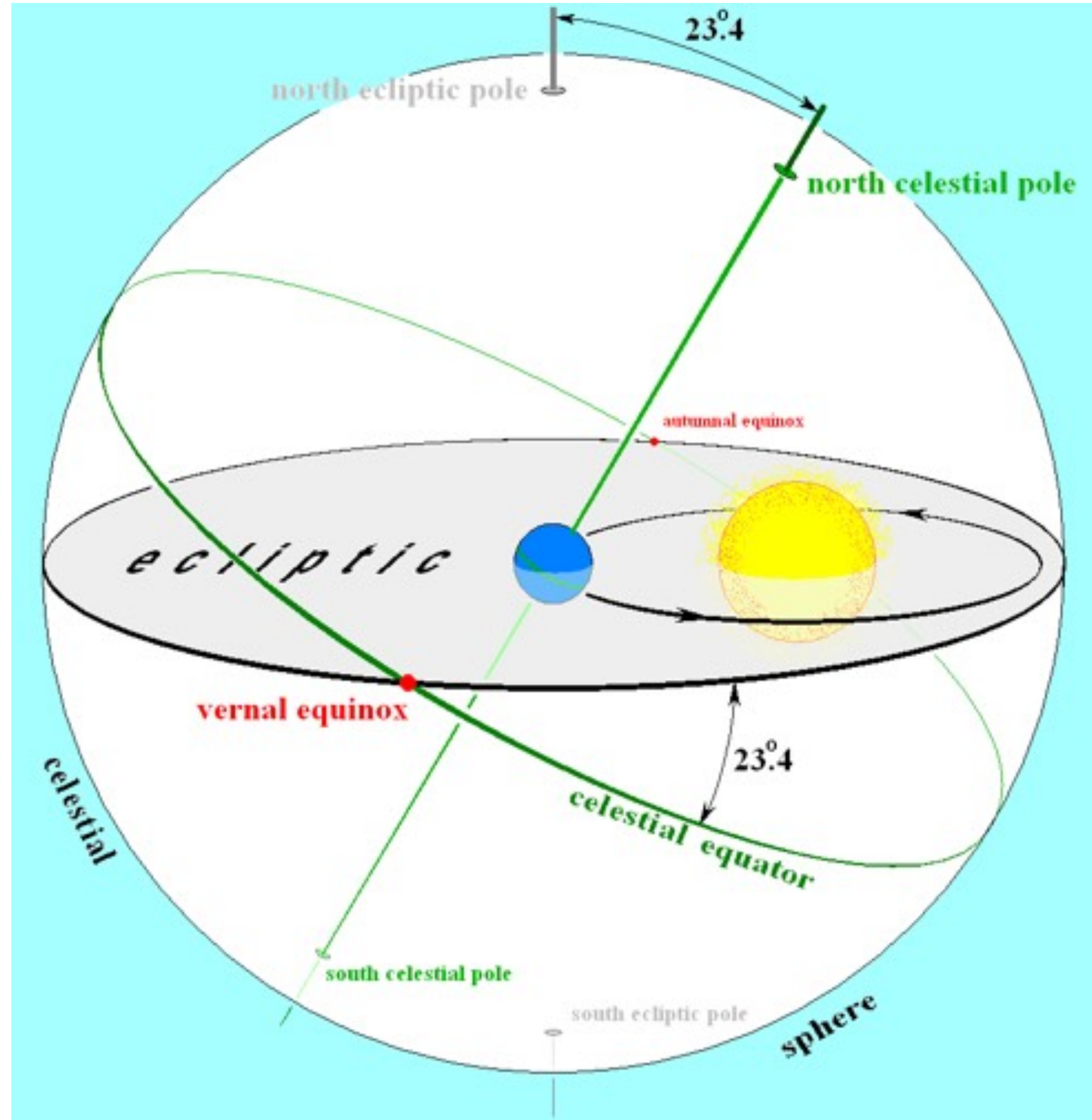
Earth’s axis is tilted with respect to its orbit → the ecliptic is **NOT** the same as the celestial equator

Motion of the Sun in the Sky

equator and ecliptic intersect in two points: the equinoxes

why are they called equinoxes?

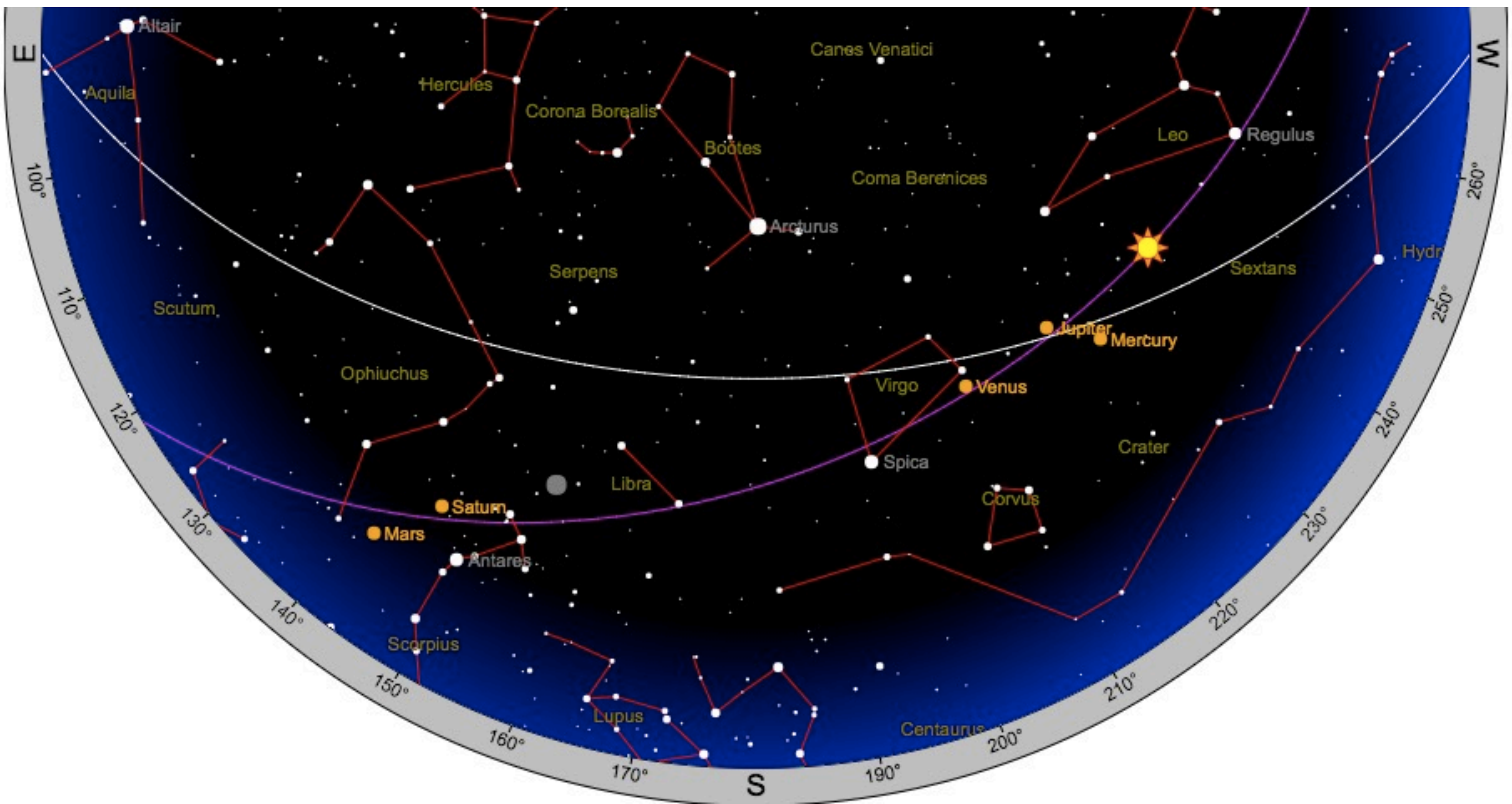
the vernal (spring) equinox marks RA=0h



Other Solar System objects

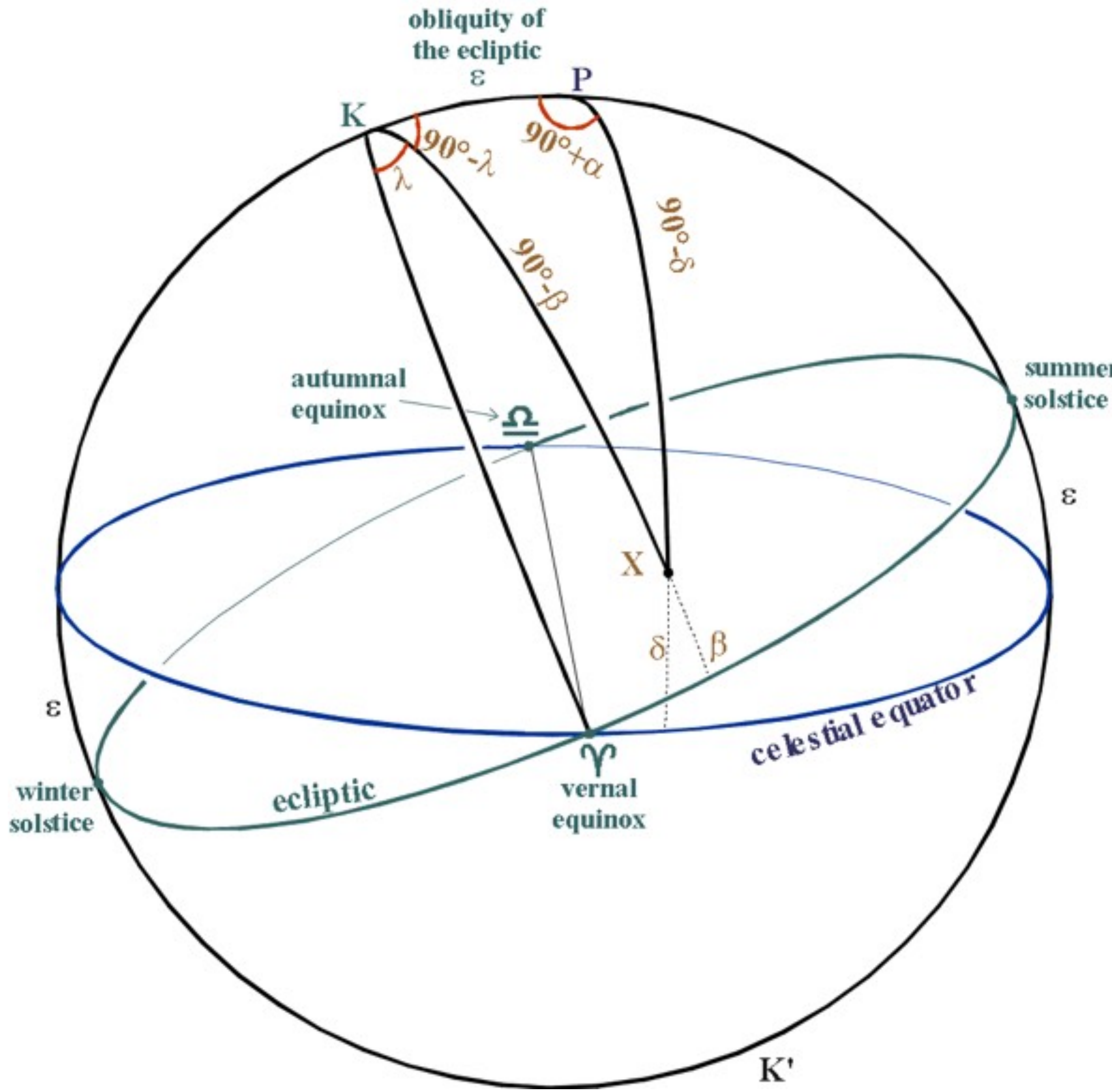
the orbital planes of most planets (and moons) are similar to Earth's orbital plane

→ Moon and planets also approximately follow the ecliptic



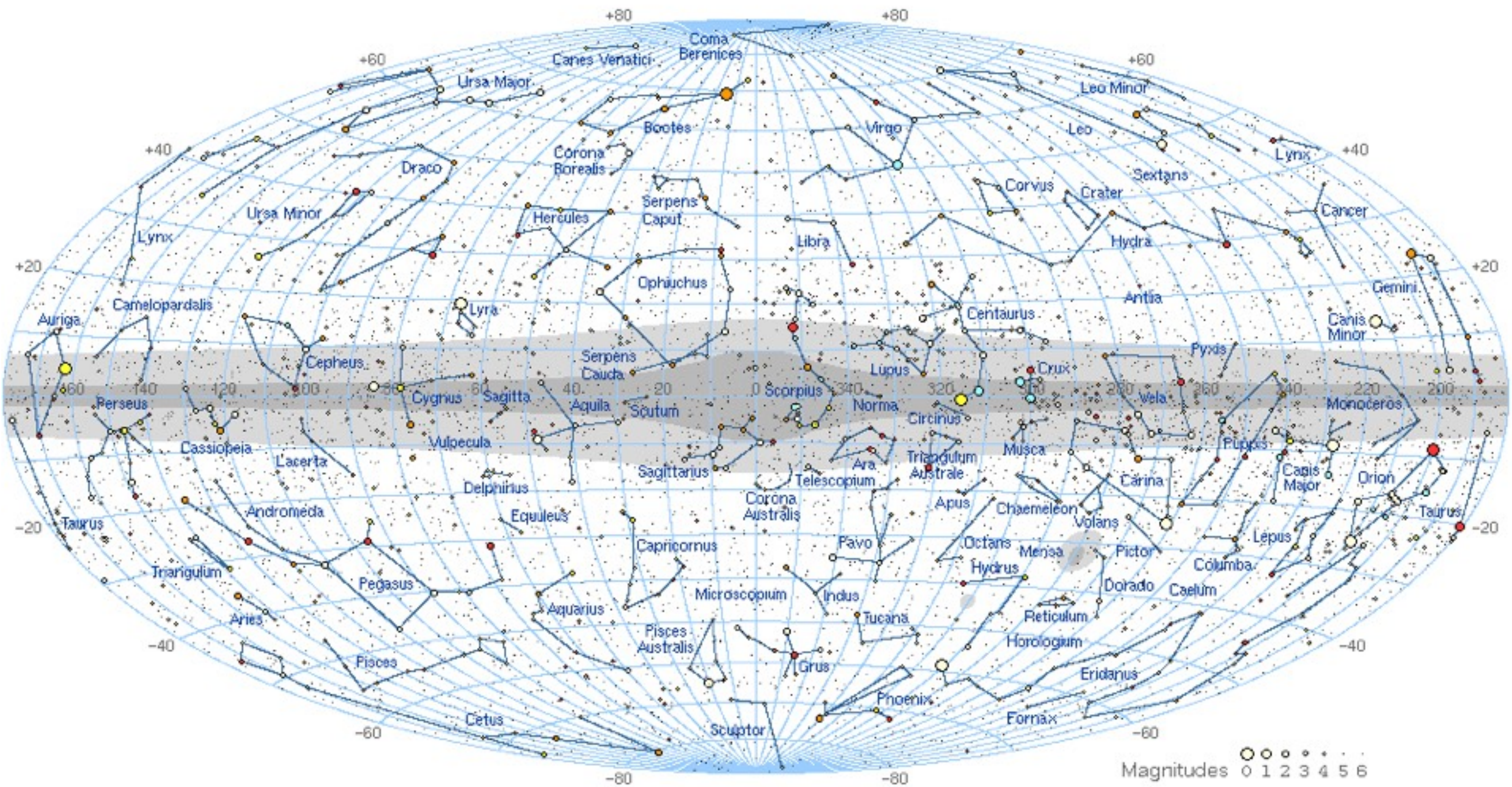
Ecliptic coordinates

use ecliptic as "equator"



Galactic coordinates

use the plane of the Galaxy as "equator"



Time

Need to know the current time!

Your telescope needs to know the LST in order to convert (α,δ) to altitude+azimuth

You need to know when you took your observations

Much of the Sky is variable! E.g. supernovae, variable stars, gamma-ray burst, ...

Need a common, precise reference time

Sidereal time

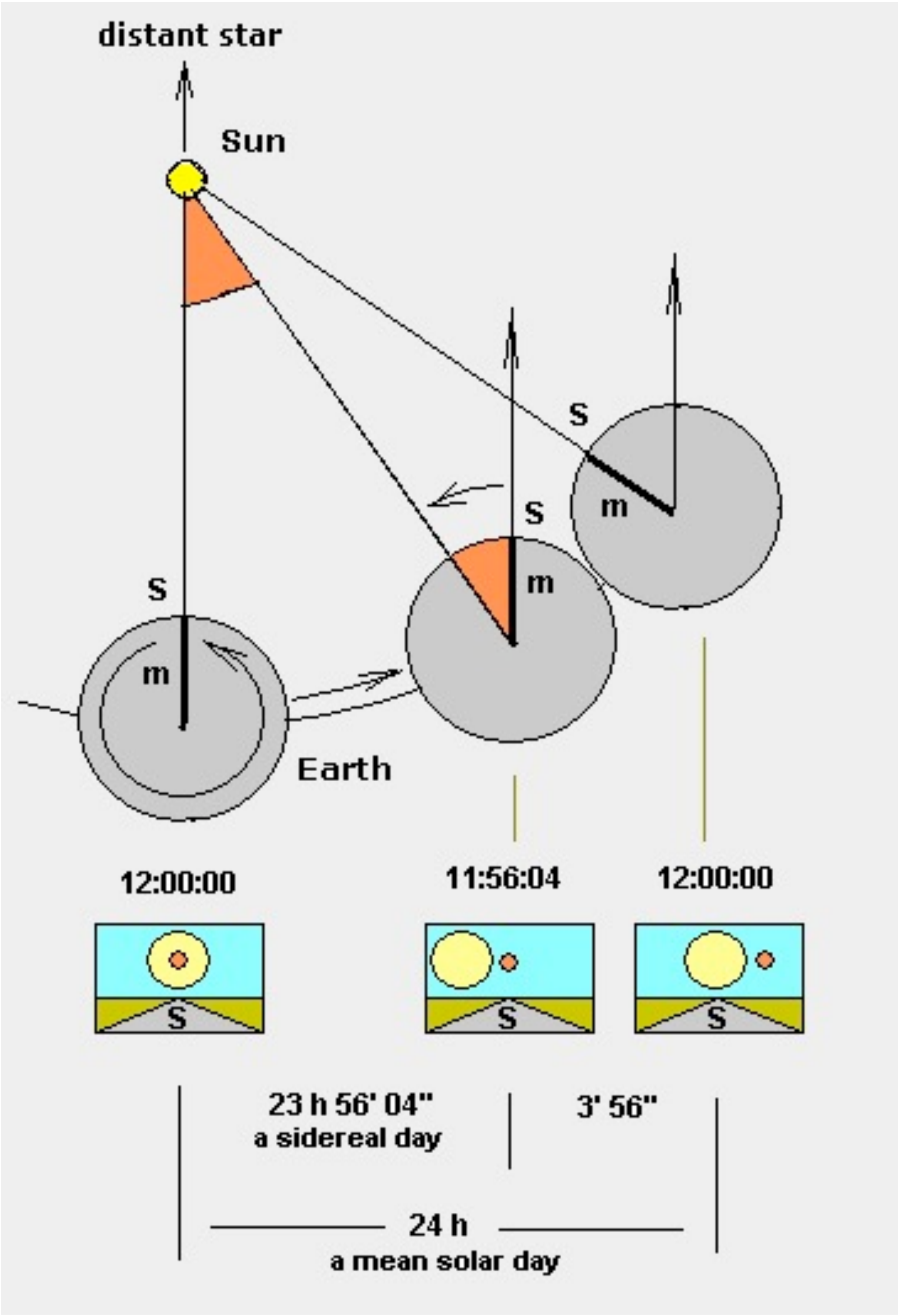
"sidereal" = "of the stars"

sidereal time: defined with respect to the stars

one rotation takes 23h 56min (a sidereal day)

same sky is overhead after 23h 56min

solar day: defined with respect to the Sun, takes 24h

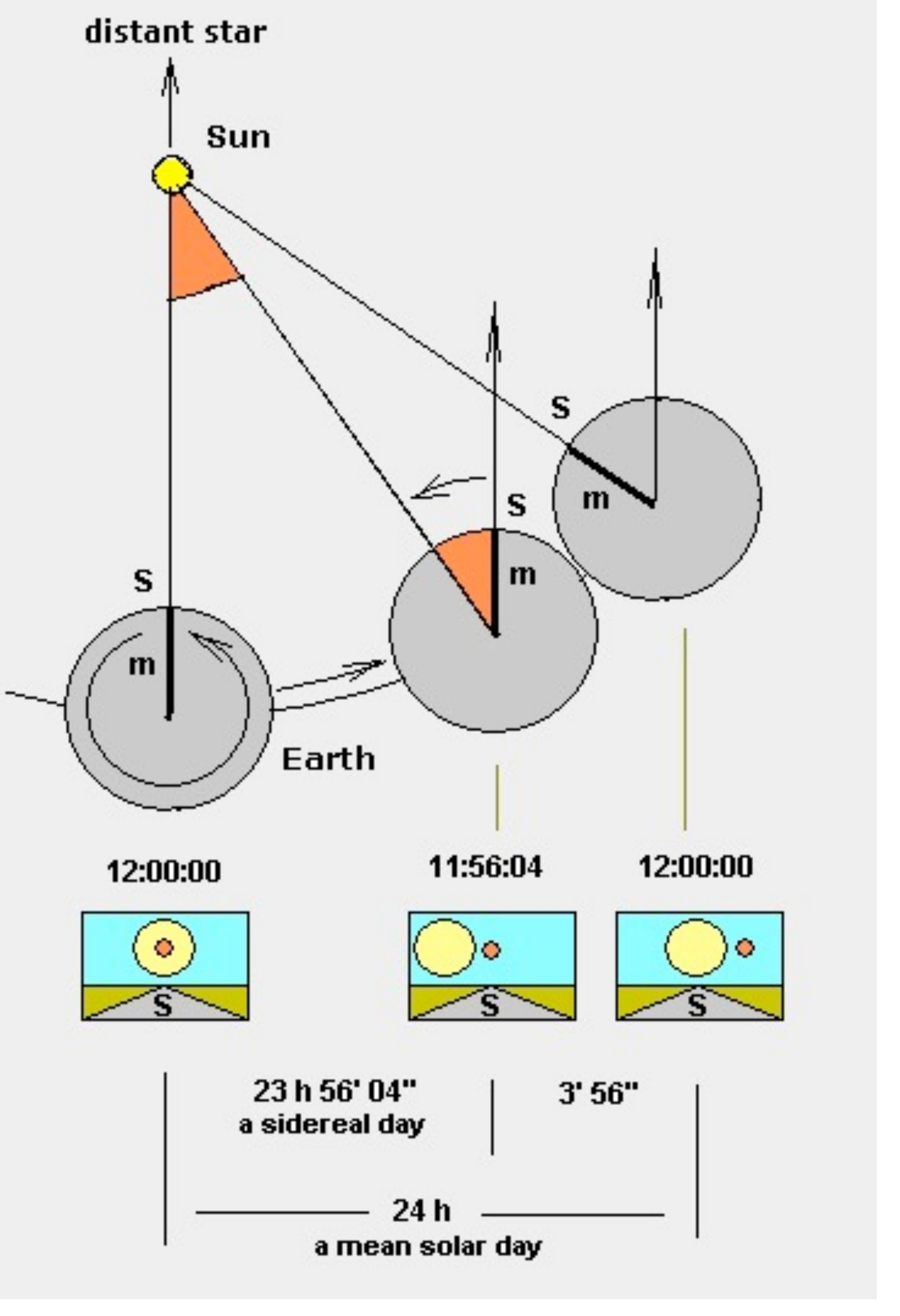


This means...

from one night to the next, stars rise 4 min earlier

one year has 365+1 sidereal days

HW question: Orion culminates at 1am in September; at what time does it rise 3 months later?



Solar time

apparent solar day: time between two passes of the meridian

problem: variable length (Earth's orbit is elliptical)

mean solar day: based on fictitious mean Sun that moves along the Sky at constant rate (measured on equator)

Universal Time (UT1): mean solar time at 0° longitude (Greenwich)

Coordinated Universal Time (UTC): based on atomic clocks, kept within 0.9s of UT1; international time standard

How to specify time

For common time format, quote UTC

```
OBSID    = 'ct4m20130615t234758' / Unique Observation ID
DATE-OBS= '2013-06-15T23:47:58.454694'  /  UTC epoch
TIME-OBS= '23:47:58.454694'    / Time of observation start (UTC)
MJD-OBS =       56458.99164878 / MJD of observation start
```

Purely numerical format: Julian Date

- days since noon on Jan 1, 4713 BC (JD=0)

- JD of Aug 30, 6pm in Stony Brook: 2457996.416667

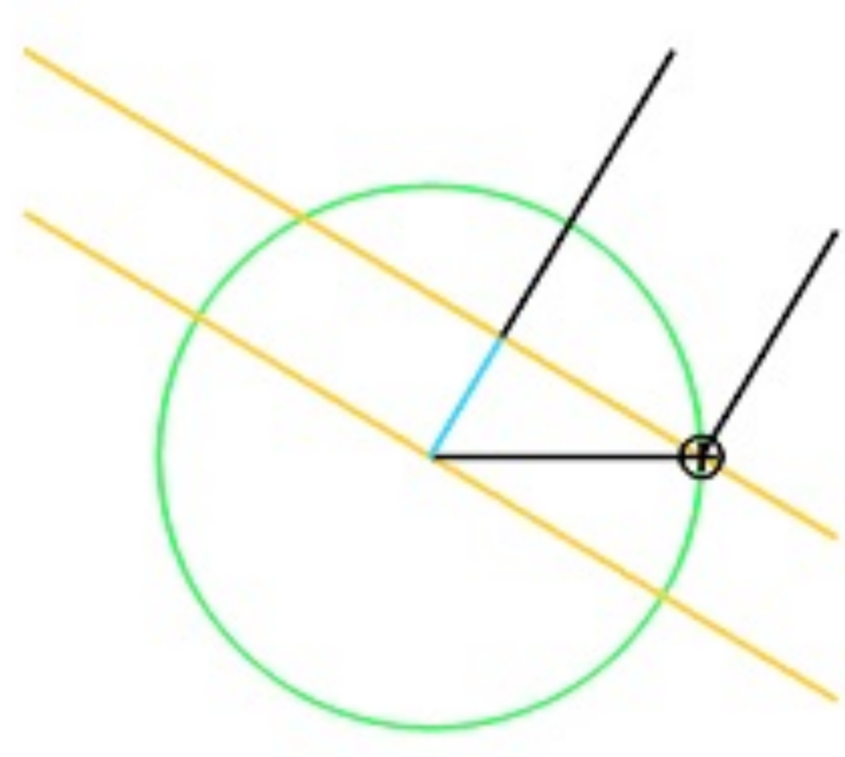
- Modified Julian Date (MJD):   MJD = JD - 2400000.5

http://aa.usno.navy.mil/data/docs/JulianDate.php

Heliocentric time

on short timescales, light travel path through Solar System becomes important

1 AU (astronomical unit; distance Earth-Sun) = 8.3 light-minutes



Heliocentric Julian Date: adjusted to the center of the Sun

Epochs

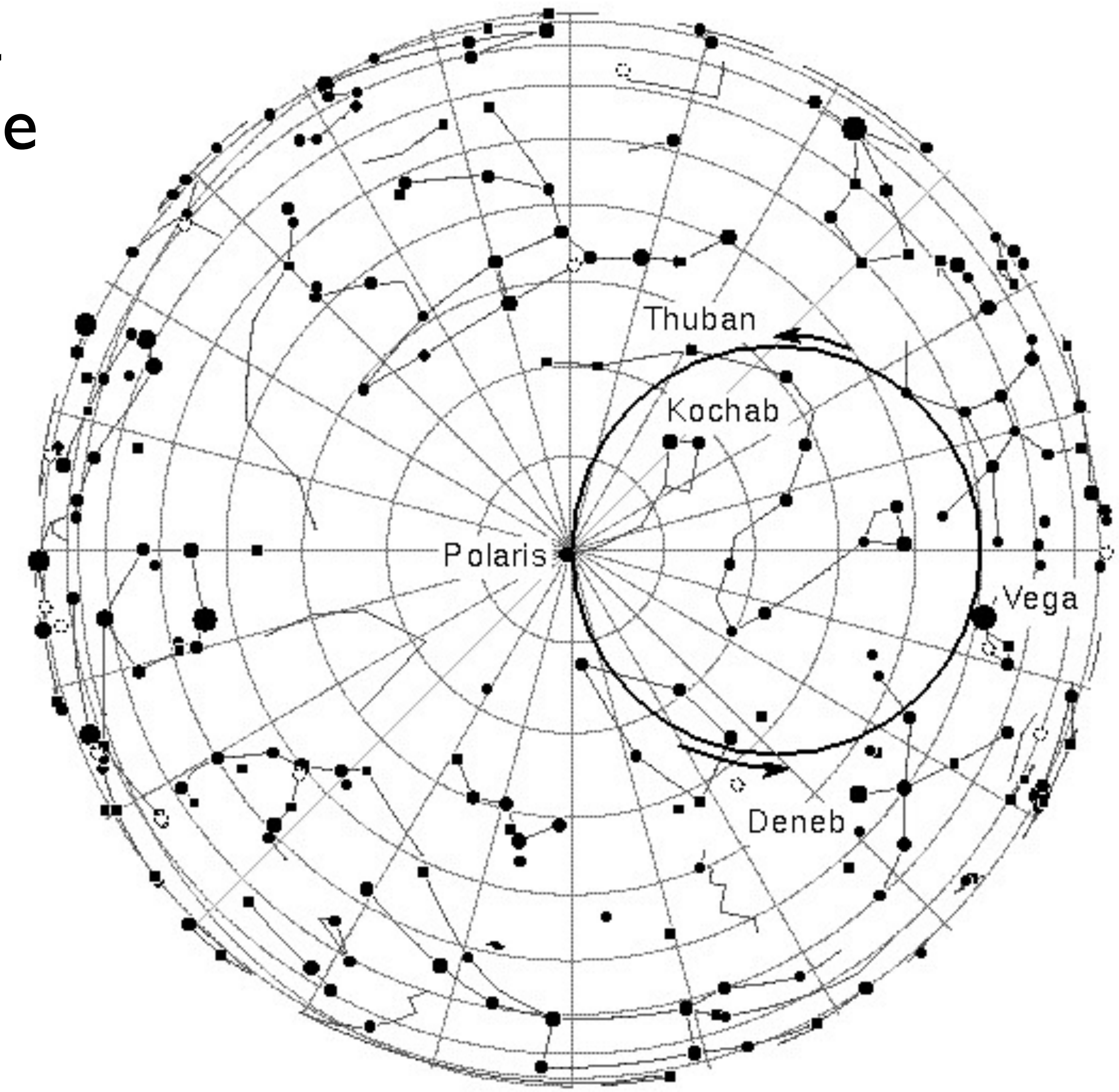
Earth's rotation axis is not constant in space with time

- precession, nutation
(Earth is a big gyroscope!)

- Earthquakes

All coordinates need to specified at a certain time (epoch), e.g.

J2000.0 :
- JD 2451545.0
- January 1, 2000, noon



The path of the precession of the Earth's rotation axis.
It takes 26,000 years to complete a full 360° wobble.