

# **PHY 517 / AST 443:** **Observational Techniques in Astronomy**

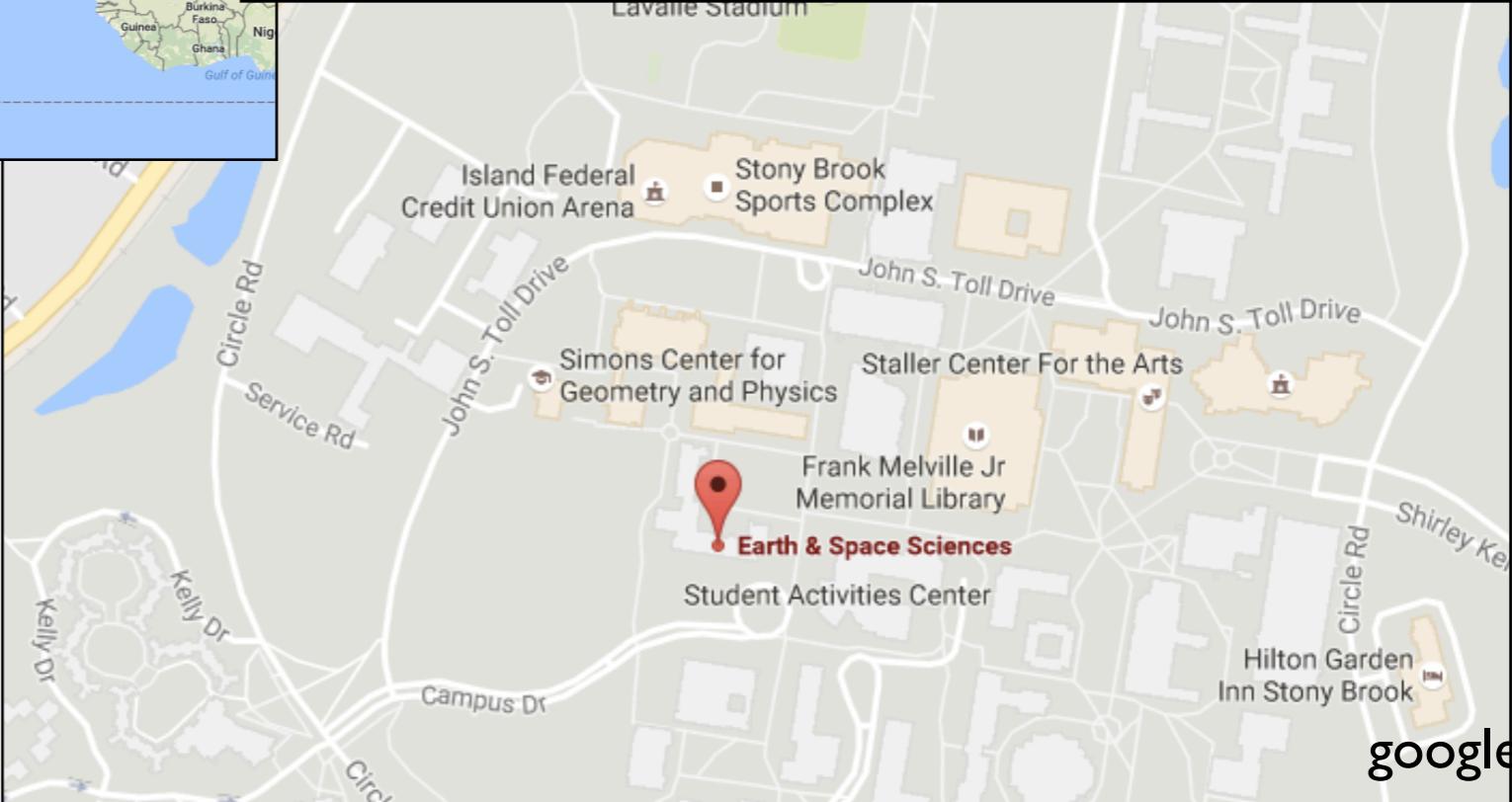
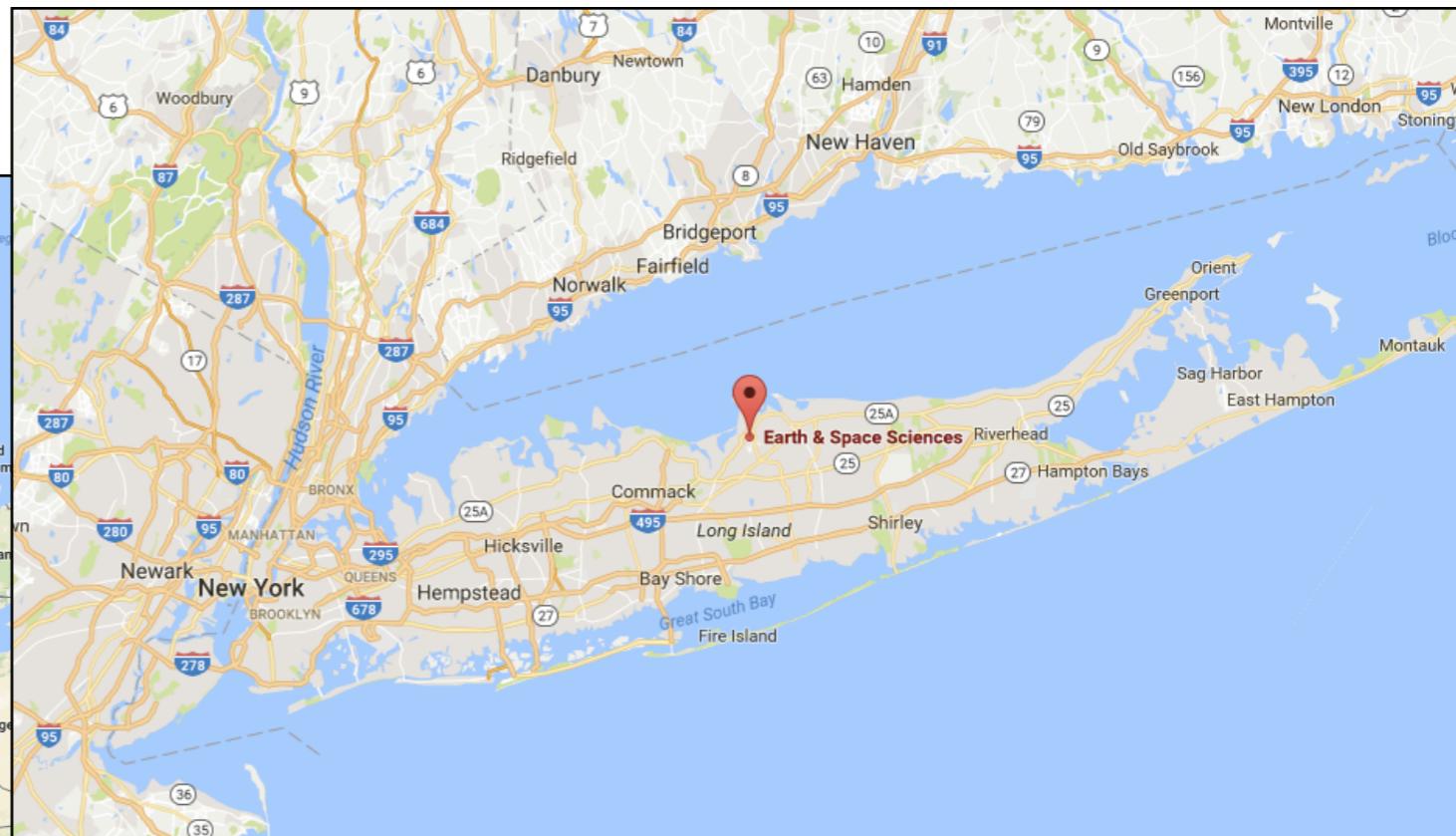
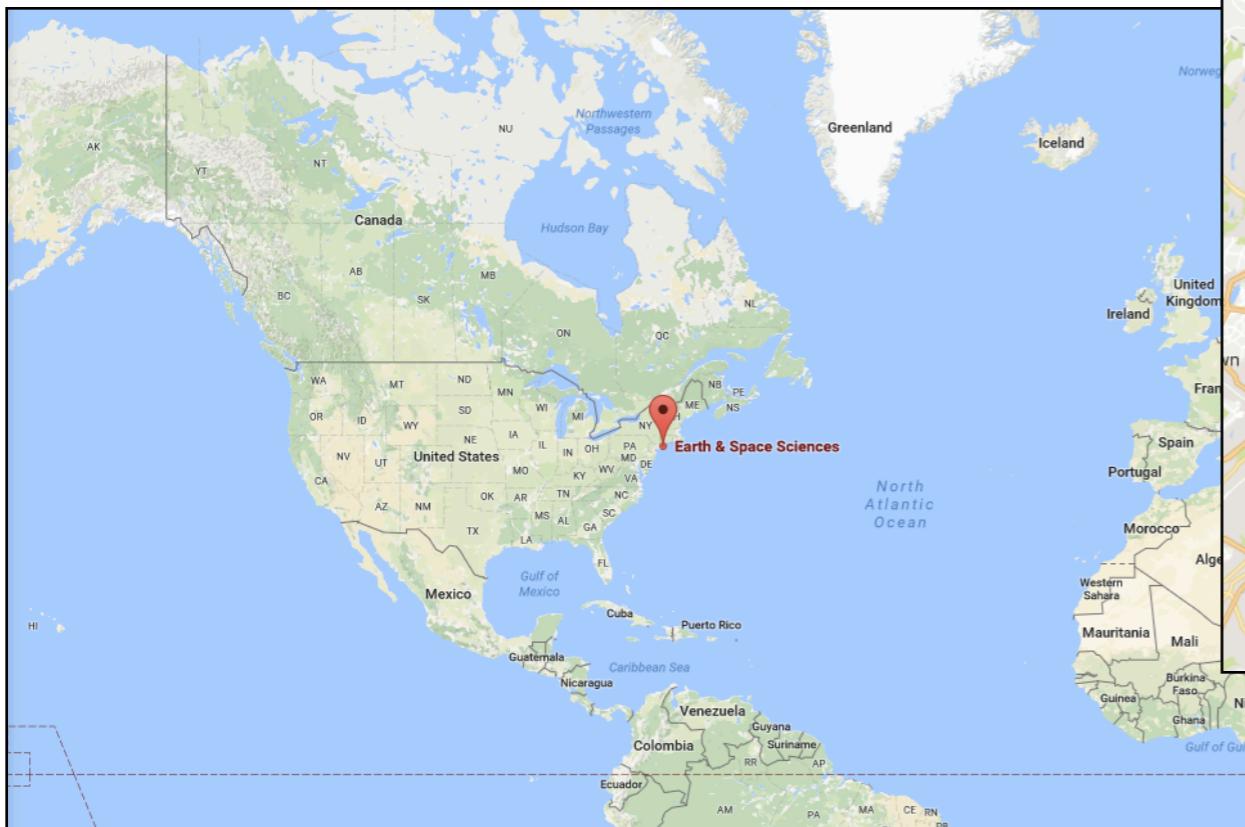
**Lecture I:**  
**How to find things in the Sky /**  
**Astronomical Coordinate Systems /**  
**Time**

**How do you find things in the Sky?**

How do you find things **on Earth?**

# How do you find things on Earth?

## I. maps

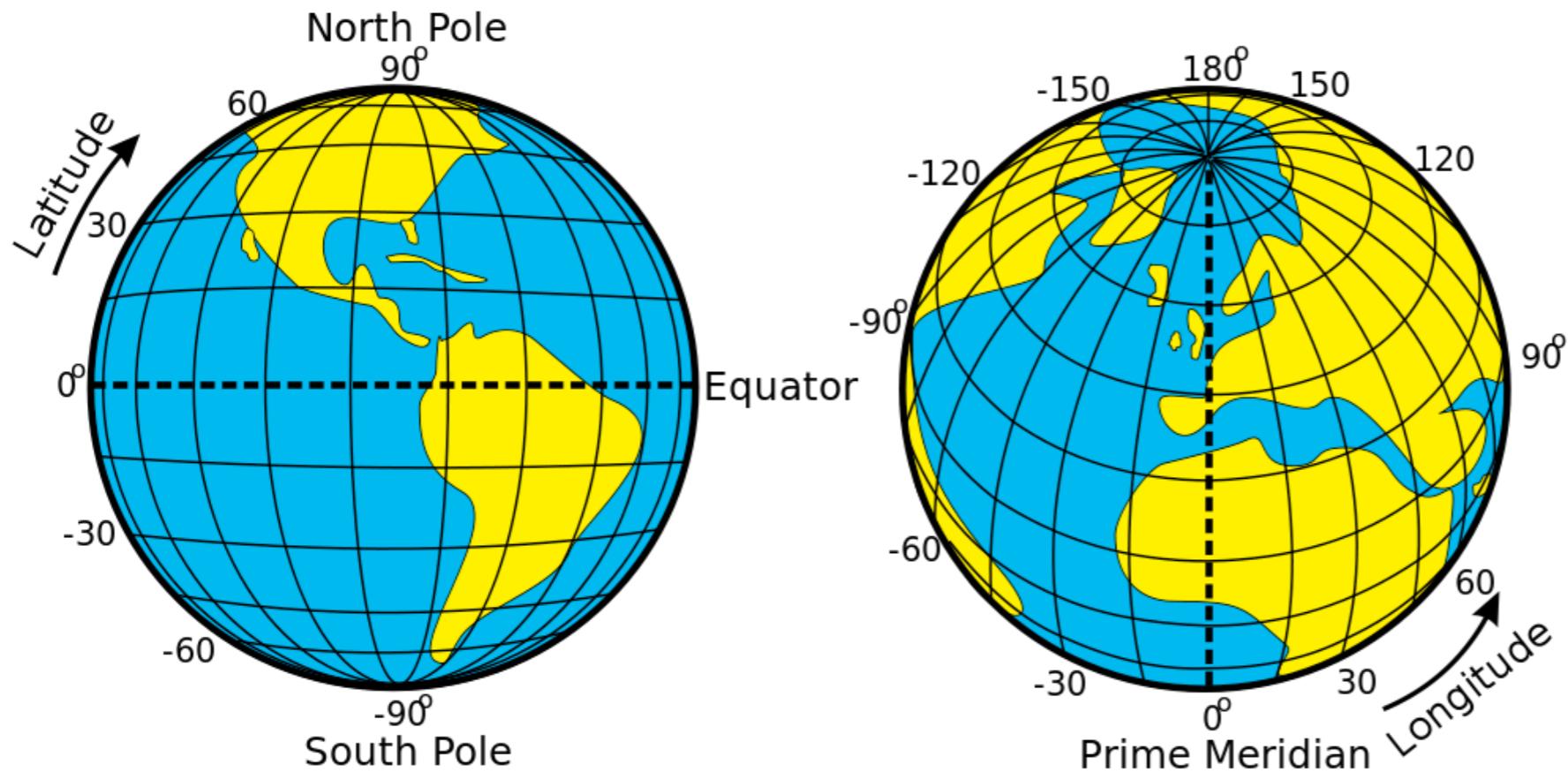


“pattern matching”

# How do you find things on Earth?

Coordinates:  40.914224°N 73.11623°W

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



## Stony Brook University

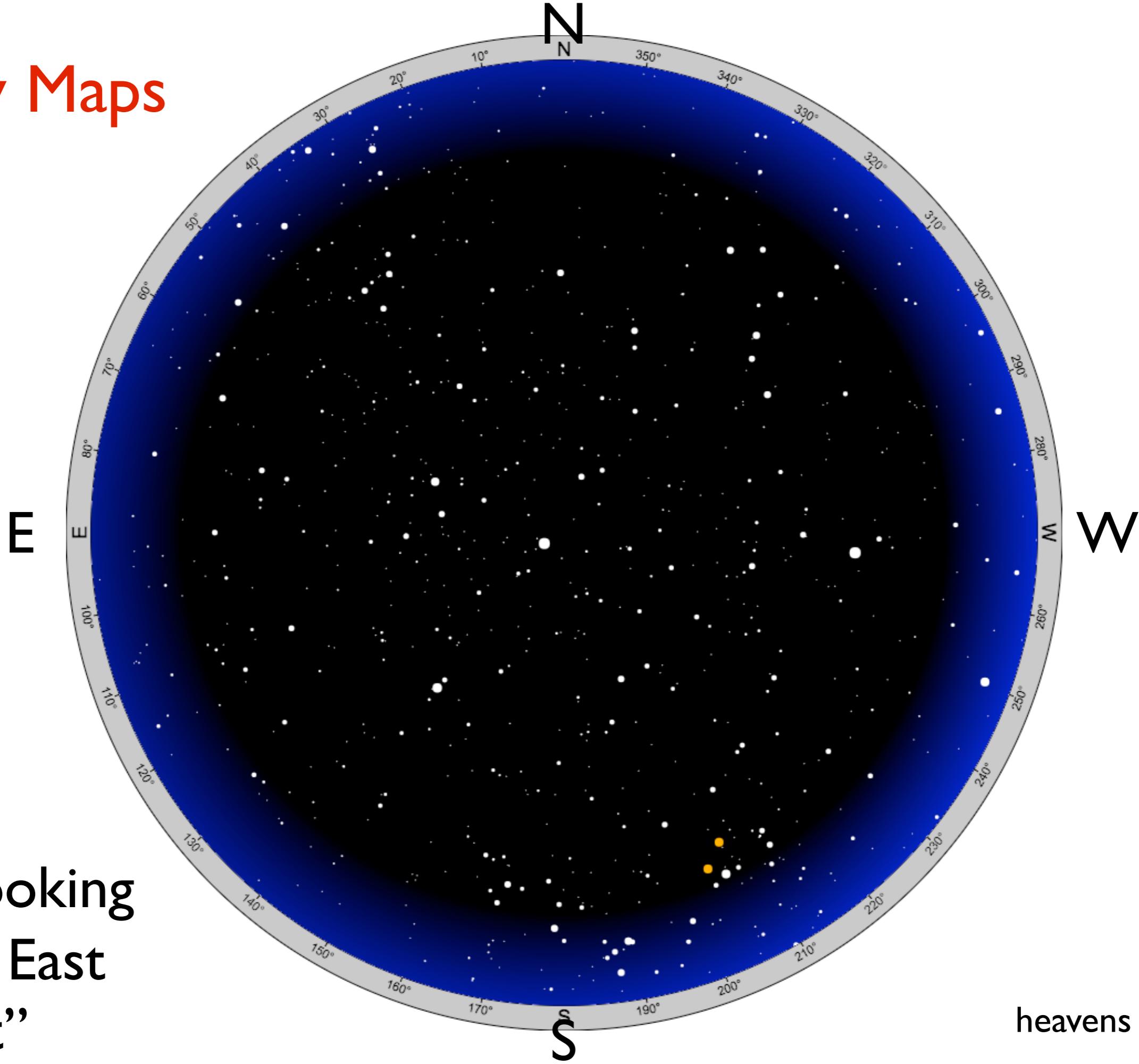


Former names	State University College on Long Island (1957–1962)
Type	• Public • Research university • Sea-grant • Space-grant
Established	1957
Endowment	\$247.4 million (2015) <sup>[1]</sup>
President	Samuel L. Stanley
Provost	Dennis Assanis
Academic staff	2,471 (fall 2013)
Students	21,115 (West Campus)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

# How do you find things on the Sky?

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

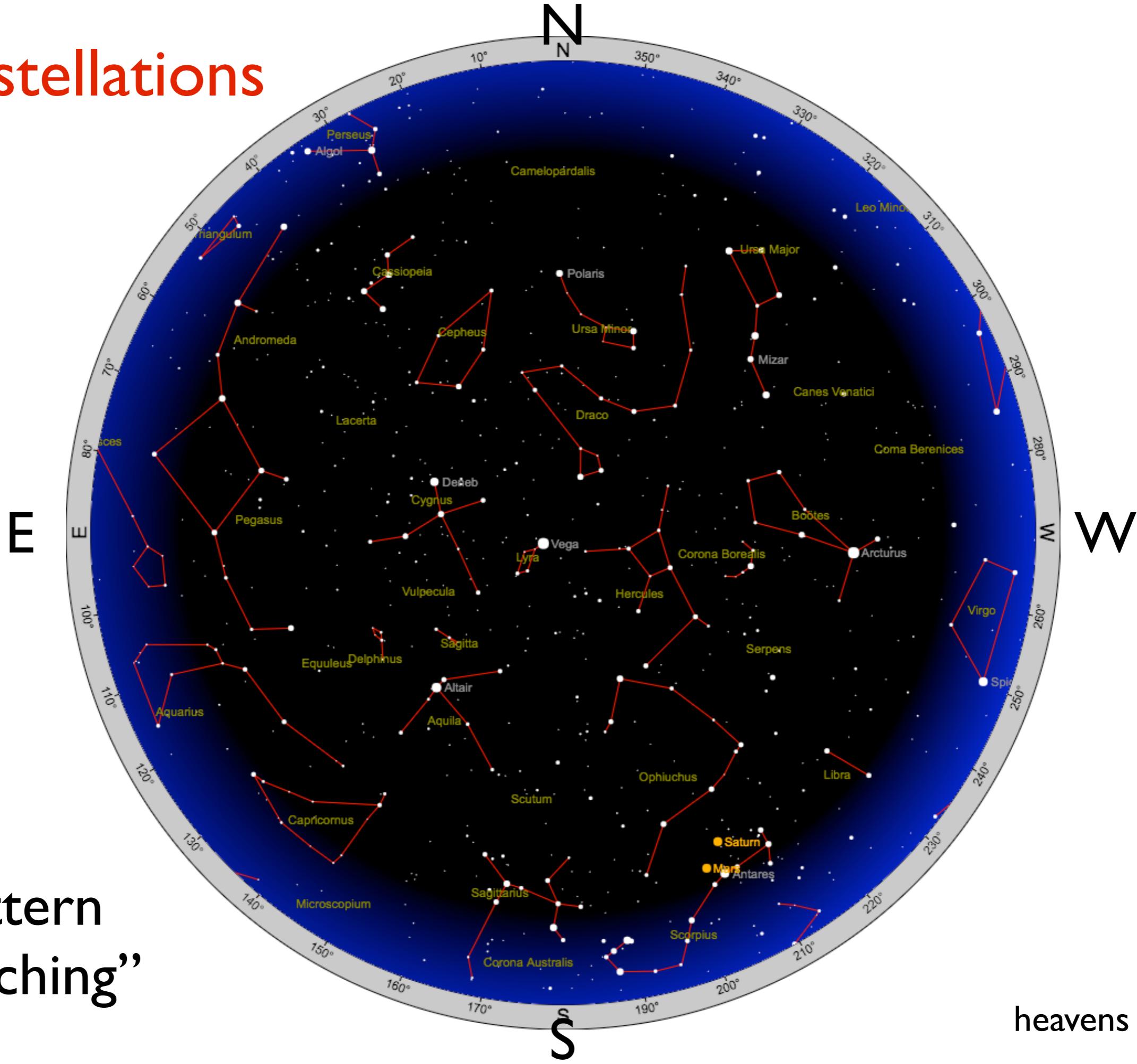
# Sky Maps



NB: looking  
up → East  
is “left”

heavens above

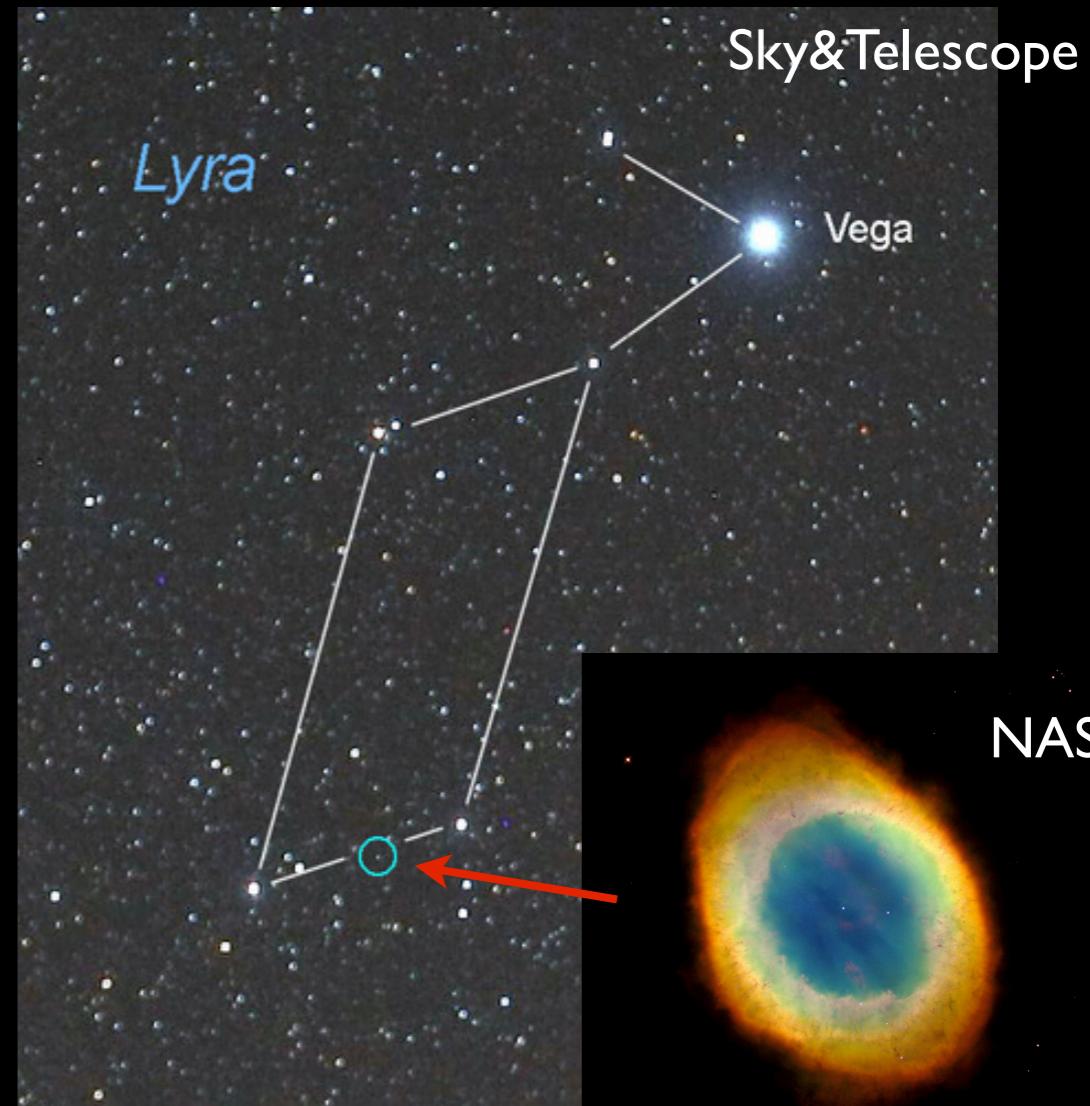
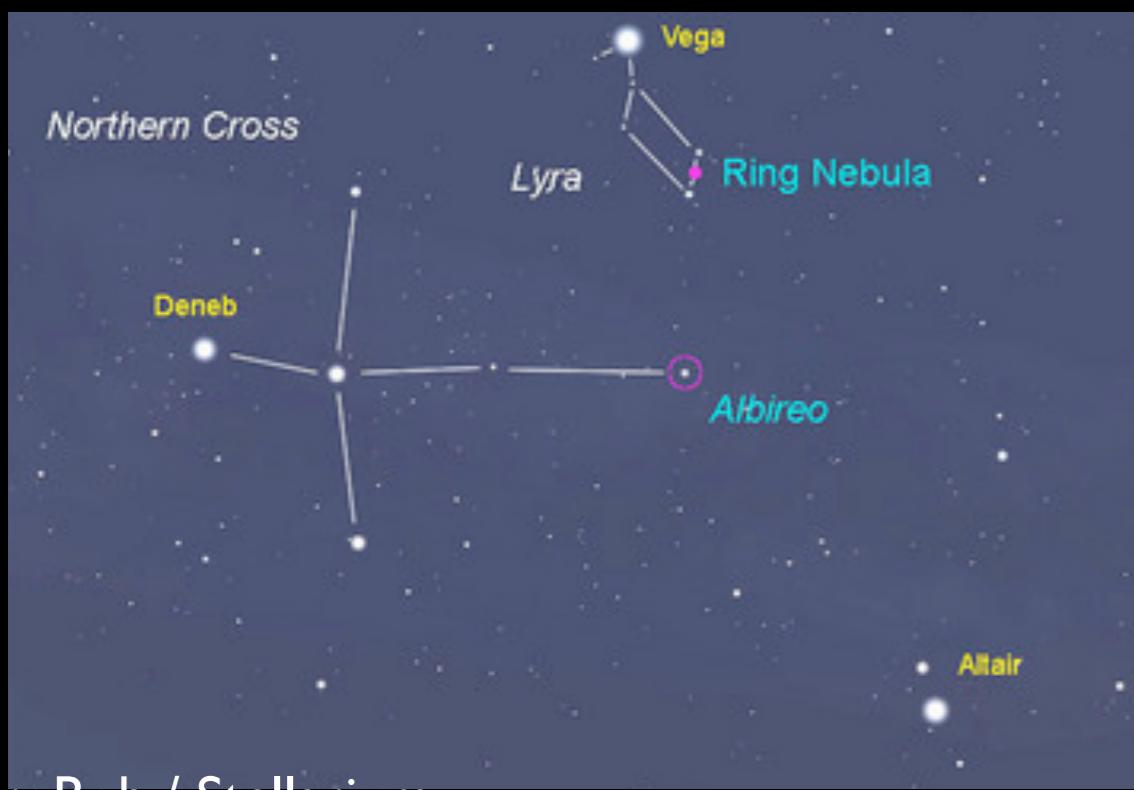
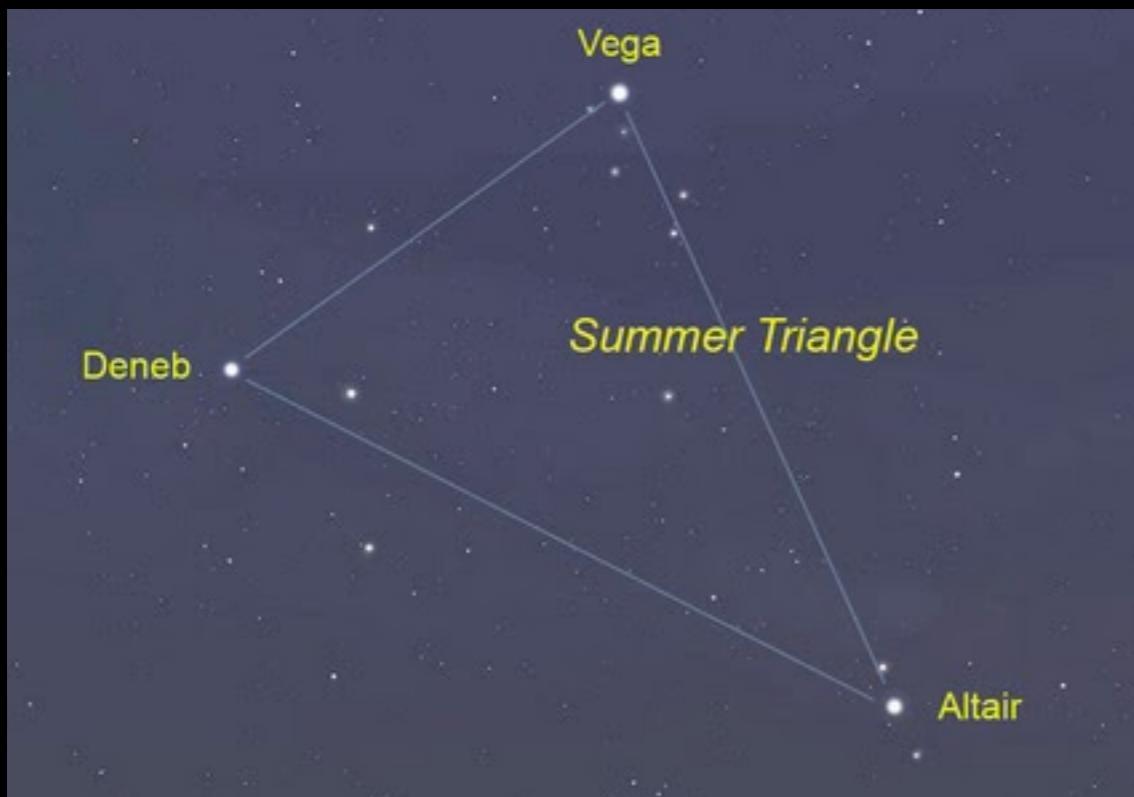
# Constellations



“pattern  
matching”

heavens above

# How to find the Ring Nebula (M57)



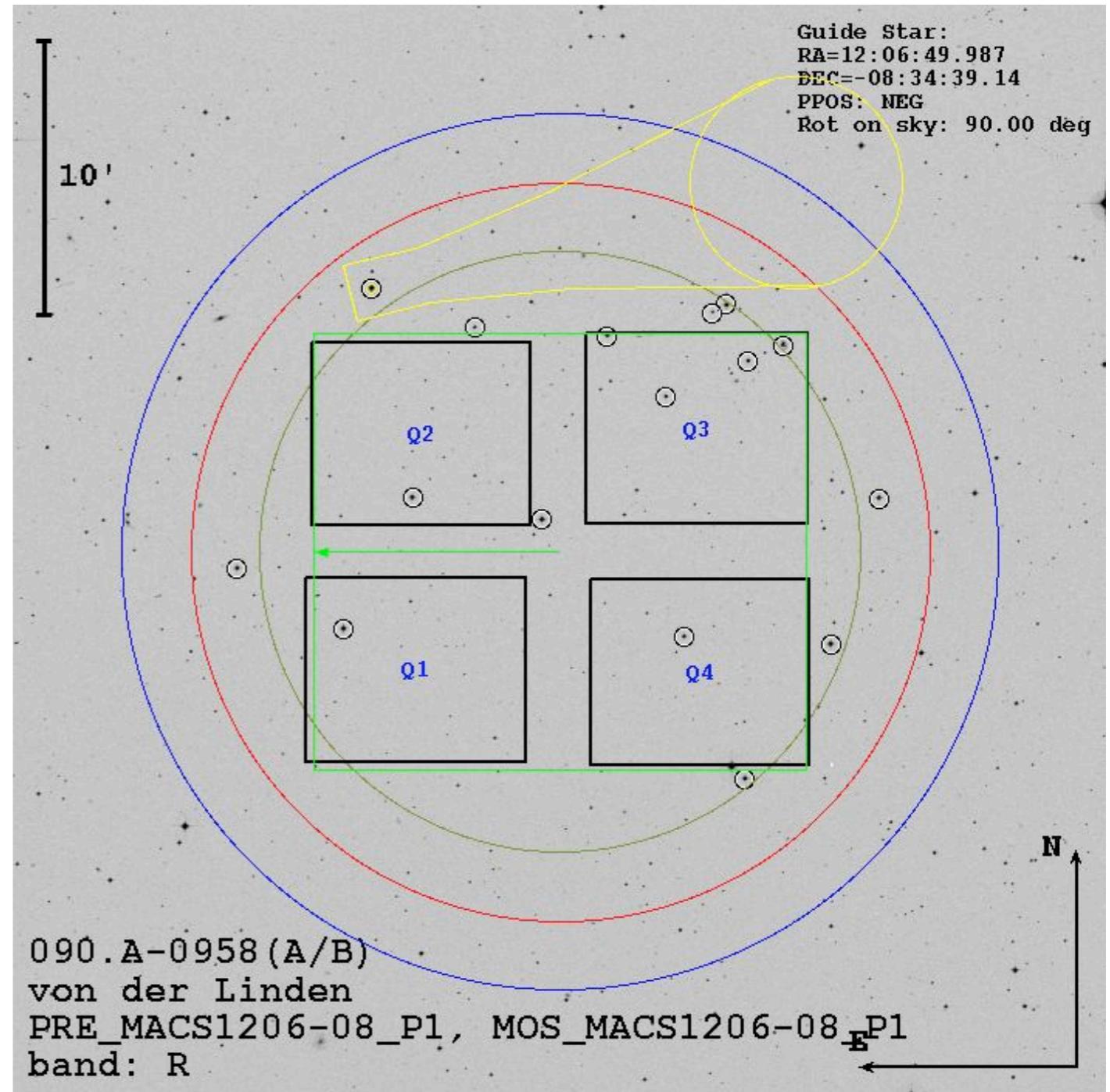
**asterisms:** easy-to-recognize  
star groupings  
**constellations:** officially  
defined sky regions, based on  
historical asterisms

# 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

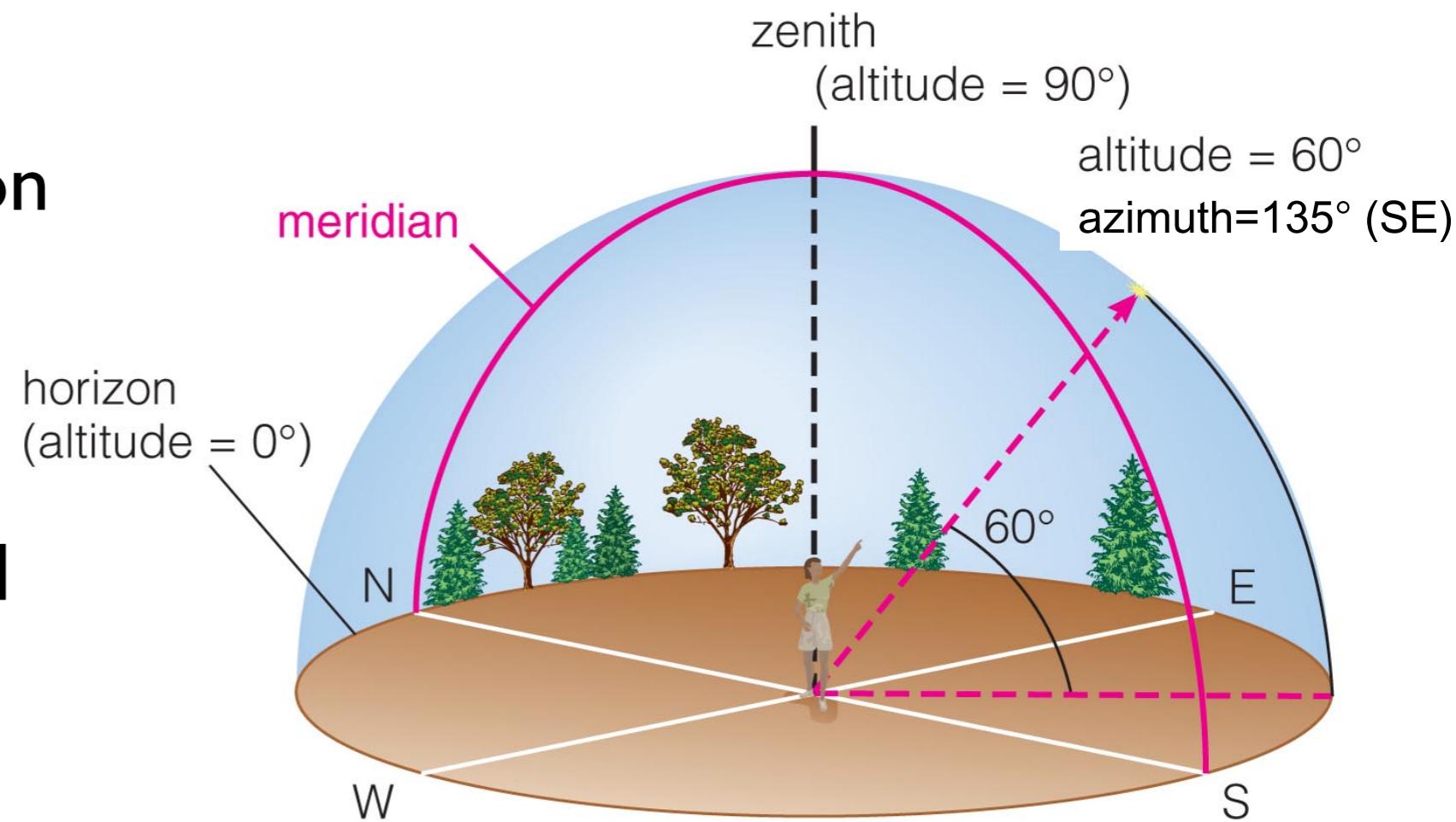
the sky above a specific location, at a specific time, is half a sphere - can be described with 2 (positive) angular coordinates

**altitude:** angular distance to the horizon

**azimuth:** angular distance from north

**zenith:** point overhead

**meridian:** north-south line



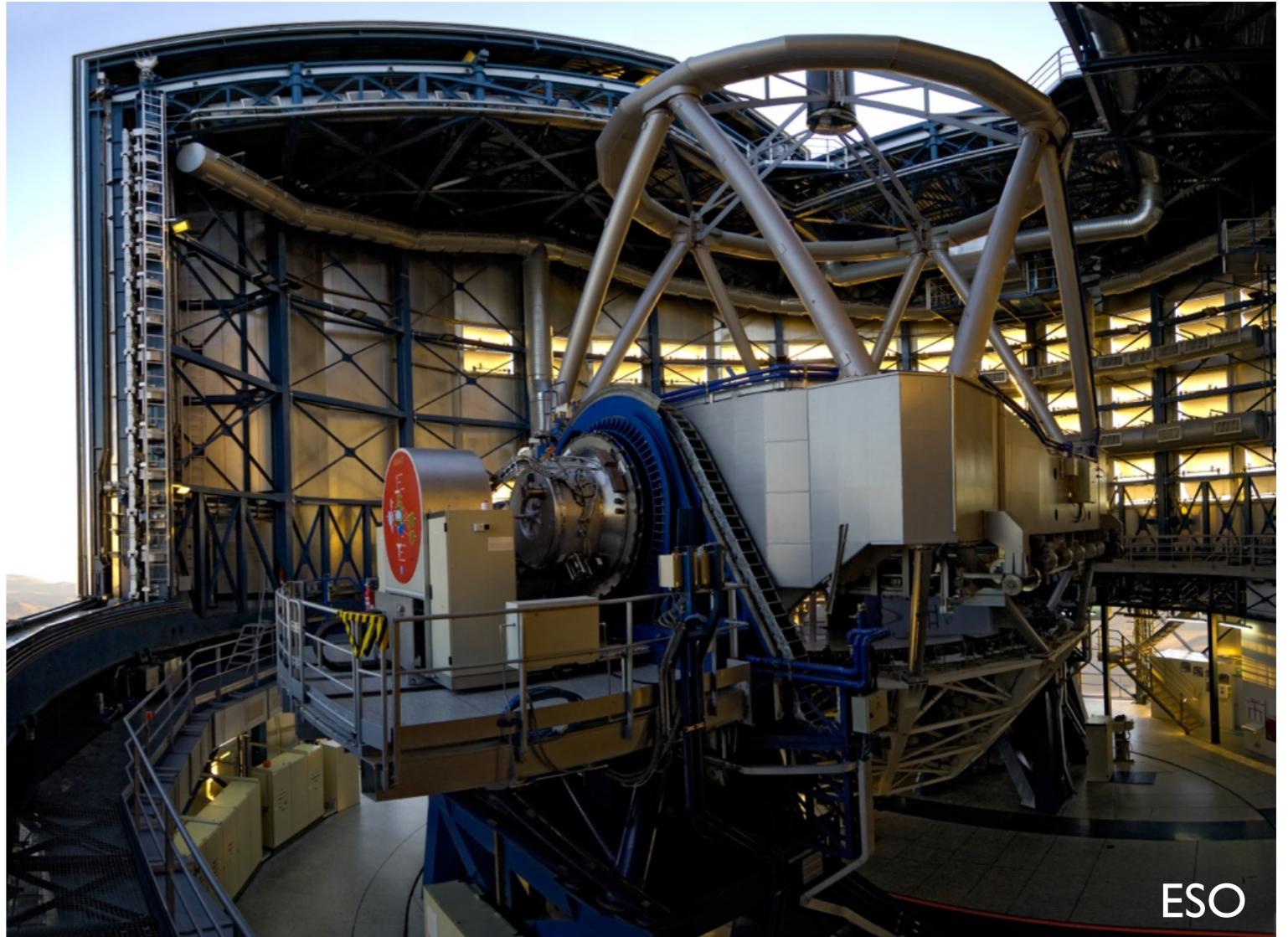
# Horizontal (or “Alt/Az”) Coordinate System

alt-az telescope mounts: simple, very stable



M. Rahman

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

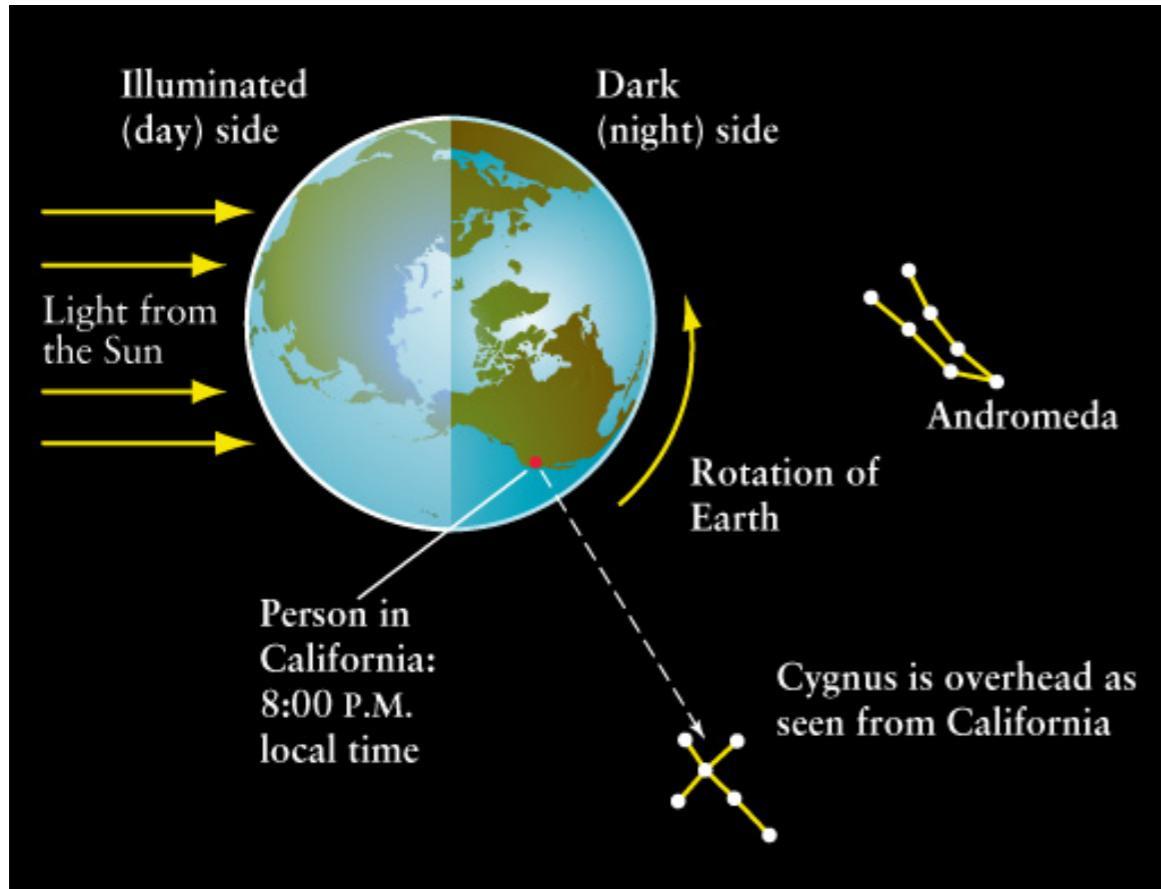
is my target “up” ? ( $\text{altitude} > 0^\circ$ )

is my target “observable” ? ( $\text{altitude} > 30^\circ / 40^\circ / 50^\circ$ )

# Rotation of the Earth

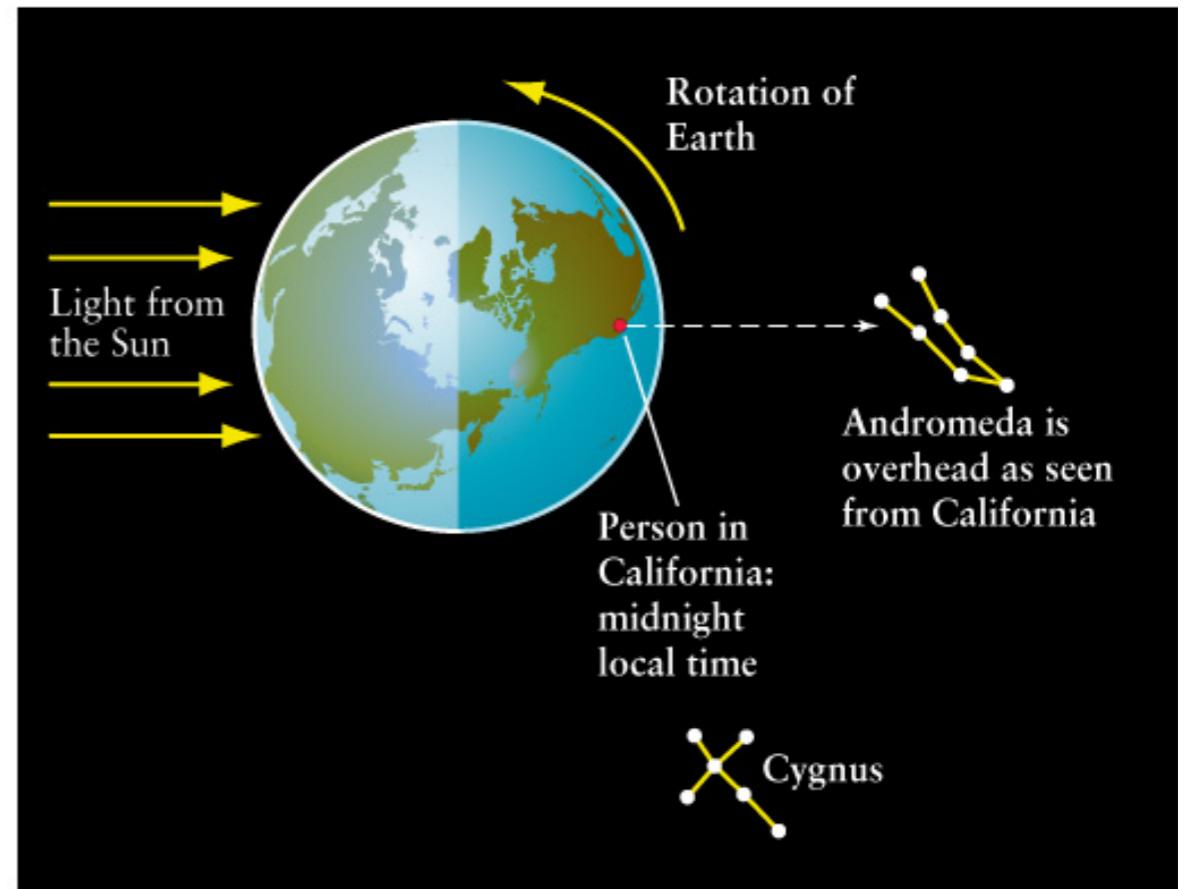
looking down on the north pole, Earth rotates counter-clockwise

Bailey, Slater & Slater



(a) Earth as seen from above the north pole

Andromeda is to the East;  
Cygnus is overhead

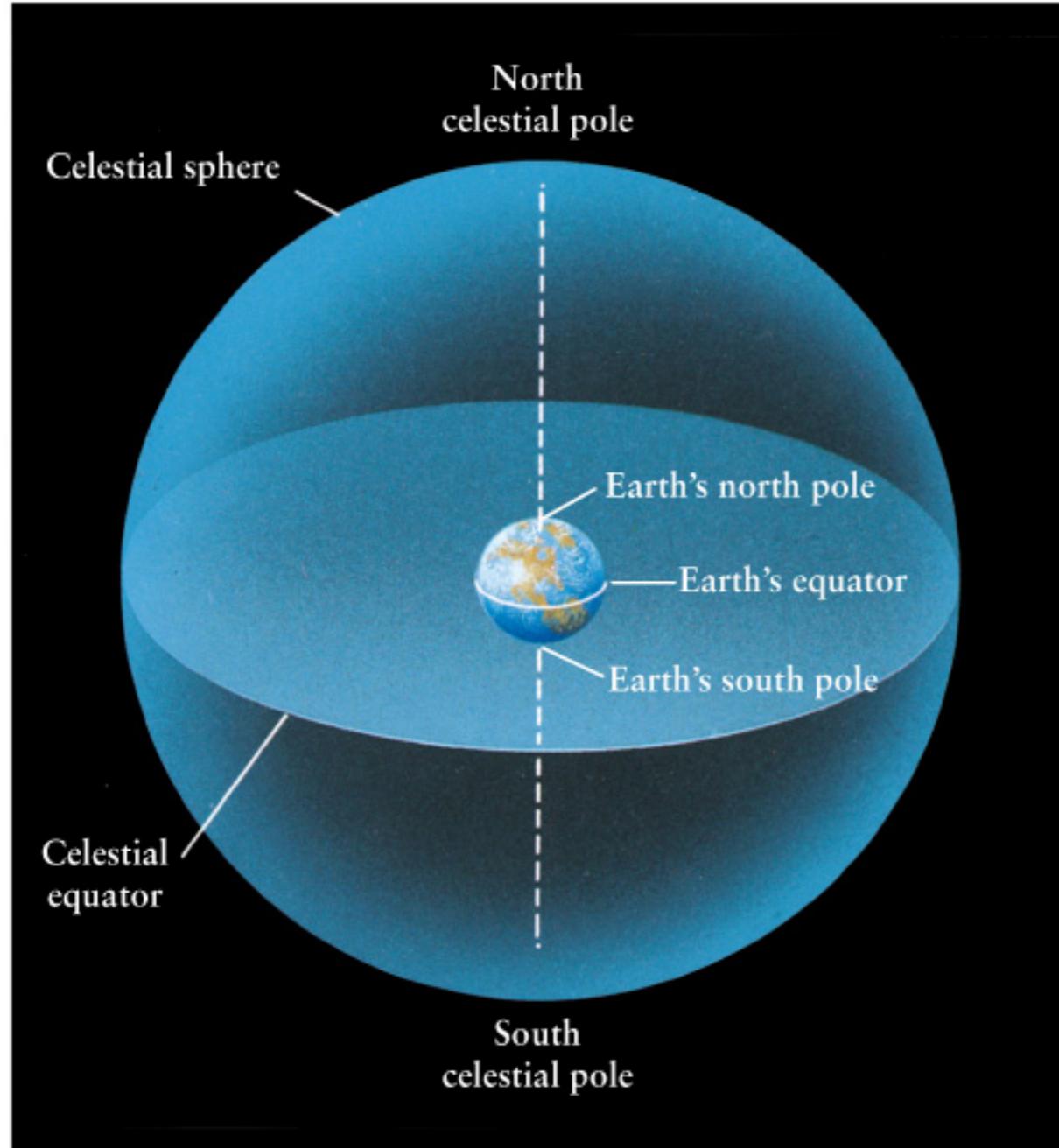


(b) 4 hours (one-sixth of a complete rotation) later

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

the Sky appears to rotate East to West

# Celestial Sphere

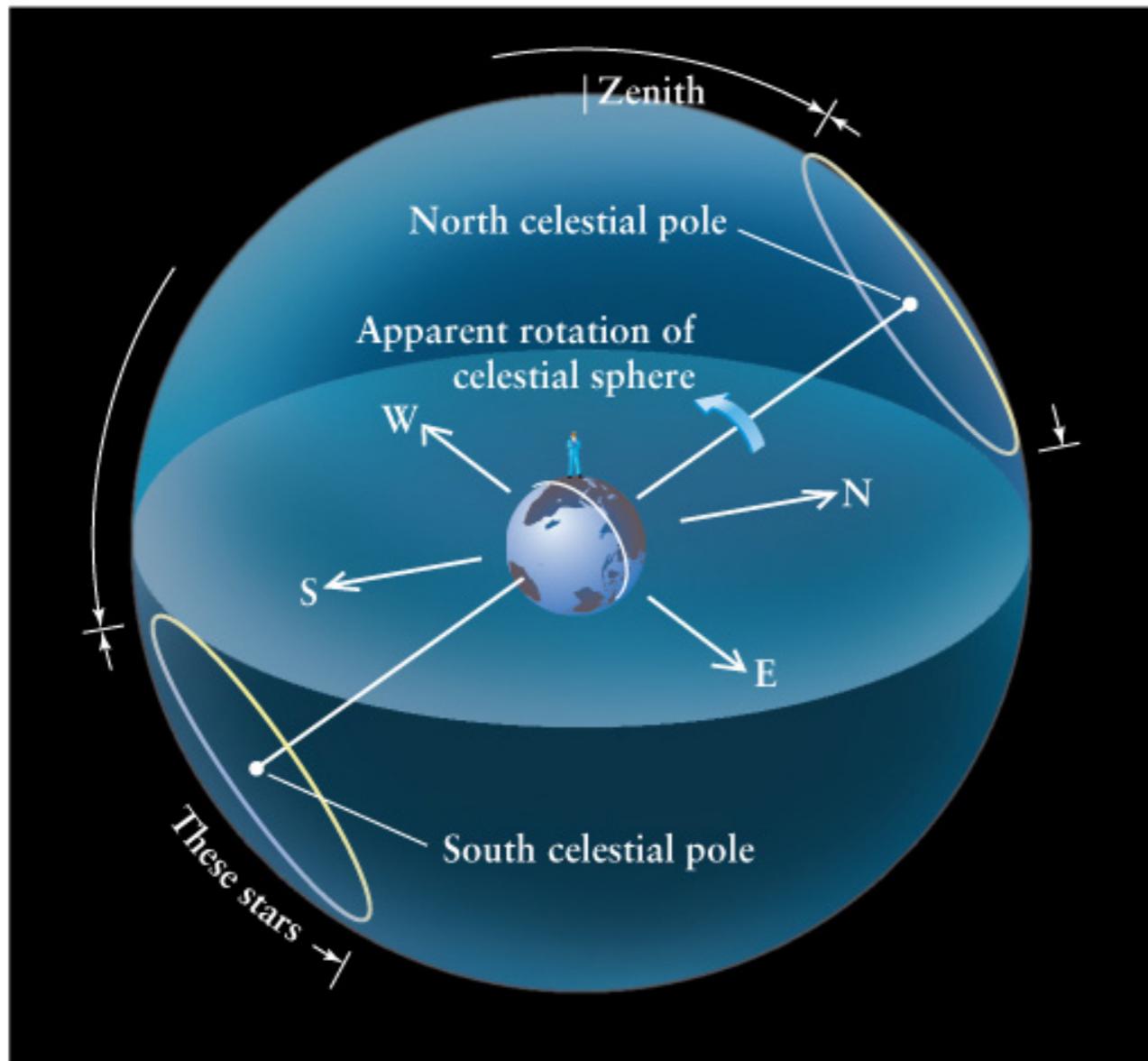


celestial sphere: describe objects by their position on a sphere centered on rotating Earth

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

**celestial equator:** projection of Earth's equator

# Apparent motion in the Sky

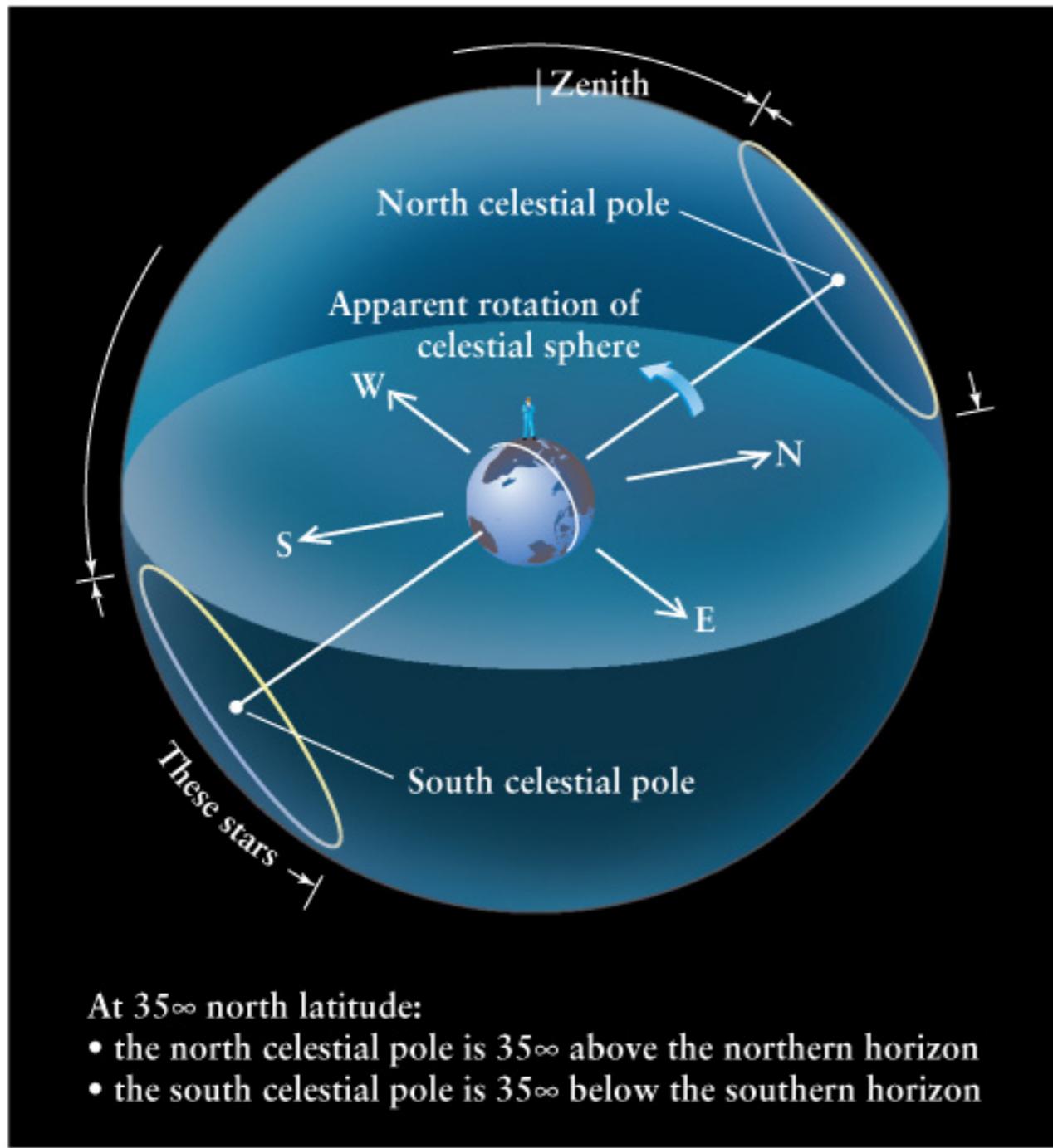


apparent sky motion depends on latitude of observer

e.g. SB is  $41^\circ$  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



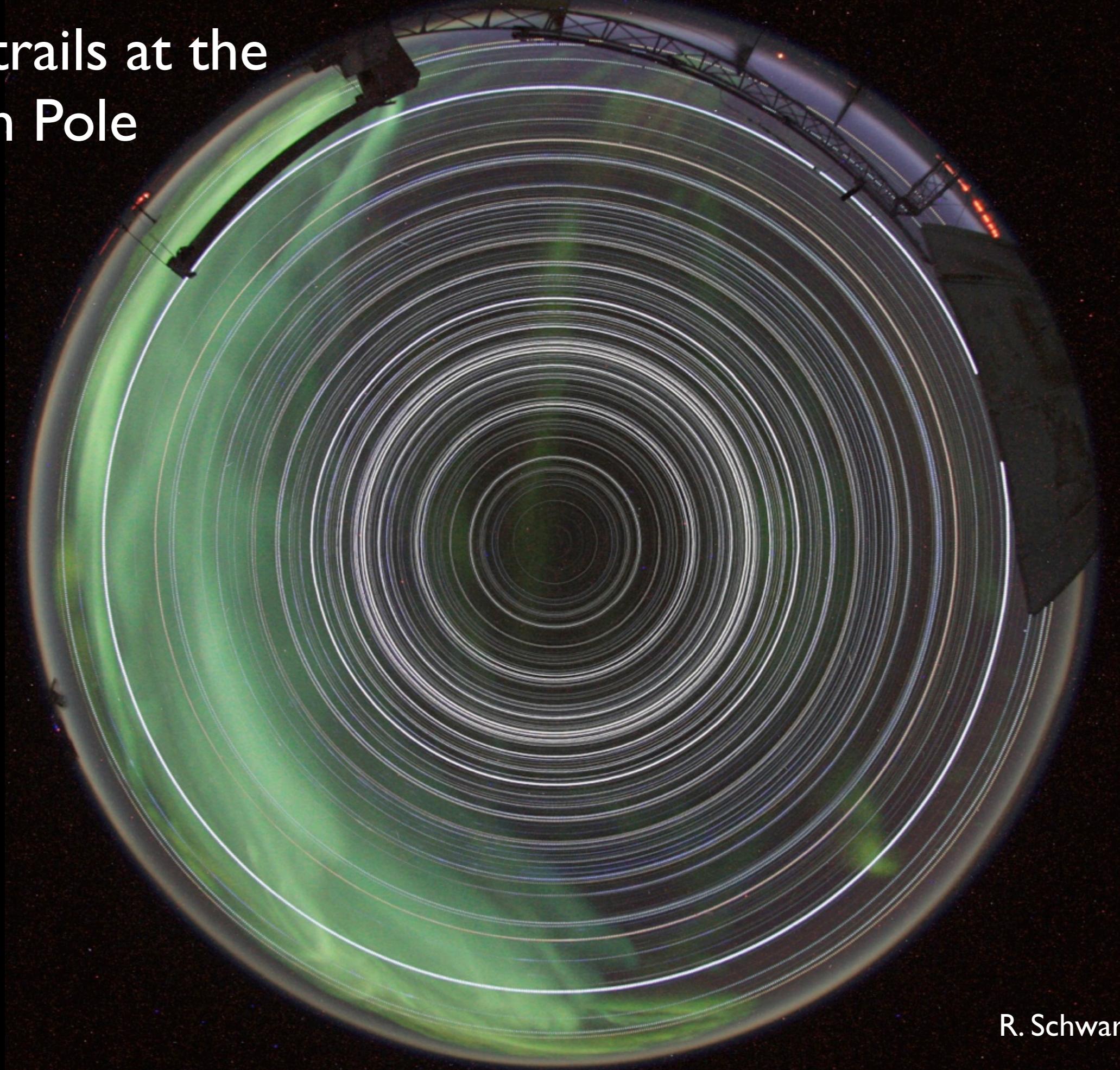
Star trails over CTIO, (c) Jose Delgado

# Star trails at the equator



© Stéphane Guisard

# Star trails at the South Pole



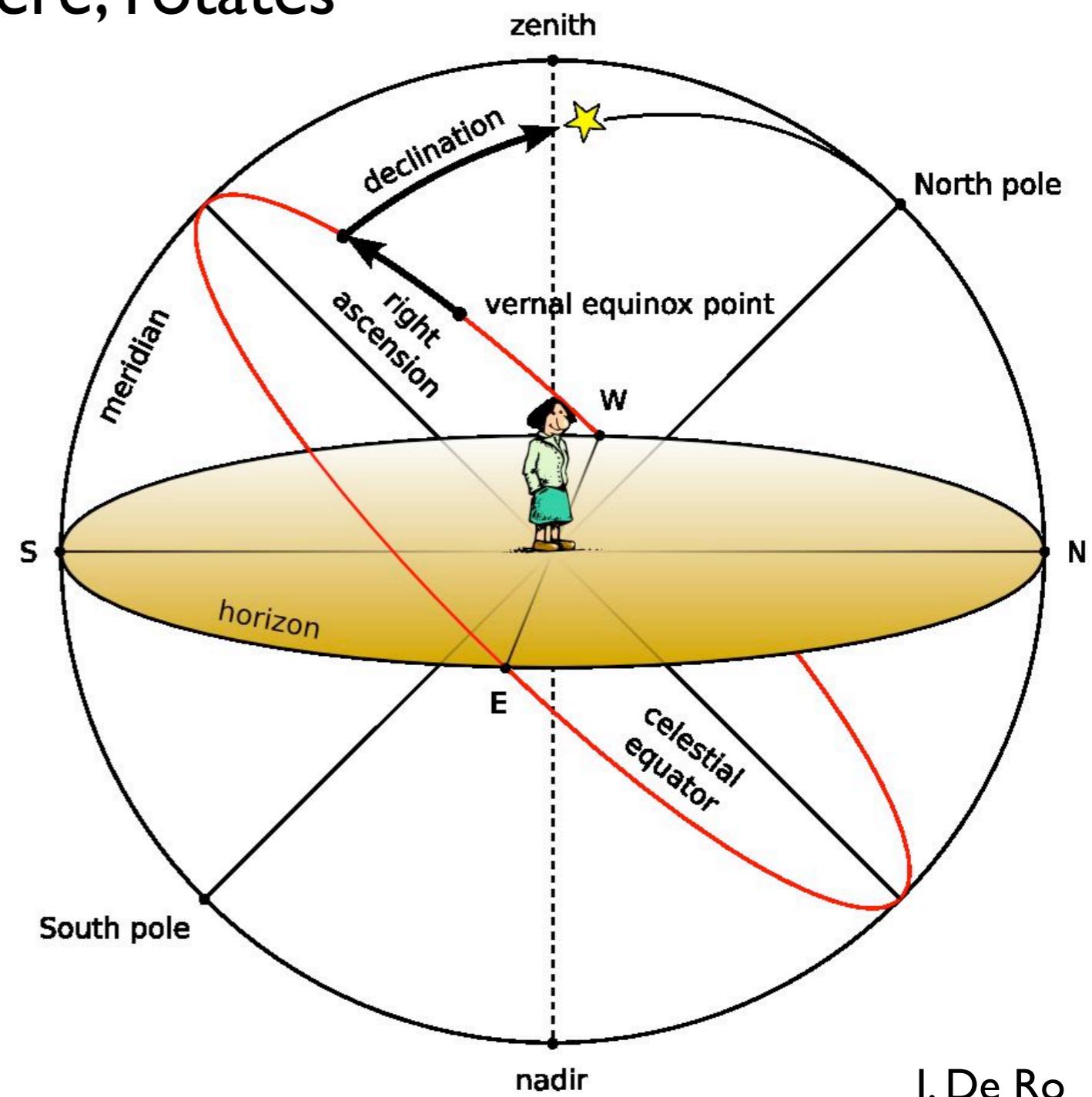
R. Schwarz

# Equatorial (RA/Dec) Coordinate System

“fixed” to the celestial sphere, rotates with the sky

**declination  $\delta$ :** angular distance from the celestial equator

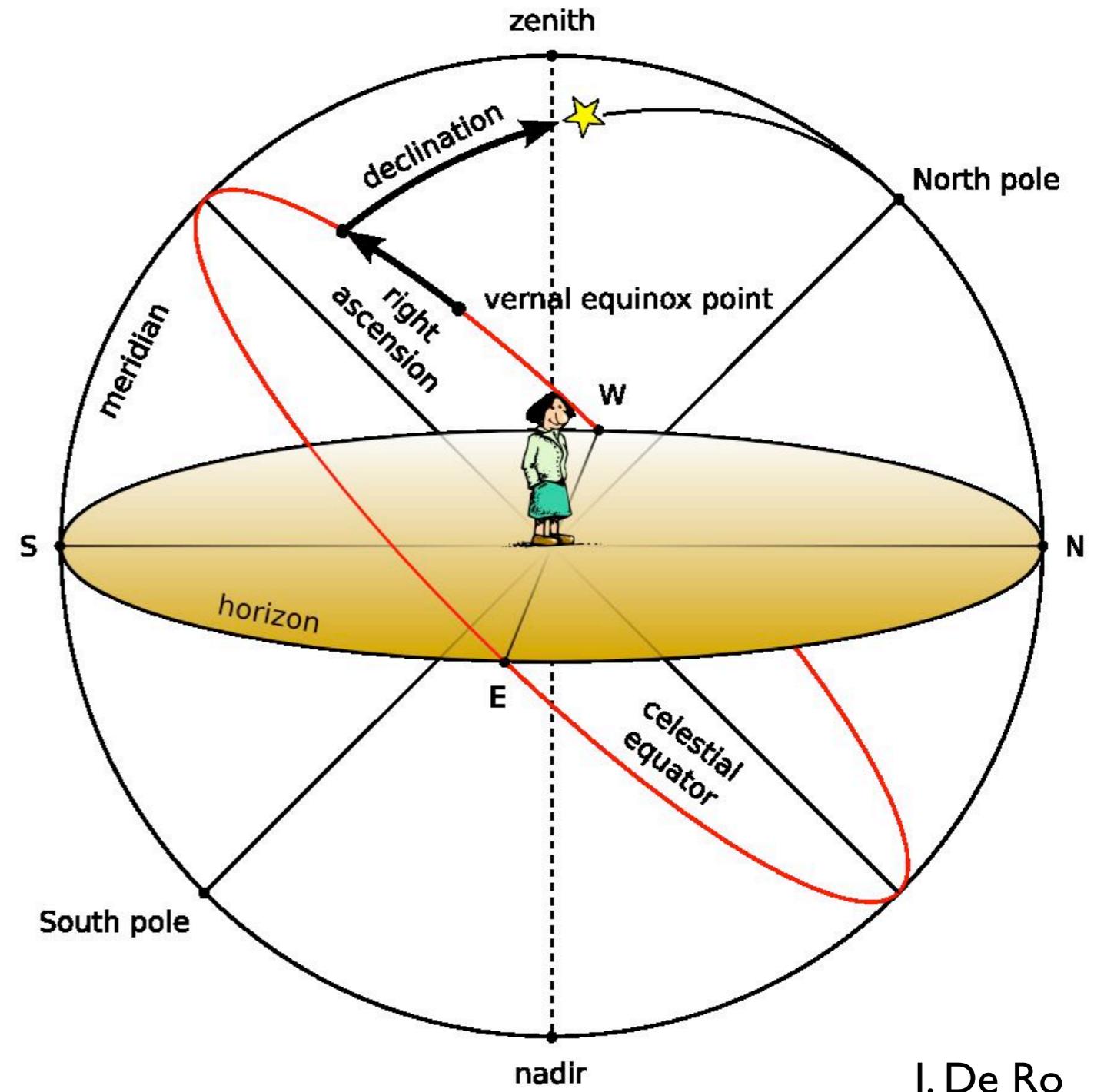
**right ascension  $\alpha$ :** angular distance from vernal equinox (later; special point on equator)



# Equatorial (RA/Dec) Coordinate System

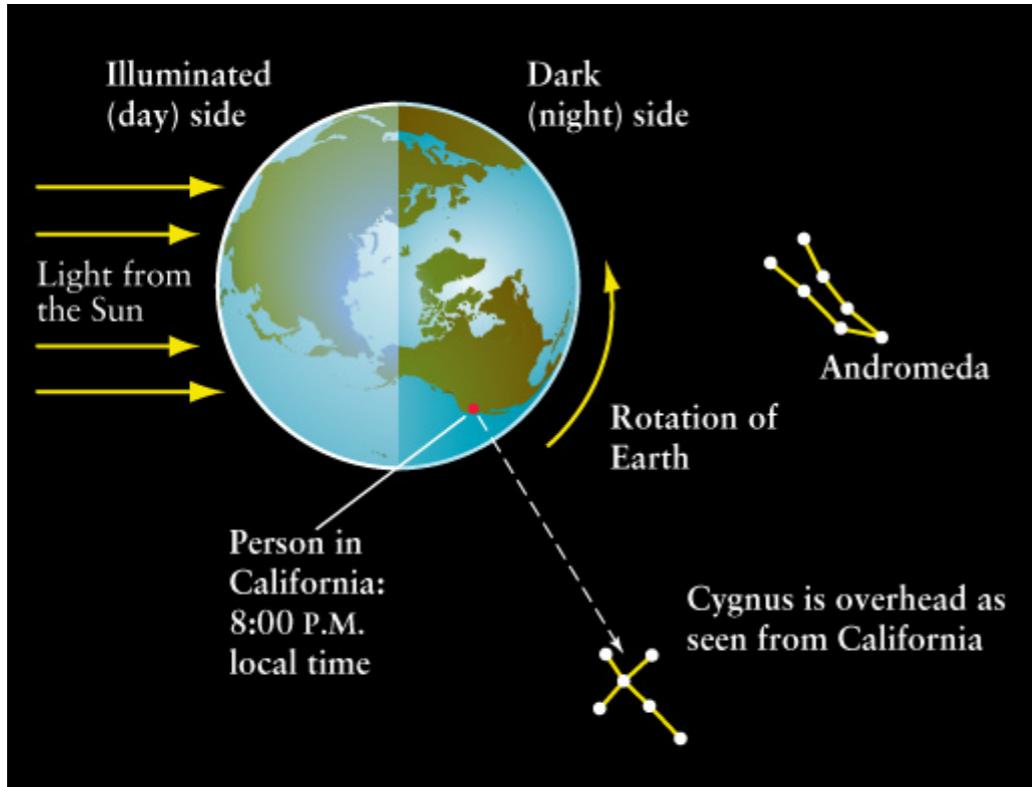
**declination  $\delta$ :** measured in degrees,  $-90^\circ \leq \delta \leq 90^\circ$  (like latitude)

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

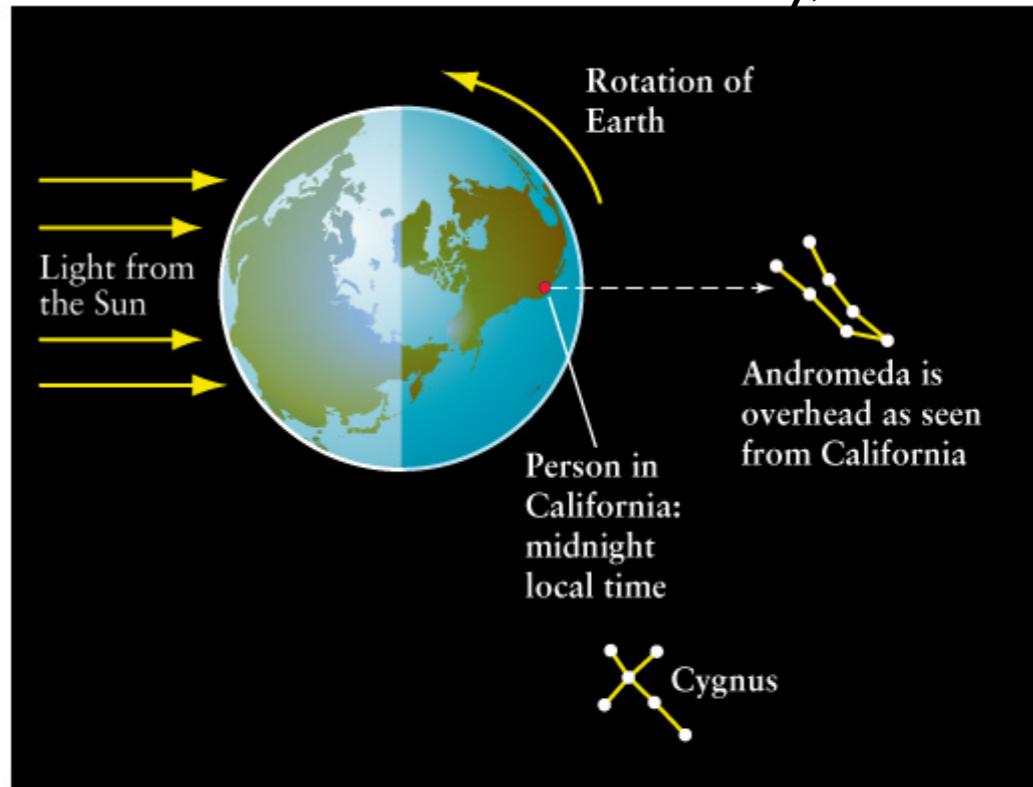


# Right ascension (RA)

Bailey, Slater & Slater



(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

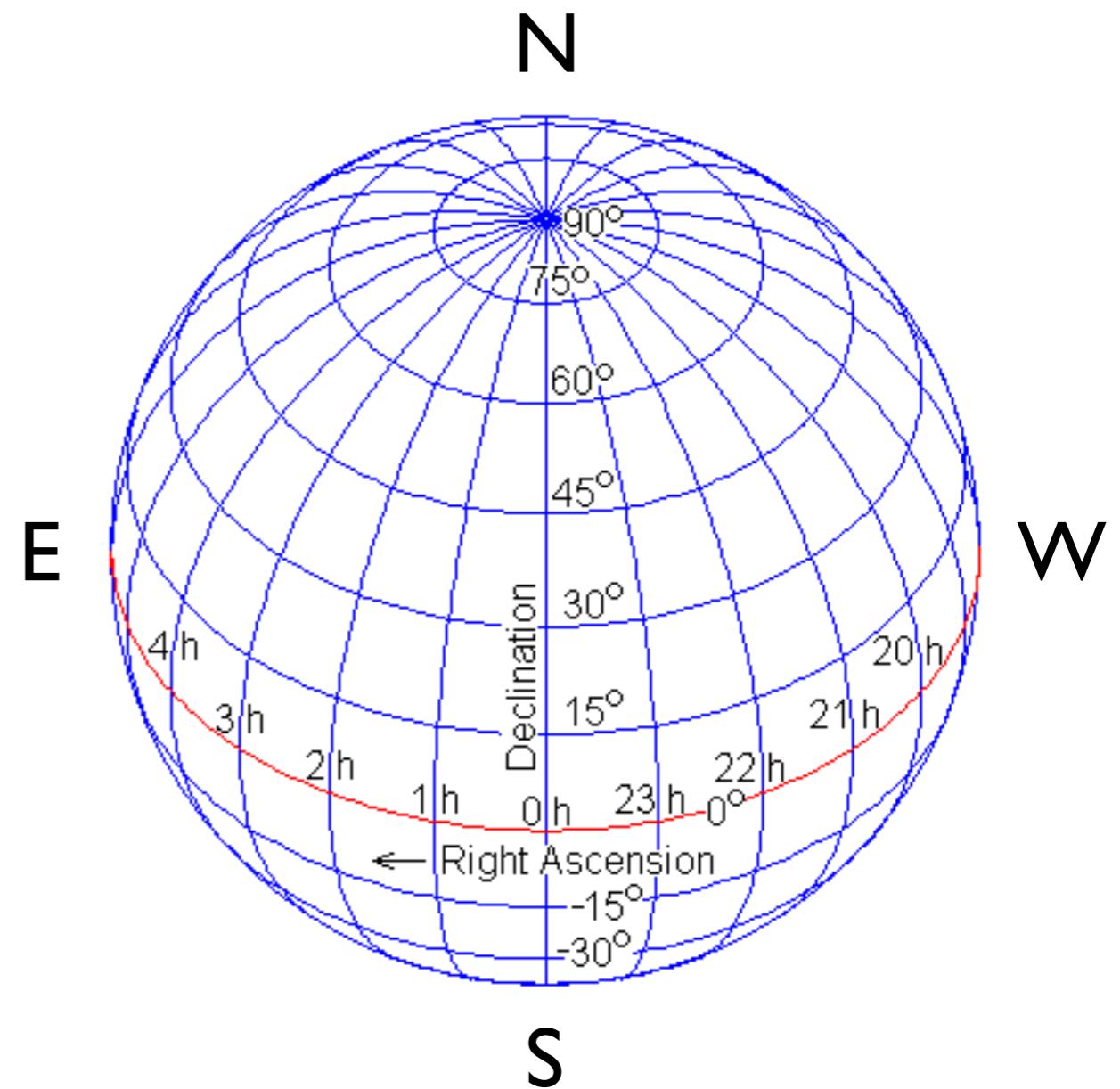
e.g.: reference point (0h) culminates (passes meridian) at midnight; all points that culminate 4 hours later have  $\alpha = 4h$

# 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)



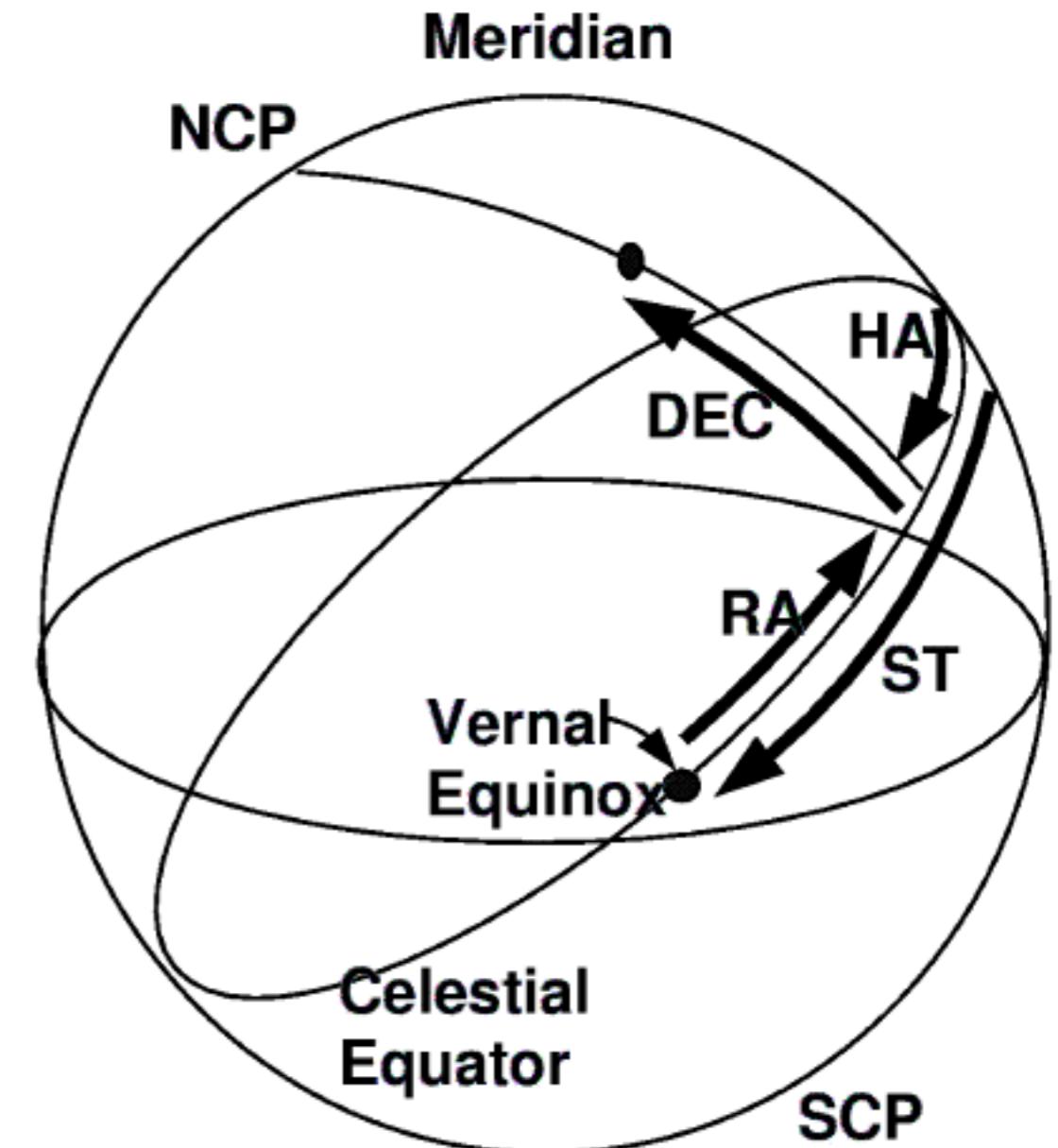
# RA, LST, and Hour Angle

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

$$HA = LST - \alpha_{\text{object}}$$

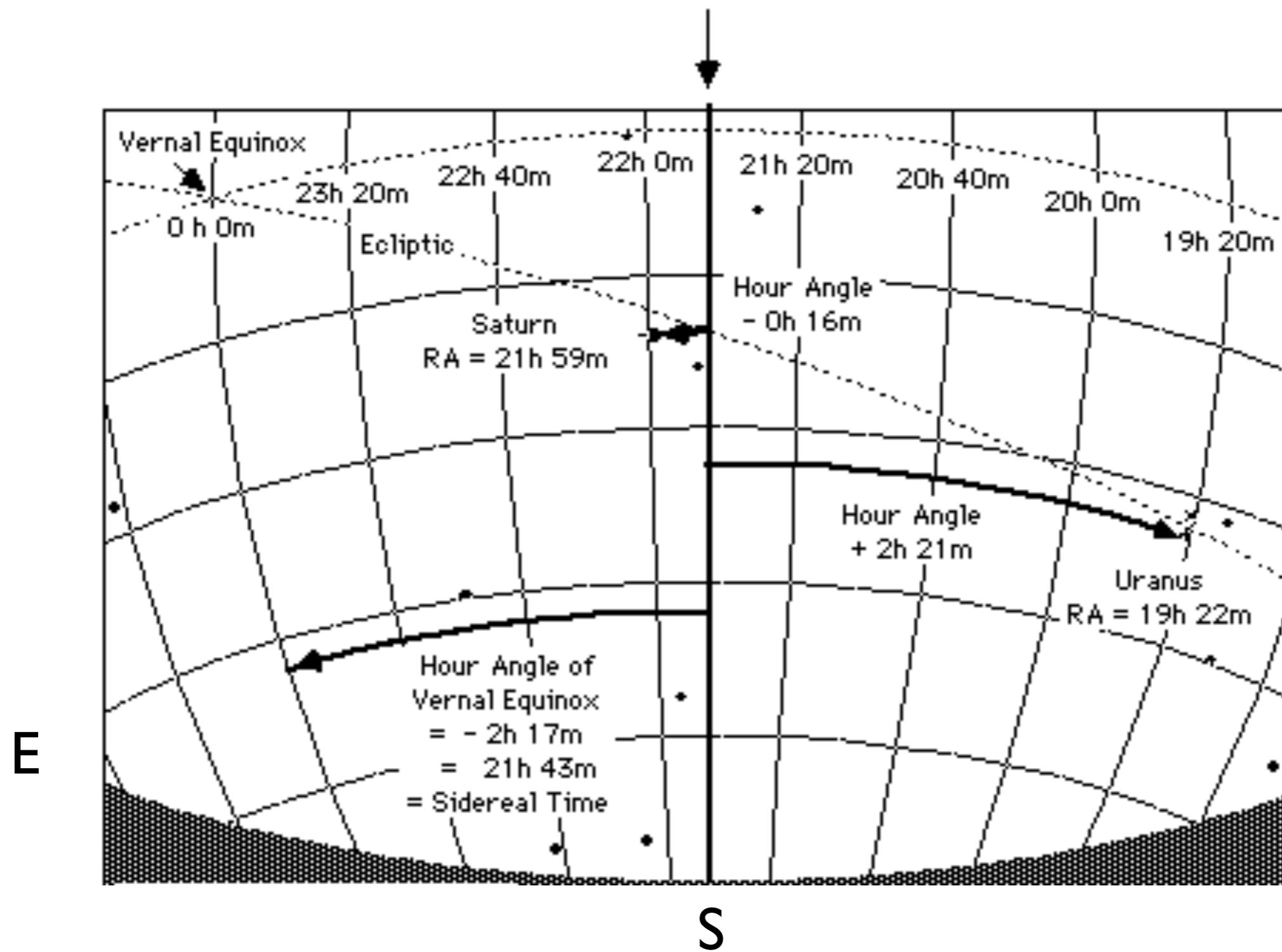
HA > 0h: object has already culminated, it is “setting” and in the western half of the sky

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



# Example

Sidereal Time  
= Right Ascension on Meridian  
= 21 hrs 43 min



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

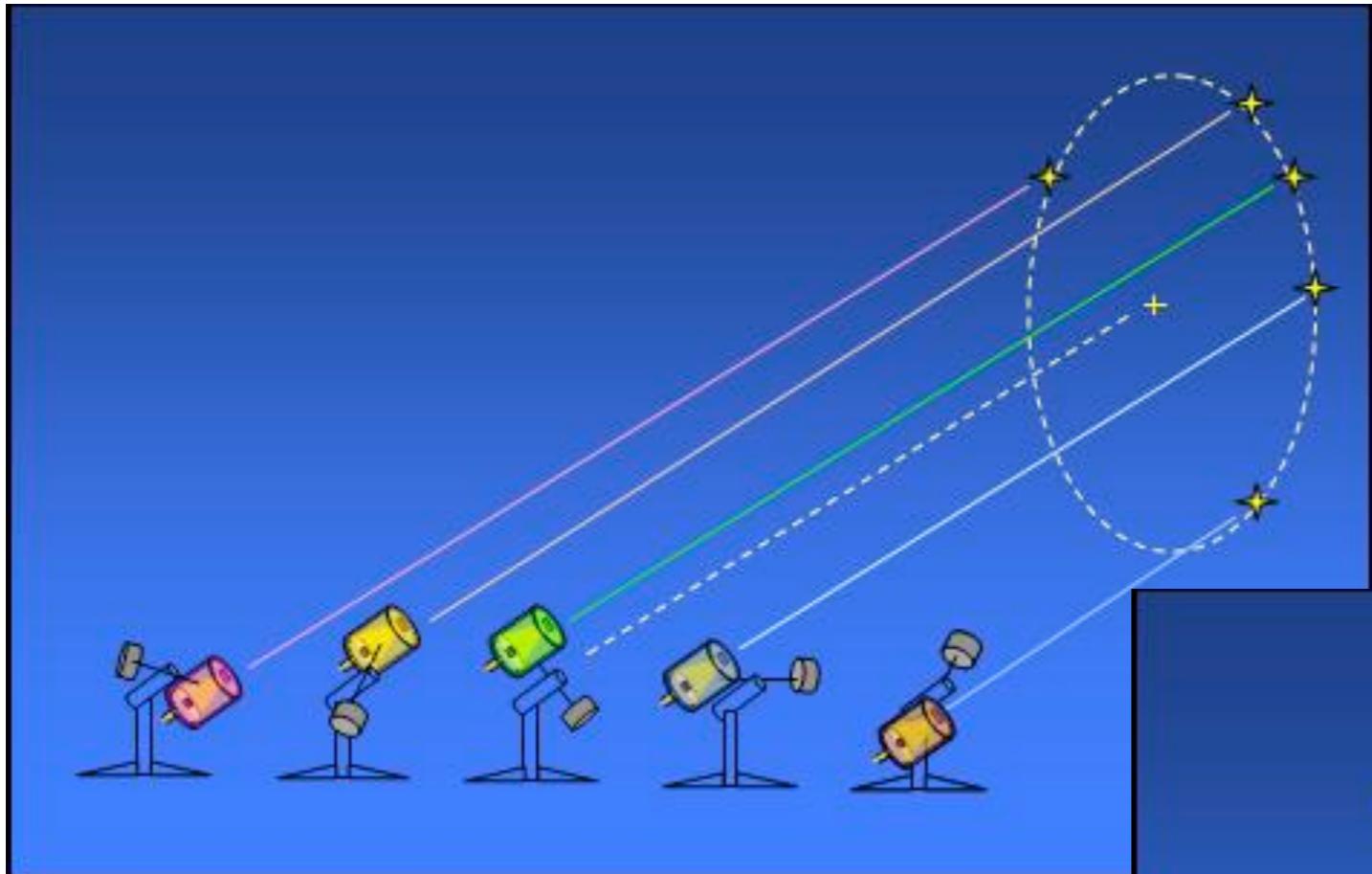
Alt/az mounts: need to track object in two axis, with variable speed

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



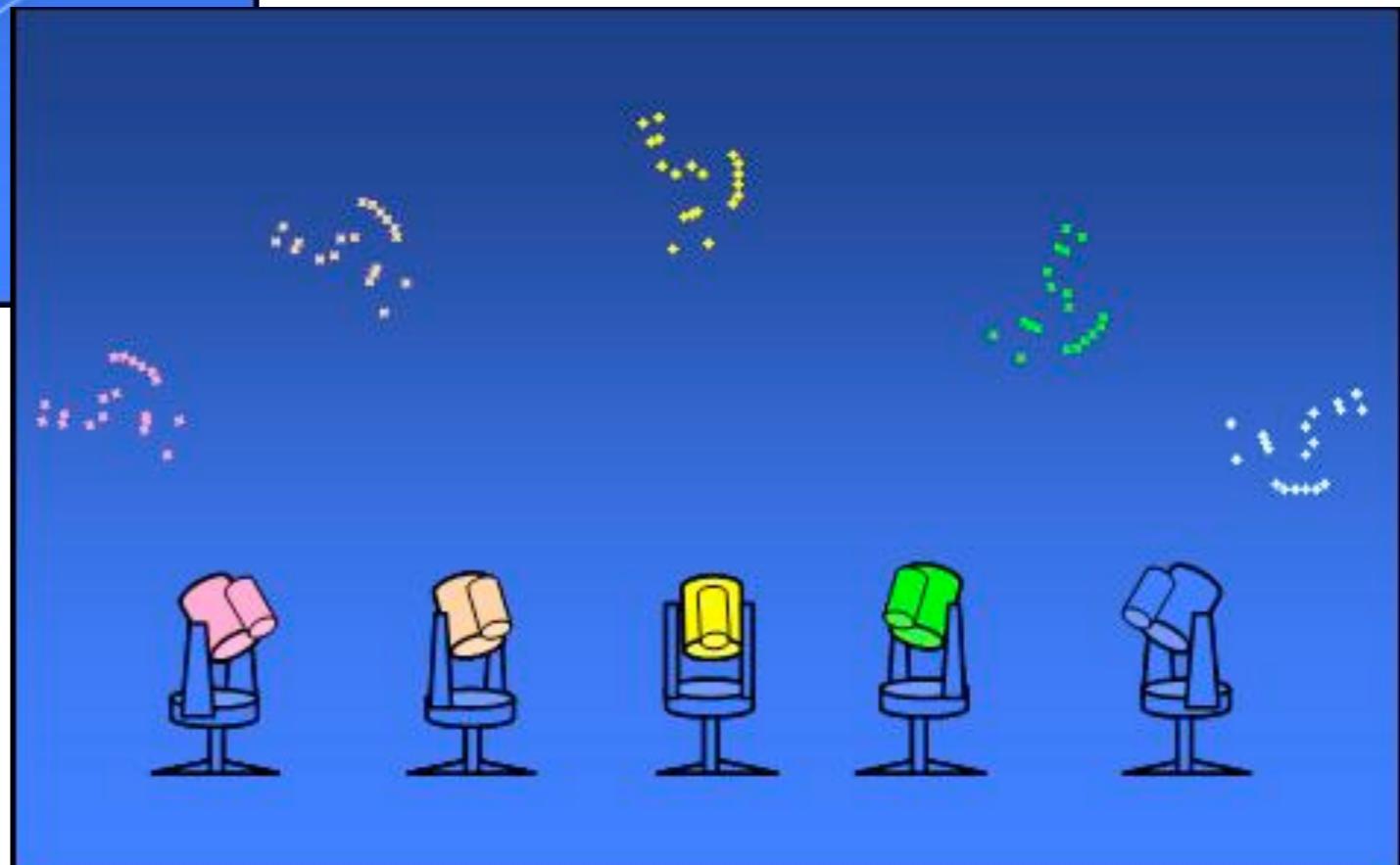
# Equatorial telescope mounts

removes the need for a **field de-rotator**



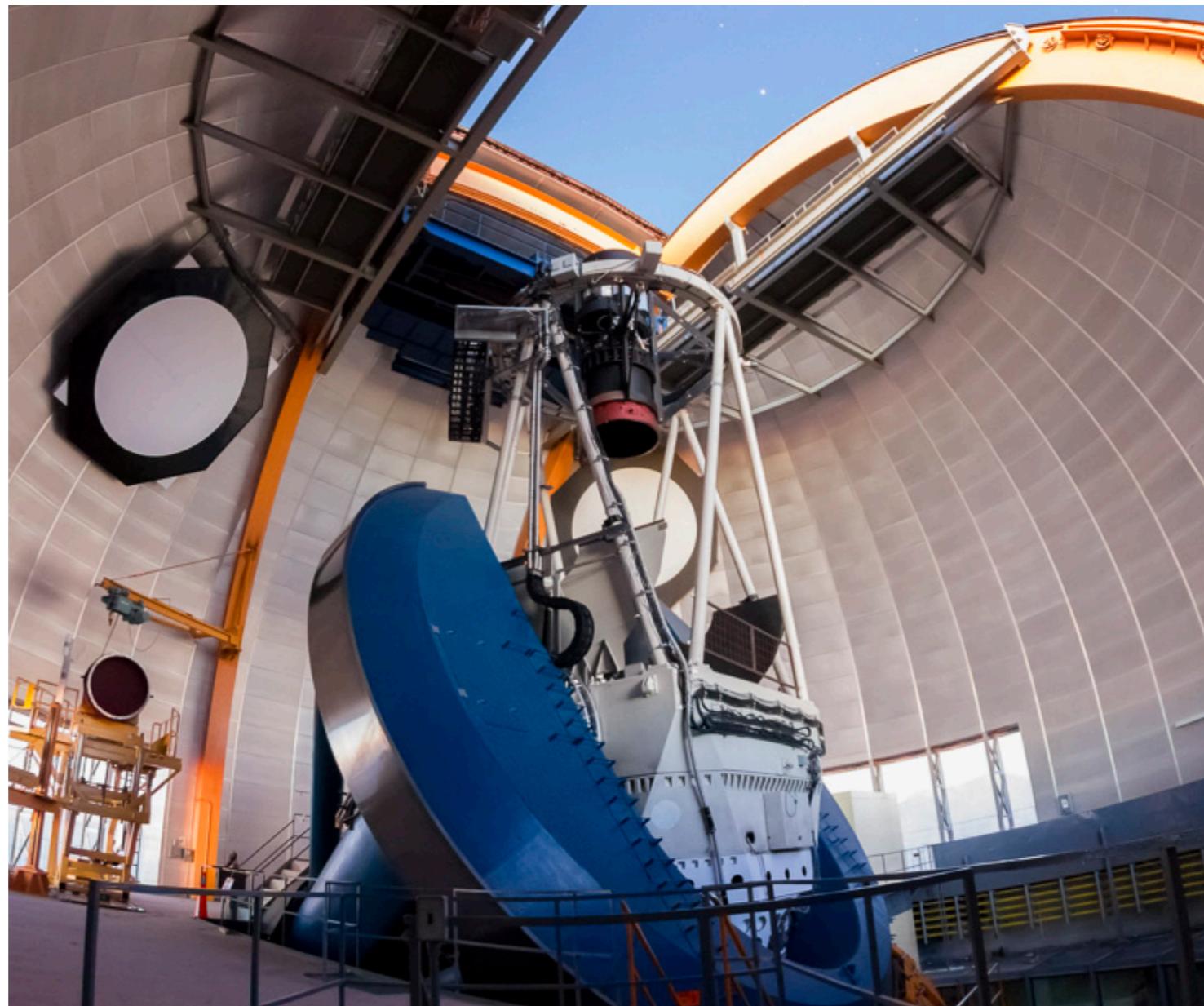
equ. mount

alt/az 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



A. von der Linden



# 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:

$00^{\text{h}}42^{\text{m}}44.33^{\text{s}}, +41^\circ16'07.5''$

$00:42:44.33, +41:16:07.5$

note:  $24^{\text{h}} = 360^\circ$

$1^{\text{h}} = 15^\circ$

$1^{\text{m}} = 15^\circ/60 = 0.25^\circ = 15'$

$1^{\text{s}} = 15^\circ/3600 = 0.25' = 15''$

# Looking up coordinates / information

SIMBAD astronomical database:

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

simbad.u-strasbg.fr/simbad/sim-basic?Ident=AR+Sco&submit=SIMBAD+search

CDSSIMBAD

AR Sco

**other query modes :** Identifier query Coordinate query Criteria query Reference query Basic query Script submission TAP Output options Help

Query : AR Sco C.D.S. - SIMBAD4 rel 1.5.8 - 2016.08.31CEST02:44:42

**Available data :** Basic data • Identifiers • Plot & images • Bibliography • Measurements • External archives • Notes • Annotations

---

**Basic data :** 

**V\* AR Sco -- Variable Star of delta Sct type**

Other object types: V\* (V\*,AN), IR (2MASS,SSTc2d), ds\* ([Ref](#))

**ICRS** coord. (ep=J2000) : 16 21 47.28 -22 53 10.3 (Infrared) [ 60 60 90 ] B [2003yCat.2246....0C](#)

**FK5** coord. (ep=J2000 eq=2000) : 16 21 47.28 -22 53 10.3 [ 60 60 90 ]

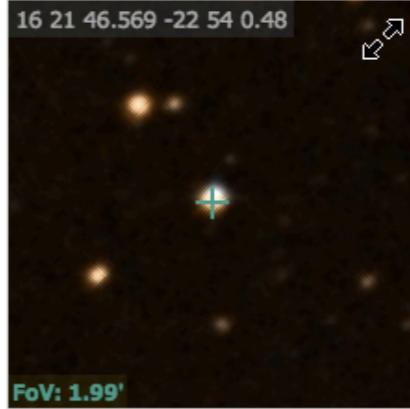
**FK4** coord. (ep=B1950 eq=1950) : 16 18 47.99 -22 46 07.8 [ 60 60 90 ]

**Gal** coord. (ep=J2000) : 353.5192 +18.7121 [ 60 60 90 ]

Fluxes (4) :  
B 14.1 [~] V2 E [2003AstL...29..468S](#)  
J 12.696 [0.027] C [2003yCat.2246....0C](#)  
H 12.080 [0.024] C [2003yCat.2246....0C](#)  
K 11.715 [0.024] C [2003yCat.2246....0C](#)

SIMBAD [query around](#) with radius  arcmin

Interactive AladinLite view  
16 21 46.569 -22 54 0.48



FoV: 1.99'  2MASS  DSS  SDSS

# Looking up coordinates / information

## NASA/IPAC Extragalactic Database (NED)

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

NED results for object MESSIER 031

1 objects found in NED.

SOURCE LIST

Row No.	Object Name (* => Essential Note)	RA	DEC	Object Type	Velocity/Redshift km/s	Mag./z	Separ. Qual Filter arcmin	Number of Refs Notes Phot Posn Vel/z Diam Assoc Images Spectra
1	MESSIER 031	00h42m44.3s	+41d16m09s	G	-300 -0.001001	4.36	...	<a href="#">4055</a> <a href="#">23</a> <a href="#">147</a> <a href="#">20</a> <a href="#">31</a> <a href="#">7</a> <a href="#">2 Retrieve</a> <a href="#">Retrieve</a>

Detailed information for each object

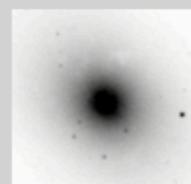
Object No. 1 - MESSIER 031

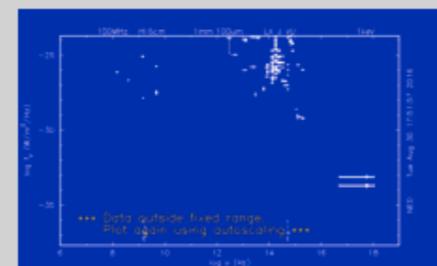
INDEX for MESSIER 031

Essential Data (jump to sub-section of this query report):

- [Essential Note](#)
- [Cross-IDs](#)
- [Coordinates](#)
- [Basic Data](#)
- [Quantities Derived from Redshift](#)
- [Redshift-Independent Distances](#)
- [Quick-Look Photometry and Luminosities](#)
- [Quick-Look Angular and Physical Sizes](#)
- [Classifications](#)
- [Foreground Galactic Extinction](#)
- [External Services](#)

Detailed Data (NED queries):

 [Images](#)

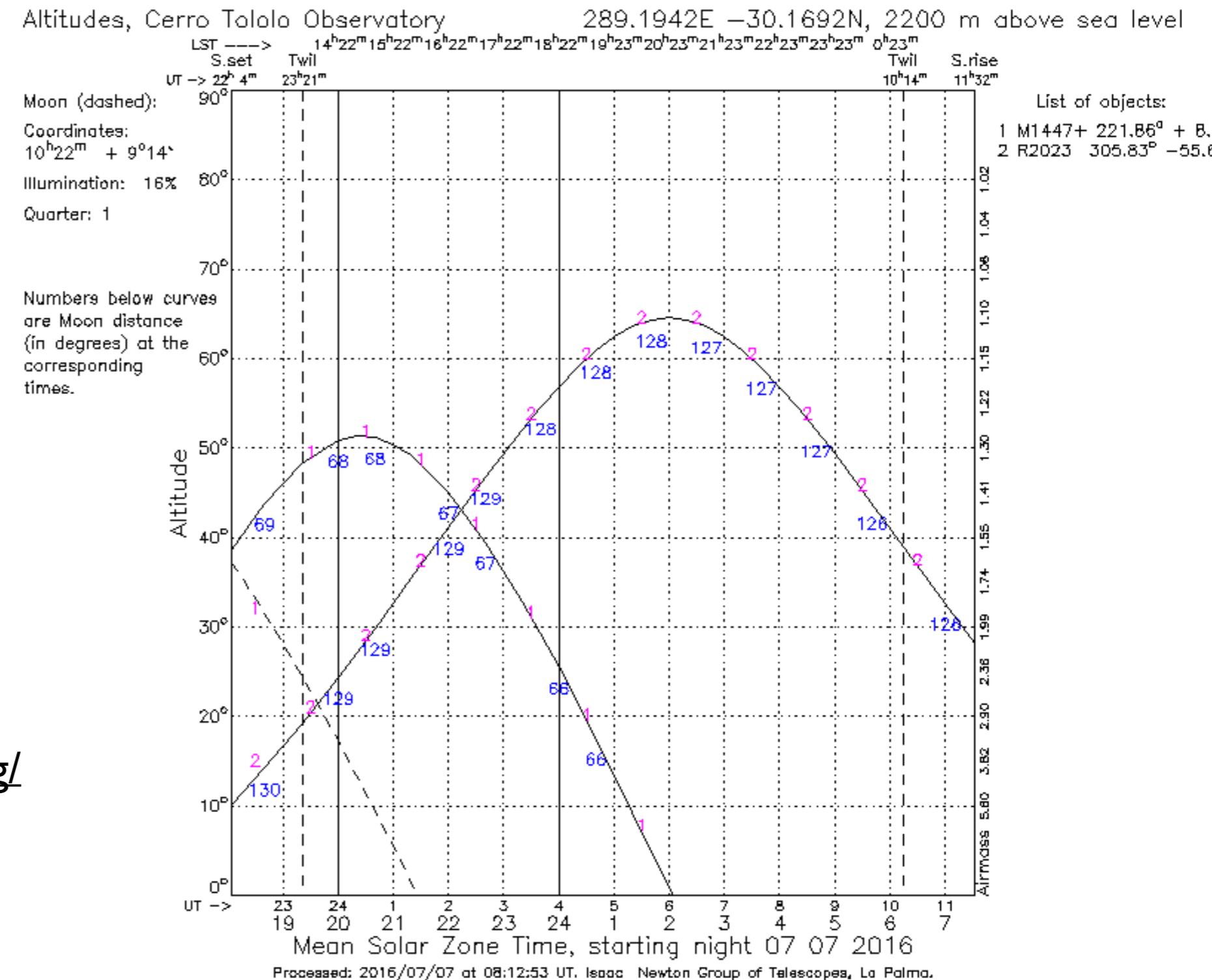
 [147 Photometric data point\(s\) and SED](#)

Spectra  
[Redshift-Independent Distances](#)  
[4055 Reference\(s\)](#)  
[20 Position data point\(s\)](#)  
[31 Redshift data point\(s\)](#)  
[7 Diameter data point\(s\)](#)  
[23 Note\(s\)](#)  
[2 Association\(s\)](#)  
[UGC data](#)  
[RC3 data](#)

# 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)

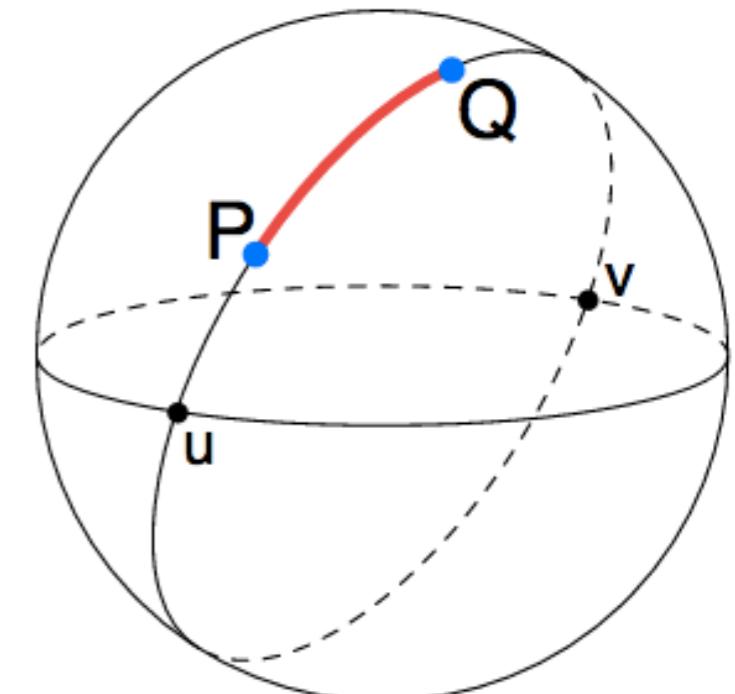


# Distance between two objects

two objects at  $(\alpha_1, \delta_1)$  and  $(\alpha_2, \delta_2)$  - 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

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

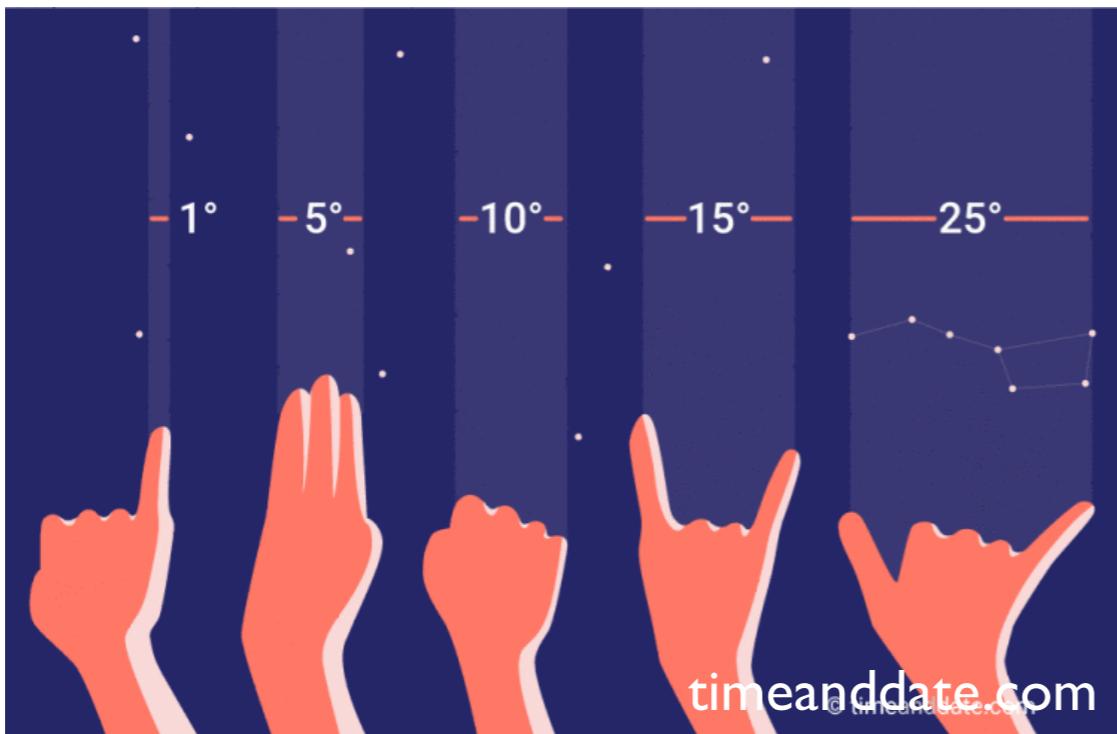
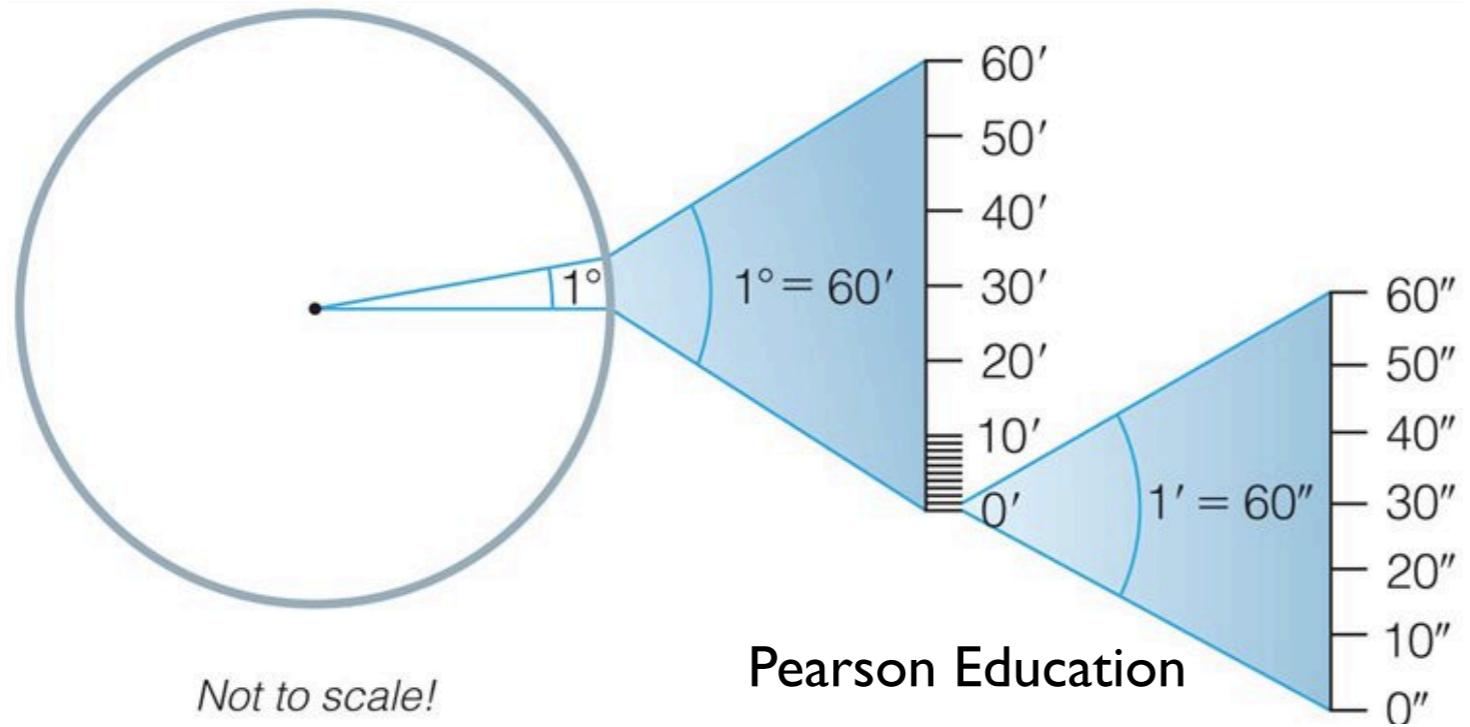


for small distances, can use Euclidian approximation;  
HOWEVER, need to include  $\cos(\delta)$

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

# Lengths and distances on the Sky

usually given in degrees ( $^{\circ}$ ), arcminutes ( $'$ ), arcseconds ( $''$ )

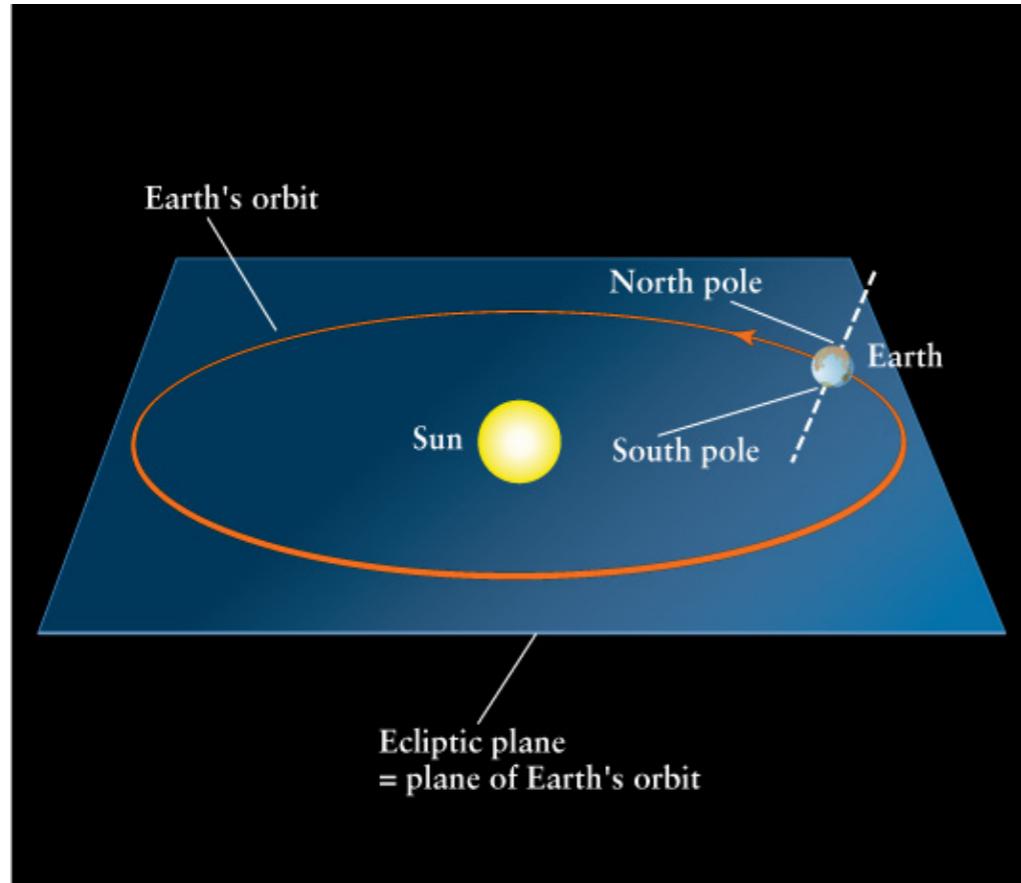


Moon: diameter is  
 $\sim 0.5^{\circ} = 30'$

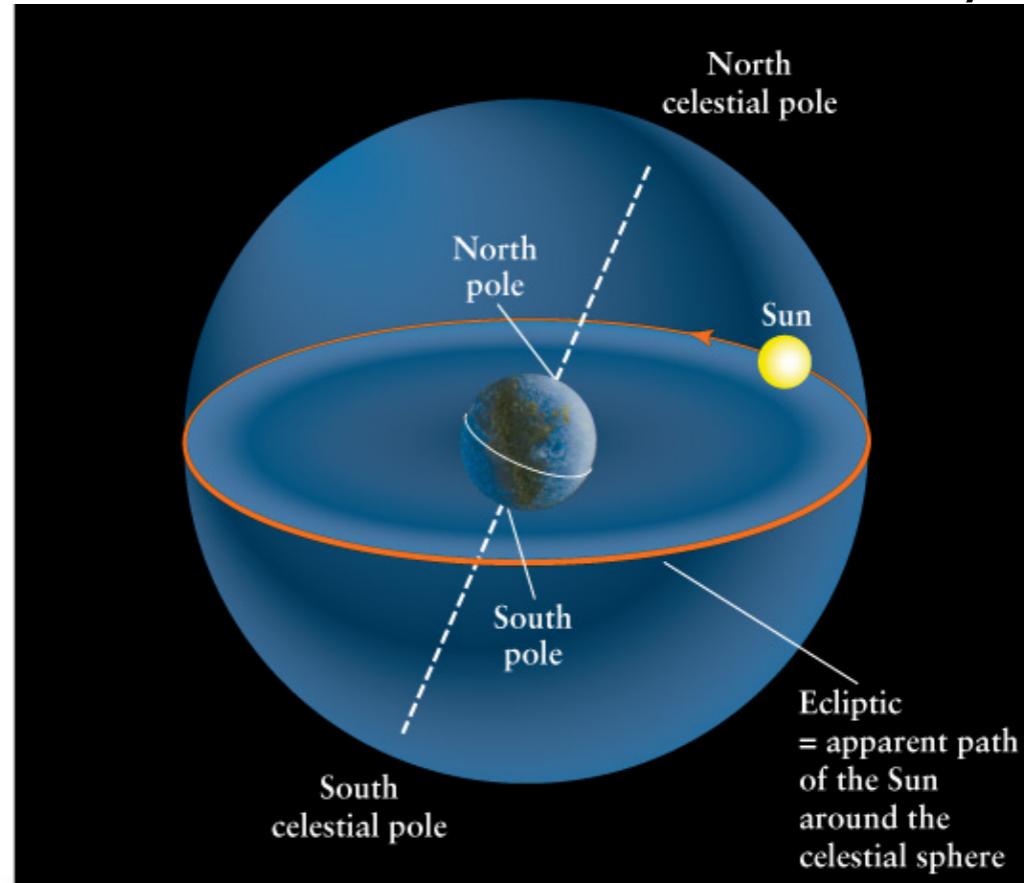


# Motion of the Sun in the Sky

Bailey, Slater & Slater



(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**

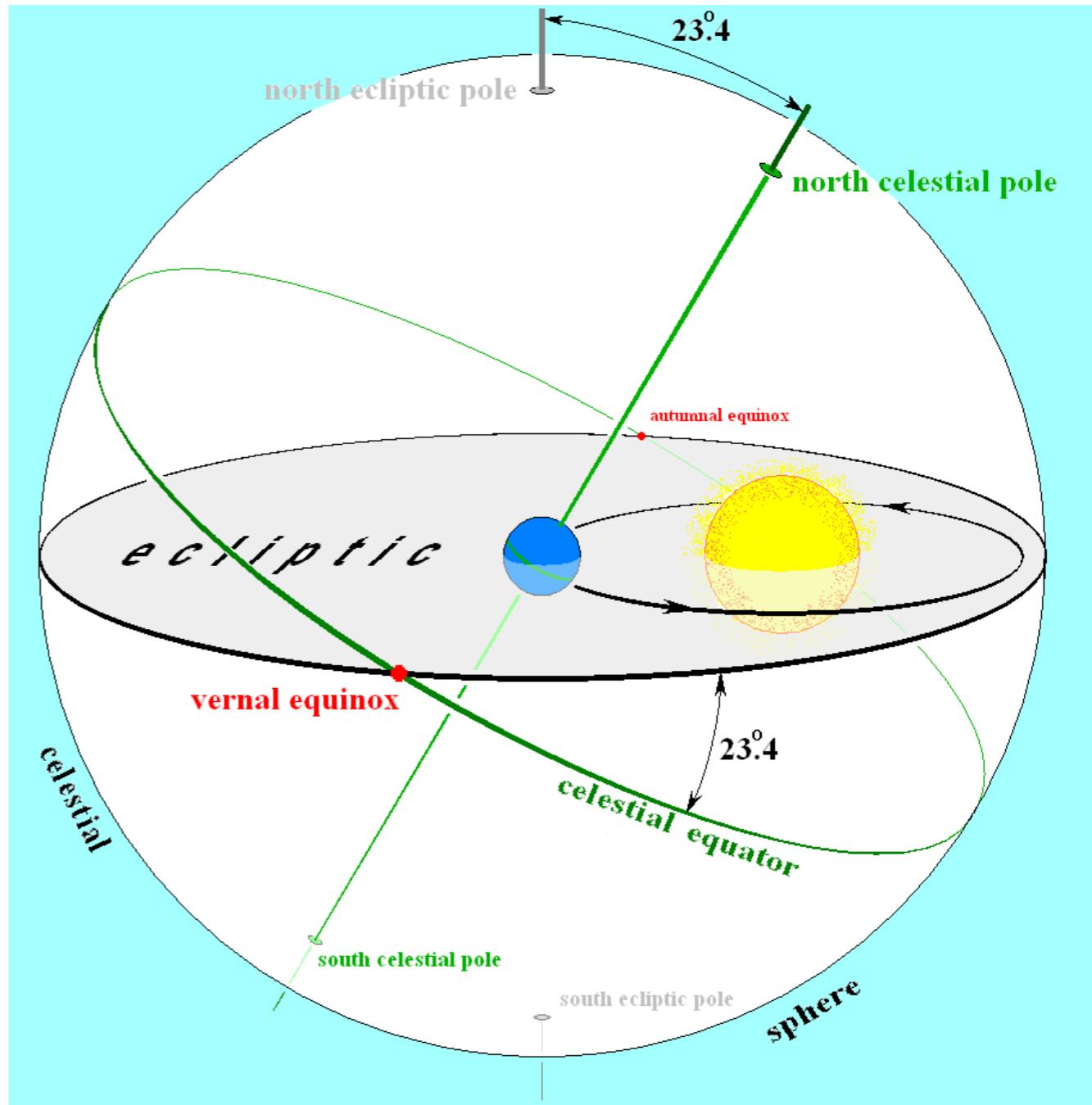
Earth's axis is tilted with respect to its orbit → the ecliptic is **NOT** the same as the celestial equator

# 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

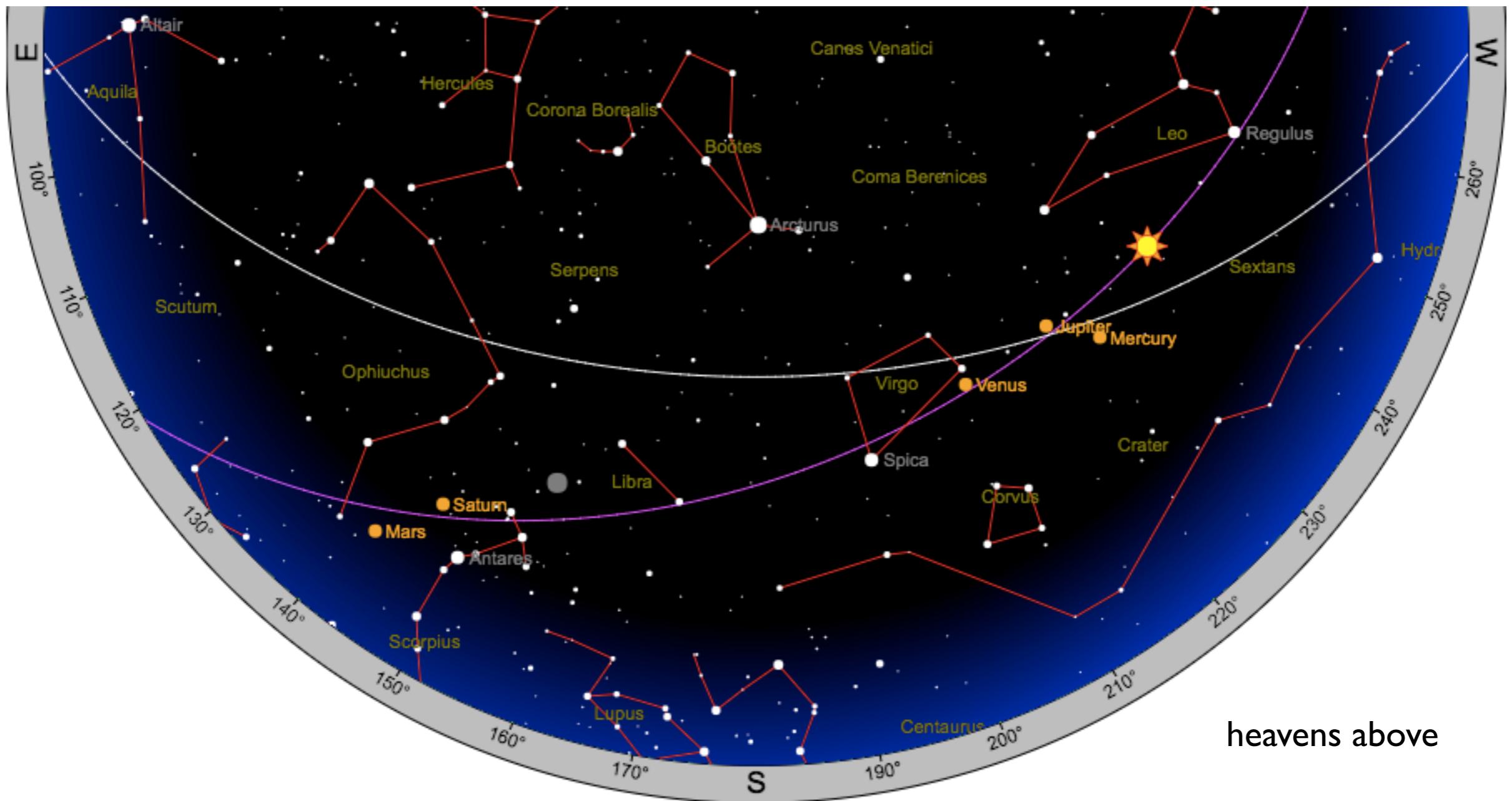


wikipedia

# Other Solar System objects

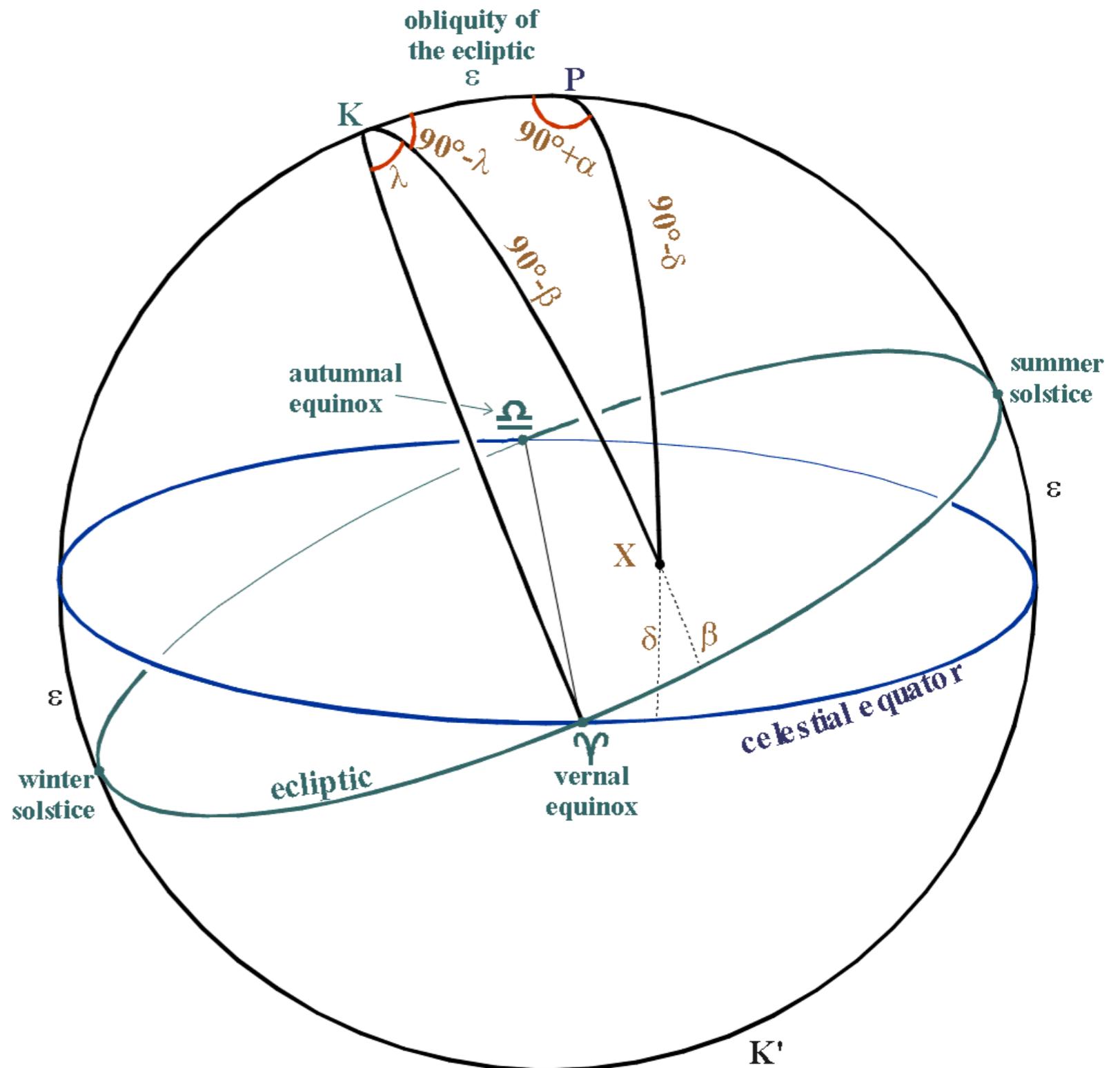
the orbital planes of most planets (and moons) are similar to Earth's orbital plane

→ Moon and planets also approximately follow the ecliptic



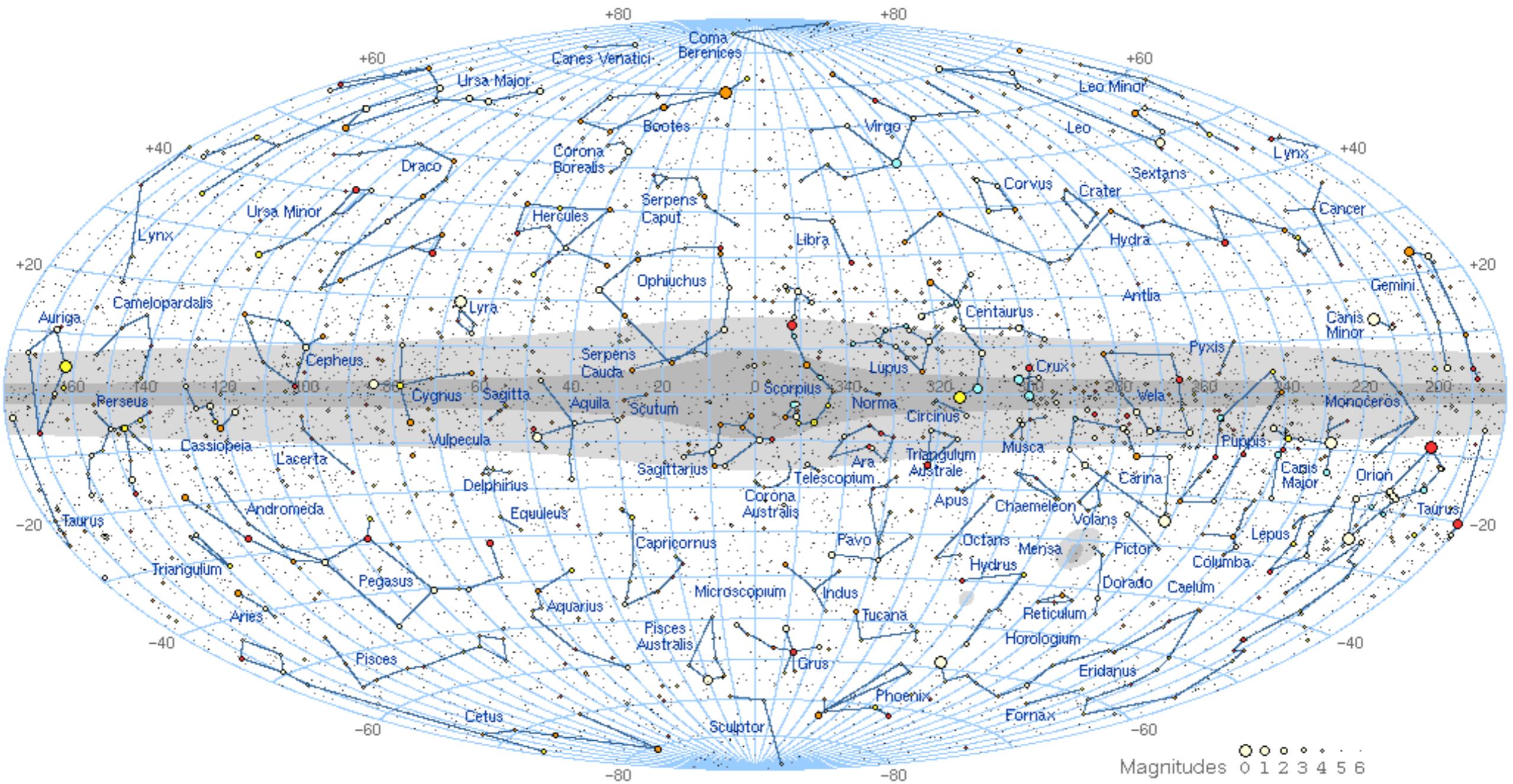
# Ecliptic coordinates

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  
 $(\alpha, \delta)$  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

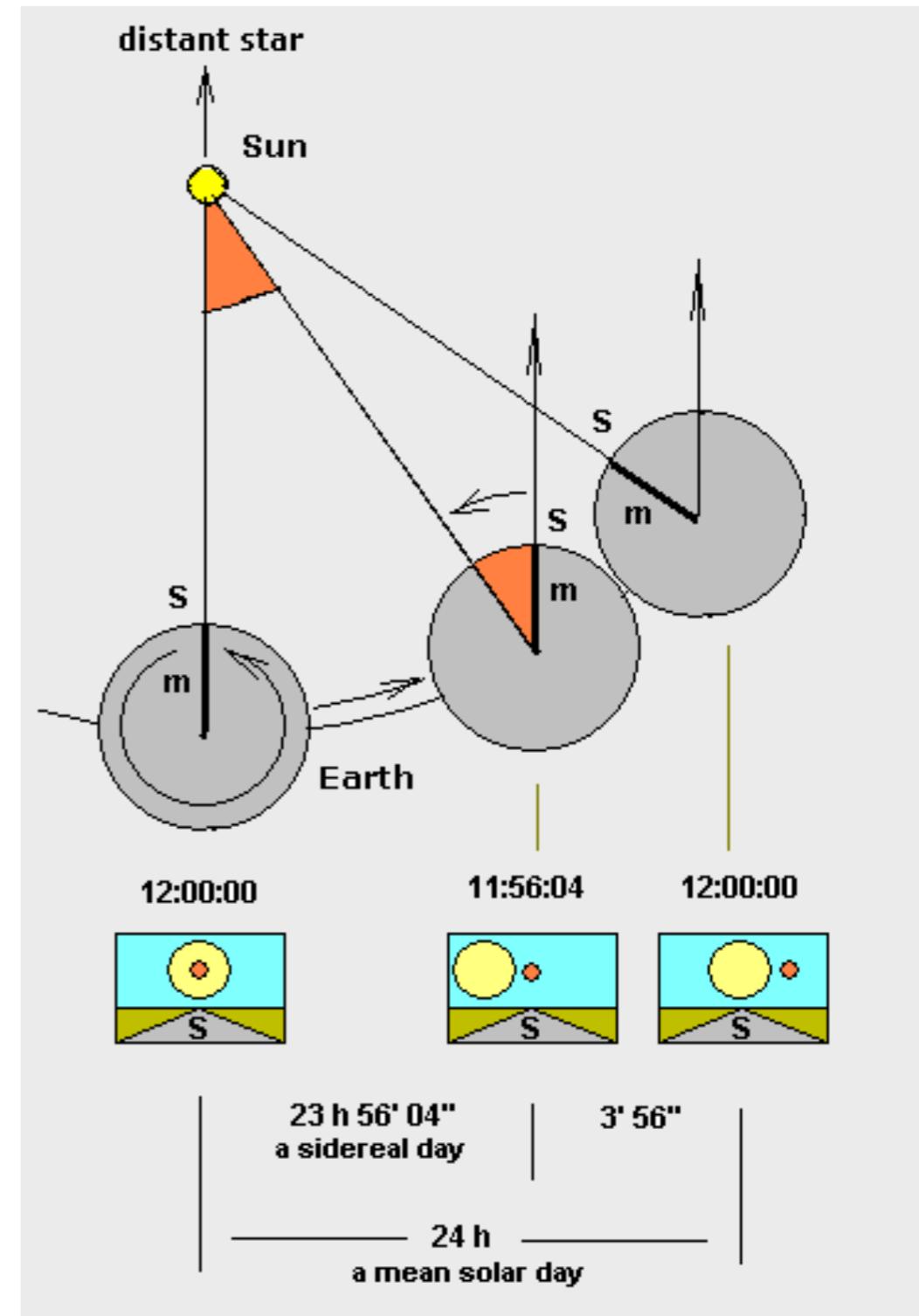
“sidereal” = “of the stars”

**sidereal time:** defined with respect to the stars

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

same sky is overhead after 23h 56min

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

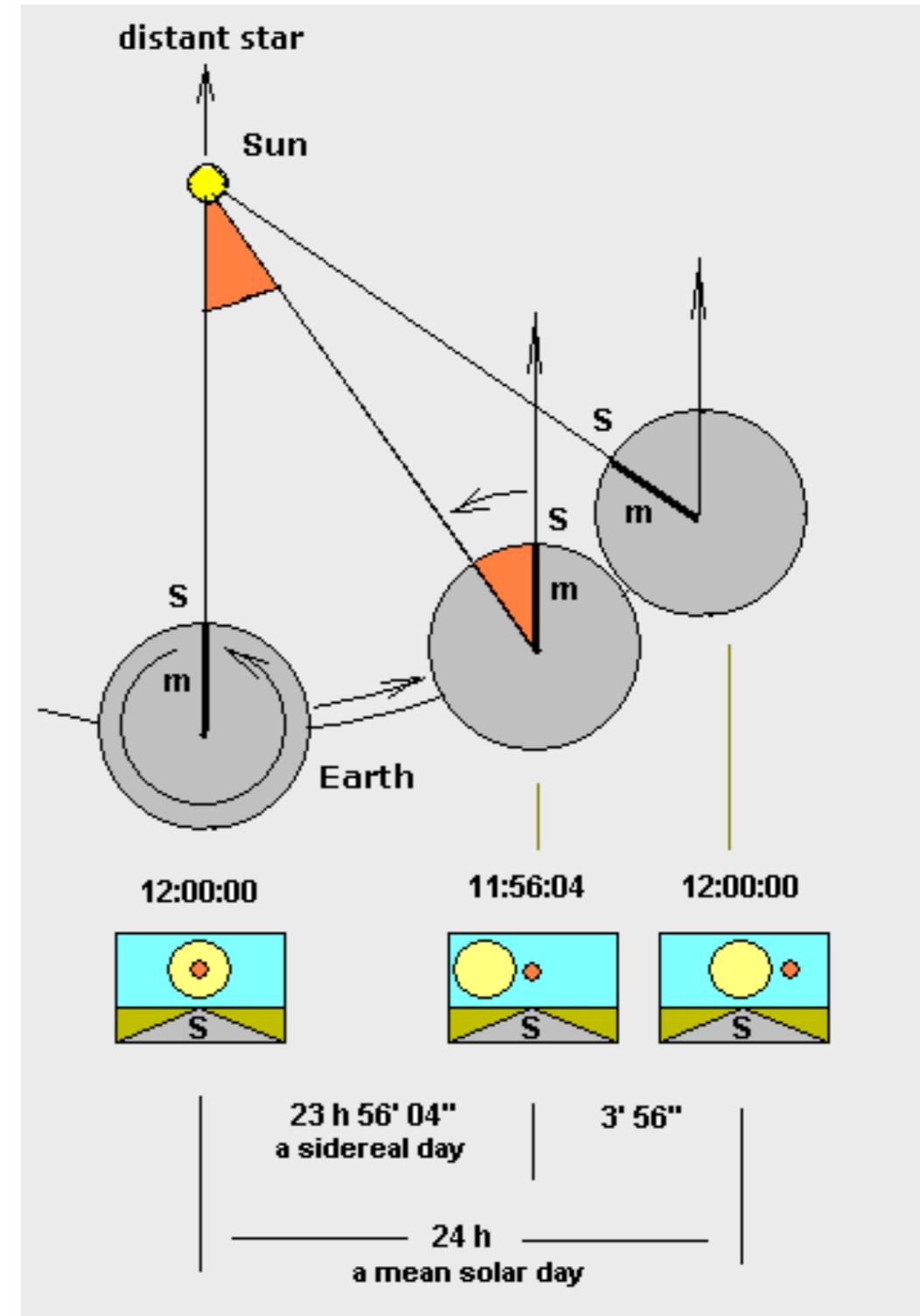


# This means...

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 culminate 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  $0^\circ$  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
APPROXIMATE_DATE = 2013-06-15T23:47:58.454694
```

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):  $MJD = JD - 2400000.5$

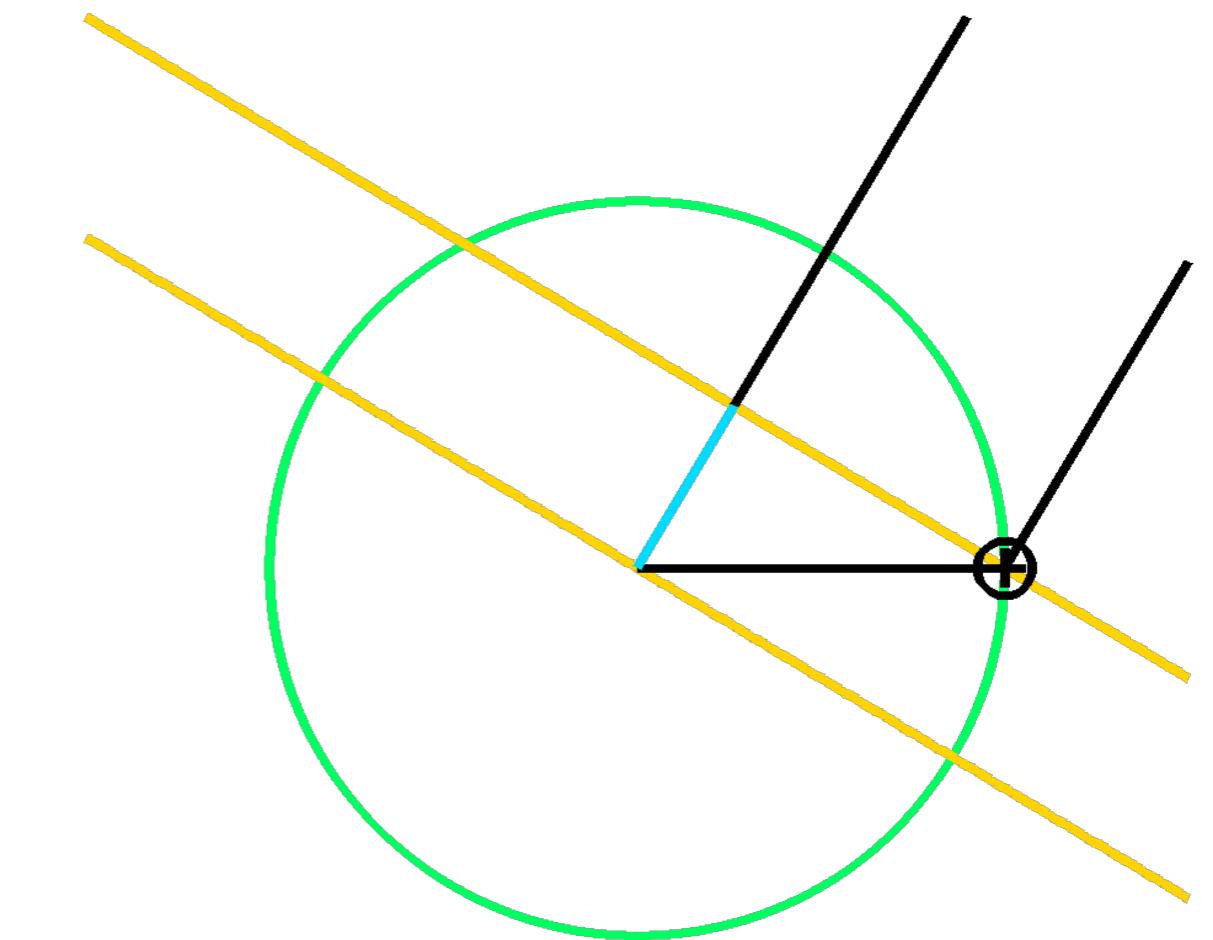
<http://aa.usno.navy.mil/data/docs/JulianDate.php>

# 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



J. Eastman

# Epochs

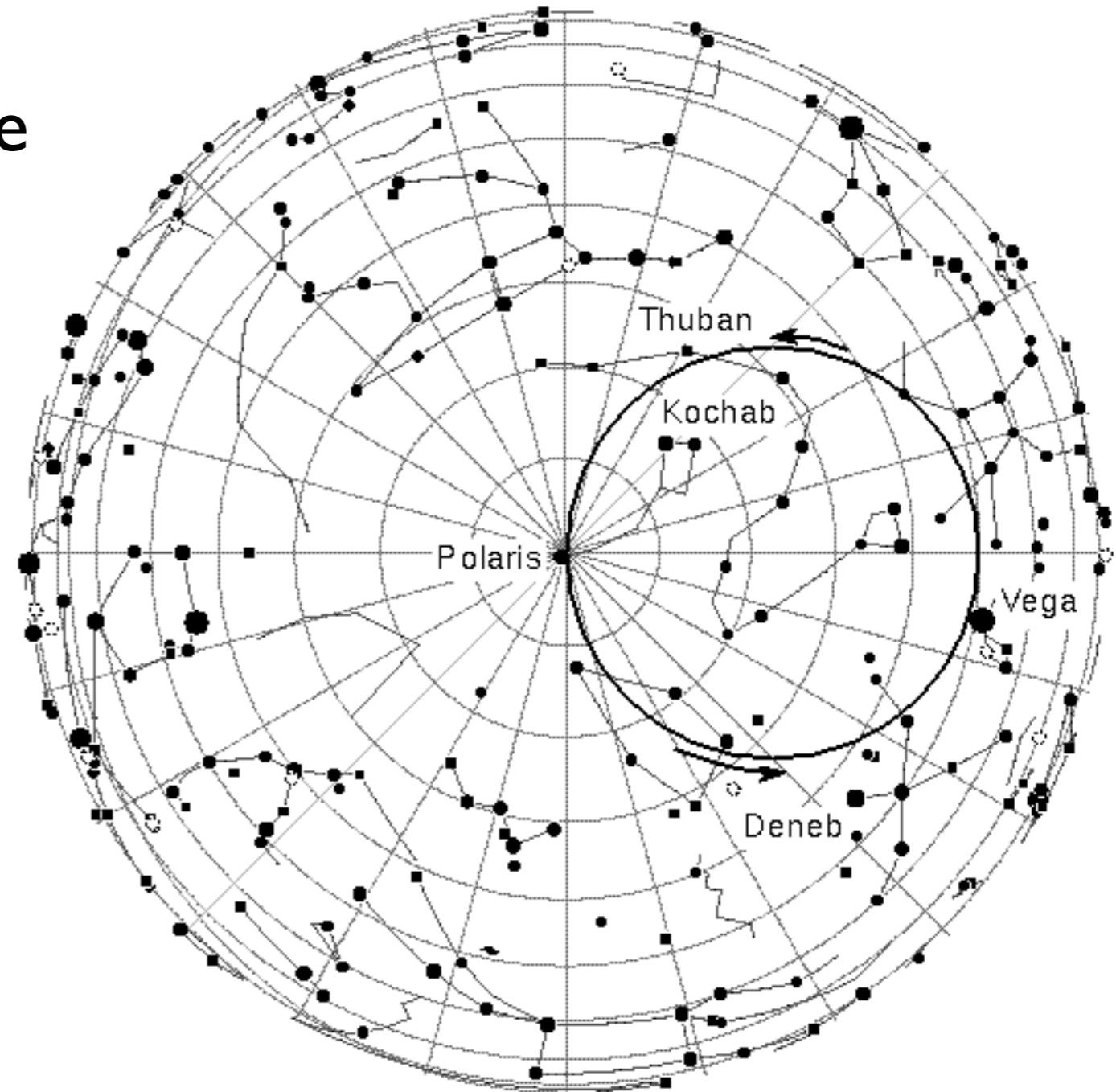
Earth's rotation axis is not constant in space with time

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

All coordinates need to be 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.