PHY 517 / AST 443:
Observational Techniques in Astronomy

Lecture 2:
Coordinate Systems (cont'd) /
Time /
Flux and magnitude /
Earth's atmosphere

Course webpage

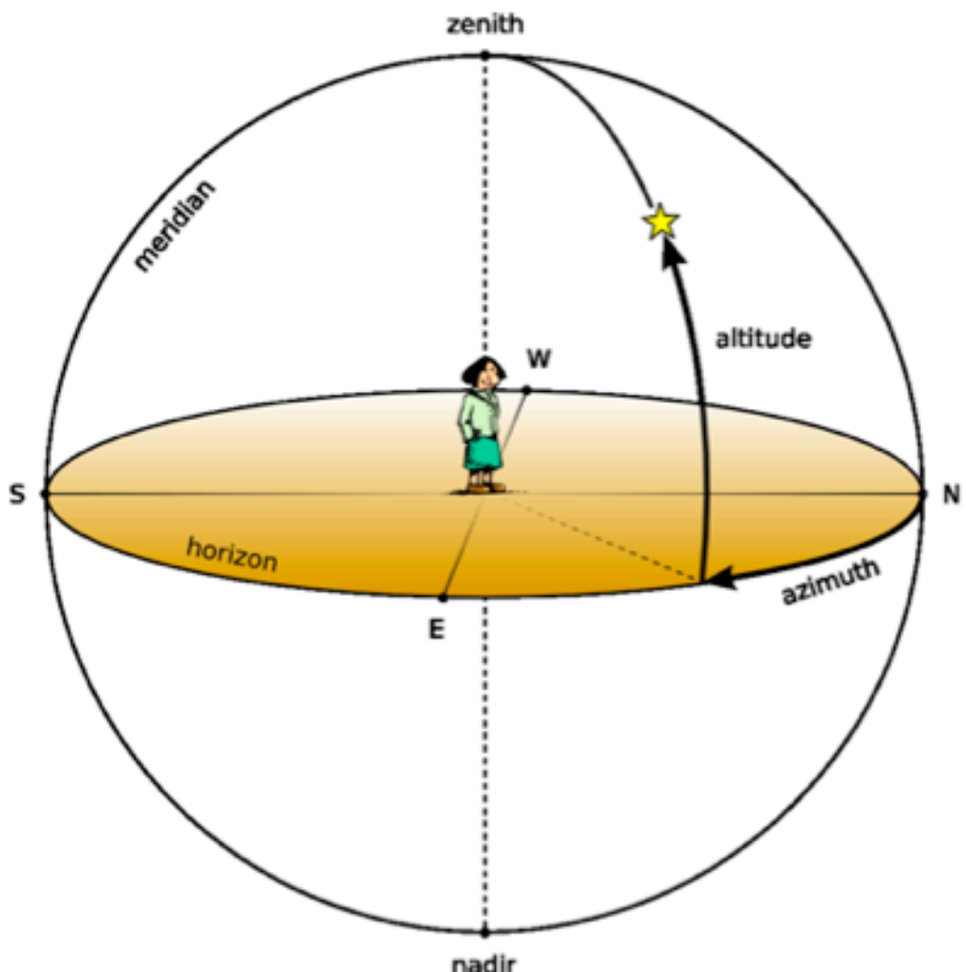
http://www.astro.sunysb.edu/anja/PHY517_AST443/

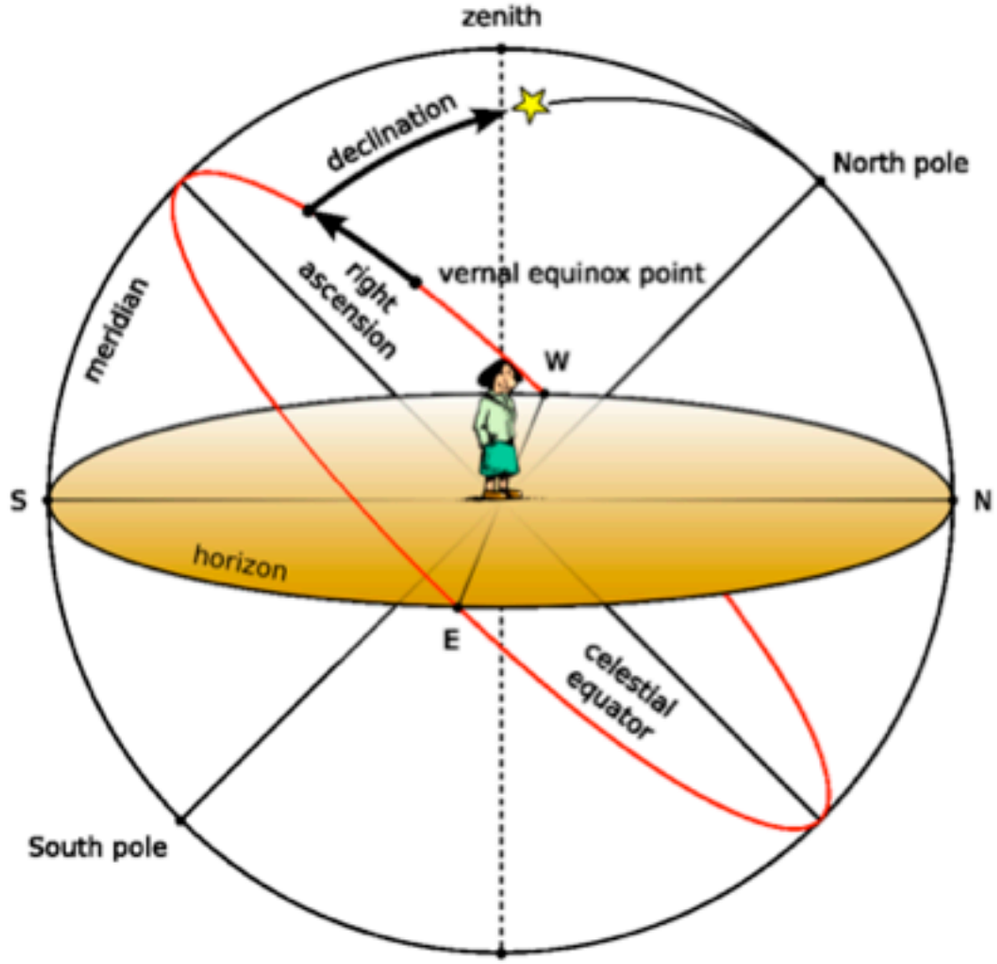
(might change to something more modern...)

Last time...

positions on a sphere can be described with 2 angular coordinates:

Earth: latitude and longitude
Observatory: altitude and azimuth
Sky: right ascension and declination





Last time...

the equatorial coordinate system (R.A. and Dec.) is fixed to the Sky, and rotates with the Sky

on sky maps, East is left when North is up (because you're looking up, not down)

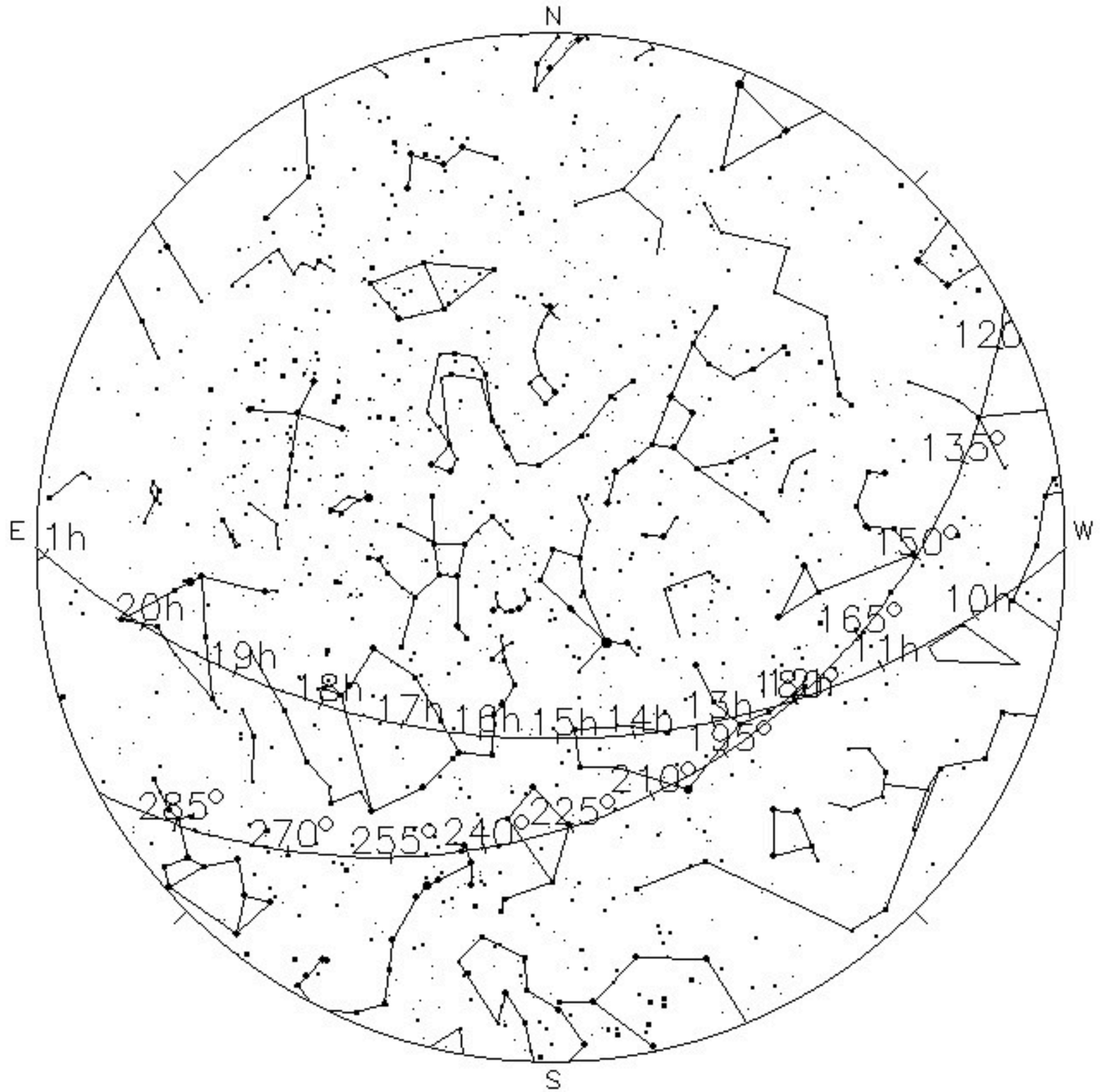
the sky "moves" East to West

R.A. is defined by time intervals between passing the meridian - it runs right to left on sky maps

Last time...

local sidereal time:
R.A. of the objects
on the meridian

hour angle:
distance in R.A. to
the meridian



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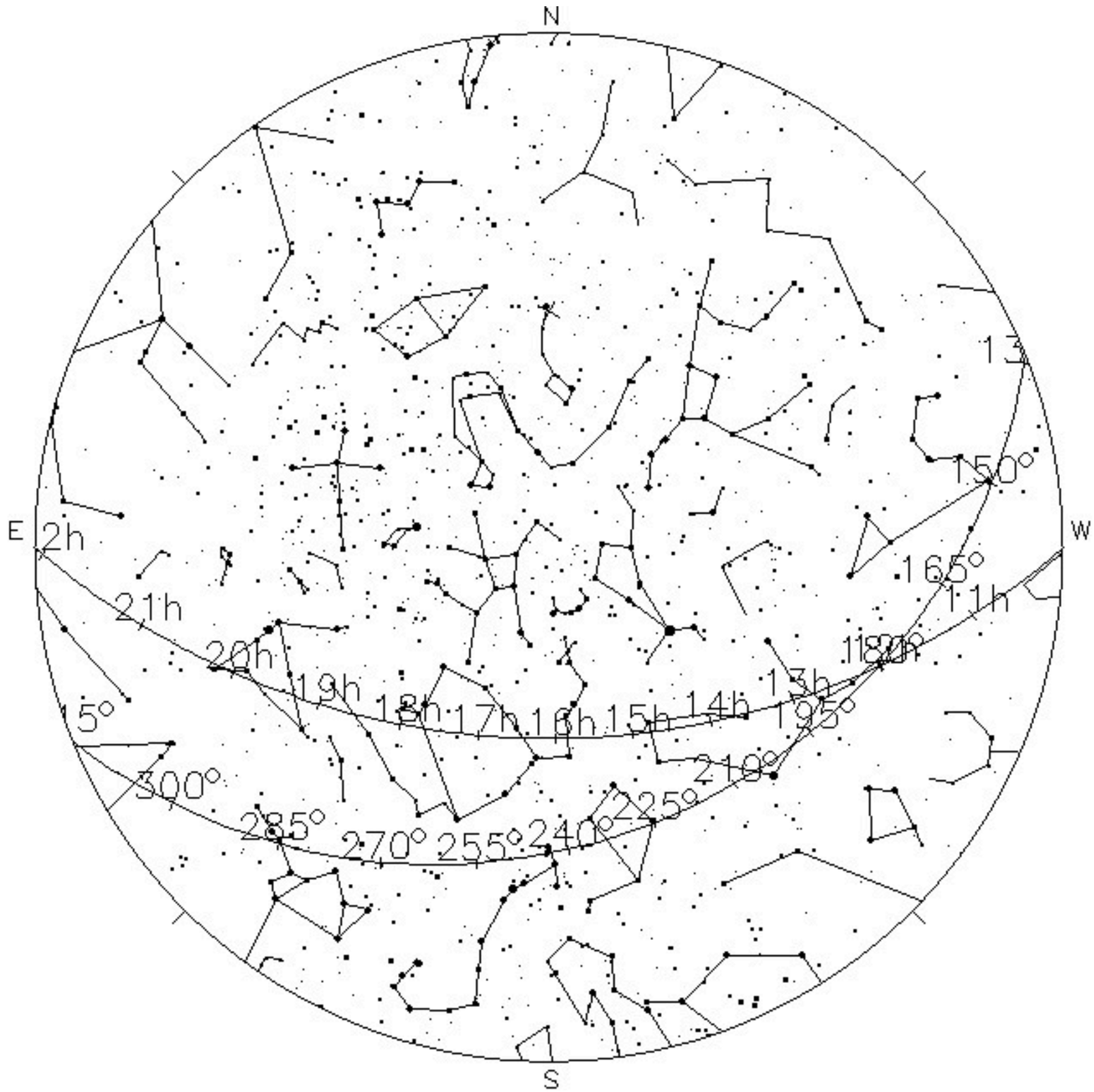


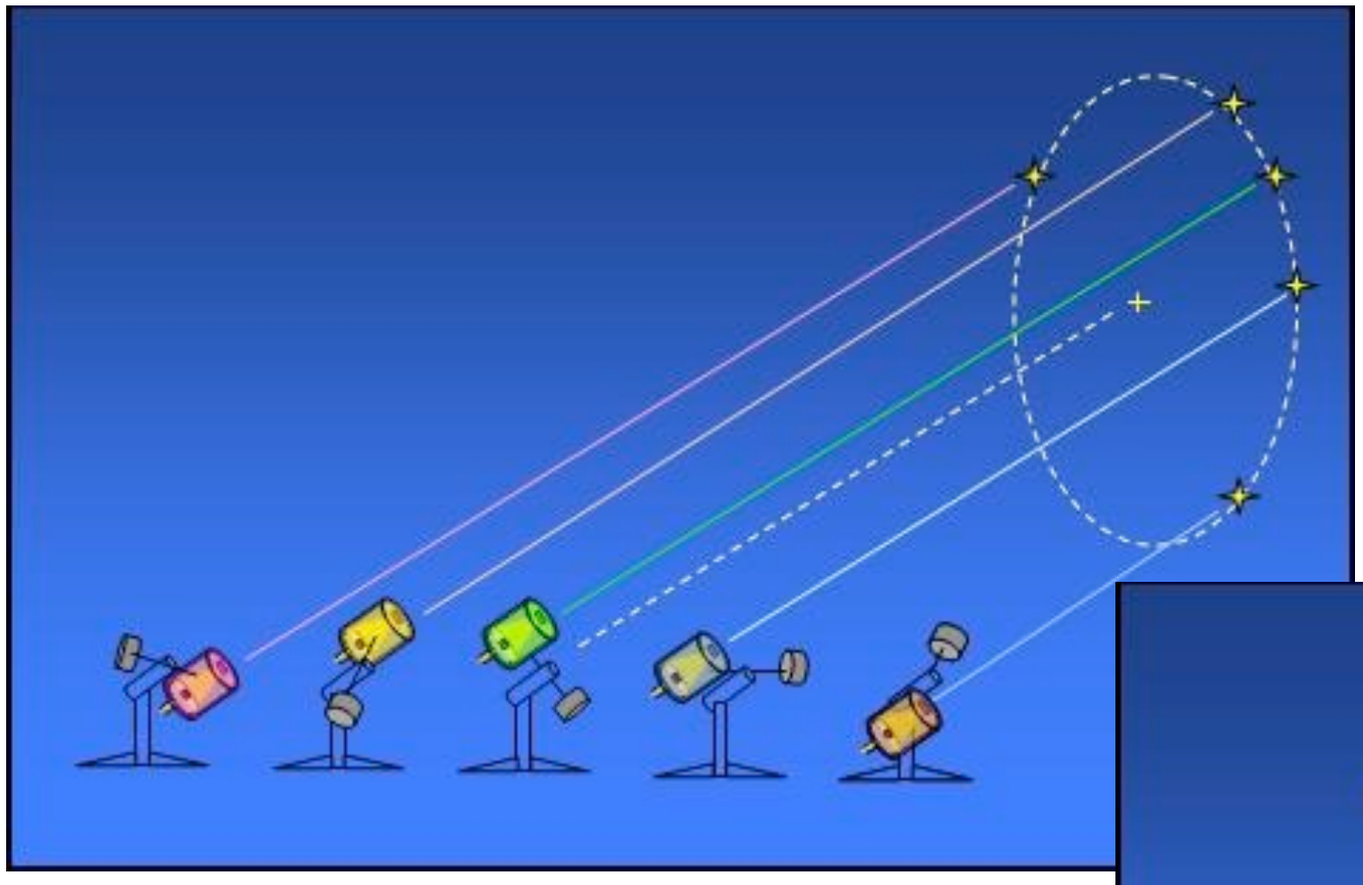
Equatorial telescope mounts

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

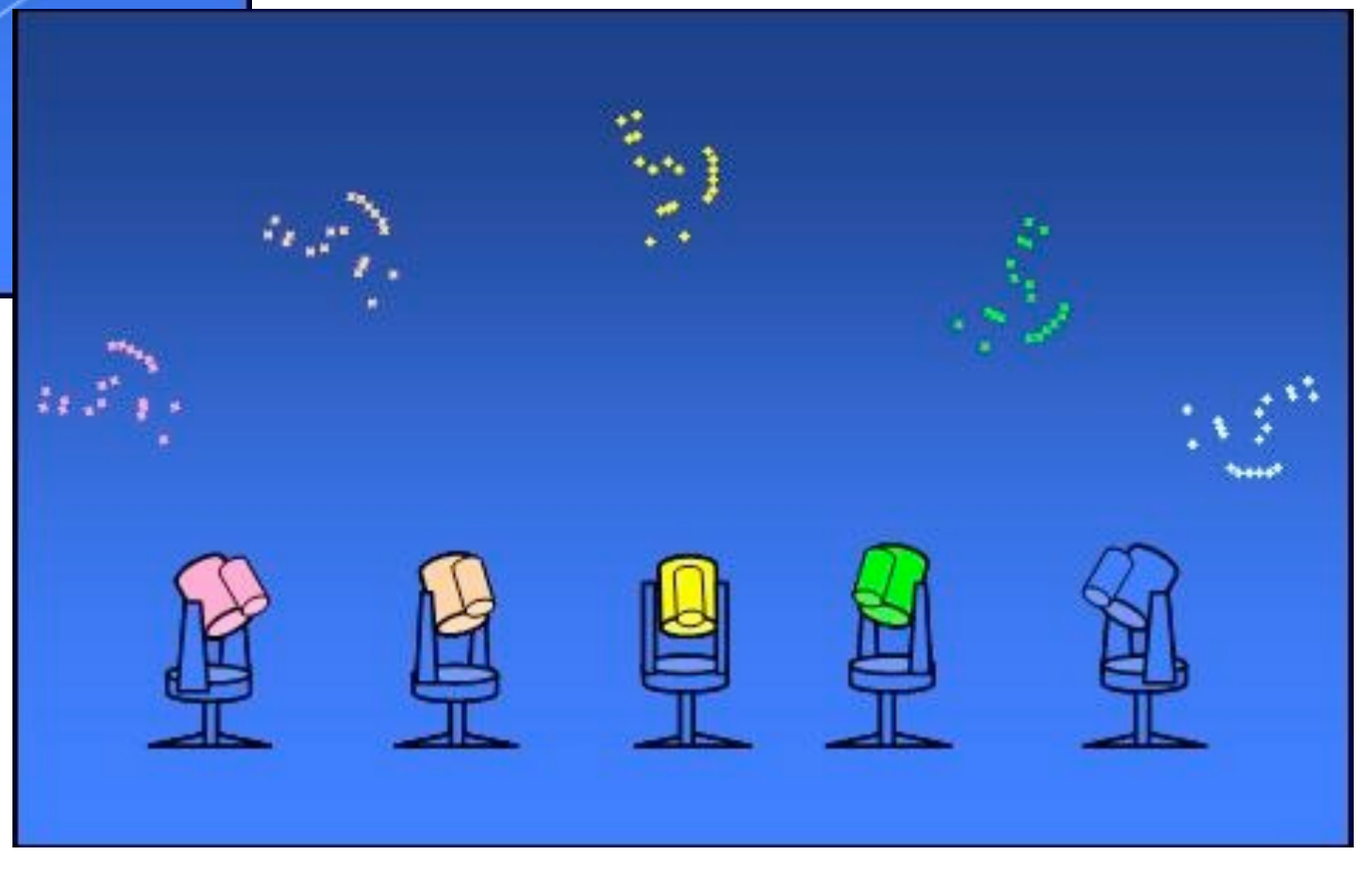
Equatorial telescope mounts

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

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:

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

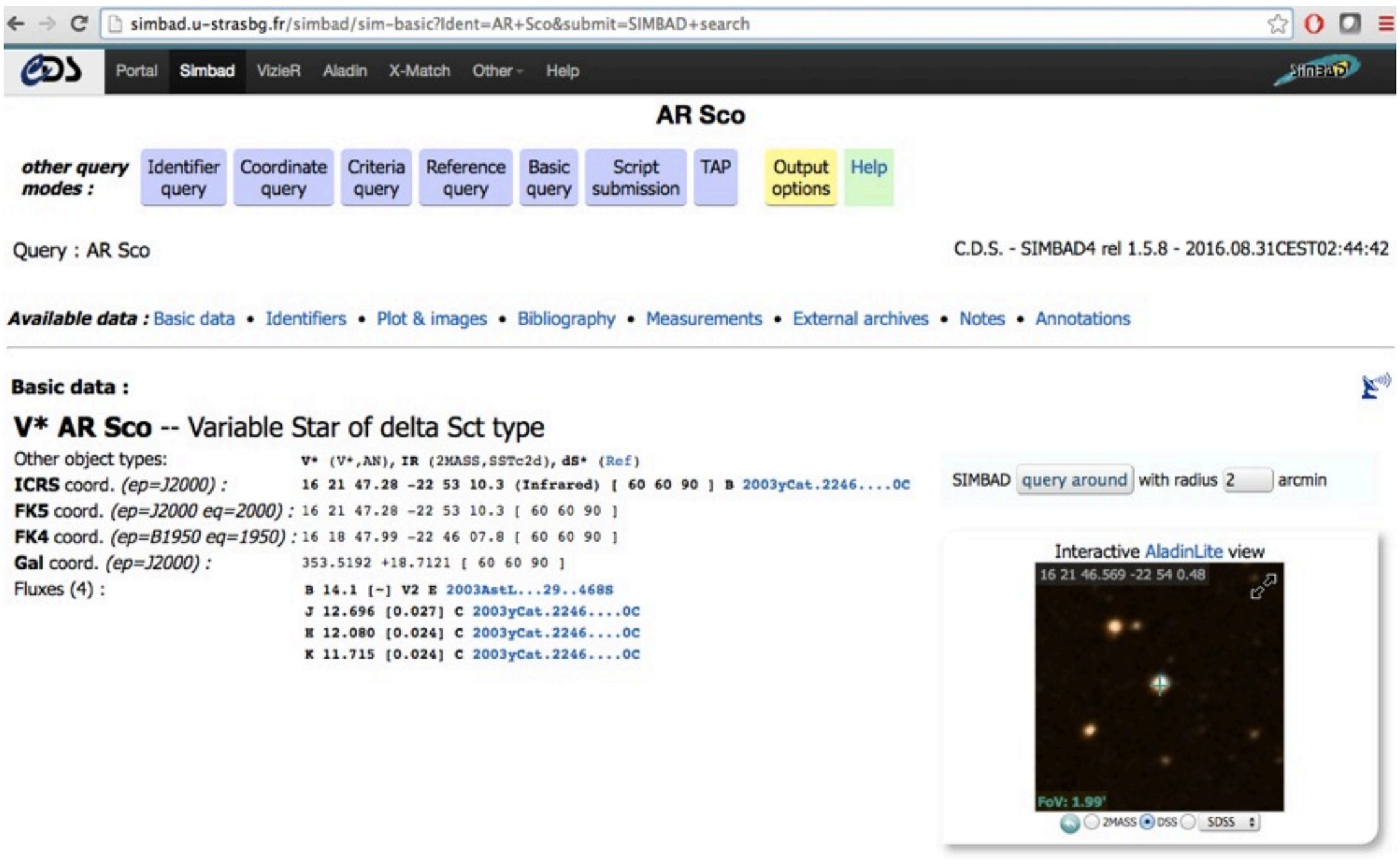
note:

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

Looking up coordinates / information

SIMBAD astronomical database:

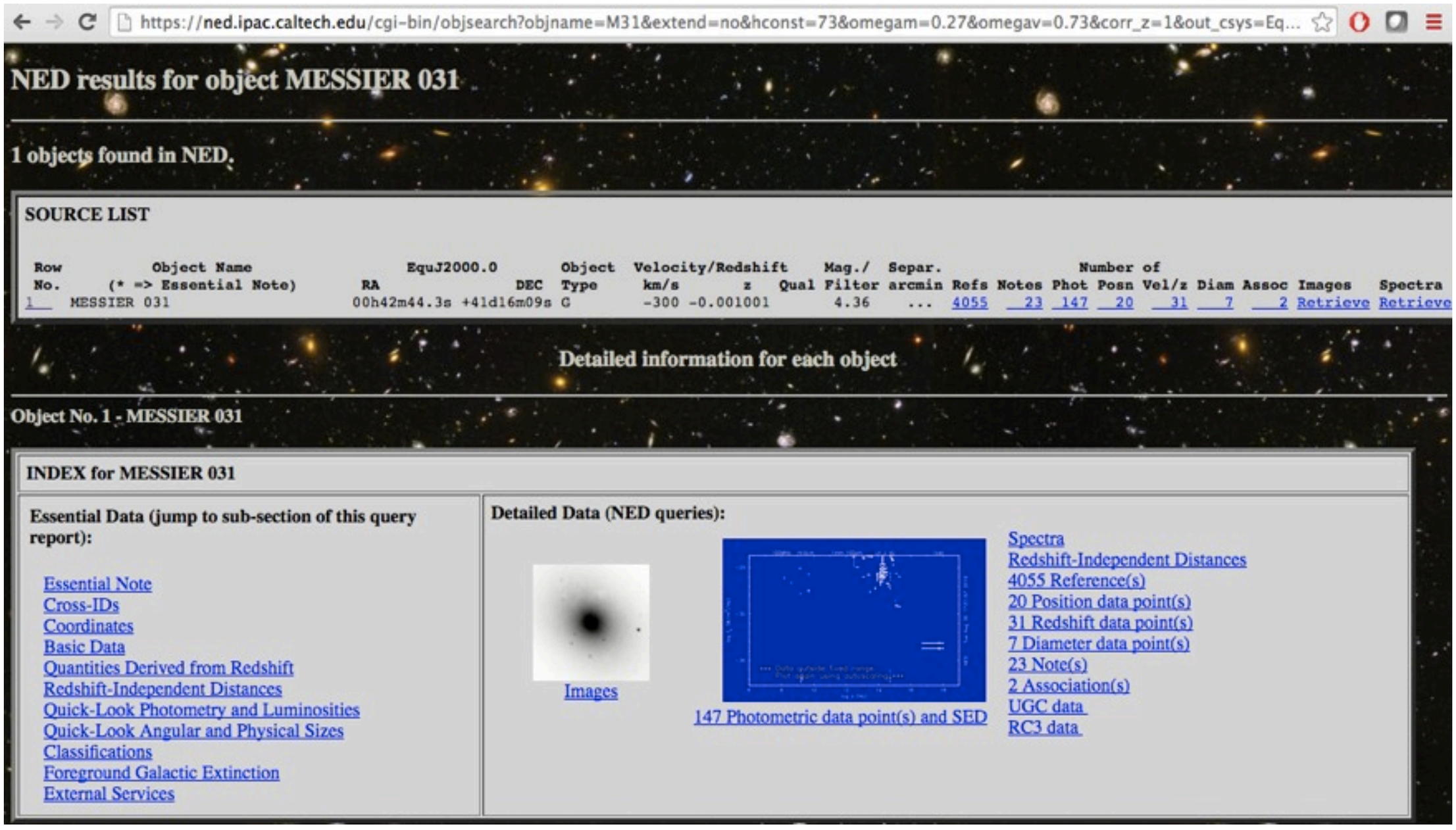
http://simbad.u-strasbg.fr/simbad/



Looking up coordinates / information

NASA/IPAC Extragalactic Database (NED)

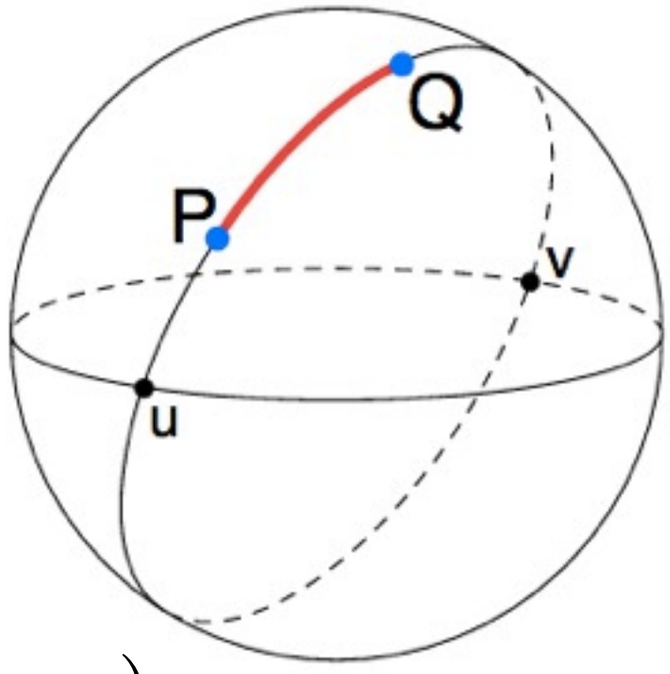
https://ned.ipac.caltech.edu/



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˚
- need to use spherical geometry



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

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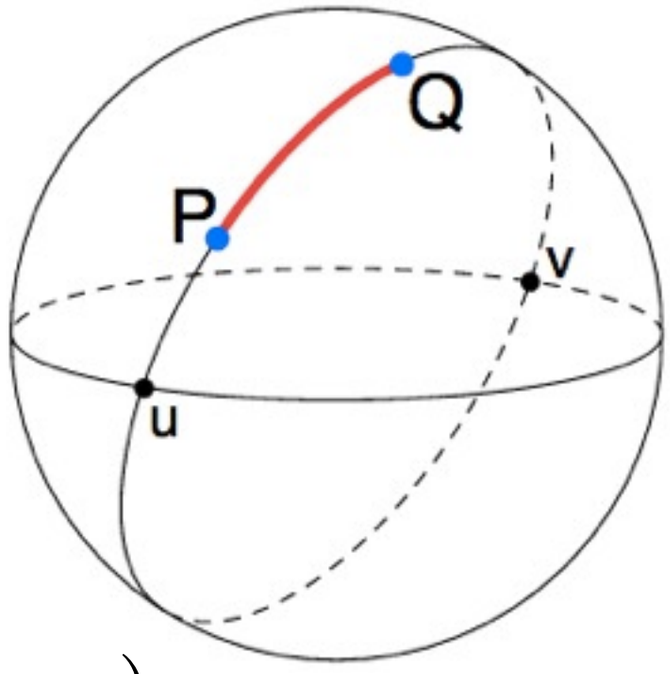


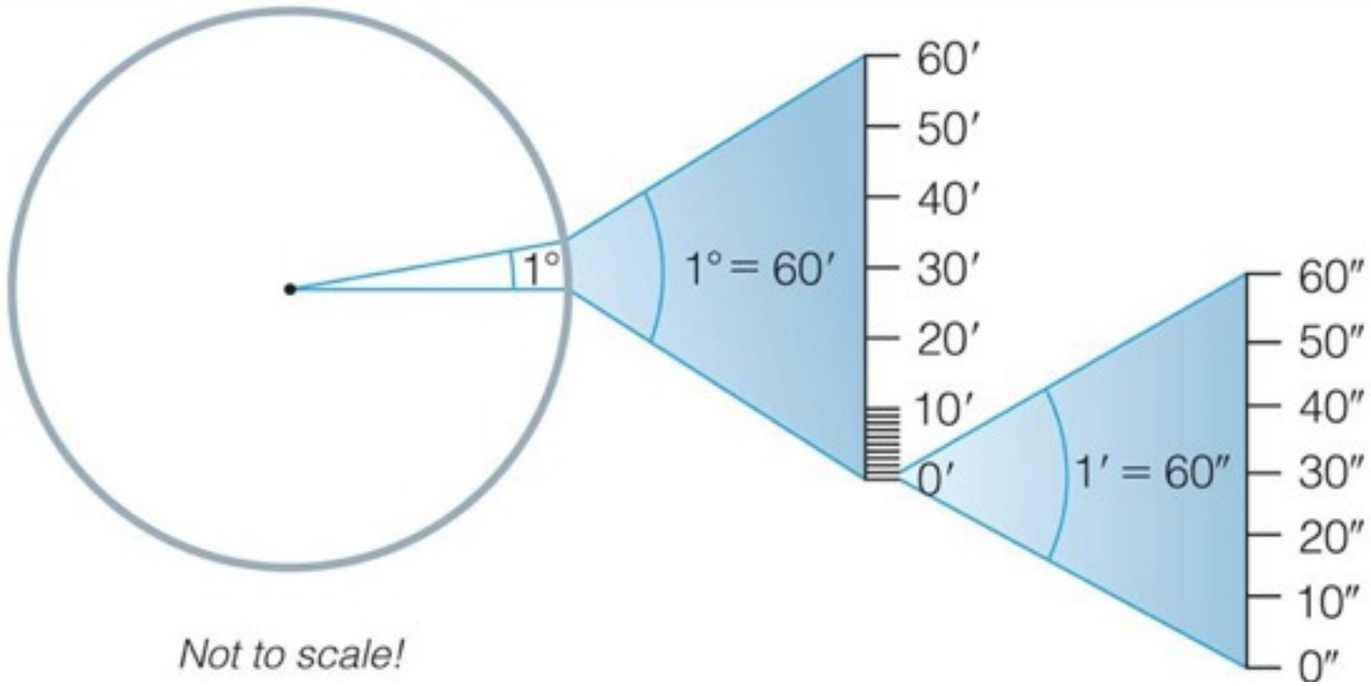
$$\cos(\gamma) = \cos(90^\circ - \delta_1)\cos(90^\circ - \delta_2) + \sin(90^\circ - \delta_1)\sin(90^\circ - \delta_2)\cos(\alpha_1 - \alpha_2)$$

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

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

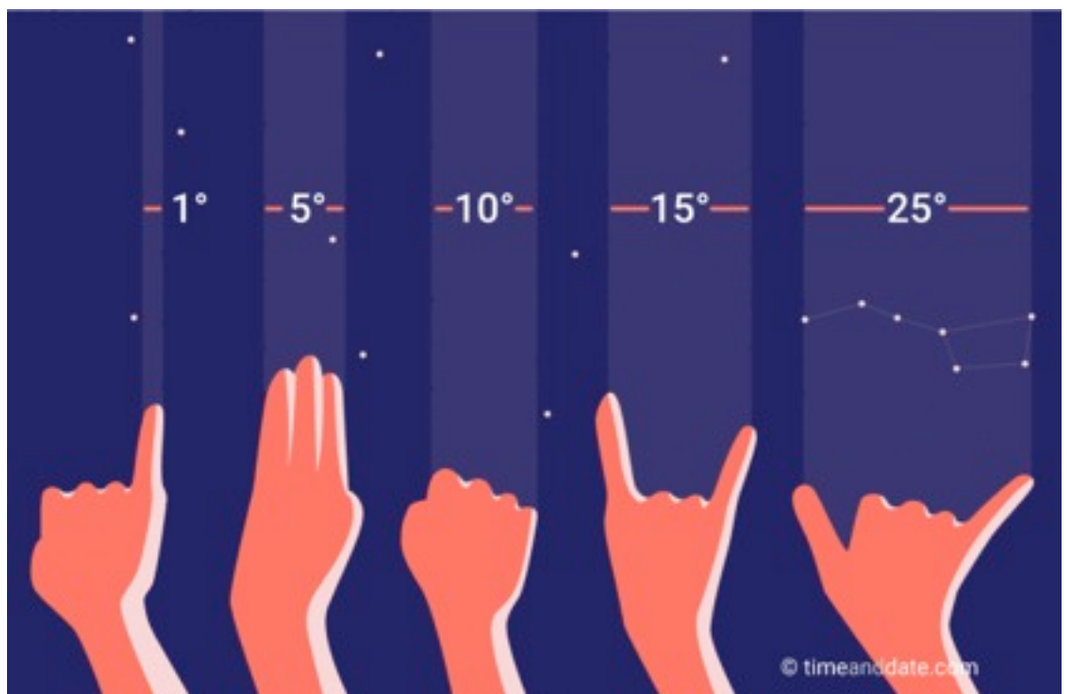
Lengths and distances on the Sky

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

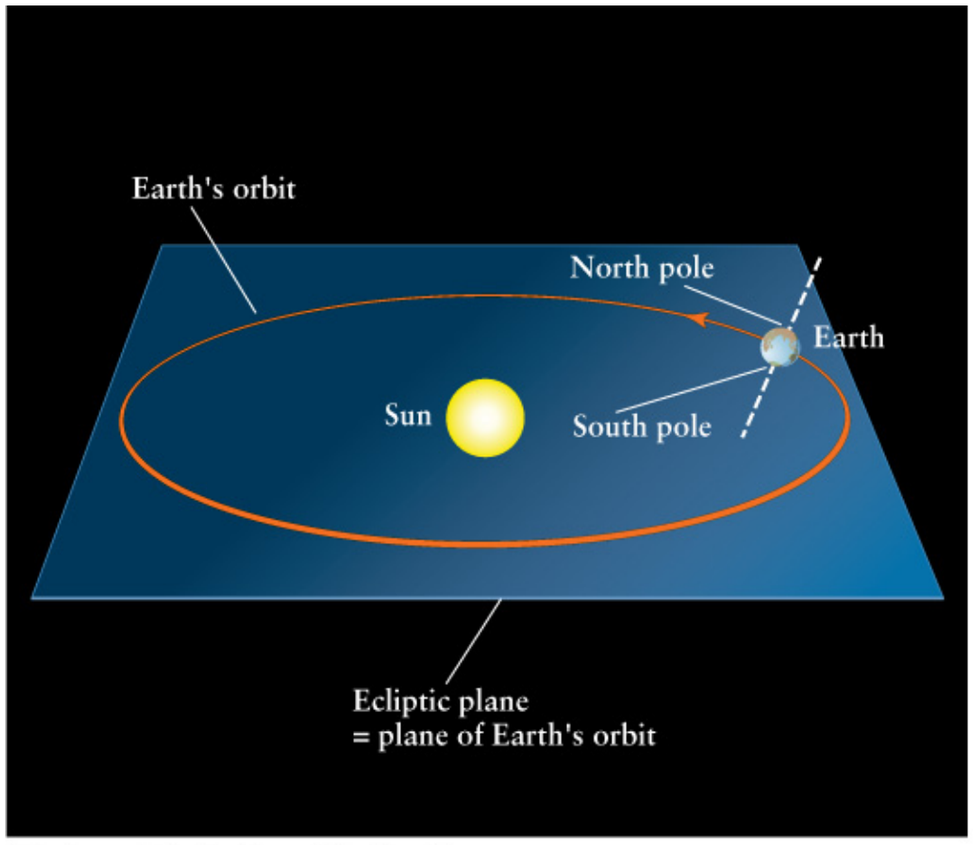


Not to scale!

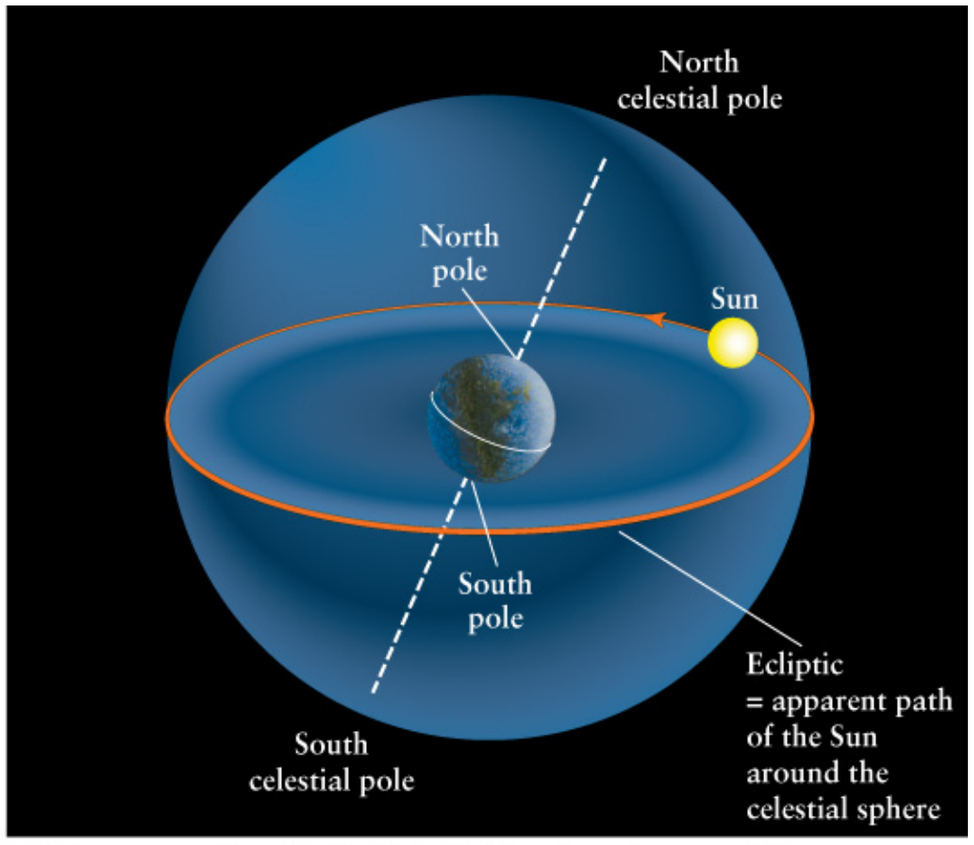
Moon: diameter is
~ 0.5° = 30’



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

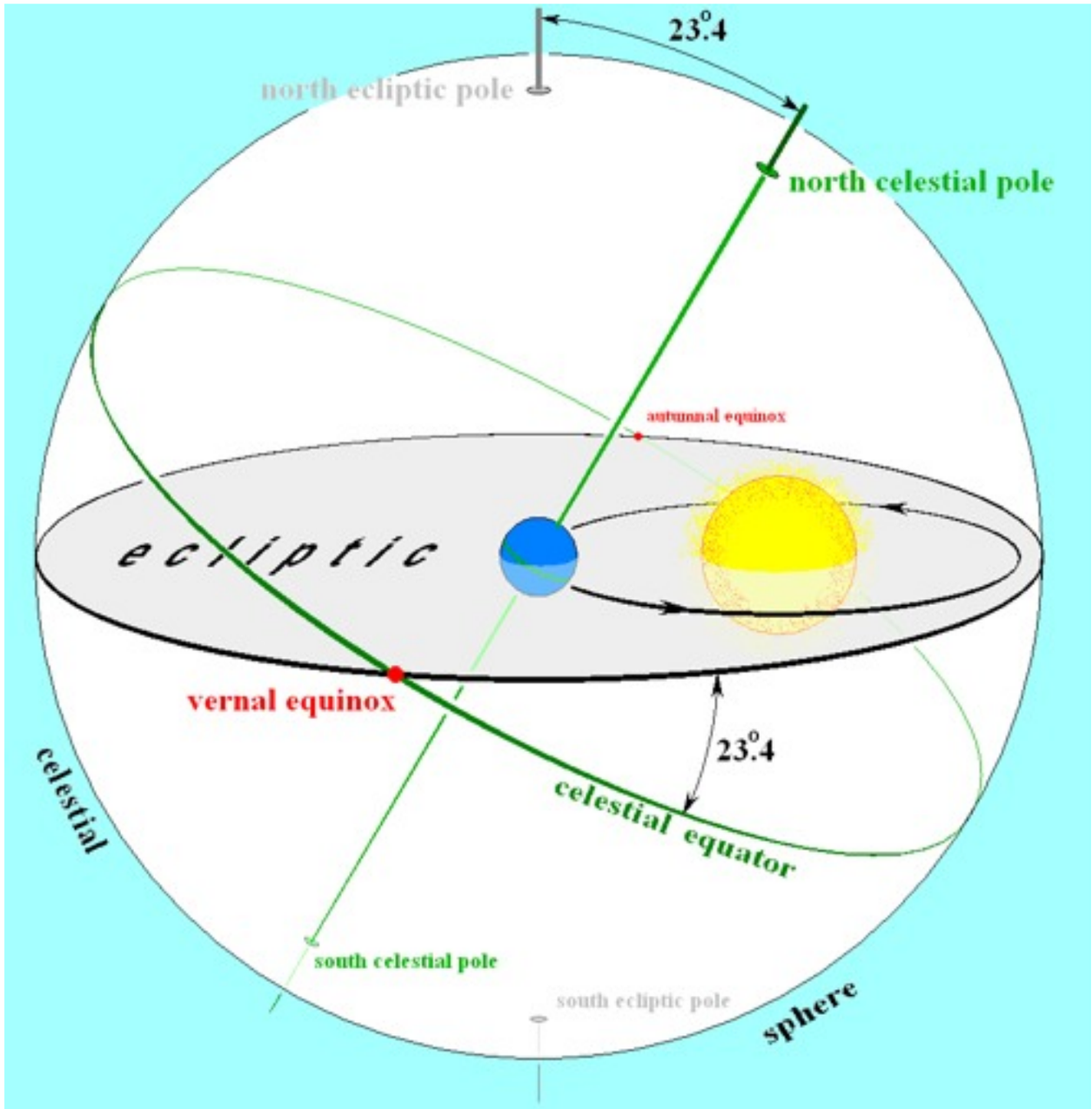
Earth's axis is tilted with respect to its orbit → the ecliptic is **NOT** the same as the celestial equator

Motion of the Sun in the Sky

equator and ecliptic intersect in two points: the equinoxes

why are they called equinoxes?

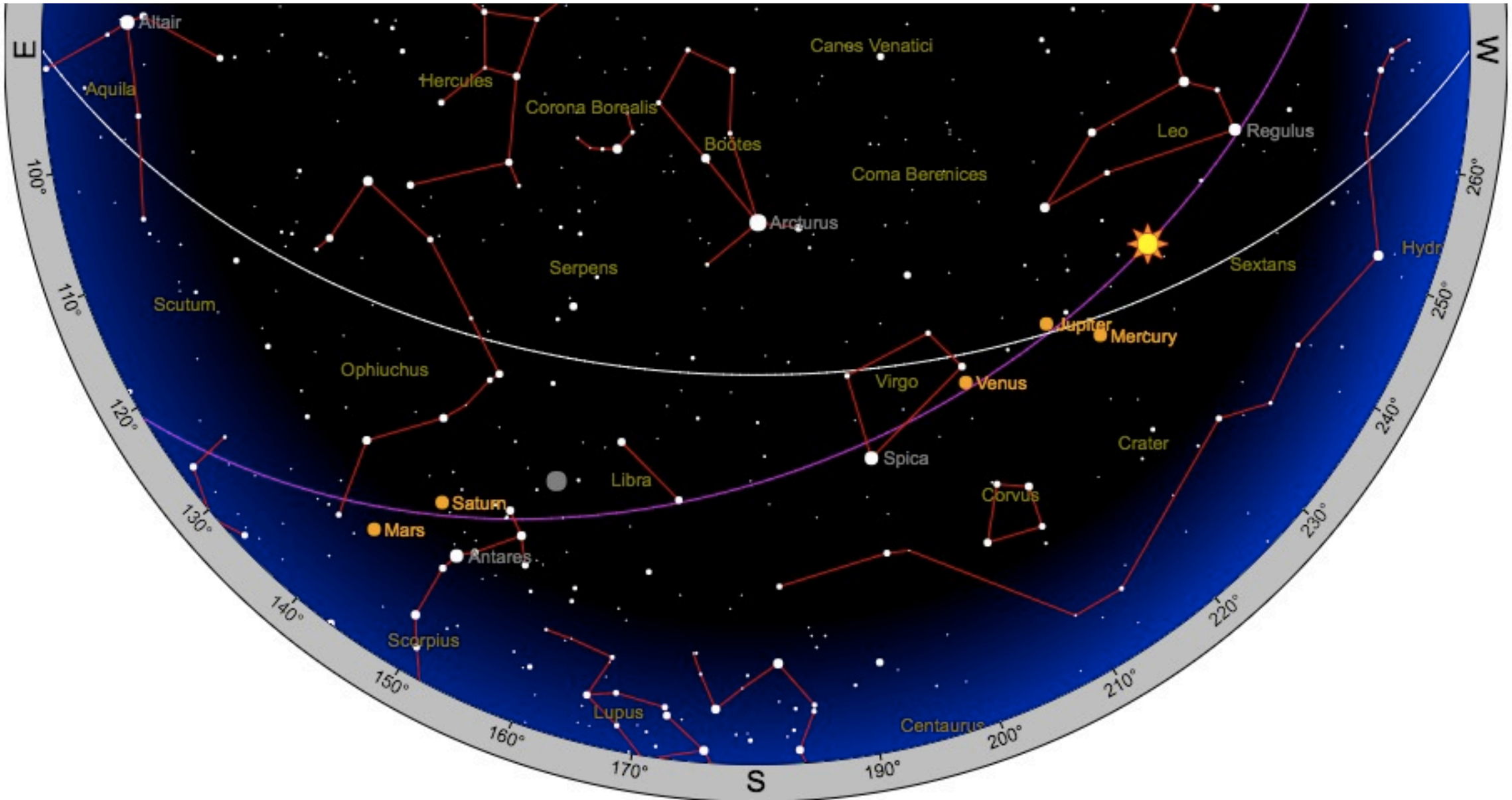
the vernal (spring) equinox marks RA=0h



Other Solar System objects

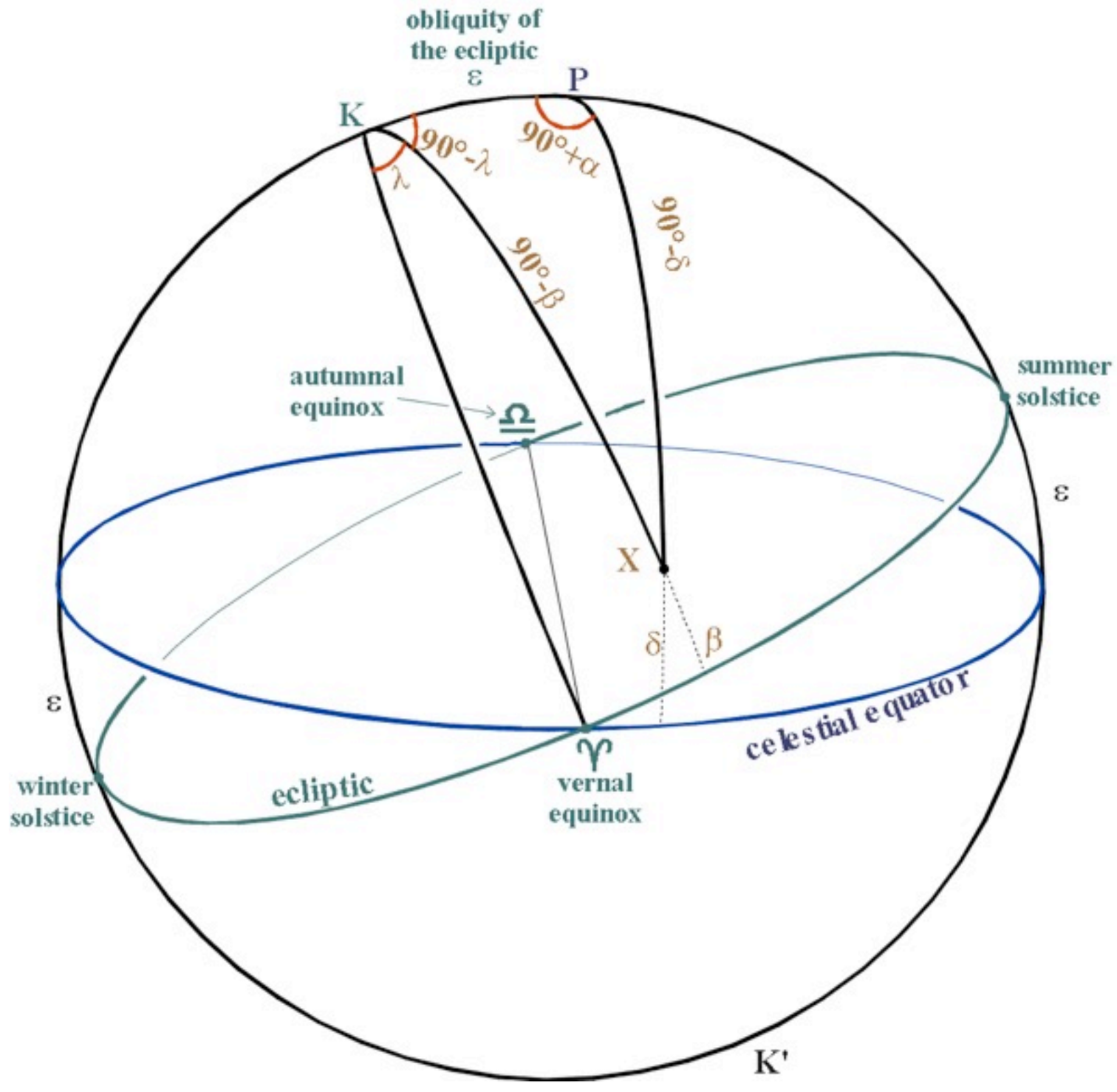
the orbital planes of most planets (and moons) are similar to Earth's orbital plane

→ Moon and planets also approximately follow the ecliptic



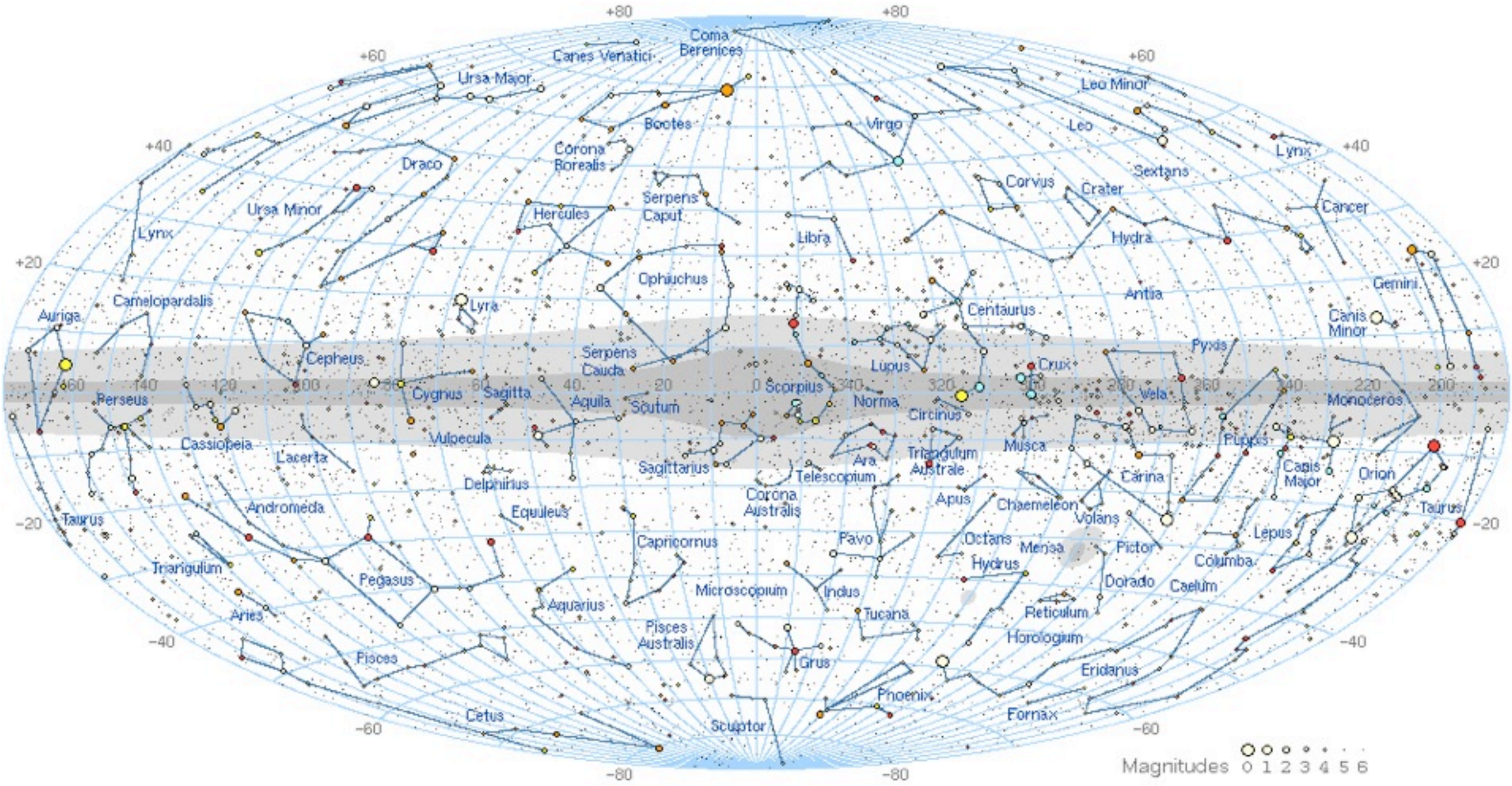
Ecliptic coordinates

use ecliptic as "equator"



Galactic coordinates

use the plane of the Galaxy as “equator”



Time

Need to know the current time!

Your telescope needs it 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

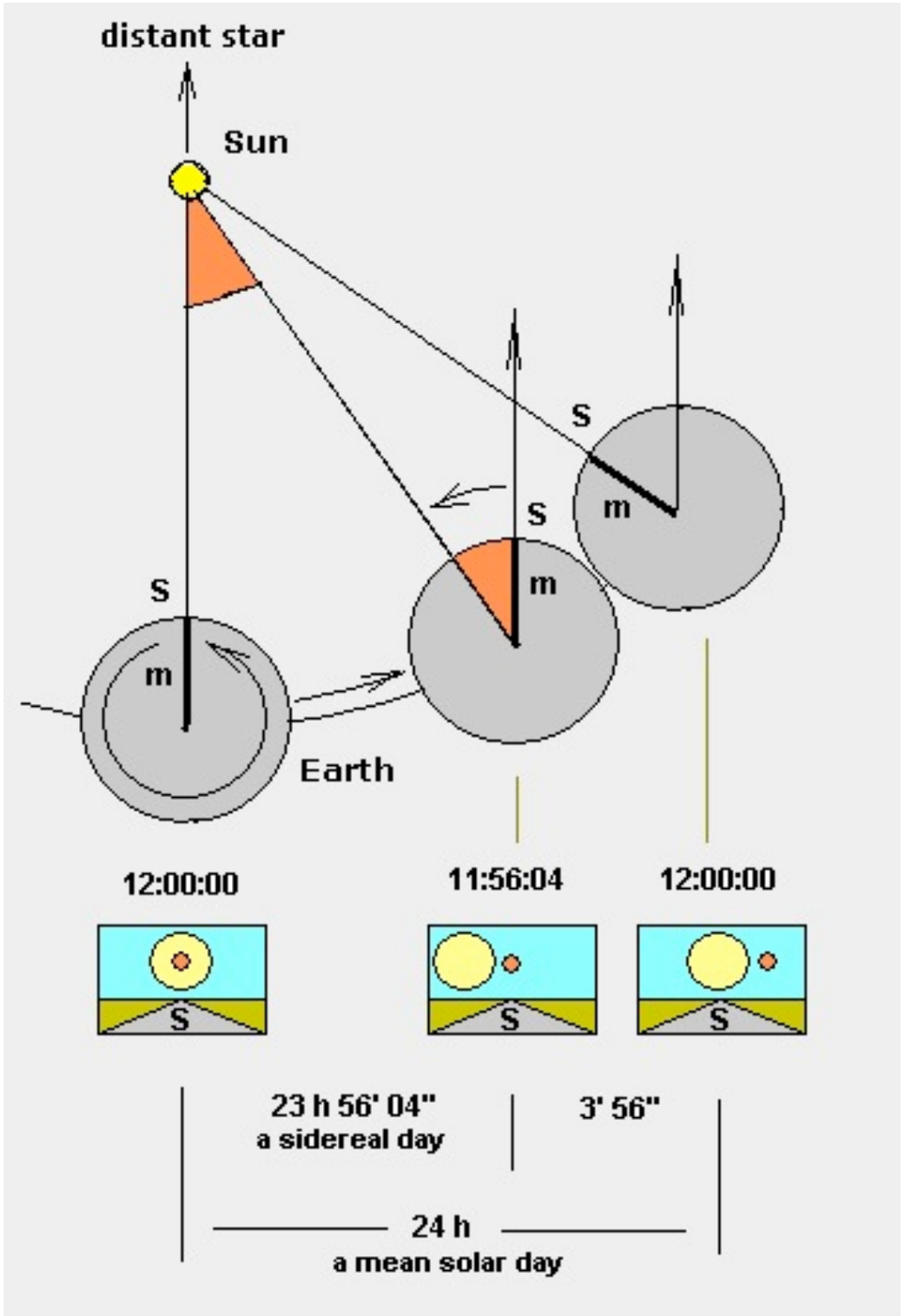
"sidereal" = "of the stars"

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

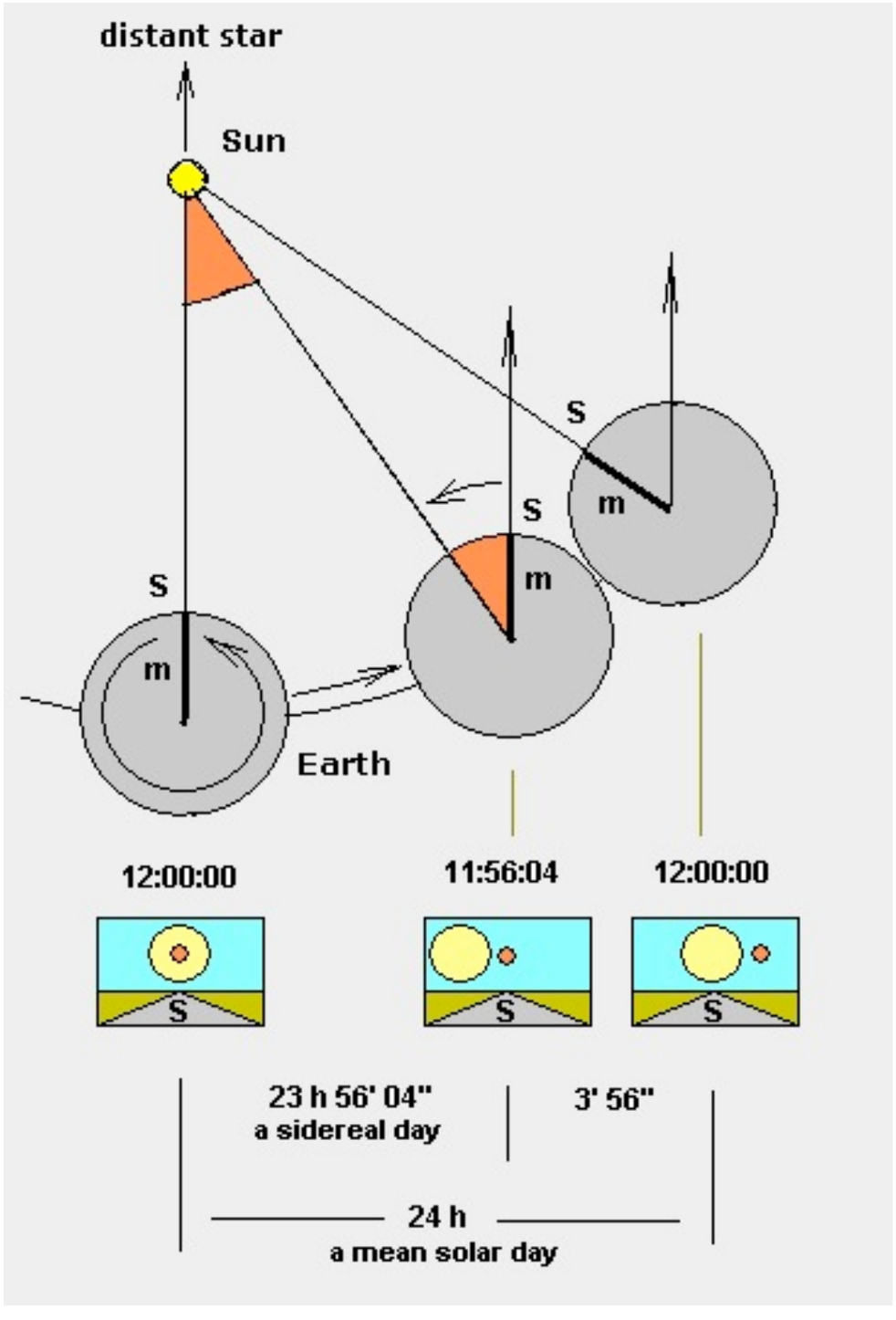


This means...

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

one year has 365+1 sidereal days

example: 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)

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

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

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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

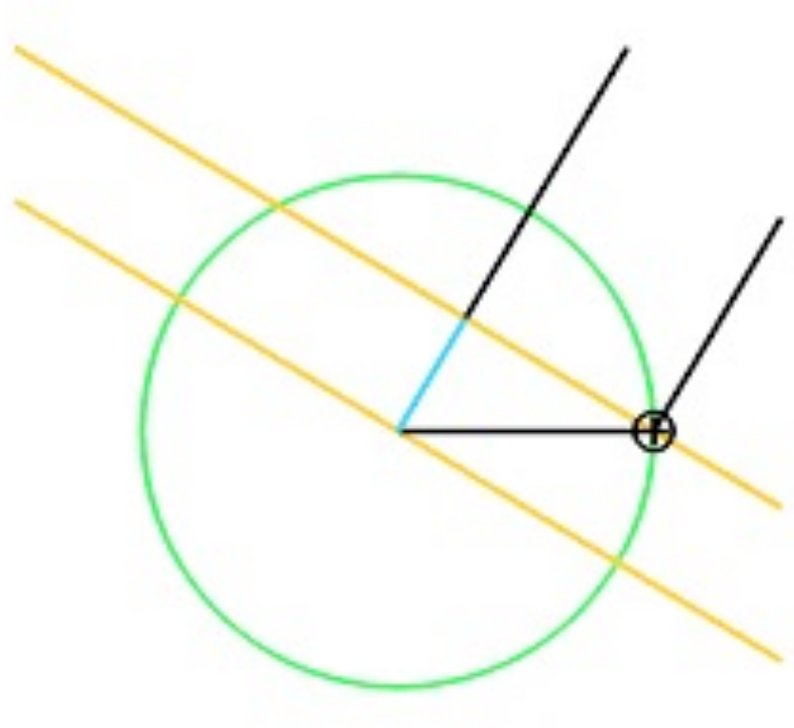
- days since noon on Jan 1, 4713 BC (JD=0)
- JD of Aug 31, 6pm in Stony Brook: 2457632.25
- Modified Julian Date (MJD): MJD = JD - 2400000.5

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

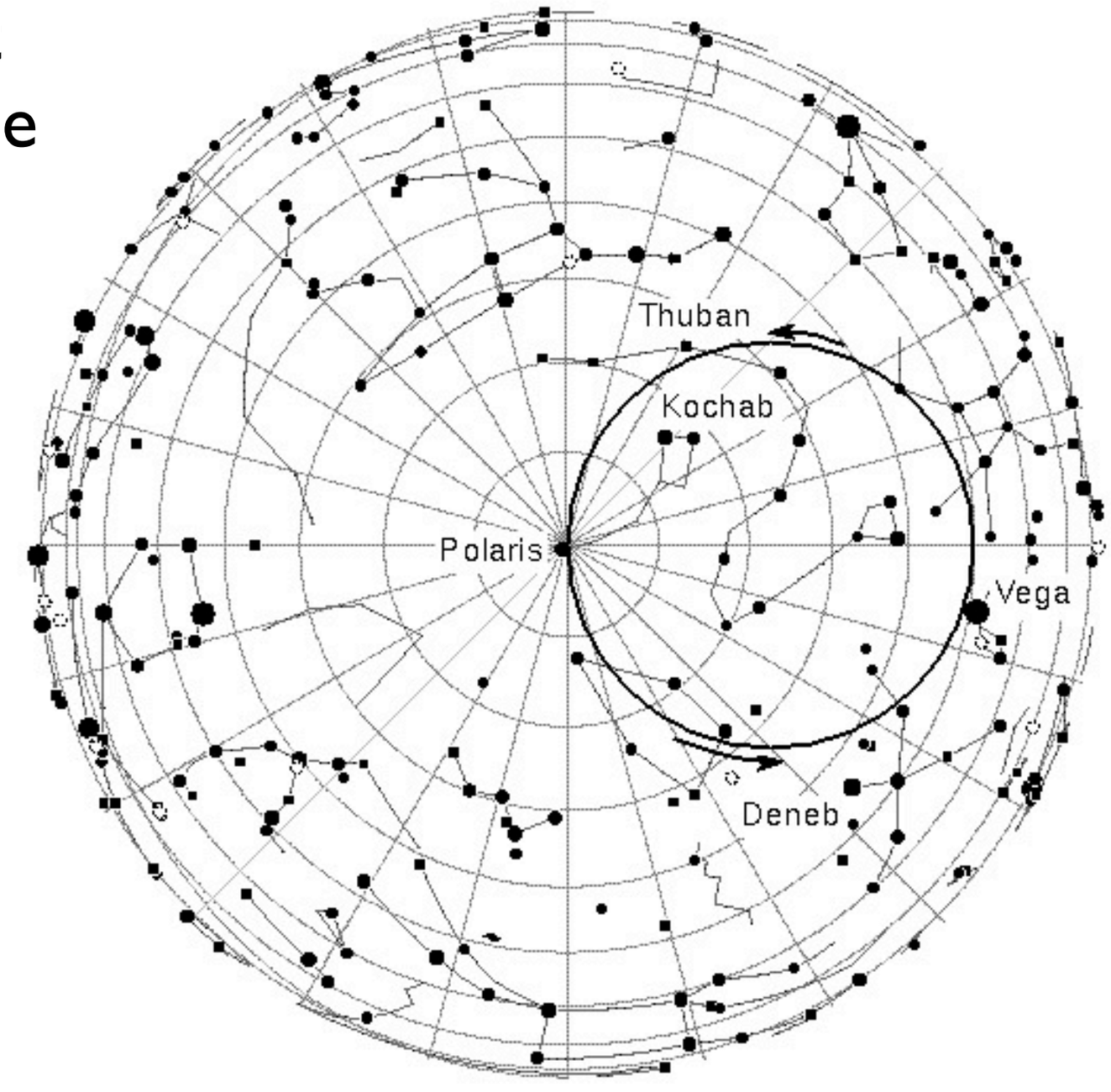
Earth's rotation axis is not constant in space with time

- 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.

Flux and magnitude:

“How bright is it?”

Astronomical magnitudes

Ancient greeks categorized stars into 6 brightness classes:

- 0th magnitude: Vega
- 6th magnitude: faintest stars visible under dark sky

the eye responds ~logarithmically to flux

modern definition:

$$m_1 - m_2 \;=\; -2.5 \;\log\left(\frac{F_1}{F_2}\right)$$

the difference in magnitude describes the ratio in flux;
magnitudes are always defined relative to a reference flux

the bigger the magnitude, the fainter the object!

Astronomical magnitudes

$$m_1 - m_2 \;=\; -2.5 \;\log\left(\frac{F_1}{F_2}\right)$$

visual astronomy: keep old definition by making Vega the reference:

$$m \;=\; -2.5 \;\log\left(\frac{F}{F_{\rm Vega}}\right)$$

examples:

Sun: -27 mag

Moon: -12.5 mag

Iridium flare: -8 mag

faintest galaxies in Hubble Ultra Deep Field: 30 mag

Physical descriptions

amount of energy passing through area *dA* , within *dω* (at an angle θ from normal), in frequency range [ν,ν+*d*ν], during time *dt* is:

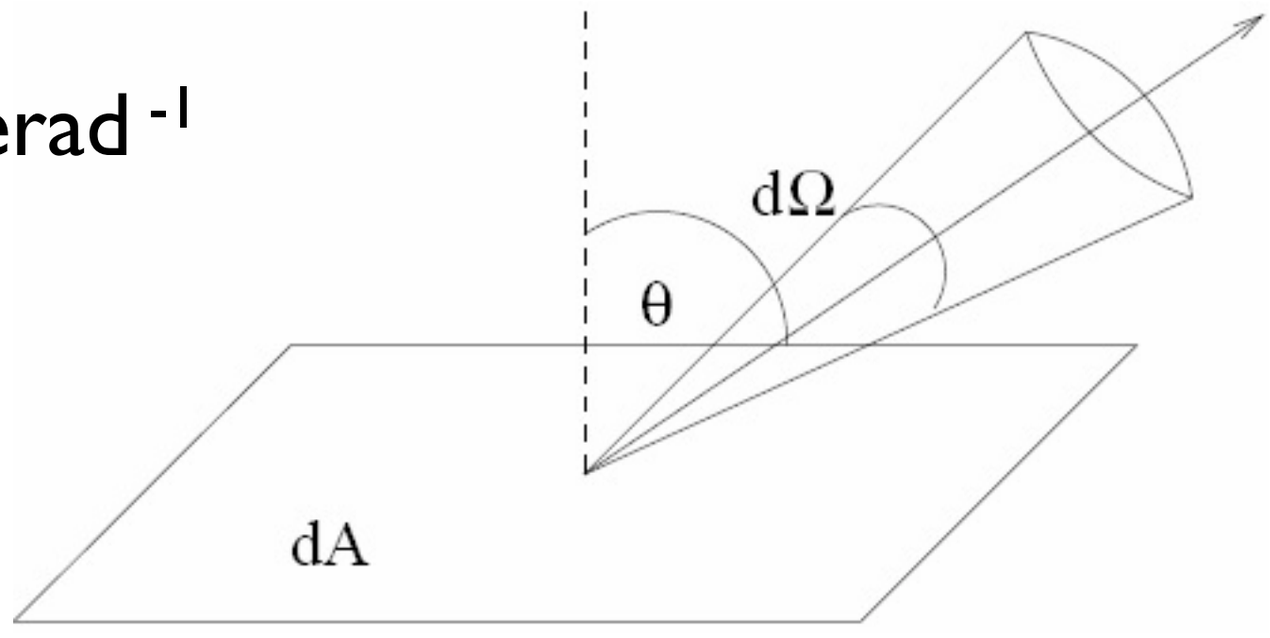
$$dE_\nu = I_\nu \cos\delta \; dA \; d\nu \; d\omega \; dt$$

specific intensity: I_ν

units: ergs s^{-1} cm^{-2} Hz^{-1} $sterad^{-1}$
or Jansky $sterad^{-1}$

intrinsic property of the object!

(e.g. *dA* on surface of star)



Physical descriptions

$$dE_\nu = I_\nu \cos\delta \; dA \; d\nu \; d\omega \; dt$$

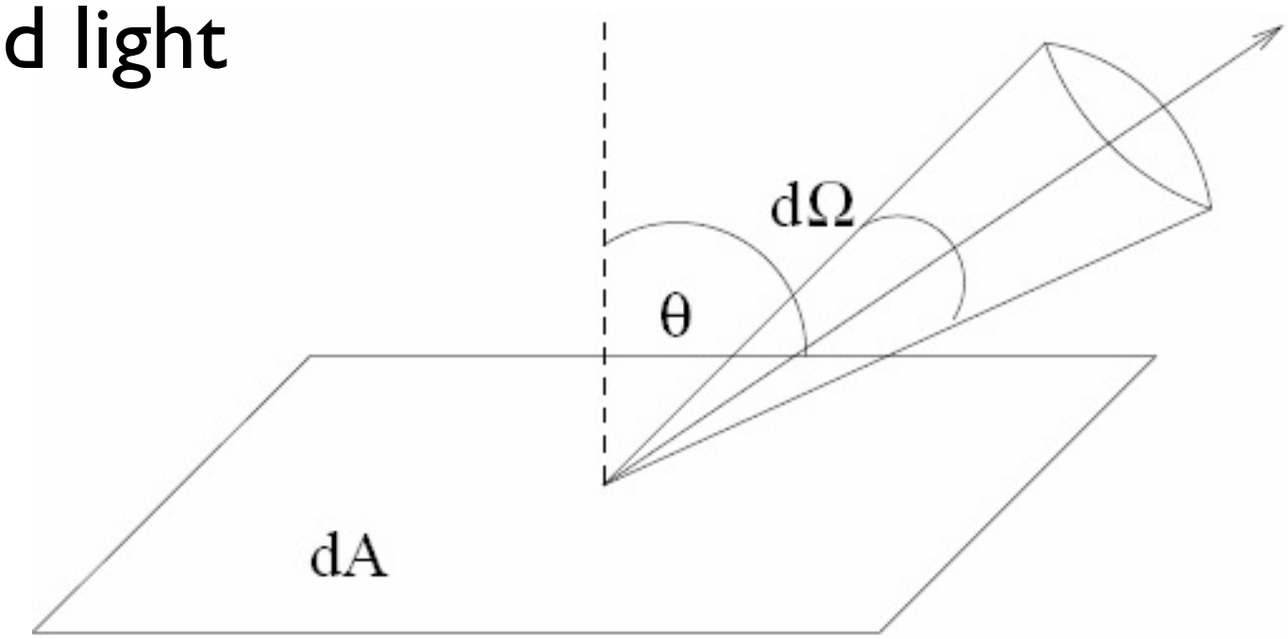
spectral flux density: $$f_\nu = \int I_\nu \; \cos\delta \; d\omega$$

units: ergs s^{-1} cm^{-1} Hz^{-1} = Jansky

e.g. point sources, integrated light from extended sources

observable quantity

(e.g. $d\omega$ is solid angle of your eye, seen from star)



Physical descriptions

spectroscopy: can determine f_ν

otherwise: need to integrate f_ν over observed frequency (wavelength) interval

flux (density):

$$F = \int_{\rm passband} f_\nu \, d\nu$$

$$= \int_{-\infty}^{\infty} T_\nu \; f_\nu \, d\nu$$

T_ν: system response curve (e.g. filter transmission)

(note: usually specified as fl ;)

$$f_\lambda = \frac{c}{\lambda^2} f_\nu$$

Physical descriptions

$$dE_\nu = I_\nu \cos\delta \; dA \; d\nu \; d\omega \; dt$$

luminosity:

$$L_\nu = \int f_\nu dA$$

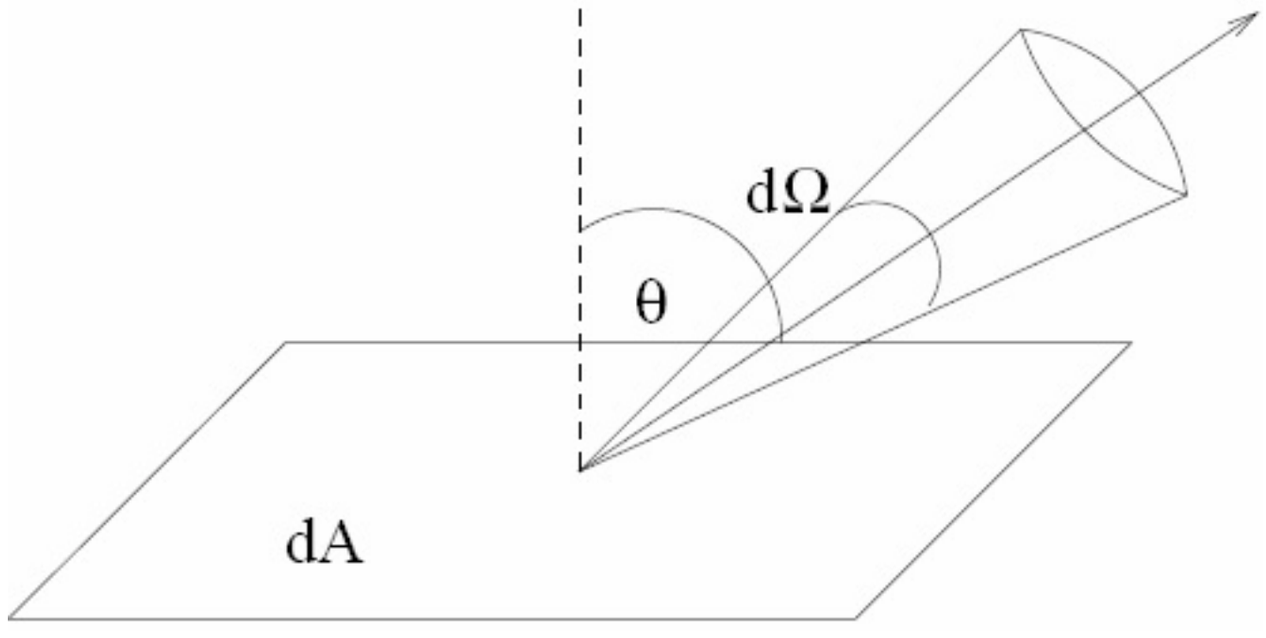
units: ergs s^{-1} Hz^{-1}

$$= f_\nu \int dA = f_\nu \; 4\pi d^2 \quad \text{(assuming isotropy)}$$

intrinsic property of the object !

bolometric luminosity:

$$L_{\rm bol} = \int_{-\infty}^{\infty} L_\nu \; d\nu$$



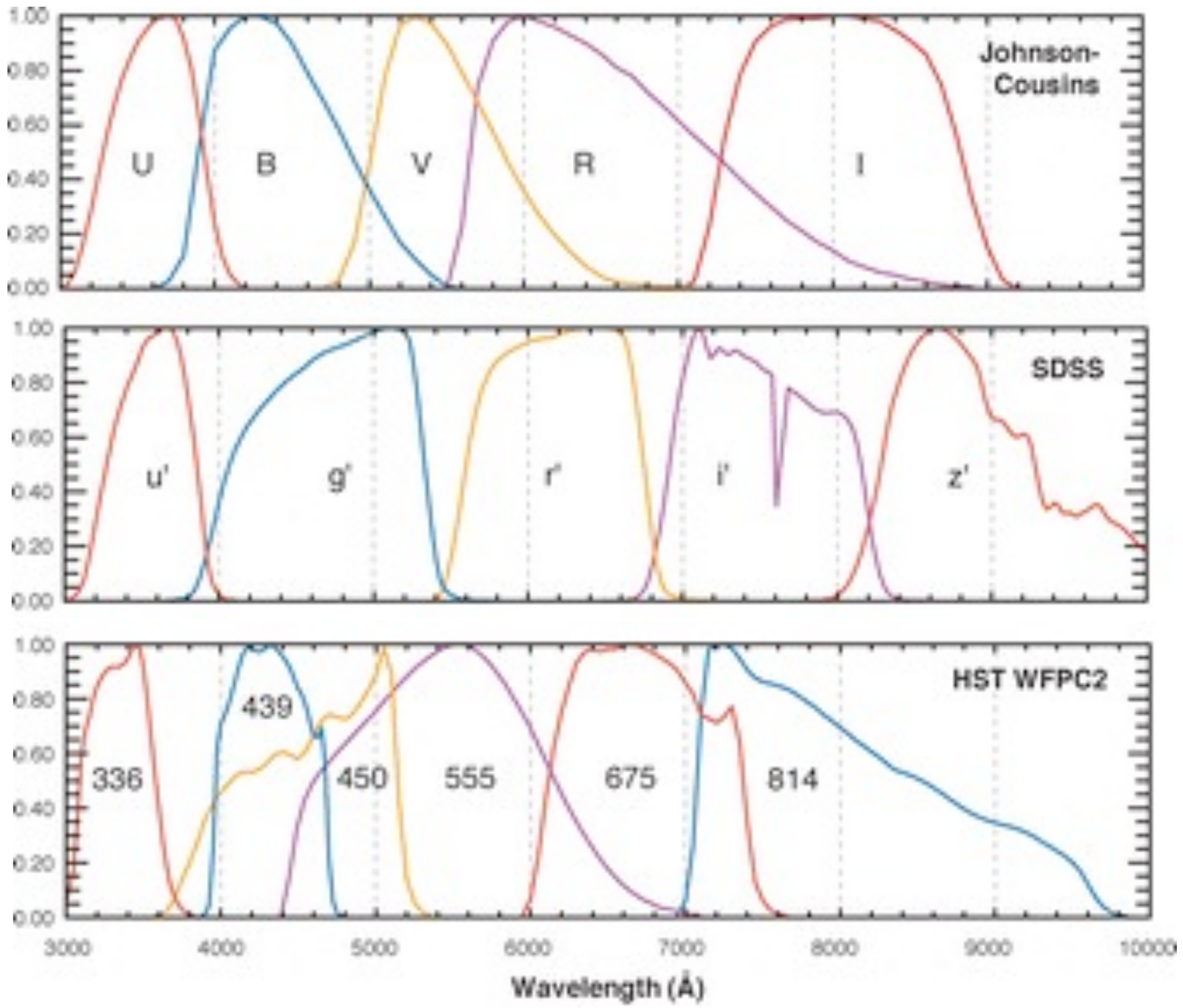
Filter systems

optical astronomy:

several standard photometric systems, "filter sets"

Johnson-Cousins:
UBVRI

SDSS:
ugriz



Color

difference between magnitudes in two bands (e.g. B,V):

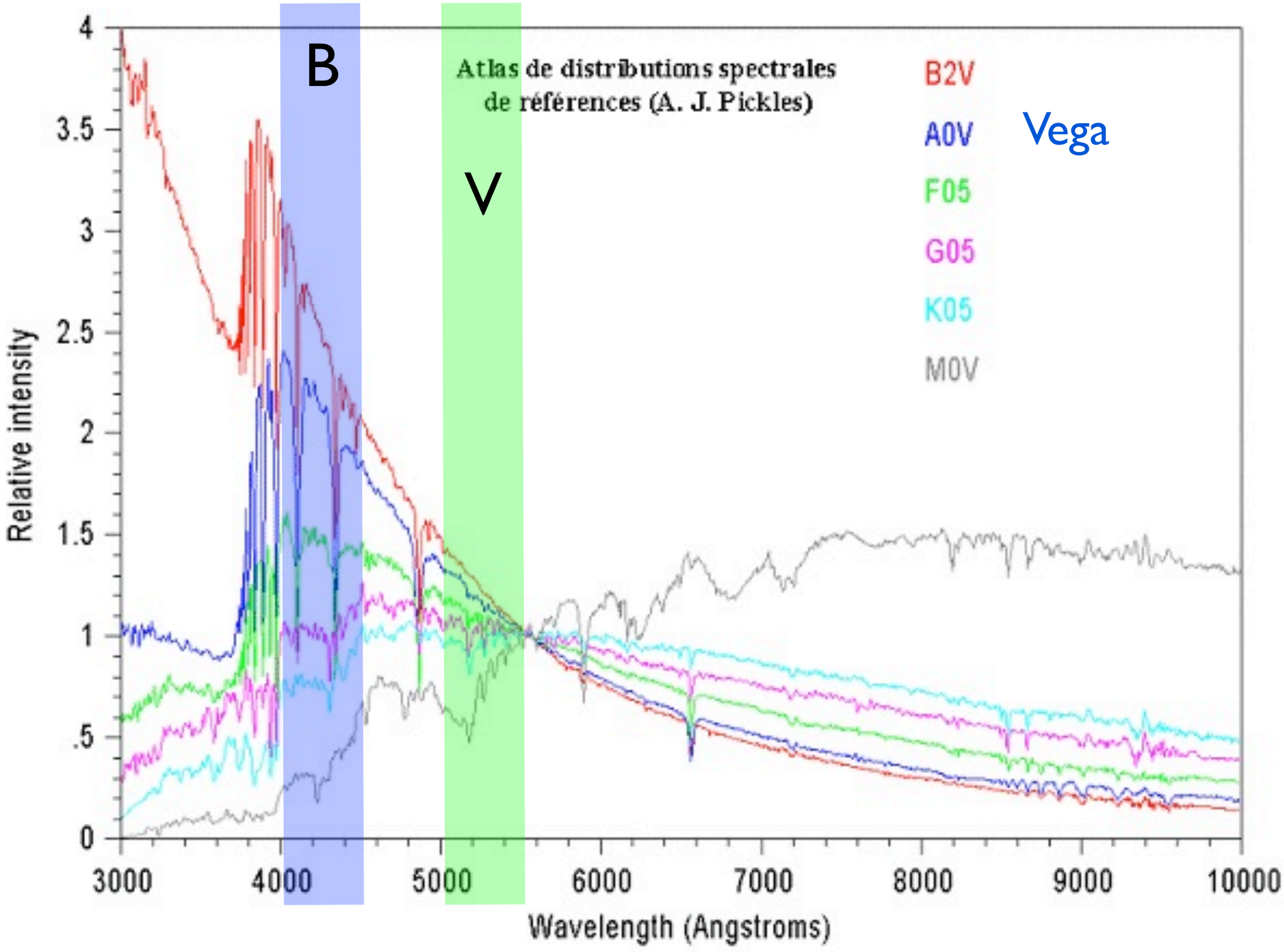
$$B - V = m_B - m_V = -2.5 \log \left(\frac{F_B}{F_V} \right)$$

$$= -2.5 \log \left(\frac{F_B}{F_{B,\mathrm{Vega}}} \right) + 2.5 \log \left(\frac{F_V}{F_{V,\mathrm{Vega}}} \right)$$

Vega has 0 color, by definition

"blue" star: flux ratio (to Vega) in *B* filter greater than in *V*

Color

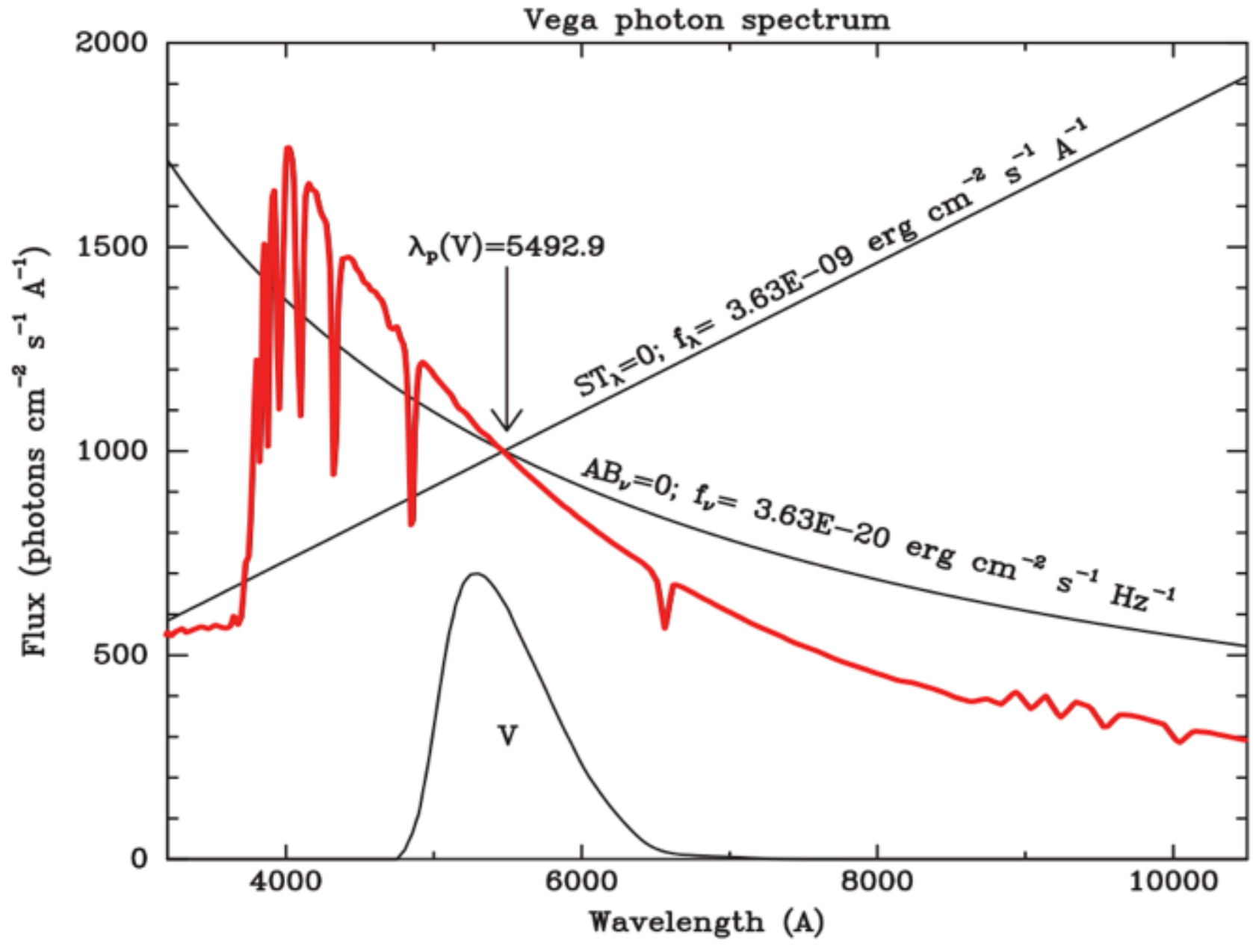

B
V
Atlas de distributions spectrales
de références (A. J. Pickles)
B2V
A0V
F05
G05
K05
M0V
Vega
Relative intensity
4
3.5
3
2.5
2
1.5
1
.5
0
3000
4000
5000
6000
7000
8000
9000
10000
Wavelength (Angstroms)

AB magnitudes

defined relative to *constant flux per unit frequency*

$$m_{\rm AB} \;=\; -2.5\,\log\left(\frac{f_\nu}{3631\ {\rm Jy}}\right)$$

normalized so that Vega is ~ 0 mag in *V* filter



Absolute magnitudes

so far: magnitudes (based on flux) are apparent, not intrinsic, properties of objects → depend on distance

absolute magnitude M: apparent magnitude if the object were at a distance of 10 parsec

distance modulus:

$$
\begin{aligned}
m - M &= -2.5 \log \left(\frac{F(d)}{F(10\mathrm{pc})} \right) \\
&= -2.5 \log \left(\frac{L/4\pi d^2}{L/4\pi (10\mathrm{pc})^2} \right) \\
&= 5 \log \left(\frac{d}{10pc} \right) = 5 \log(d[pc]) - 5
\end{aligned}
$$

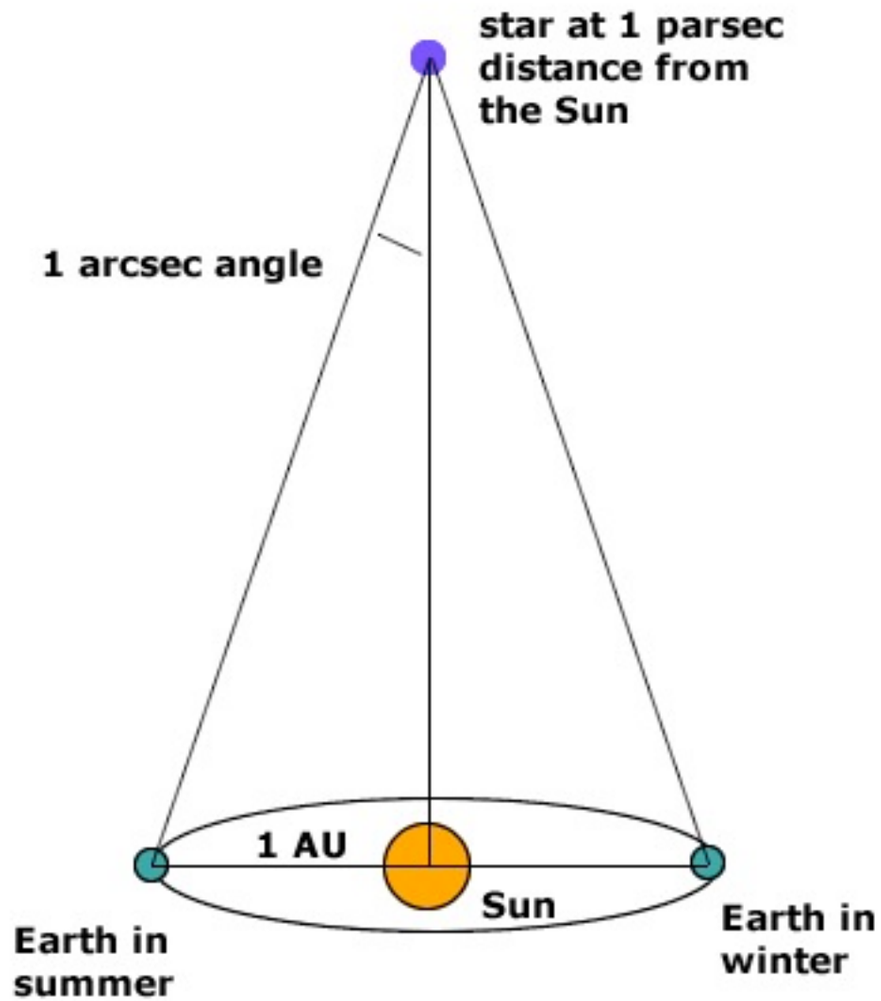
Parallax and parsecs

due to Earth's motion around the Sun, positions of (nearby) stars appears to shift

1 pc: distance to a star whose position shifts by 1" from 1 AU baseline

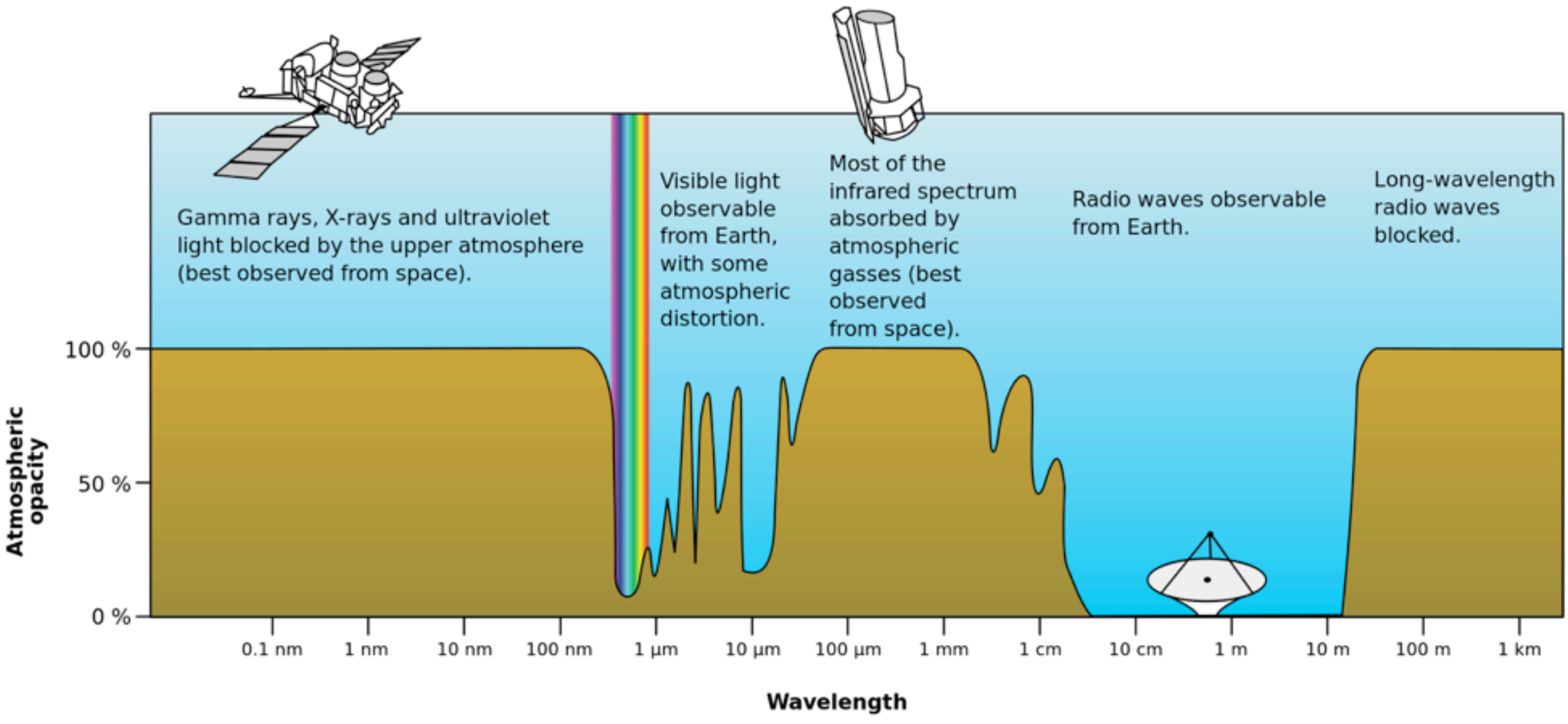
1 pc = 3.26 light-years = 3×10^{16}m

Proxima Centauri: ~1.3 pc



Earth's atmosphere

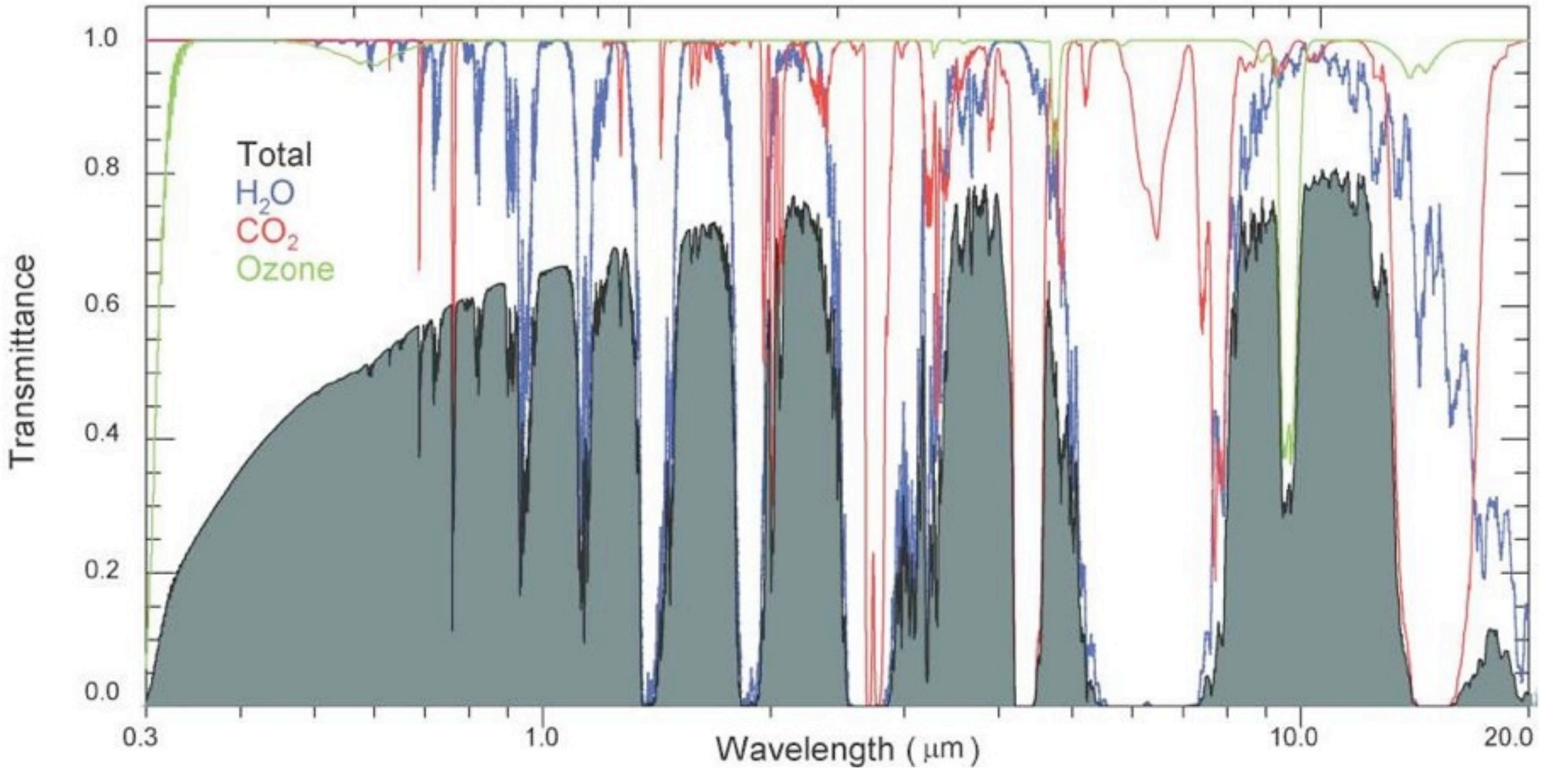
the atmosphere is opaque to most of the electromagnetic spectrum



Earth's atmosphere

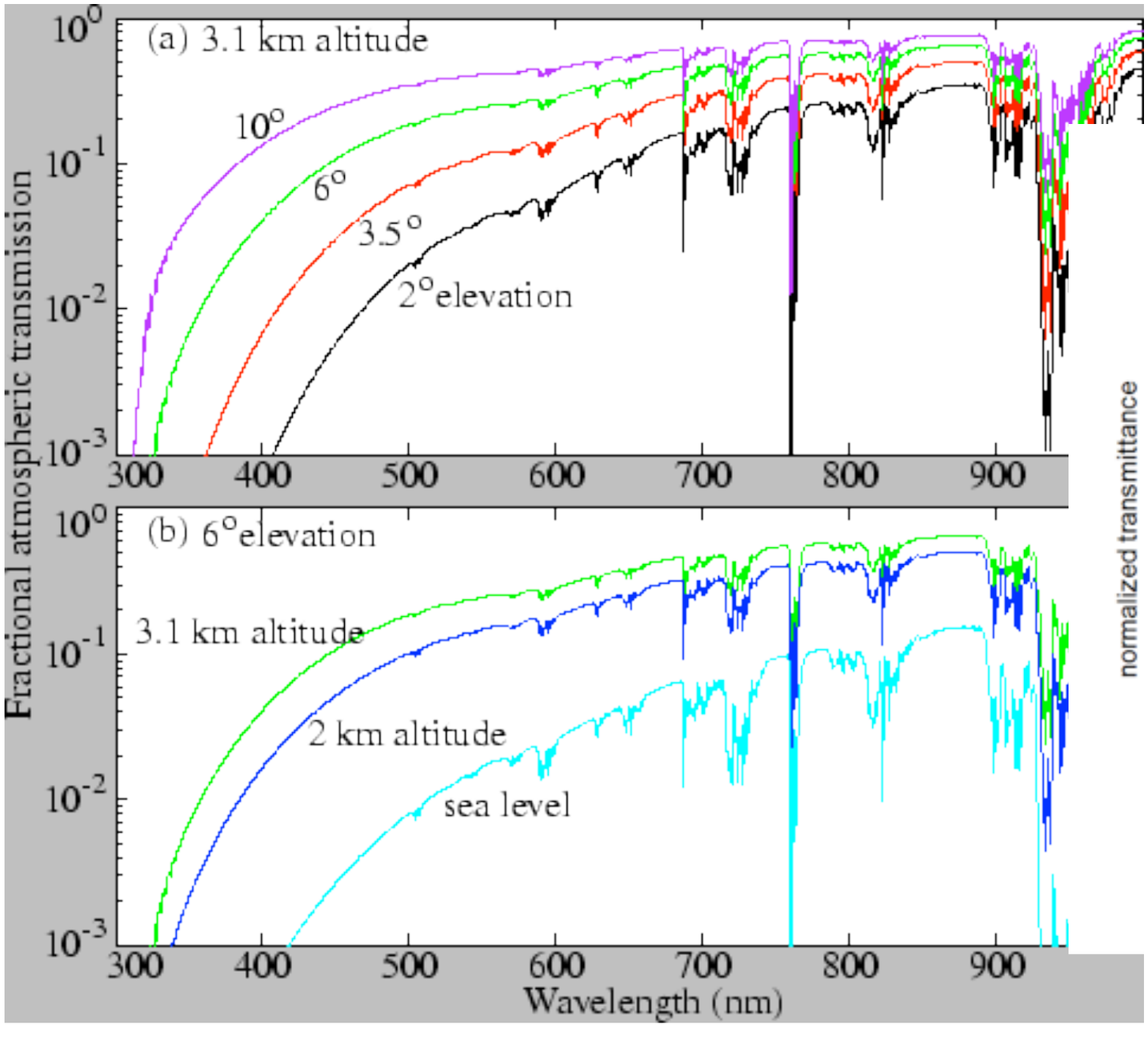
in the optical (~300nm - 1 μm) and near-infrared, extinction due to:

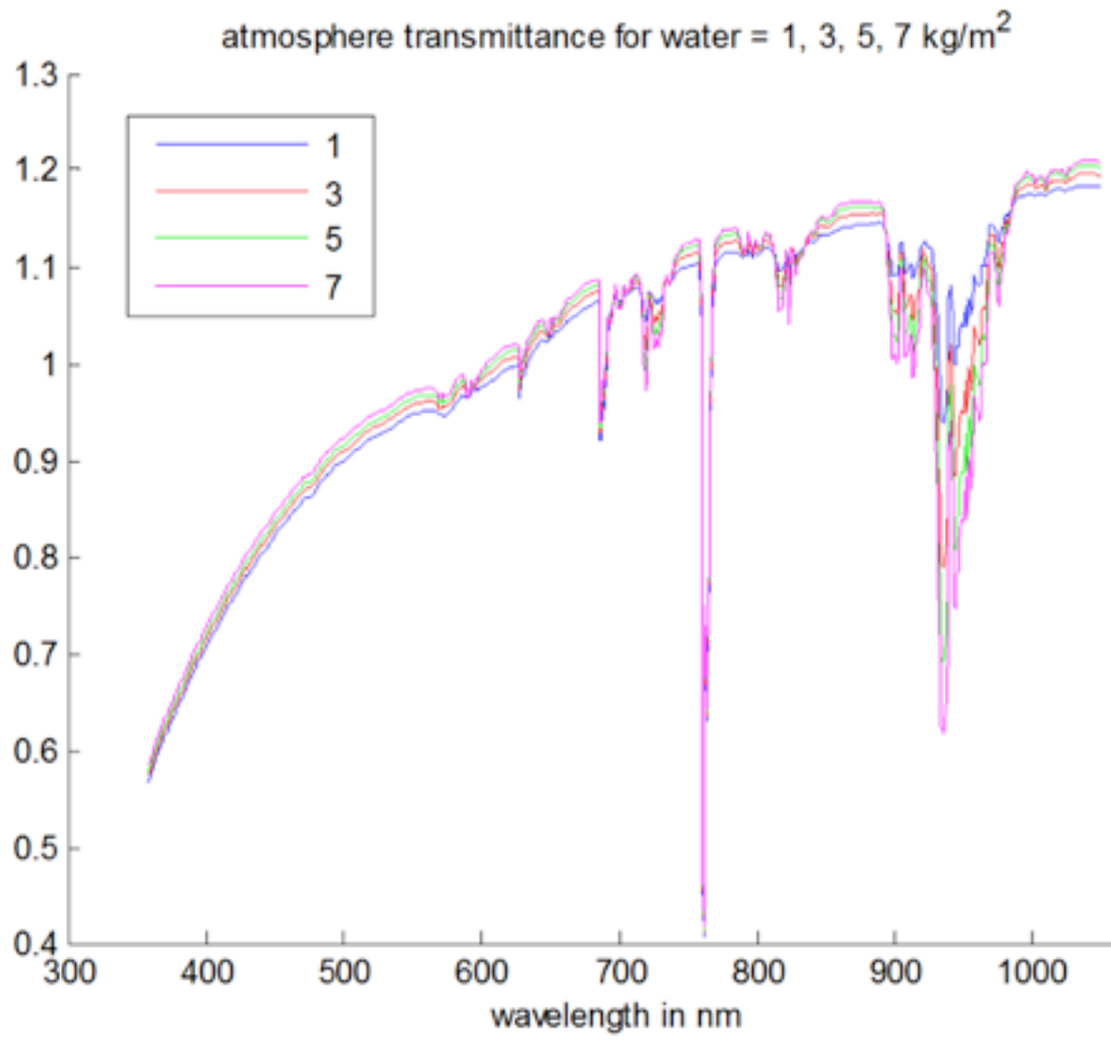
- scattering, e.g. Rayleigh $\propto \lambda^{-4}$
- absorption bands, mainly water



Earth's atmosphere

details depend sensitively on observatory location, target altitude (elevation), water and aerosol content



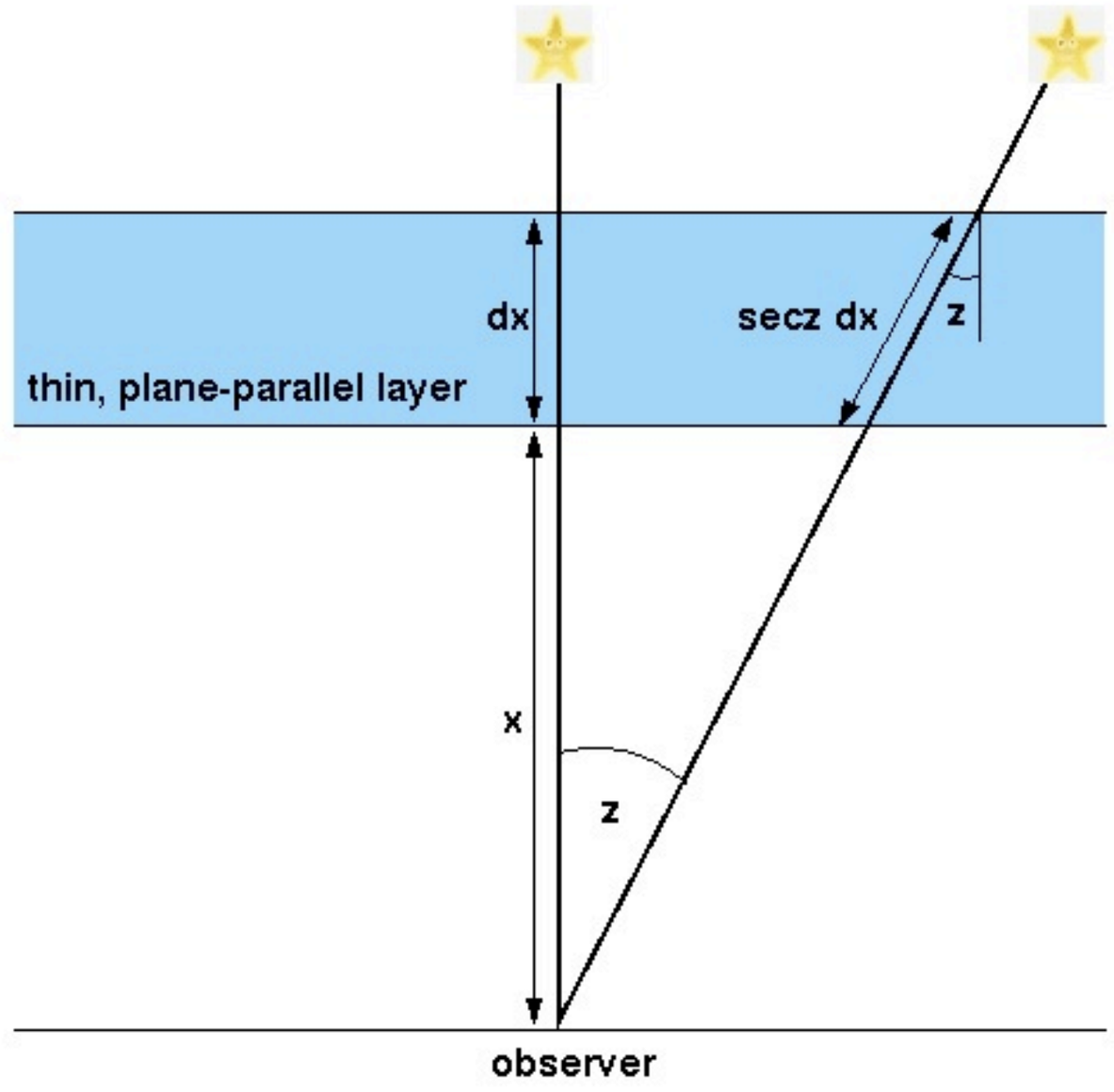


Airmass

expresses the amount of air the light of an object passed through, relative to zenith

plane-parallel approximation:

$$\mathrm{AM} = \sec(z) = \frac{1}{\cos(z)}$$



zenith distance:

z = 90° - altitude h

h=90°: AM=1

h=50°: AM=1.3

h=30°: AM=2

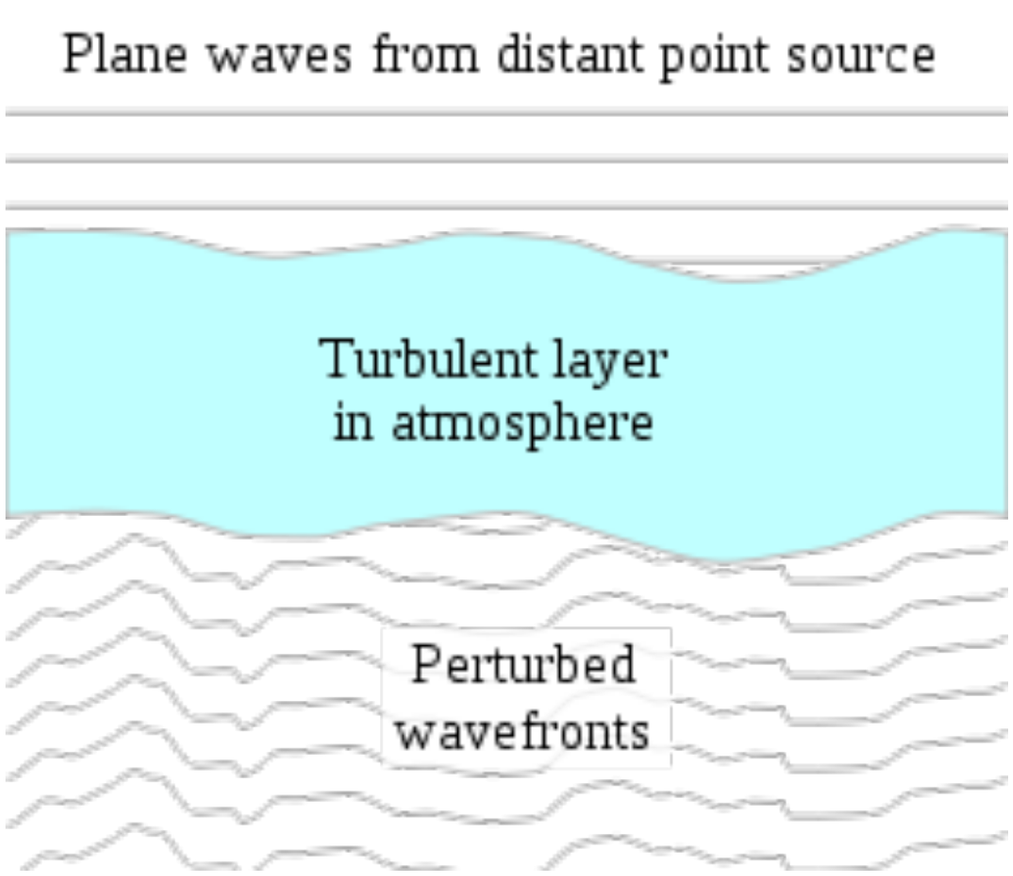
Seeing

diffraction-limited resolution of a telescope with entrance pupil *D*:

$$\theta_{\min} = 1.22 \, \frac{\lambda}{D}$$

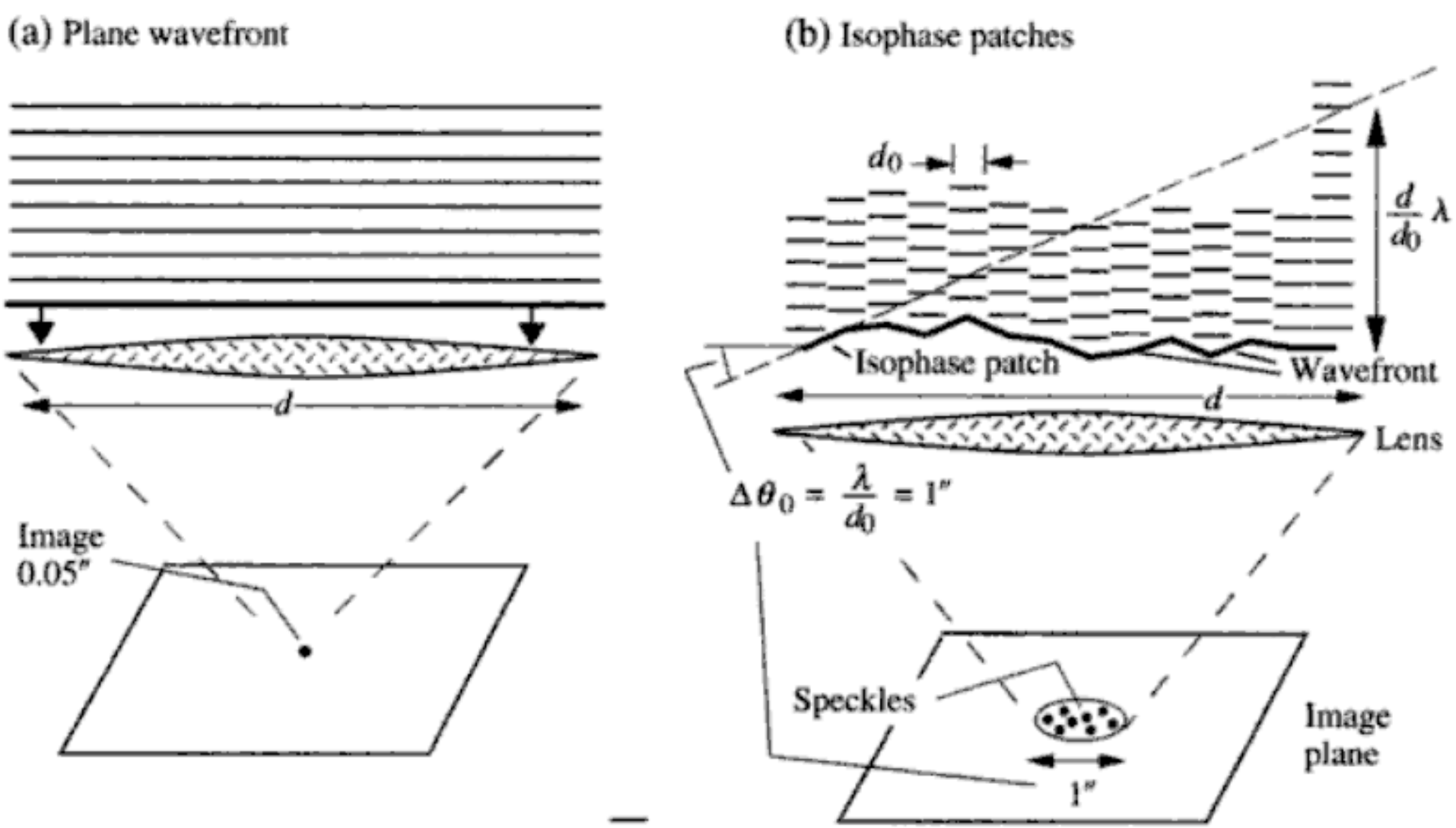
theoretical resolution of 14 inch telescope: ~0.3”

seeing: turbulence in the atmosphere, leads to “blurring” of images



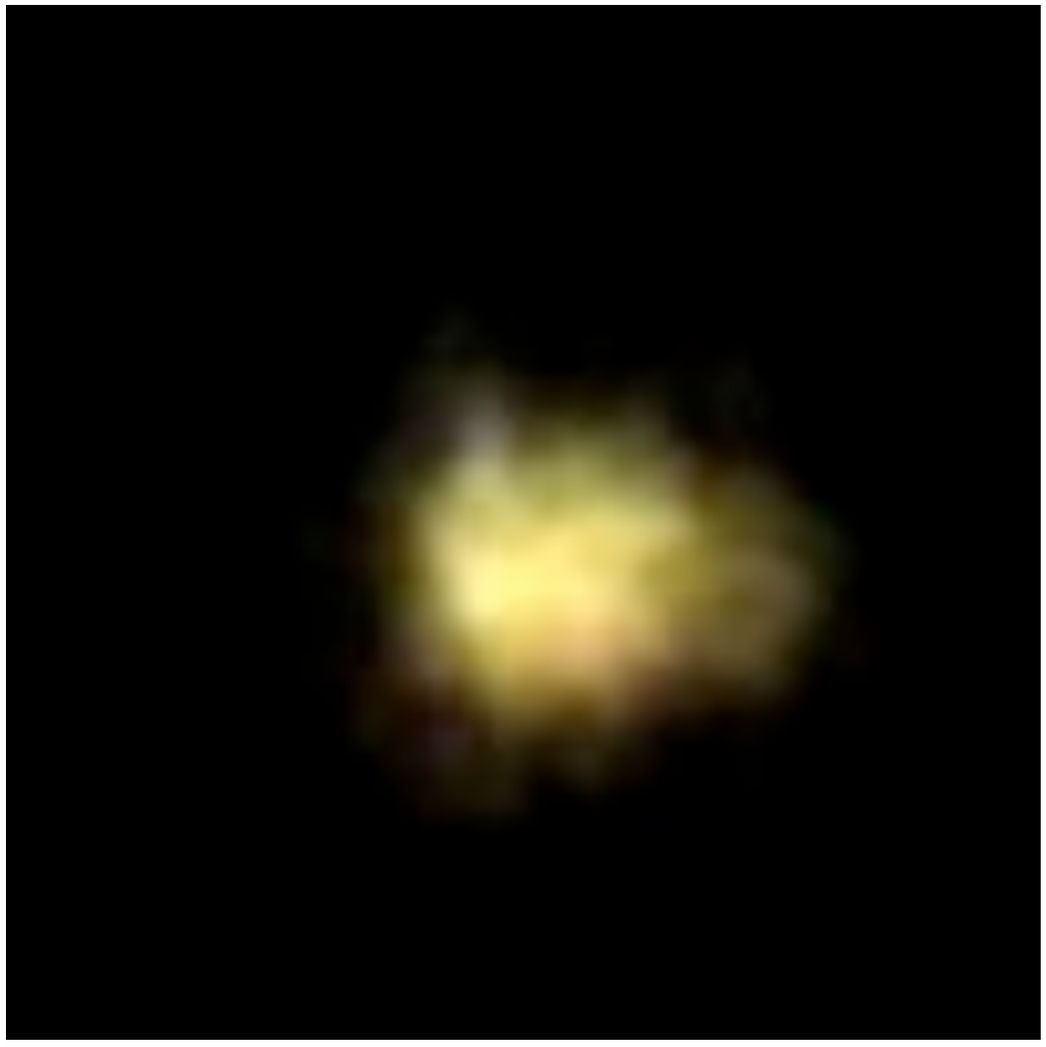
Seeing

wavefront gets broken into isophase patches, each is a "mini-image" - interference leads to "speckles"



Seeing

wavefront gets broken into isophase patches, each is a “mini-image” - interference leads to “speckles”



Seeing

depends on airmass: $\propto \mathrm{AM}^{0.6}$

and on wavelength: $\propto \lambda^{-1/5}$

Seeing

seeing gets better than 1” only at the world’s best observing sites (Mauna Kea, Chile)

highly dependent on local conditions

telescope dome can contribute significantly!

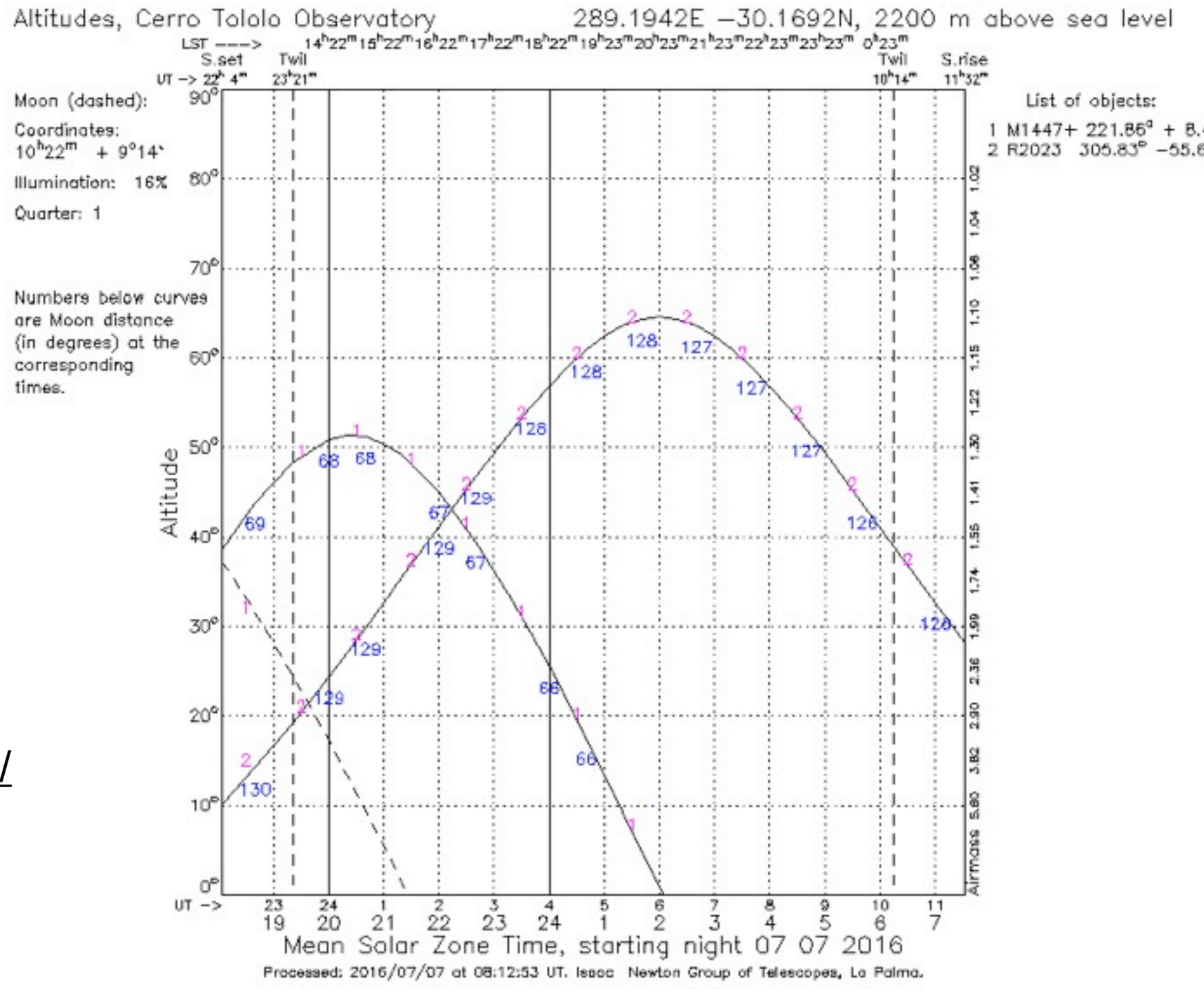
modern domes have lots of windows, day-time AC

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

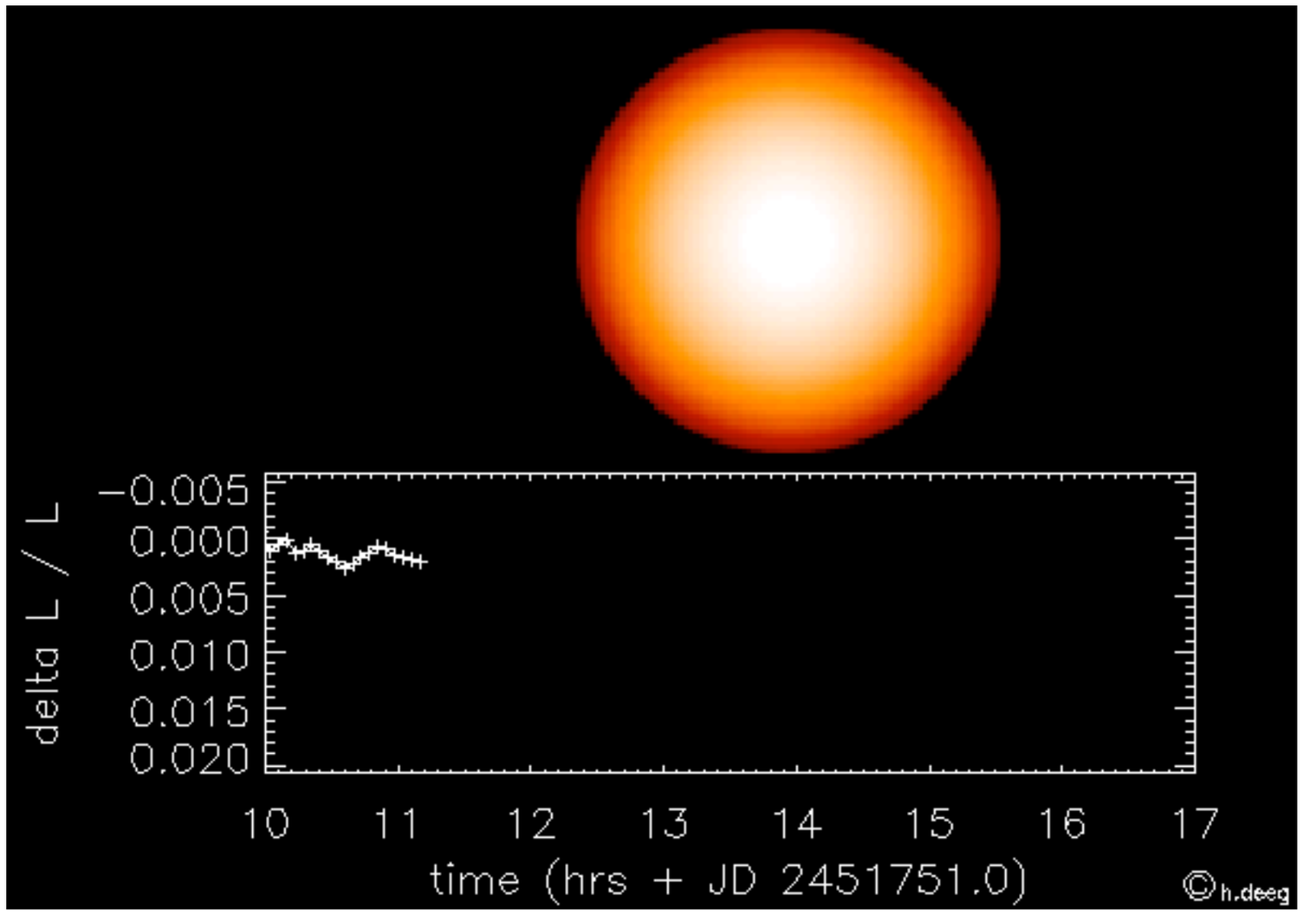


Preparing for your observations

Homework

Start preparations for Lab 1:

- optical astronomical imaging
- time-series photometry
- detect an exoplanet transit!



Homework

database of all known exoplanets, pre-selected for transiting exoplanets:

http://exoplanet.eu/catalog/all_fields/?f=%22transit%22+IN+detection

pick suitable targets:

- which host stars are visible from Mt Stony Brook?
- ... at night-time in September / October?
- (... at a time you can get the TAs / instructor to be awake?)
- what is the dimming due to the planet? (need to calculate!) need at least 0.008 mag
- is the host star bright enough? (V<12.5)

Homework

triple-check your calculations!!!

pick 3 transits / observing nights between September 8 and October 7 (spread out to accommodate the weather), e-mail your request to me (first-come, first-serve)

if you don’t have a group yet, send in your observing request anyway