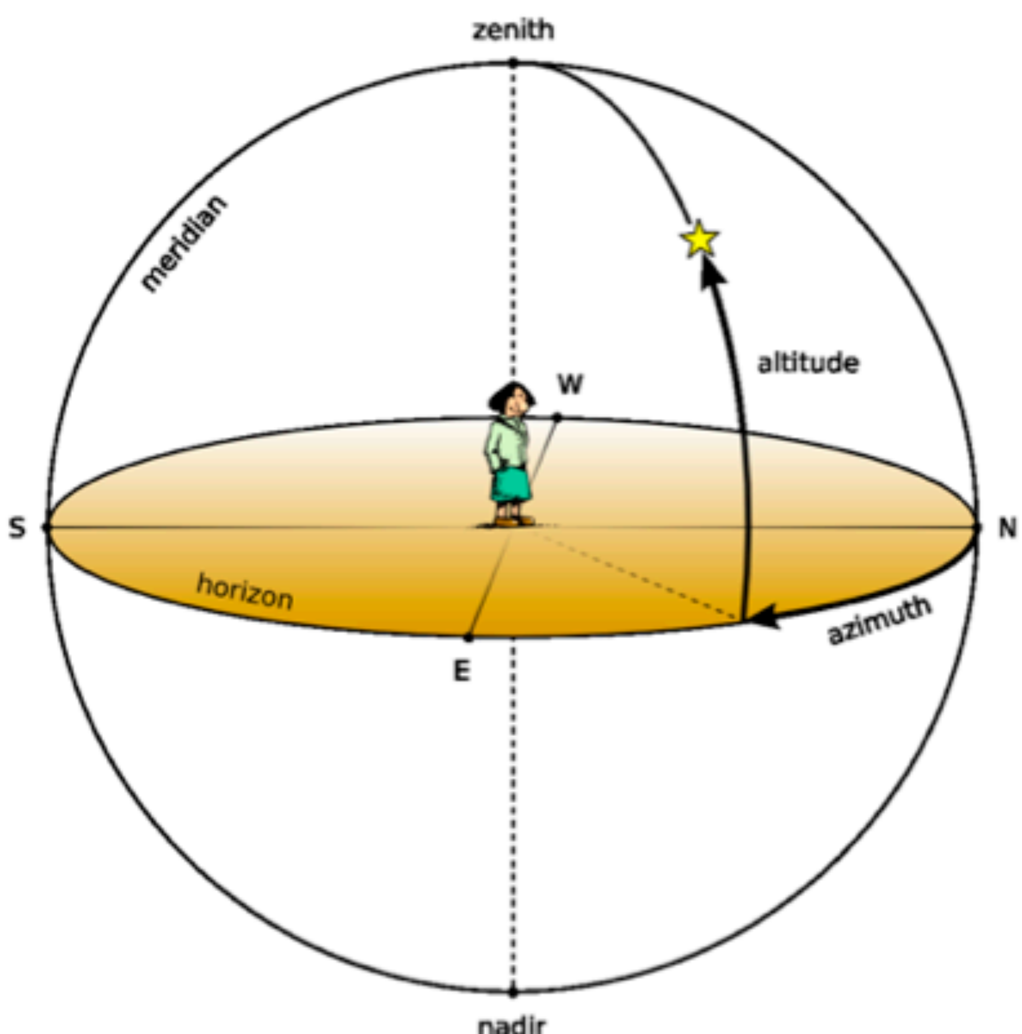
PHY 517 / AST 443: Observational Techniques in Astronomy

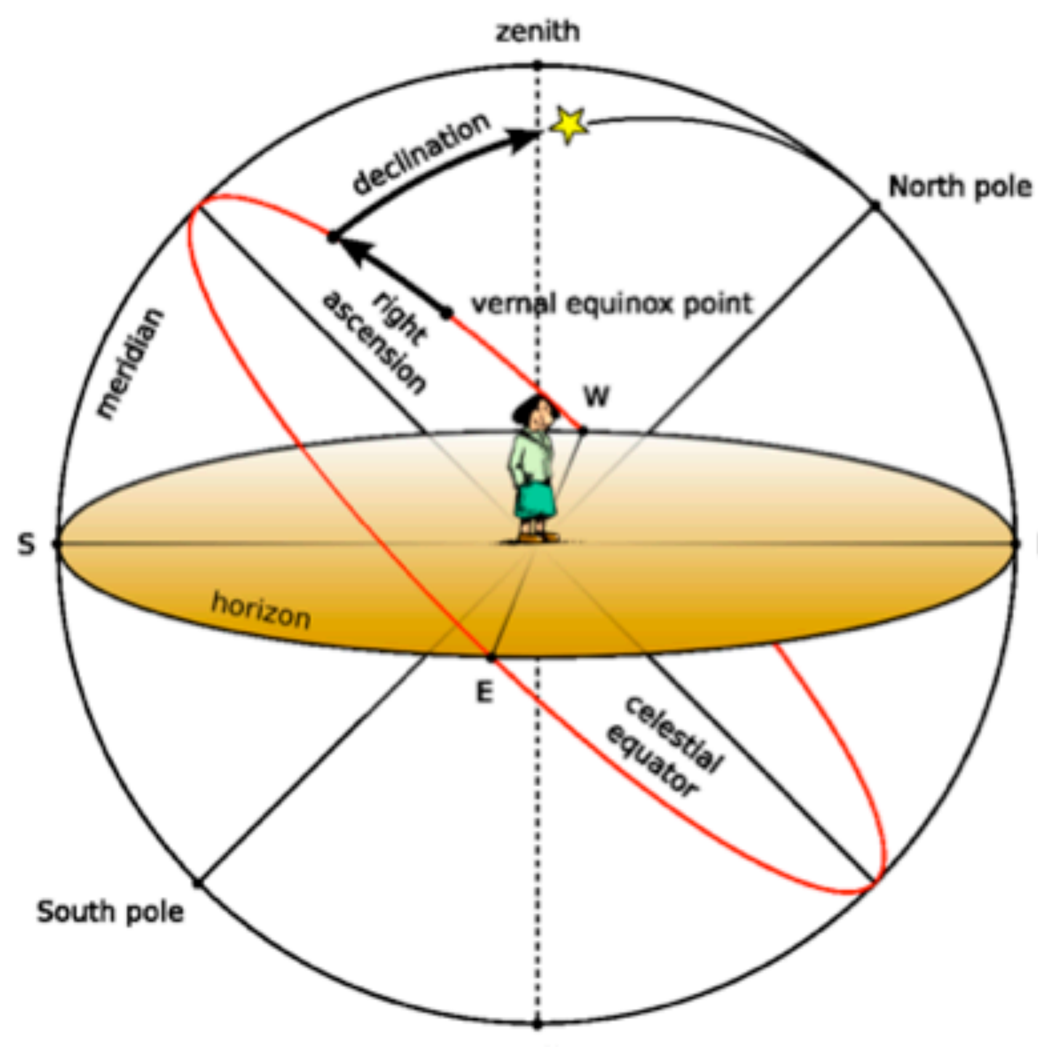
Lecture 2: Flux and magnitudes / Earth's atmosphere / Telescopes / CCDs

Last time...

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

Position on Earth: latitude and longitude
View from observatory: altitude and azimuth
Position on 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)

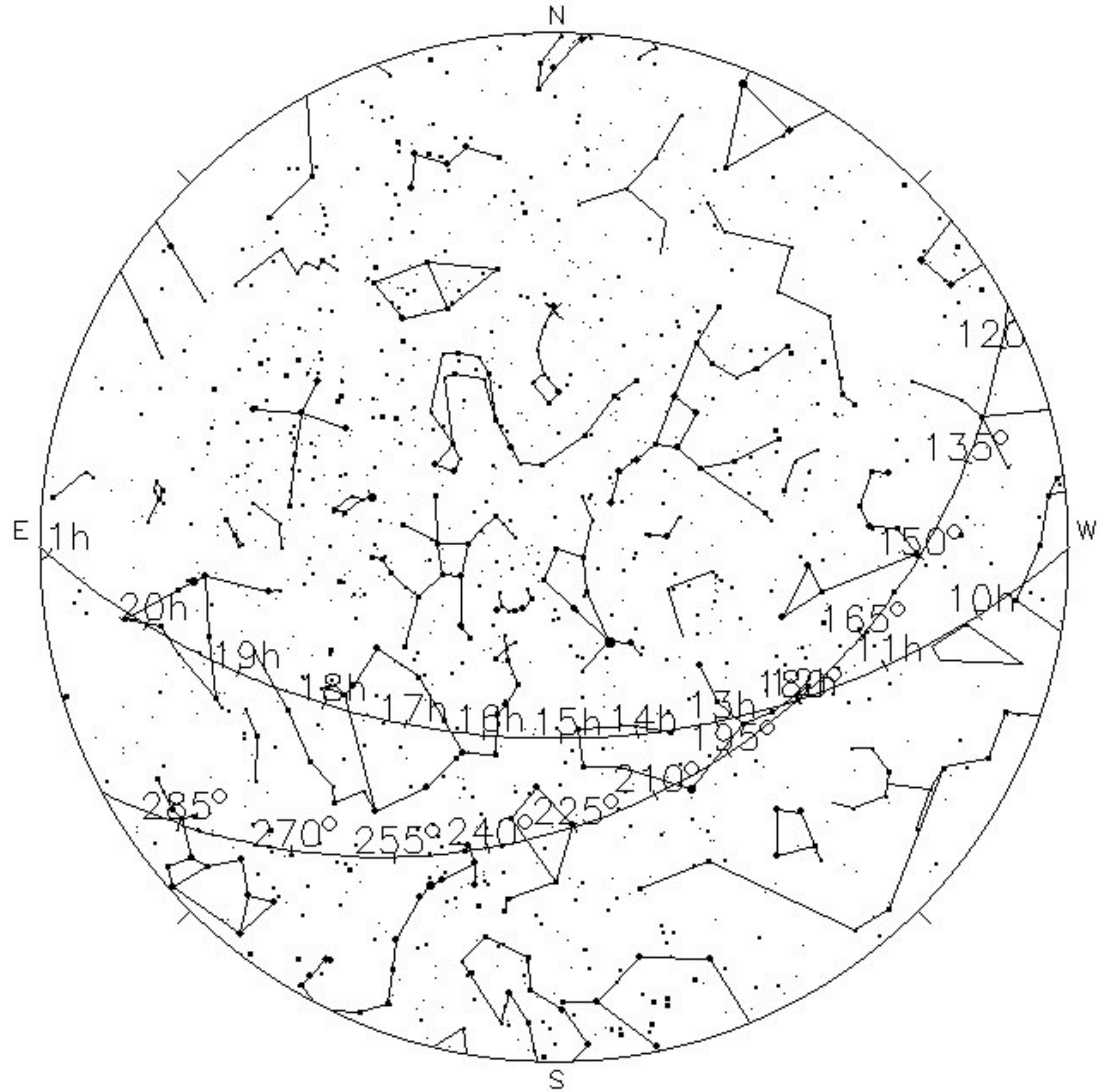
the sky "moves" East to West

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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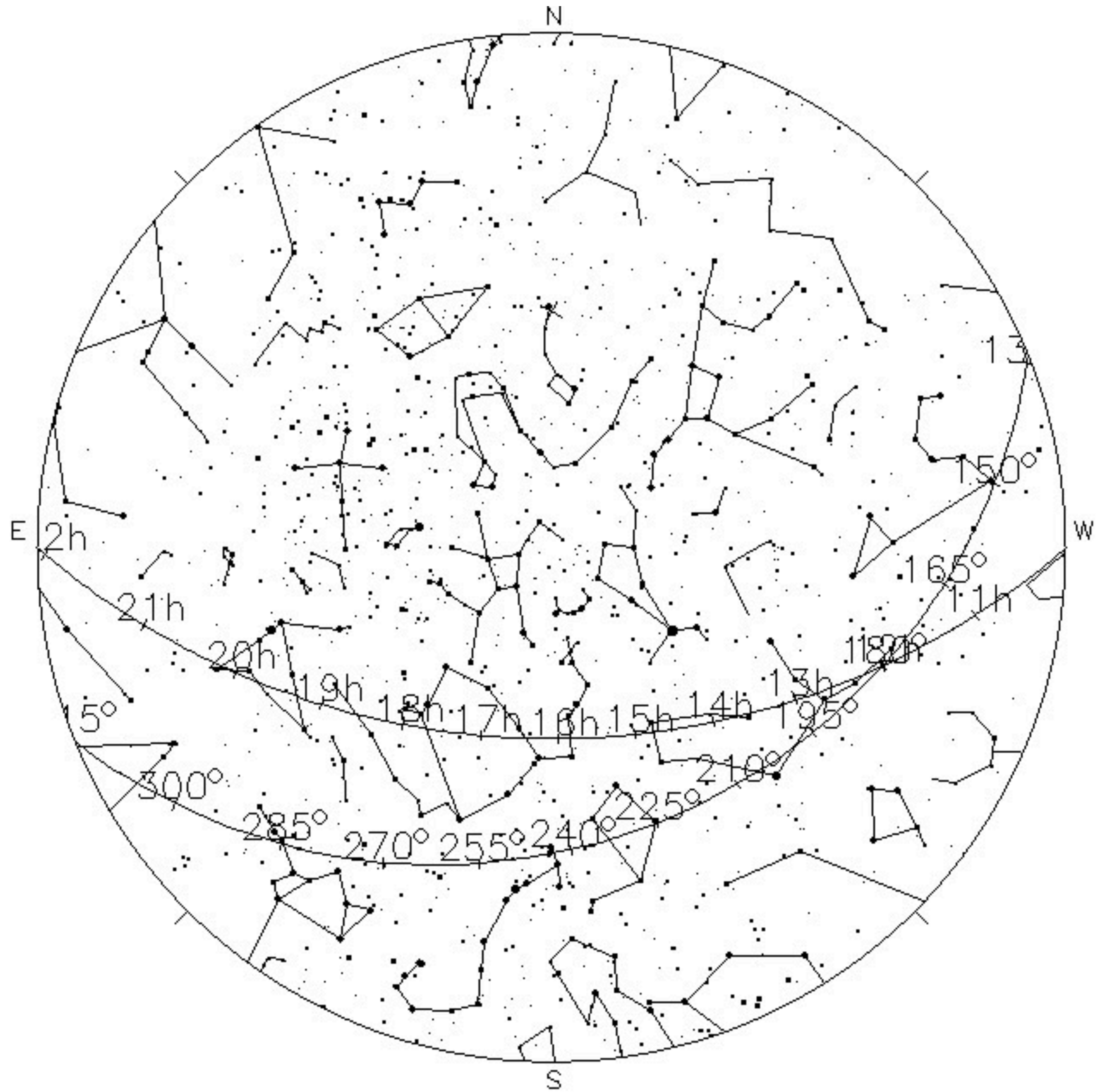


Flux and magnitude:
"How bright is it?"

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!

Q: if $F_1/F_2 = 10$, how big is Δm?

Astronomical magnitudes

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

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

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

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 *d*ω (at an angle θ from normal), in frequency range [ν,ν+*d*ν], during time *dt* is:

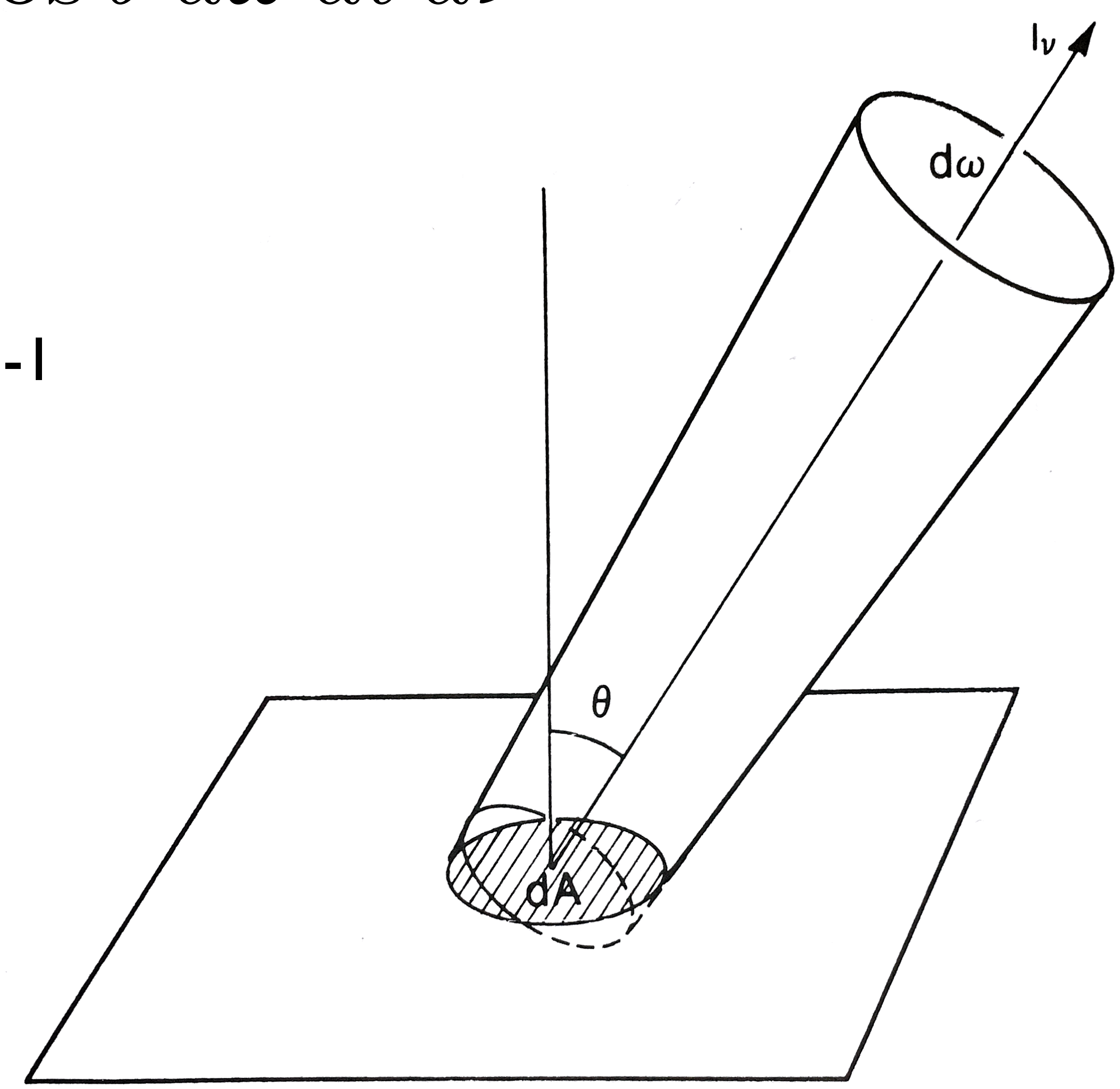
$$dE_\nu = I_\nu \, dA \cos\theta \, d\omega \, dt \, d\nu$$

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: energy (leaving the surface of the star) per area, per time, per frequency interval:

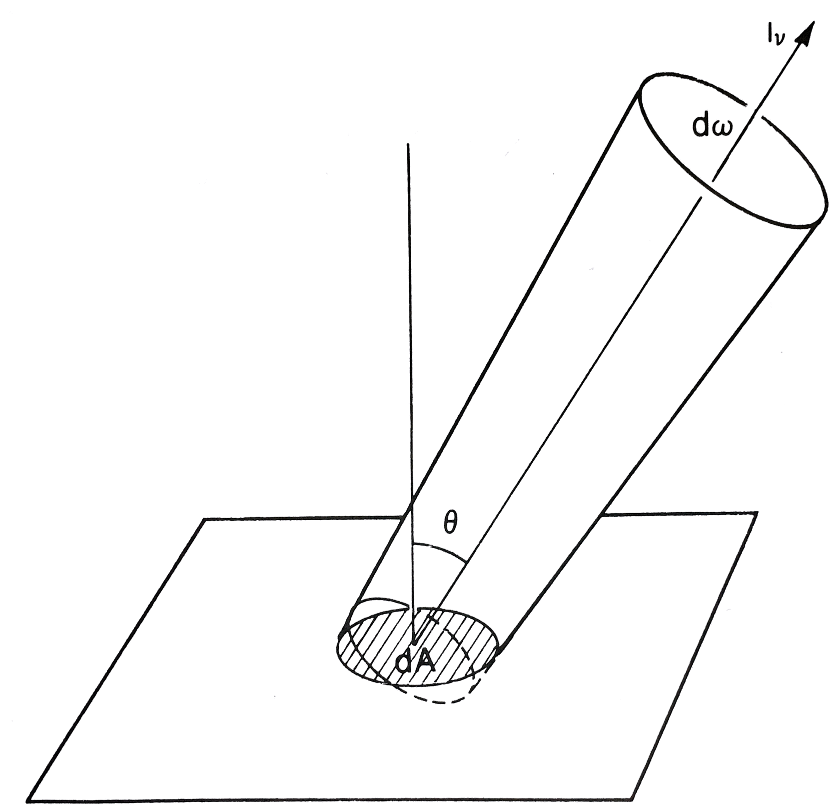
$$f_\nu = \frac{1}{dA\, dt\, d\nu} \int_\Omega dE_\nu$$
$$= \int_\Omega d\omega \; I_\nu \; \cos\theta$$

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)

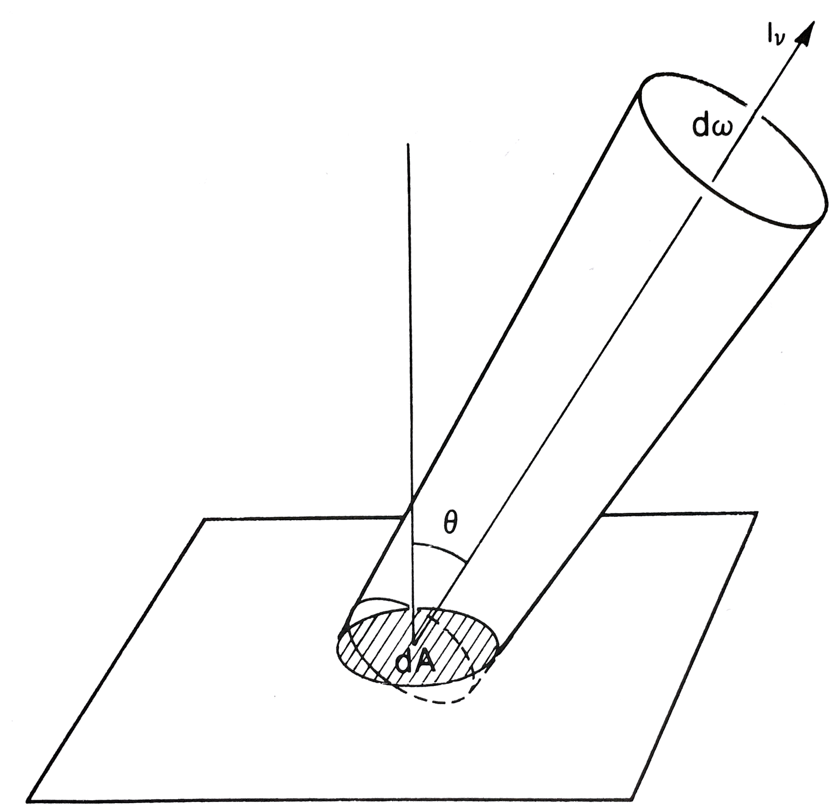


Physical descriptions

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

if radiation is isotropic (I_ν independent of direction), can show that flux density emitted into one hemisphere is:

$$f_\nu = \pi I_\nu$$



Physical descriptions

spectroscopy: can determine f_ν

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

flux (density):

$$F = \int_{\mathrm{passband}} f_\nu \, d\nu$$
$$= \int_{-\infty}^{\infty} T_\nu \, f_\nu \, d\nu$$

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

(note: usually specified for f_λ) $$f_\lambda = \frac{c}{\lambda^2} f_\nu$$

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}

$$= f_\nu \int dA = f_\nu \, 4\pi d^2$$ (assuming isotropy)

- integrate over surface area of star, flux through surface
- or: over sphere at distance d, flux drops as d^{-2}

➡ same result (because of conservation of photons)

intrinsic property of the object !

bolometric luminosity:

$$L_{\mathrm{bol}} = \int_{-\infty}^{\infty} L_\nu \, d\nu$$

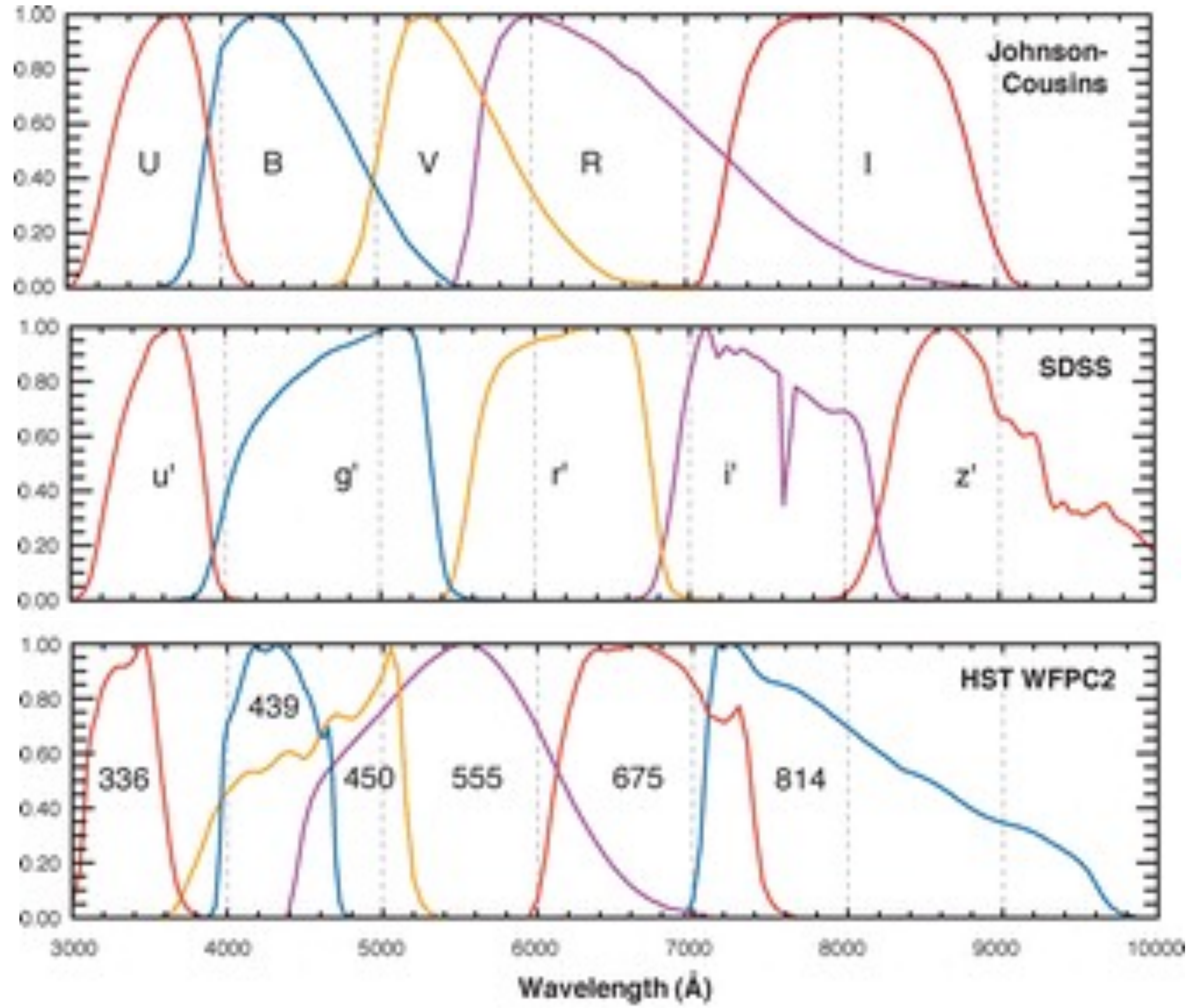
Filter systems

optical astronomy:

several standard photometric systems, "filter sets"

Johnson-Cousins: *UBVRI*

SDSS: *ugriz*



Color

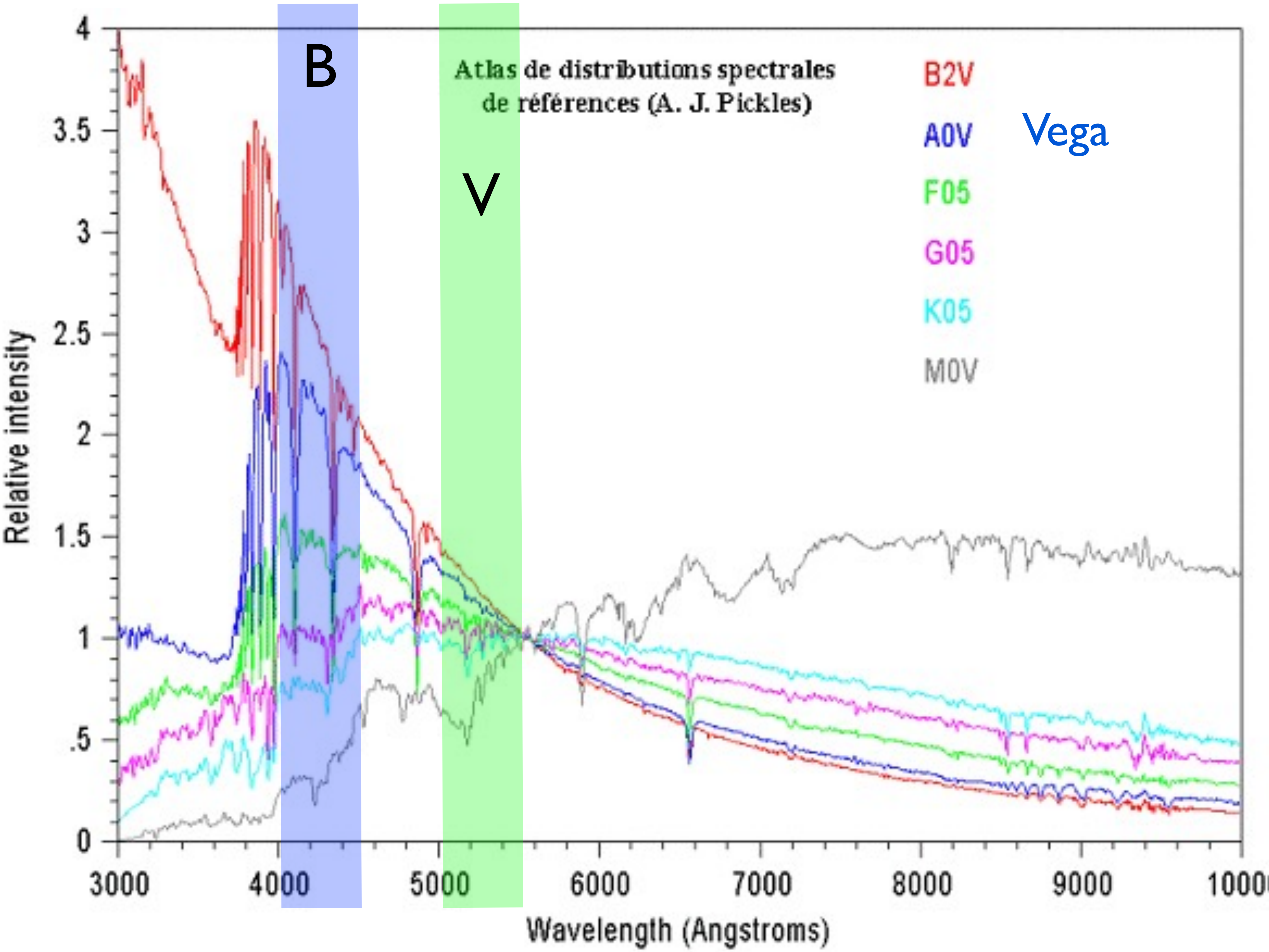
difference between magnitudes in two bands (e.g. B,V):

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

Vega has 0 color, by definition

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

Color



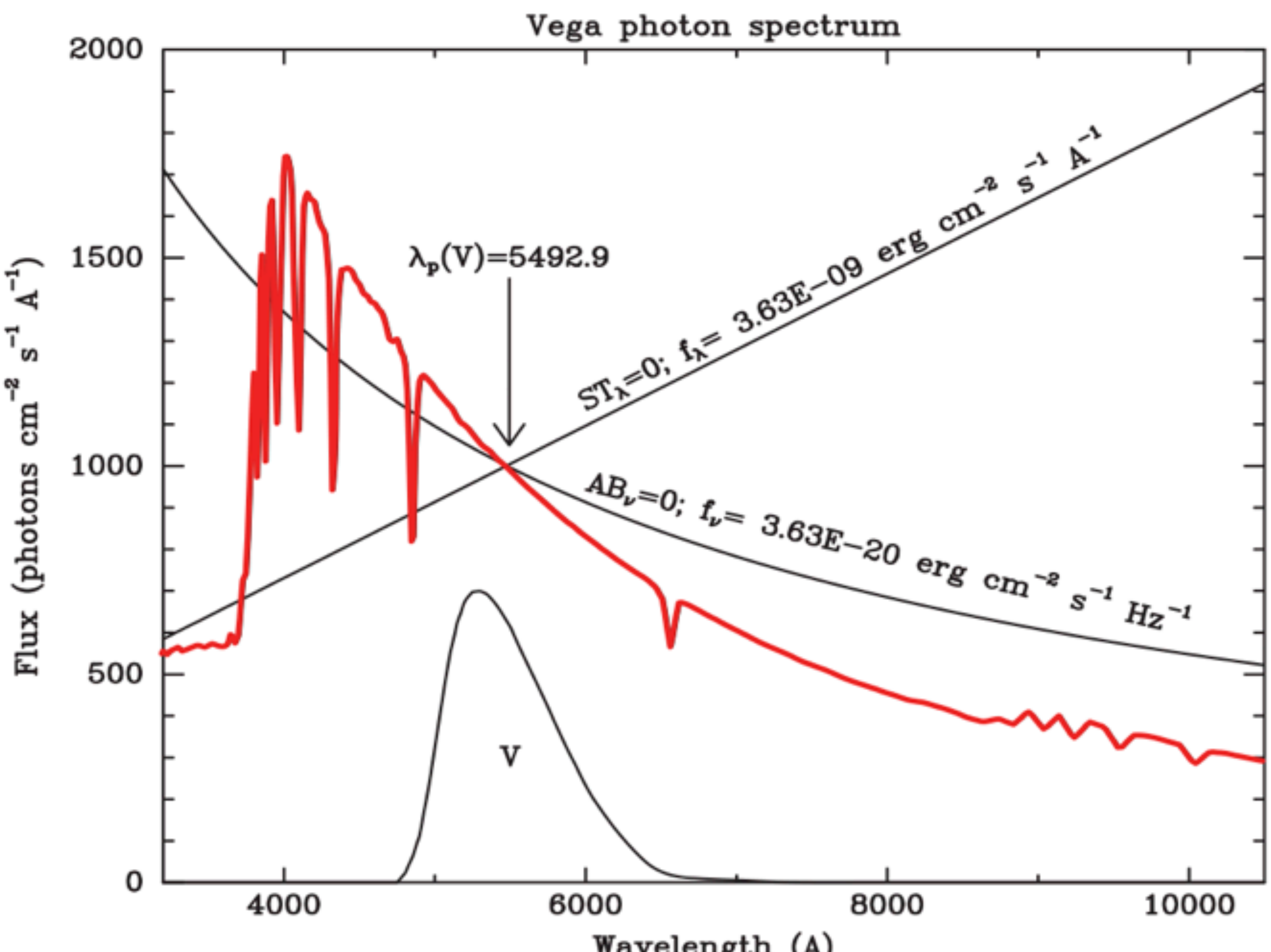
B
V
Atlas de distributions spectrales
de références (A. J. Pickles)
B2V
A0V
Vega
F05
G05
K05
M0V
Relative intensity
Wavelength (Angstroms)
0
.5
1
1.5
2
2.5
3
3.5
4
3000
4000
5000
6000
7000
8000
9000
10000

AB magnitudes

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

defined relative to *constant flux per unit frequency*

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:

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

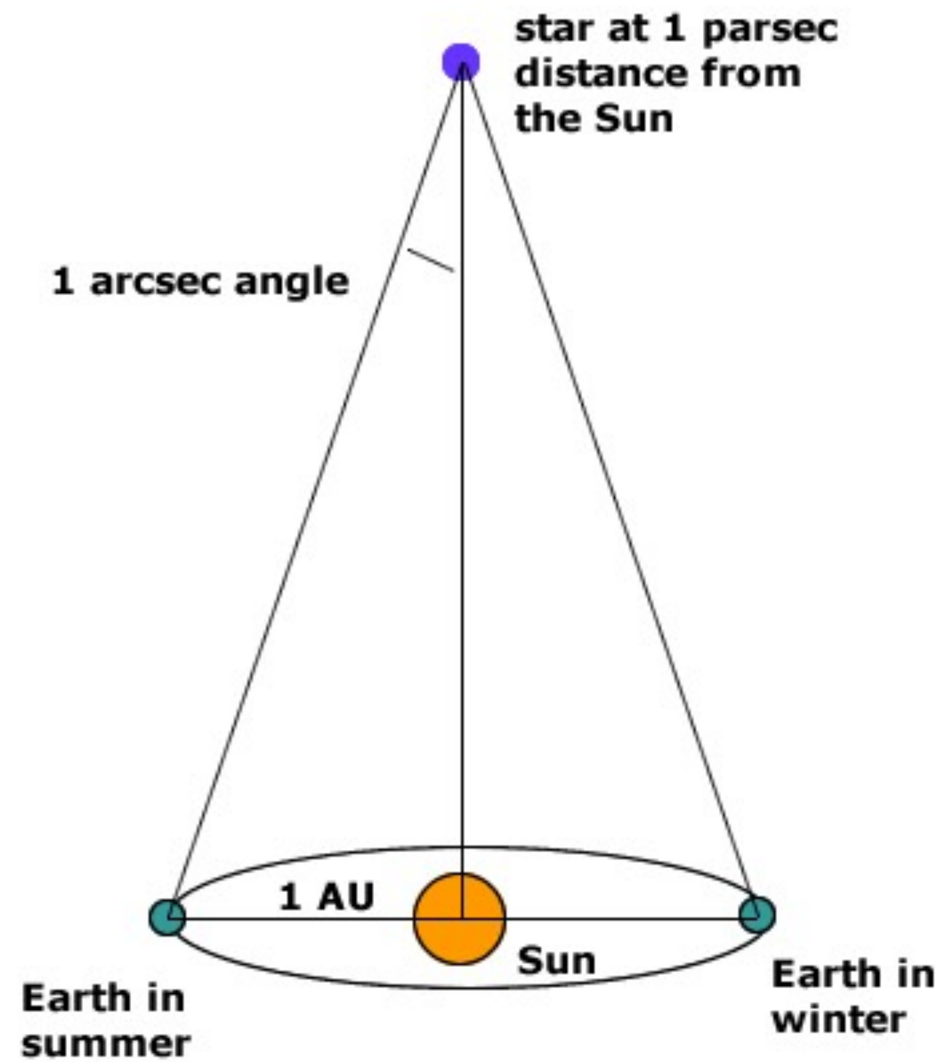
Parallax and parsecs

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

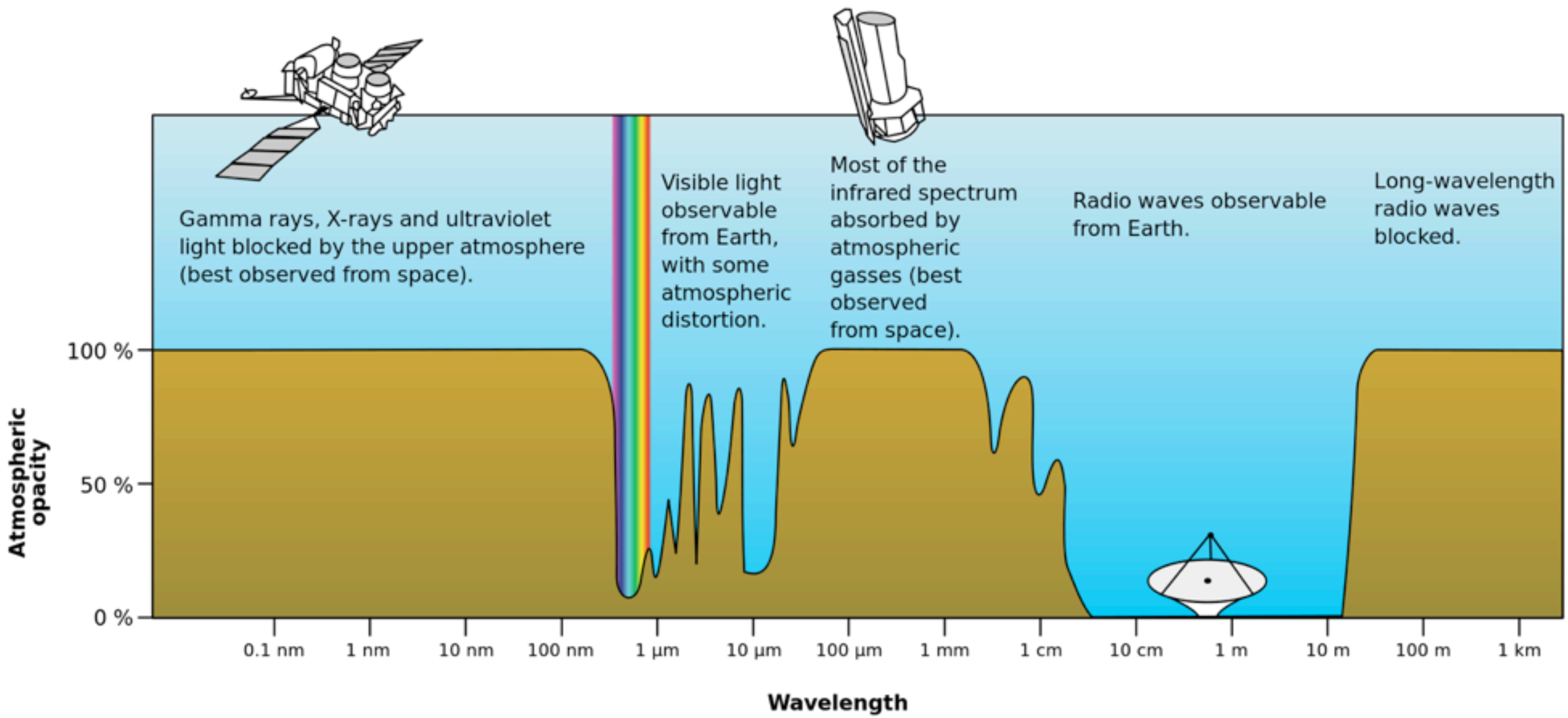
1 pc = 3.26 light-years = 3 x 10^{16}m

Proxima Centauri: ~1.3 pc



Earth's atmosphere

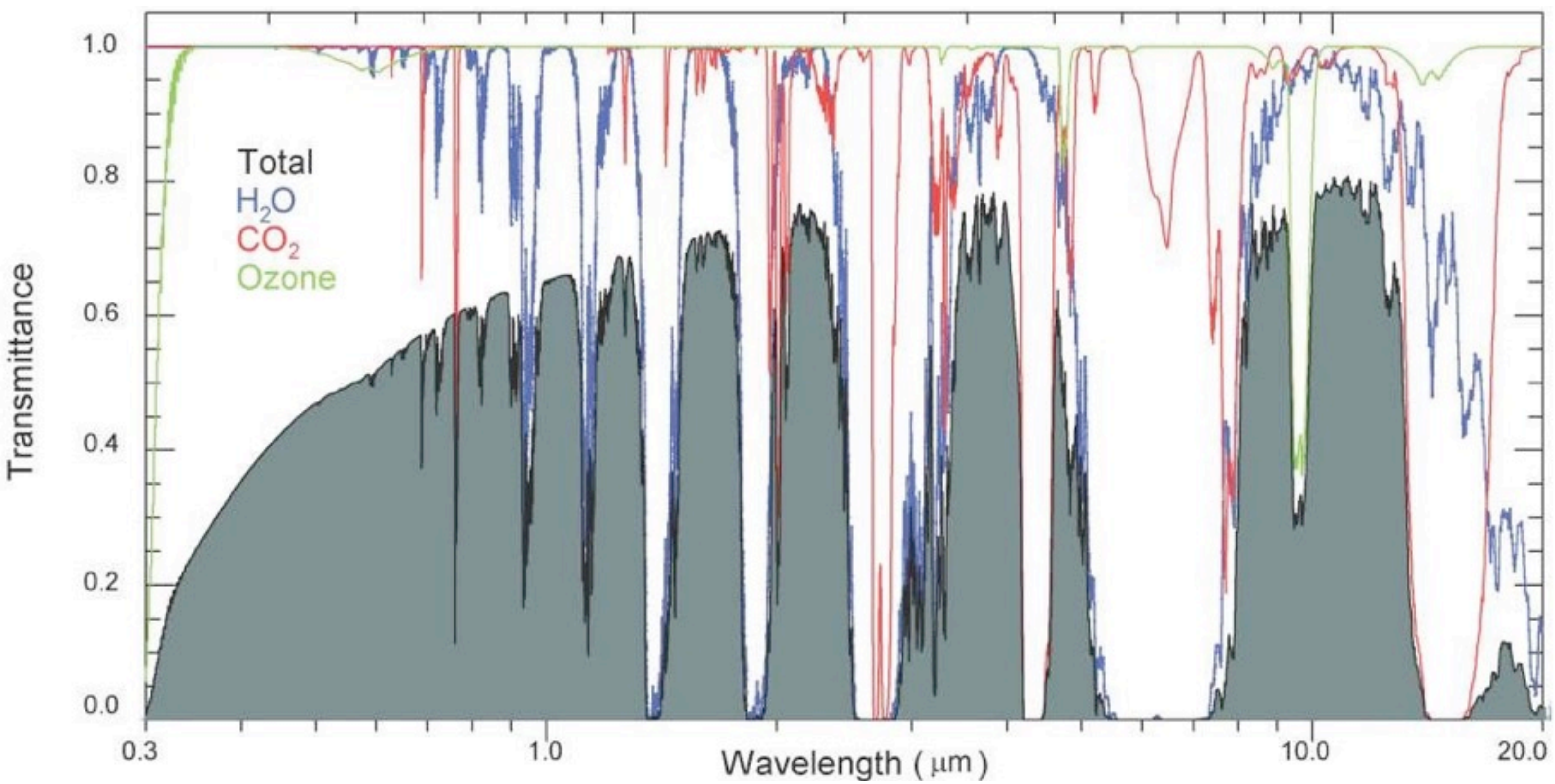
the atmosphere is opaque to most of the electromagnetic spectrum



Earth's atmosphere

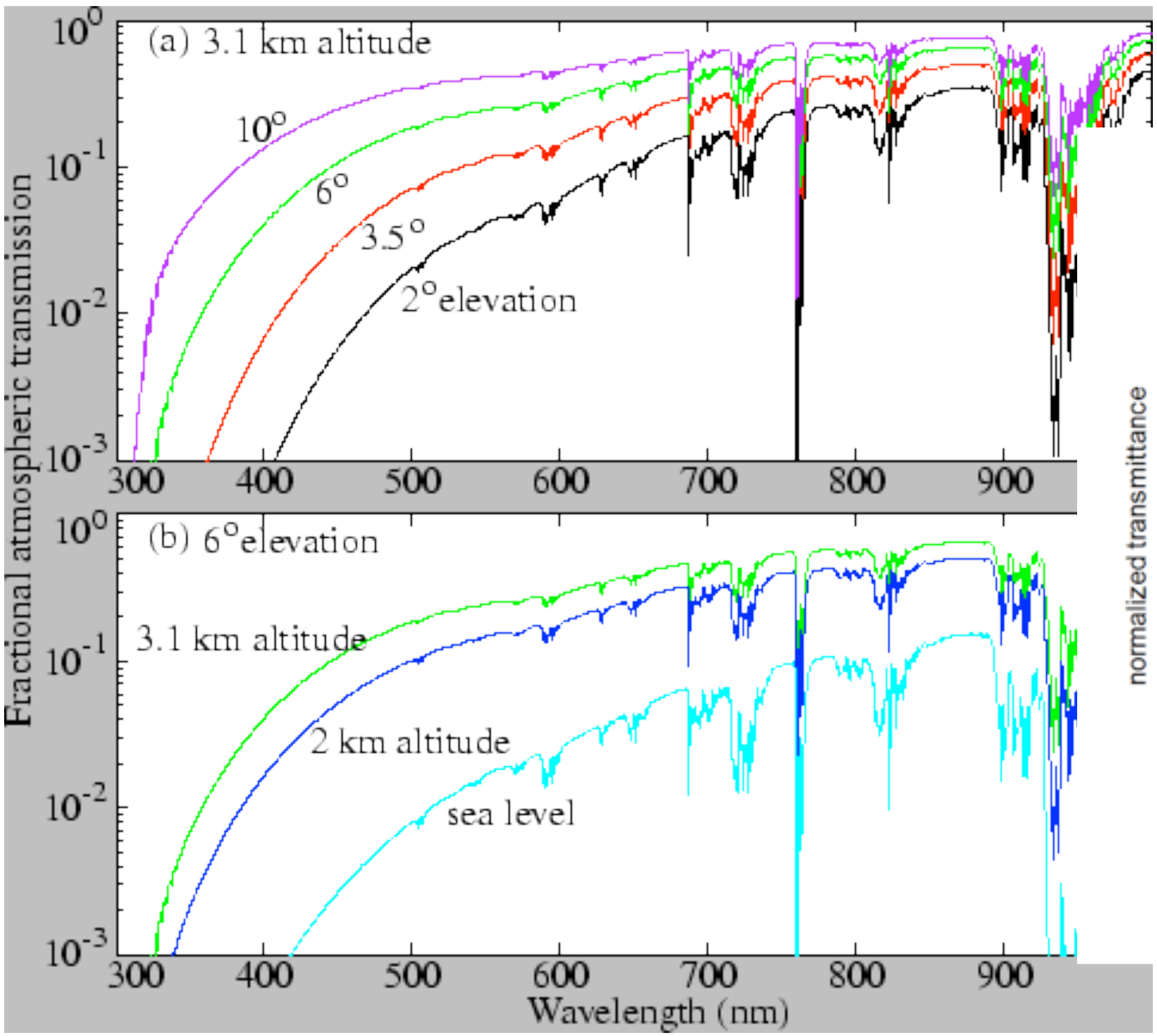
in the optical (~300nm - 1 μm) and near-infrared, extinction due to:

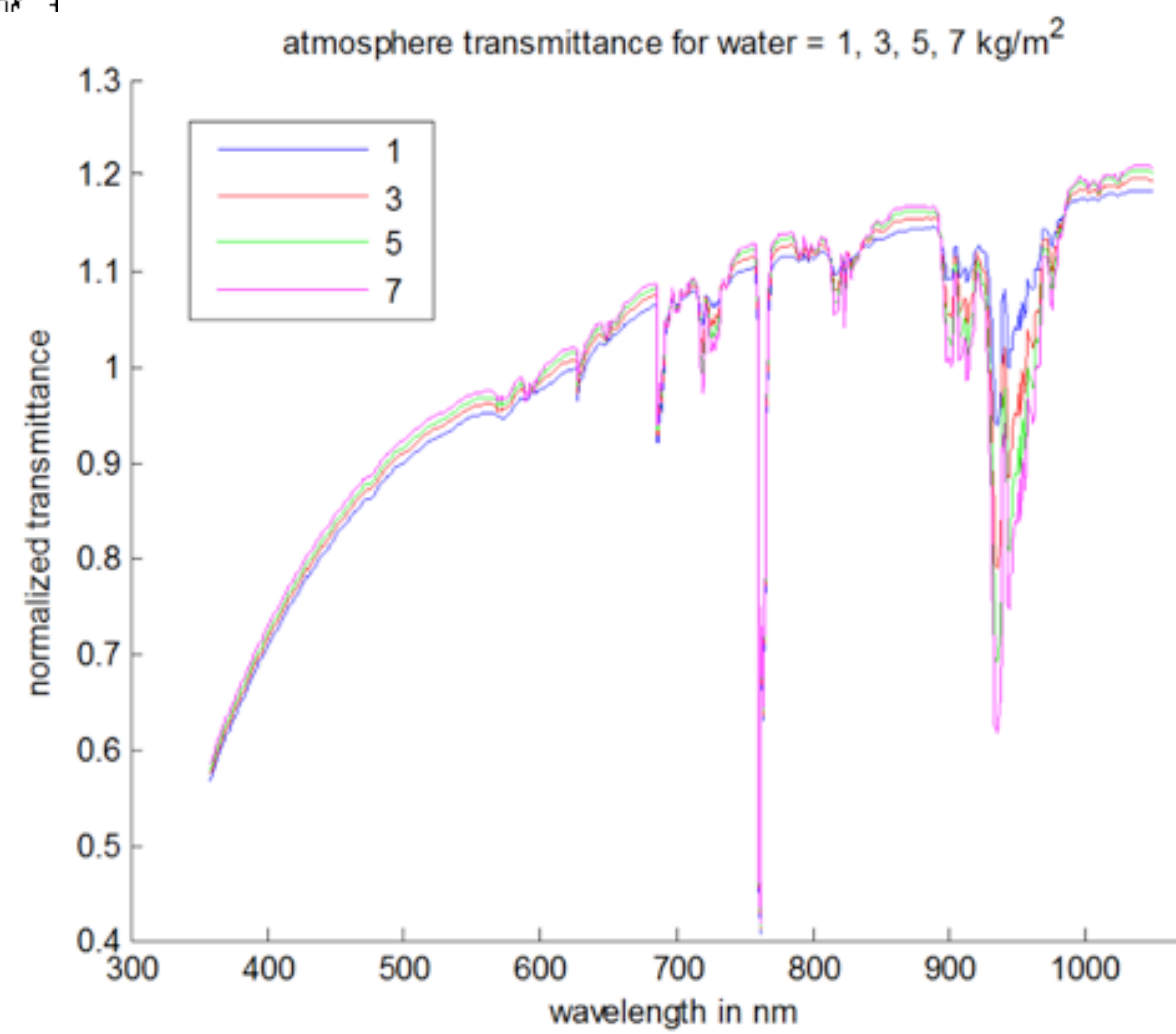
- scattering, e.g. Rayleigh $\propto \lambda^{-4}$
- absorption bands, mainly water



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:

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

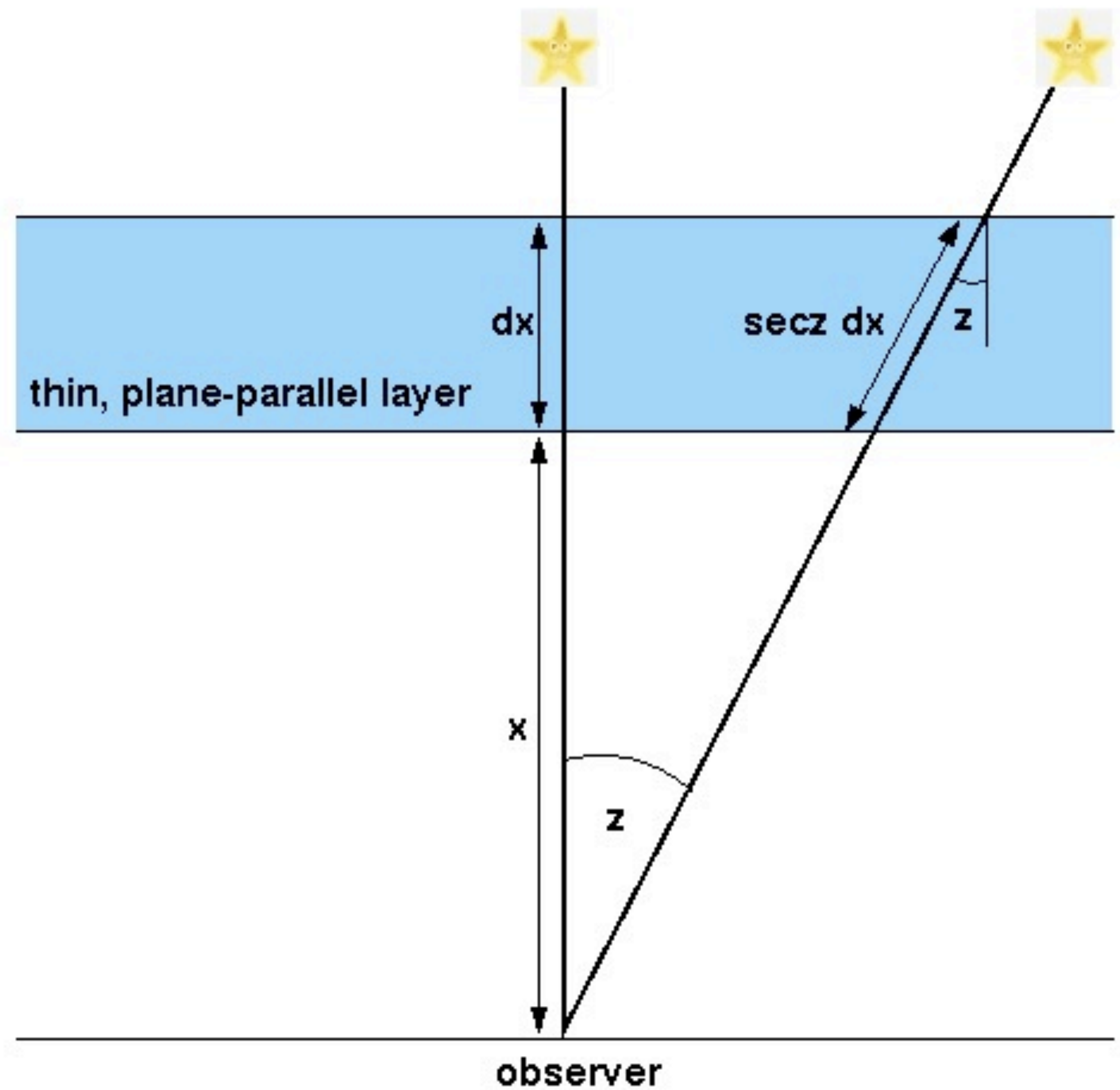
zenith distance:

z = 90° - altitude h

h=90°: AM=1

h=50°: AM=1.3

h=30°: AM=2



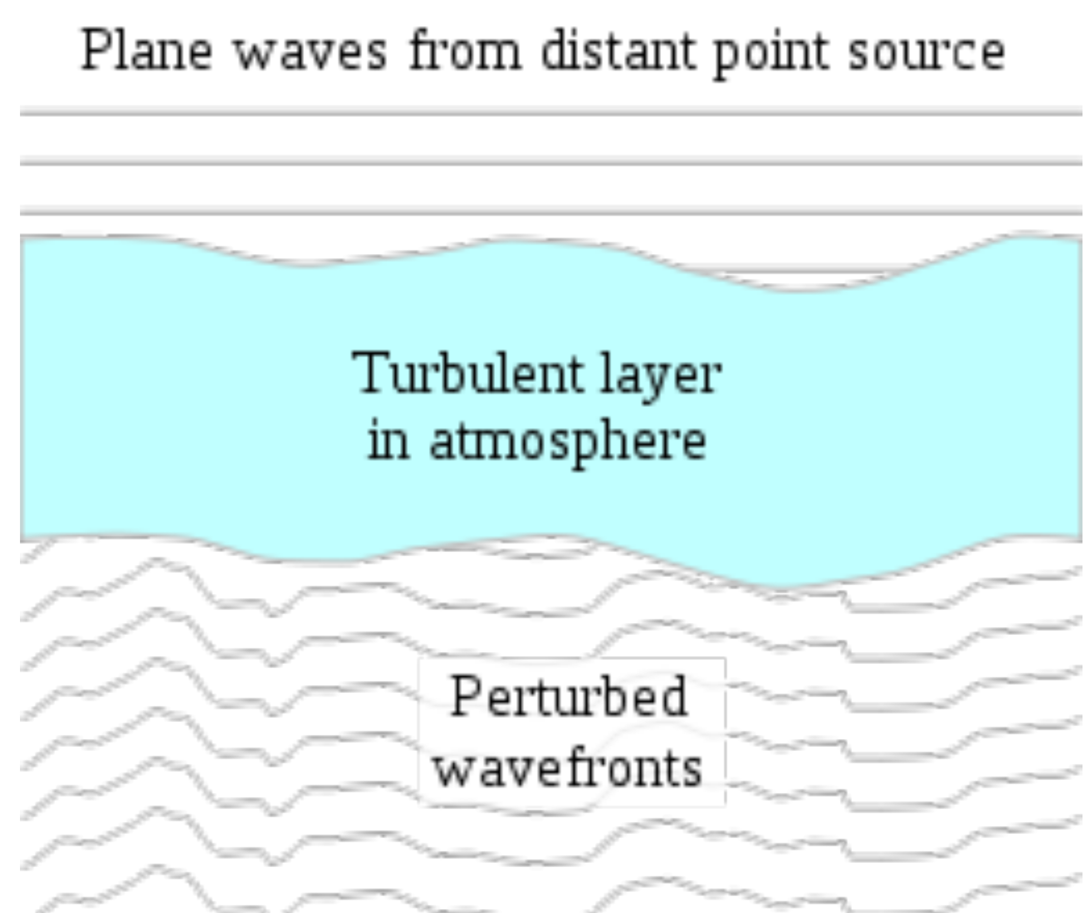
Seeing

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

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

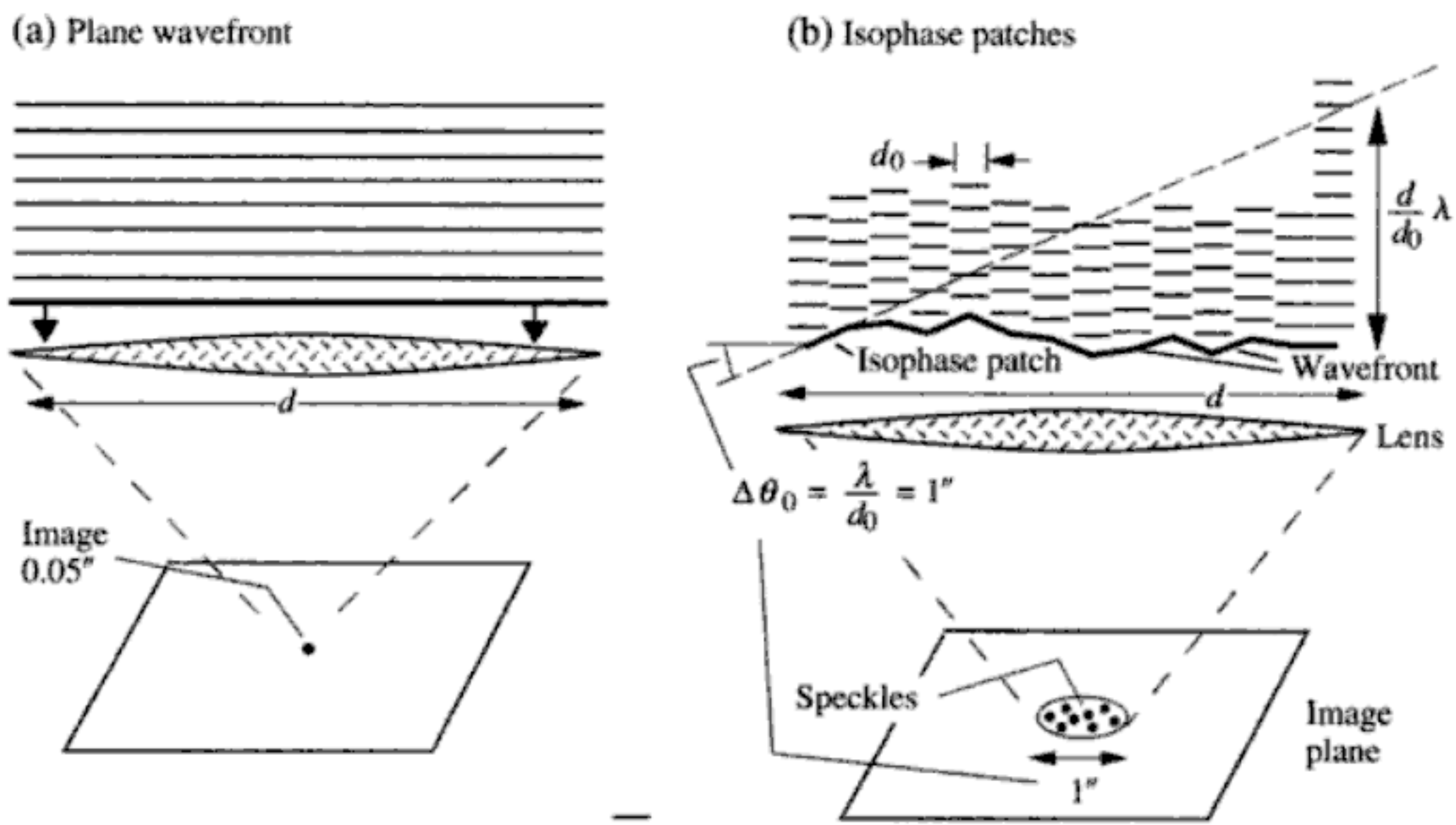
theoretical resolution of 14 inch telescope: ~0.3”

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"



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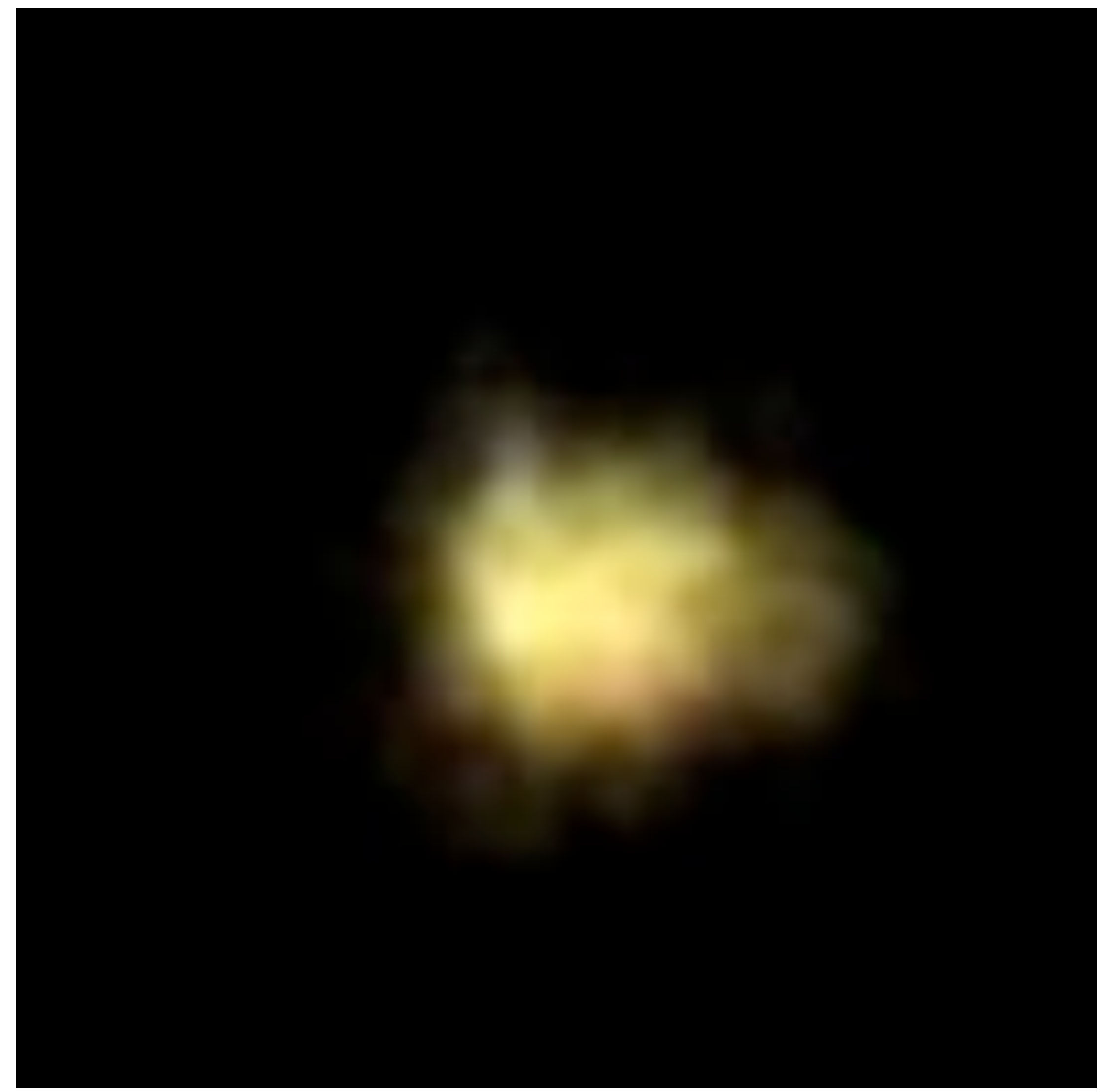


Seeing

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!

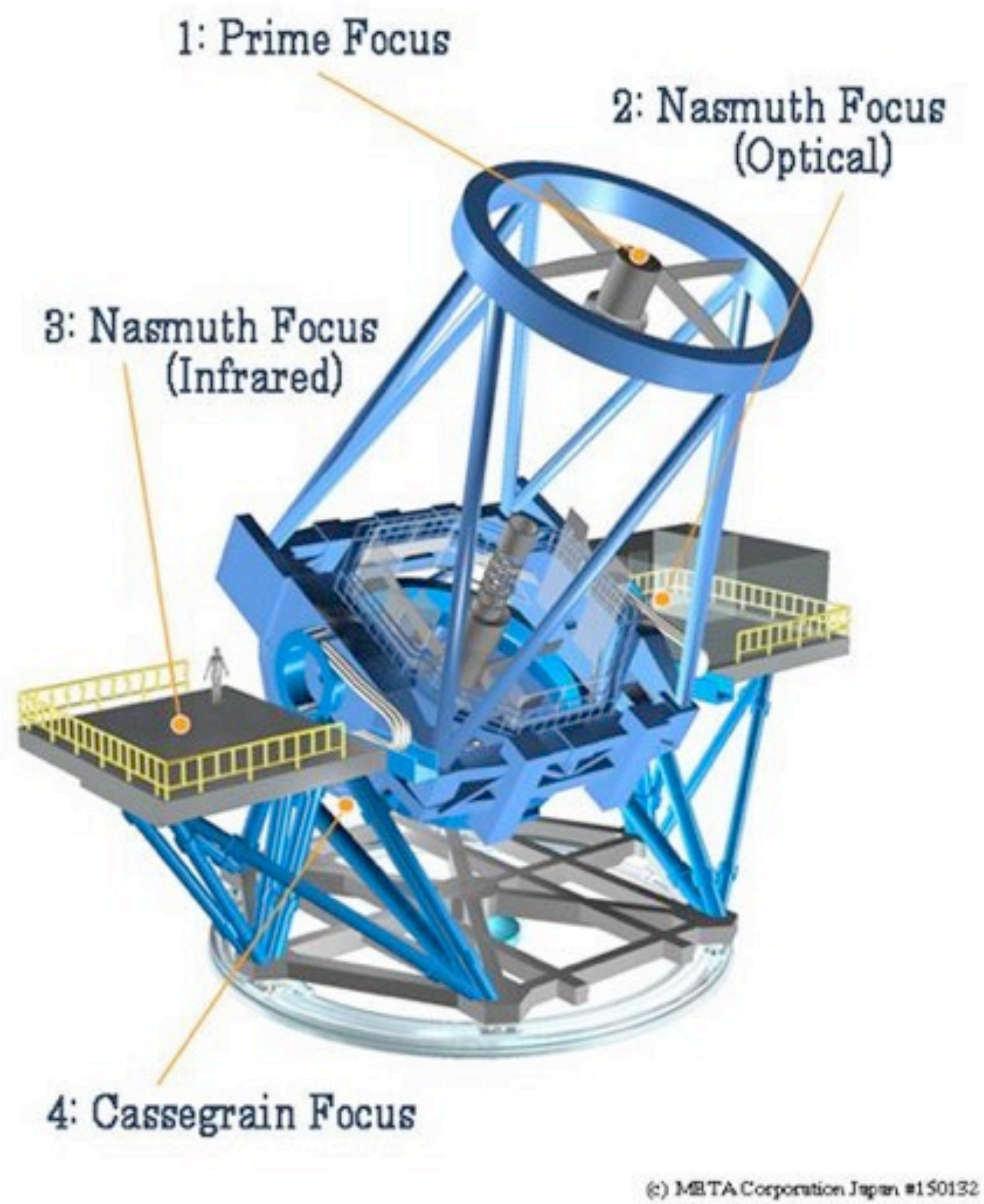
modern domes have lots of windows, day-time AC

(A little bit about)

Telescopes

Big telescopes

- all big telescopes are reflectors (mirror telescopes)
- big lenses are too expensive / impossible to make
- many big telescopes have several instruments mounting points (at different foci)

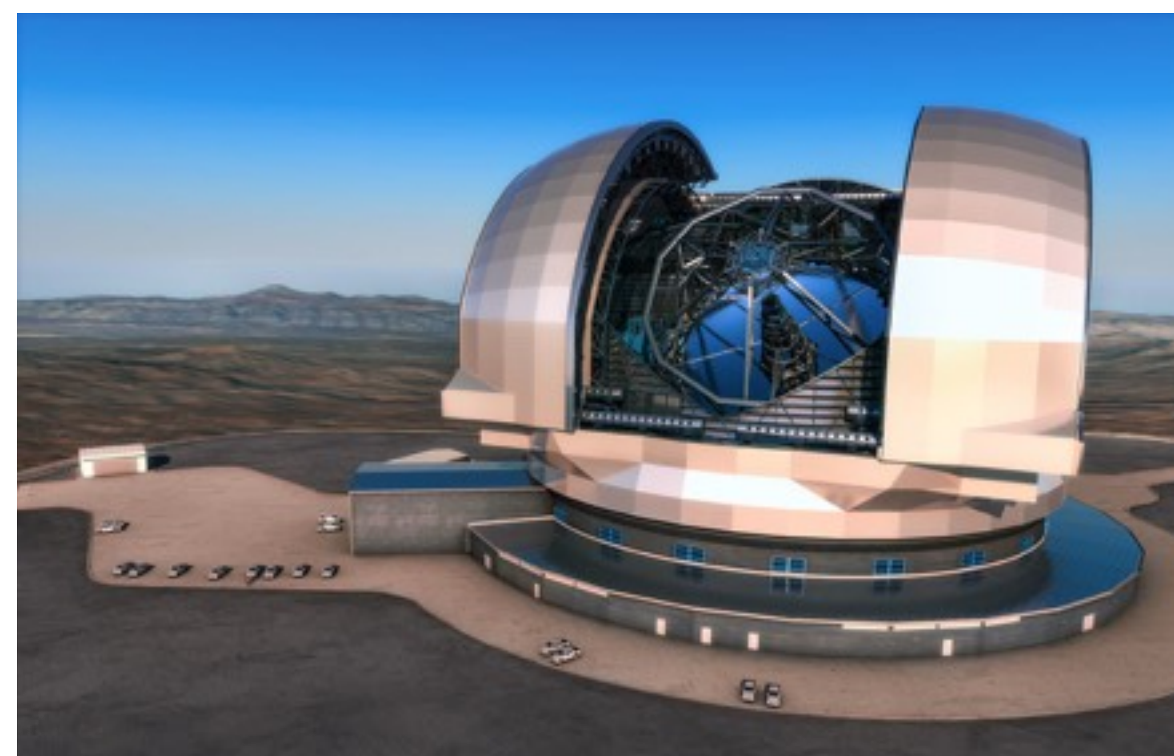


Aperture

- most (new) things in astronomy are faint (but not all!)
- need to gather as much light as possible
- the diameter of the mirror (aperture) is one of the main characteristics of a telescope

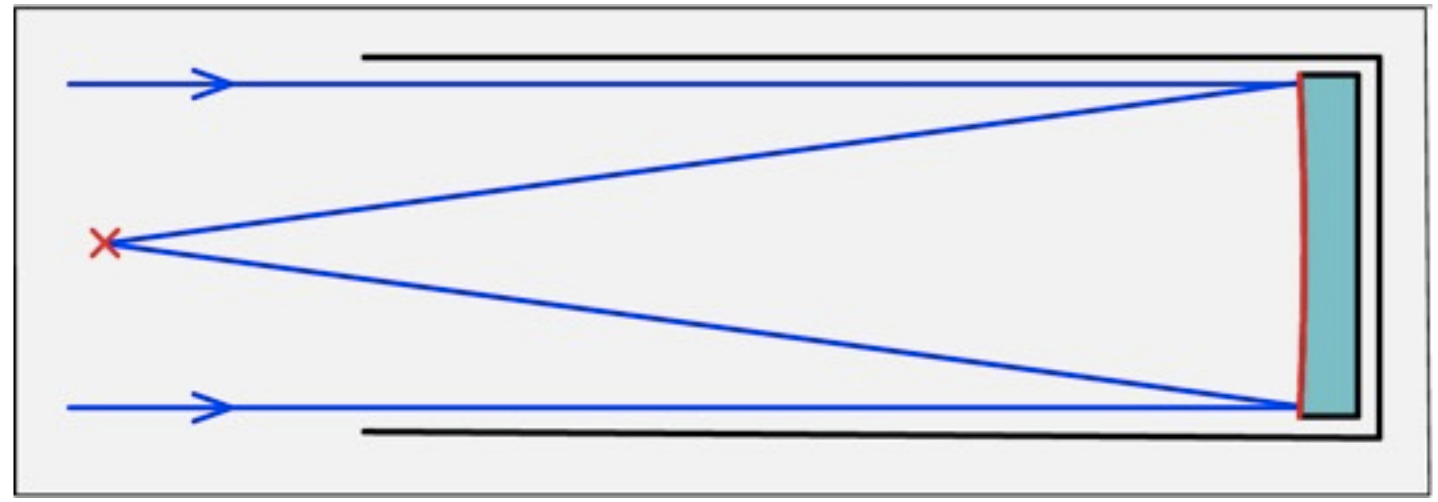
Keck Telescopes: 10m

next generation: 30m telescopes (~2025)

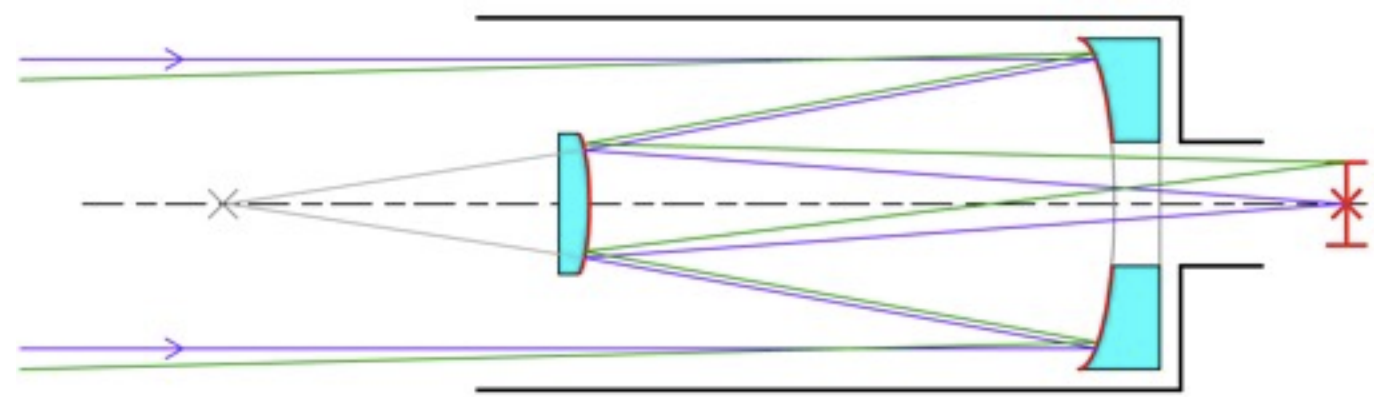


Telescope foci

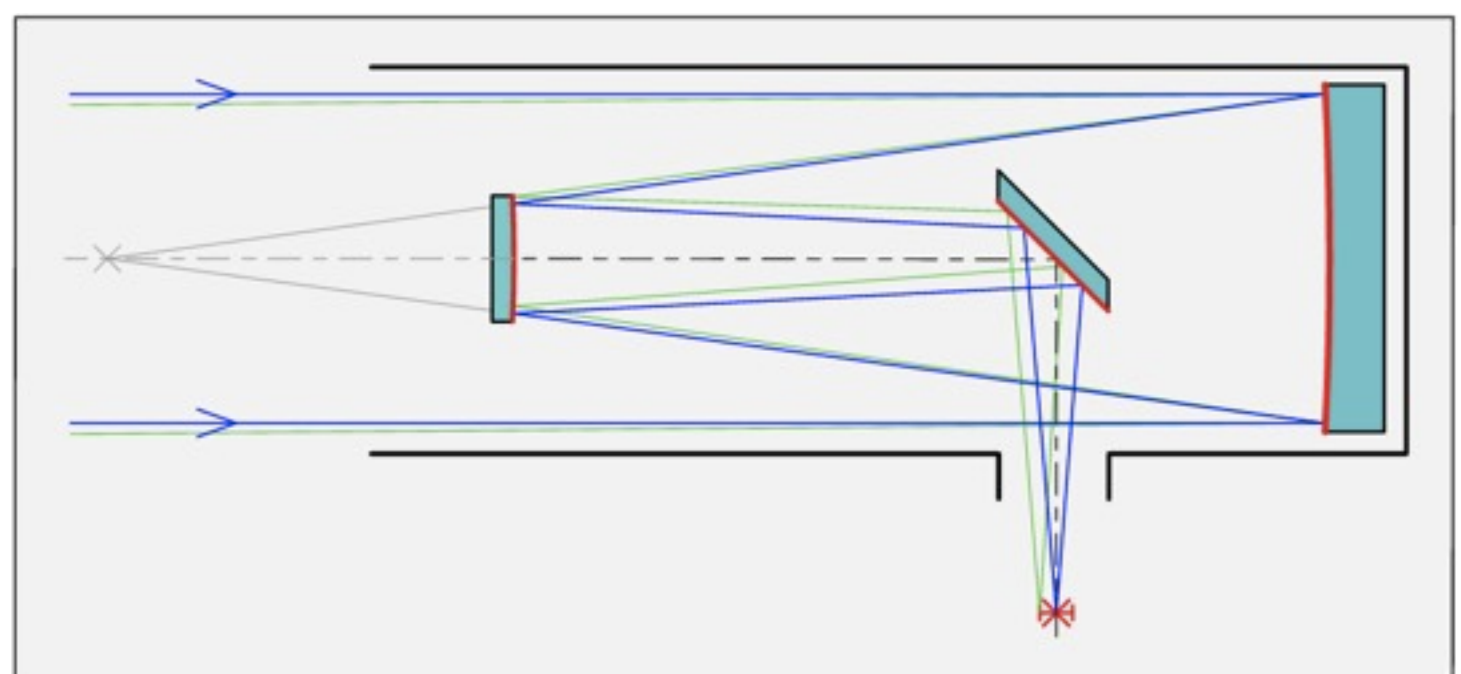
- prime focus: focus of primary mirror



- Cassegrain focus: secondary mirror in front of prime focus; secondary focus behind primary mirror

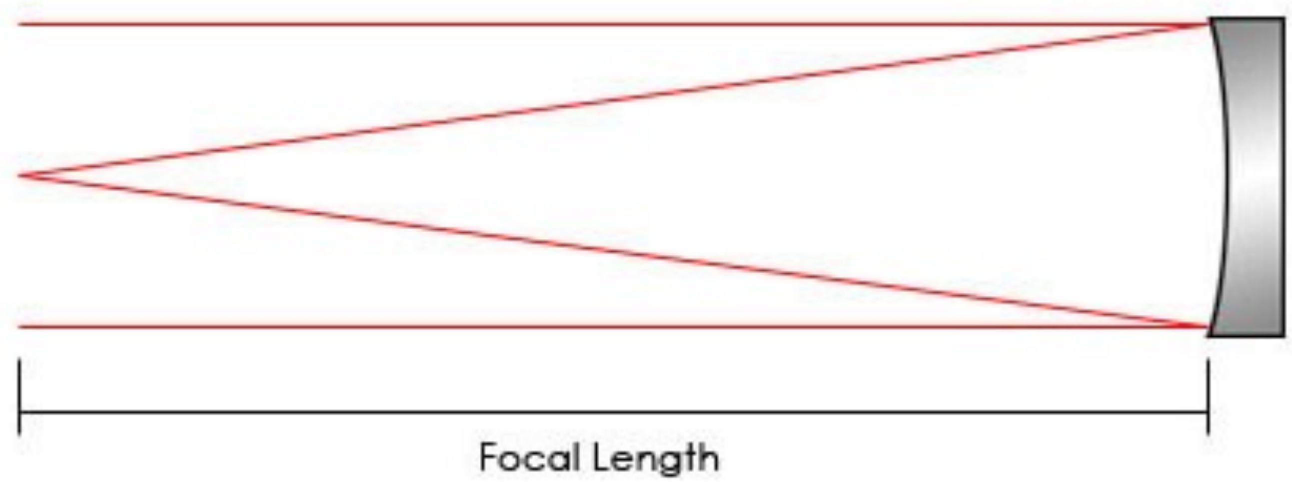


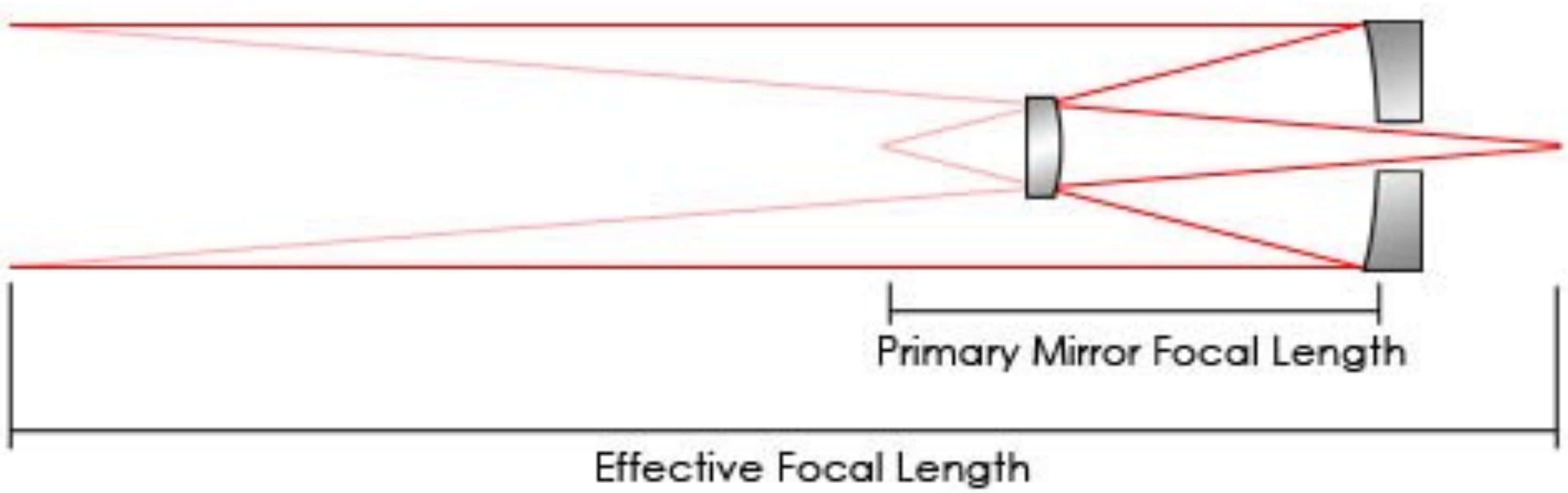
- Nasmyth focus: pick-up mirror, can be placed through mount axis



Focal length

distance from mirror / lens to the focus place





Focal ratio (“f number”)

distance from mirror / lens to the focus place

$$\text{focal ratio} = \frac{\text{focal length}}{\text{aperture}}$$

measure of how “fast” the lens / mirror is

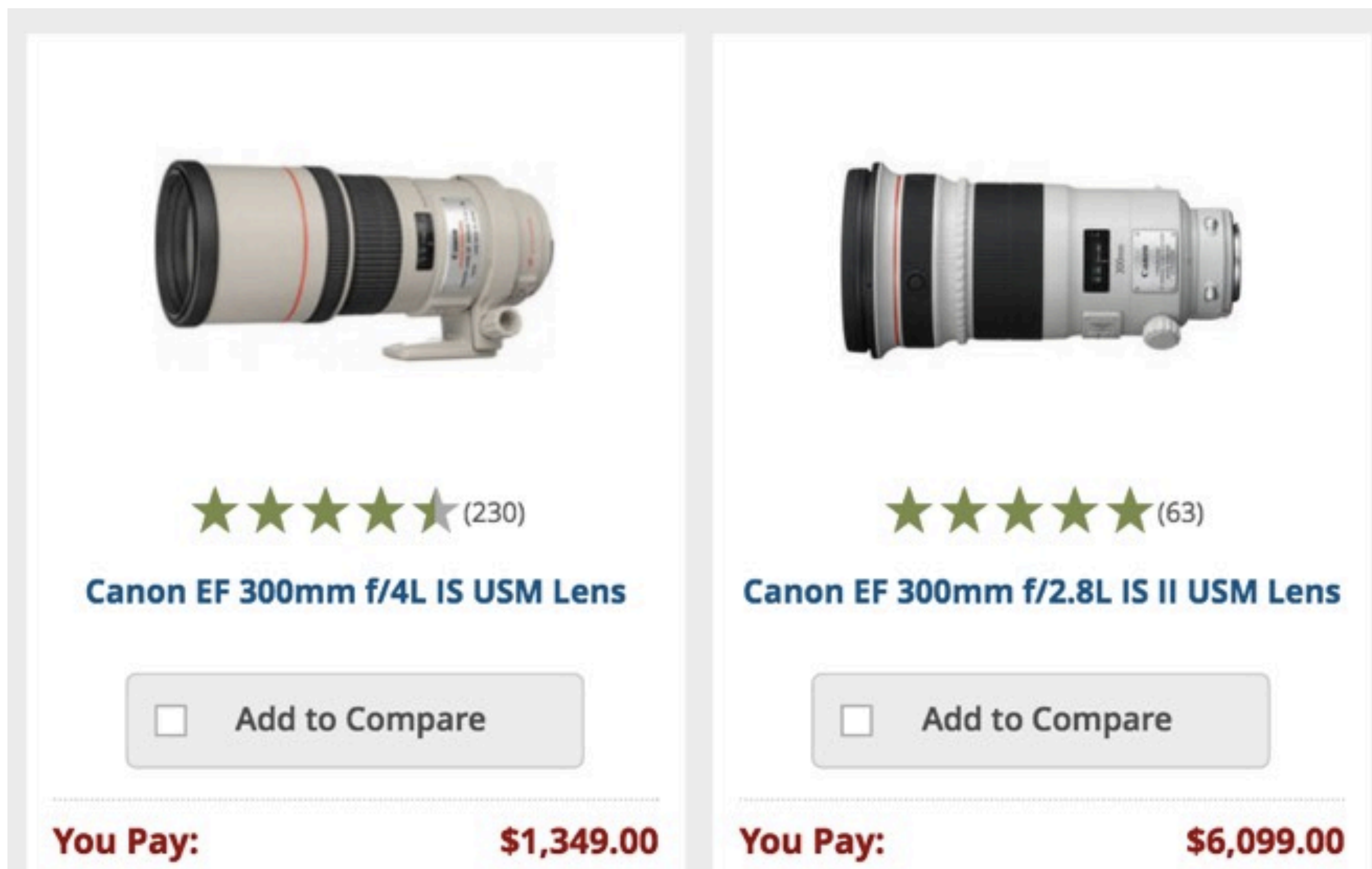


Plate Scale

how big is the image / how much sky does the detector see?

$$\theta \approx \tan\theta = \frac{y}{f}$$

$$\frac{d\theta}{dy} = \frac{1}{f}$$

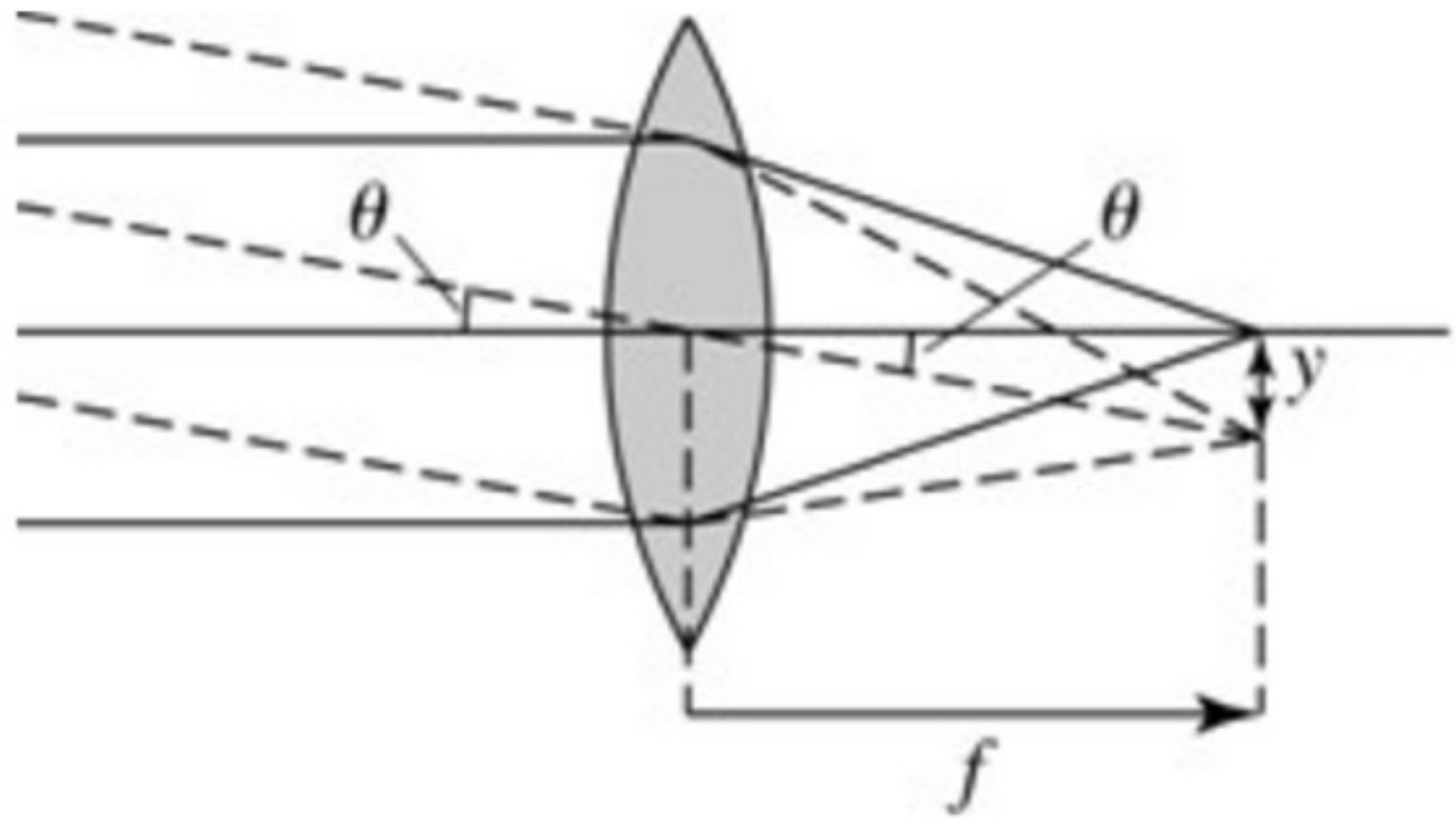


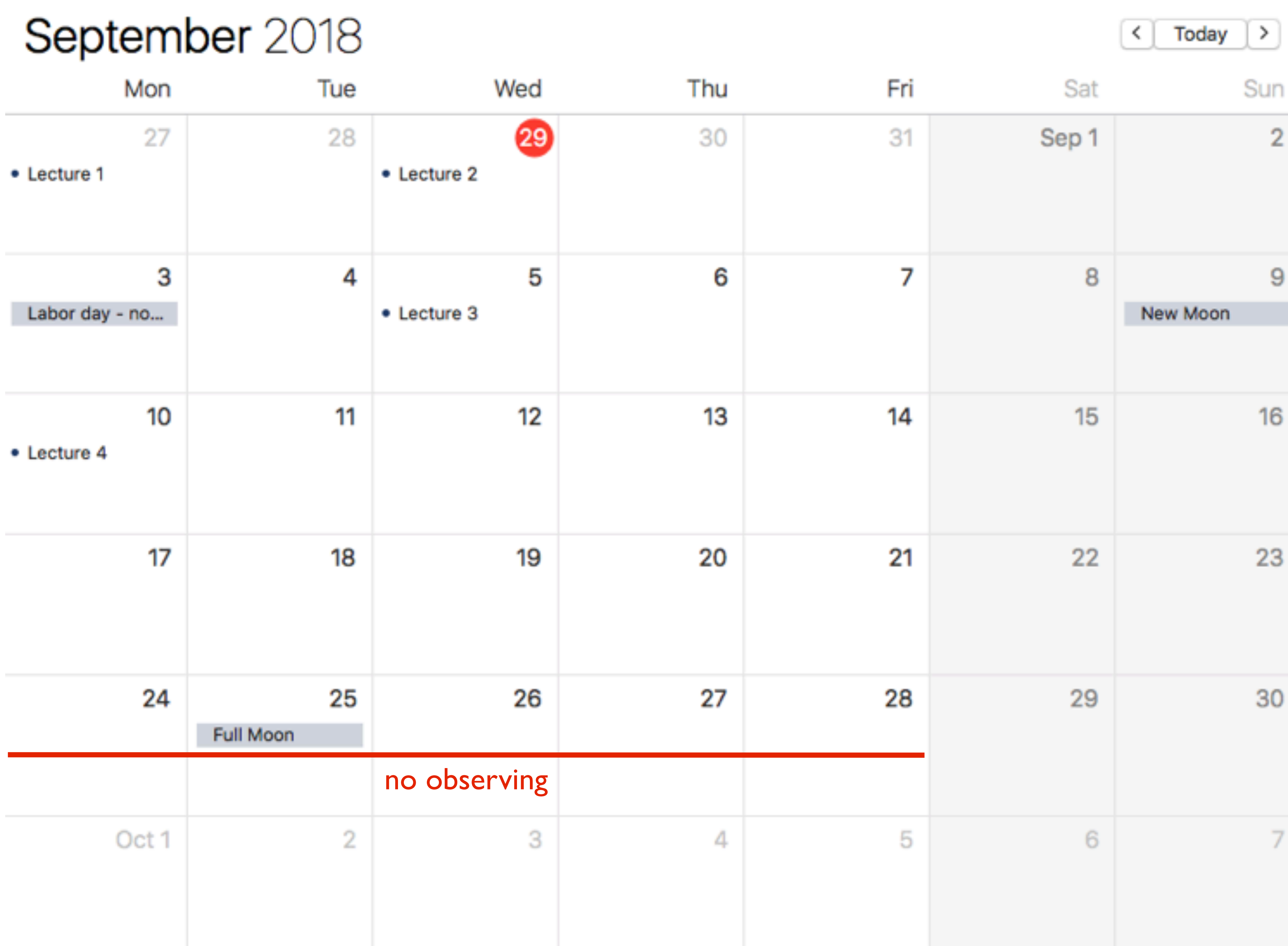
plate scale = (focal length)$^{-1}$

units: arcseconds / mm

Preparing for your observations

Homework

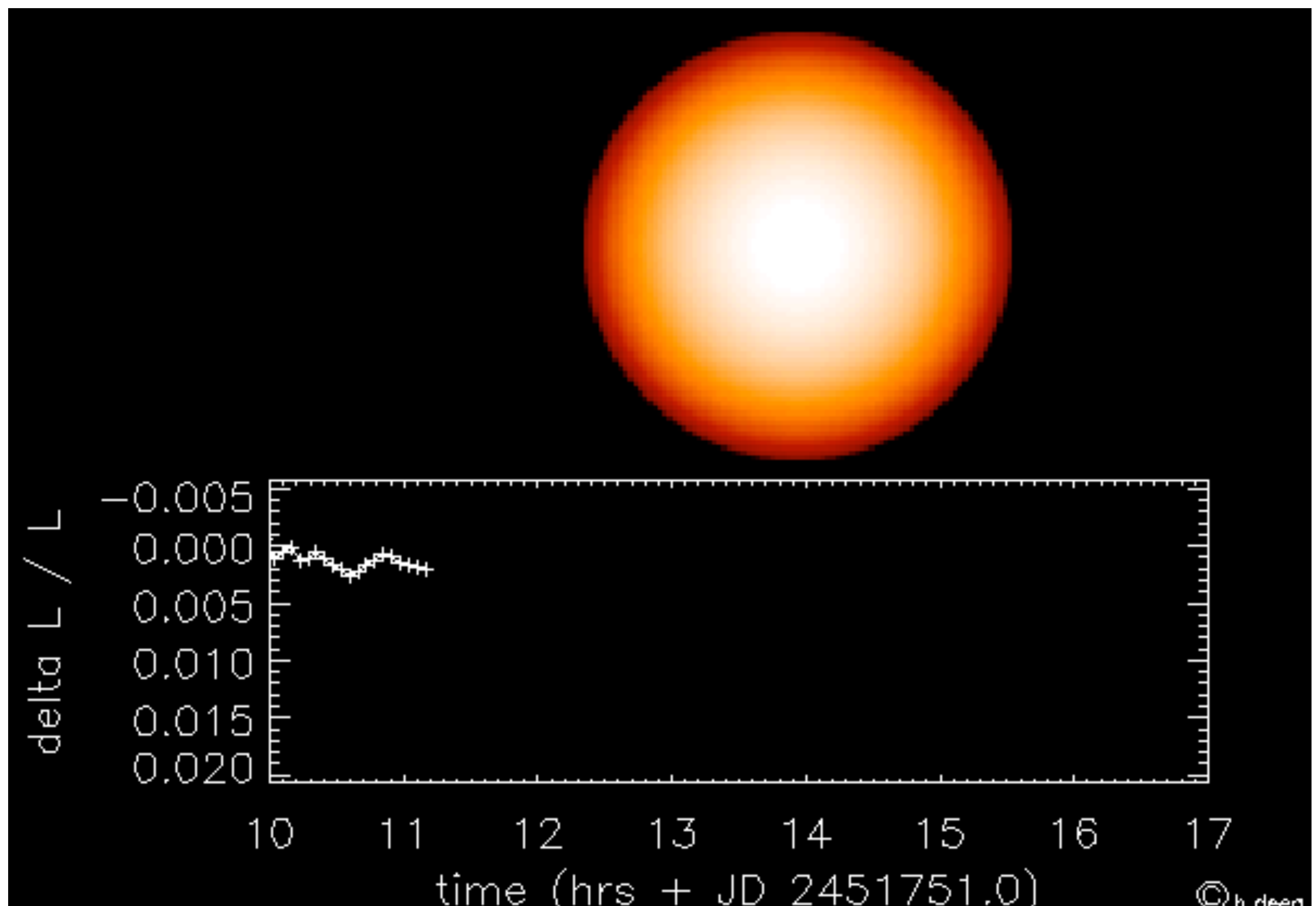
Schedule Lab 0 and Lab 1 - Lab 0 has to be done first!



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 6 and October 6 (spread out to accommodate the weather), e-mail your request to me (first-come, first-serve)