PHY 517 / AST 443:
Observational Techniques in Astronomy

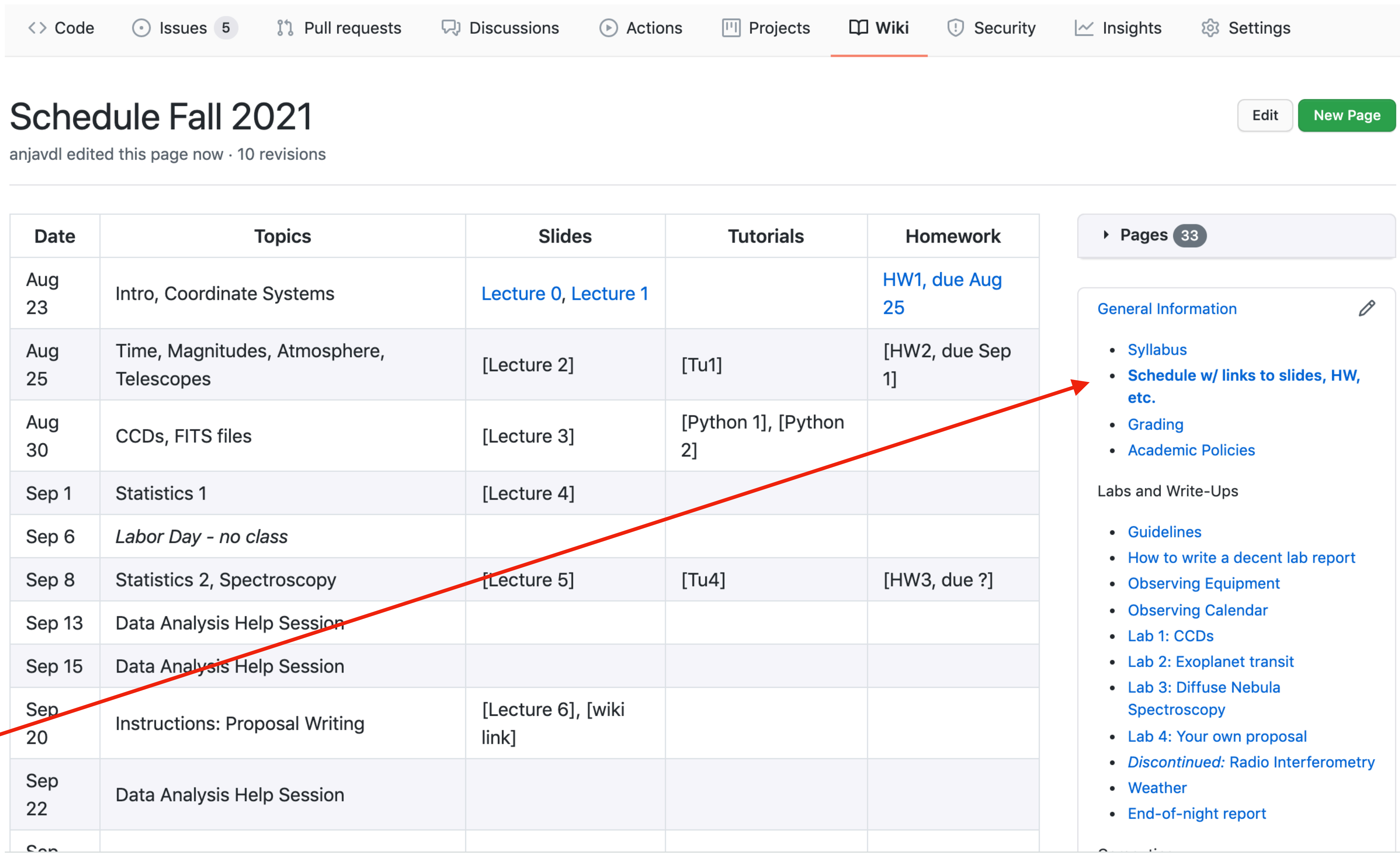
Lecture 2:
Time /
Flux and magnitudes /
Earth's atmosphere

Lab 1 (CCDs)

- Please schedule Lab 1 with the TAs ASAP
- Lab 1 is mainly in the Computing Lab (ESS 445-B); part is in the Telescope Dome
- Wear a mask at all times!
- There are disinfectant wipes in the Computing Lab; please wipe down the equipment when you are done, *especially* the laptop's keyboard
- Come prepared! The TAs will quiz you before you can start.

Class Material

slides, homeworks, tutorials, etc. *as used in this year's class* are linked from the schedule on the wiki



Date	Topics	Slides	Tutorials	Homework
Aug 23	Intro, Coordinate Systems	Lecture 0, Lecture 1		HW1, due Aug 25
Aug 25	Time, Magnitudes, Atmosphere, Telescopes	[Lecture 2]	[Tu1]	[HW2, due Sep 1]
Aug 30	CCDs, FITS files	[Lecture 3]	[Python 1], [Python 2]	
Sep 1	Statistics 1	[Lecture 4]		
Sep 6	*Labor Day - no class*			
Sep 8	Statistics 2, Spectroscopy	[Lecture 5]	[Tu4]	[HW3, due ?]
Sep 13	Data Analysis Help Session			
Sep 15	Data Analysis Help Session			
Sep 20	Instructions: Proposal Writing	[Lecture 6], [wiki link]		
Sep 22	Data Analysis Help Session			

Office Hours

- easiest way to get in touch with me: slack
- office hours:
  - Wednesdays 10-11am, ESS 453
  - by appointment
  - during data analysis sessions

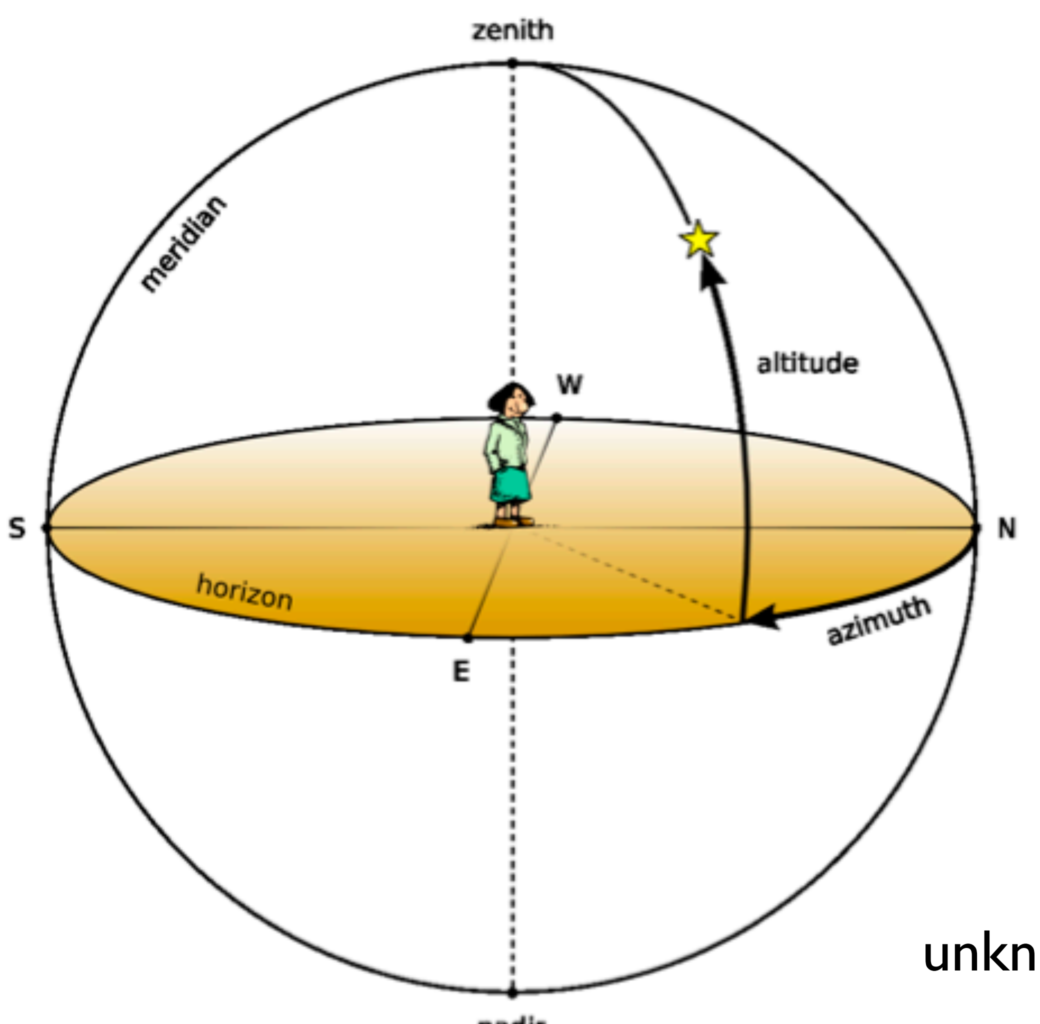
Last time...

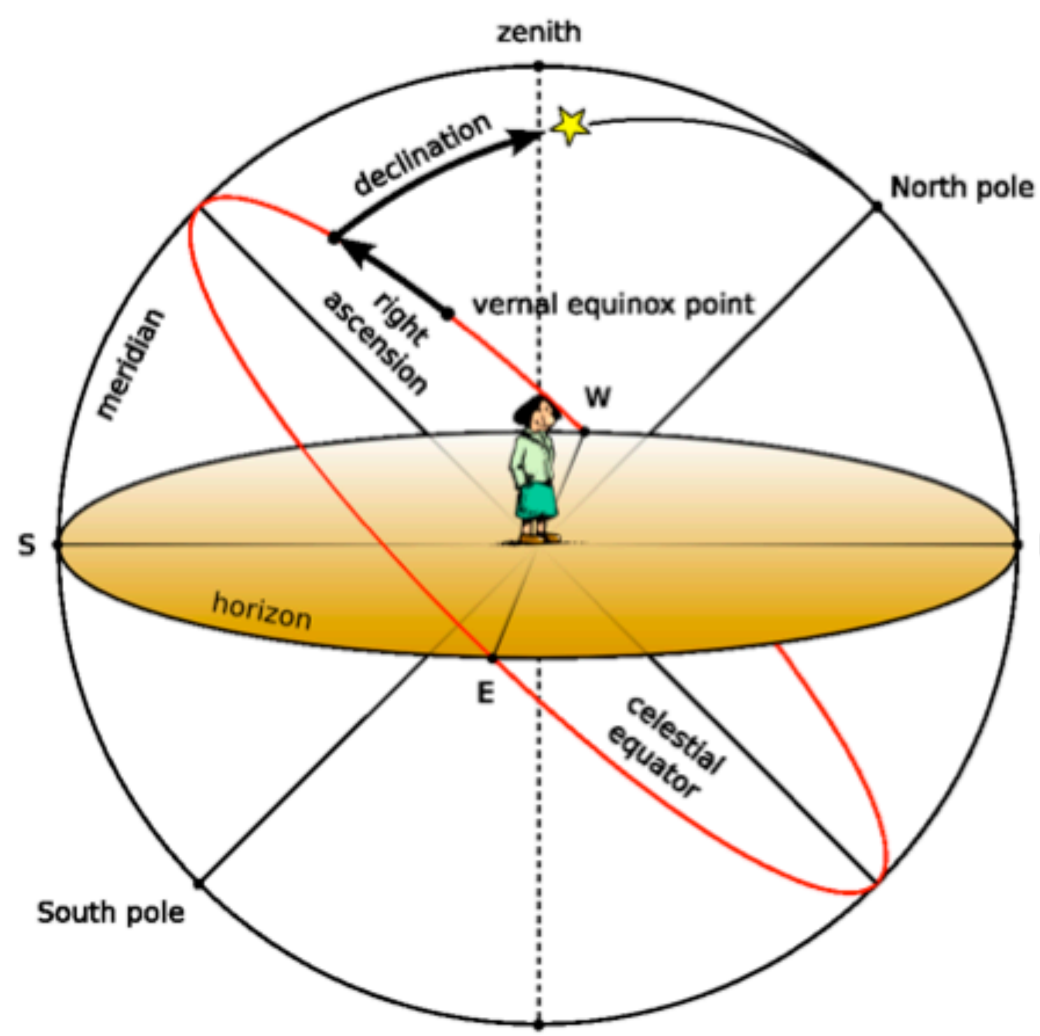
positions on a sphere can be described with 2 angular coordinates:

Position on Earth: latitude and longitude

View from observatory: altitude and azimuth

Position on sky: right ascension and declination



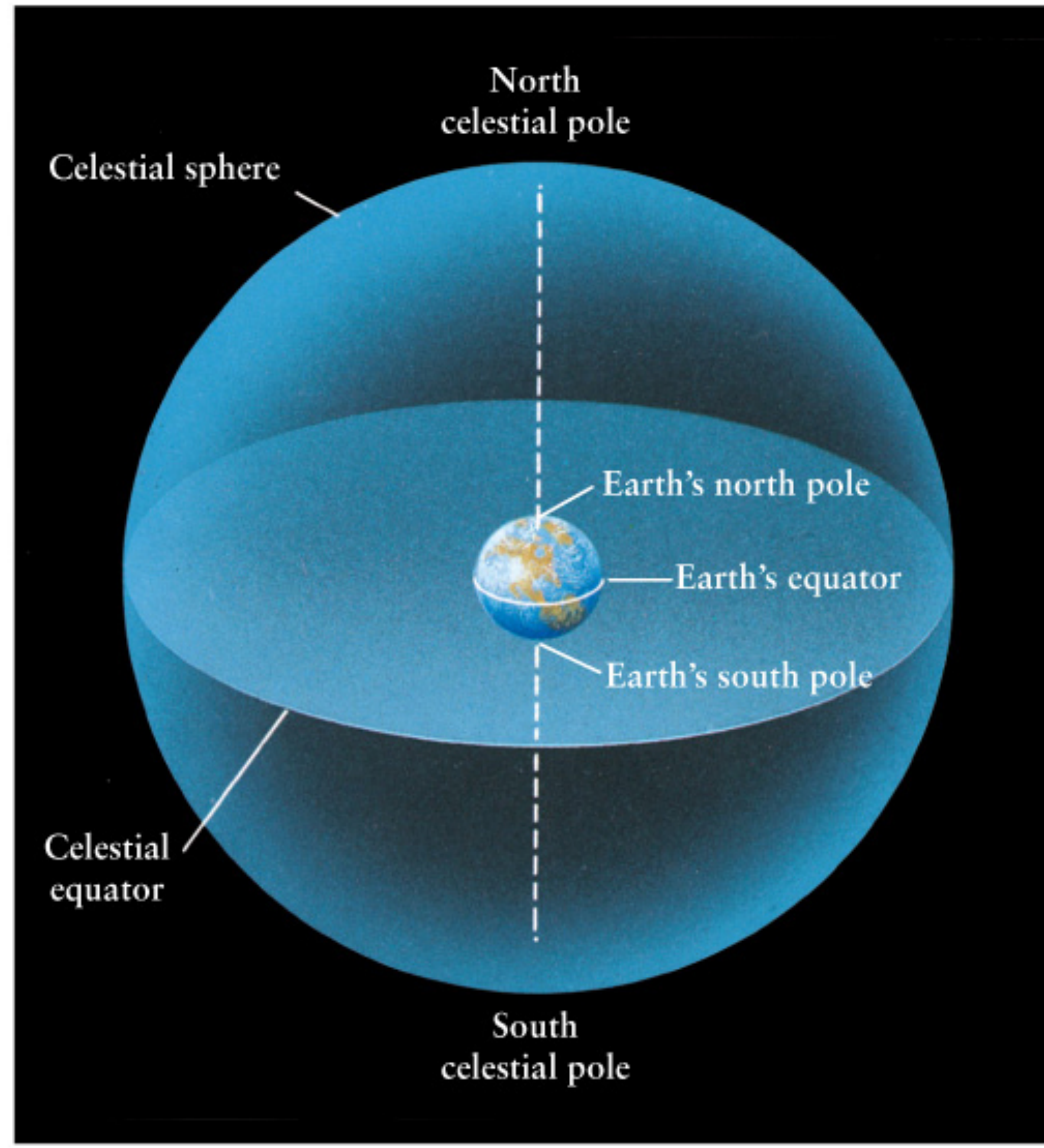


unknown

Last time...

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

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



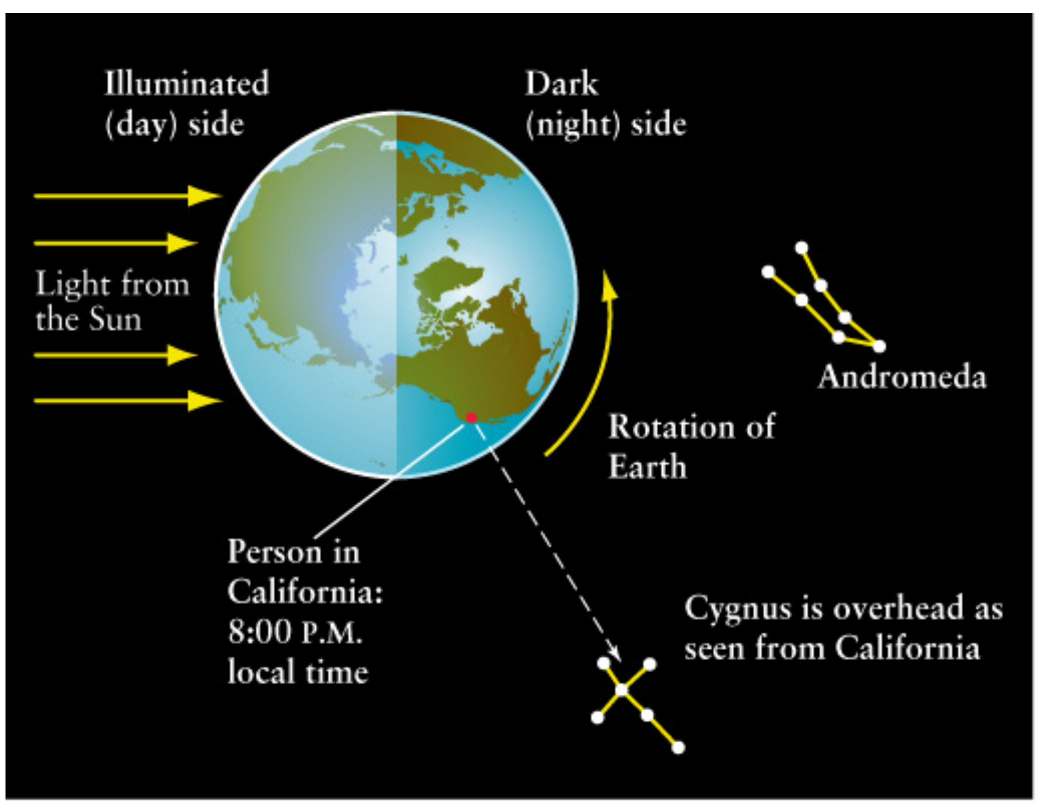
Bailey, Slater & Slater

Last time...

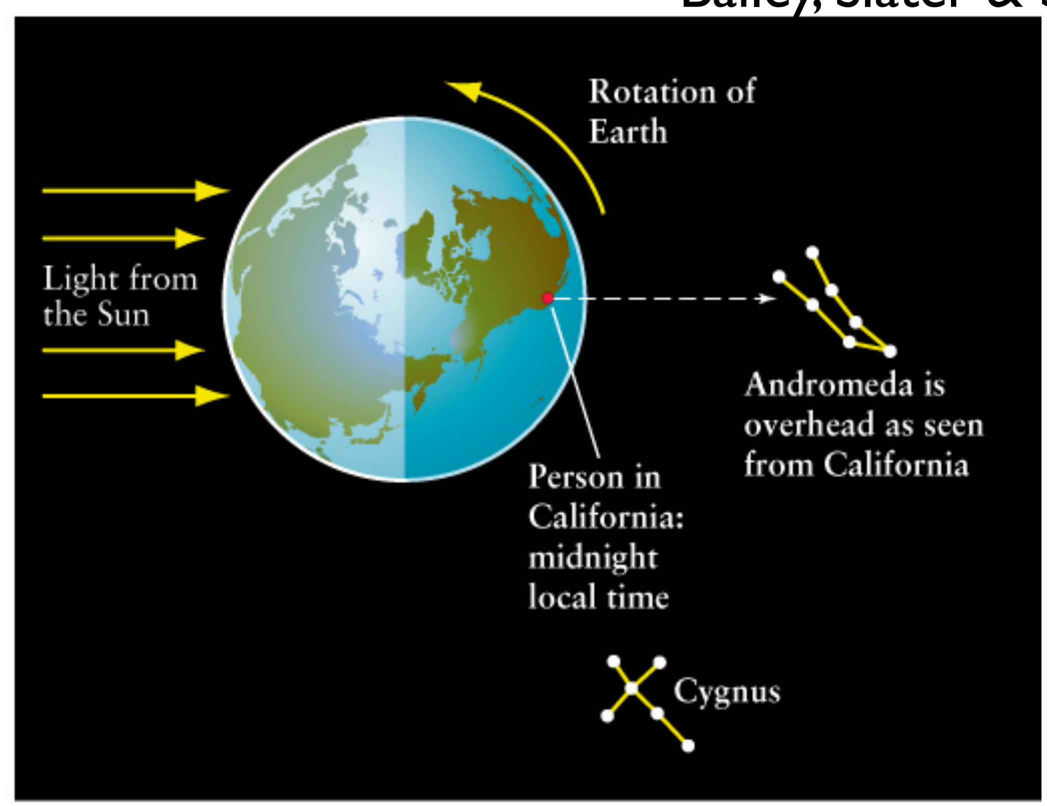
the sky "moves" East to West

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

Bailey, Slater & Slater



(a) Earth as seen from above the north pole

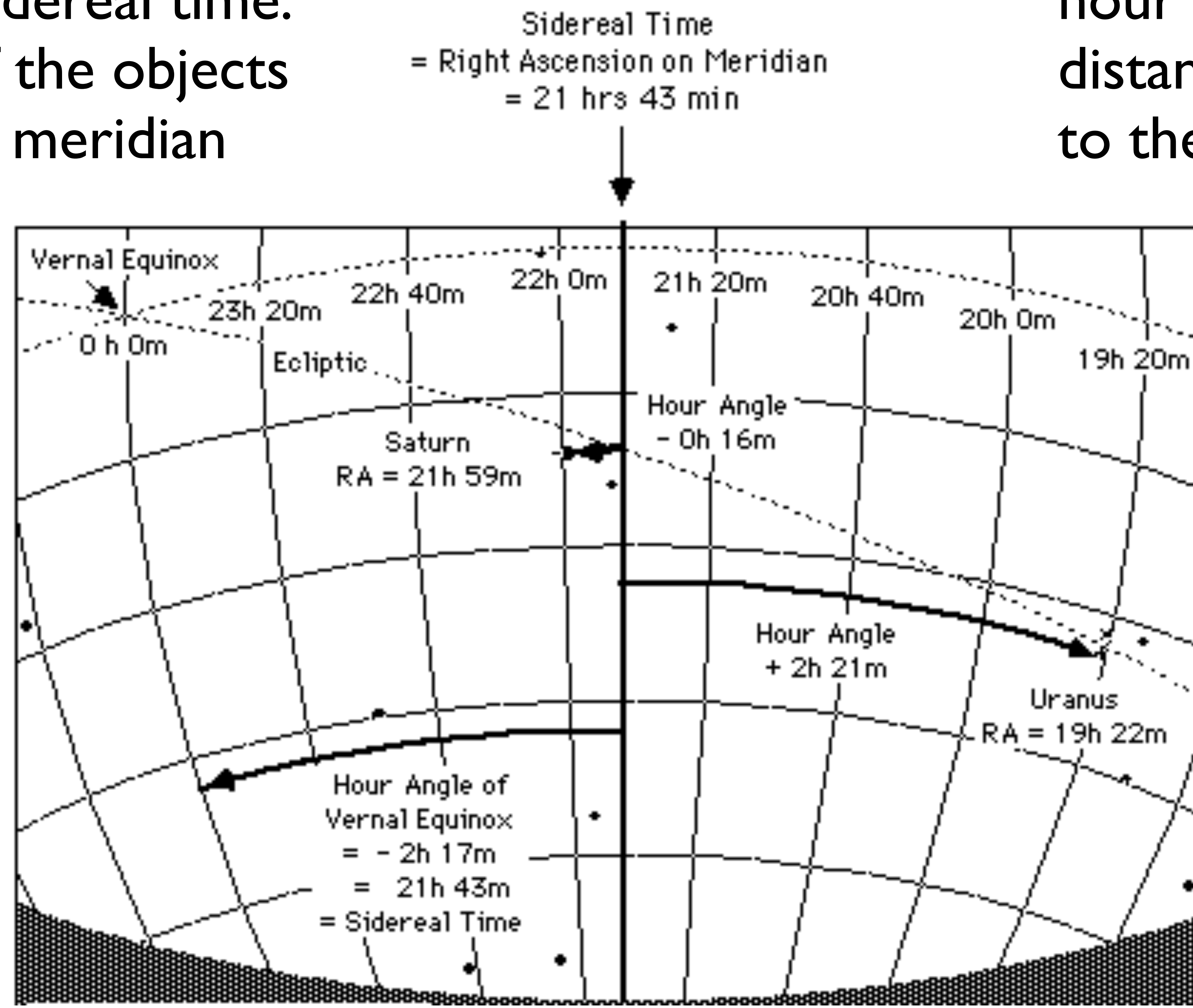


(b) 4 hours (one-sixth of a complete rotation) later

Last time...

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

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



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

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

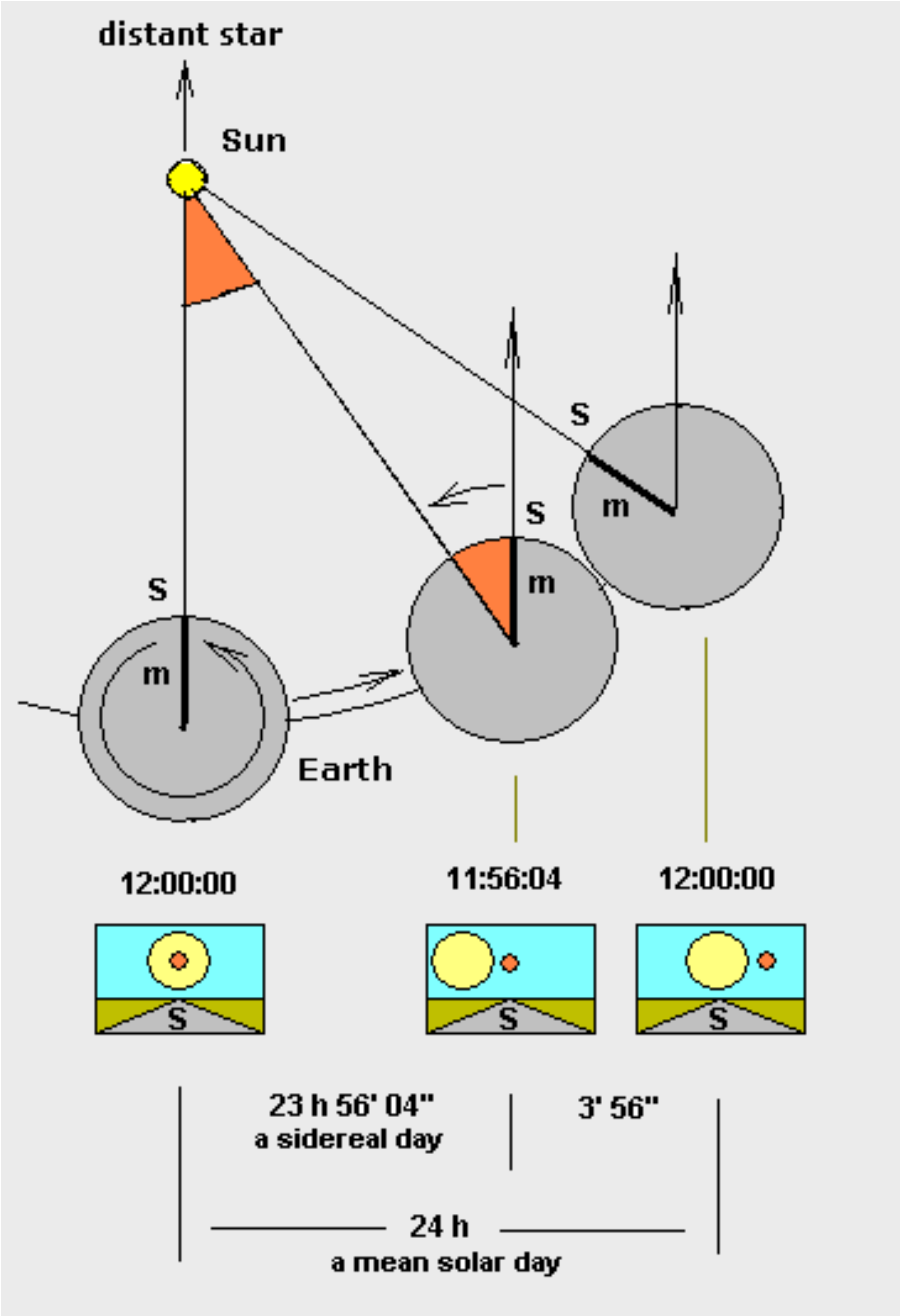
"sidereal" = "of the stars"

sidereal time: defined with respect to the stars

one 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

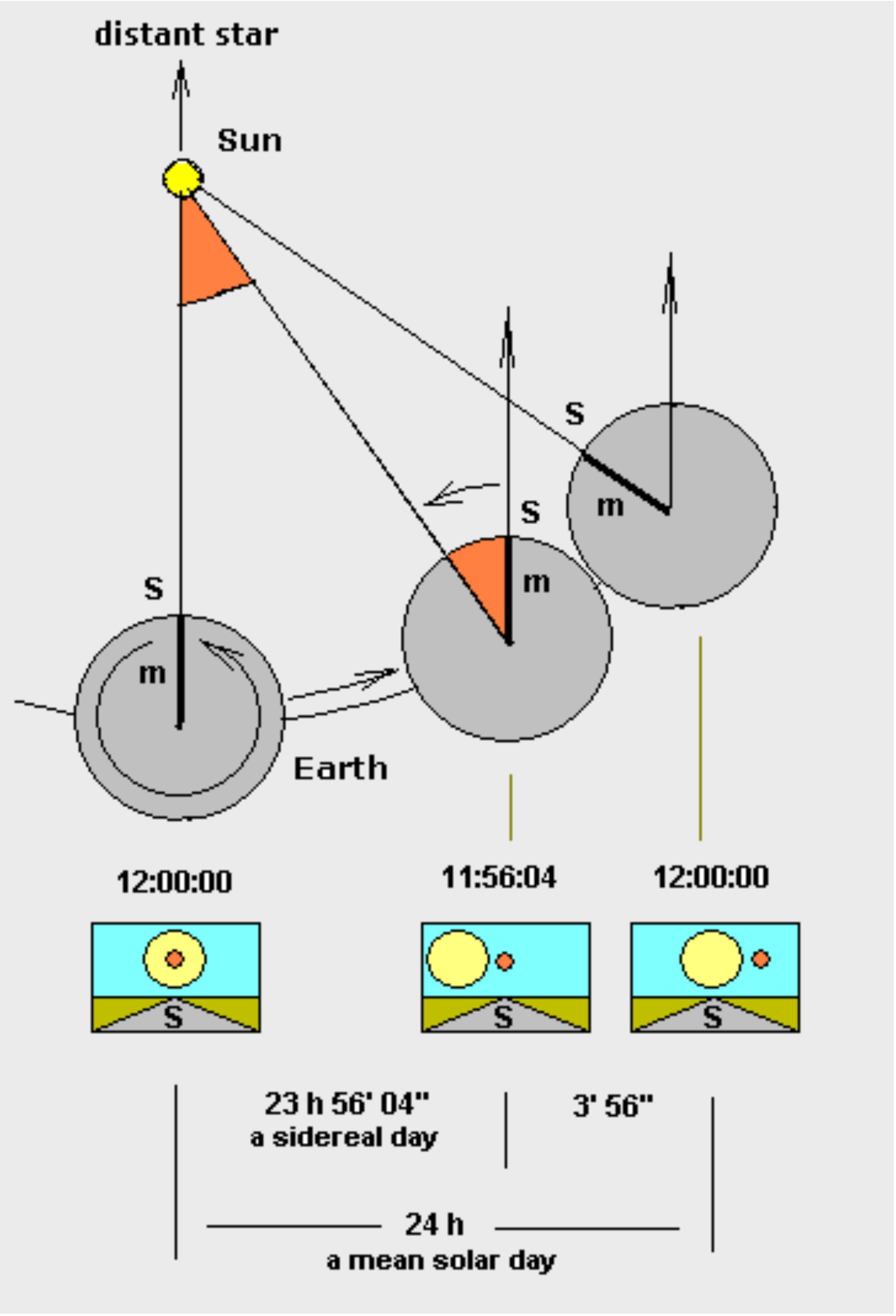


wikipedia

This means...

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

one year has 365+1 sidereal days



wikipedia

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

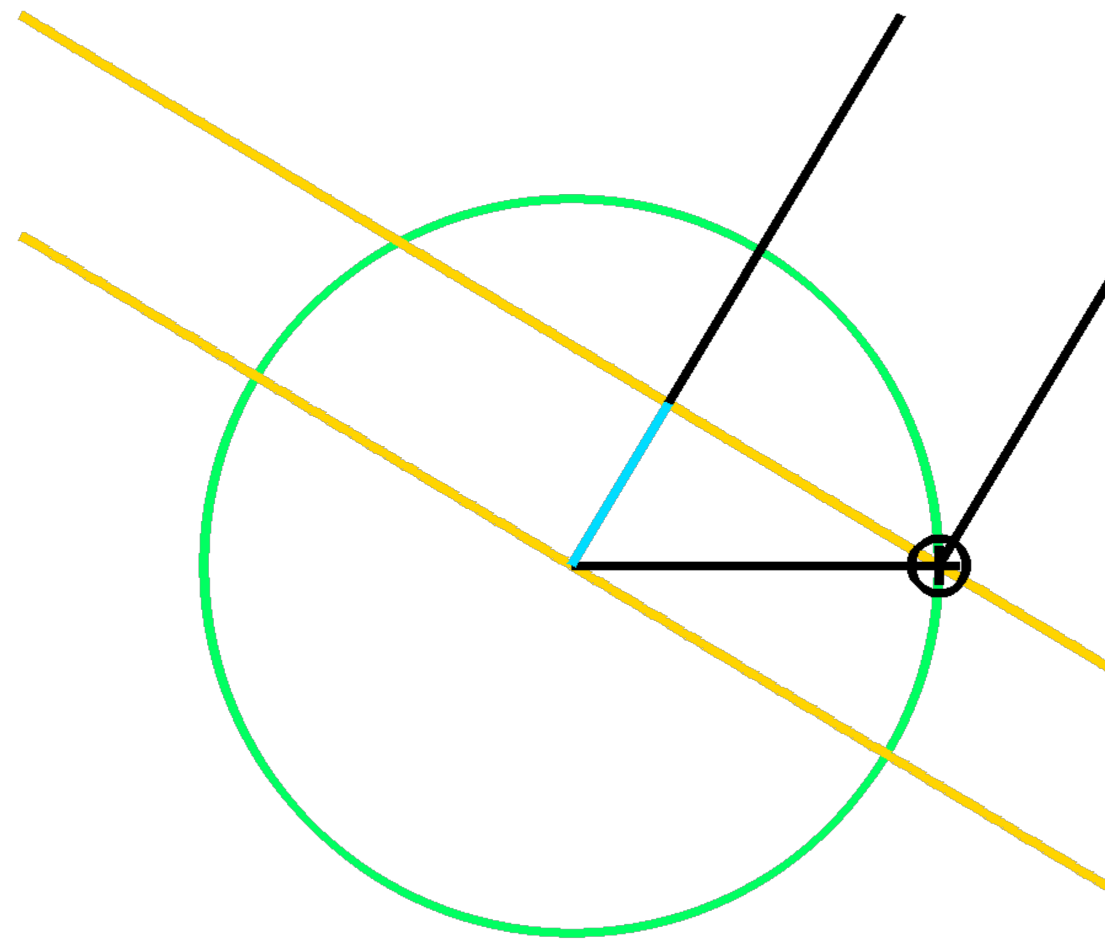
http://aa.usno.navy.mil/data/docs/JulianDate.php

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



J. Eastman

Epochs

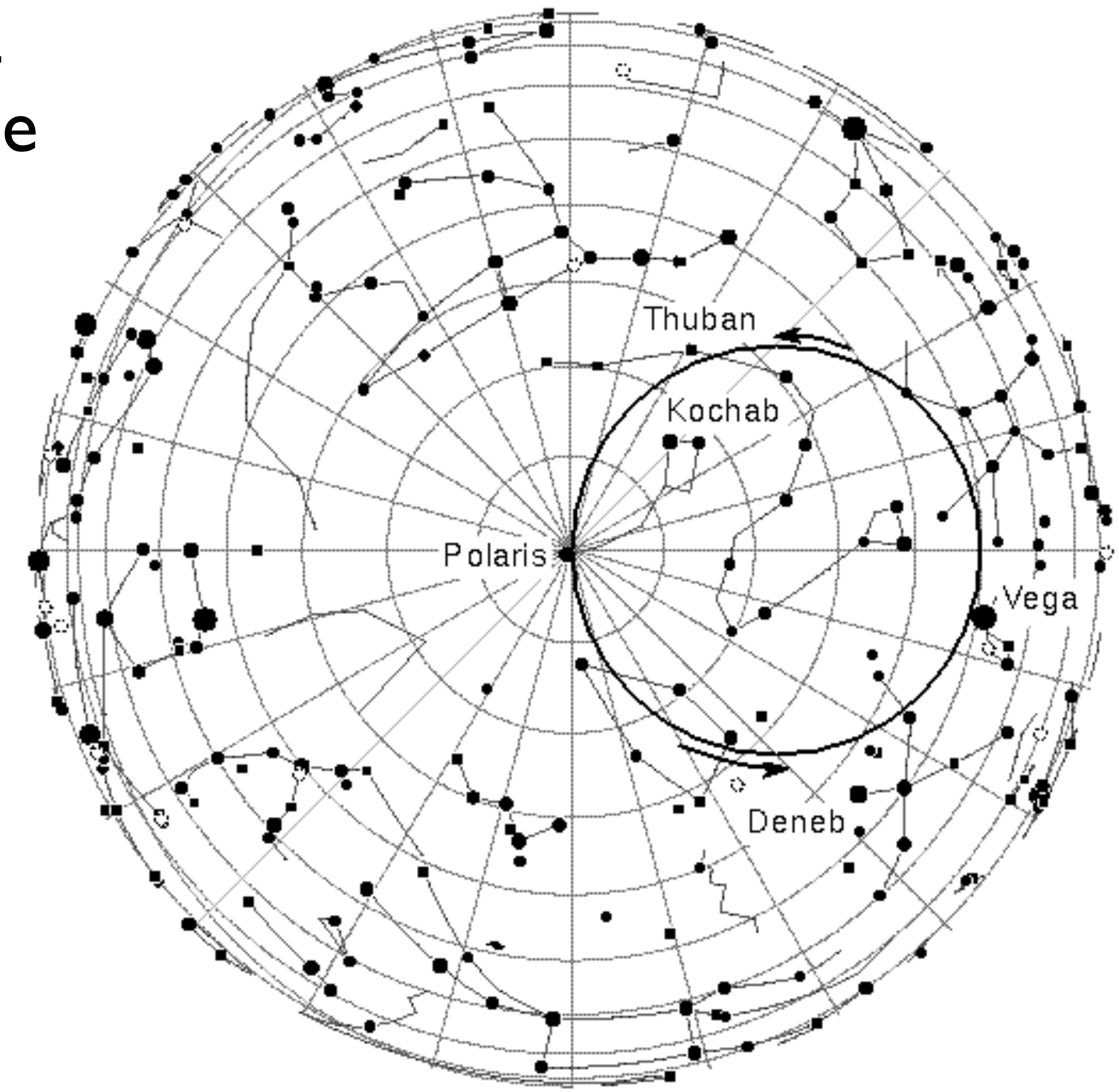
Earth's rotation axis is not constant in space with time

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

- Earthquakes

All coordinates need to 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.

N. Strobel

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 $d\omega$ (at an angle θ from normal), in frequency range $[\nu,\nu+d\nu]$, during time *dt* is:

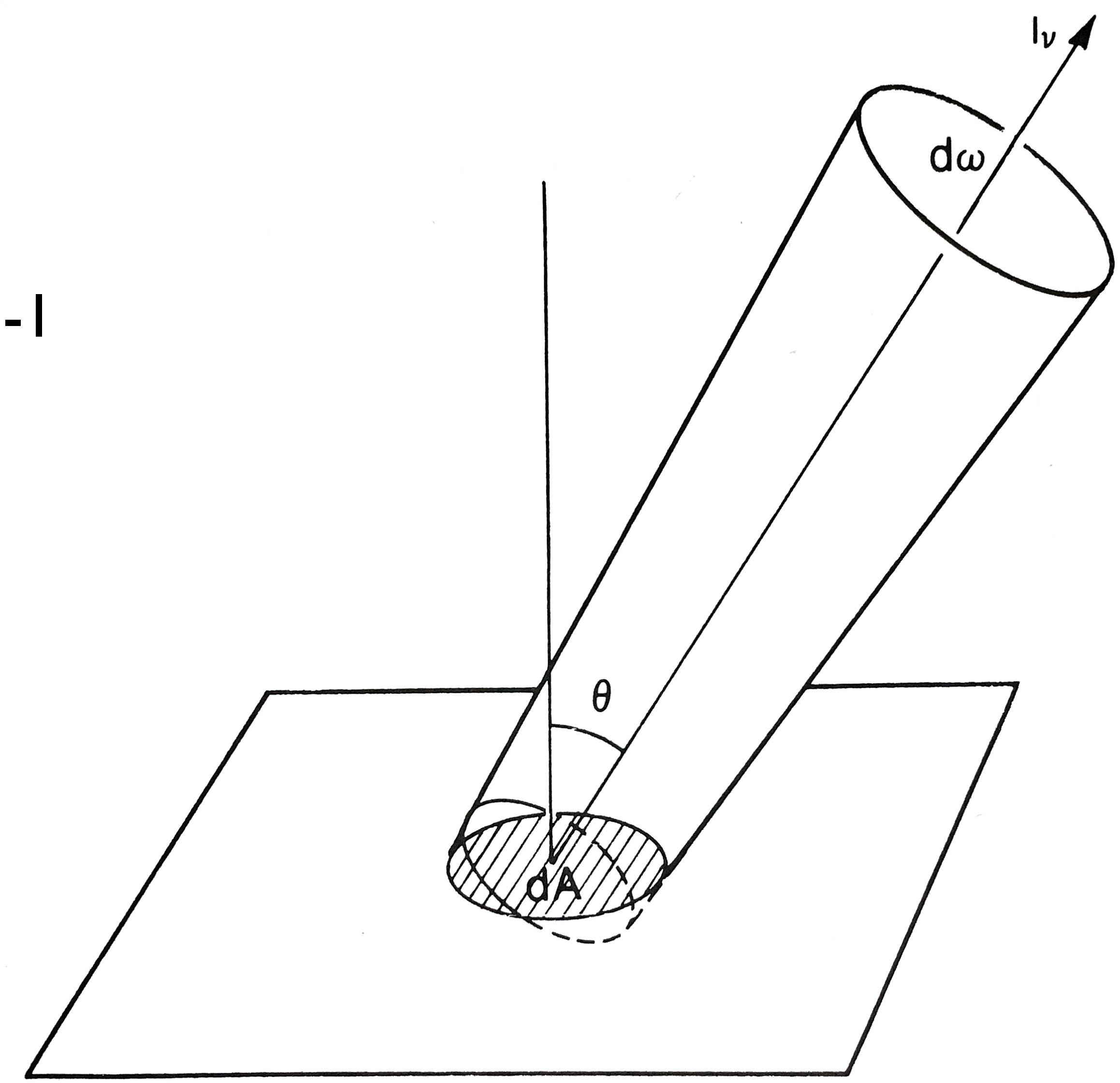
$$dE_\nu = I_\nu \, dA \cos\theta \, d\omega \, dt \, d\nu$$

specific intensity: I_ν

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

dA: any surface along light path; e.g. surface of star, or surface of detector

I_ν: intrinsic property of the object!



Karttunen et al.

Physical descriptions

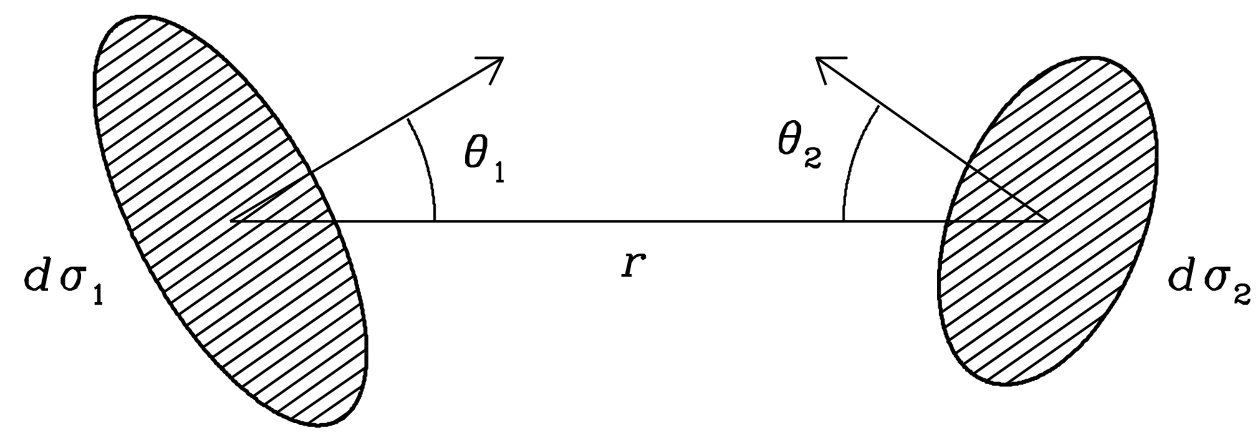
amount of energy passing through area dA , within $d\omega$ (at an angle θ from normal), in frequency range $[\nu,\nu+d\nu]$, during time dt is:

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

specific intensity: I_ν

I_ν is constant along any ray in empty space

(Proof: $d\omega_1$ solid angle that $d\sigma_2$ subtends seen from $d\sigma_1$; $d\omega_2$ … $dE_1 = dE_2$)

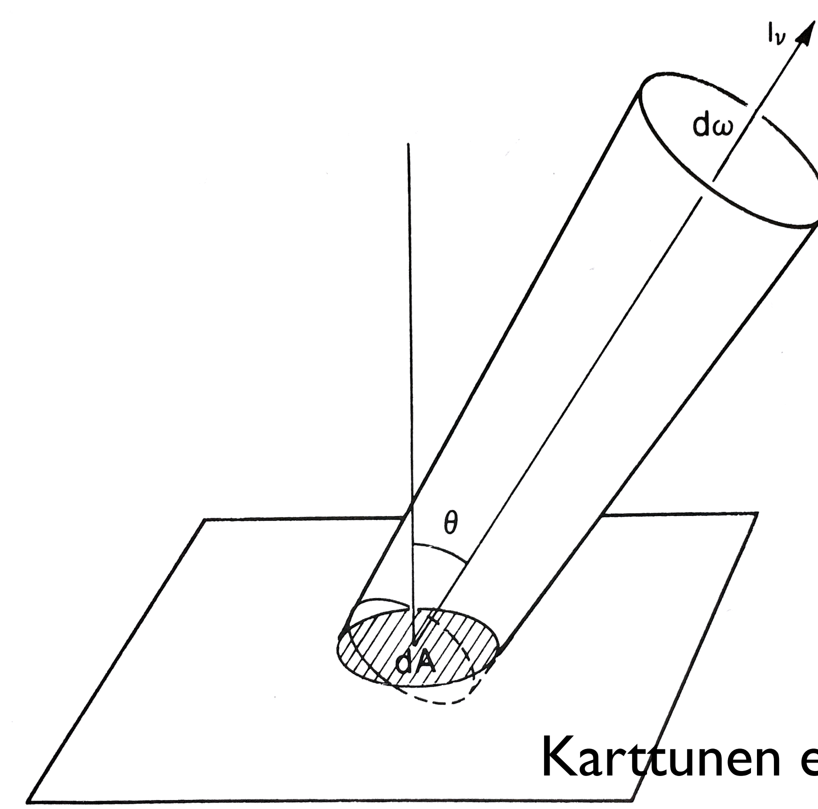


Physical descriptions

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

integrate over solid angle:

$$f_\nu = \int_\Omega d\omega \cos\theta \; I_\nu$$



Karttunen et al.

Physical descriptions

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

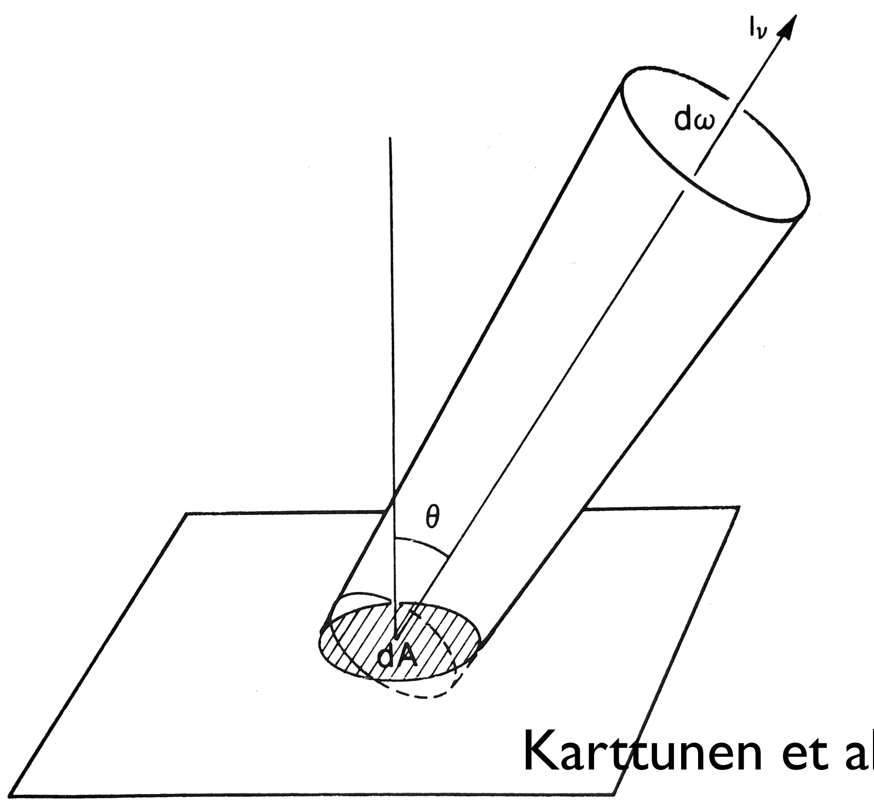
integrate over solid angle:

$$f_\nu = \int_\Omega d\omega \cos\theta \; I_\nu$$

$$= \frac{1}{dA \;\, dt \;\, d\nu} \int_\Omega dE_\nu$$

spectral flux density f_ν: energy (leaving the surface of the star) per area, per time, per frequency interval

units: ergs s^{-1} cm^{-2} Hz^{-1} = Jansky



Karttunen et al.

Physical descriptions

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

integrate over solid angle:

$$f_\nu = \int_\Omega d\omega \cos\theta \; I_\nu$$

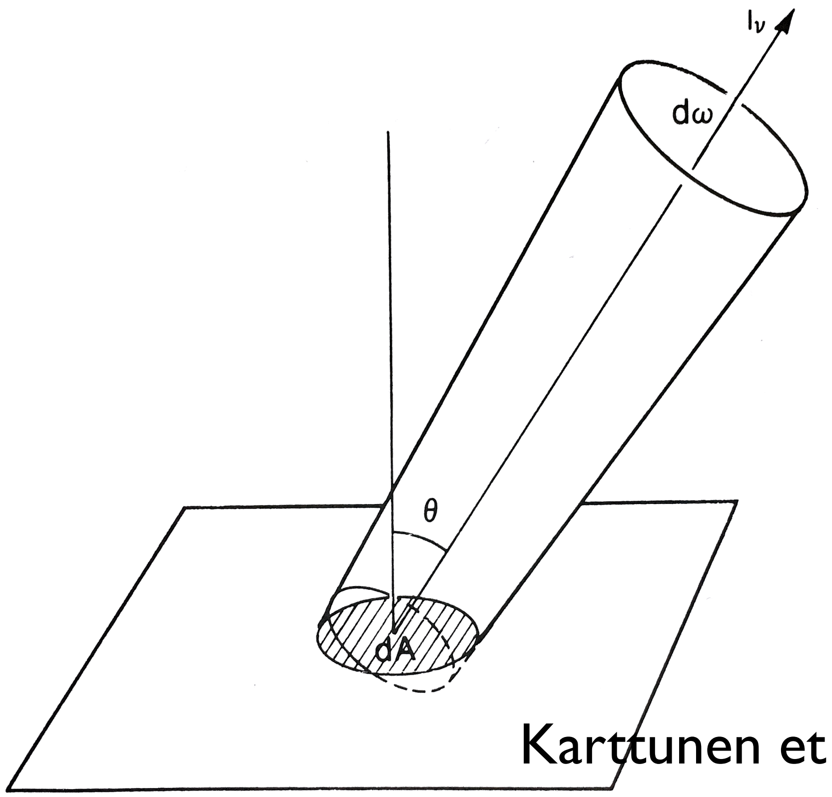
$$= \frac{1}{dA \; dt \; d\nu} \int_\Omega dE_\nu$$

spectral flux density f_ν: energy (leaving the surface of the star) per area, per time, per frequency interval

for the observer: ($d\omega \, \cos\theta$) is the solid angle of the star seen from your eye

f_ν is usually what we observe

f_ν depends on distance source - observer



Karttunen et al.

Physical descriptions

spectroscopy: can determine f_ν

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

flux:

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

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

(note: usually specified 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:

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

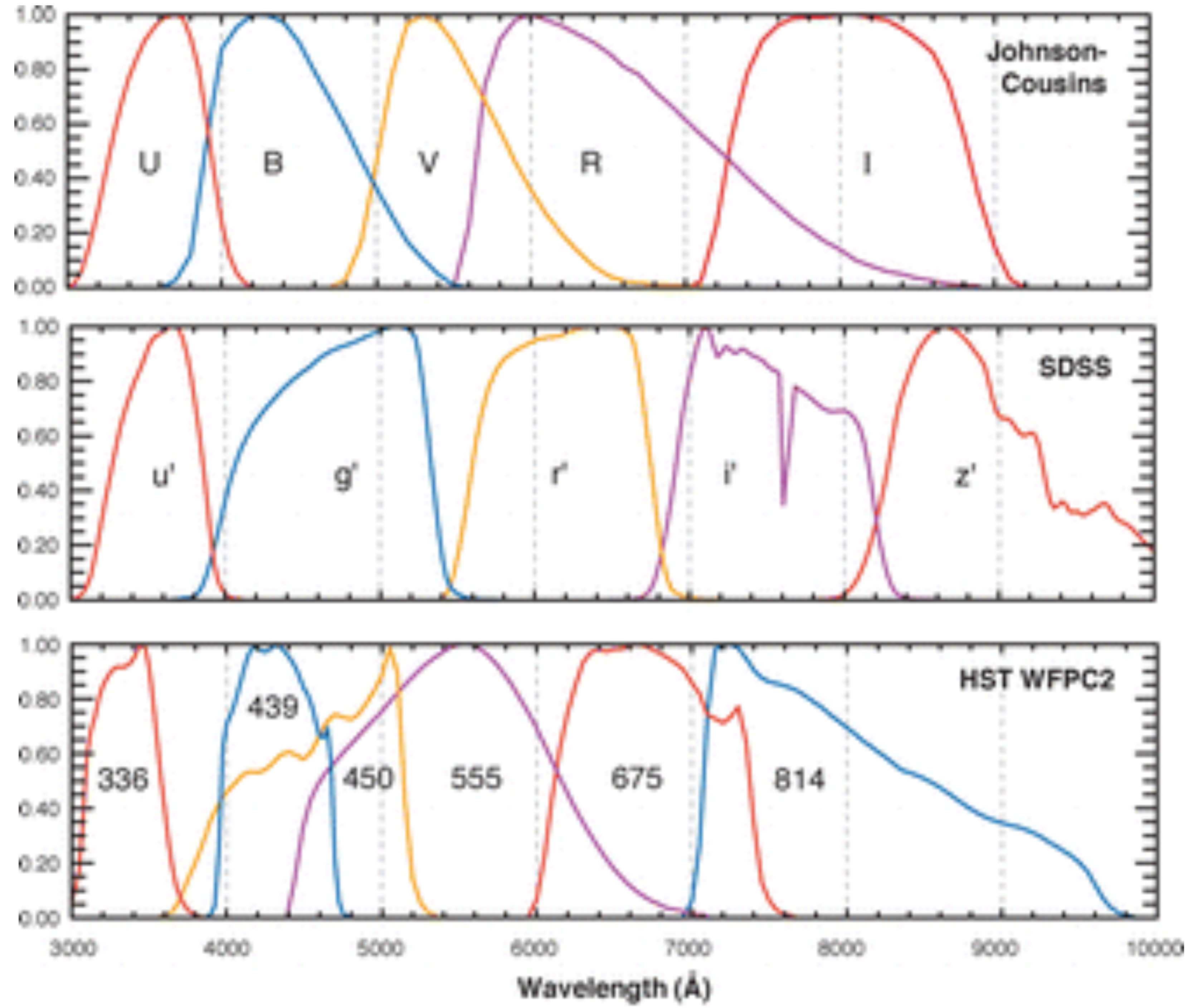
Filter systems

optical astronomy:

several standard photometric systems, "filter sets"

Johnson-Cousins: *UBVRI*

SDSS: *ugriz*



Bessel 2005

Color

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

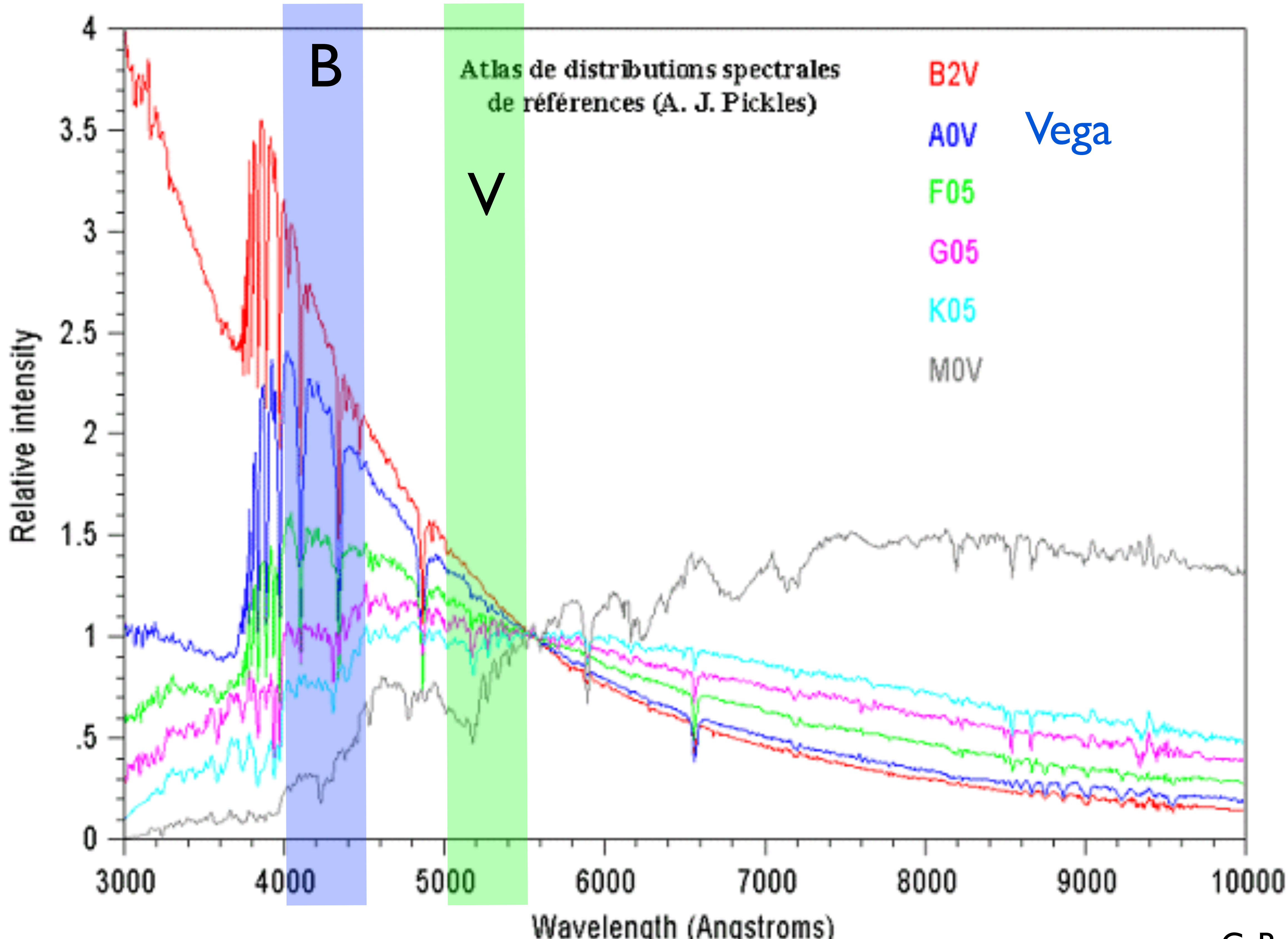
$$B - V = m_B - m_V = -2.5 \log \left(\frac{F_B}{F_V} \right)$$
$$= -2.5 \log \left(\frac{F_B}{F_{B,\mathrm{Vega}}} \right) + 2.5 \log \left(\frac{F_V}{F_{V,\mathrm{Vega}}} \right)$$

Vega has 0 color, by definition

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

Q: Is (B-V) positive or negative for a blue star?

Color



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

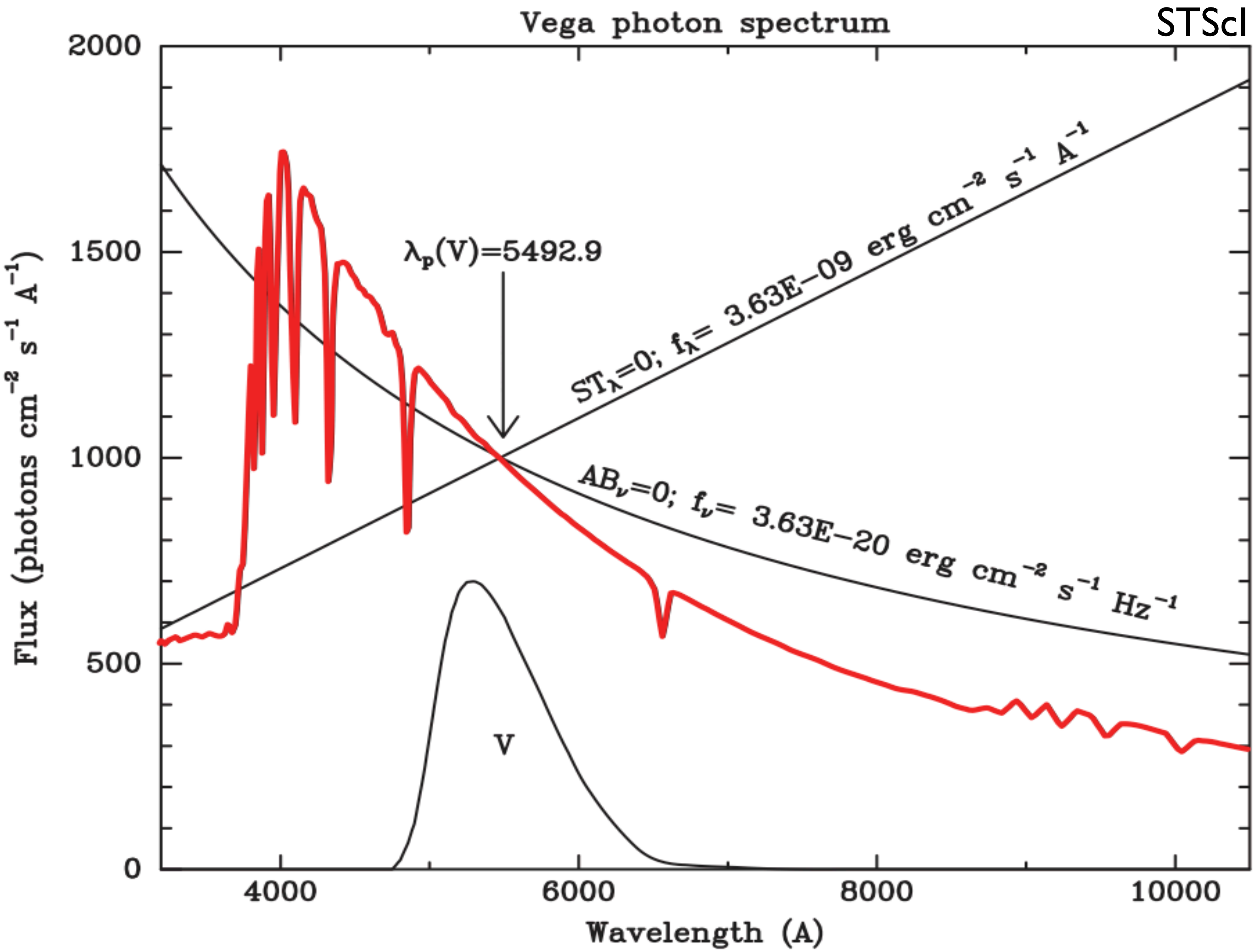
C. Buil

AB magnitudes

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

defined relative to *constant flux density*

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:

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

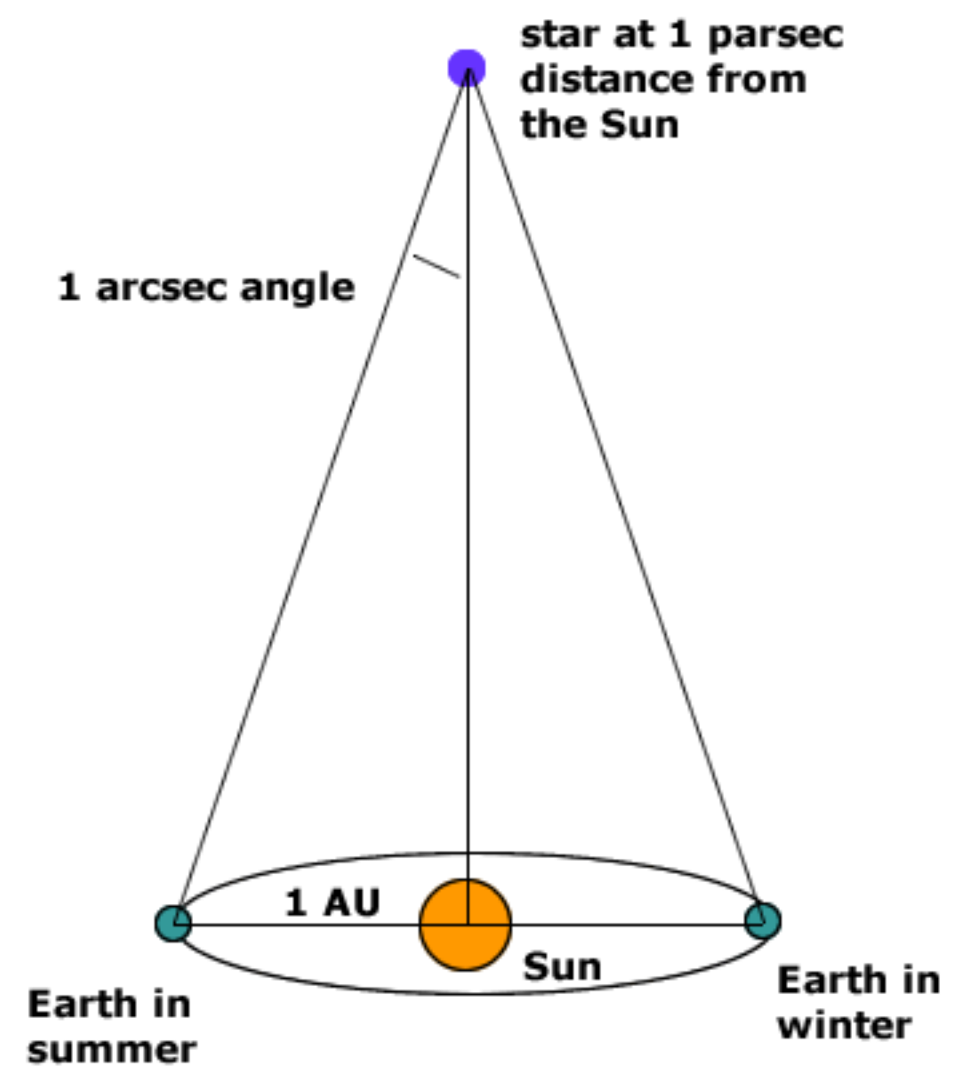
Parallax and parsecs

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

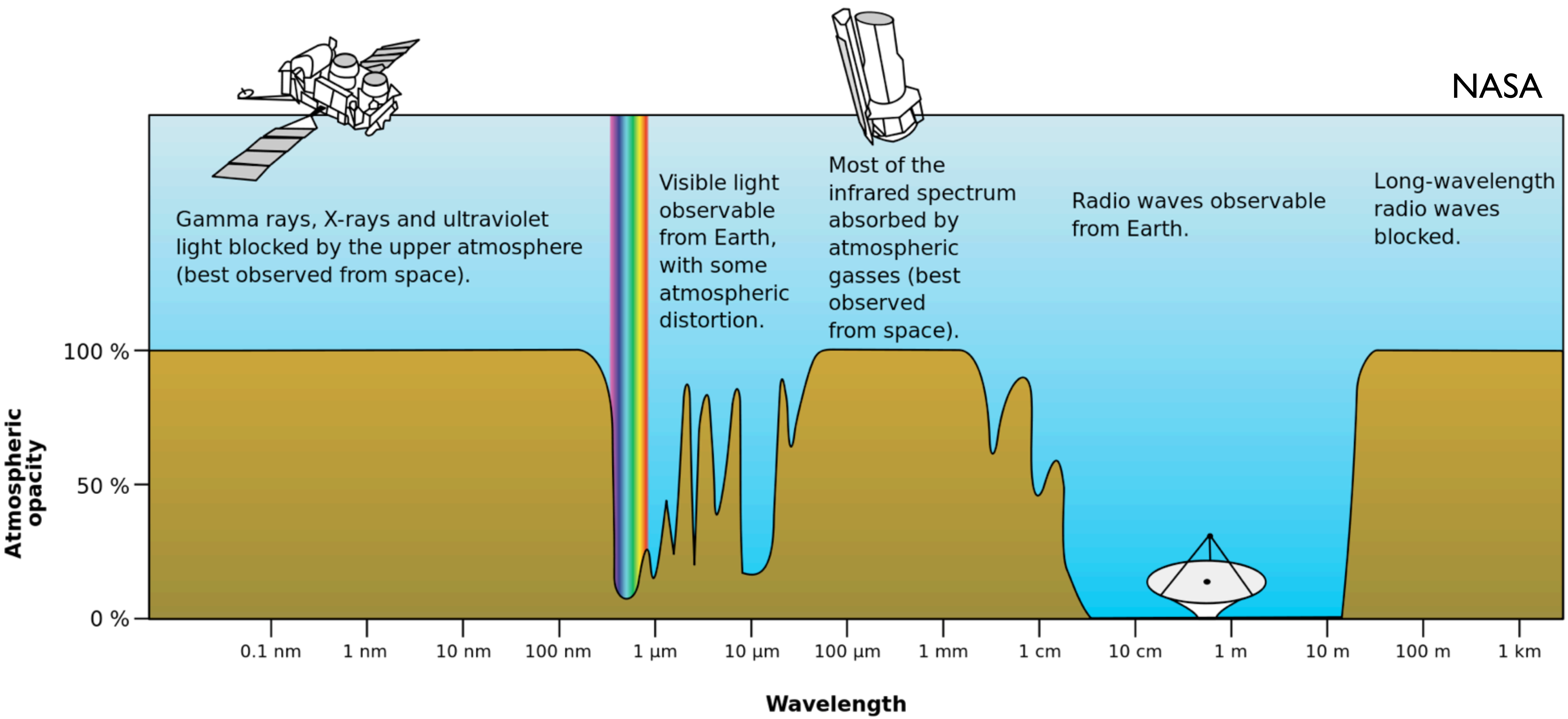
Proxima Centauri: ~1.3 pc



www.school-for-champions.com

Earth's atmosphere

the atmosphere is opaque to most of the electromagnetic spectrum

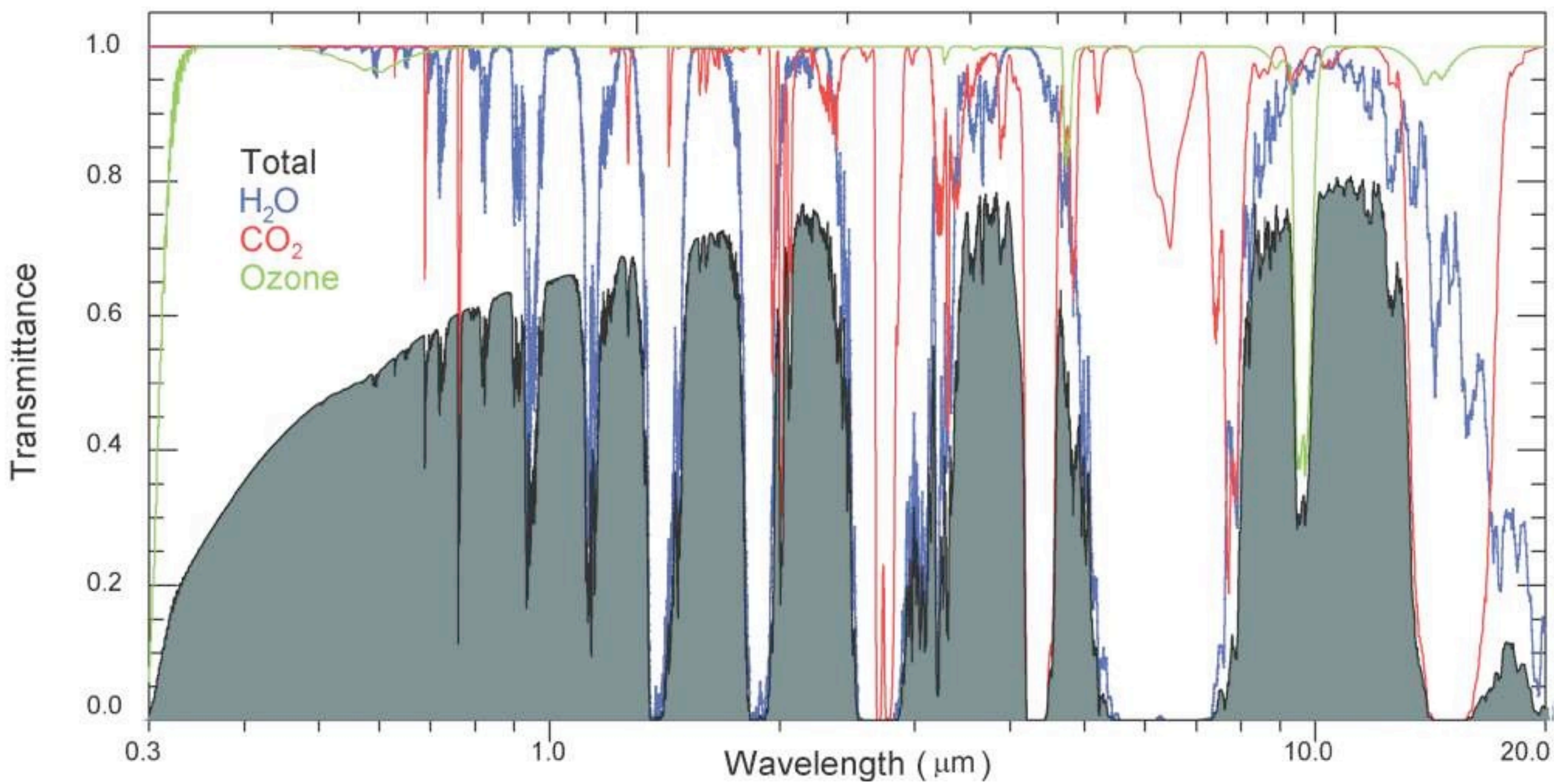


Earth's atmosphere

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

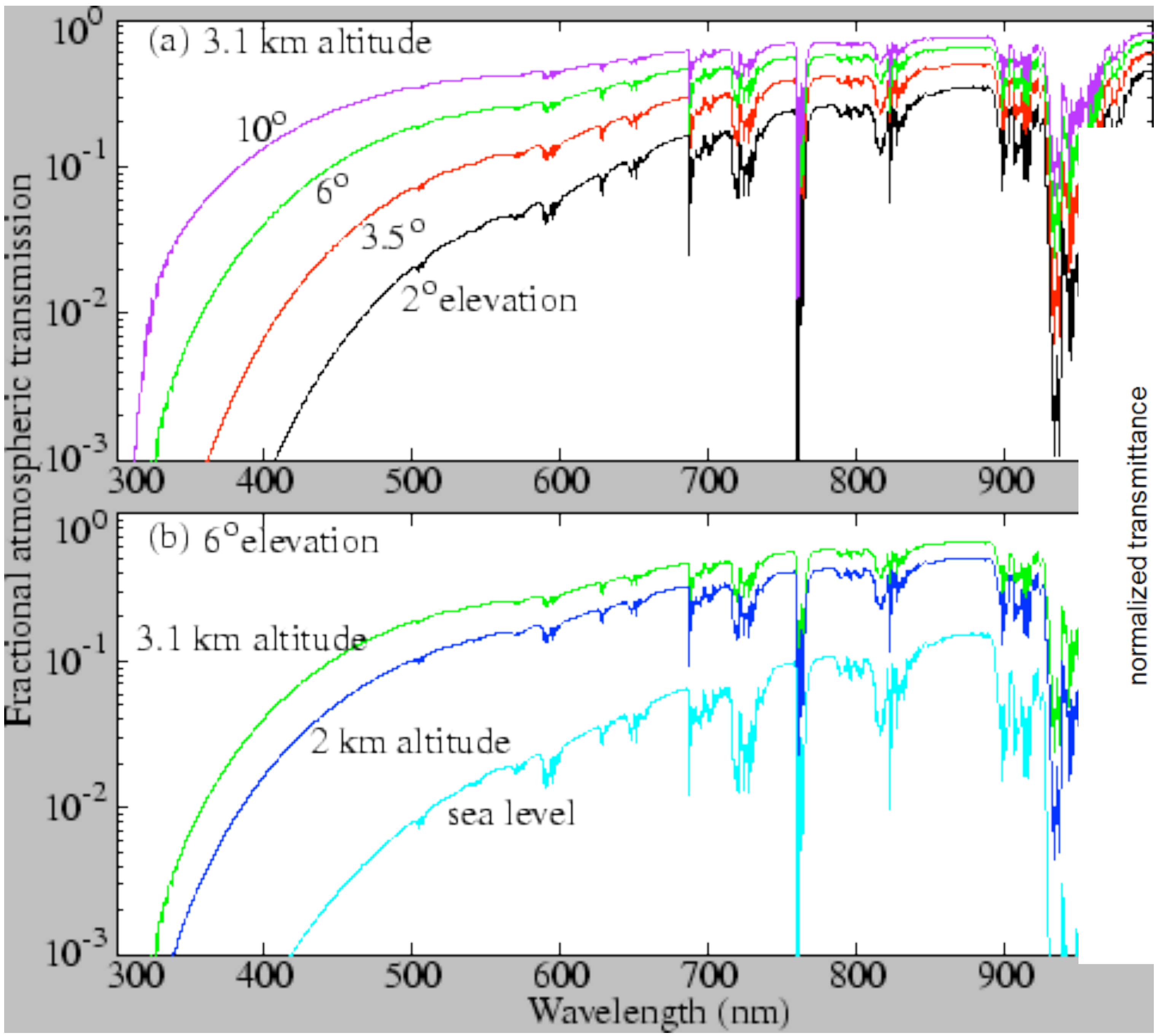
- scattering, e.g. Rayleigh $\propto \lambda^{-4}$
- absorption bands, mainly water

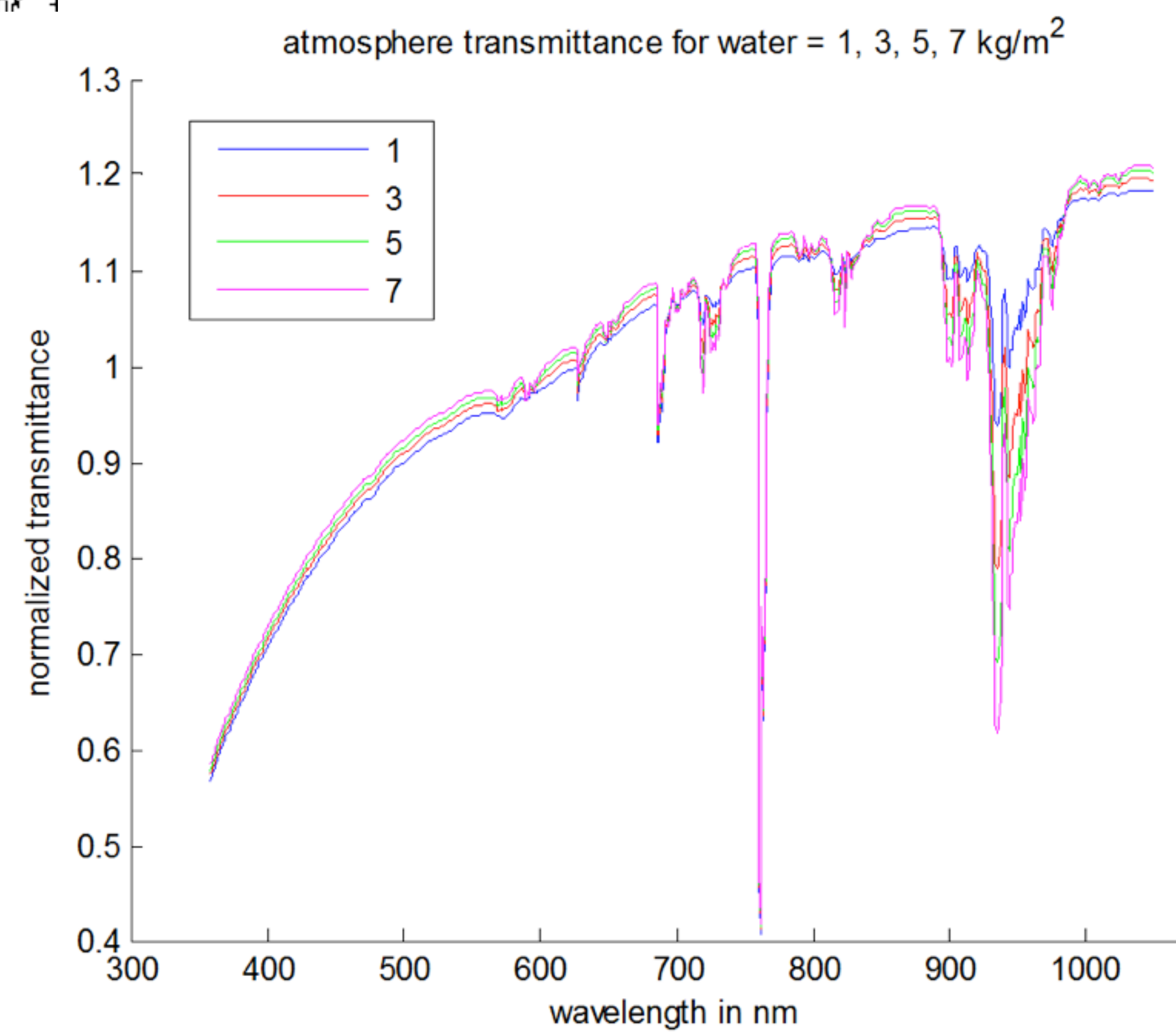
MODTRAN 4.0



Earth’s atmosphere

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





Ting Li

Airmass

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

plane-parallel approximation:

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

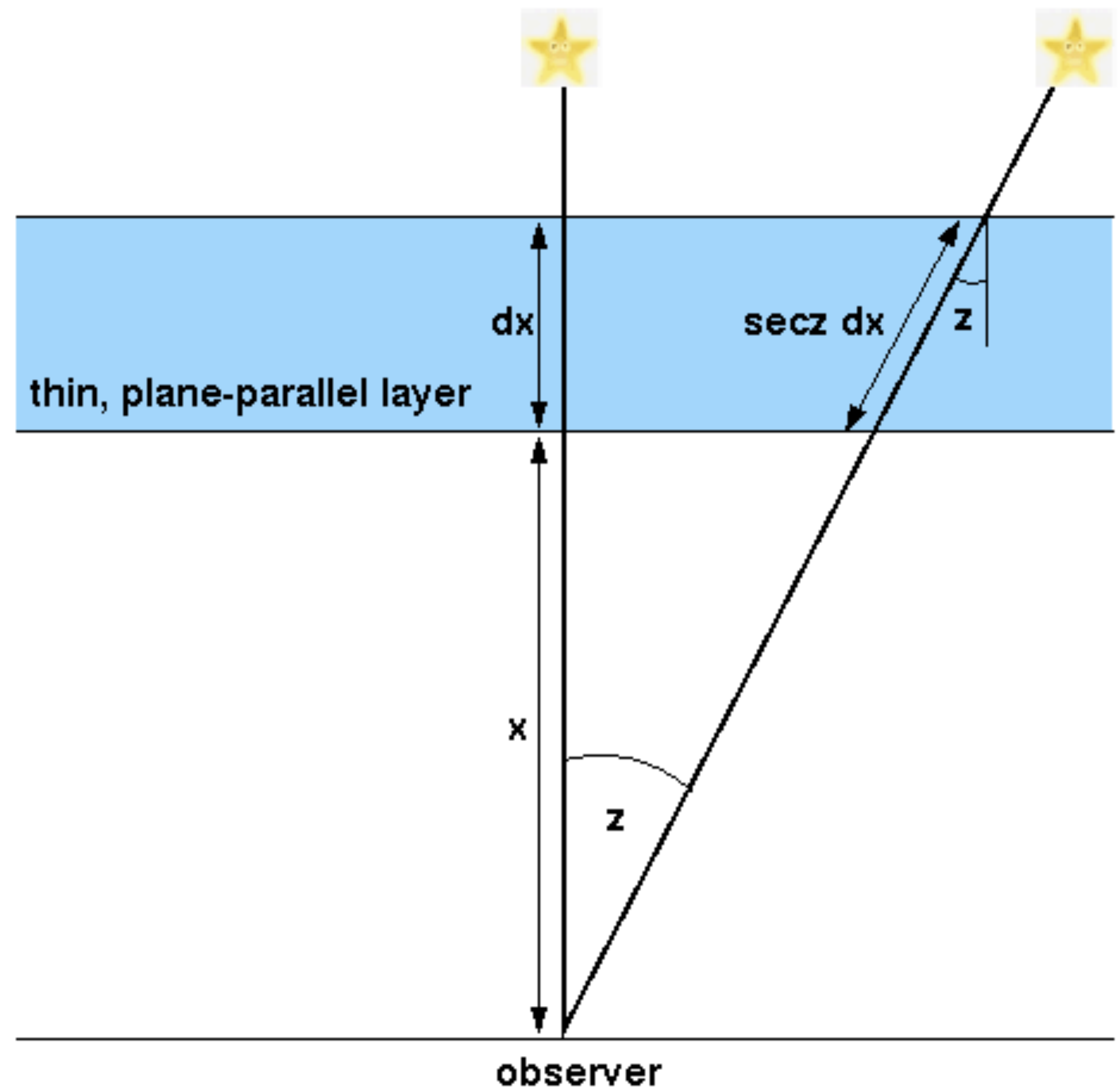
zenith distance:

z = 90° - altitude h

h=90°: AM=1

h=50°: AM=1.3

h=30°: AM=2



V. Dhillon

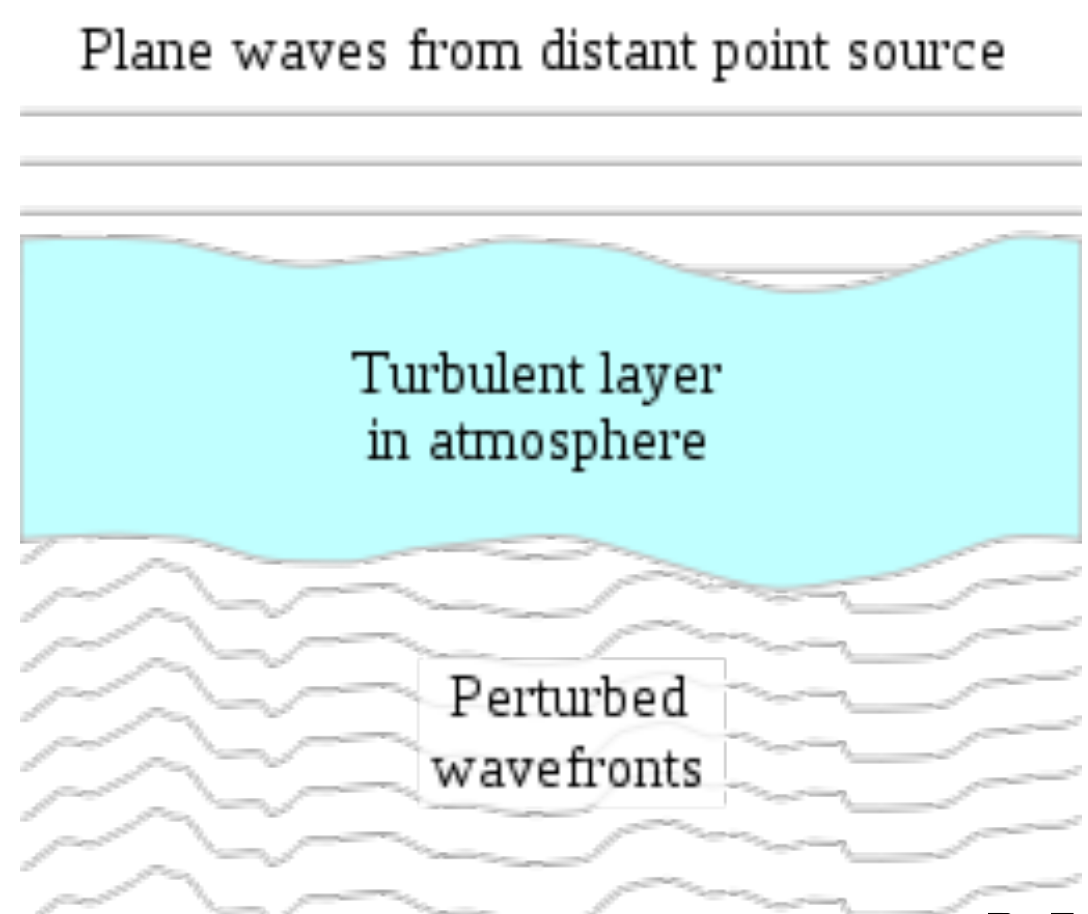
Seeing

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”

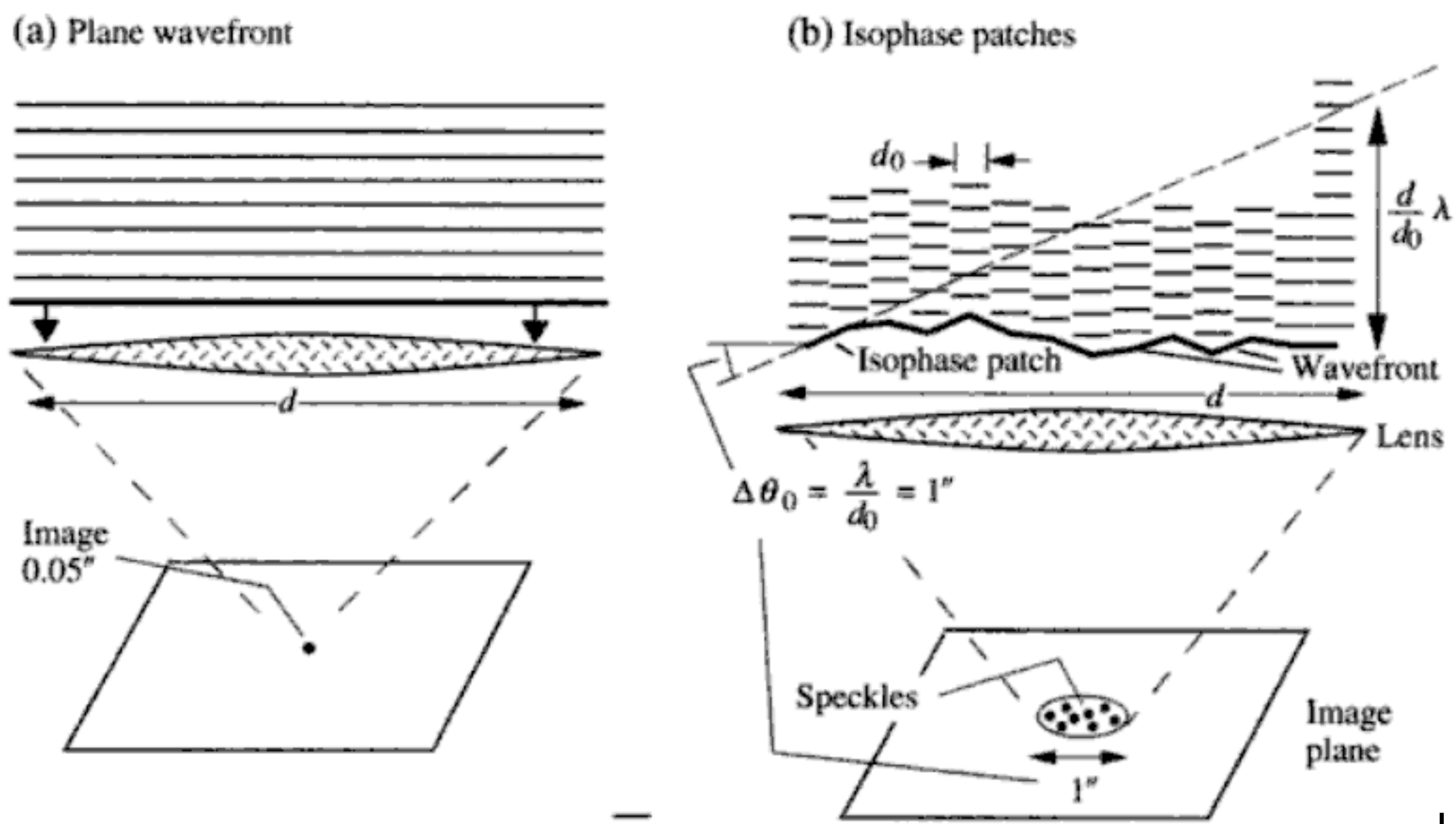
seeing: turbulence in the atmosphere, leads to “blurring” of images



D. Eccles

Seeing

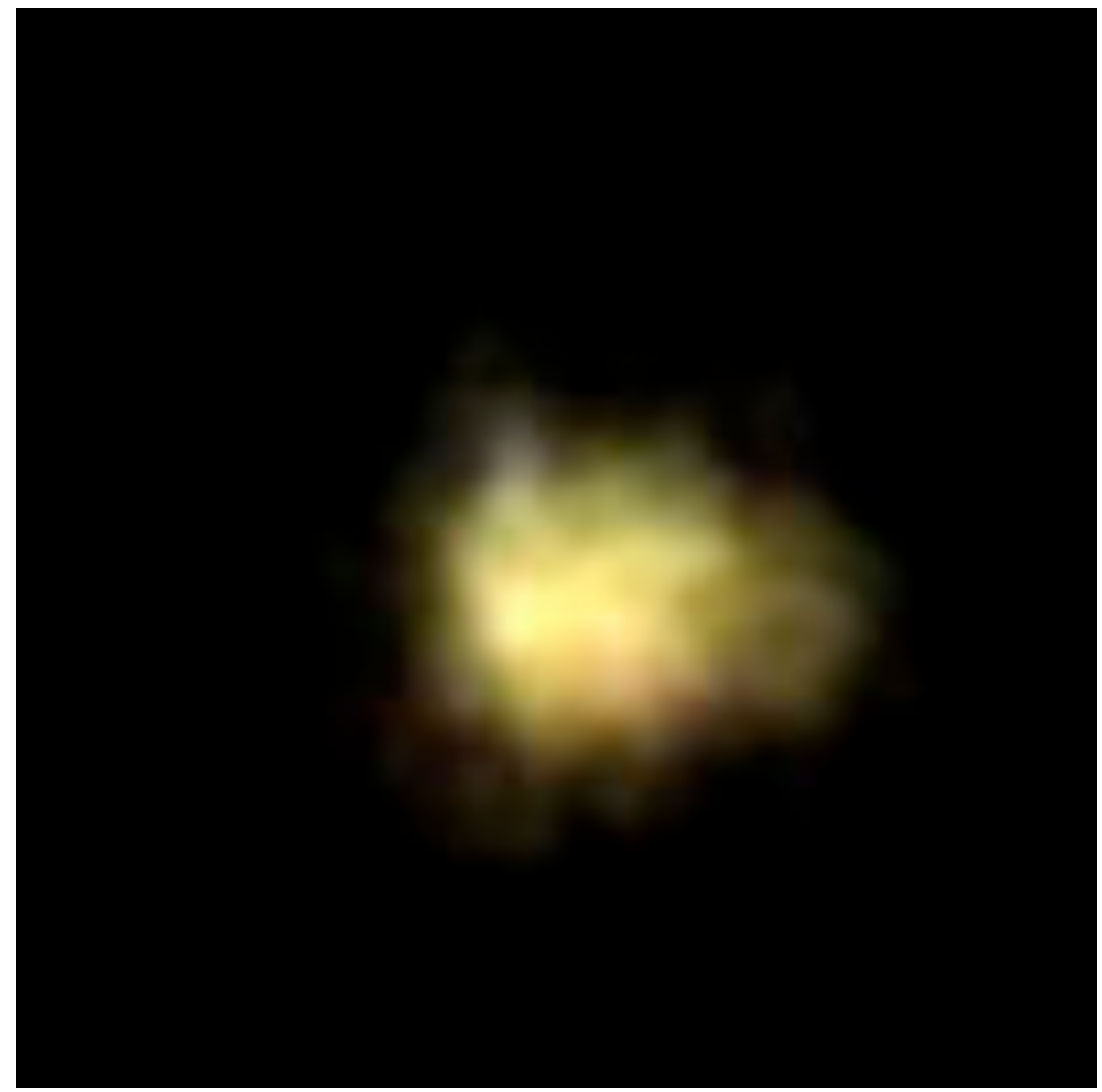
wavefront gets broken into isophase patches, each is a "mini-image" - interference leads to "speckles"



H. Bradt

Seeing

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



MPIfR

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!

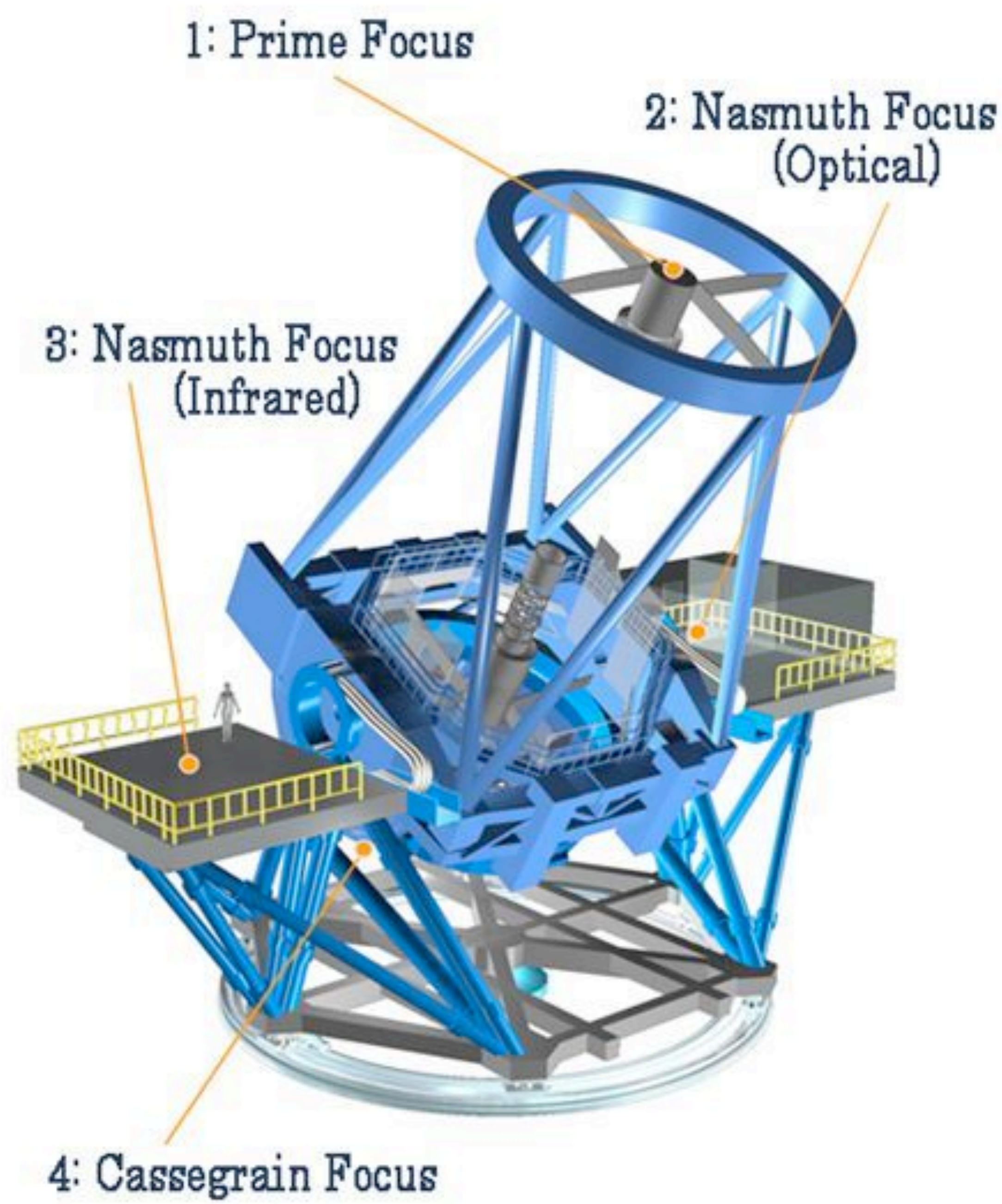
modern domes have lots of windows, day-time AC

(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)



Subaru Telescope

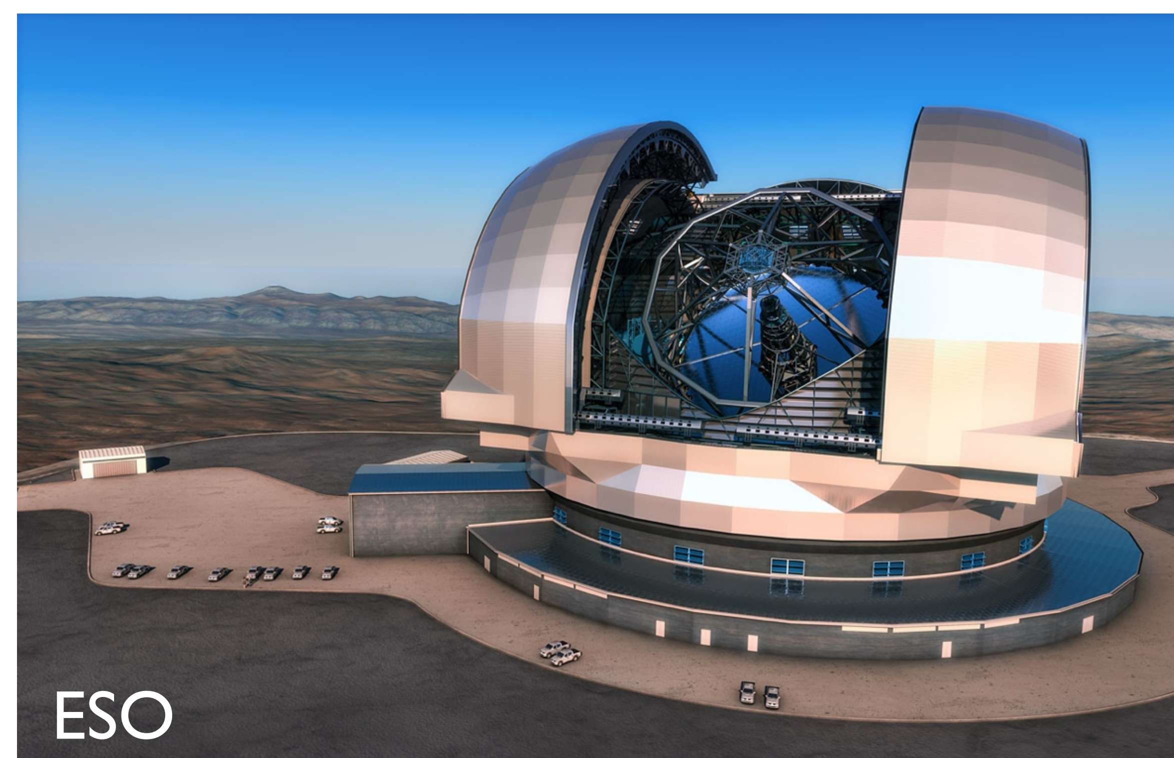
Aperture

- 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

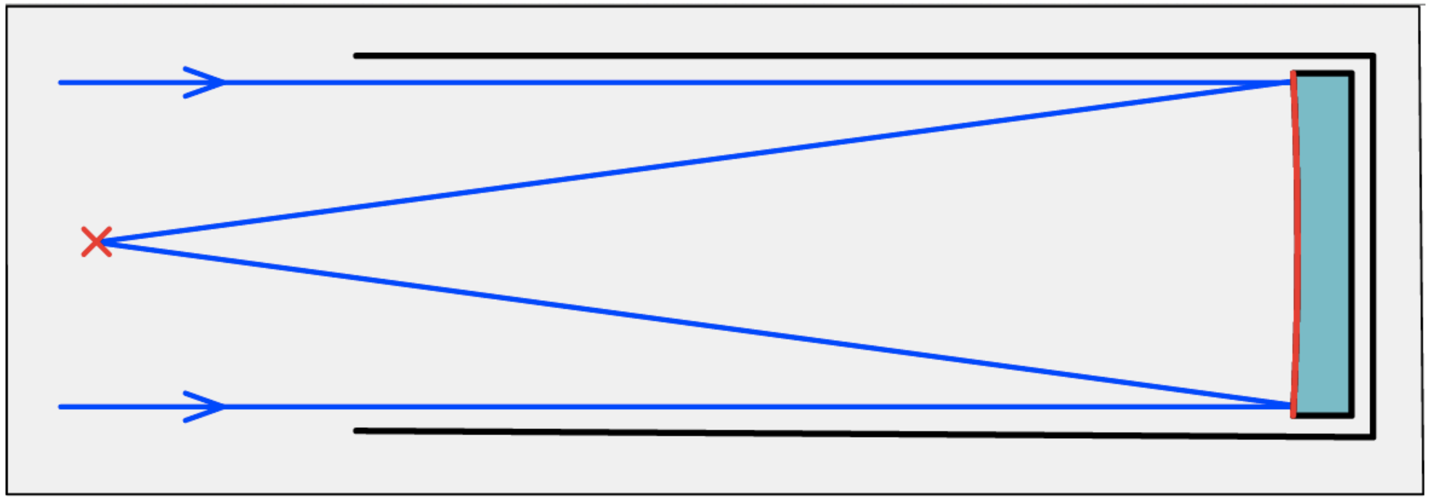
L. Hatch

next generation: 30m telescopes (~2025)

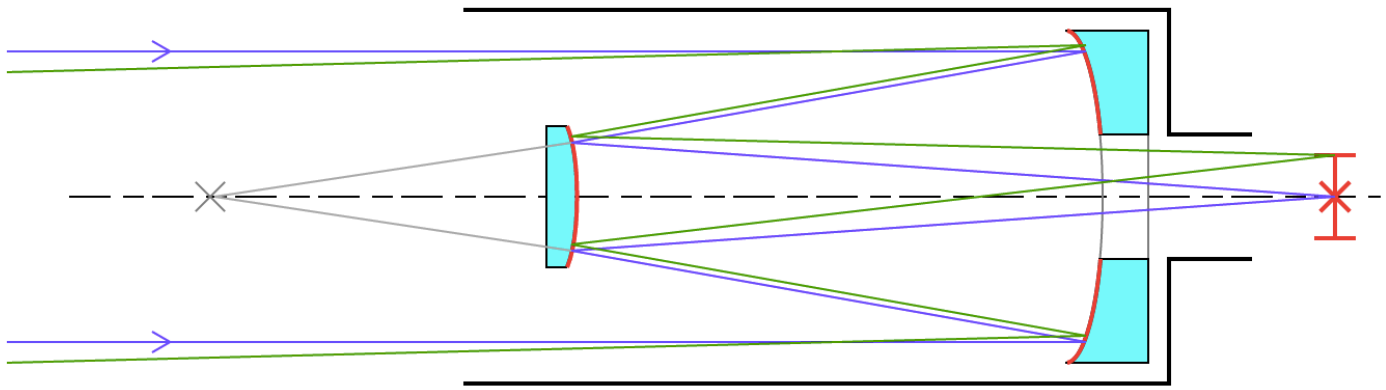


Telescope foci

- prime focus: focus of primary mirror

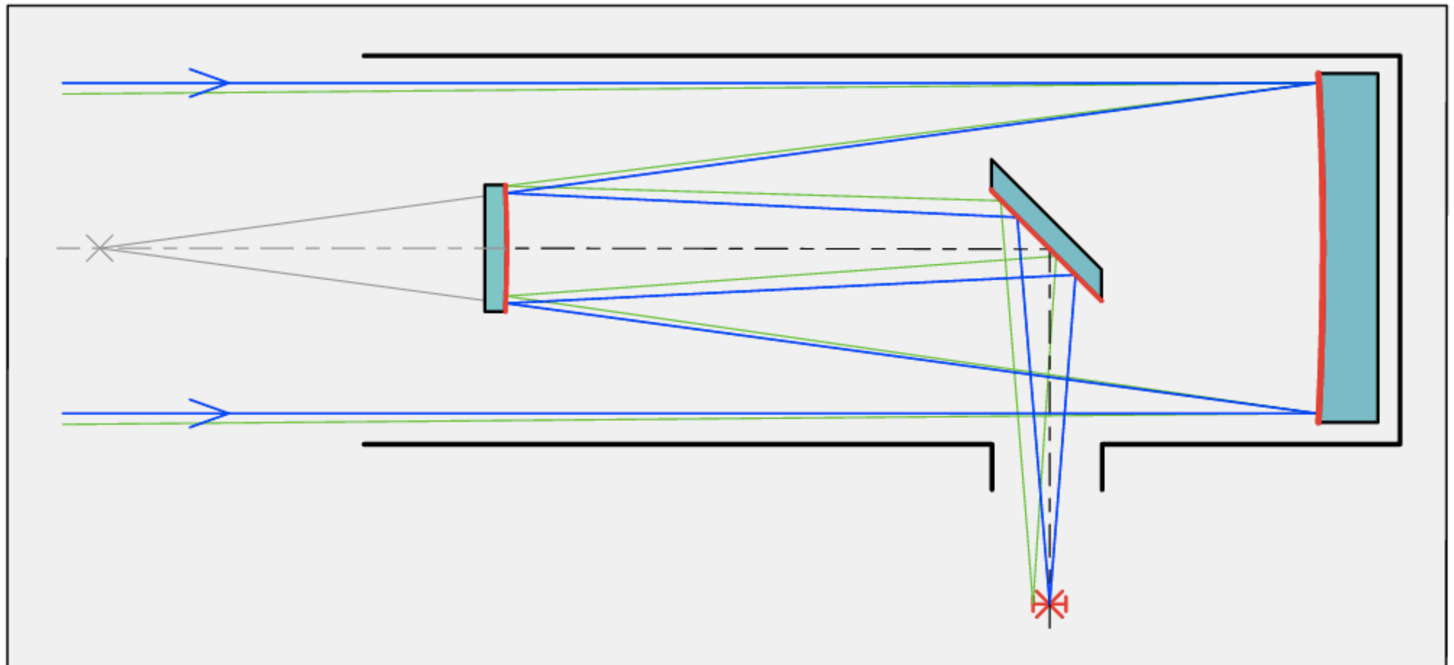


- Cassegrain focus: secondary mirror in front of prime focus; secondary focus behind primary mirror



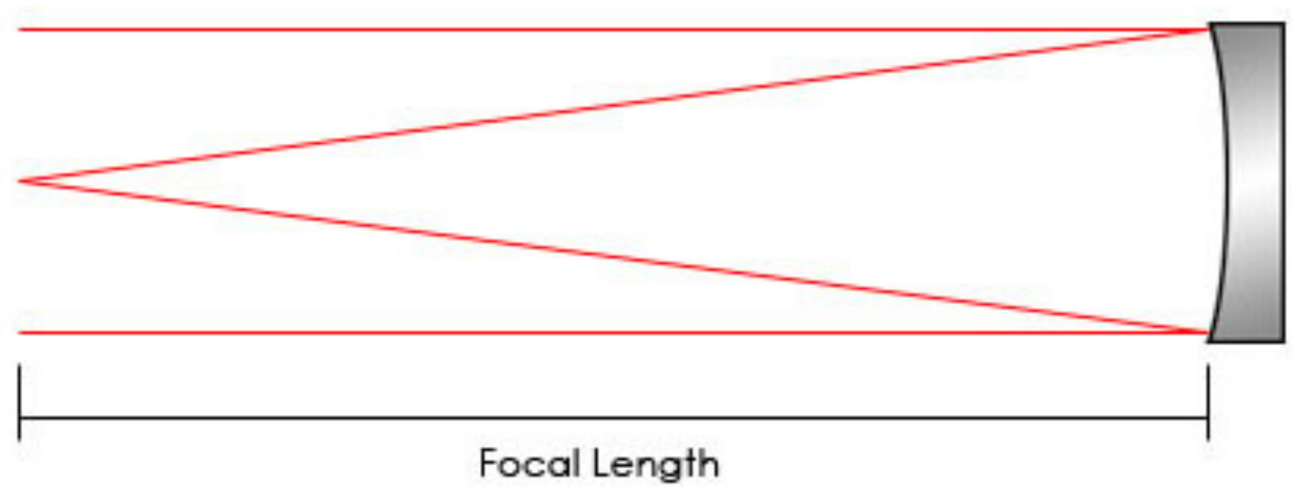
K. Vedala

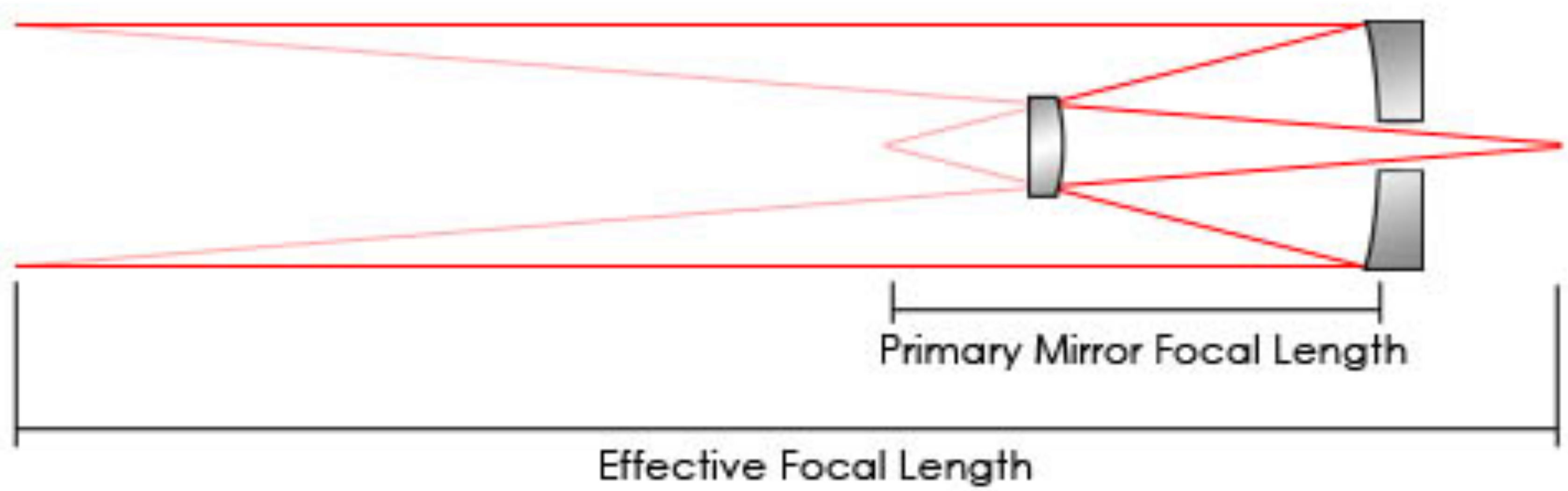
- Nasmyth focus: pick-up mirror, can be placed through mount axis



Focal length

distance from mirror / lens to the focal plane



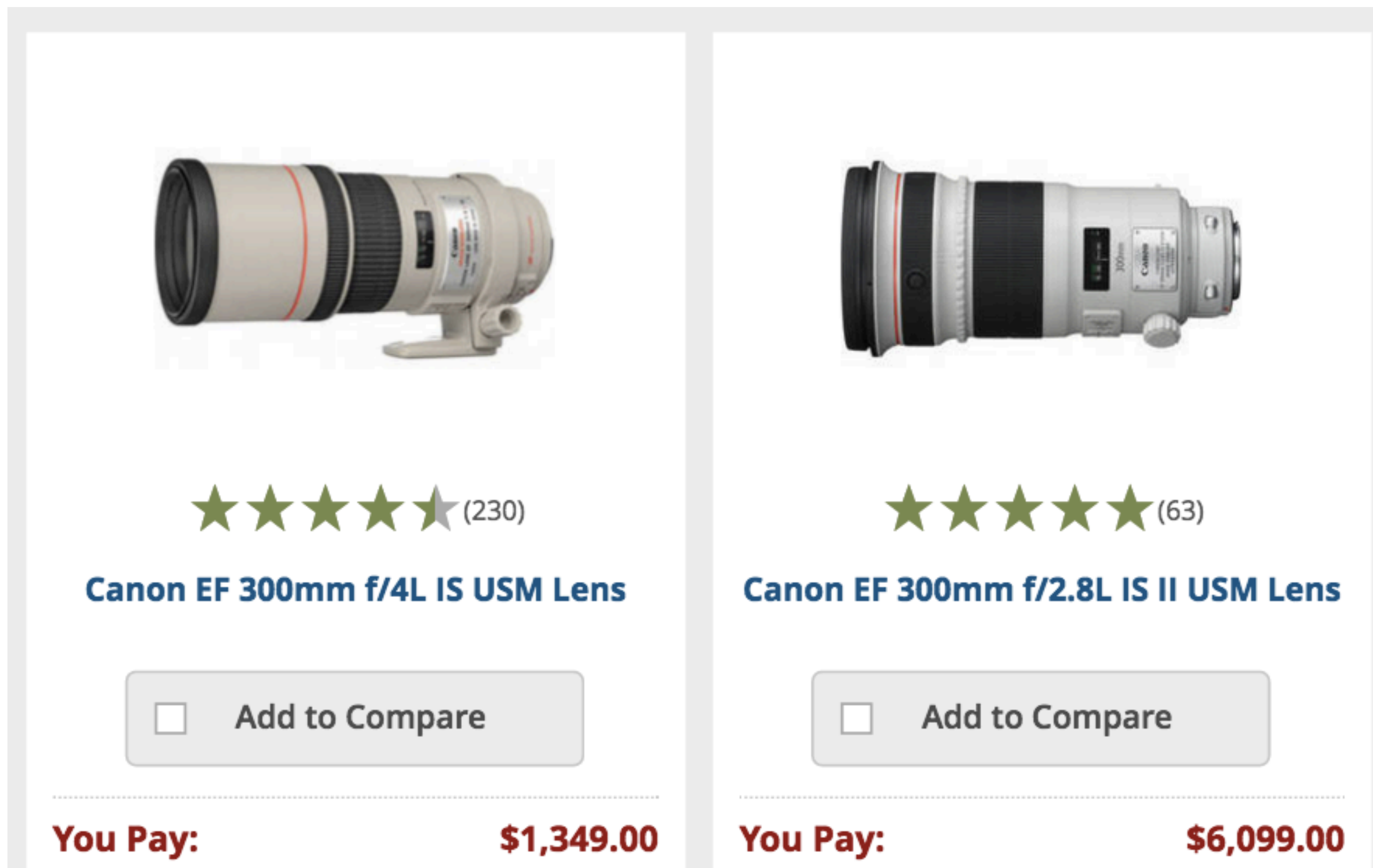


Starizona

Focal ratio ("f number")

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

measure of how "fast" the lens / mirror is



B&H

Vera C. Rubin Observatory

- 8.4m mirror
- f/1.2 focal ratio !
- will conduct *Legacy Survey of Space and Time* (LSST)

Can follow construction at

https://www.lsst.org/news/see-whats-happening-cerro-pachon

Plate Scale

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

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

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

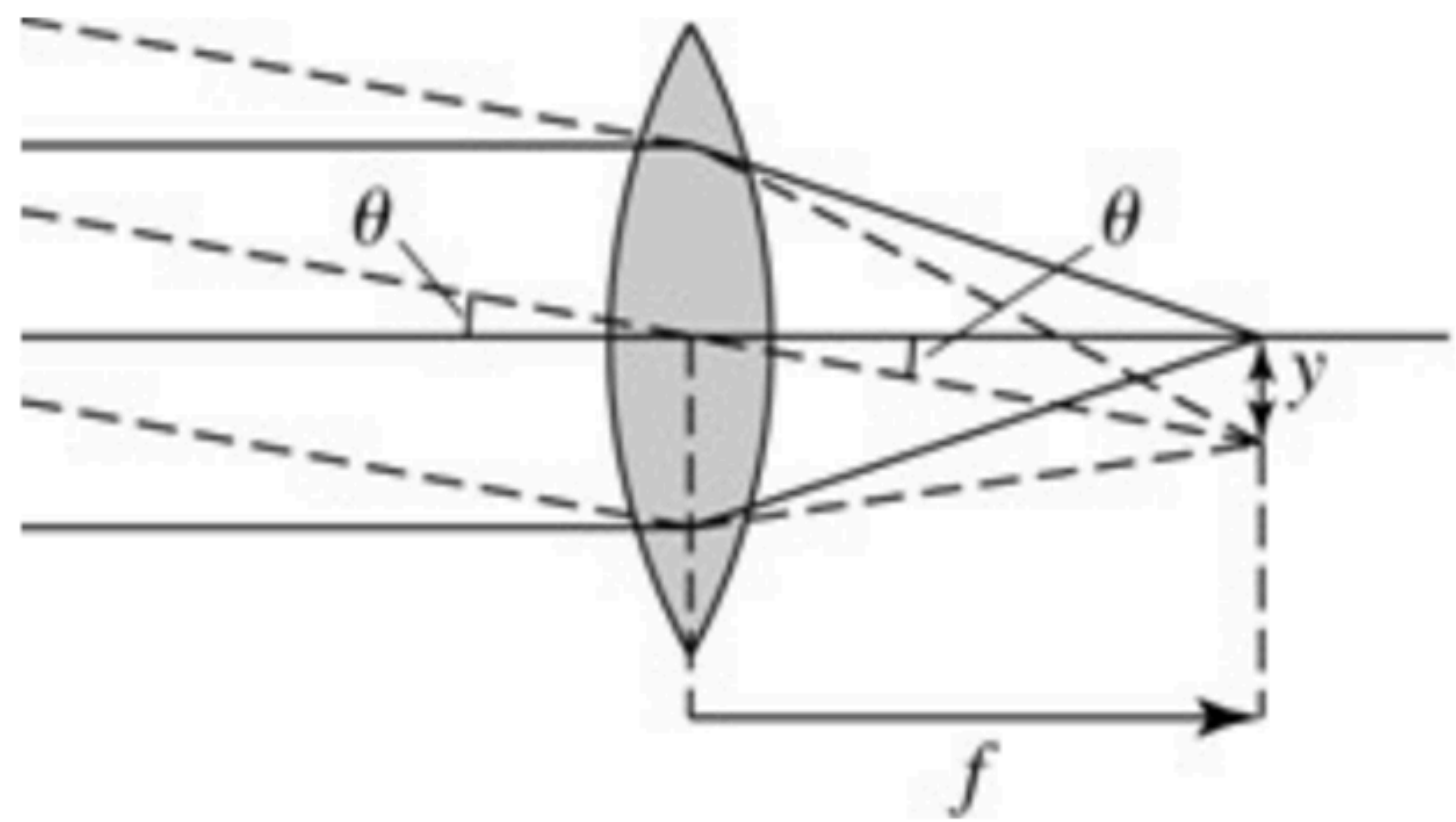


plate scale = (focal length)$^{-1}$

units: angle / length

e.g. arcseconds / mm

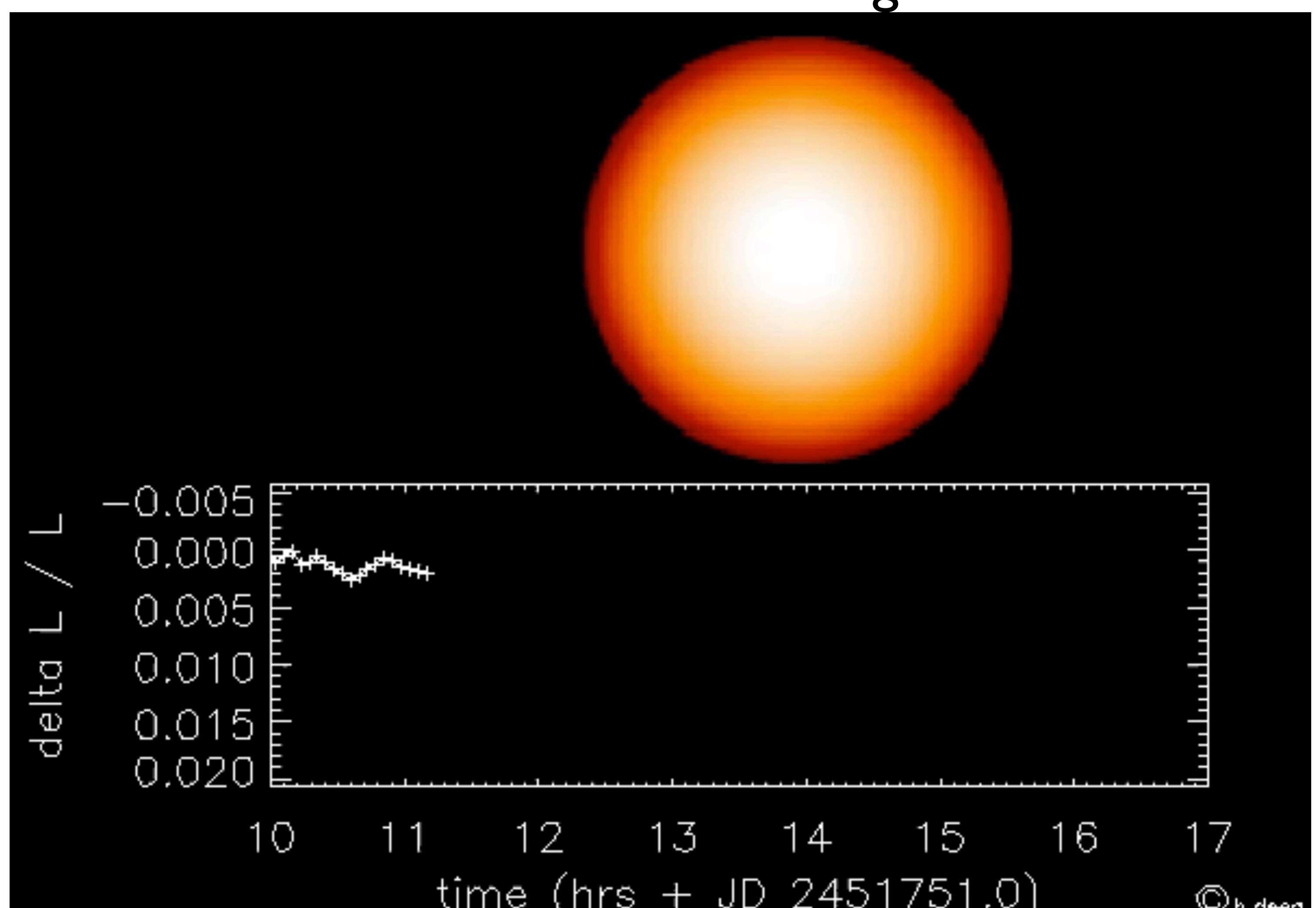
unknown

Preparing for your observations

Homework

Start preparations for Lab 2:
- optical astronomical imaging
- time-series photometry
- detect an exoplanet transit!

Deeg & Garrido 2000



Homework

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

http://exoplanet.eu/catalog/all_fields/

select planets detected via "primary transit" and download the catalog

pick suitable targets:

- which host stars are visible from Mt Stony Brook?
- ... at night-time in the next ~month?
- (... 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 2

HW (due next Wednesday): request your exoplanet nights

triple-check your calculations!!!

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

- observing dates have to be AFTER your Lab 1 date
- the earlier you get your data, the better

check observing calendar (link on github wiki) for full moon and dates already taken

excerpt from Mt. Stony Brook observing calendar