

PHY 517 / AST 443: Observational Techniques in Astronomy

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

Lab 1 (CCDs)

- You should have scheduled Lab 1 with the TAs; if you have not, do so 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*

github.com/anjavdl/PHY517_AST443/wiki/Schedule-Spring-2021

Code Issues Pull requests Actions Projects Wiki Security Insights ...

Schedule Spring 2021

anjavdl edited this page 5 hours ago · 16 revisions

Date	Topics	Slides	Tutorials	Homework
Feb 1	Snow Day			
Feb 3	Intro, Coordinate Systems, Time	Lecture 0, Lecture 1	Tu1	HW1, due Feb 8
Feb 8	Magnitudes, Atmosphere, Telescopes	[Lecture 2]	Python1	HW2, due Feb 15
Feb 10	CCDs, FITS files	[Lecture 3]	Python2	
Feb 15	Statistics 1	[Lecture 4]		[HW3, due Feb 22]
Feb 17	Statistics 2	[Lecture 4]	[Tu4]	[HW4, due Feb 24]
Feb 22	Spectroscopy; Data Analysis Help Session	[Lecture 5]		[HW5, due Mar 1]
Feb 24	Data Analysis Help Session			
Mar 1	Instructions: Proposal Writing	[Lecture 6]		
Mar 3	Data Analysis Help Session			

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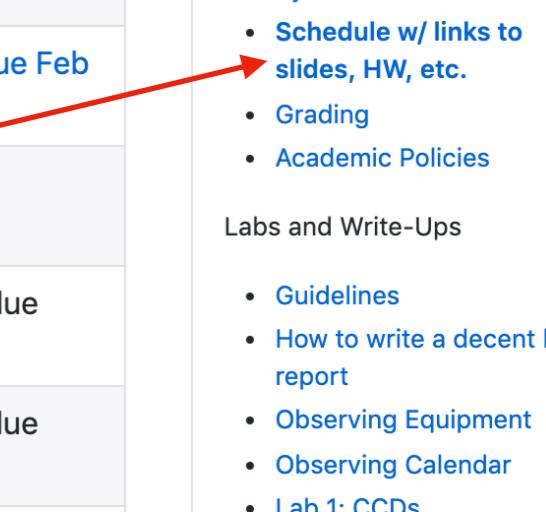
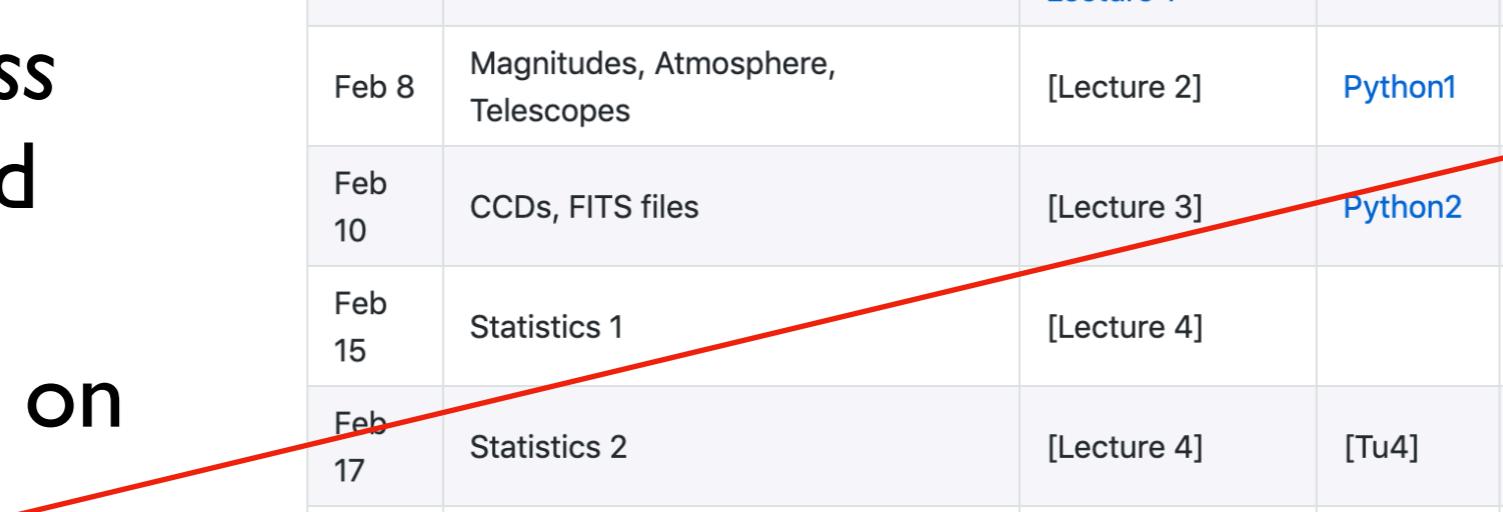
General Information

- Syllabus
- Schedule w/ links to slides, HW, etc.
- Grading
- Academic Policies

Labs and Write-Ups

- Guidelines
- How to write a decent lab report
- Observing Equipment
- Observing Calendar
- Lab 1: CCDs
- Lab 2: Exoplanet transit
- Lab 3: Your own proposal
- Discontinued: Radio Interferometry
- Weather
- End-of-night report

Computing



Office Hours

- easiest way to get in touch with me: slack
- office hours:
 - Fridays 3-4pm, zoom
 - by appointment
 - during data analysis sessions

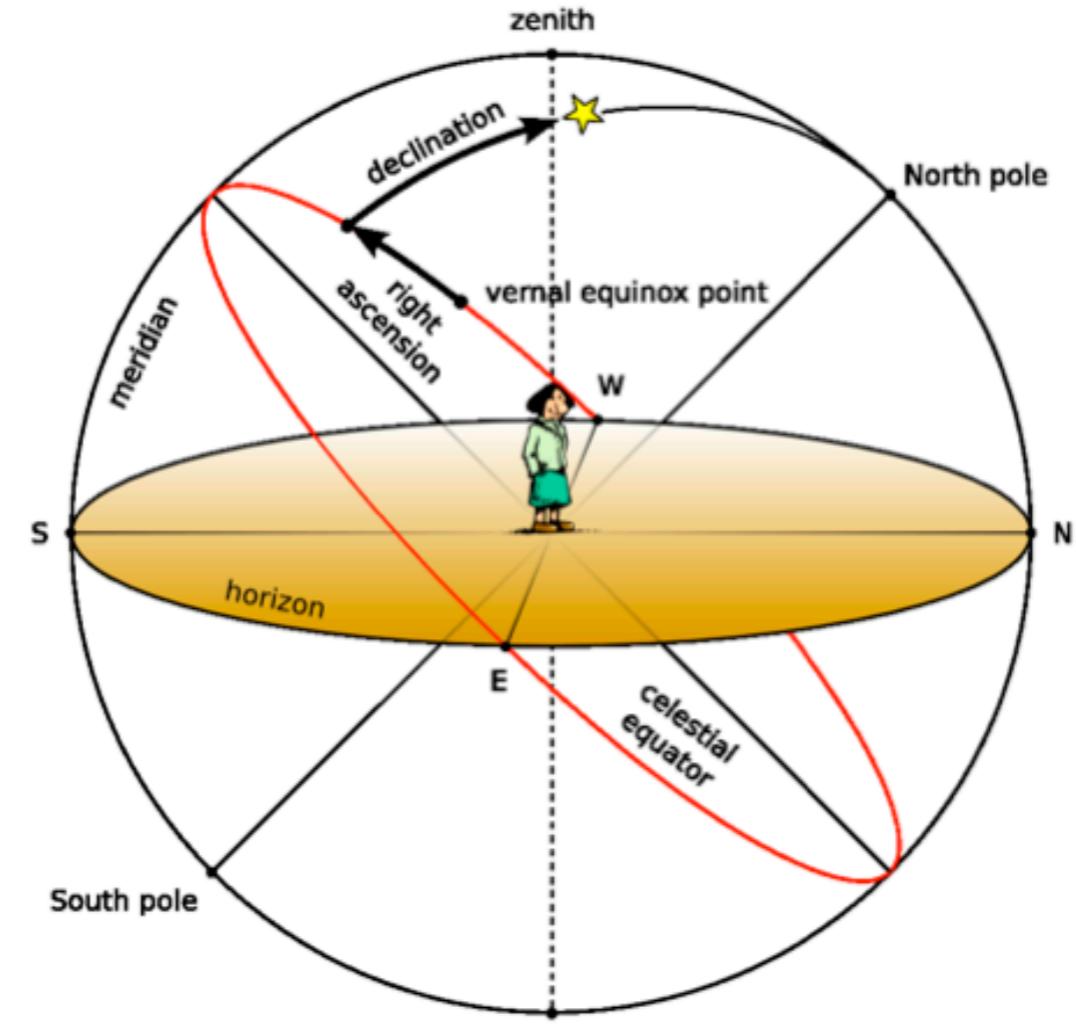
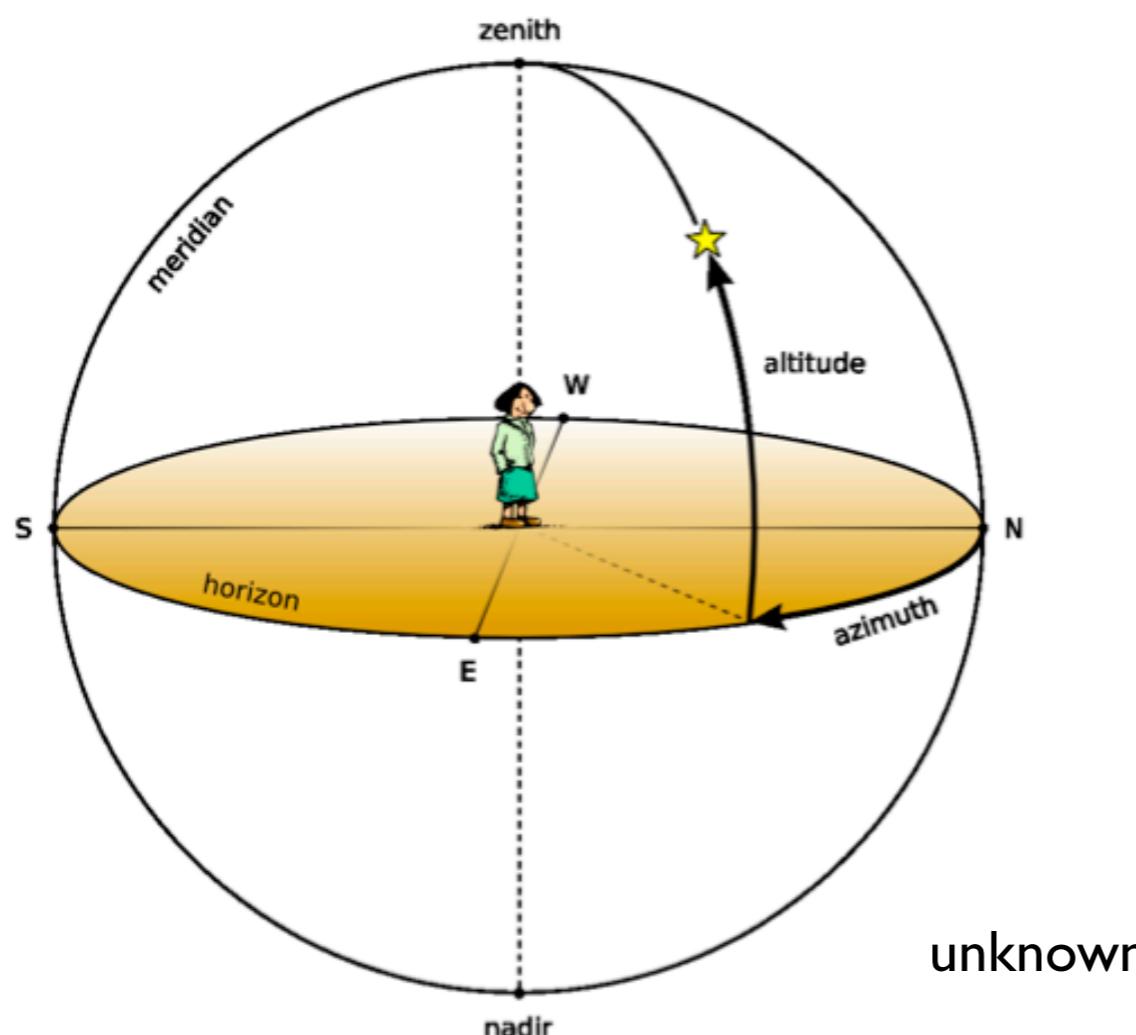
Last time...

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



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

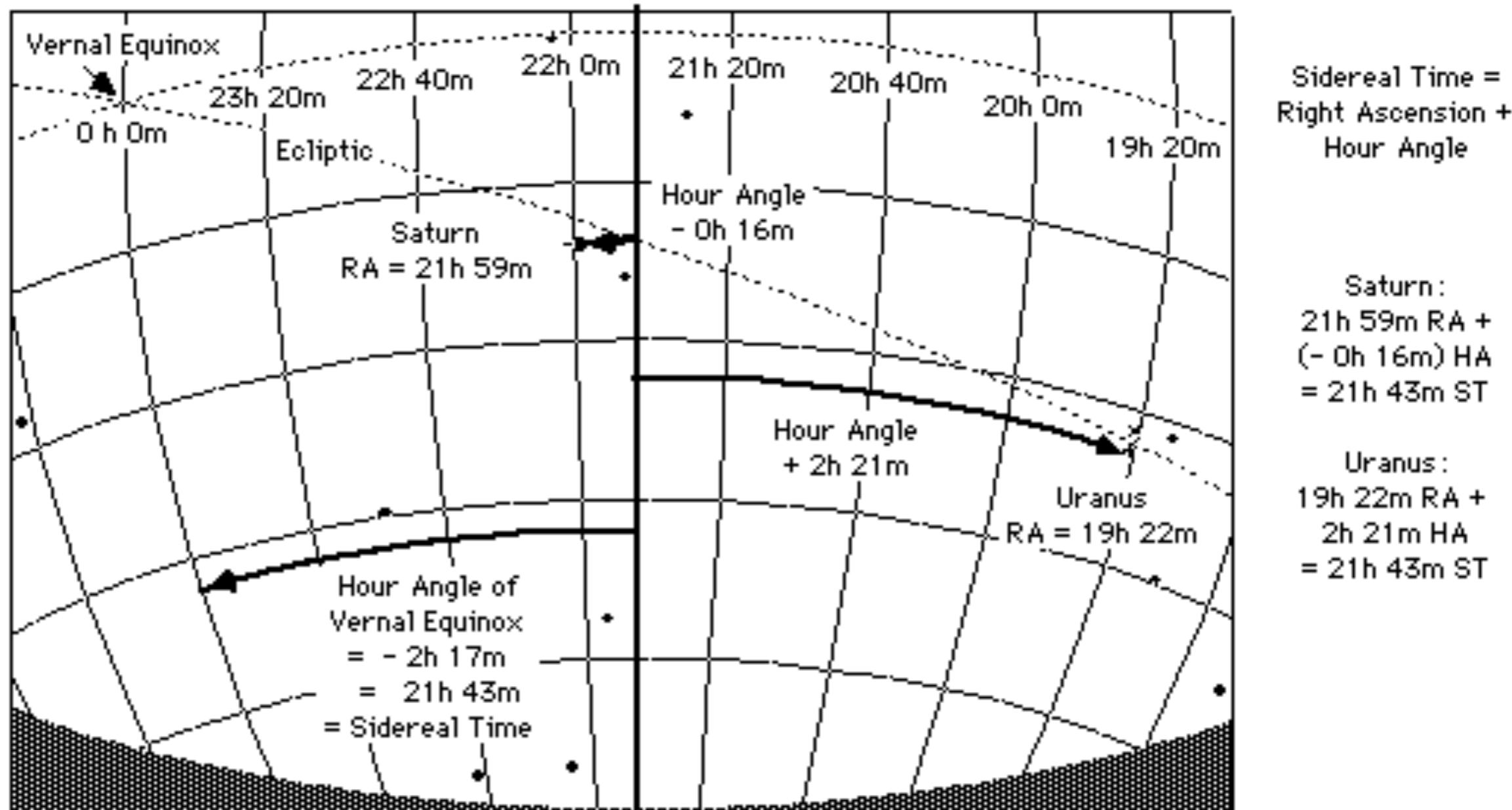
R.A. is defined by time intervals between passing the meridian - it runs right to left on sky maps

Last time...

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

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

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



**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

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

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

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

examples:

Sun: -27 mag

faintest galaxies in Hubble Ultra Deep Field: 30 mag

Moon: -12.5 mag

Iridium flare: -8 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:

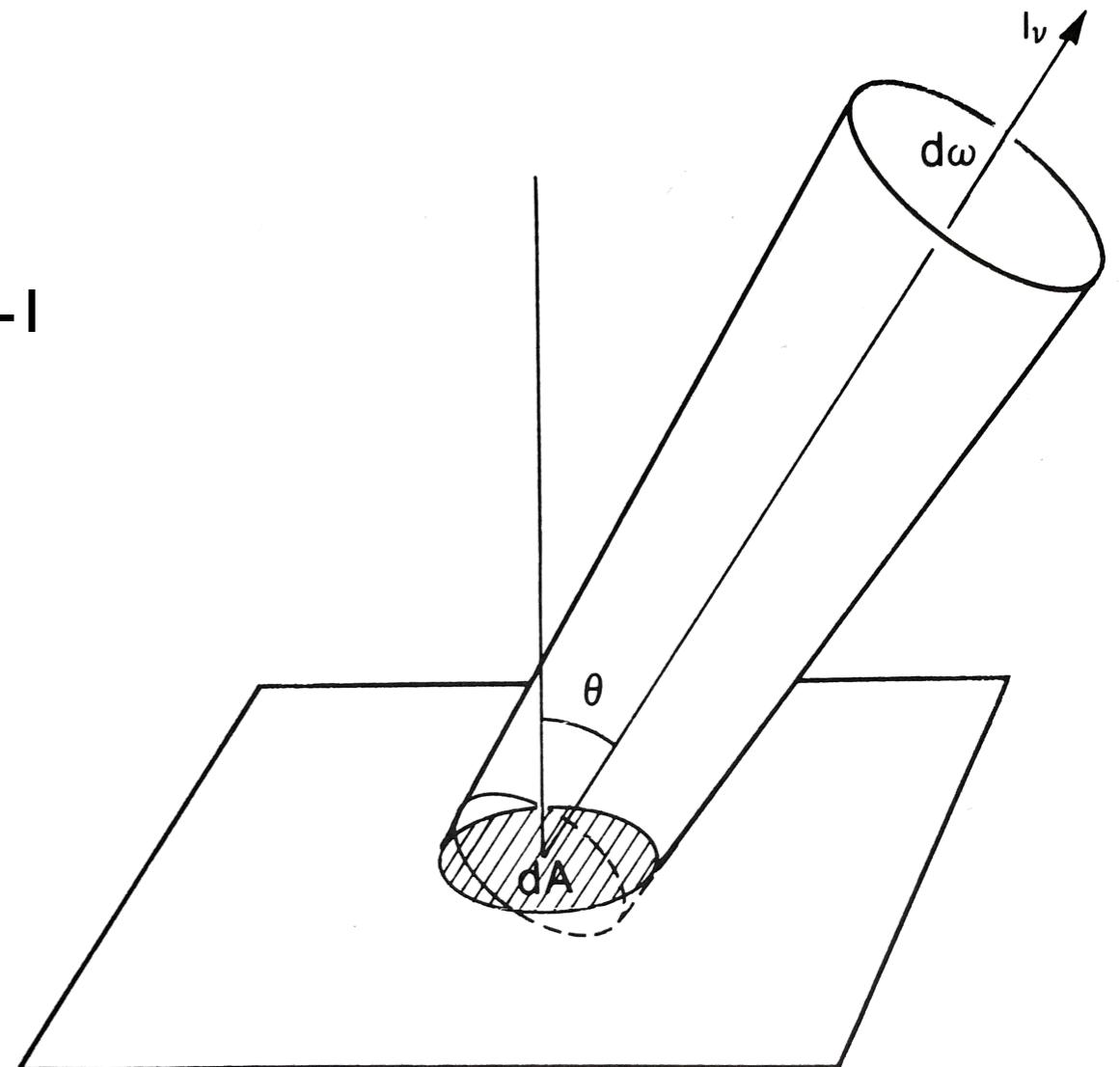
$$dE_\nu = I_\nu dA \cos \theta d\omega dt d\nu$$

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!*



Physical descriptions

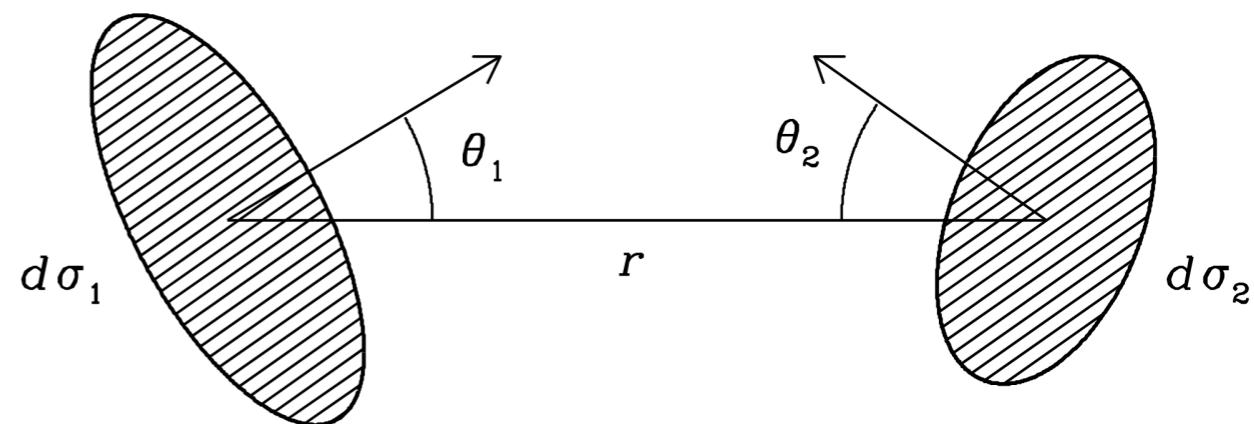
amount of energy passing through area dA , within $d\omega$ (at an angle θ from normal), in frequency range $[\nu, \nu + d\nu]$, during time dt is:

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

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 $d\sigma_1$; $d\omega_2 \dots dE_1 = dE_2$)



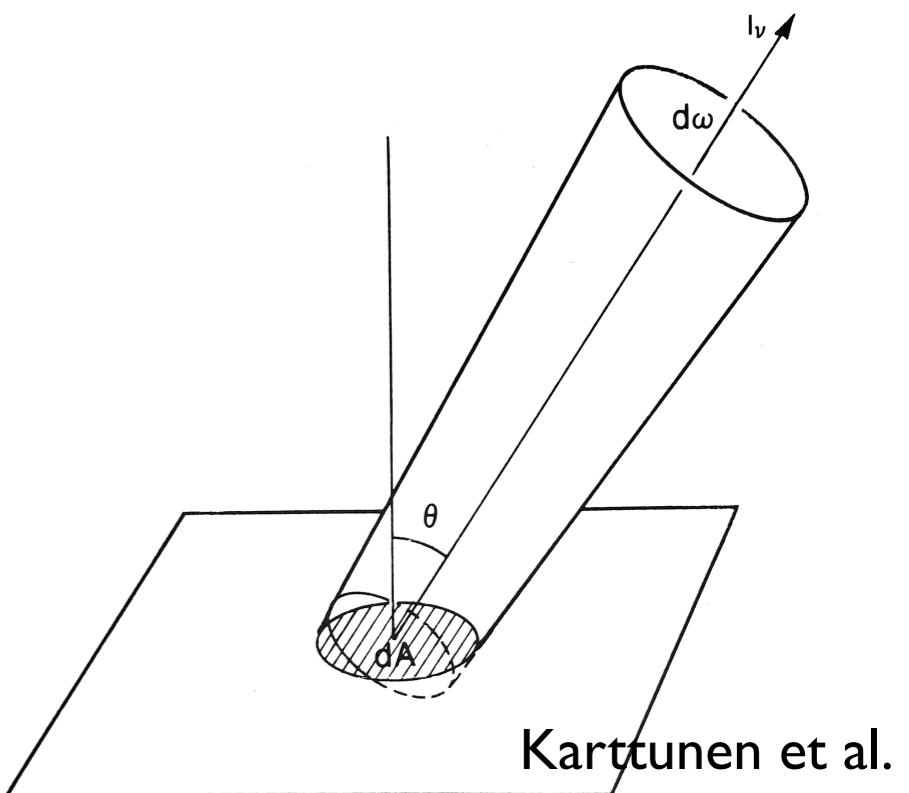
Physical descriptions

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

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

units: ergs s⁻¹ cm⁻² Hz⁻¹ = Jansky

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



Karttunen et al.

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:

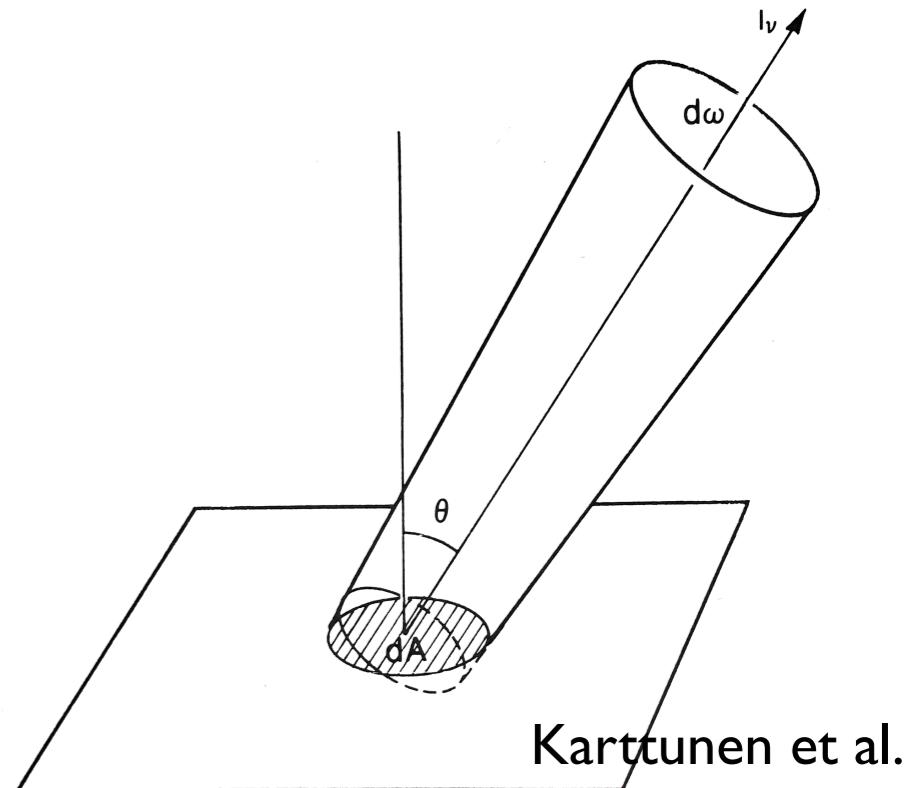
I_ν is constant

for the observer: $d\omega$ 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

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



Physical descriptions

spectroscopy: can determine f_ν

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

flux:

$$\begin{aligned} F &= \int_{\text{passband}} f_\nu \, d\nu \\ &= \int_{-\infty}^{\infty} T_\nu \, f_\nu \, d\nu \end{aligned}$$

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

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

- 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:

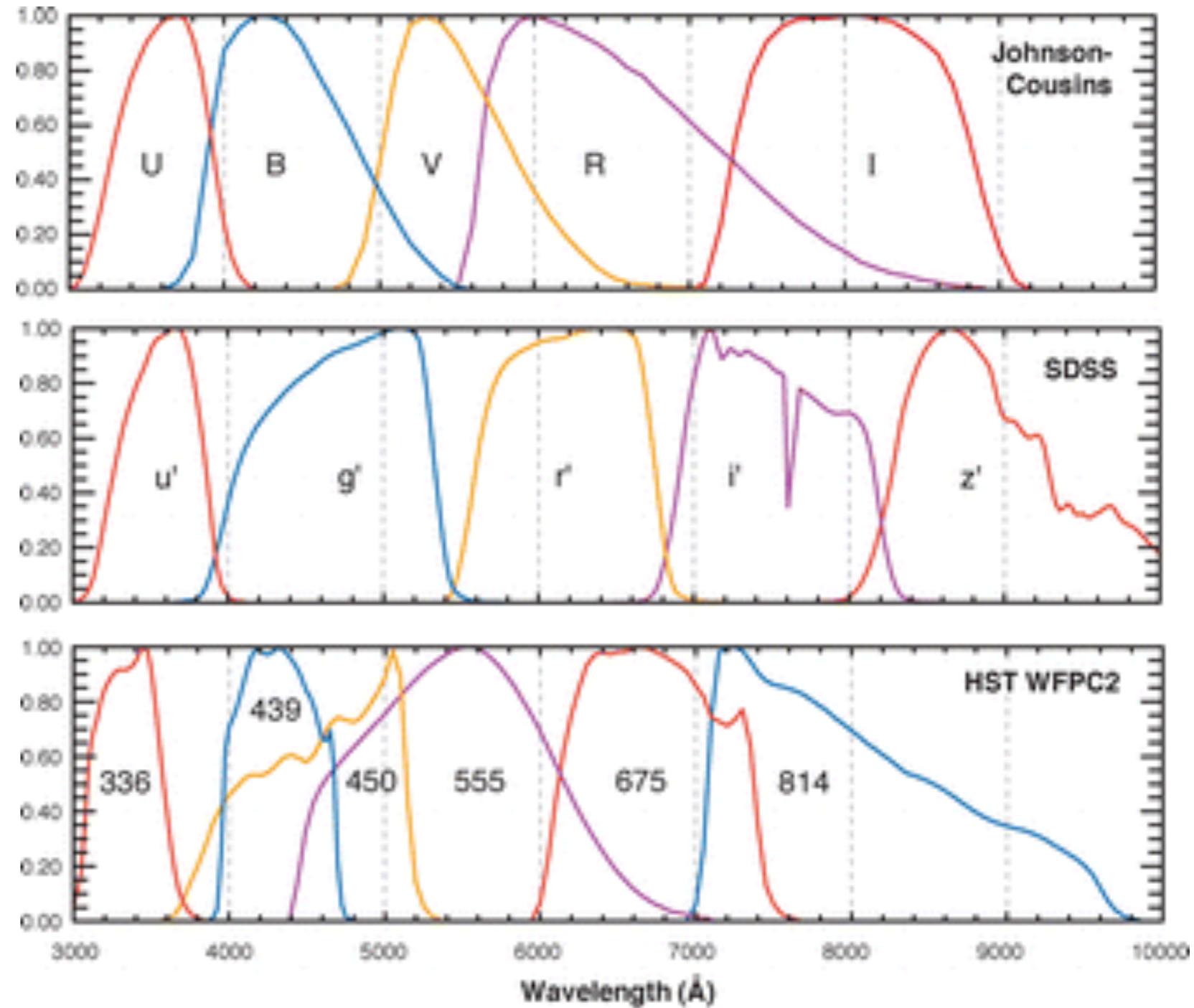
$$L_{\text{bol}} = \int_{-\infty}^{\infty} L_\nu \, d\nu$$

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):

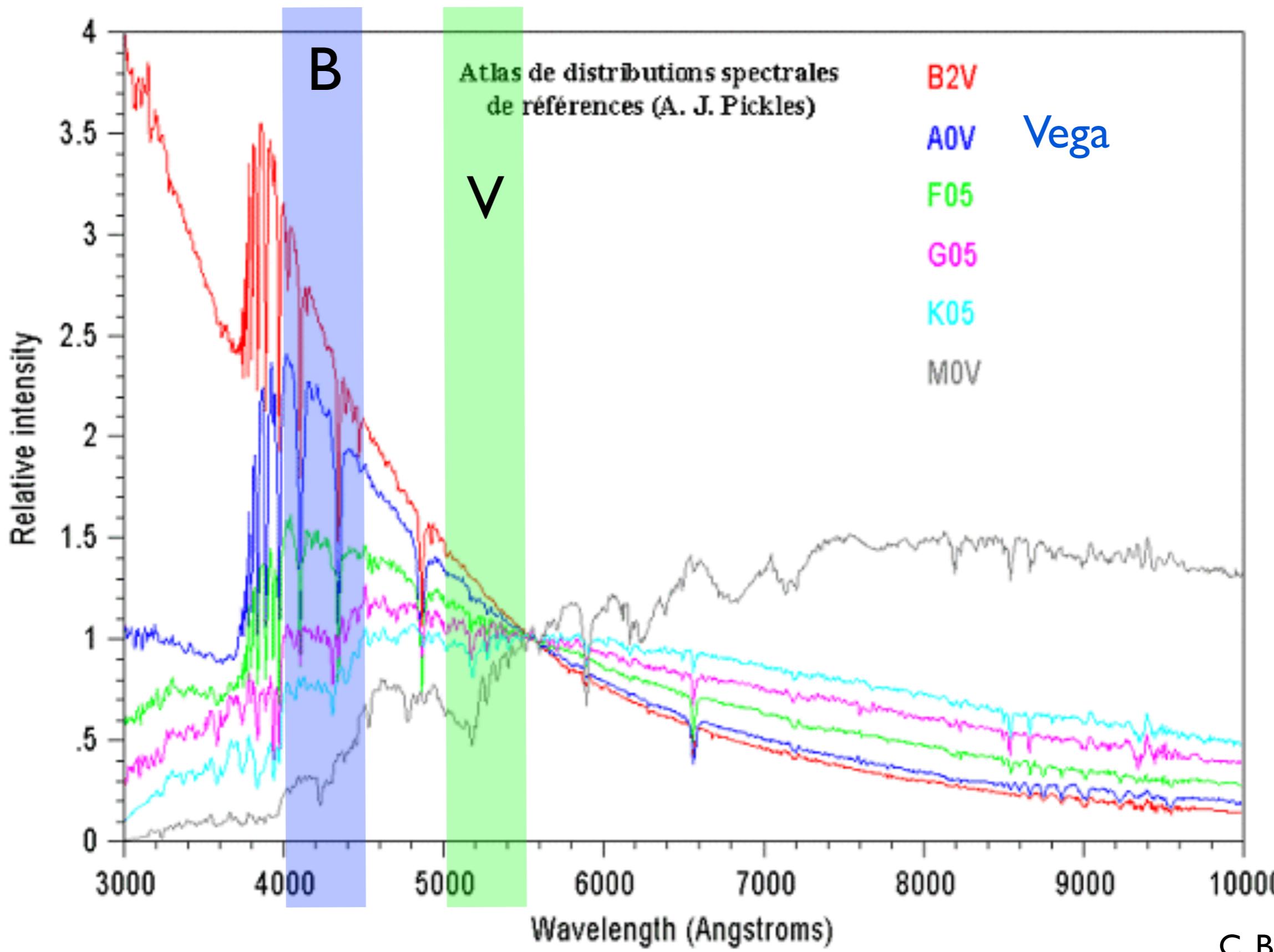
$$\begin{aligned} B - V = m_B - m_V &= -2.5 \log \left(\frac{F_B}{F_V} \right) \\ &= -2.5 \log \left(\frac{F_B}{F_{B,\text{Vega}}} \right) + 2.5 \log \left(\frac{F_V}{F_{V,\text{Vega}}} \right) \end{aligned}$$

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

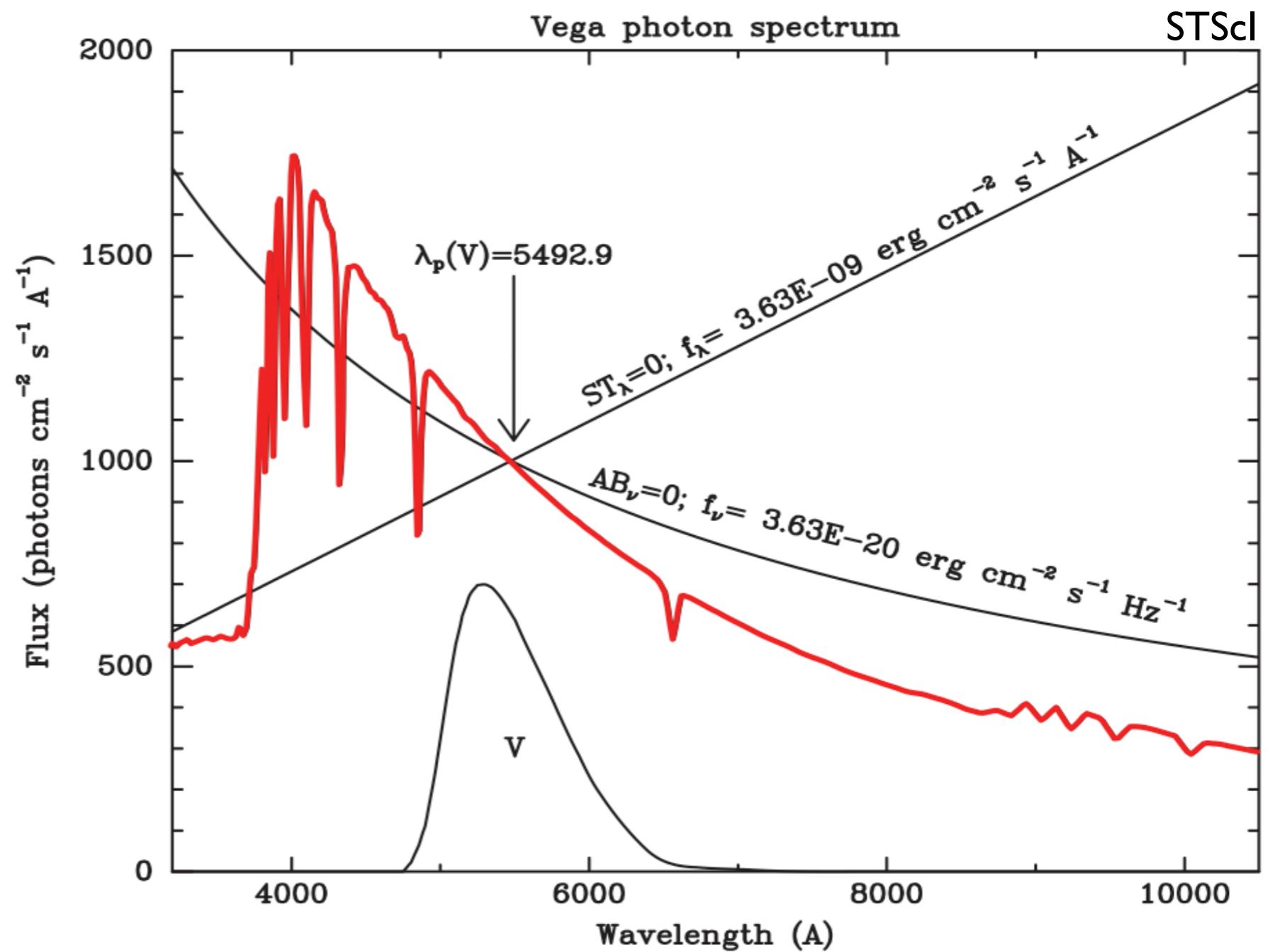


AB magnitudes

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

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:

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

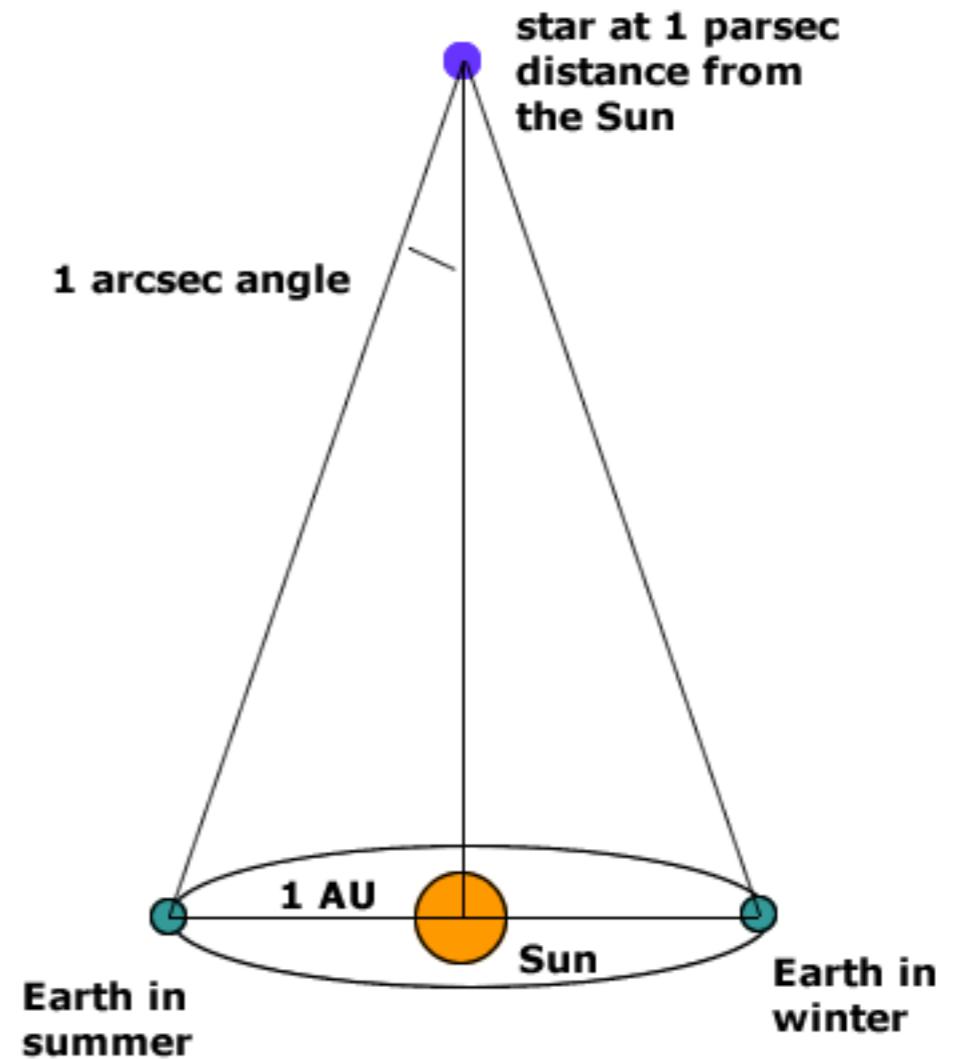
Parallax and parsecs

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

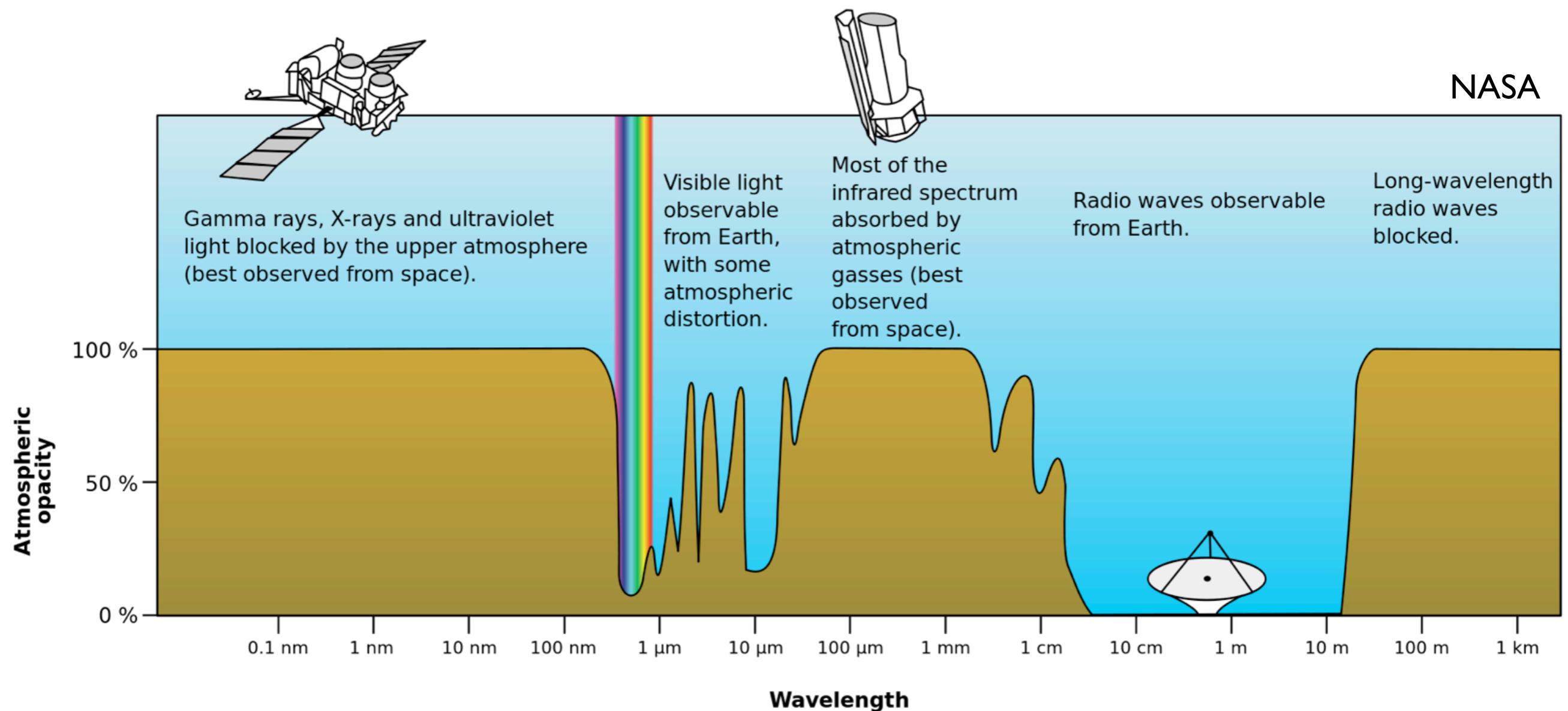
$$1 \text{ pc} = 3.26 \text{ light-years} = 3 \times 10^{16} \text{ m}$$

Proxima Centauri: ~ 1.3 pc



Earth's atmosphere

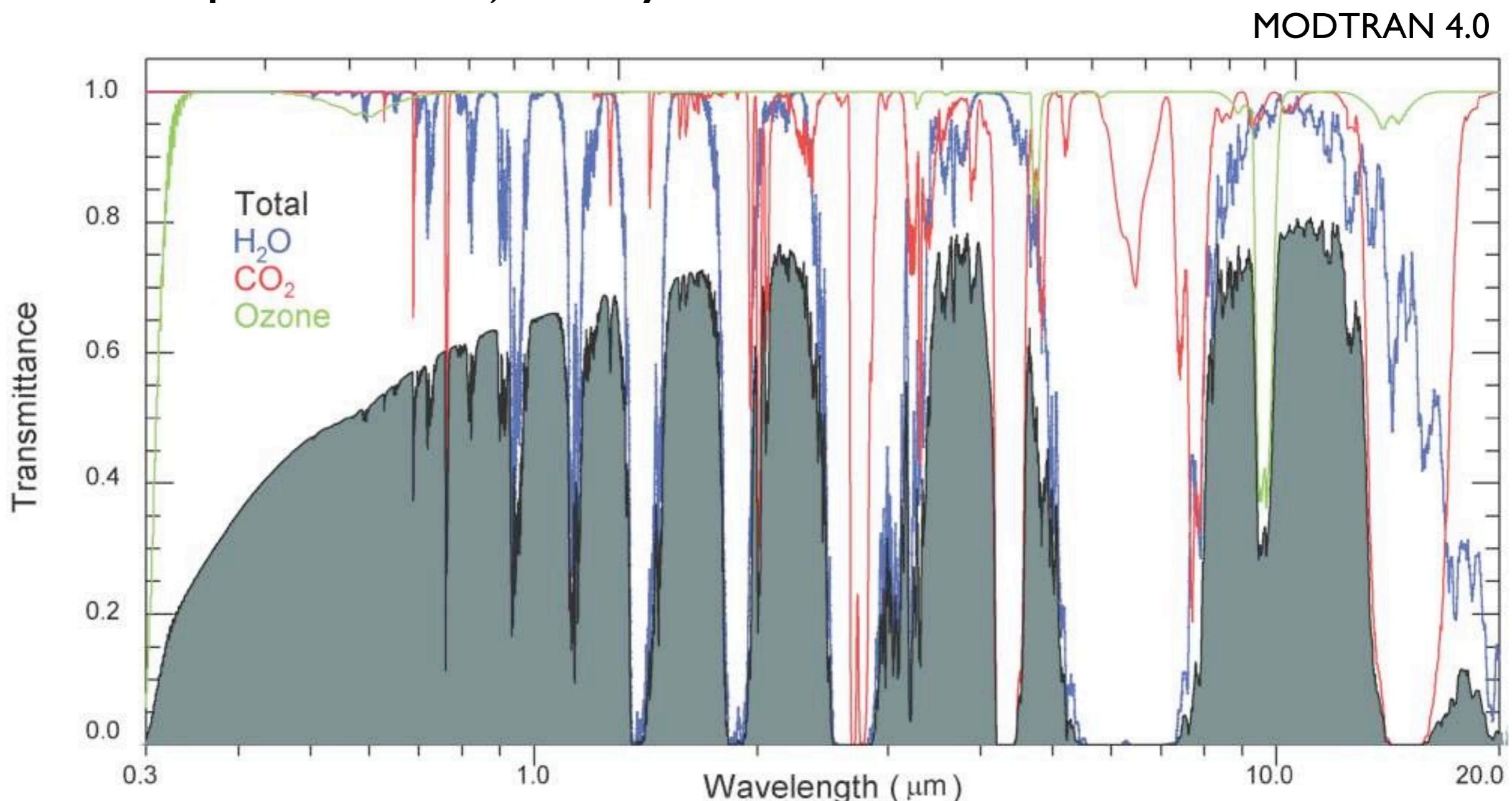
the atmosphere is opaque to most of the electromagnetic spectrum



Earth's atmosphere

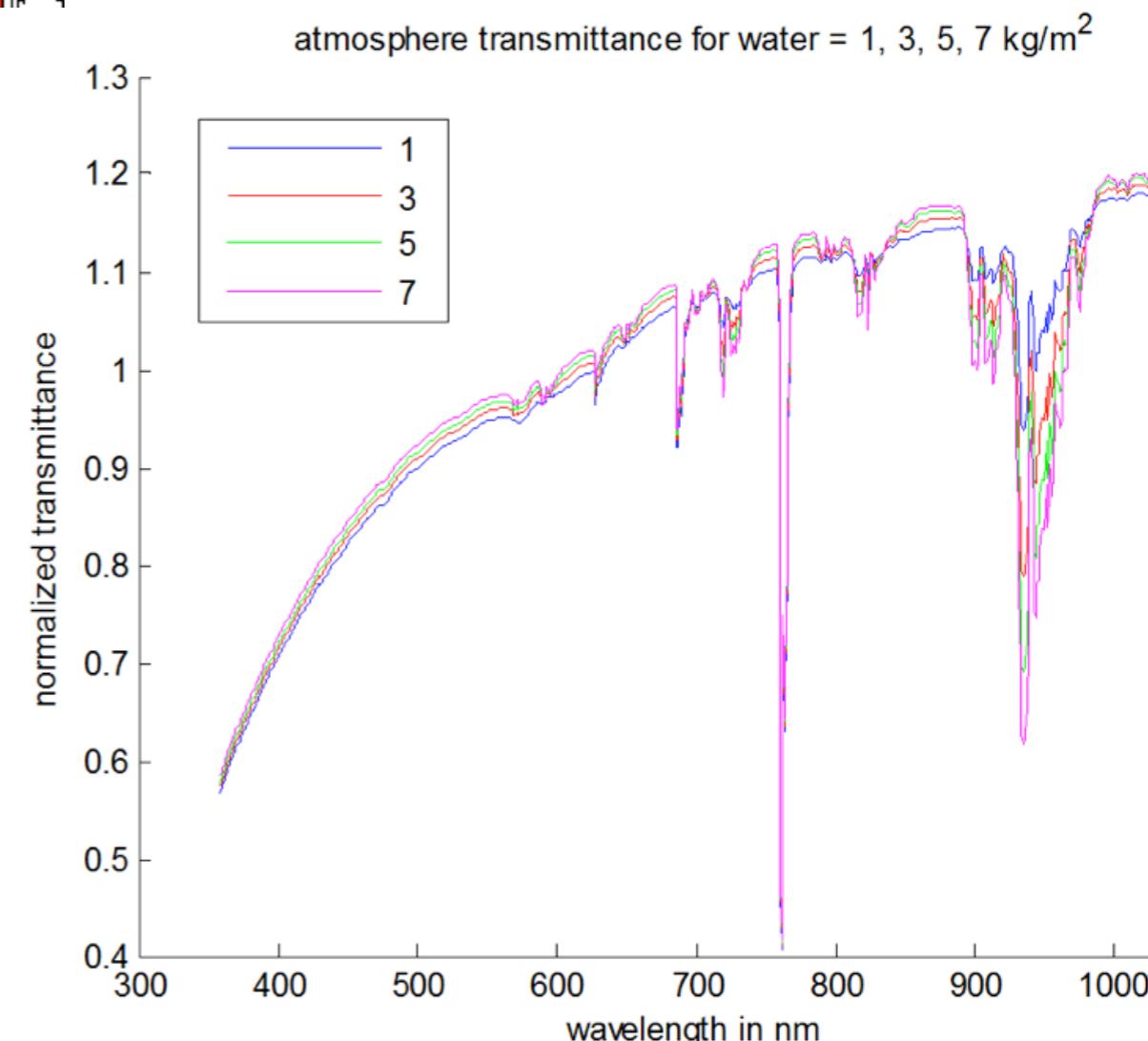
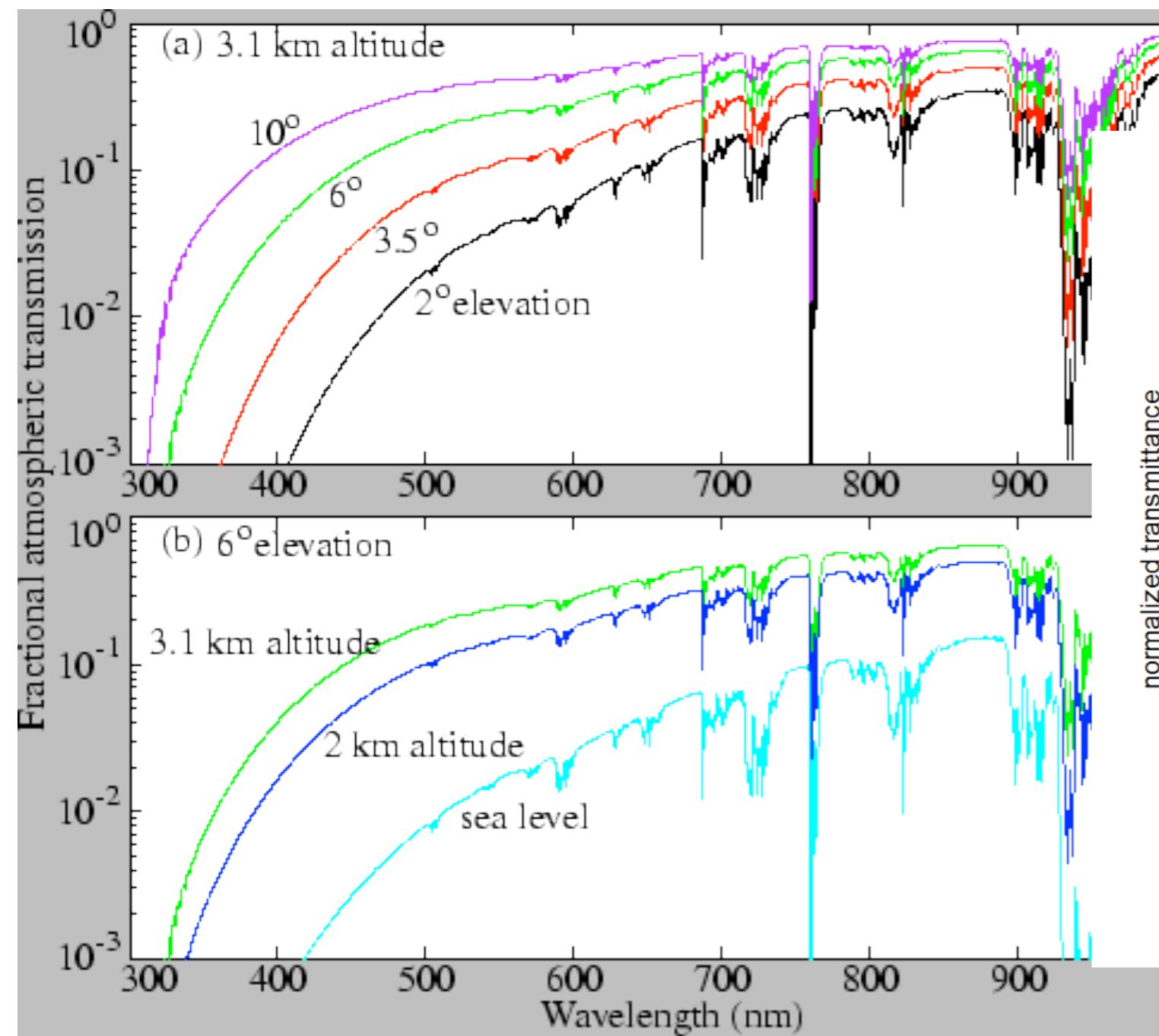
in the optical ($\sim 300\text{nm} - 1\ \mu\text{m}$) and near-infrared, extinction due to:

- 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:

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

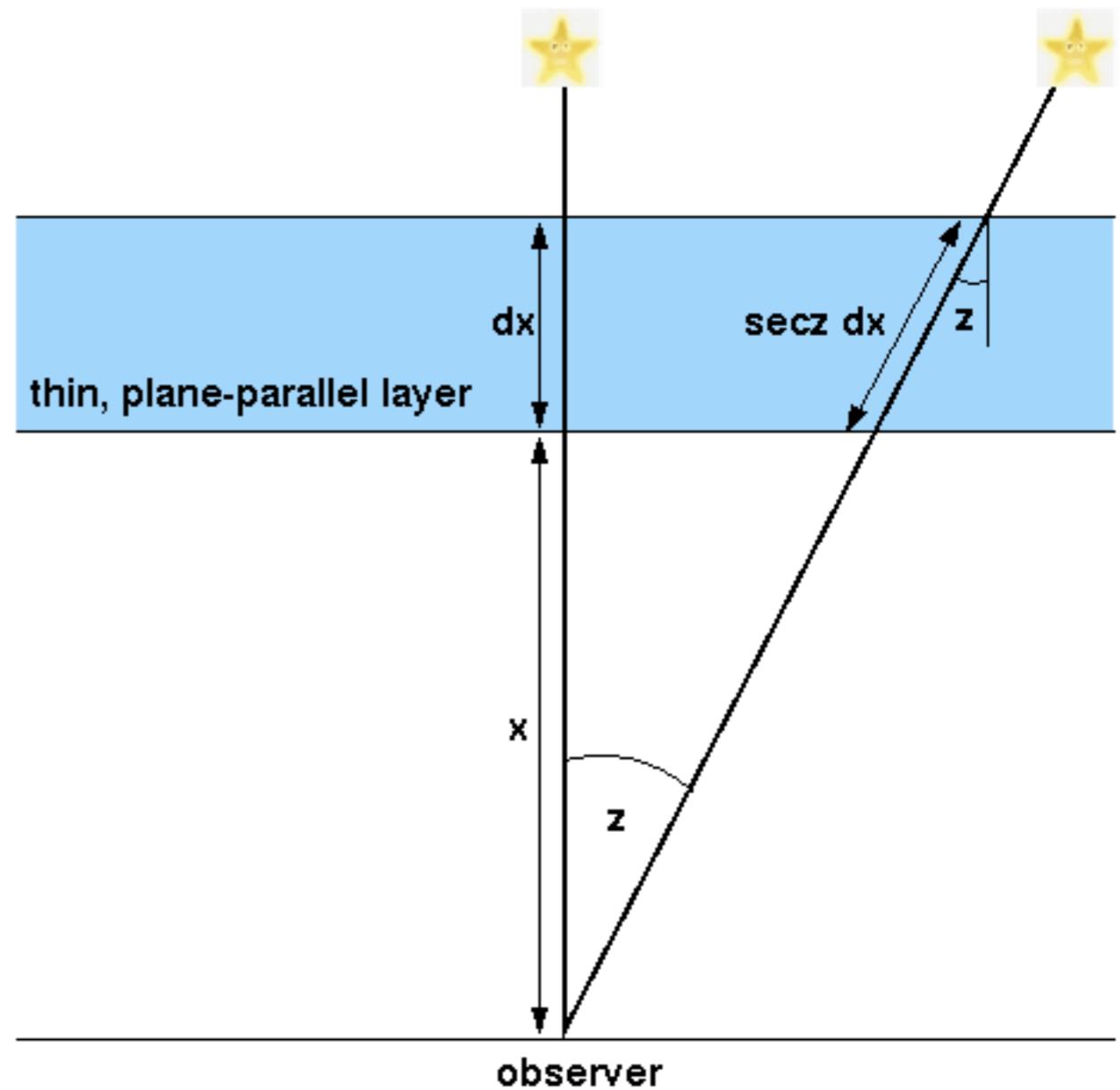
zenith distance:

$$z = 90^\circ - \text{altitude } h$$

$$h=90^\circ: AM=1$$

$$h=50^\circ: AM=1.3$$

$$h=30^\circ: AM=2$$



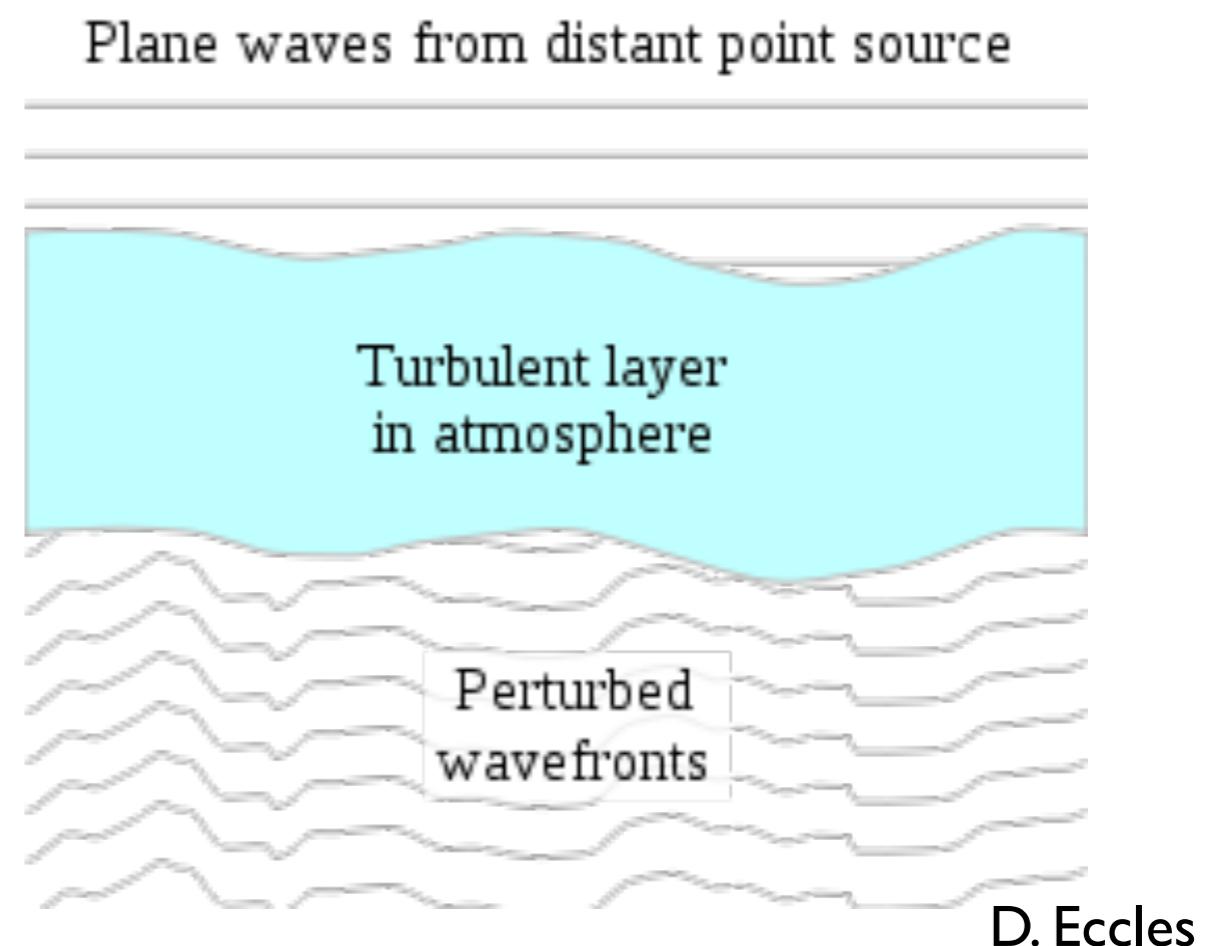
Seeing

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

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

theoretical resolution of 14 inch telescope: $\sim 0.3''$

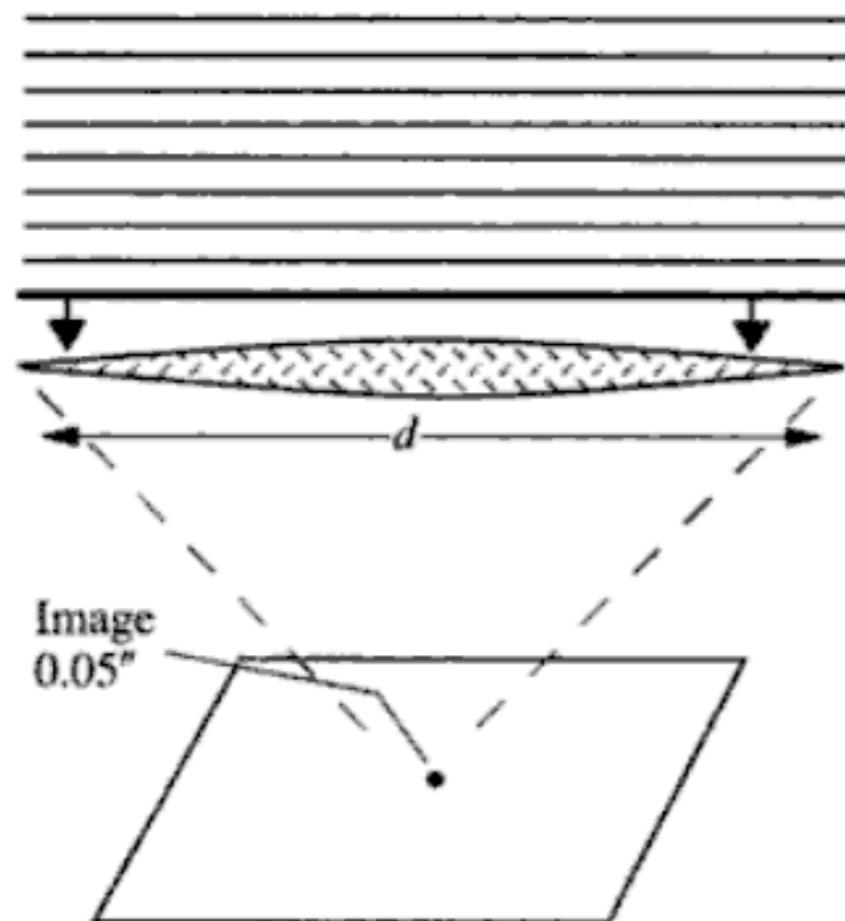
seeing: turbulence in the atmosphere, leads to “blurring” of images



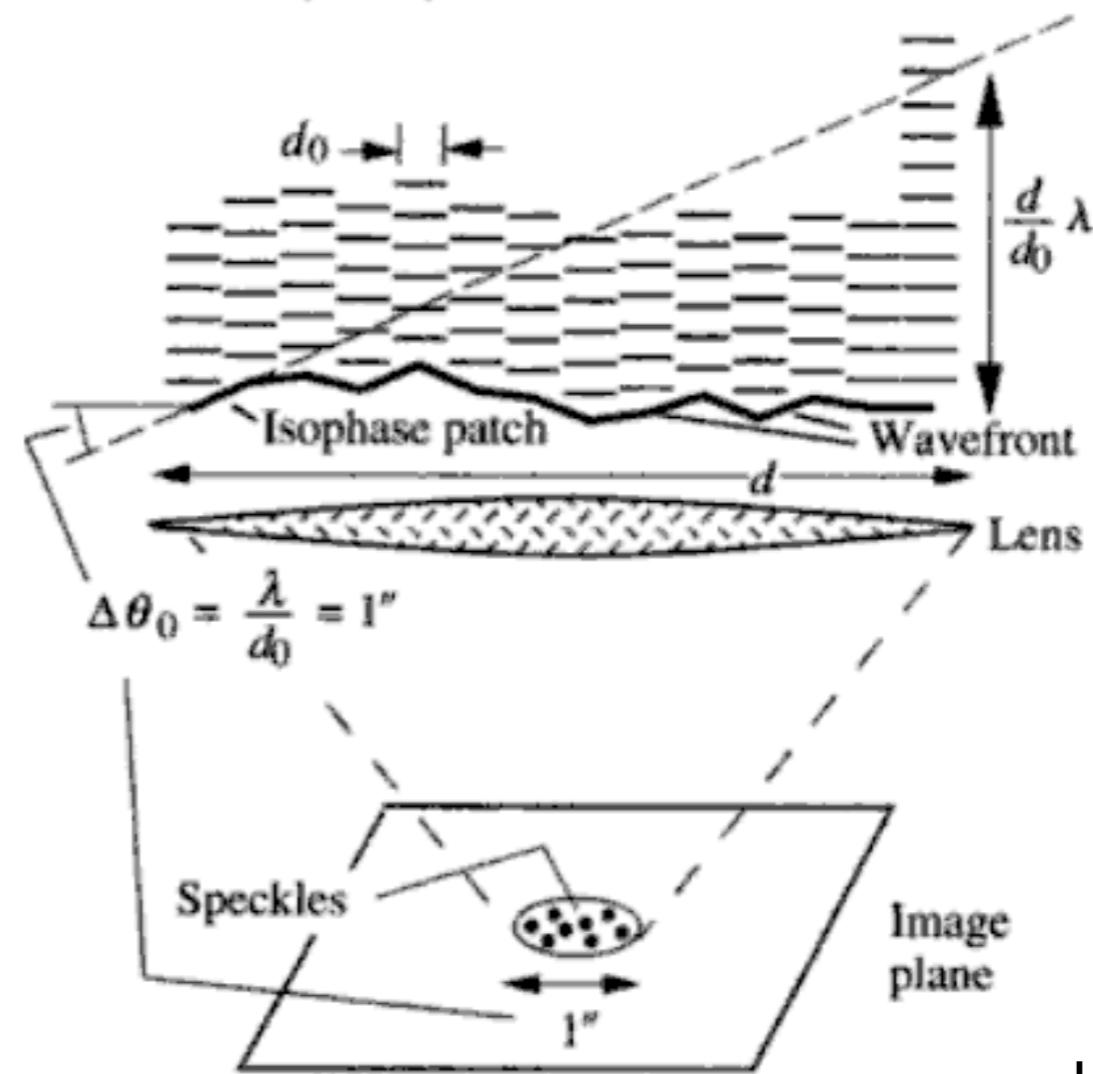
Seeing

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

(a) Plane wavefront

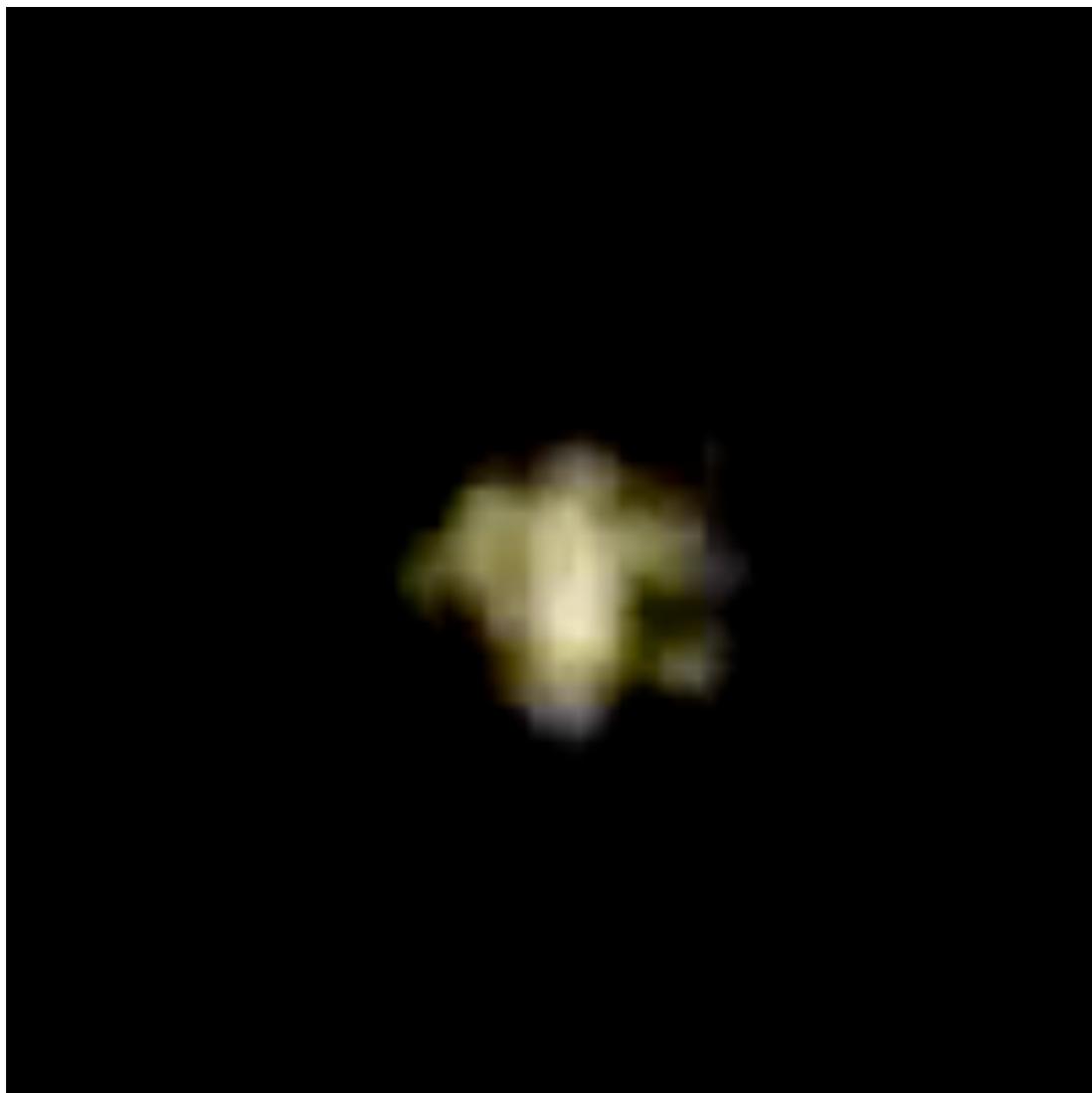


(b) Isophase patches



Seeing

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



Seeing

depends on airmass:

$$\propto AM^{0.6}$$

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

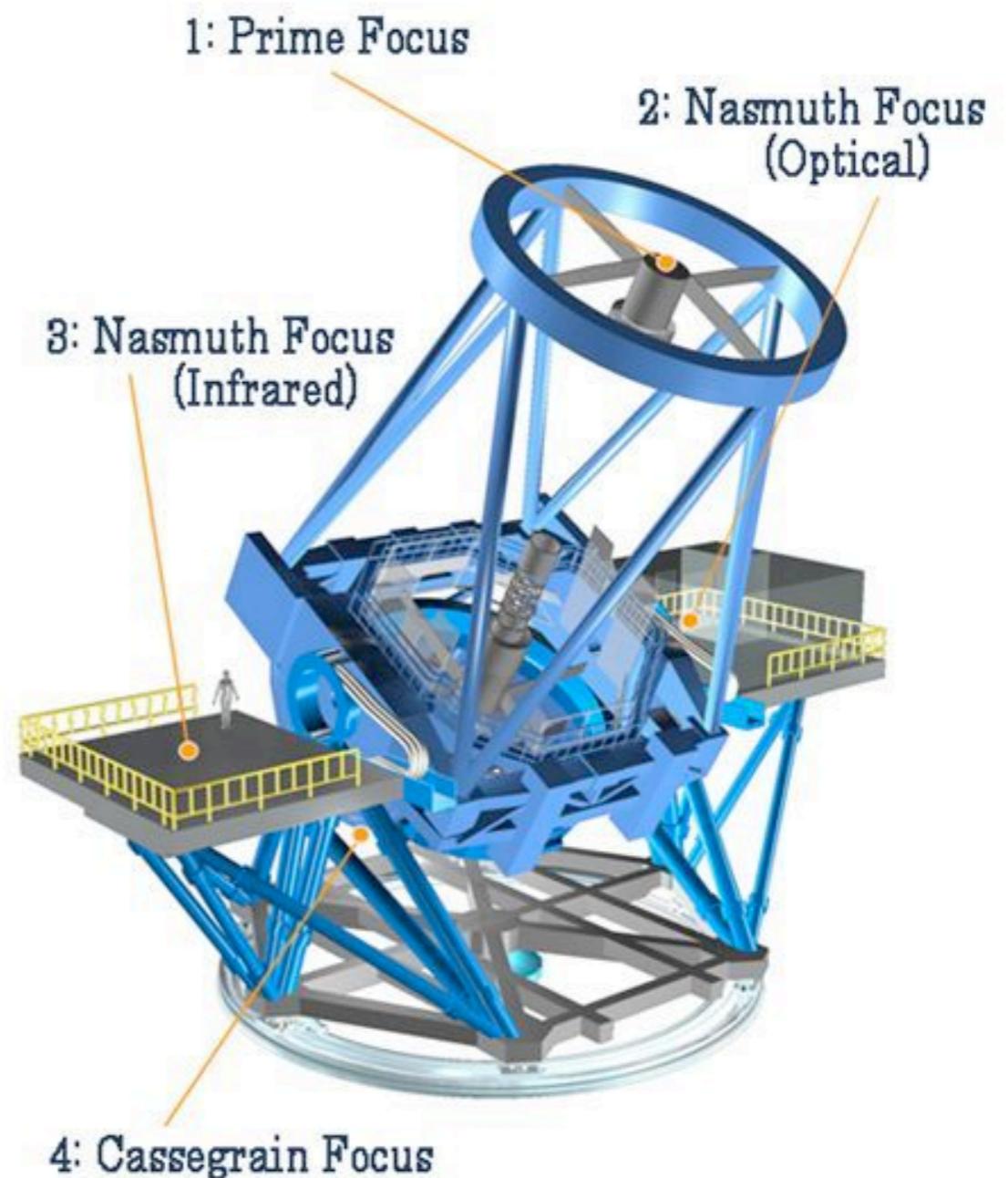


Gemini

(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)



(c) MITA Corporation Japan #150132

Subaru Telescope

Aperture

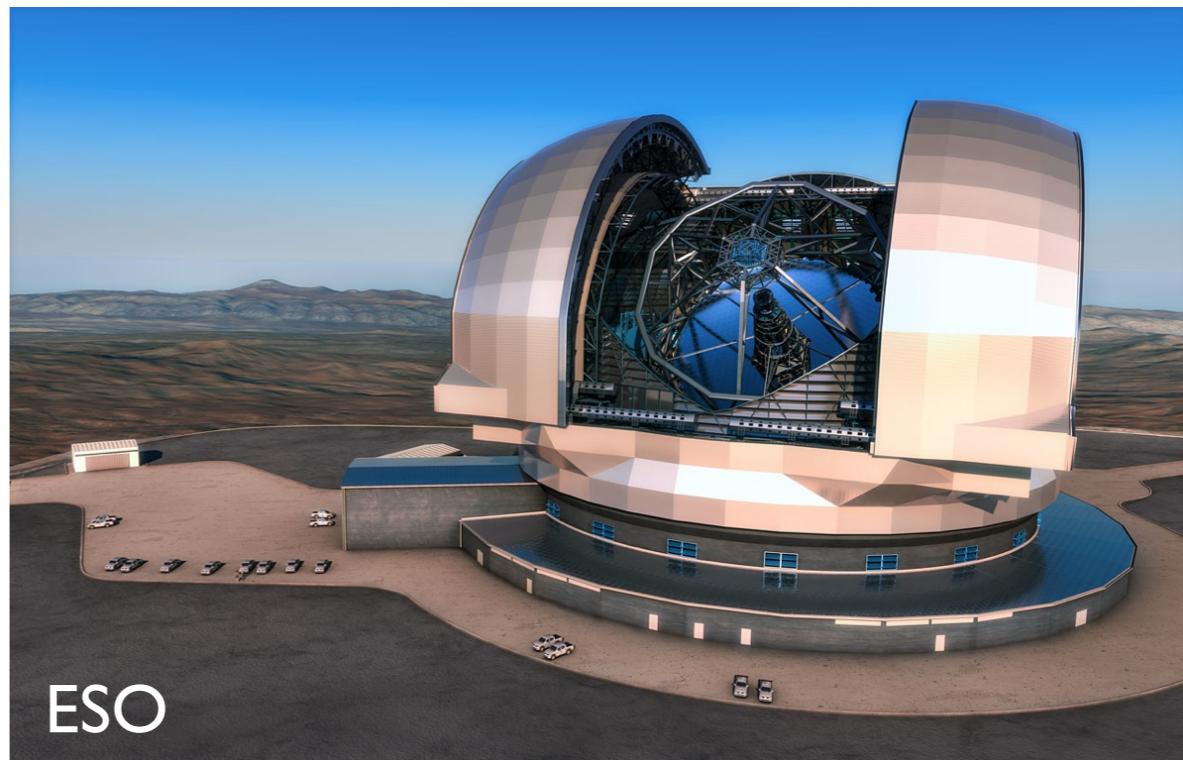
- most (new) things in astronomy are faint (but not all!)
- need to gather as much light as possible
- the diameter of the mirror (aperture) is one of the main characteristics of a telescope

Keck Telescopes: 10m



L. Hatch

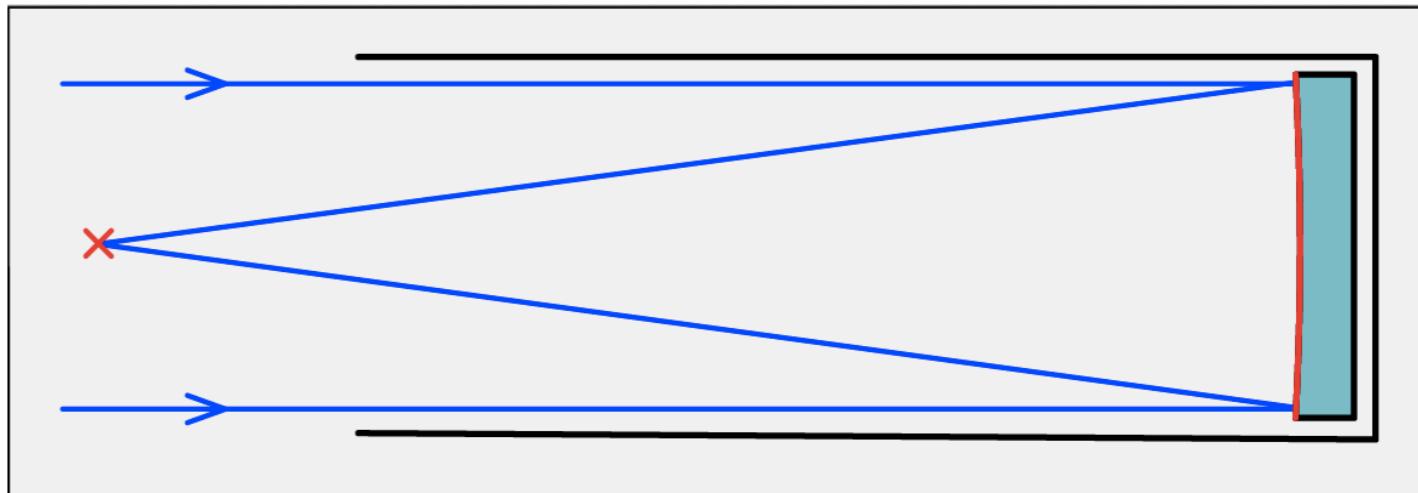
next generation: 30m telescopes (~2025)



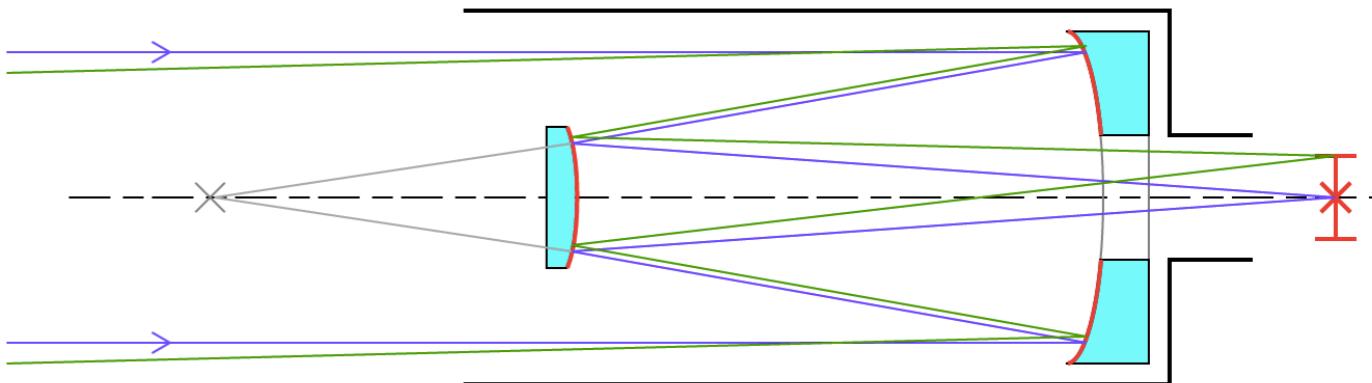
ESO

Telescope foci

- prime focus: focus of primary mirror

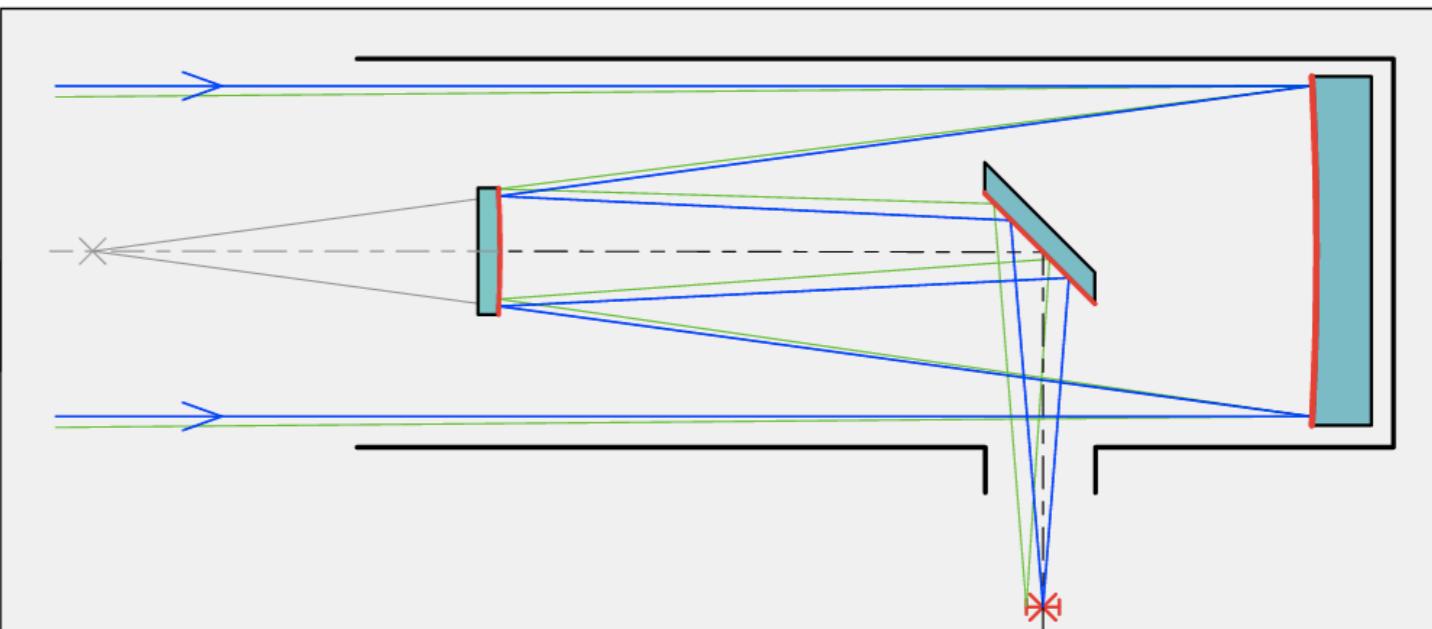


- Cassegrain focus: secondary mirror in front of prime focus; secondary focus behind primary mirror



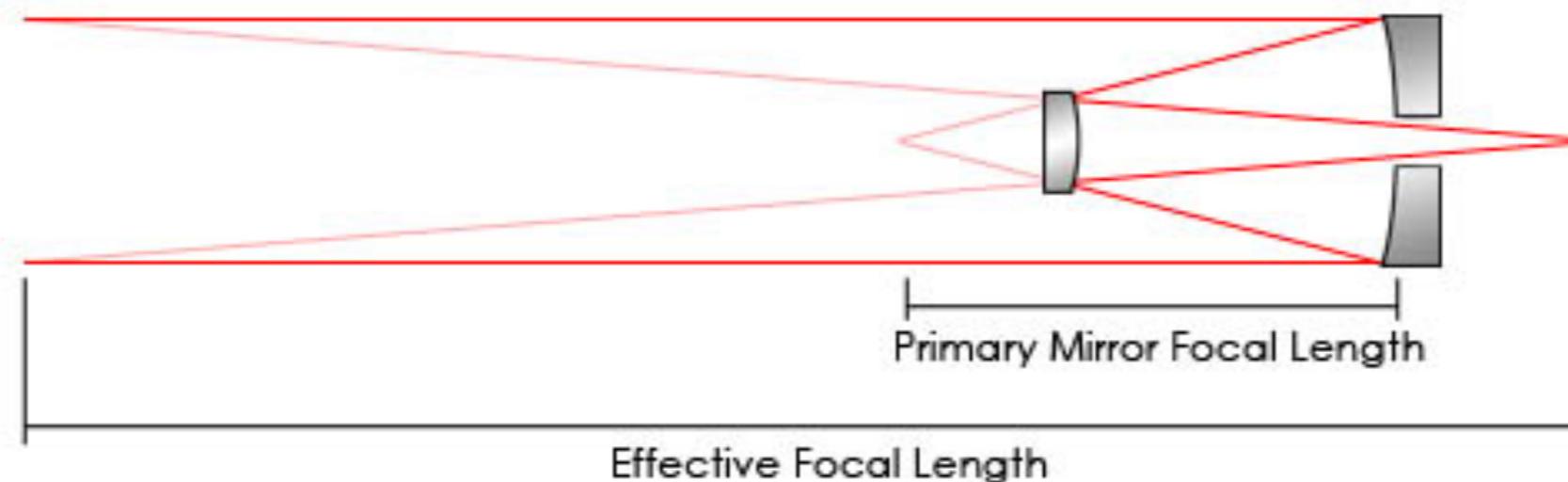
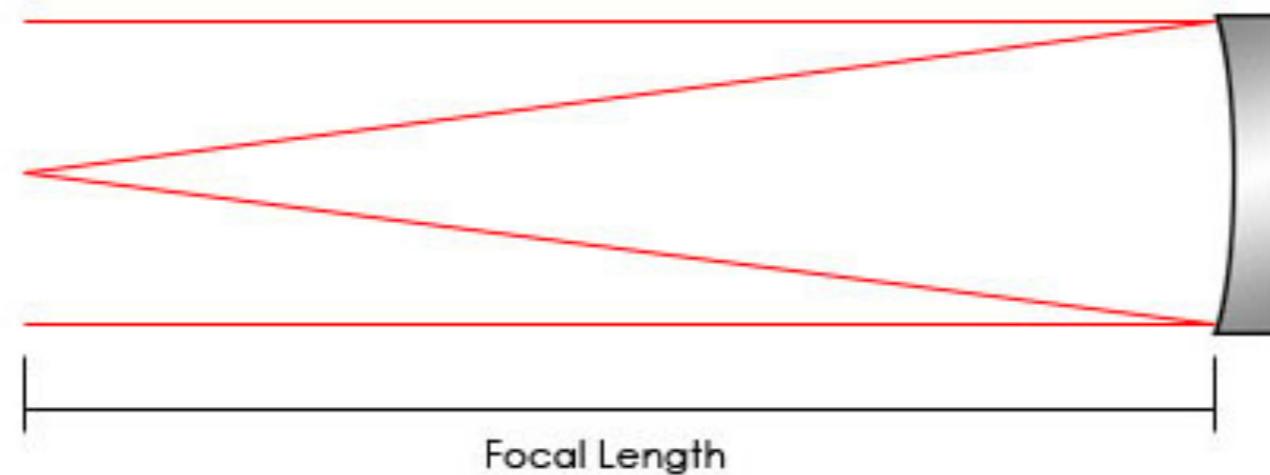
K.Vedala

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



Focal length

distance from mirror / lens to the focal plane



Focal ratio (“f number”)

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

measure of
how “fast”
the lens /
mirror is



★★★★★ (230)

[Canon EF 300mm f/4L IS USM Lens](#)

Add to Compare

You Pay:

\$1,349.00



★★★★★ (63)

[Canon EF 300mm f/2.8L IS II USM Lens](#)

Add to Compare

You Pay:

\$6,099.00

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



Plate Scale

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

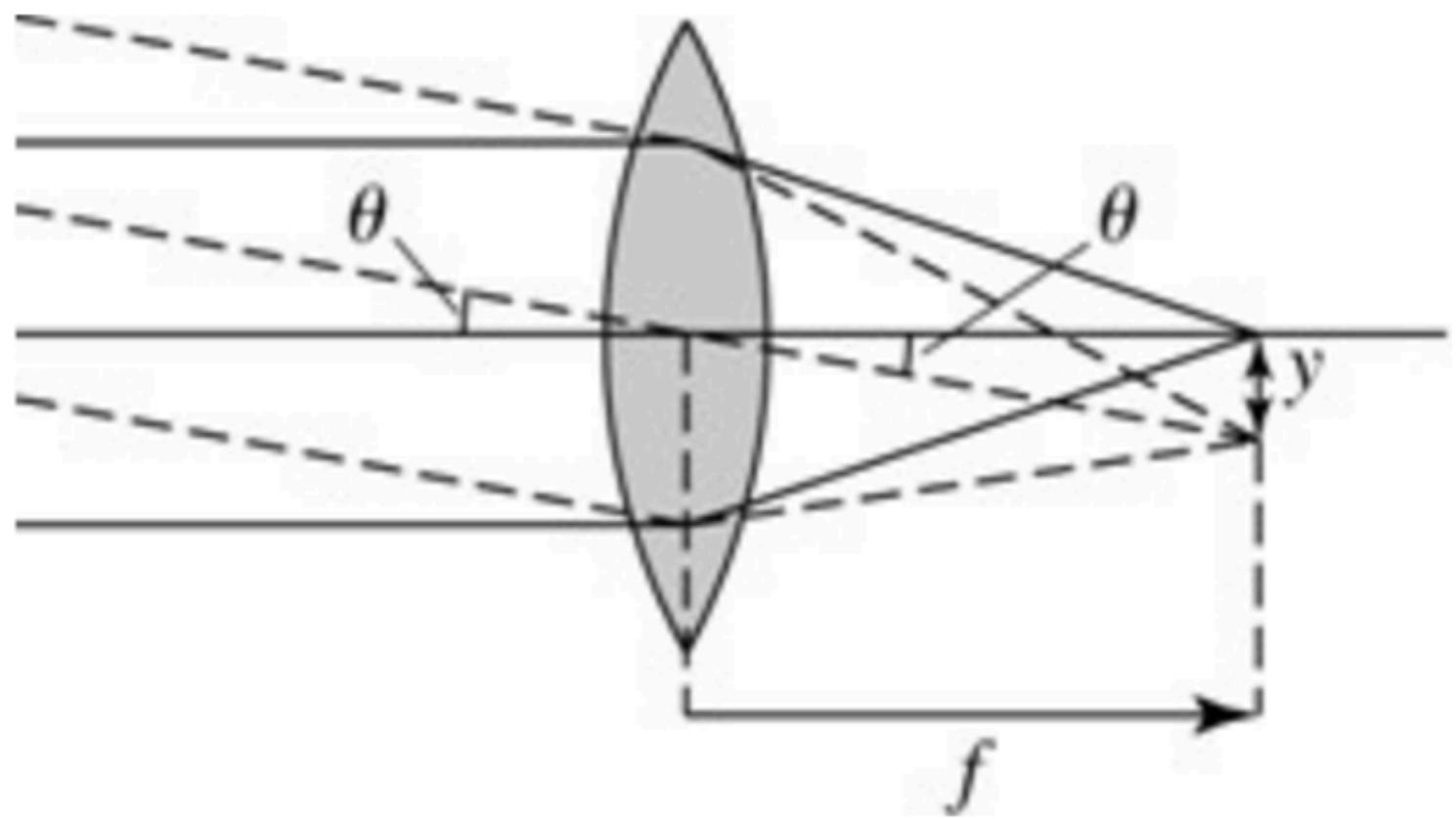
$$\theta \approx \tan \theta = \frac{y}{f}$$

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

plate scale = (focal length)⁻¹

units: angle / length

e.g. arcseconds / mm



unknown

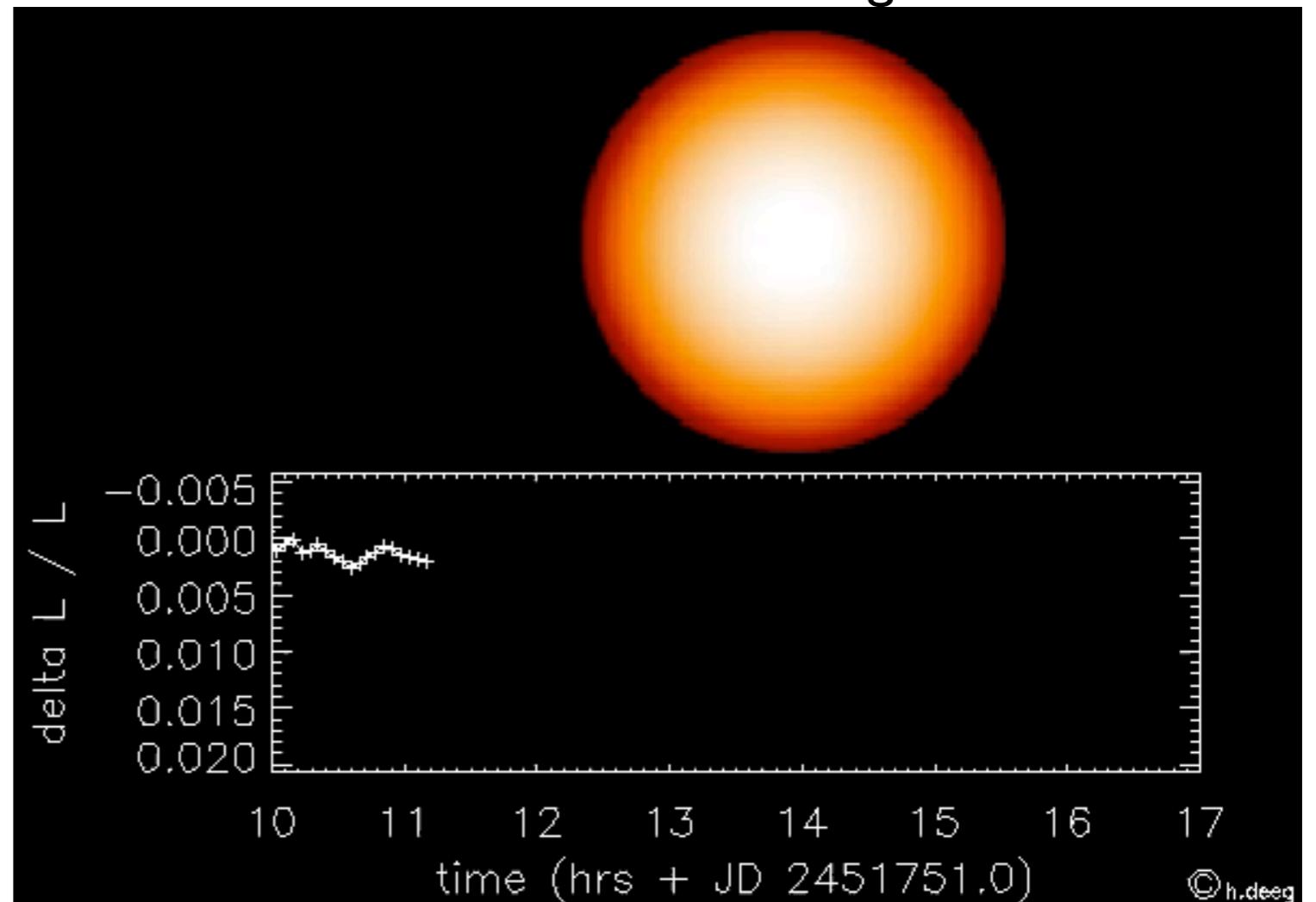
Preparing for your observations

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 Monday): request your exoplanet nights

triple-check your calculations!!!

pick 3-4 transits / observing nights between now and March 24
(spread out to accommodate the weather), e-mail your
request to me (first-come, first-serve)

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

Mt Stony Brook Observing Calendar

Today February 2021 ▾

Print Week Month Agenda ▾

Mon	Tue	Wed	Thu	Fri	Sat	Sun
Feb 1	2	3	4	5	6	7
8	9	10	11	12	13	14
1pm Lab 0: Behan, Edi						
15	16	17	18	19	20	21
22	23	24	25	26	27	28
No observing						
Full Moon						

Events shown in time zone: Eastern Time - New York

excerpt from Mt. Stony Brook observing calendar