

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 (+ make a pretty image in multiple filters)
- **Come prepared!** The TAs will quiz you before you can start.

Blind grading

- Lab reports, homeworks, etc. will be graded blindly - please submit your homeworks as HW1_<SBUID>.pdf

Class Material

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

Schedule Spring 2026

Simon Birrer edited this page last week · 5 revisions

Edit New page

Date	Topics	Slides	Tutorials	Homework	Pages 36
Jan 26	class canceled				
Jan 28	Intro, Coordinate Systems	Lecture 0 , Lecture 1		HW1, due Feb 02	
Feb 02	Time, Magnitudes, Atmosphere, Telescopes	Lecture 2		HW2, due Feb 09	
Feb 04	CCDs, FITS files	Lecture 3	Python1 , Python2		
Feb 09	Spectroscopy	Lecture 4			
Feb 11	Statistics 1	Lecture 5		HW3, due Feb 18	
Feb 16	Statistics 2	Lecture 6	Tu4	HW4, due Feb 23	
Feb 18	Data Analysis Help Session		Tu5		
Feb 23	Instructions: Proposal Writing	Lecture 7 , wiki link			
Feb 25	Data Analysis Help Session				
Mar 02	Data Analysis Help Session				
Mar 04	Data Analysis Help Session				
Mar 09	Midterm exam				

General Information

- [Syllabus](#)
- [Schedule w/ links to slides, HW, etc.](#)
- [Grading](#)
- [Academic Policies](#)

Labs and Write-Ups

- [Lab report guidelines](#)
- [Observing Equipment](#)
- [Observing Calendar](#)
- [Lab 1: CCDs](#)
- [Lab 2.1: Exoplanet transit](#)
- [Lab 2.2: Spectroscopy](#)
- [Lab 3: Your own proposal](#)
- [Discontinued: Radio Interferometry](#)
- [Astronomical Data Archives](#)
- [Weather](#)
- [End-of-night report](#)

Computing

- [Computing Resources](#)
- [Astro Software Overview](#)
- [Bash](#)
- [LaTeX](#)
- [Python](#)

Office Hours

- during class (seriously!)
- easiest way to get in touch with me: slack
- office hours:
 - TBD: Tue 3:30-4:30pm, ESS 451
 - Bela: Thu 5:00-6:00pm, ESS 451
 - Prof.: Fri 2:30-3:30pm, ESS 457-A
- by appointment

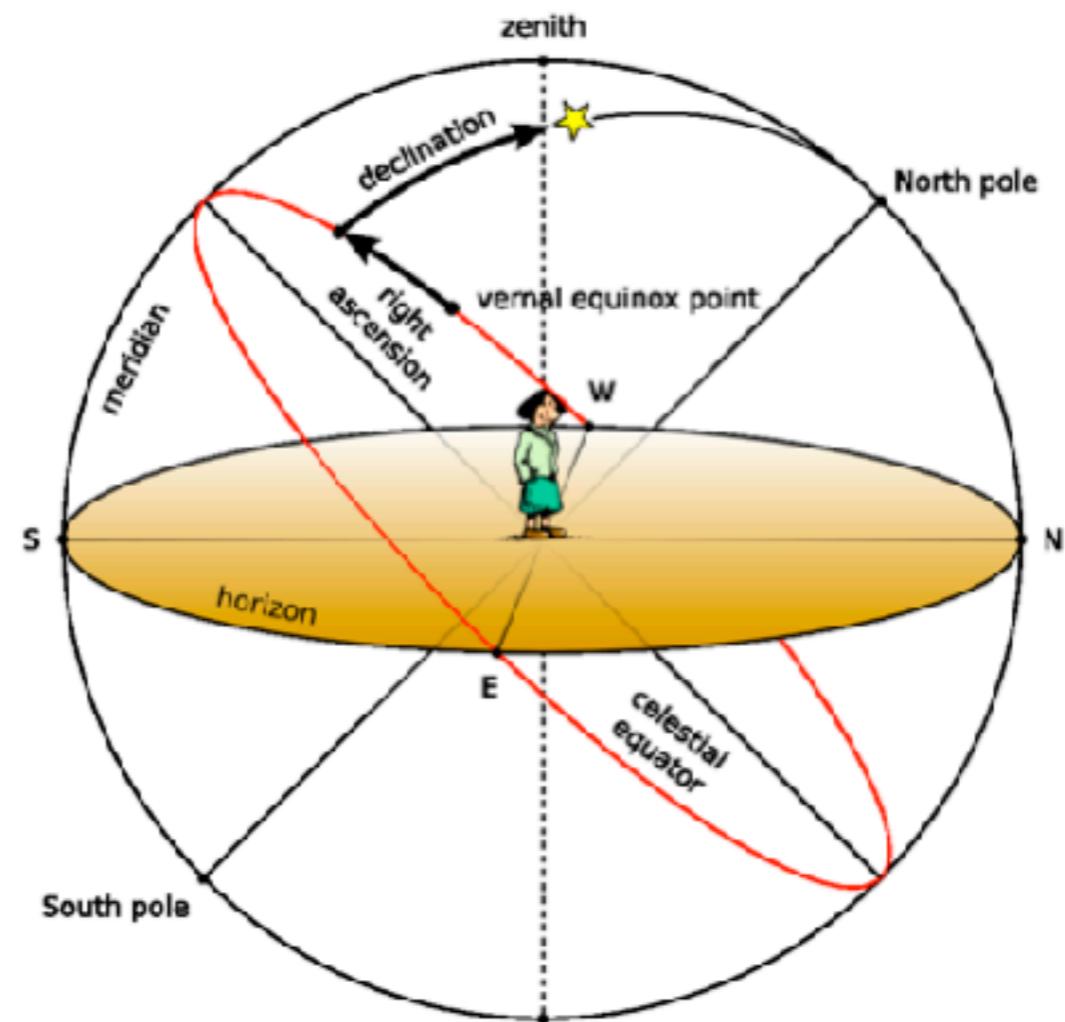
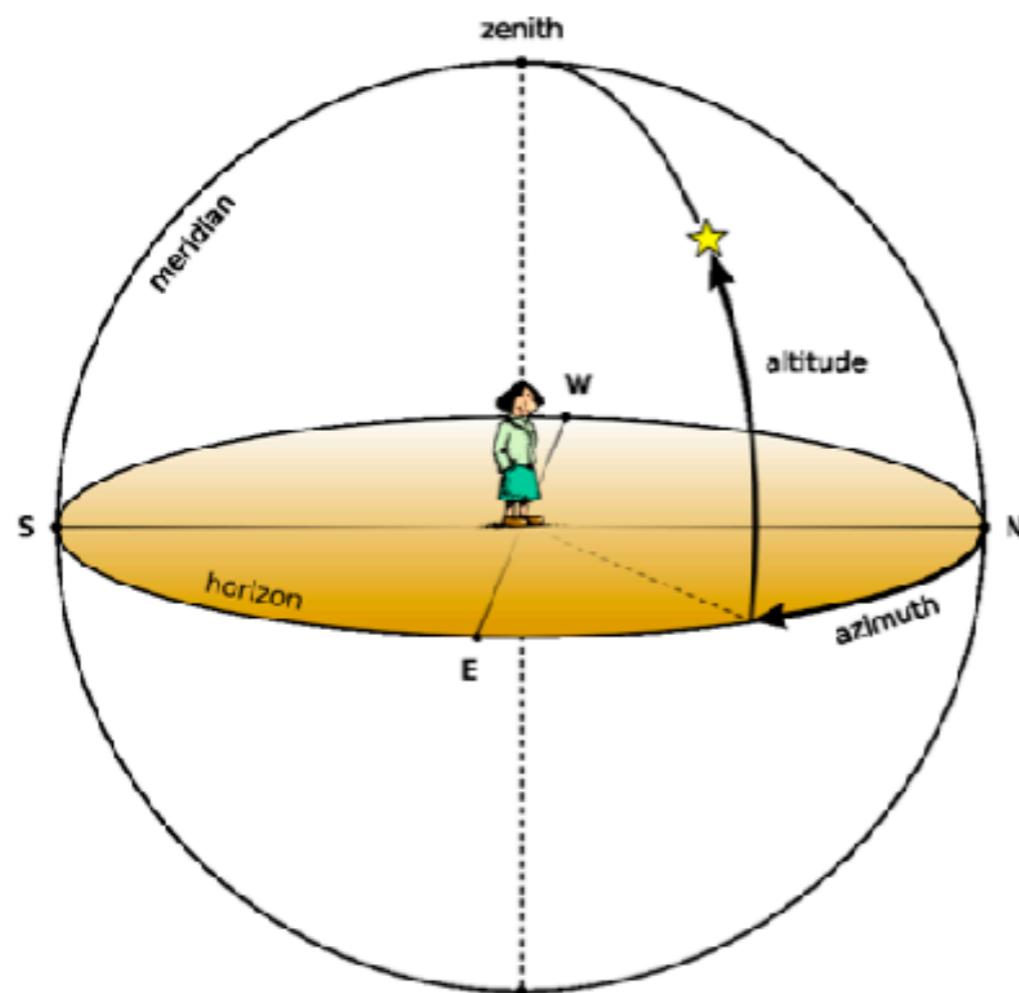
Last time...

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

Position on Earth: latitude and longitude

View from observatory: altitude and azimuth

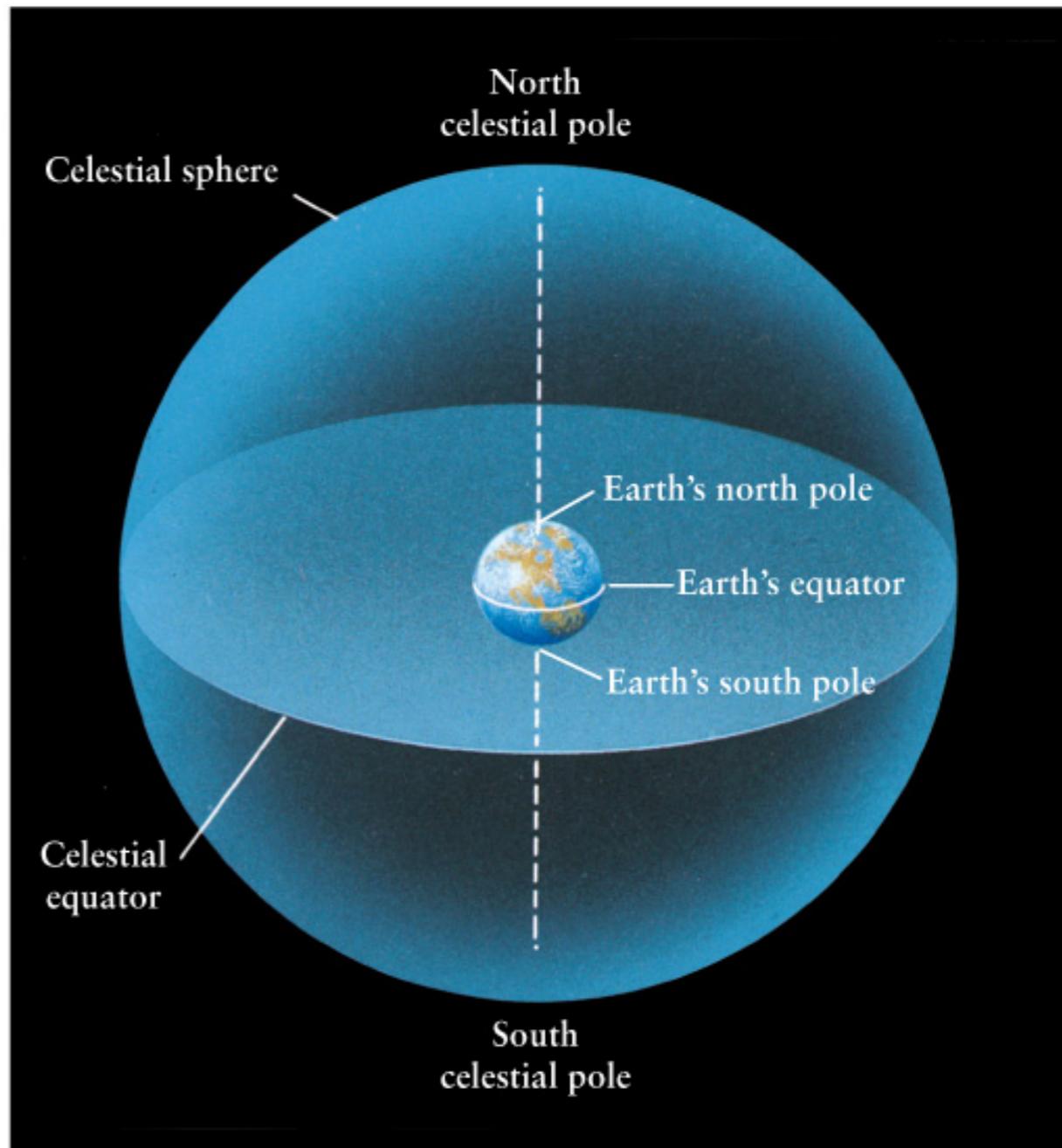
Position on sky: right ascension and declination



Last time...

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

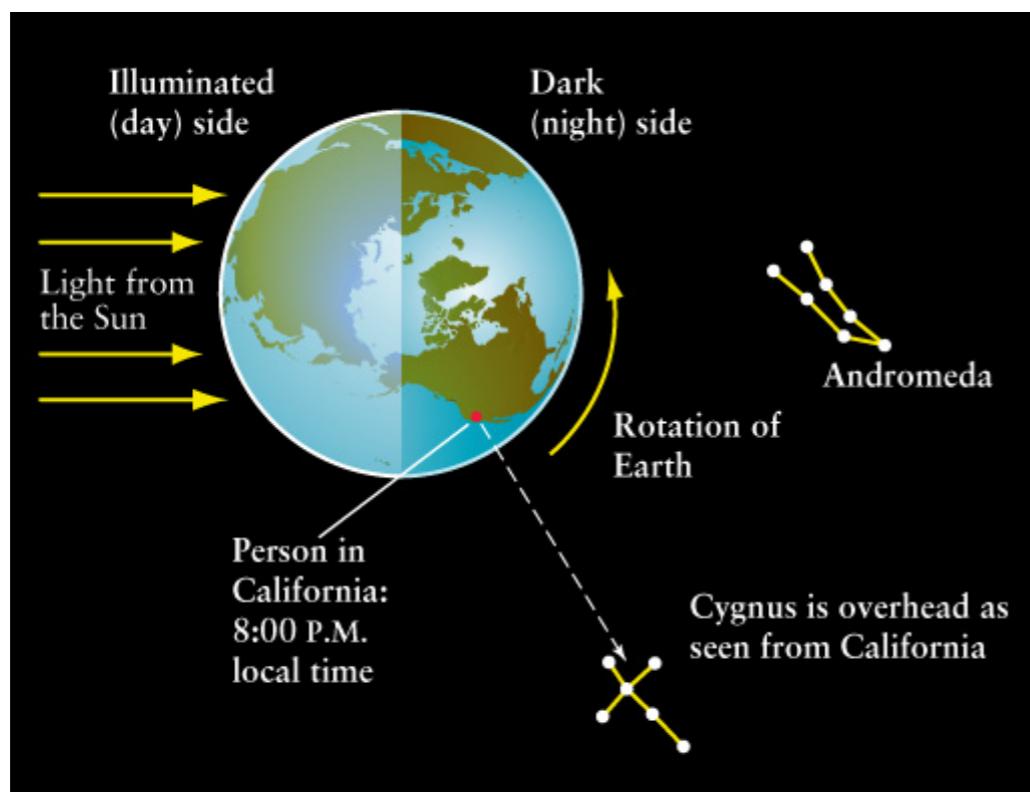


Bailey, Slater & Slater

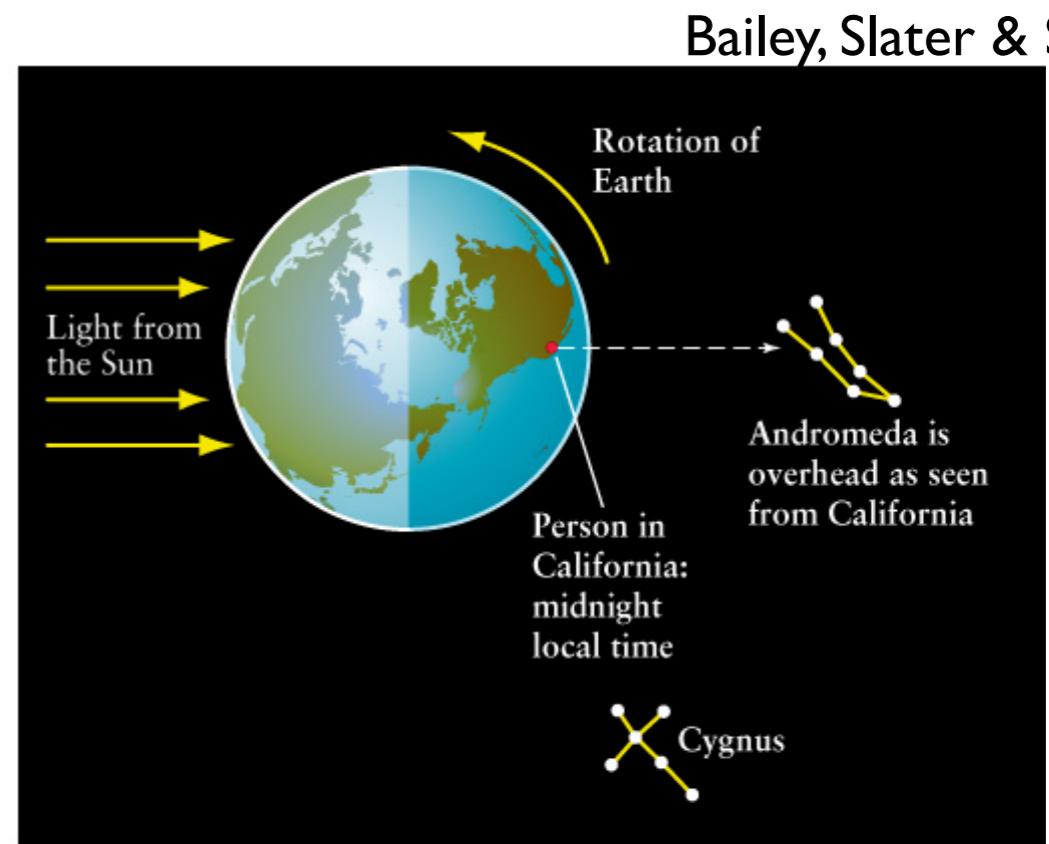
Last time...

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



(a) Earth as seen from above the north pole



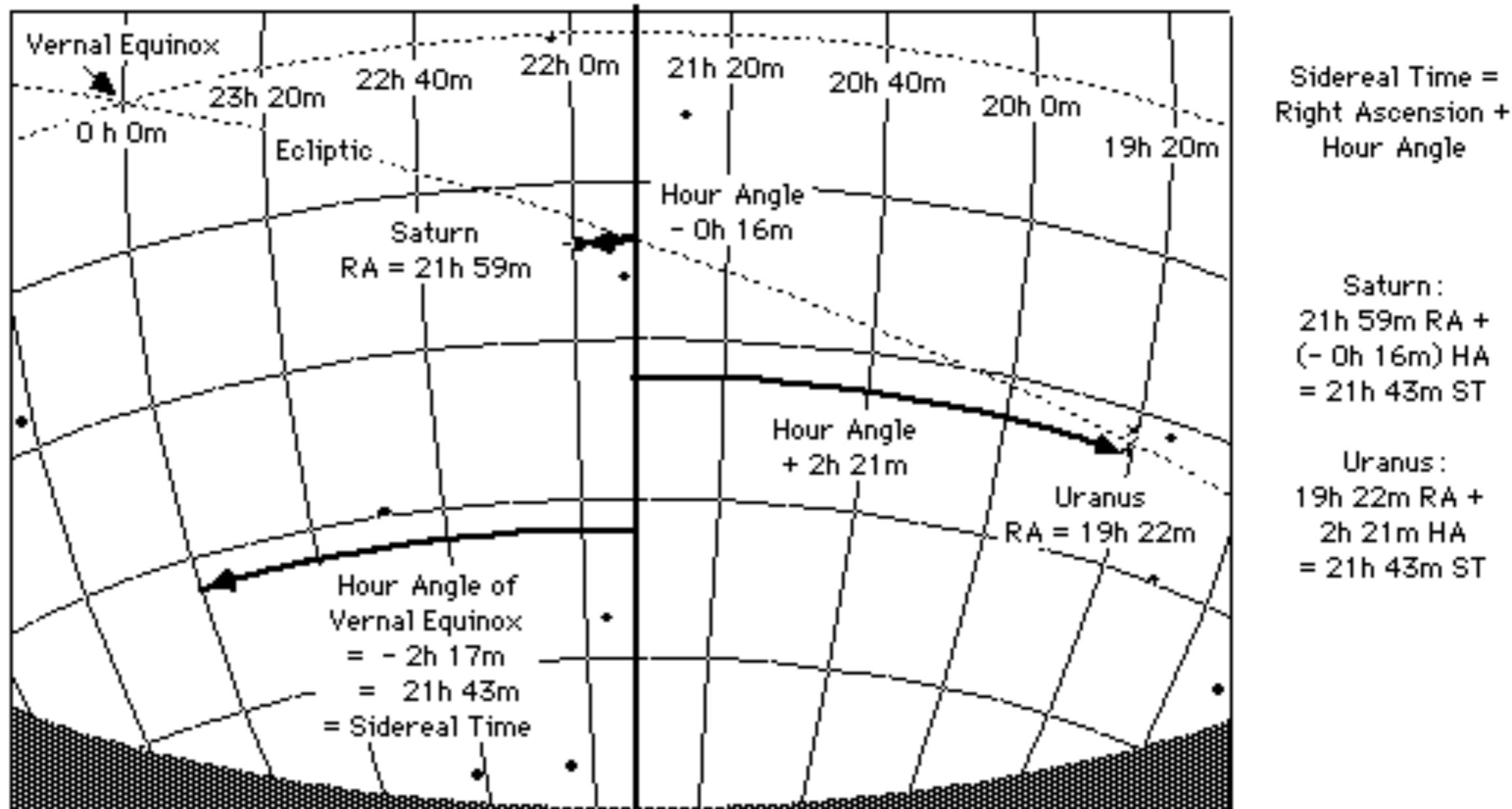
(b) 4 hours (one-sixth of a complete rotation) later

Last time...

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

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

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



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

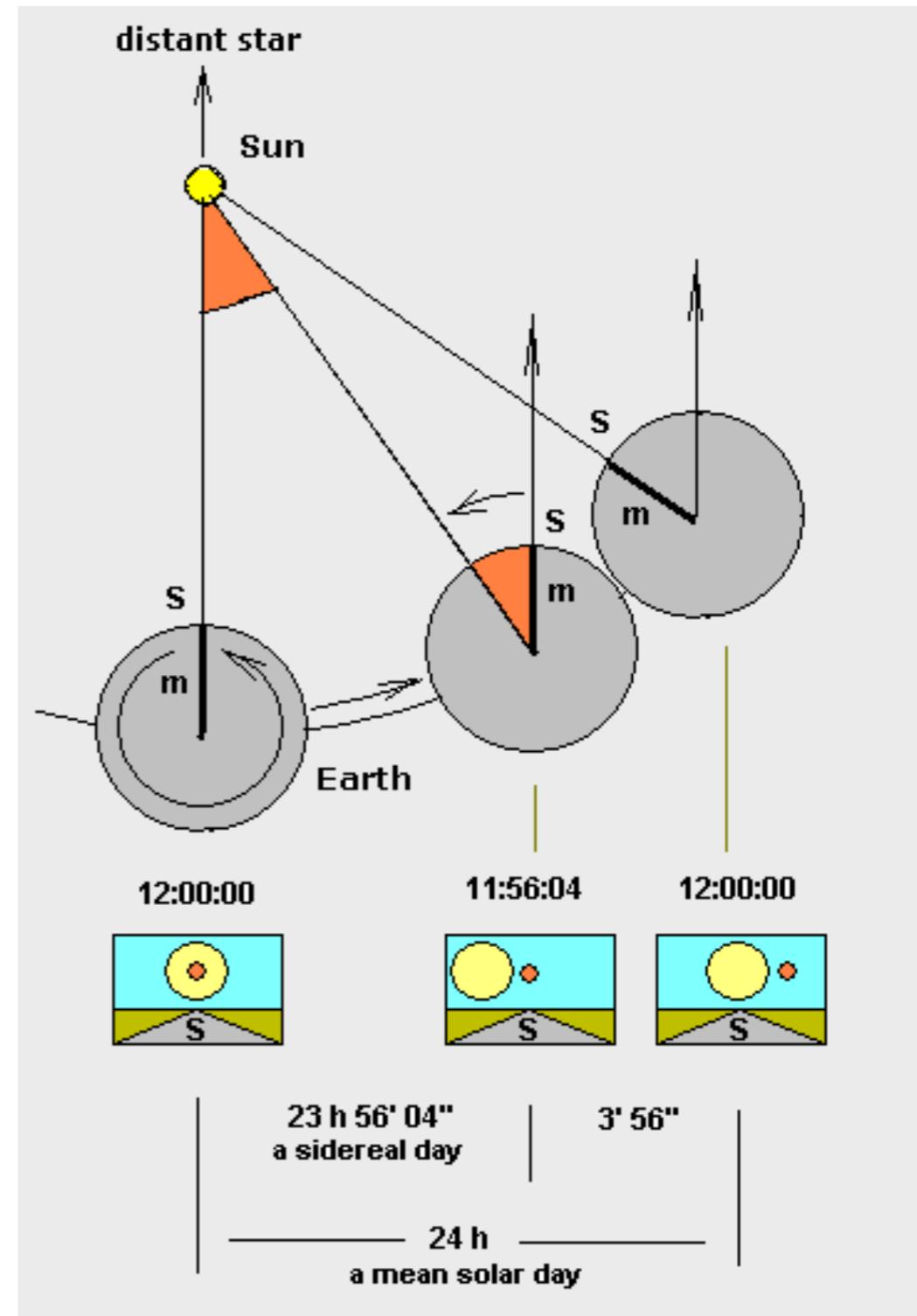
“sidereal” = “of the stars”

sidereal time: defined with respect to the stars

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

same sky is overhead after 23h 56min

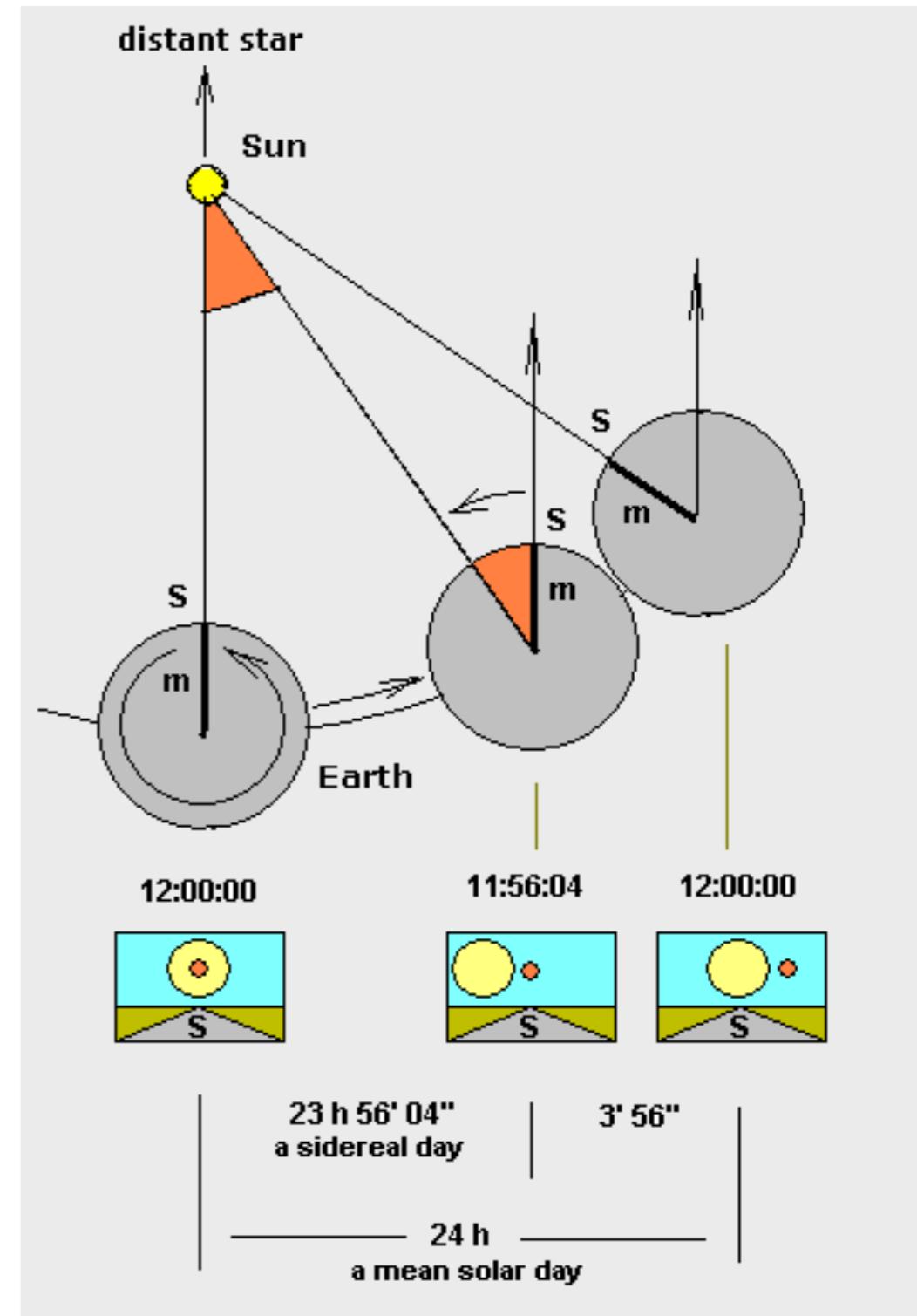
solar day: defined with respect to the Sun, takes 24h



This means...

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

one year has 365+1 sidereal
days



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

UTC time is 4h ahead of NY during daylight savings time, 5h during regular time

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 28, 3:30pm in Stony Brook: 2460551.1458
- Modified Julian Date (MJD): MJD = JD - 2400000.5

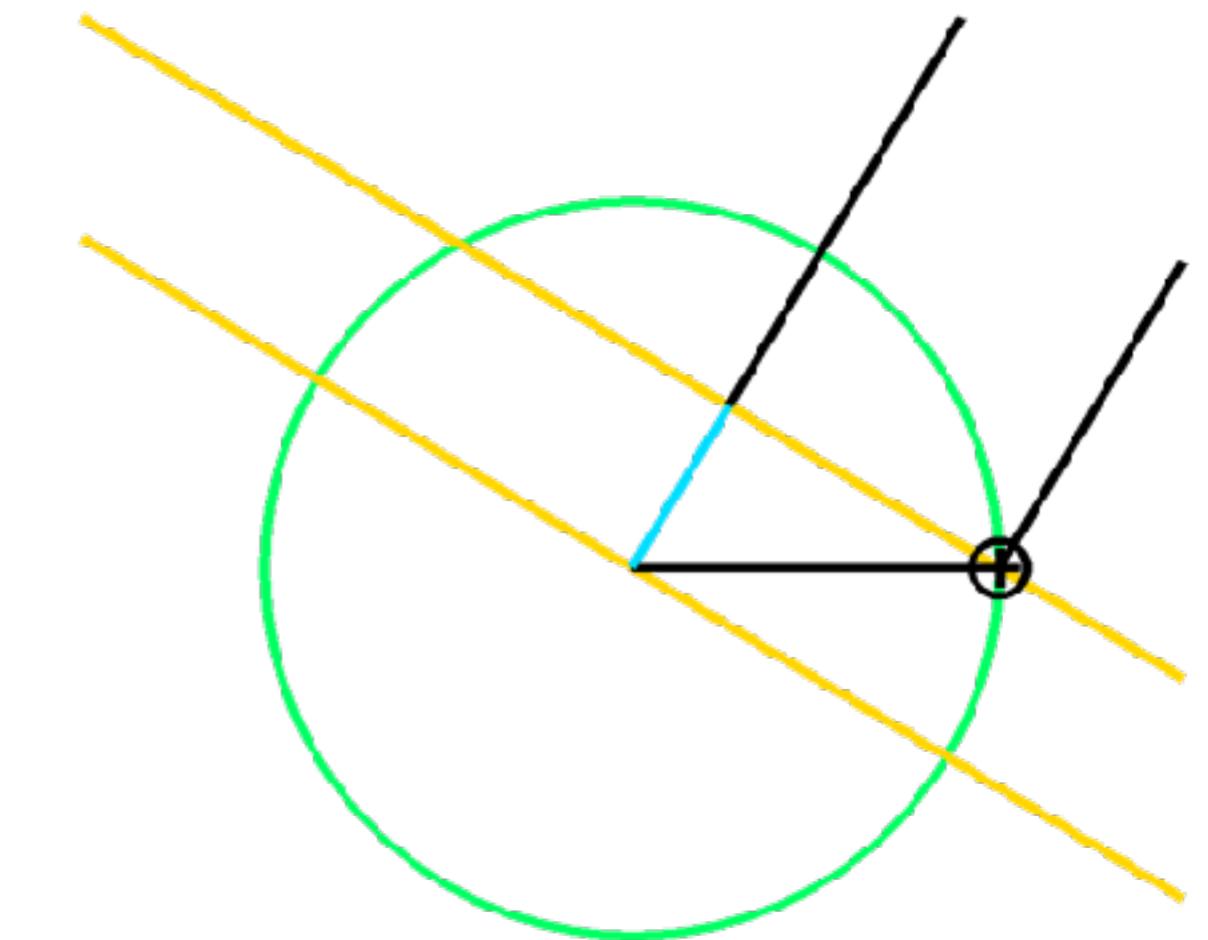
<https://www.aavso.org/jd-calculator>

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

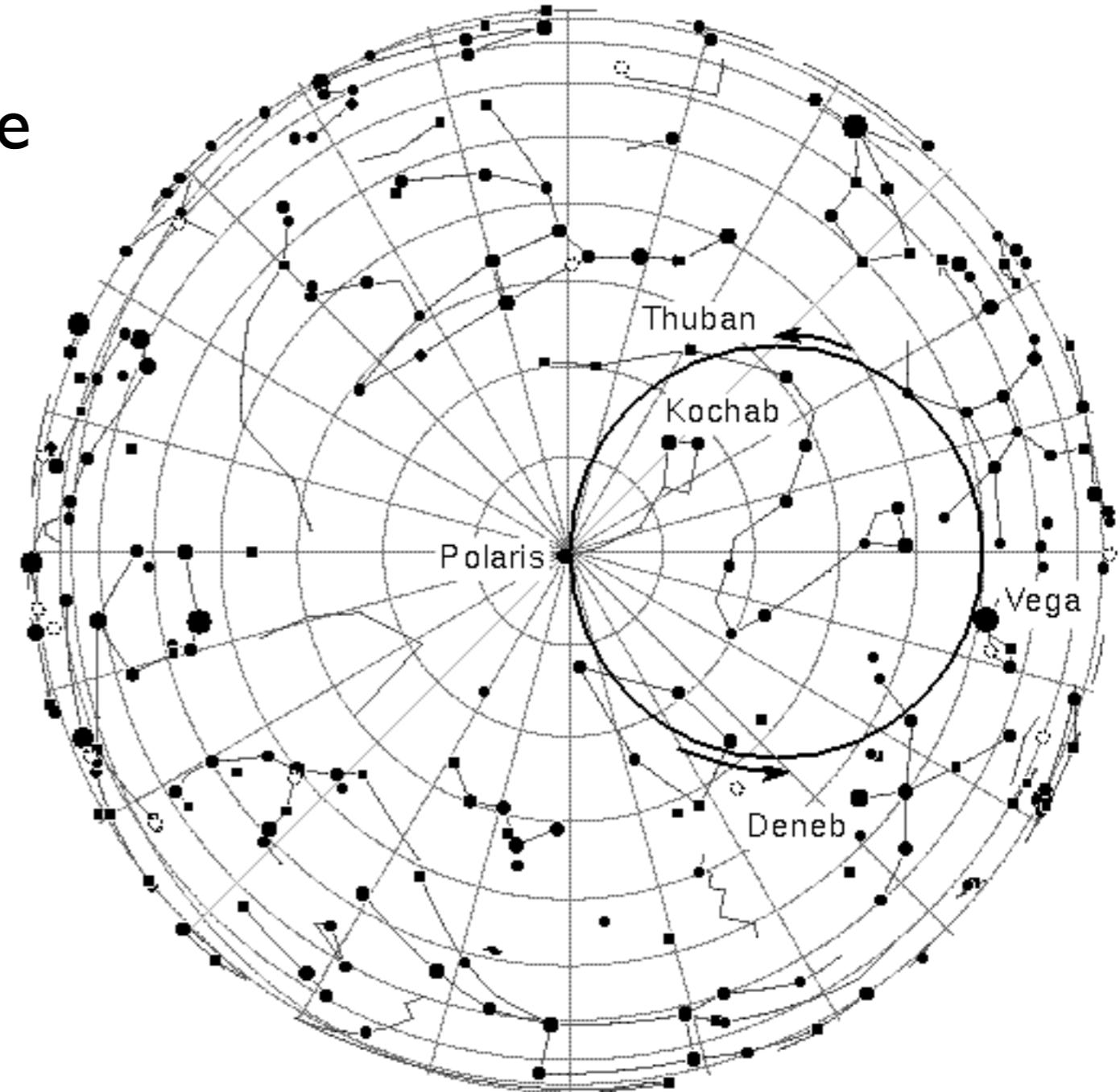
Earth's rotation axis is not constant in space with time

- 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.

**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 \sim 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:

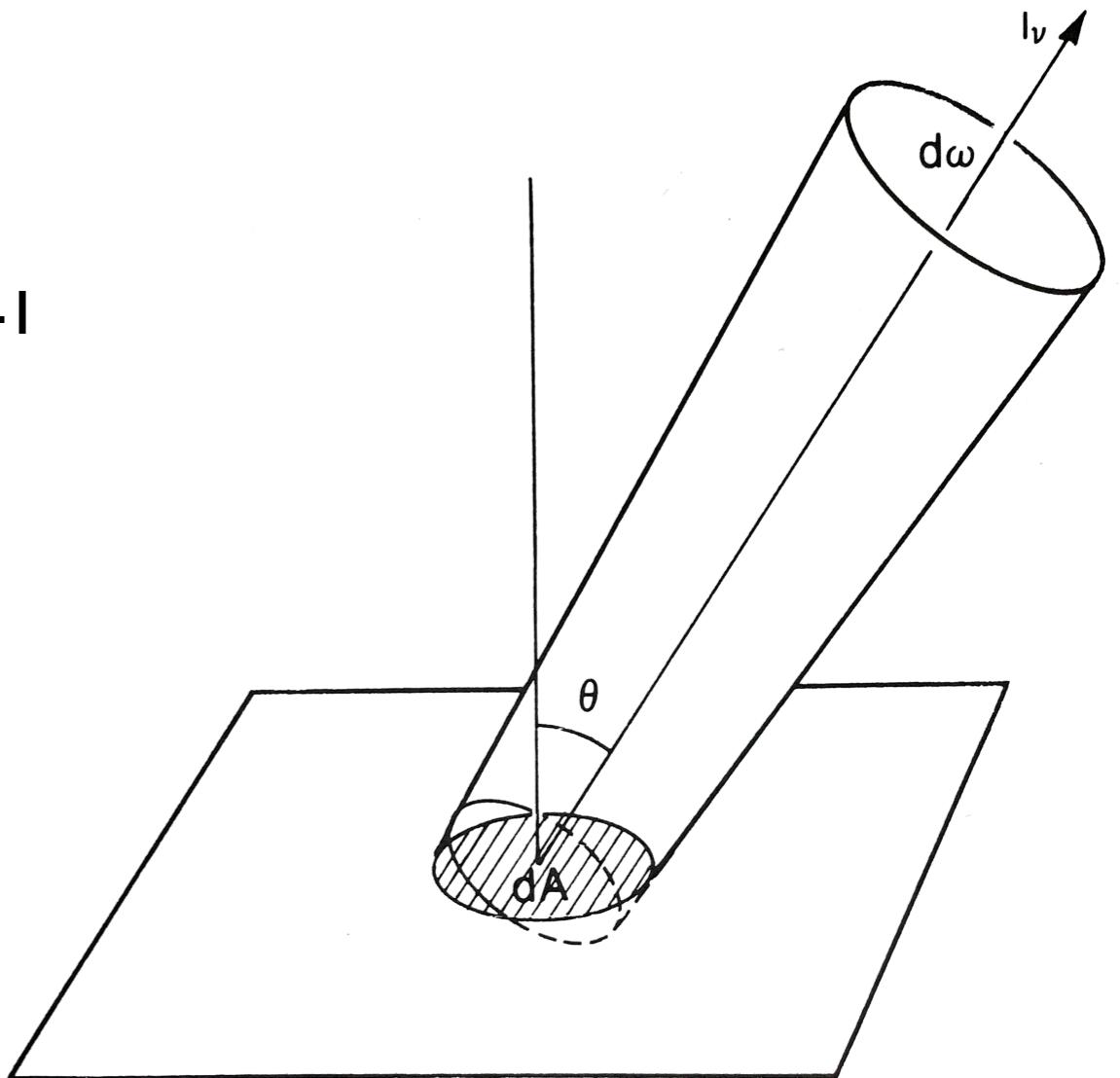
$$dE_\nu = I_\nu dA \cos \theta d\omega dt d\nu$$

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

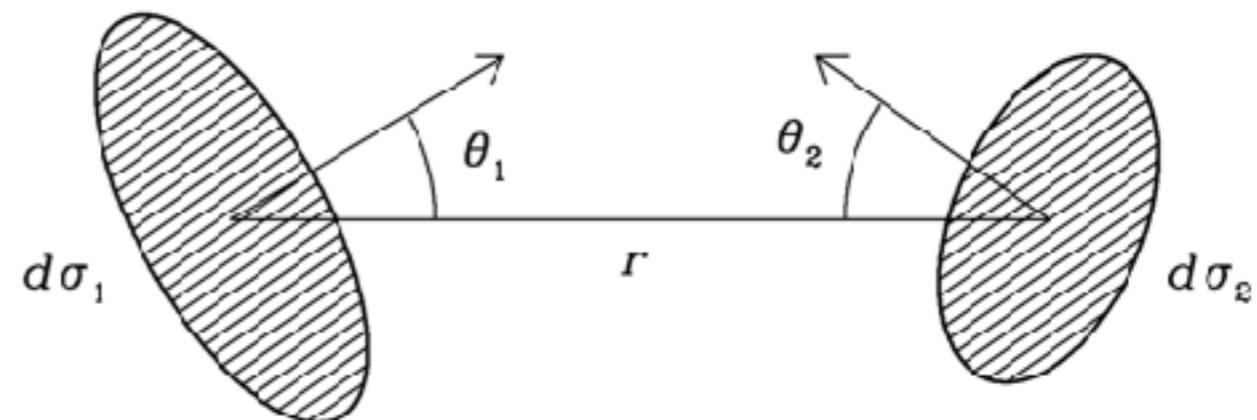
amount of energy passing through area dA , within $d\omega$ (at an angle θ from normal), in frequency range $[\nu, \nu + d\nu]$, during time dt is:

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

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

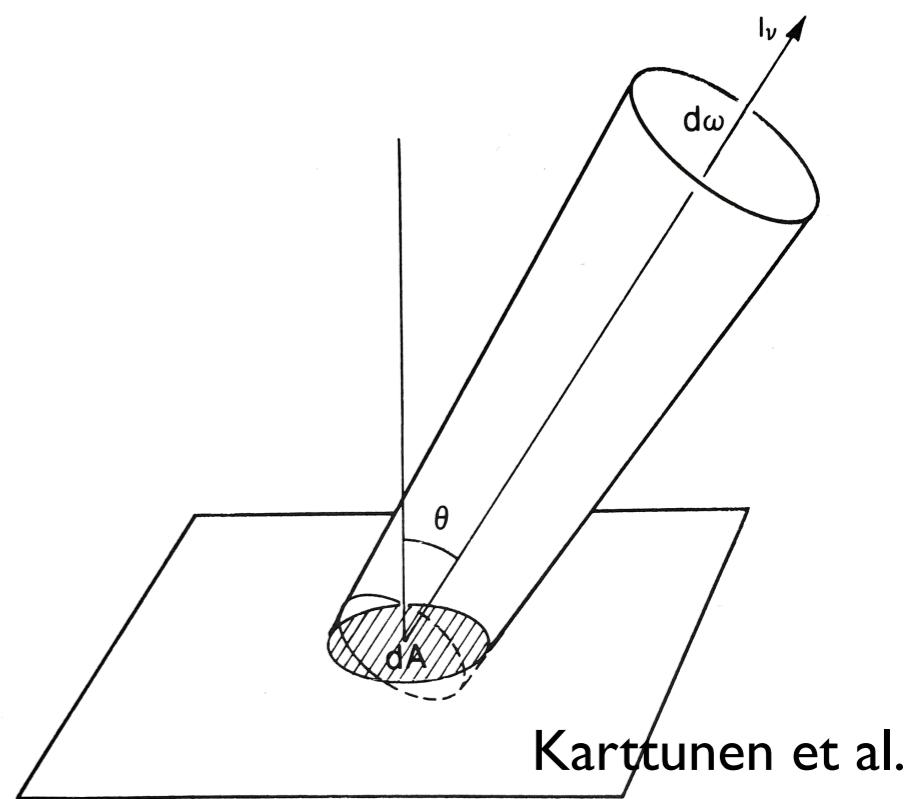


Physical descriptions

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

integrate over solid angle:

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



Karttunen et al.

Physical descriptions

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

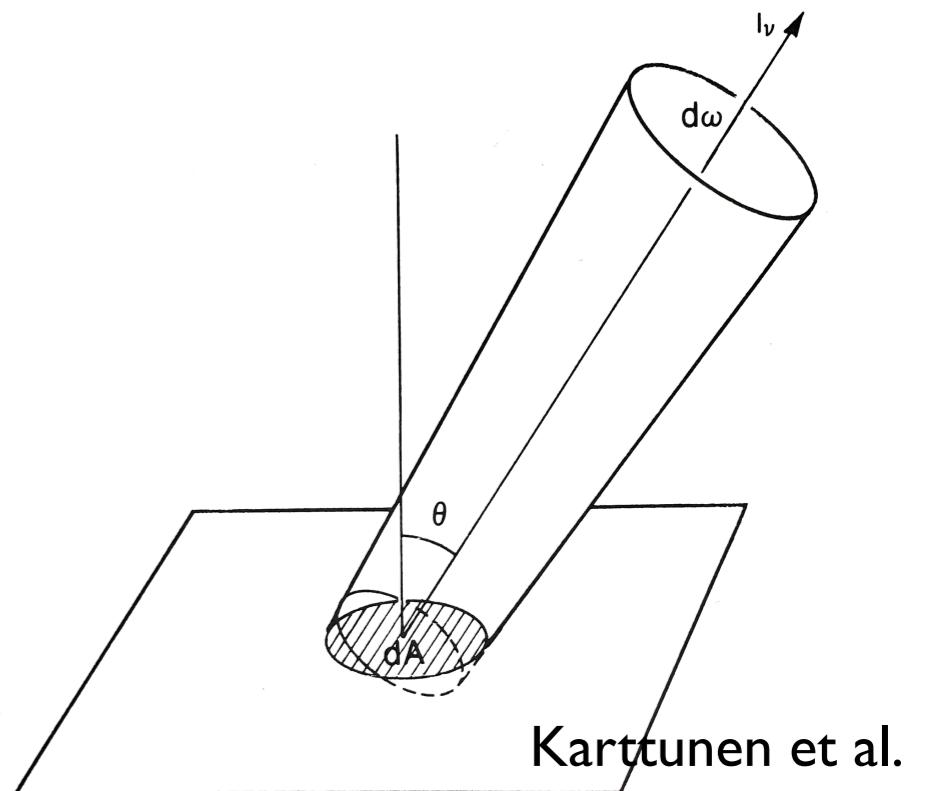
integrate over solid angle:

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

ergs: 10⁻⁷ joules

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



Karttunen et al.

Physical descriptions

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

integrate over solid angle:

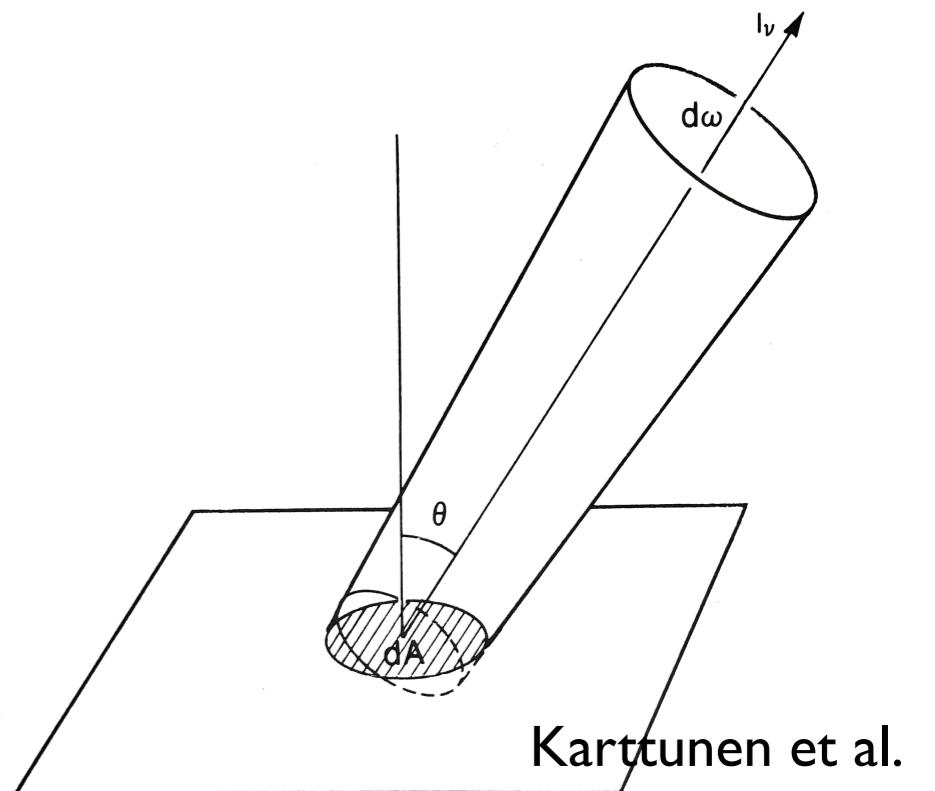
spectral flux density f_ν : energy (leaving the surface of the star) per area, per time, per frequency interval

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

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



Karttunen et al.

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

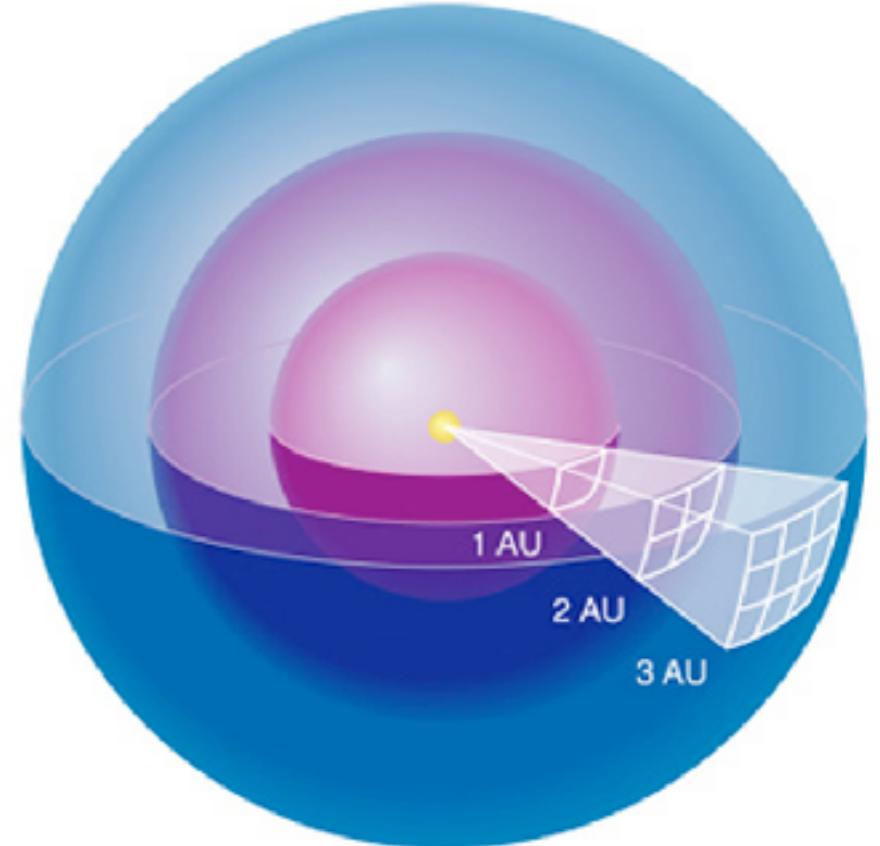
$$= f_\nu \int dA = f_\nu \, 4\pi d^2 \quad (\text{assuming isotropy})$$

- 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:

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

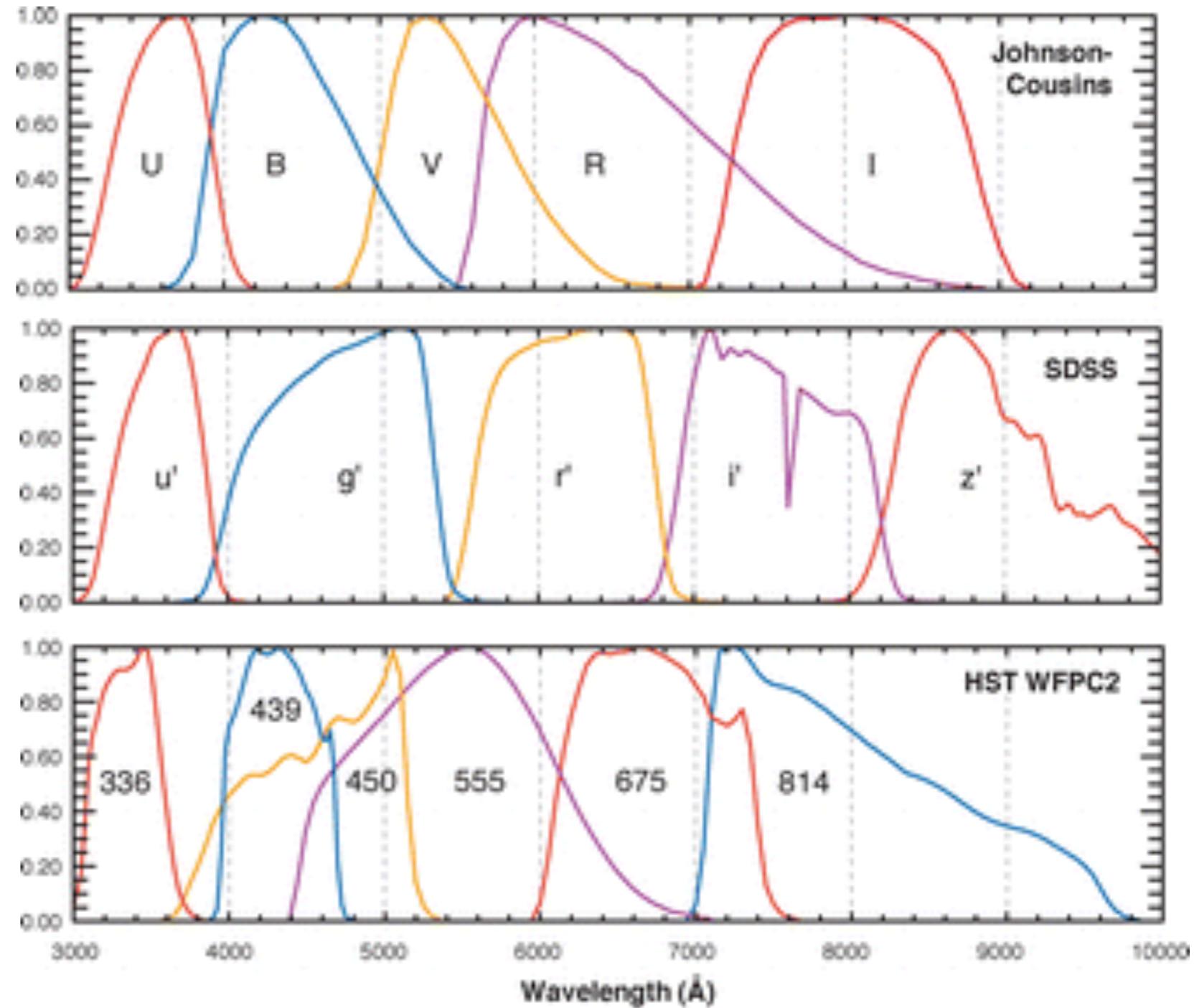


Filter systems

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):

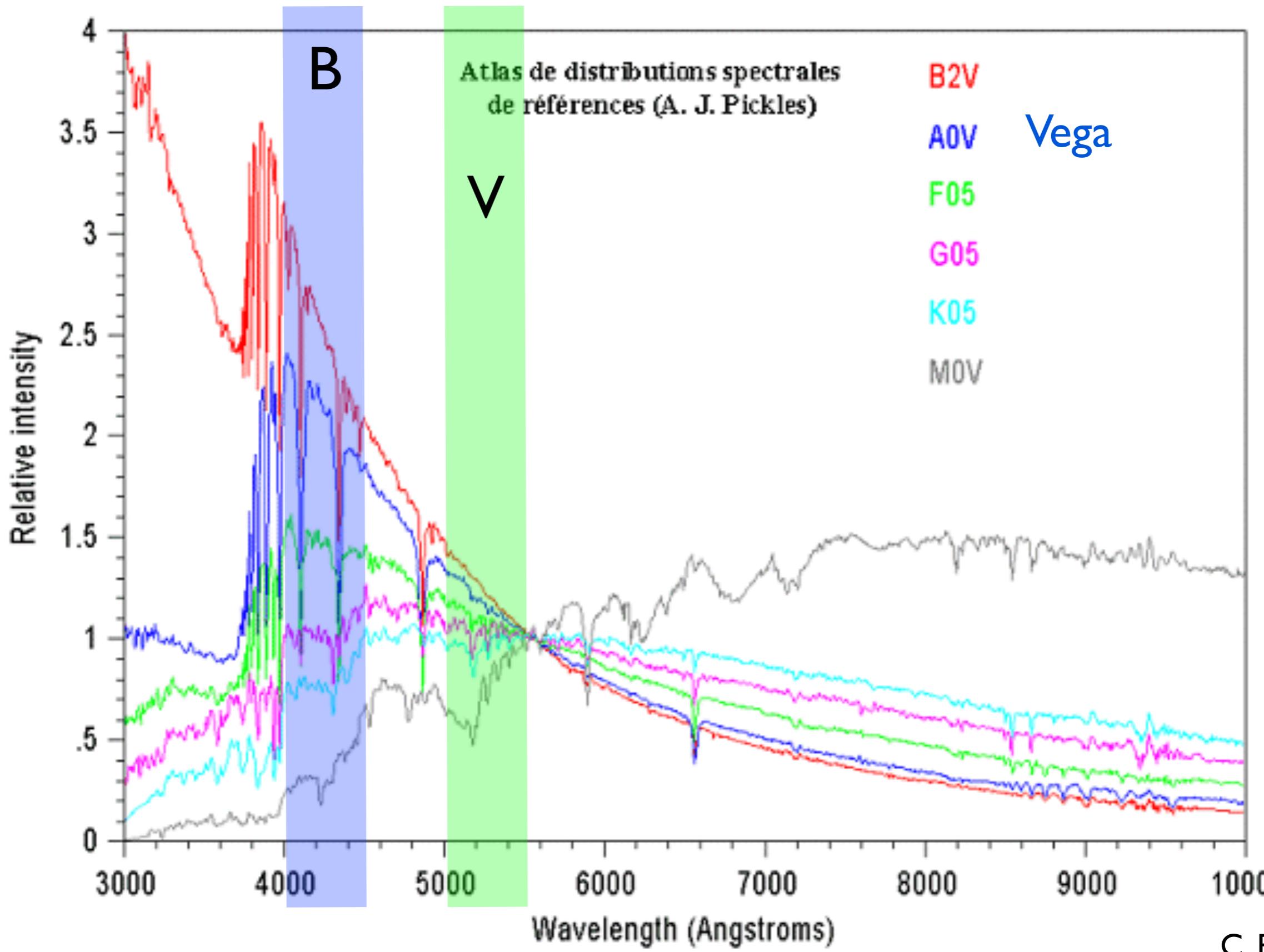
$$\begin{aligned} B - V = m_B - m_V &= -2.5 \log \left(\frac{F_B}{F_V} \right) \\ &= -2.5 \log \left(\frac{F_B}{F_{B,\text{Vega}}} \right) + 2.5 \log \left(\frac{F_V}{F_{V,\text{Vega}}} \right) \end{aligned}$$

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



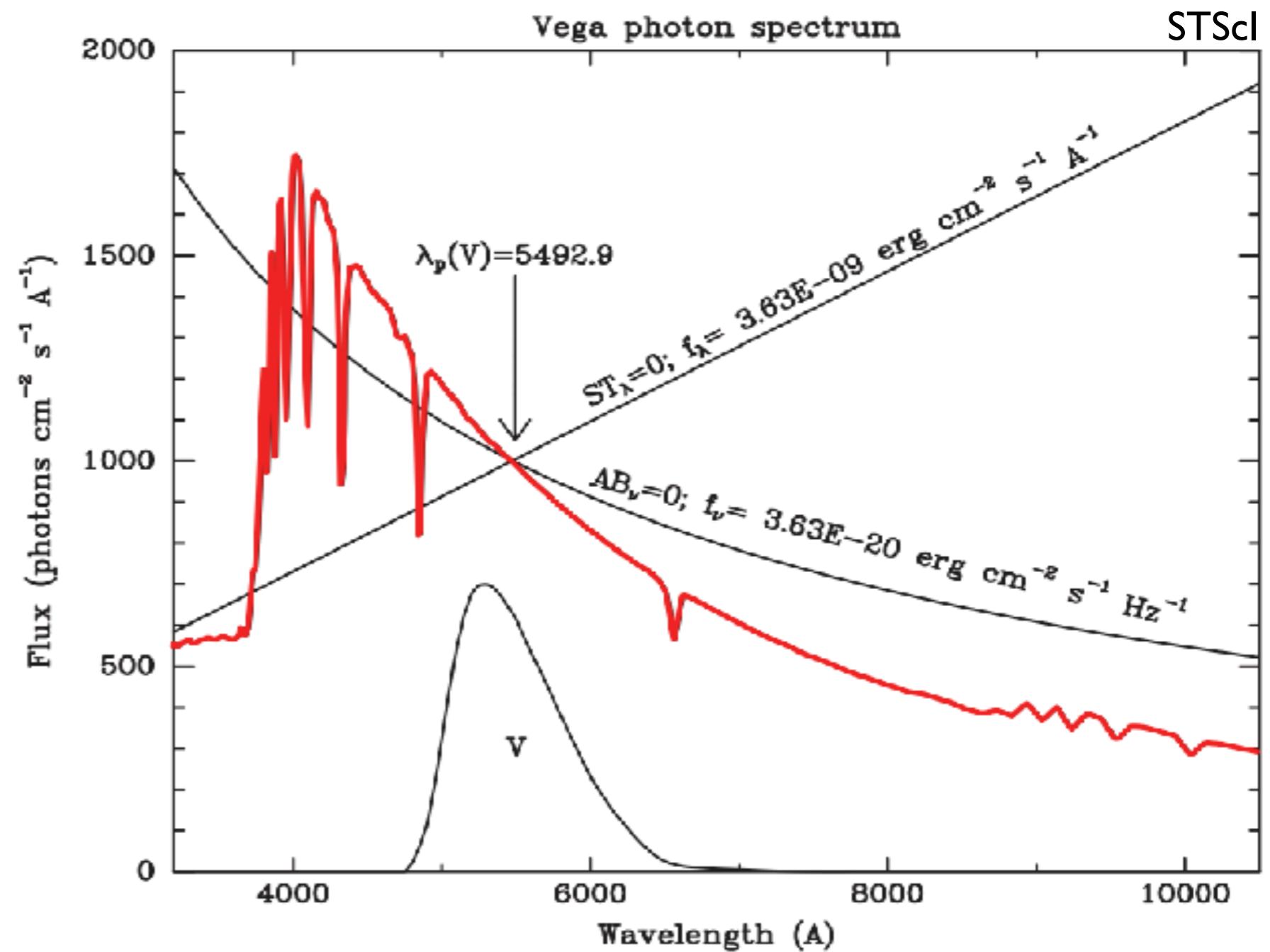
C. Buil

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:

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

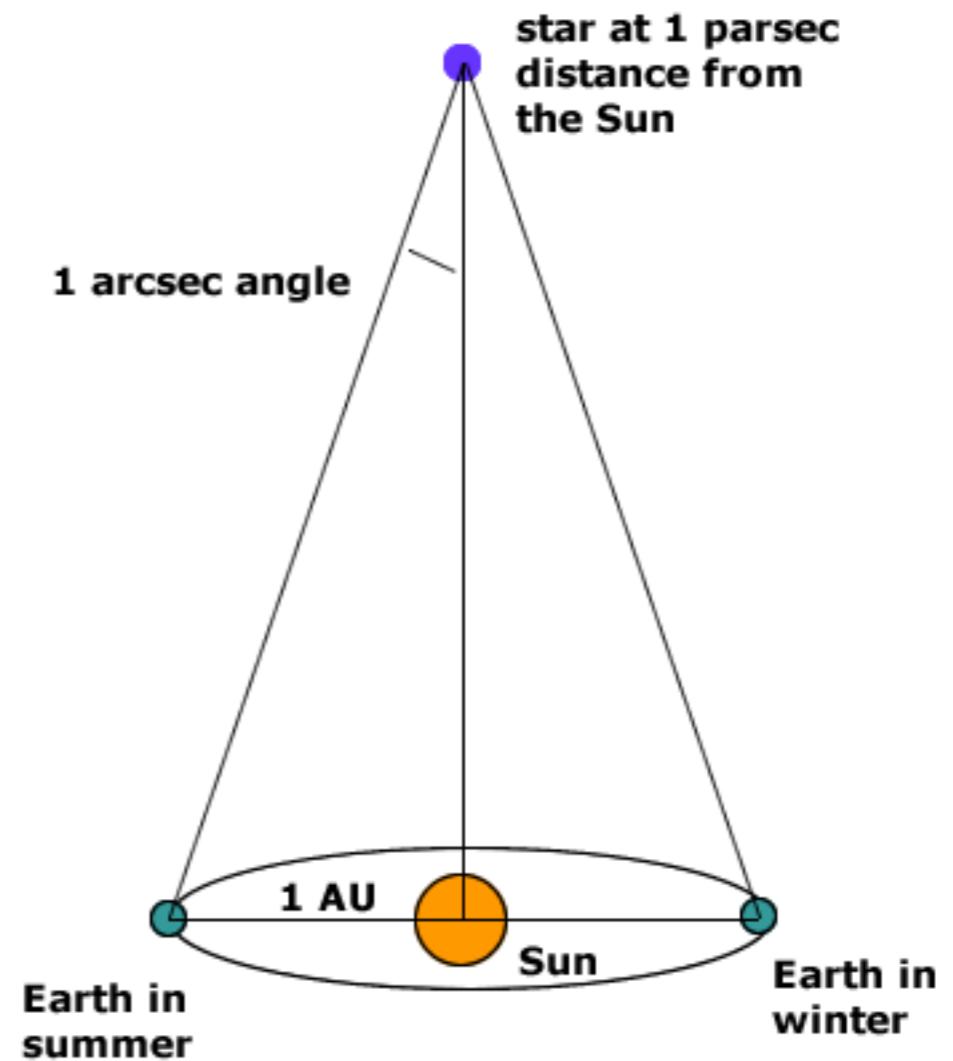
Parallax and parsecs

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

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

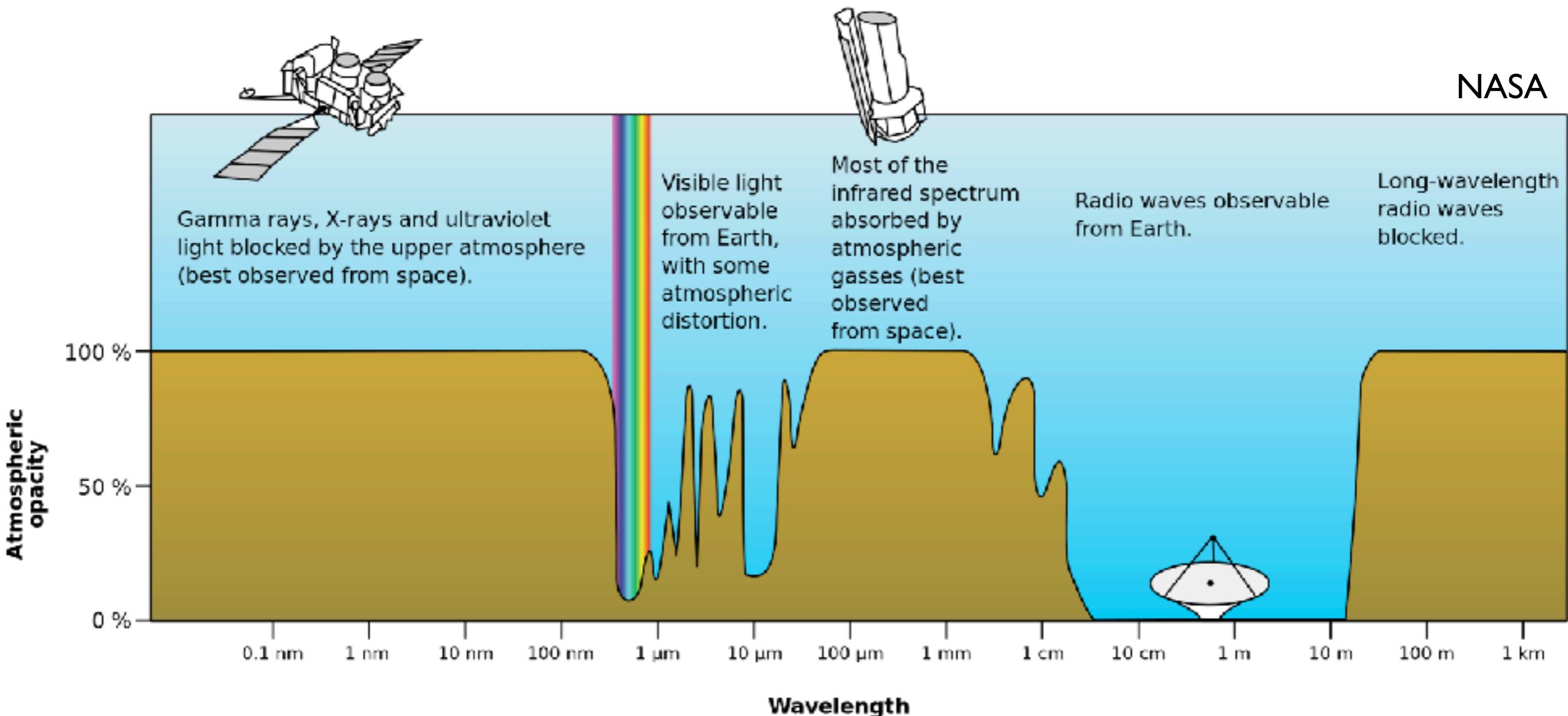
$$1 \text{ pc} = 3.26 \text{ light-years} = 3 \times 10^{16} \text{ m}$$

Proxima Centauri: ~ 1.3 pc



Earth's atmosphere

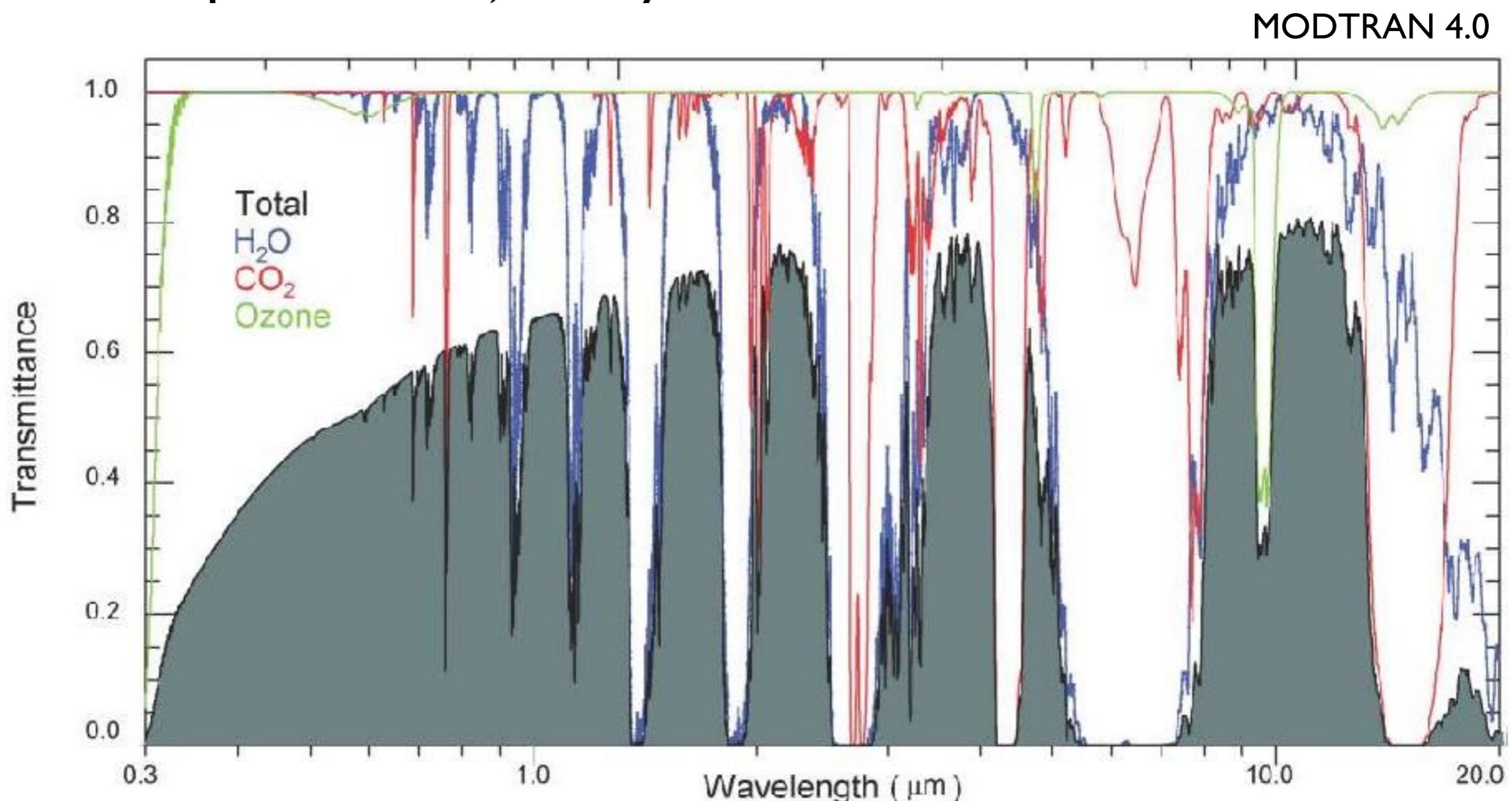
the atmosphere is opaque to most of the electromagnetic spectrum



Earth's atmosphere

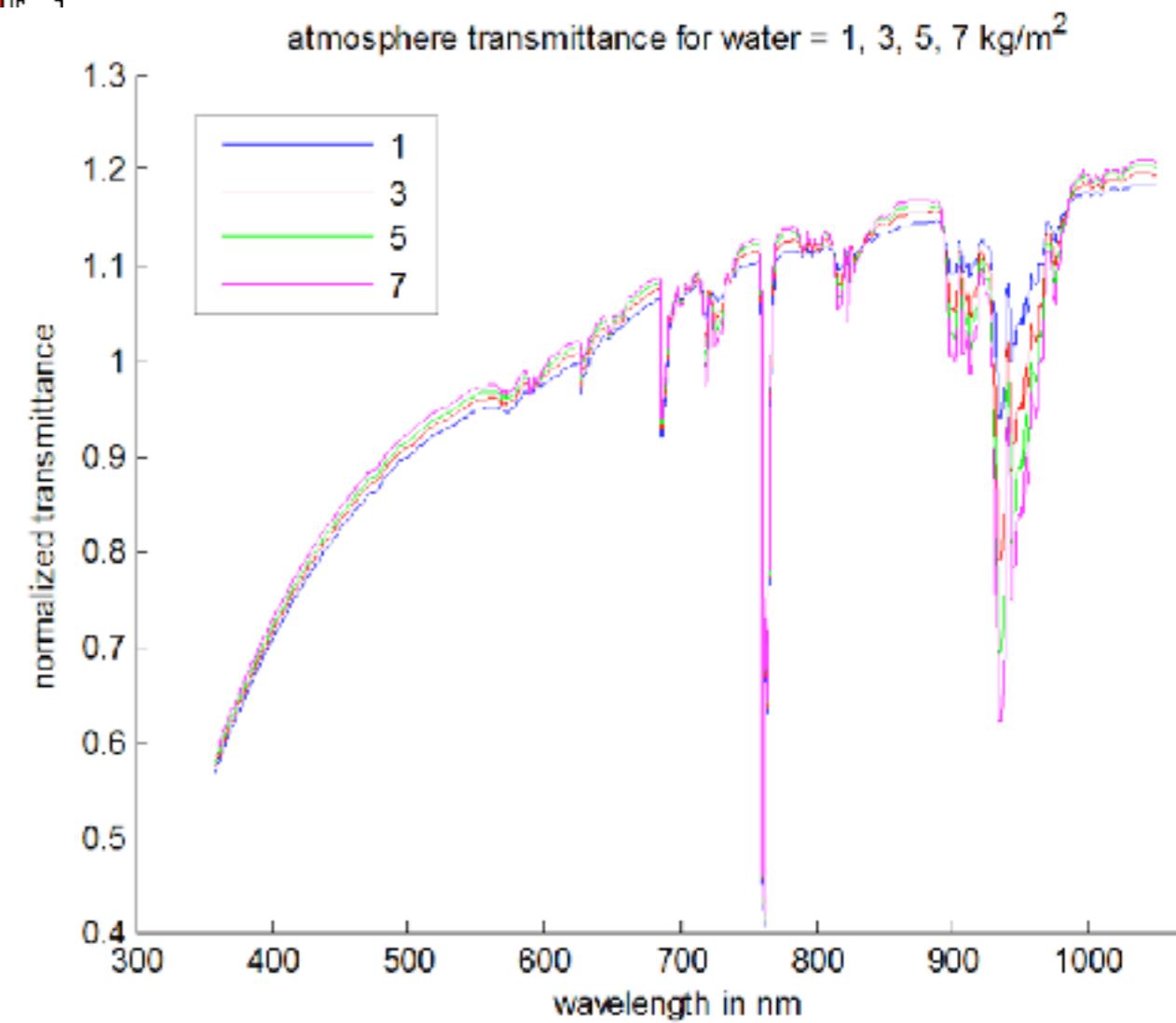
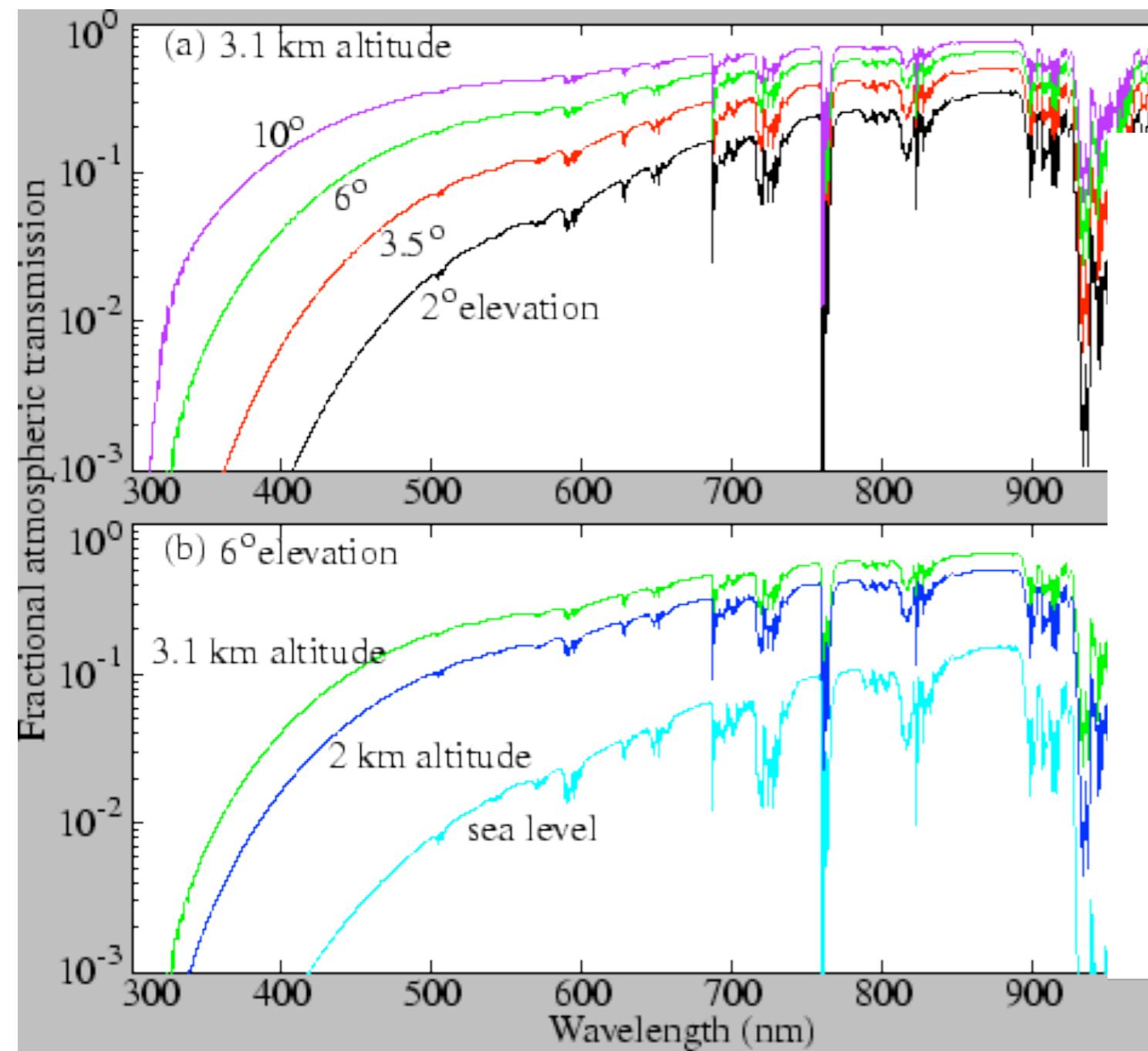
in the optical (~300nm - 1 μm) and near-infrared, extinction due to:

- 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:

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

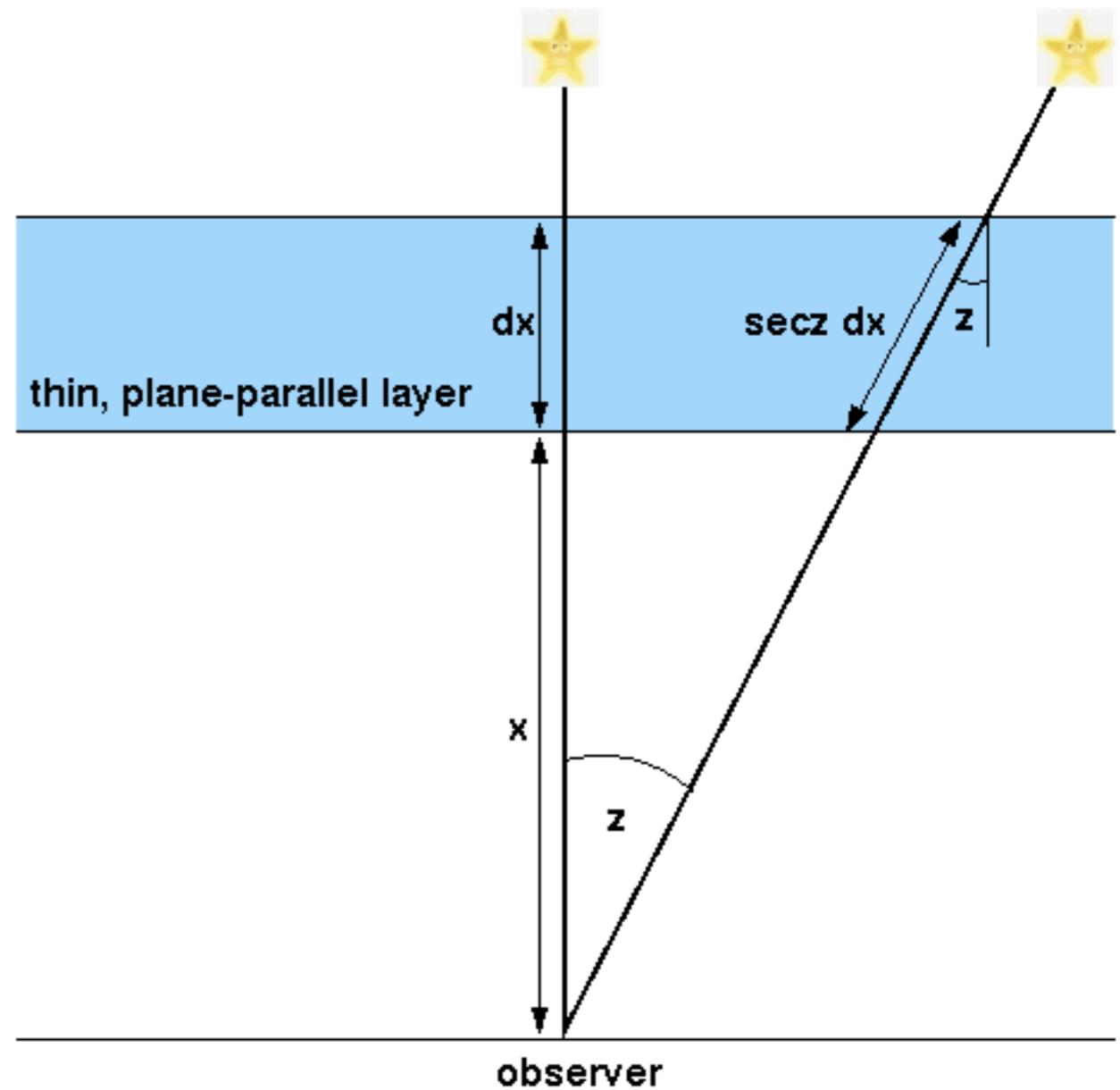
zenith distance:

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

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

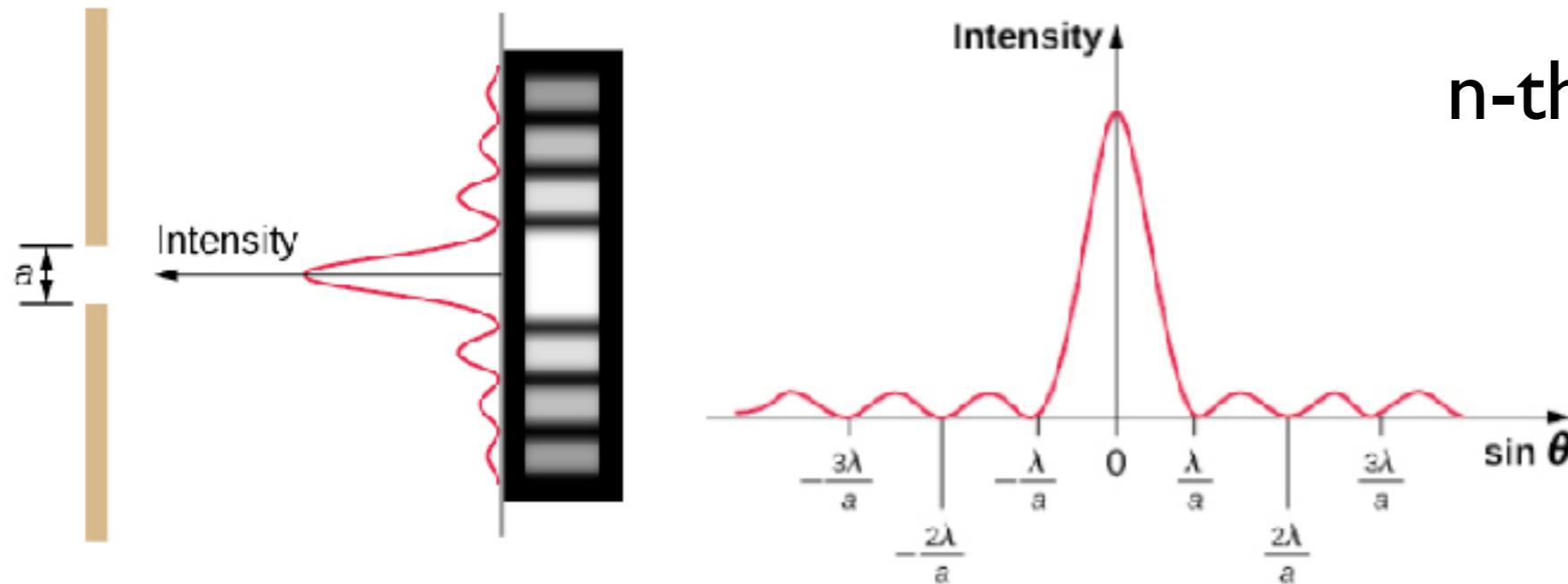
$$h=50^\circ: AM=1.3$$

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



Telescope resolution

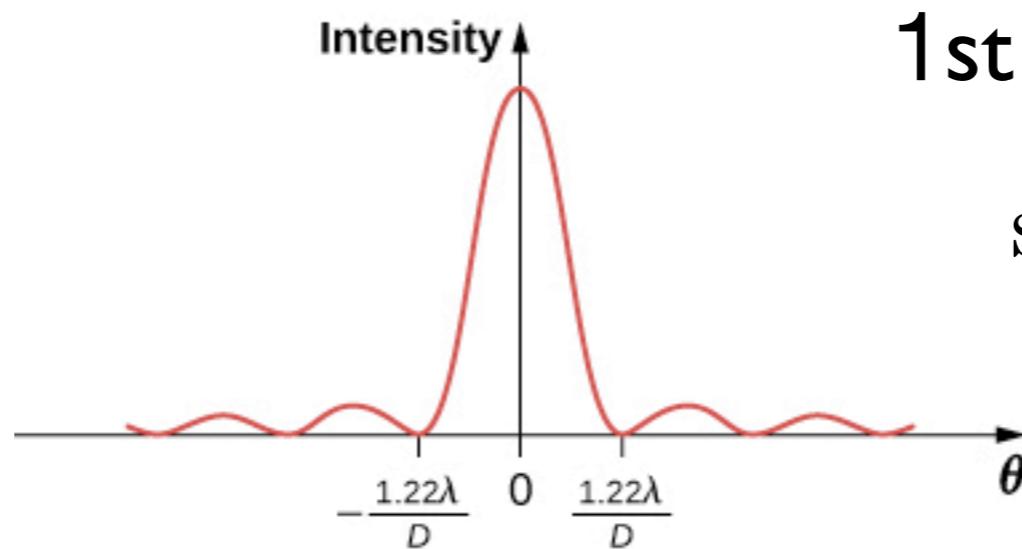
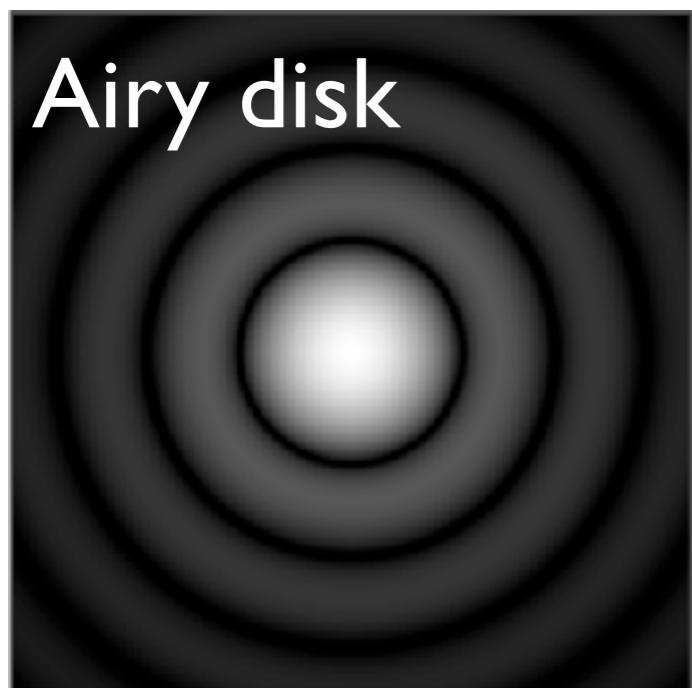
recall: single-slit diffraction



n -th minimum is at angle

$$\sin \theta = n \frac{\lambda}{a}$$

diffraction by a *circular aperture* with diameter D:



1st minimum is at angle:

$$\sin \theta \simeq \theta = 1.22 \frac{\lambda}{D}$$

radius of the
Airy disk

Telescope resolution

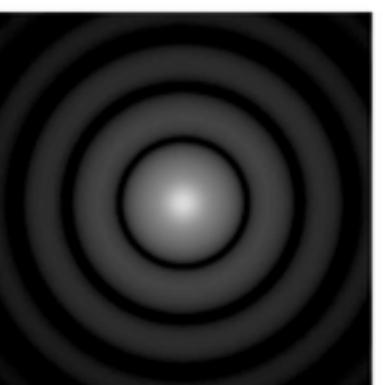
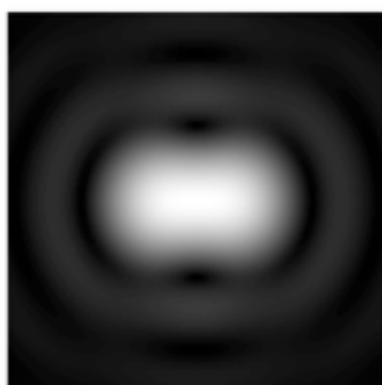
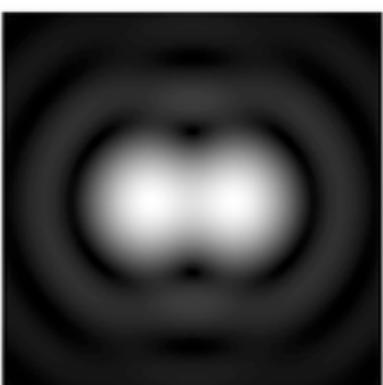
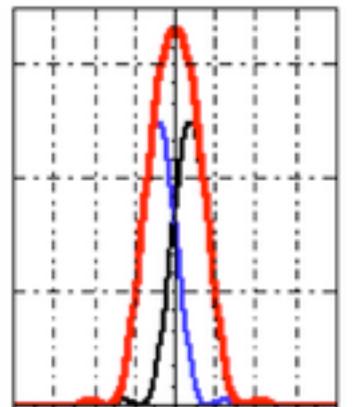
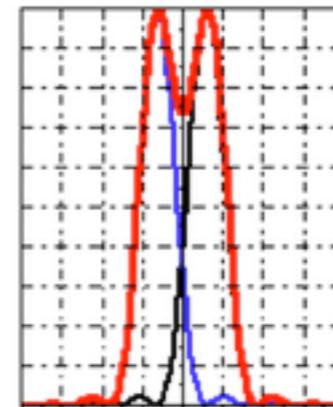
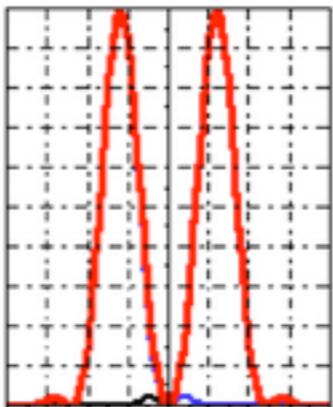
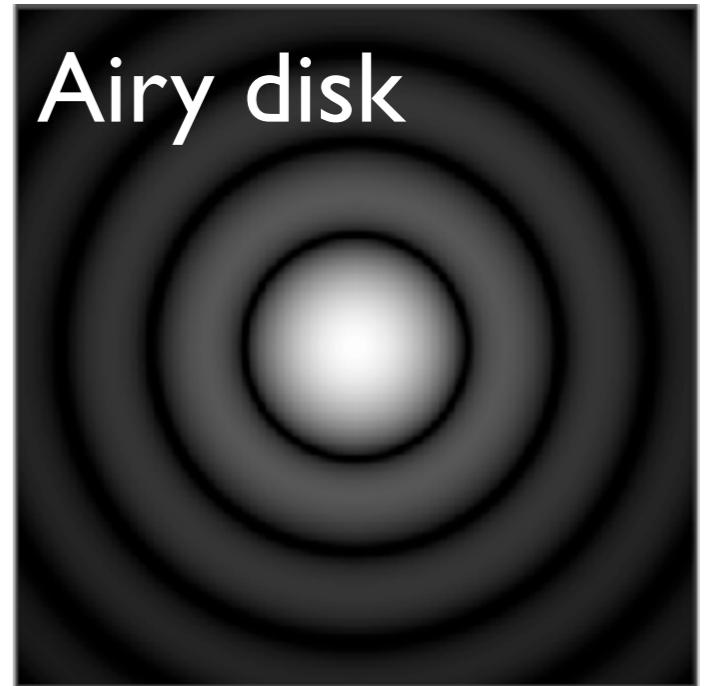
Light from a point source is imaged into an Airy disk of finite size → *fundamental resolution limit of a telescope*

Larger telescope: better resolution

Longer wavelengths: worse resolution

$$\theta = 1.22 \frac{\lambda}{D}$$

Rayleigh criterion: two point sources cannot be resolved if their separation is less than the radius of the Airy disk.

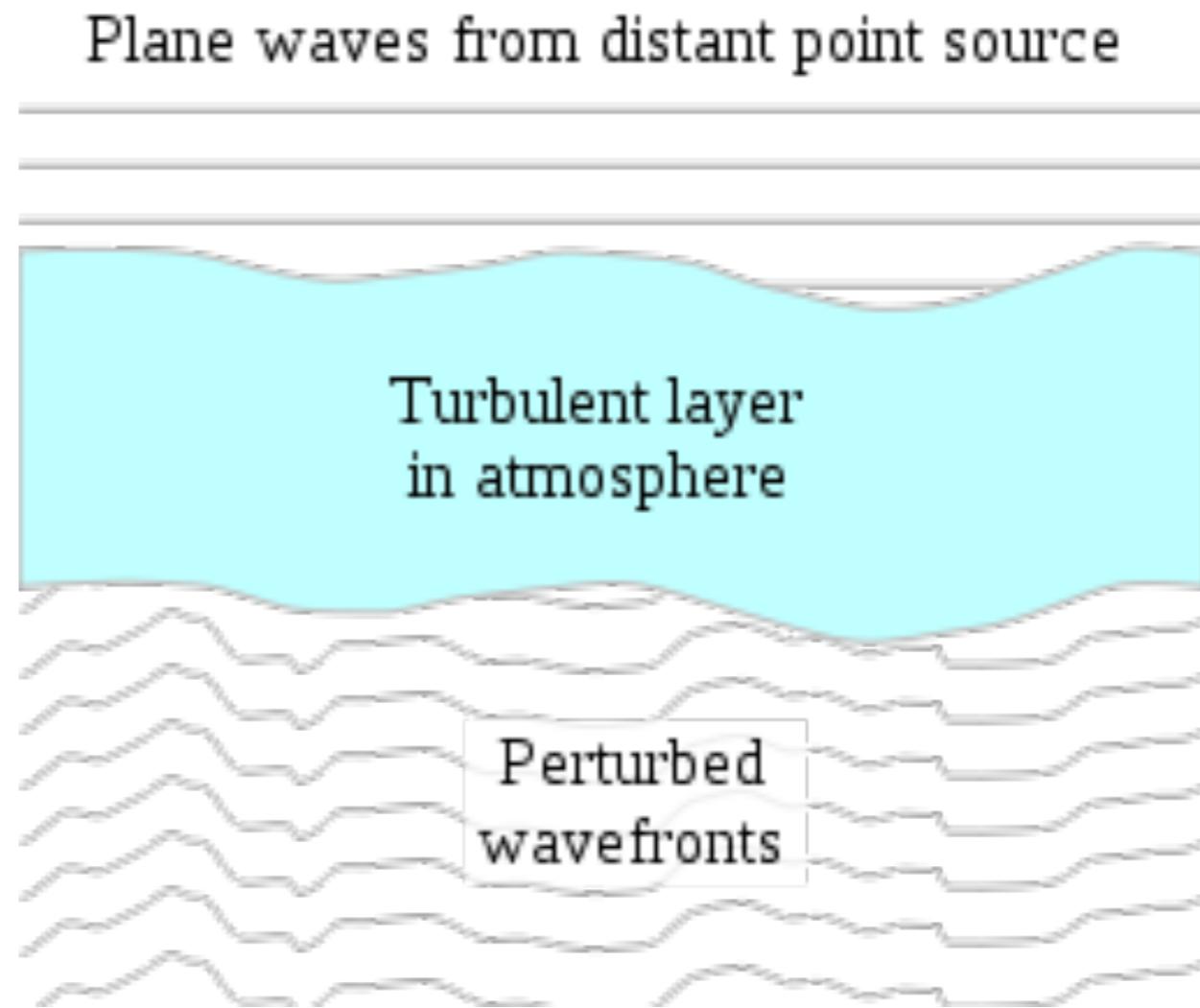


Seeing

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

in practice, the resolution of most telescope is limited by the atmosphere:

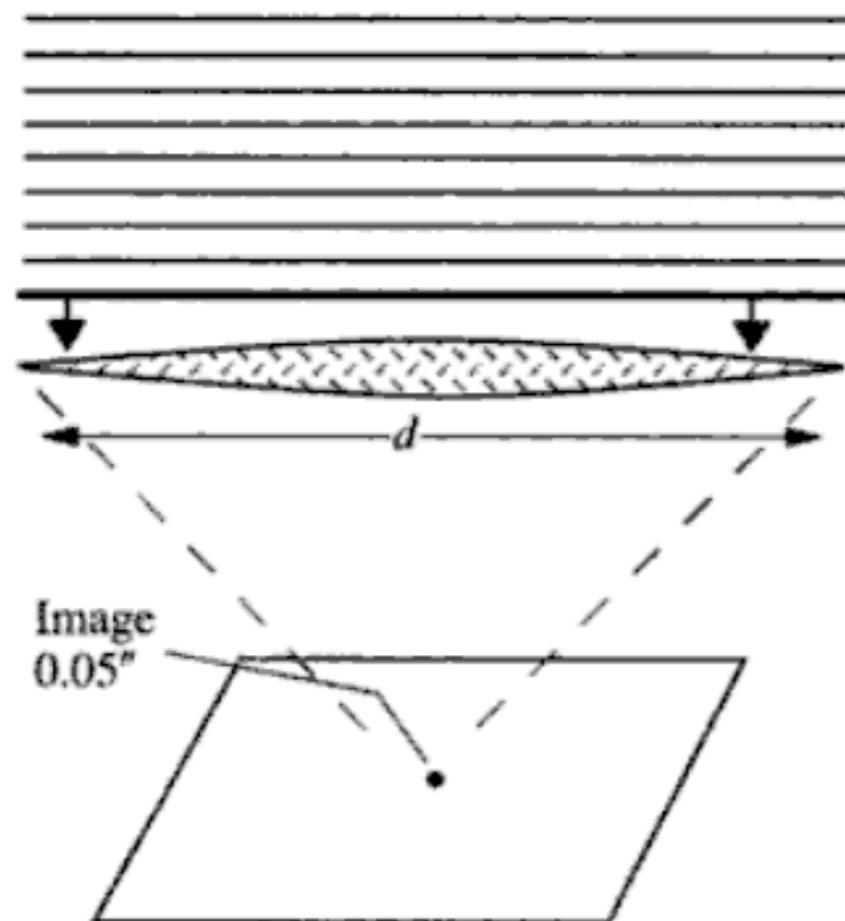
seeing: turbulence in the atmosphere, leads to “blurring” of images



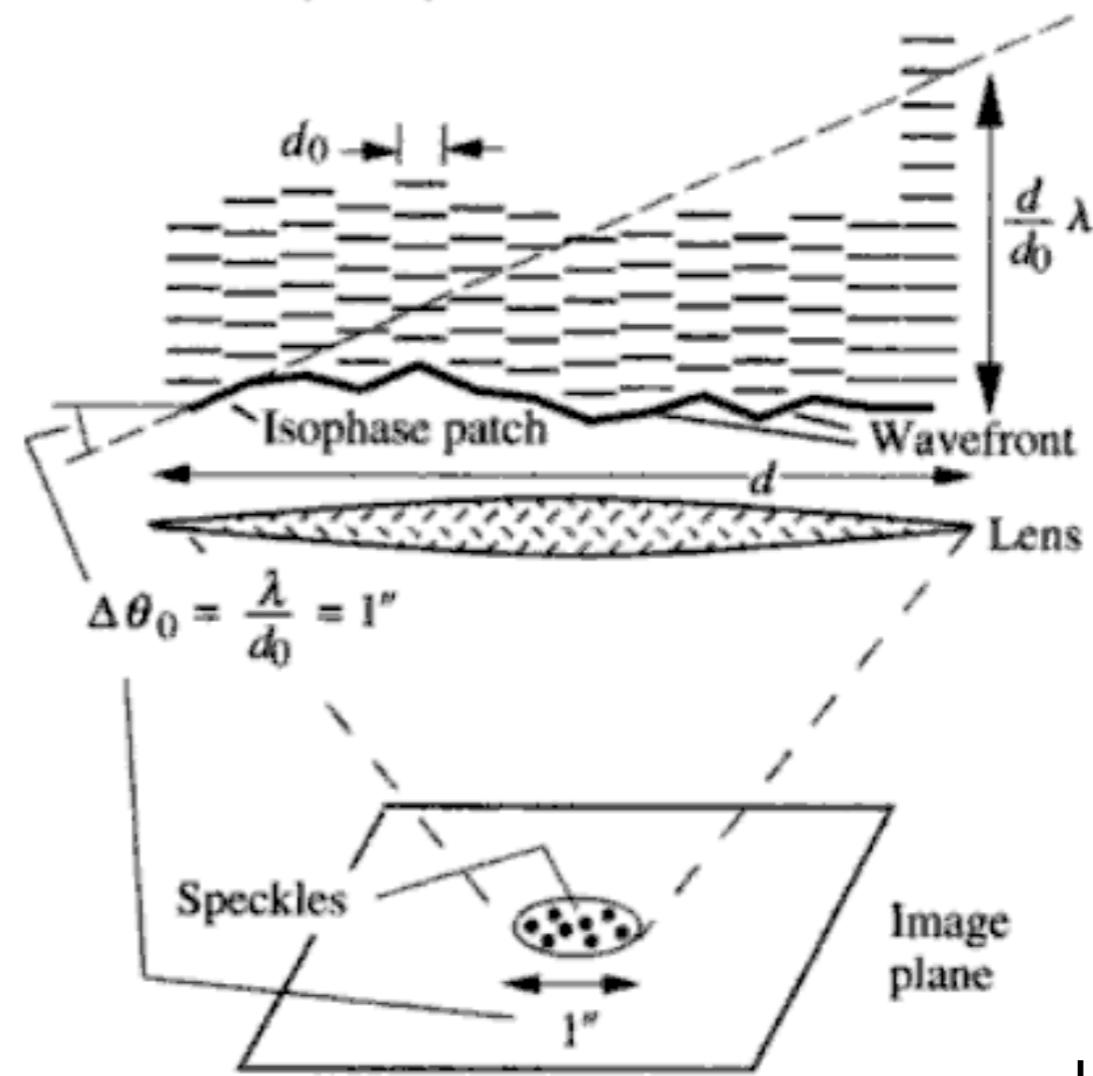
Seeing

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

(a) Plane wavefront

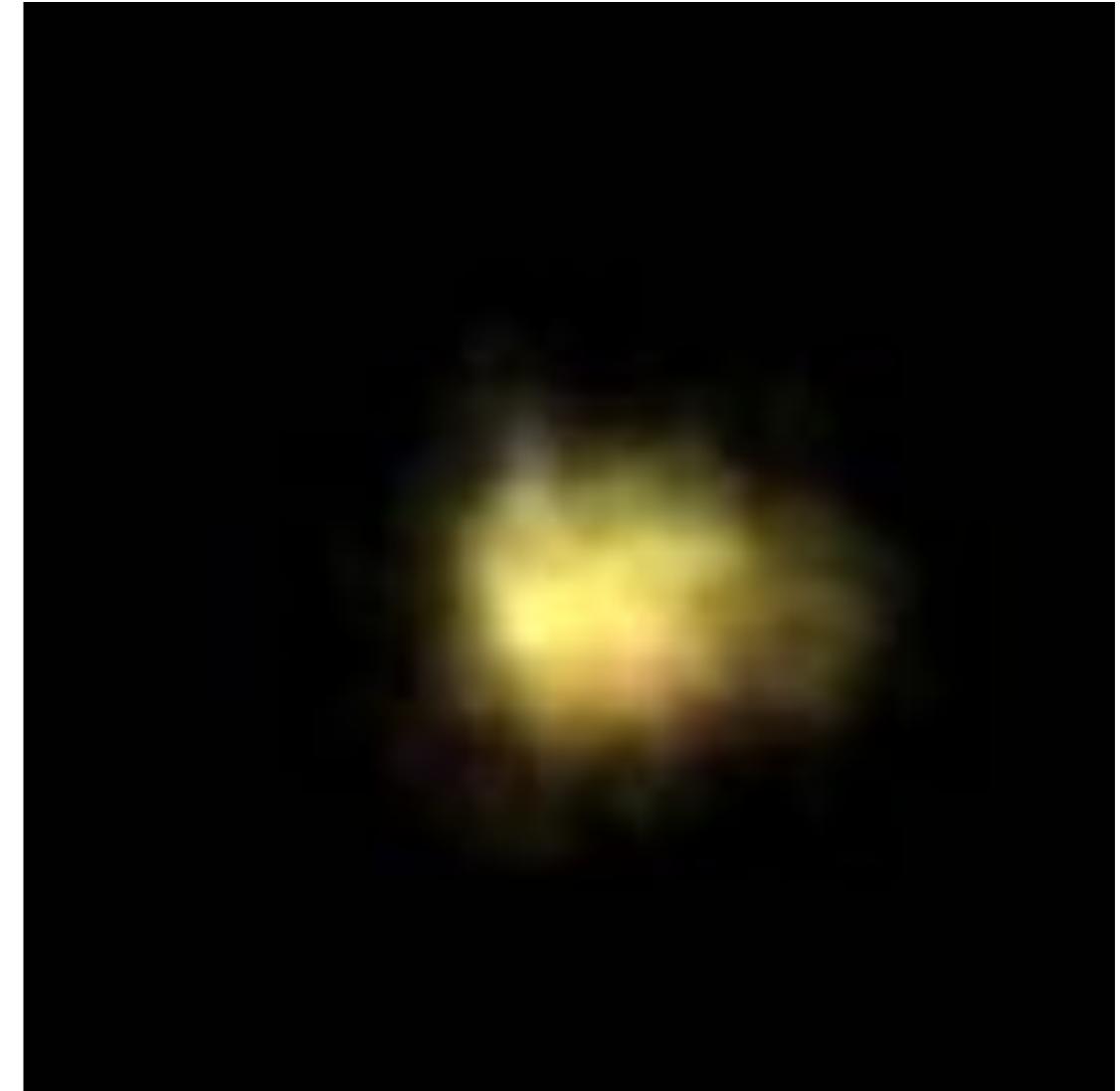
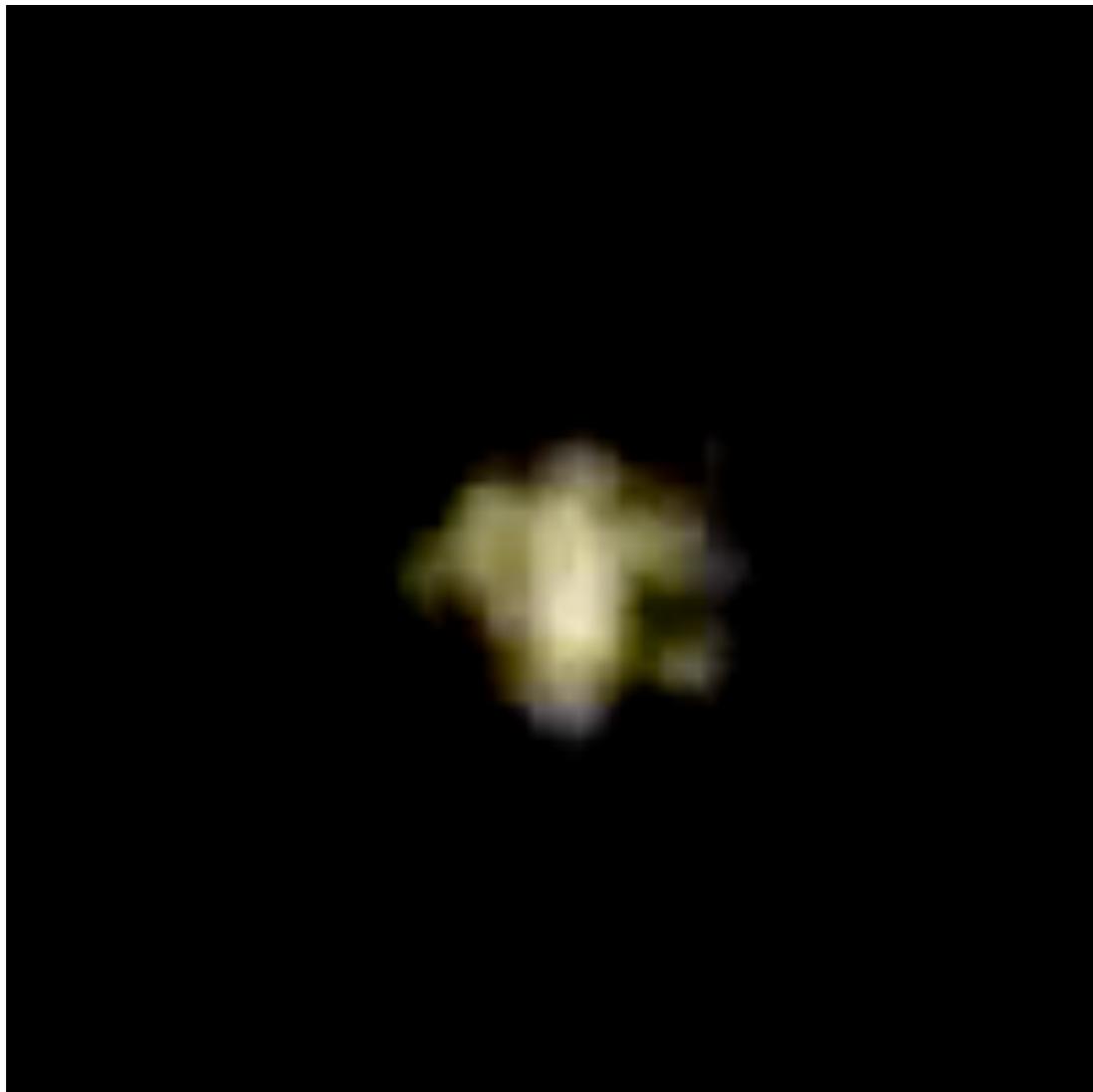


(b) Isophase patches



Seeing

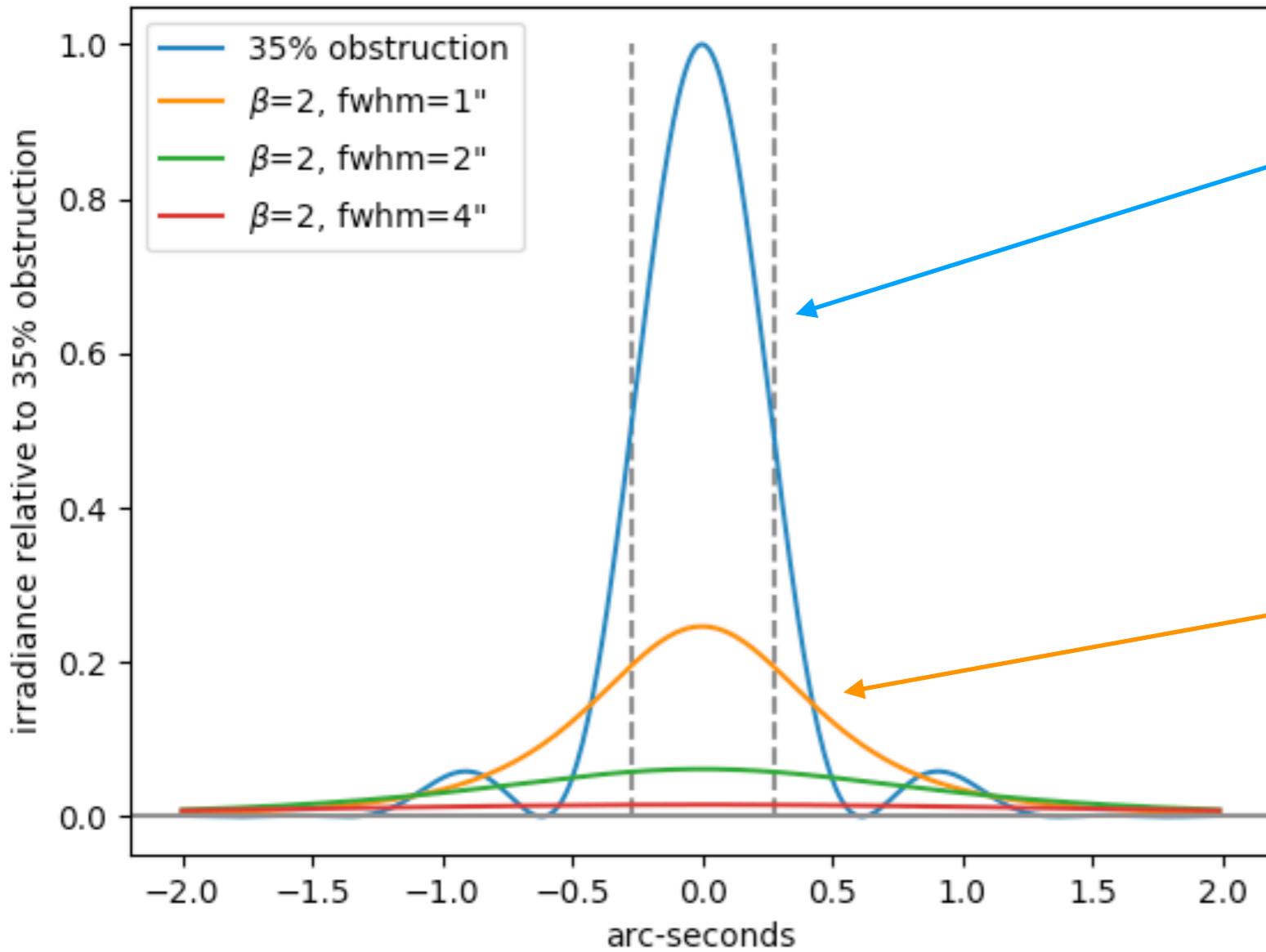
wavefront gets broken into isophase patches, each is a “mini-image” - interference leads to “speckles”



Seeing

Seeing/guiding drastically reduce peak height

Compare 35% obstruction with different Moffat α value



Airy disk for 8-inch telescope (with central obstruction), radius 0.58"

Moffat profiles with FWHM seeing 1", 2", 4"

Point Spread Function

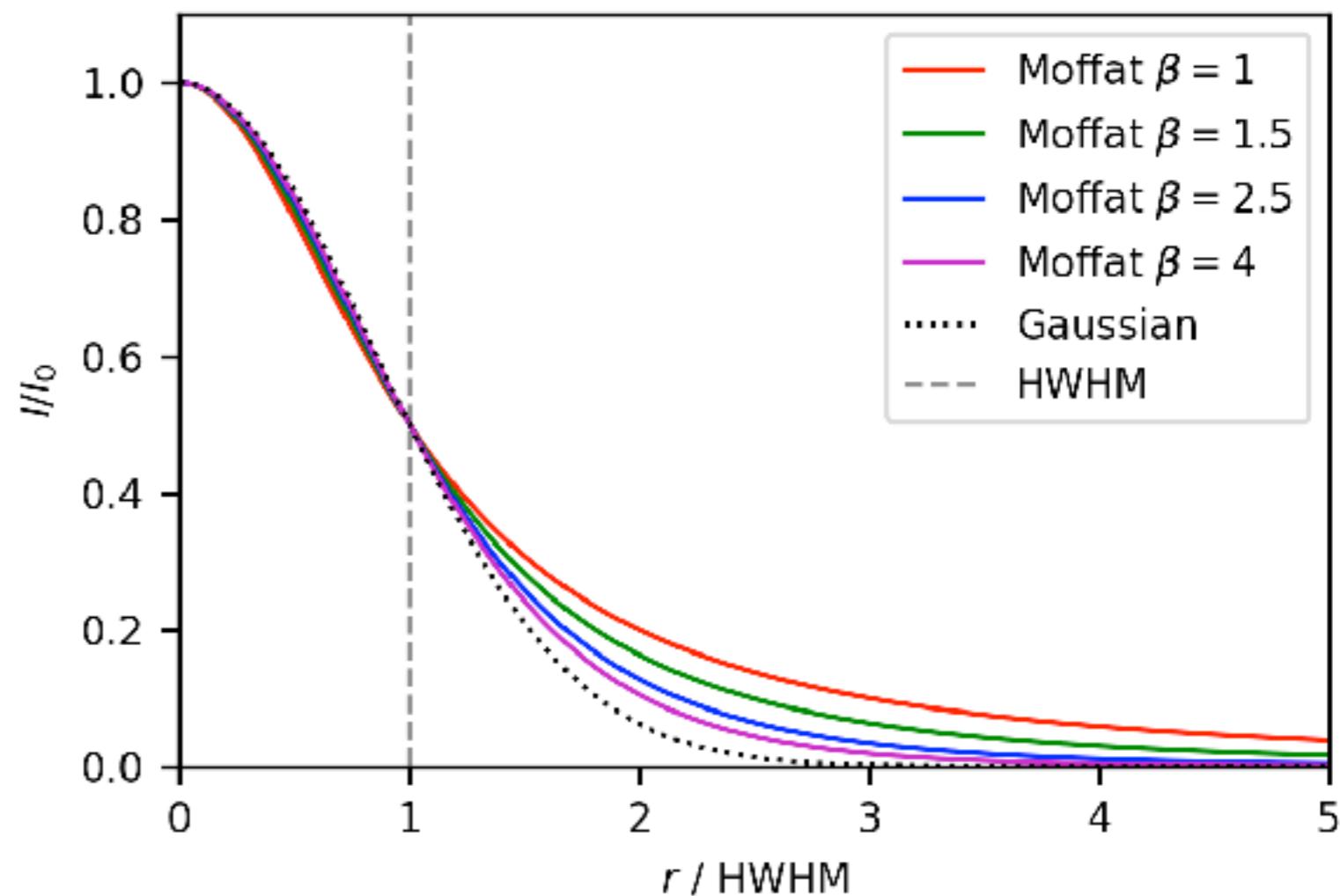
Point Spread Function

(PSF): the observed light distribution of stars in the image

determined by atmosphere and instrumentation

approximately Gaussian, but 2-parameter profiles (e.g. Moffat) are a better description

Moffat and Gaussian functions



quoted as Full Width at Half Maximum (**FWHM**),
 $\text{FWHM} \sim 2.35 \sigma$

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

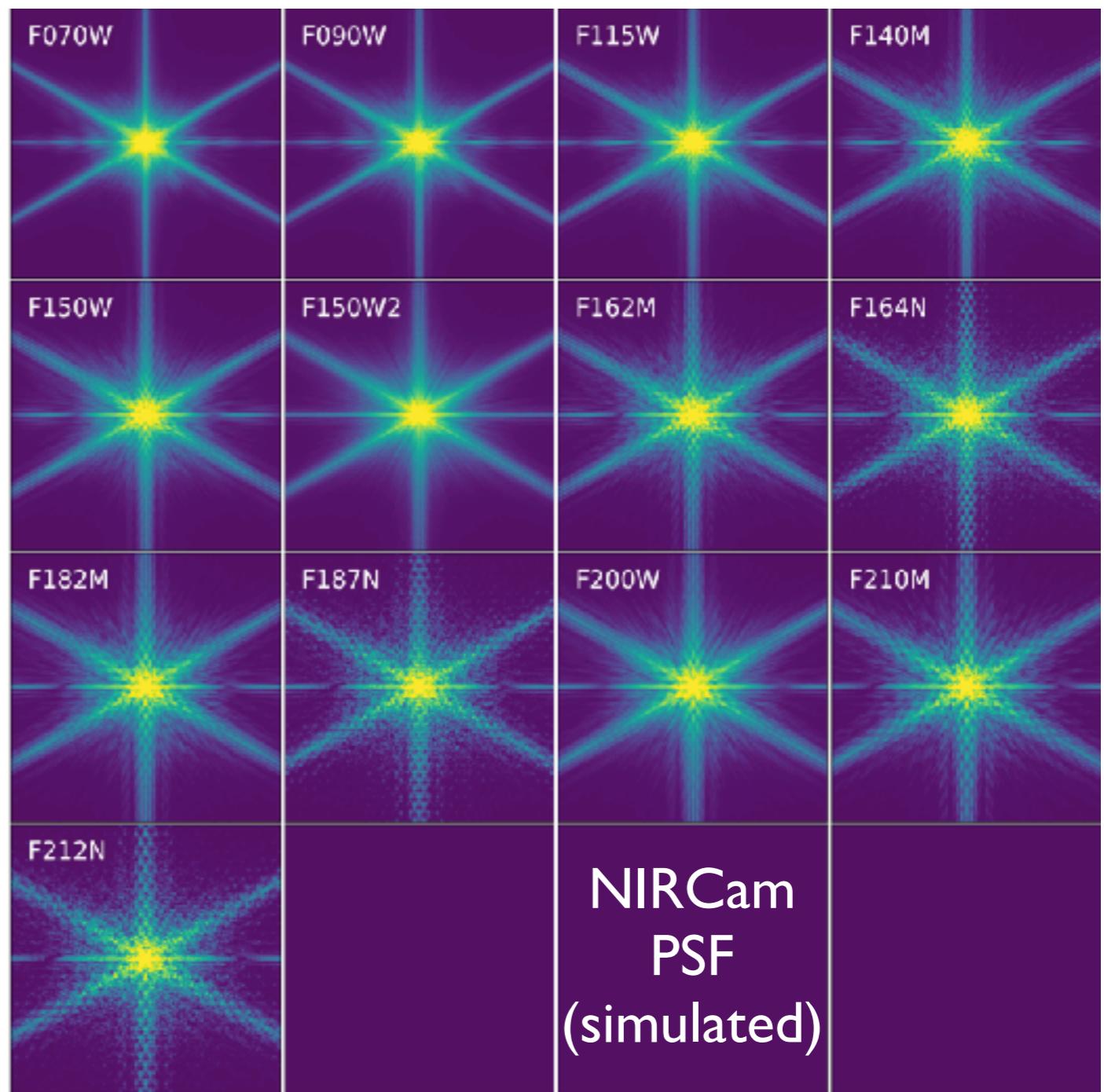
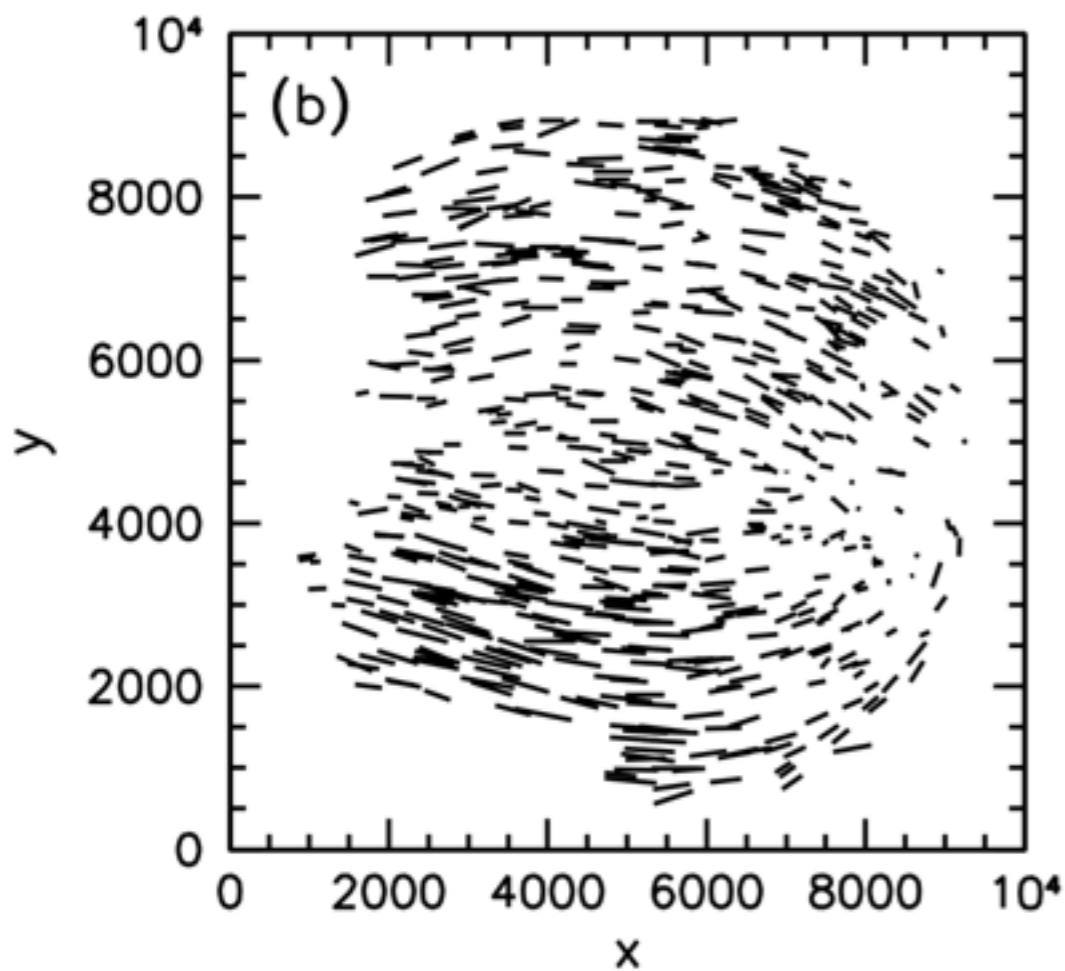


Gemini

Point Spread Function

Instrumentation limitations:

- PSF is not necessarily circularly symmetric
- PSF usually varies over the field of view



(A little bit about)
Telescopes

Aperture

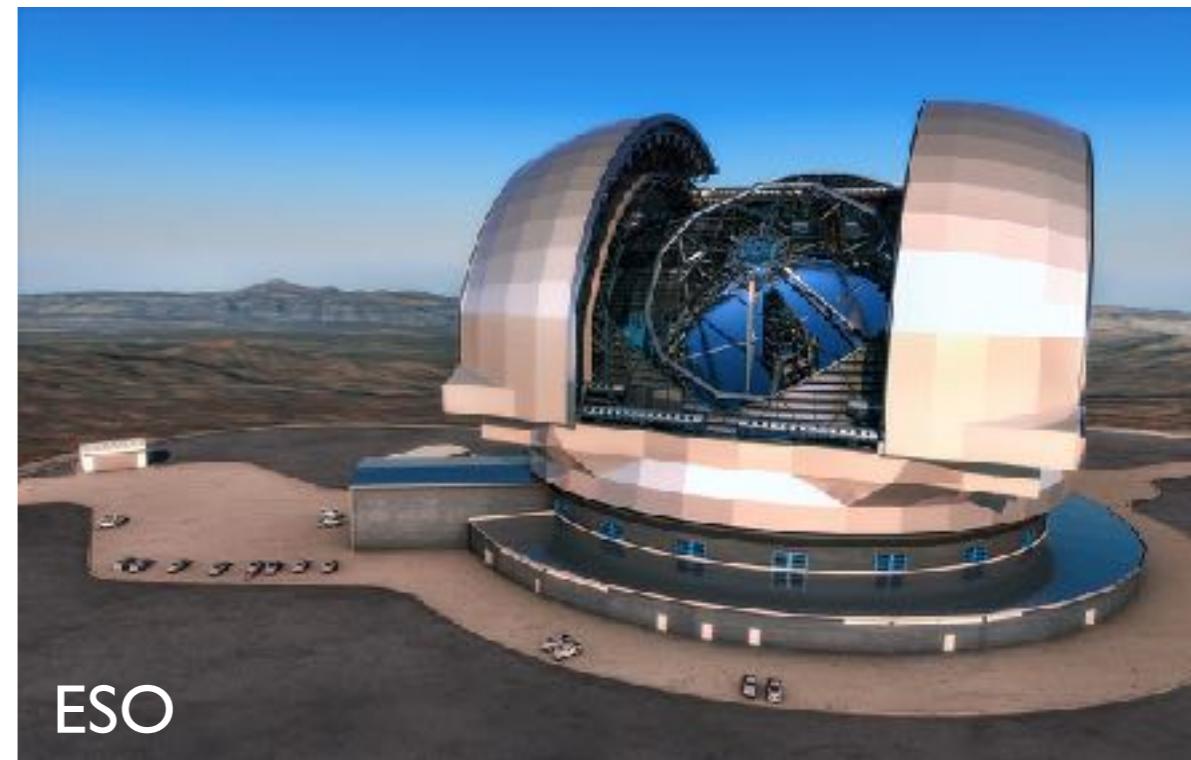
- most (new) things in astronomy are faint (but not all!)
- need to gather as much light as possible
- larger aperture → better resolution, if using adaptive optics to counteract atmospheric seeing
- the diameter of the mirror (aperture) is one of the main characteristics of a telescope

Keck Telescopes: 10m



L. Hatch

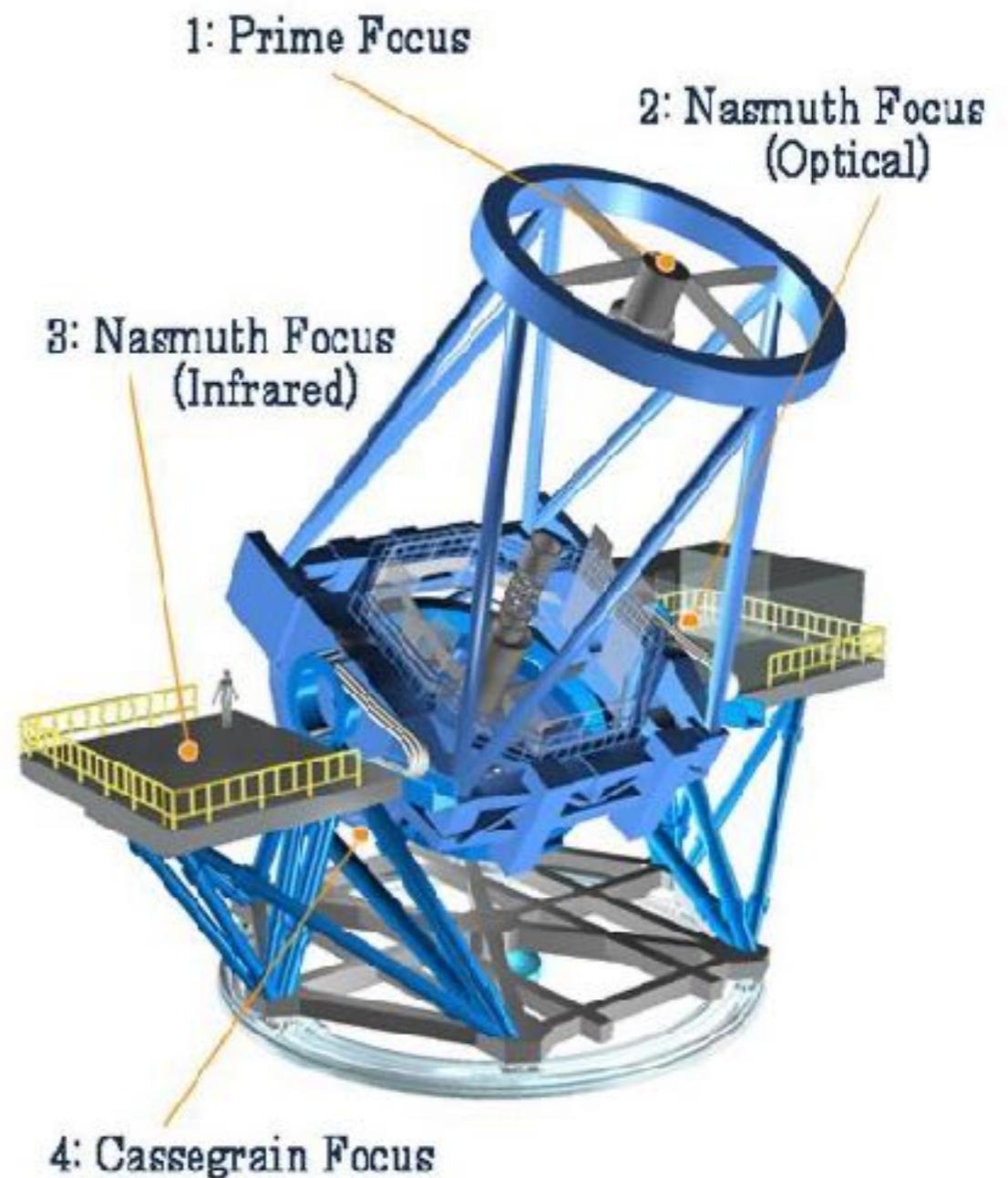
next generation: 30m telescopes (~2028)



ESO

Big telescopes

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

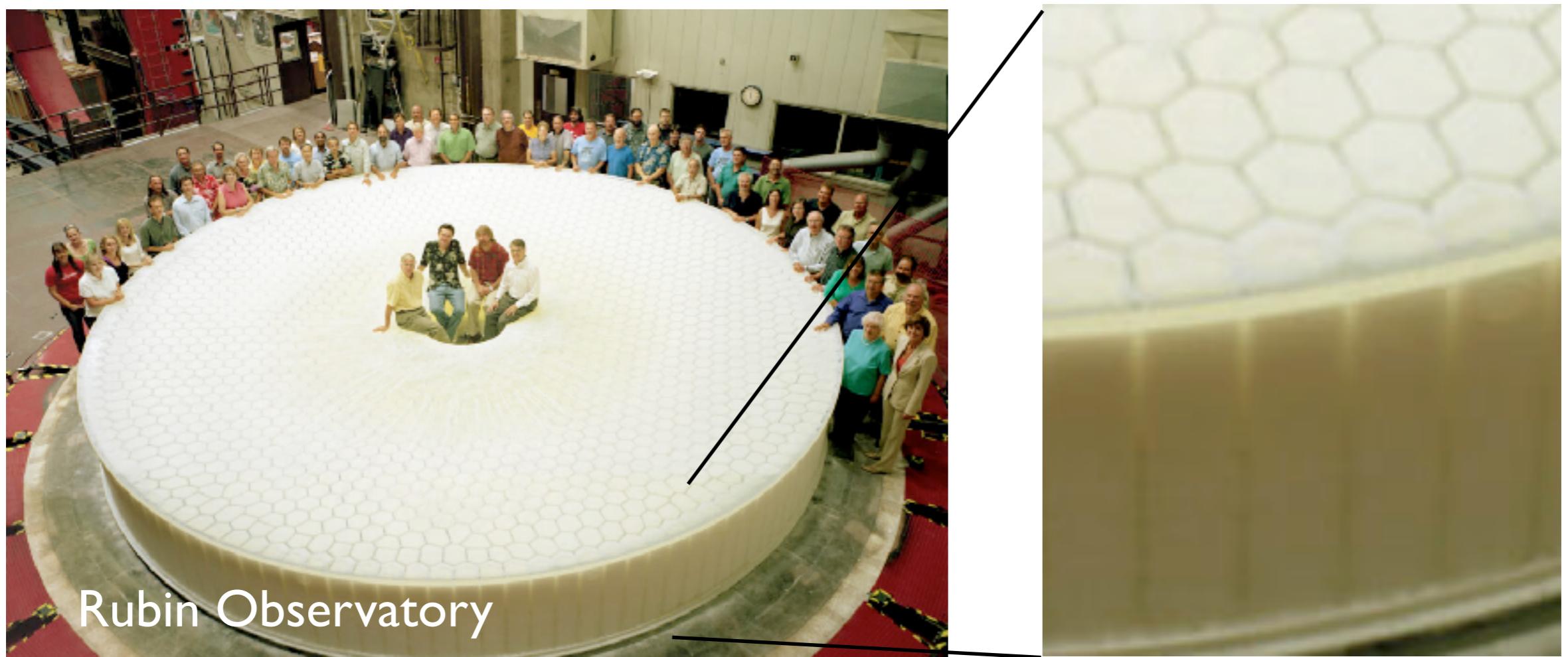


Active optics

Problem: large glass mirrors deform under gravity

Solution: thin mirrors, supported by actuators, control shape through actuators

- Corrects full field of view (FOV)
- “Slow” correction



Adaptive optics

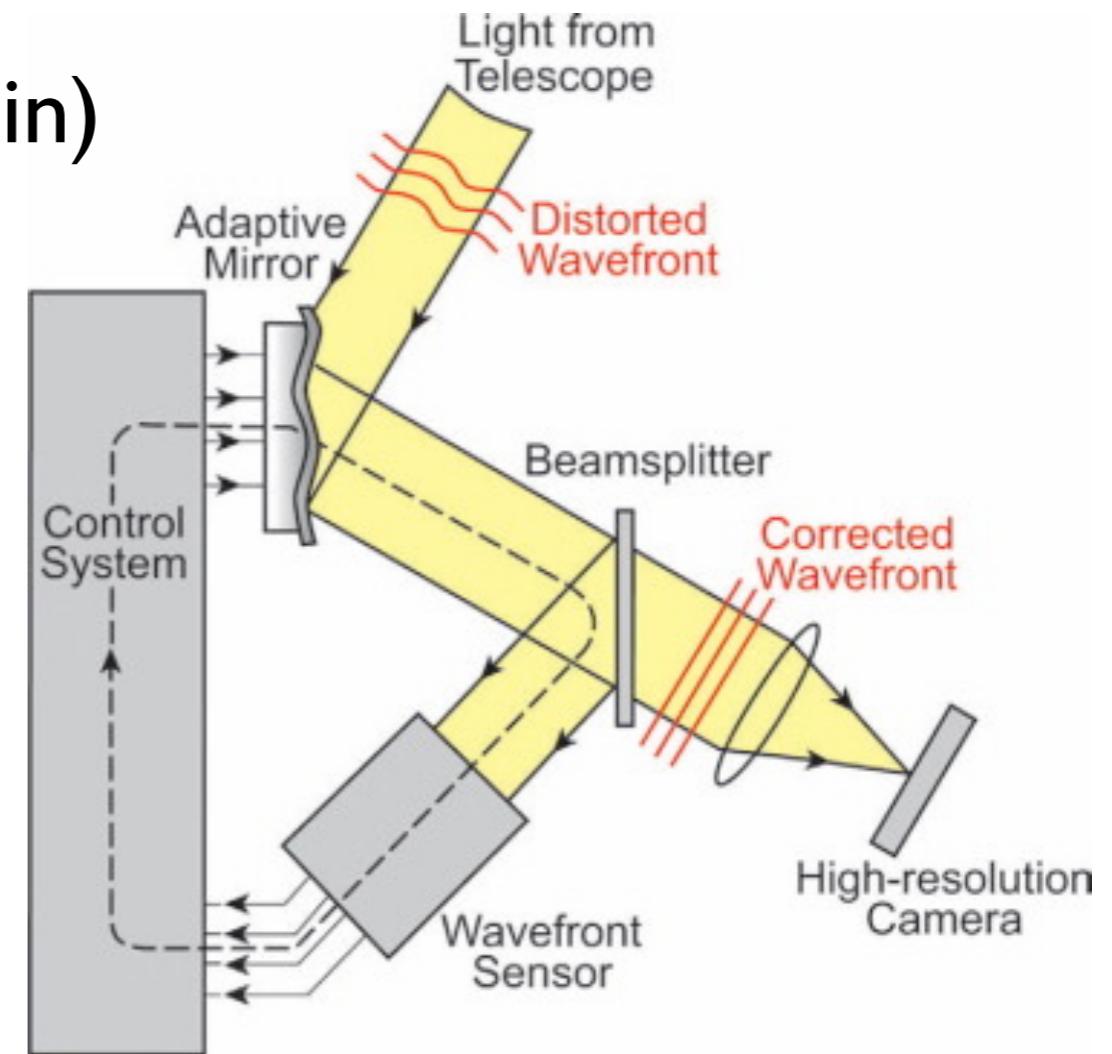
Problem: Earth's atmosphere blurs optical images

Solution: use a wavefront sensor and deformable secondary mirror to “iron out” wavefront distortions

- FOV limited by coherence length of atmospheric turbulence (a few arcmin)
- “Fast” correction (1000 Hz)

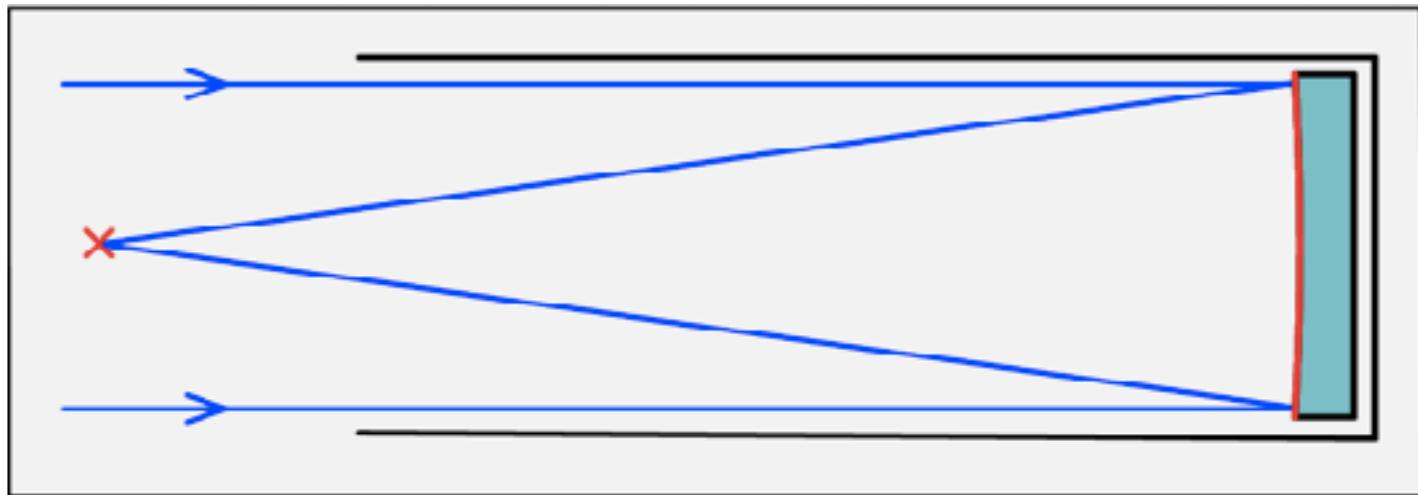


VLT: active +
adaptive optics

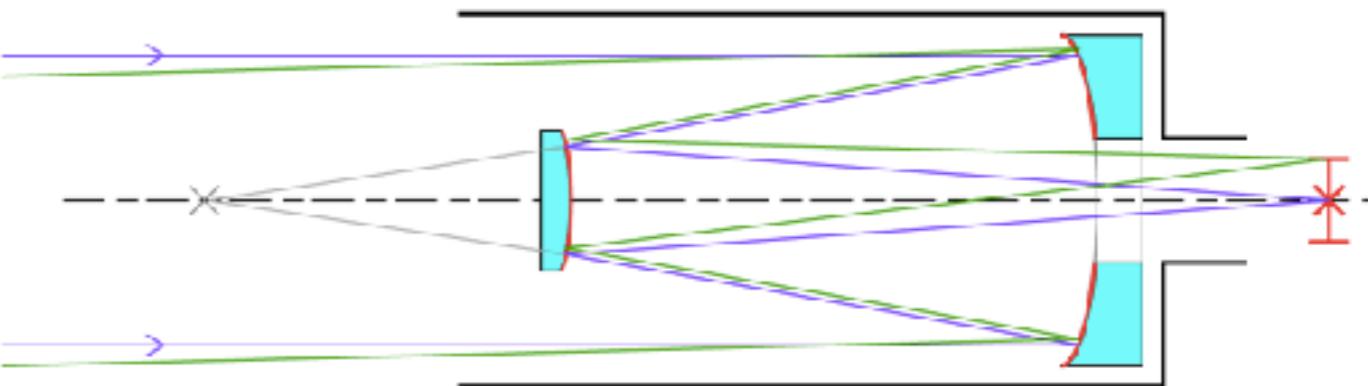


Telescope foci

- prime focus: focus of primary mirror

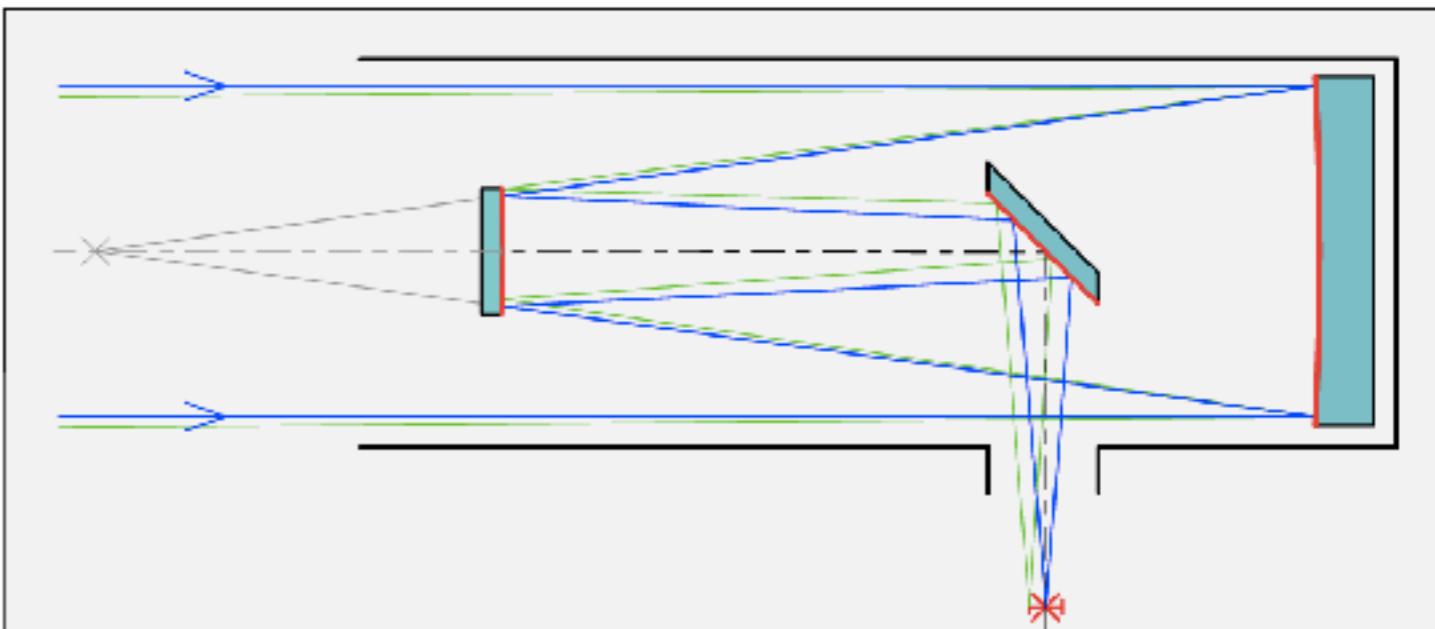


- Cassegrain focus: secondary mirror in front of prime focus; secondary focus behind primary mirror



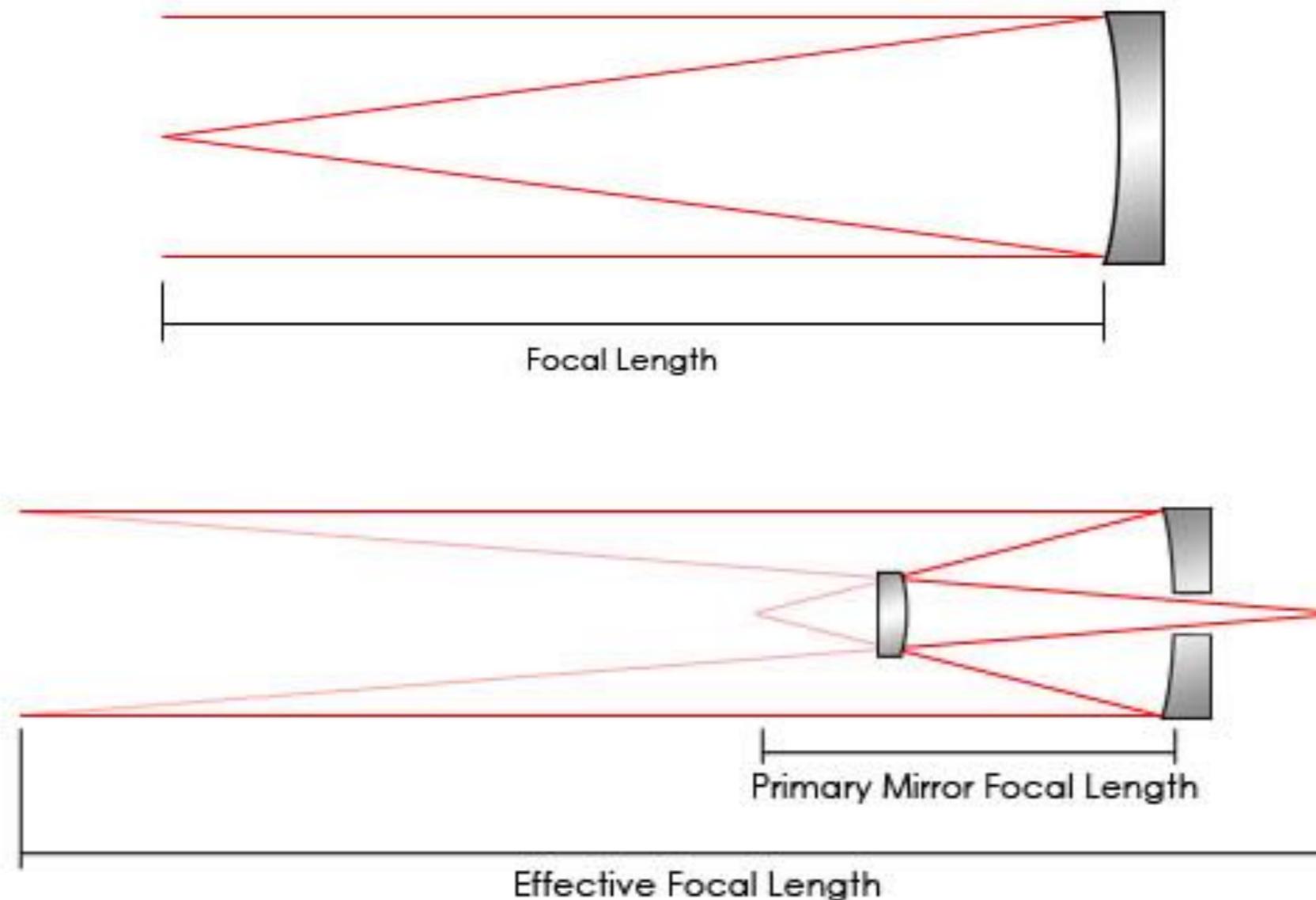
K. Vedala

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



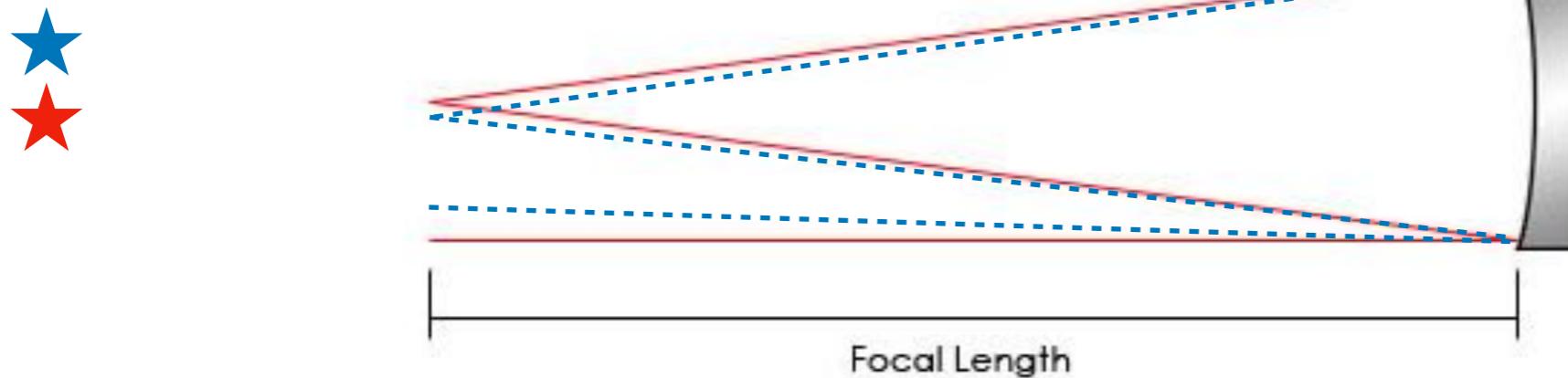
Focal length

distance from mirror / lens to the focal plane



Focal length

distance from mirror / lens to the focal plane



short focal length → large area of sky → low magnification

long focal length → small area of sky → high magnification

Plate Scale

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

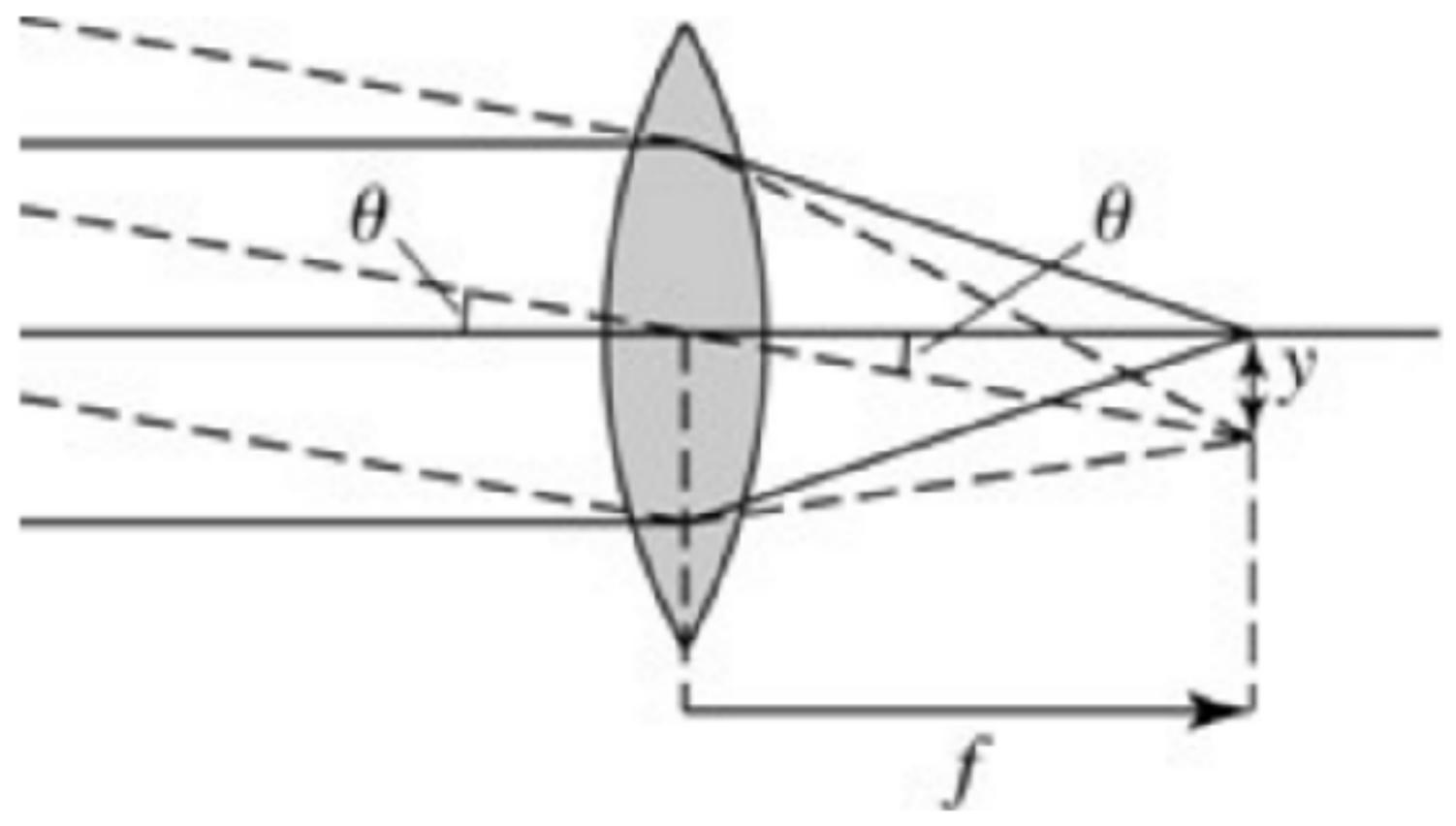
$$\theta \approx \tan \theta = \frac{y}{f}$$

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

plate scale = (focal length)⁻¹

units: angle / length

e.g. arcseconds / mm



unknown

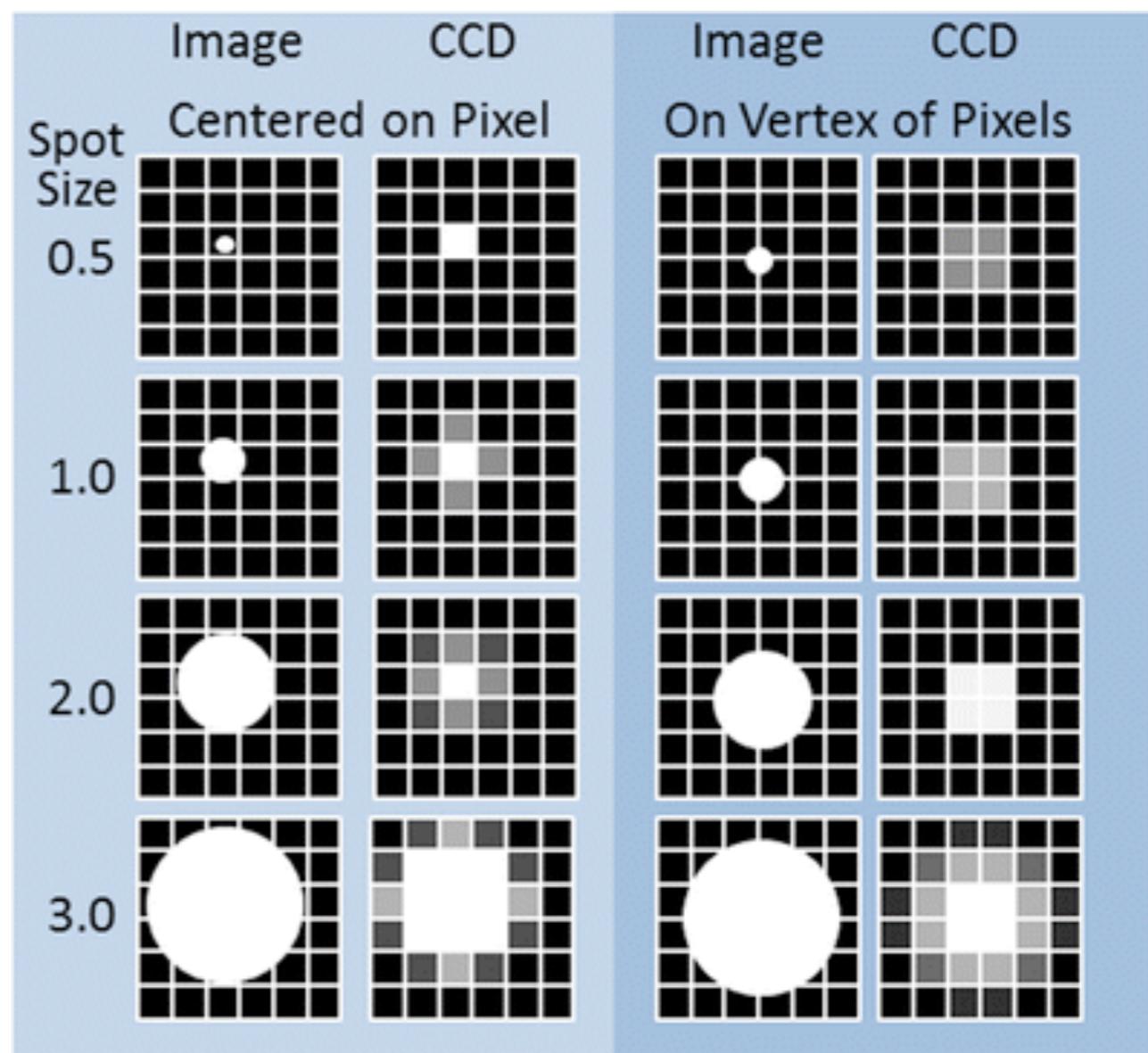
Detector resolution

- larger pixels: more photons, higher signal-to-noise, lower resolution
- smaller pixels to *resolve* the PSF, i.e. several pixels per resolution element (a few arcseconds)

Reu et al. 2014

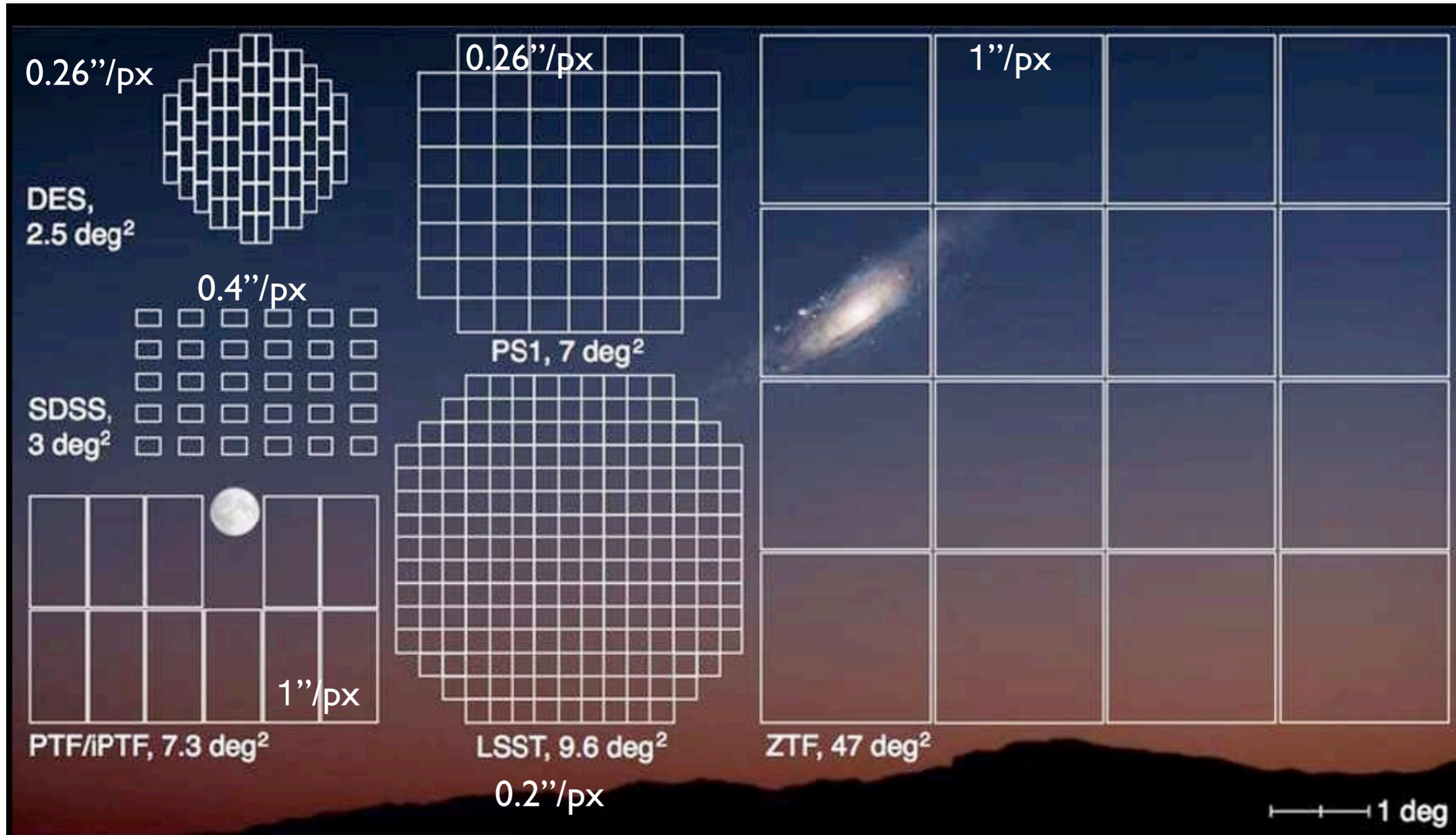
Nyquist sampling: 2 pixels per PSF width

In practice: 2.5 pixels per PSF FWHM



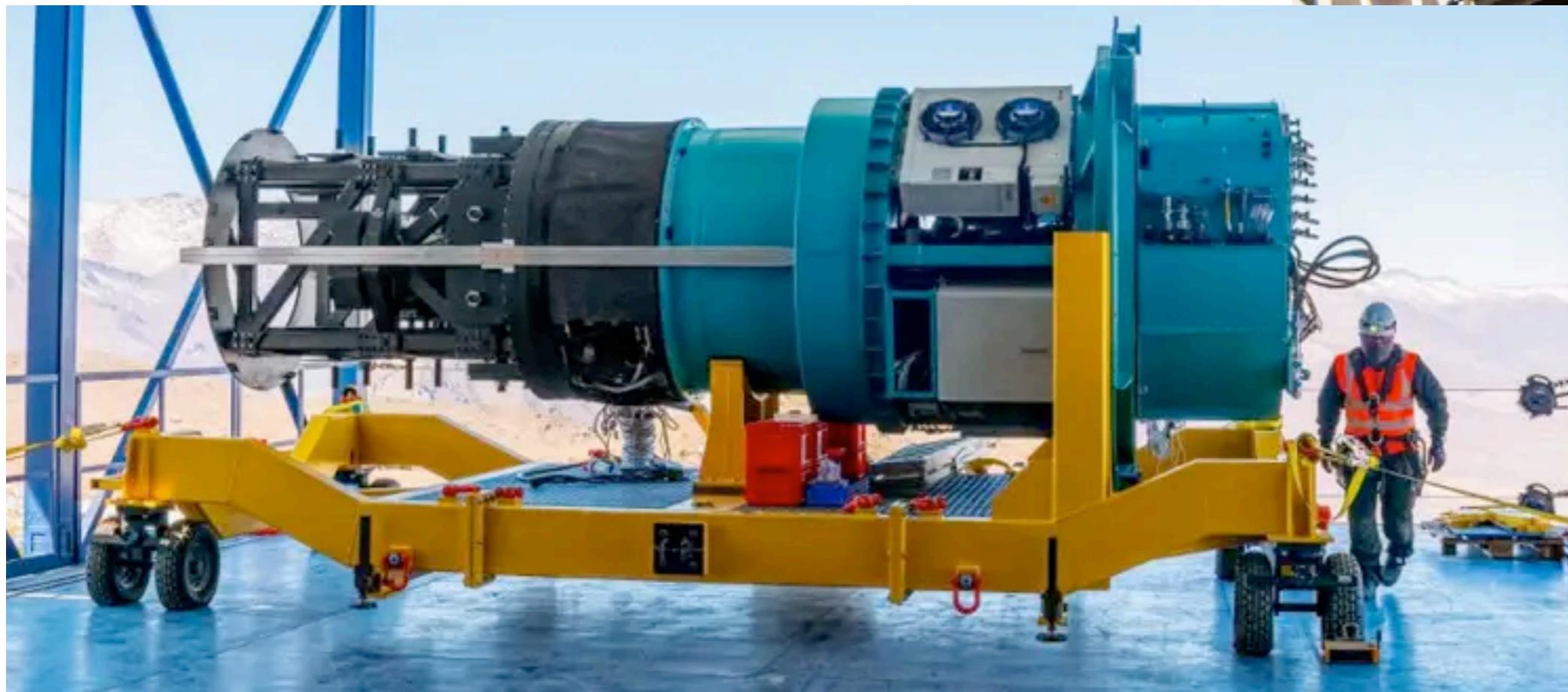
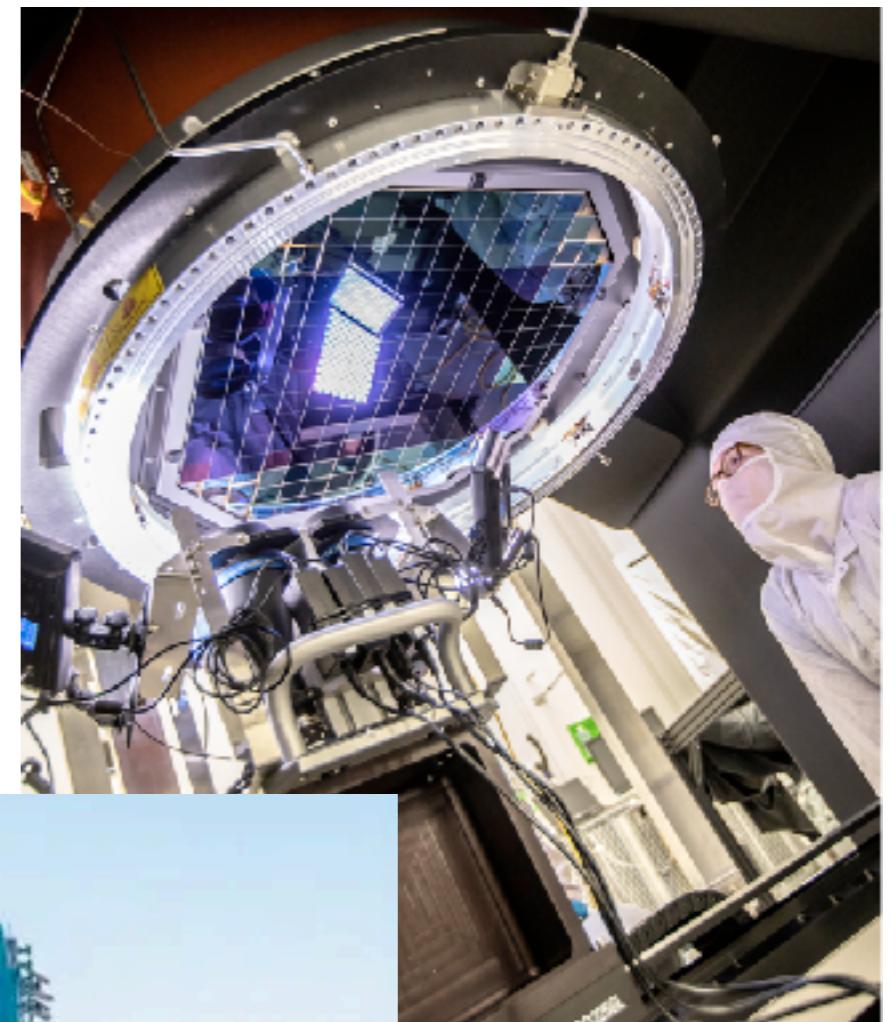
Field of View

Larger FOV - more discovery space! Trade-off with resolution.



LSSTCam

- Largest Camera ever built!
- 189 4K x 4K CCDs = 3.2 Gigapixels
- Large FOV, fully sampled



Rubin
Observatory

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)



Preparing for your observations

Homework 2 (due next Monday)

Request observing time for the Lab 1 “pretty picture”

- think of some objects you would like to image
- look up their coordinates (e.g. Simbad, wikipedia)
- look up their size and magnitude
- make a StarAlt plot to verify that the object is well observable
- check the Observing Calendar for available dates
- message / e-mail the TAs + instructor; include a justification of your request (StarAlt plot, size, brightness, choice of filters [BVRI, Ha])



Homework

- submit homework in pdf format in the google form
- use HW#_SBUID#.pdf as your file name (to remain anonymous)

Tutorials

- remaining lectures will be followed by tutorials (bash, python, some astronomy software)
- bring your laptop (if you have one)

- tutorials will take place in the computing lab
- each group “gets” (at least) one machine - note its name; this is the machine that you will log into for analyzing data

- today: bash / Linux

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

Mt Stony Brook Observing Calendar

Today February 2022

Print Week Month Agenda

Mon	Tue	Wed	Thu	Fri	Sat	Sun
31	Feb 1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
No observing						
		Full Moon				
21	22	23	24	25	26	27
28	Mar 1	2	3	4	5	6
Events shown in time zone: Eastern Time - New York						
+ Google Calendar						

The calendar shows the following events:

- February 4: 7pm Open Night
- February 5: 6pm Lab 2: Alden,
- February 9: 6pm Lab 2: Brend...
- February 11: 6pm Lab 2: John,
- February 13: No observing
- February 17: Full Moon
- February 28: 7pm Open Night

excerpt from Mt. Stony Brook observing calendar