A Quick Review From Last Lecture

Doppler Shift — Velocity and Geometry

we want to figure out this

V_t = tangential velocity

V_{tot} =total velocity

θ

V_r = radial or line of sight velocity

the Doppler shift only gives us this

A Quick Review From Last Lecture

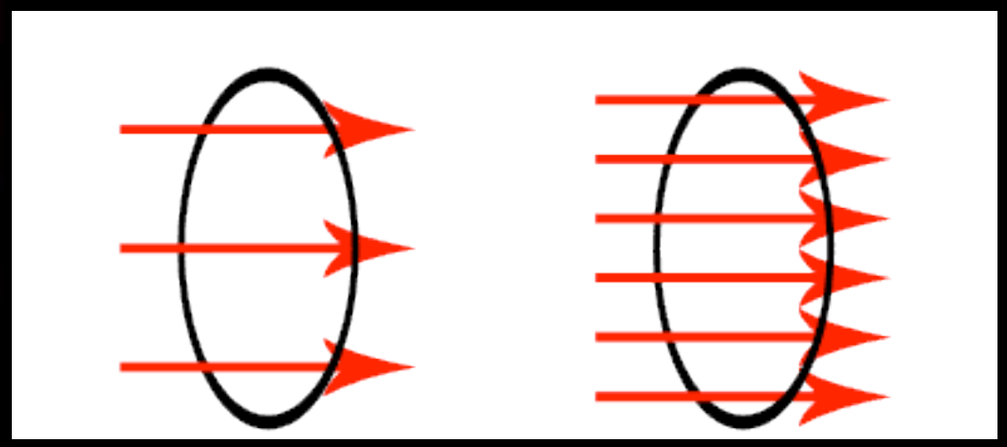
More About Flux

$F \propto T^4$

Example: Light emitted per surface area on the Sun

lower temperature

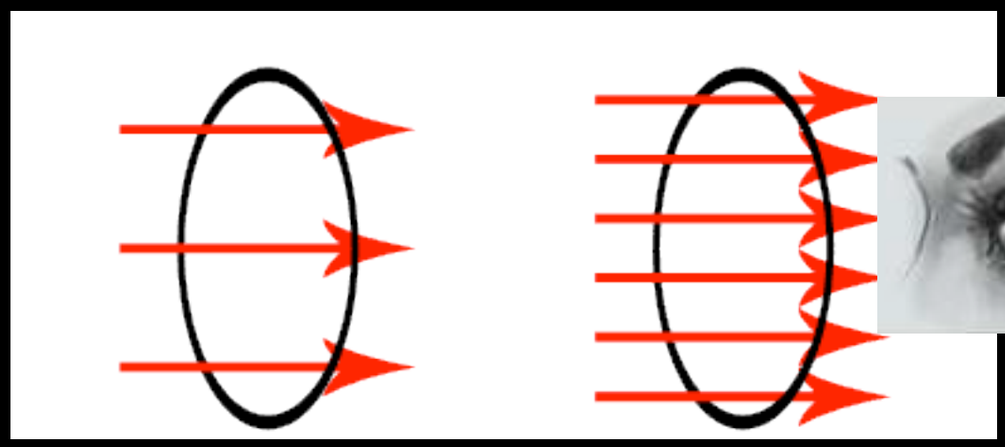
higher temperature



Example: Light gathered through the surface area of your pupil

lower brightness

higher brightness



Astronomy 103:
The Evolving Universe

This kind of
light bucket

Not this
kind of light
bucket

Lecture 5

Light Buckets

Substitute Lecturer: Paul Sell

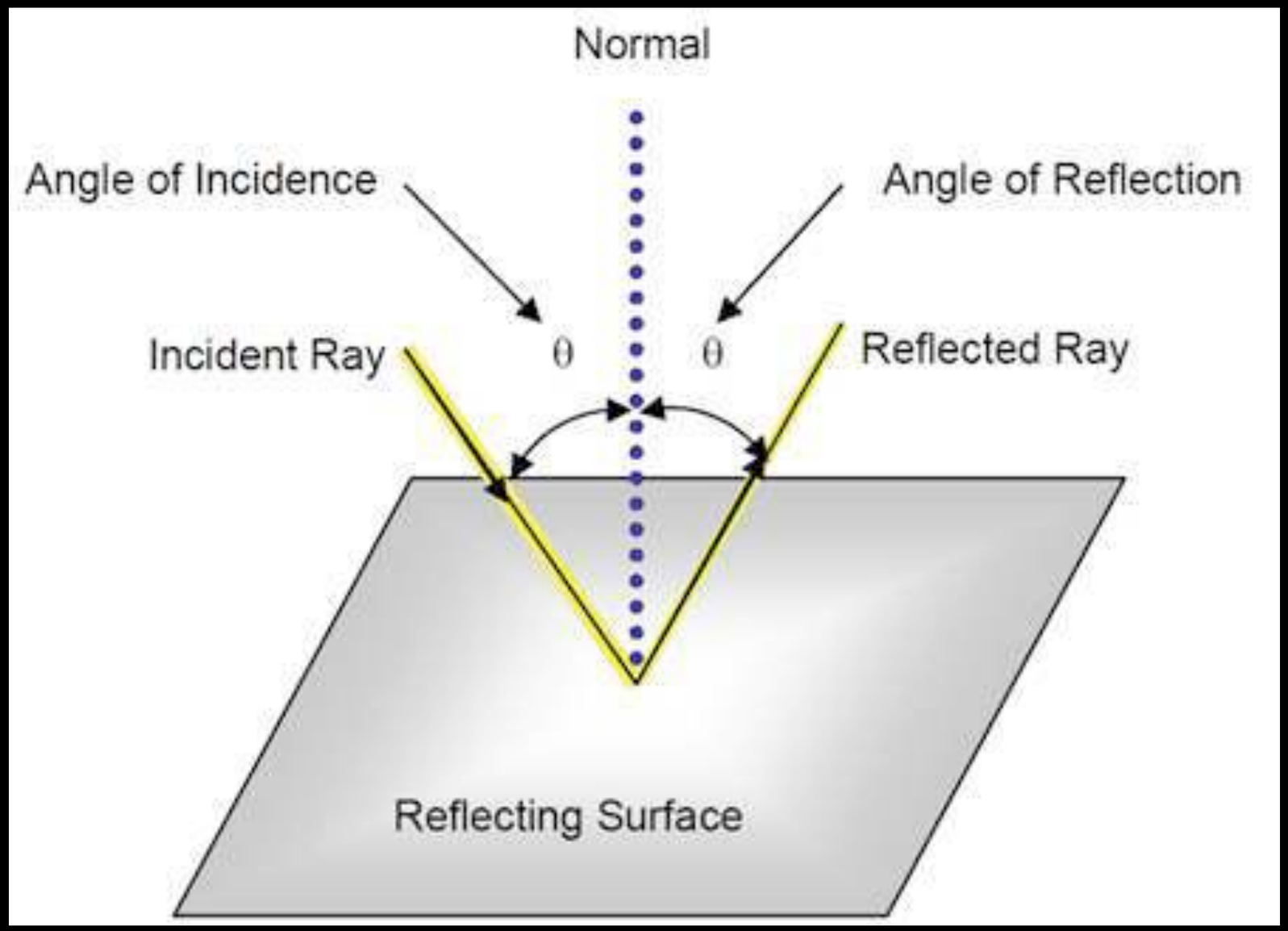
Telescopes Are Light Buckets

Telescopes collect photons like buckets collect rain water.

Two Main Types of Optical Telescopes

Reflectors — Mirrors

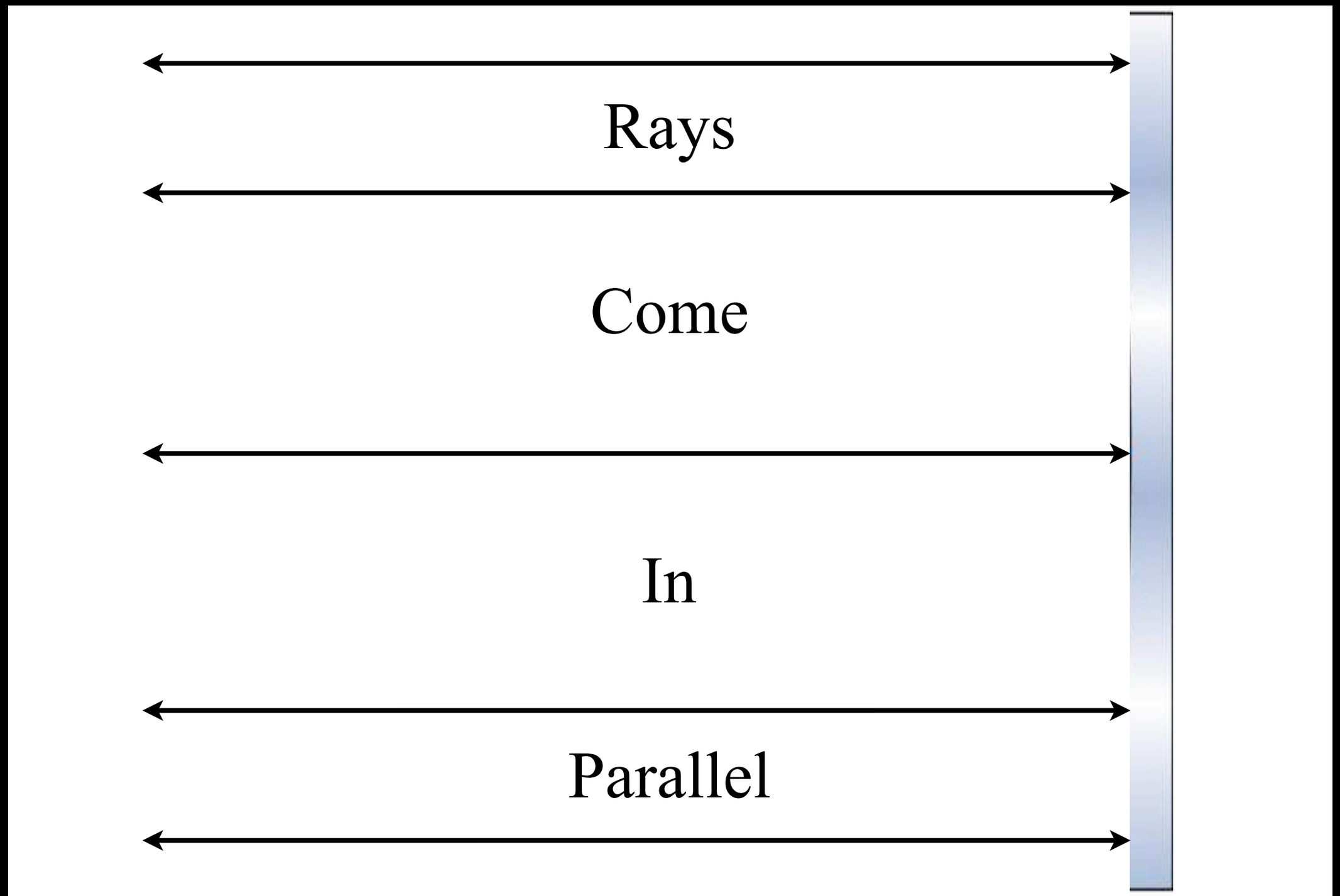
The Law of Reflection



Angle of Incidence = Angle of Reflection

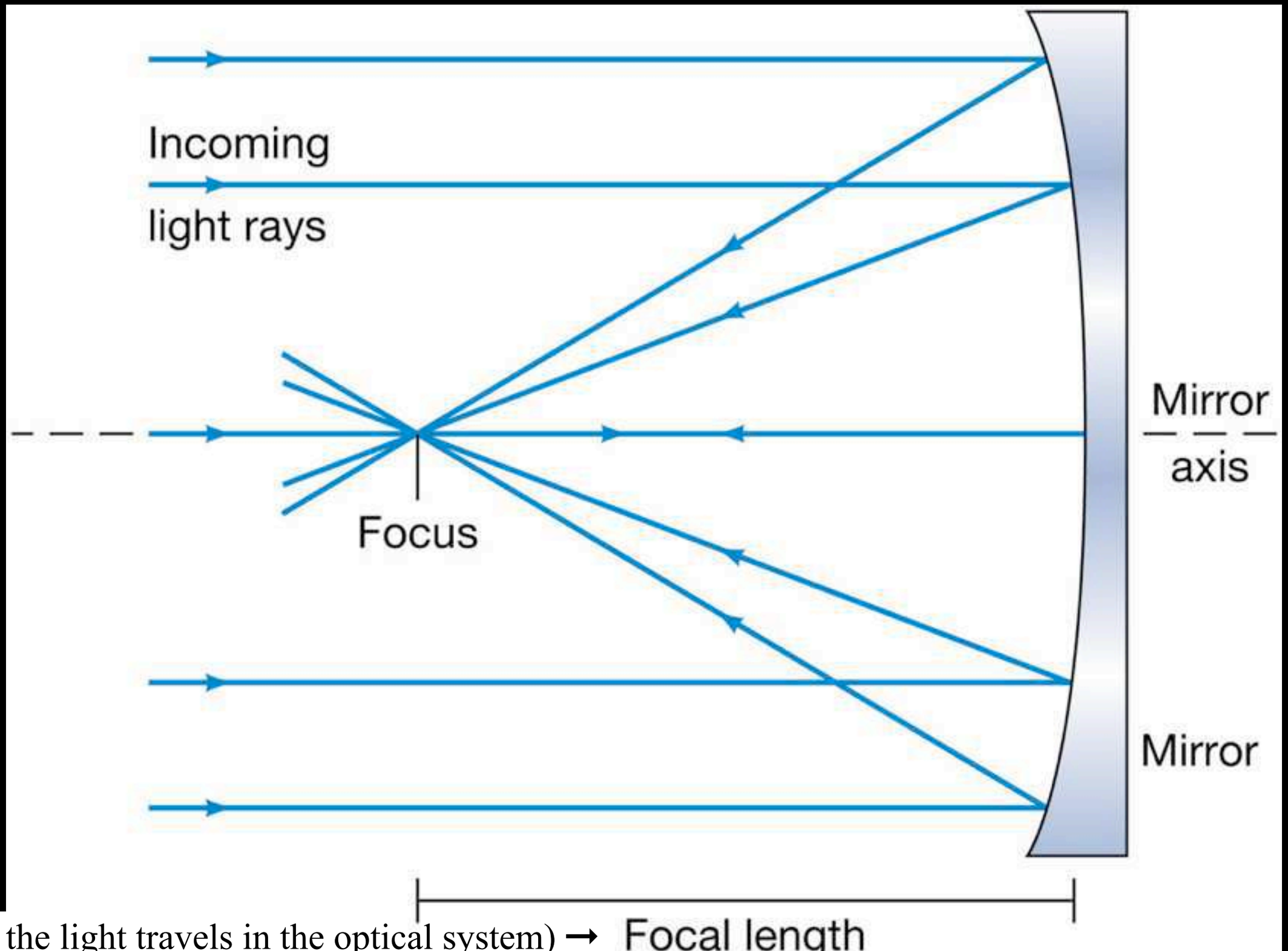
Two Main Types of Optical Telescopes

Reflectors — Mirrors



Two Main Types of Optical Telescopes

Reflectors — Mirrors

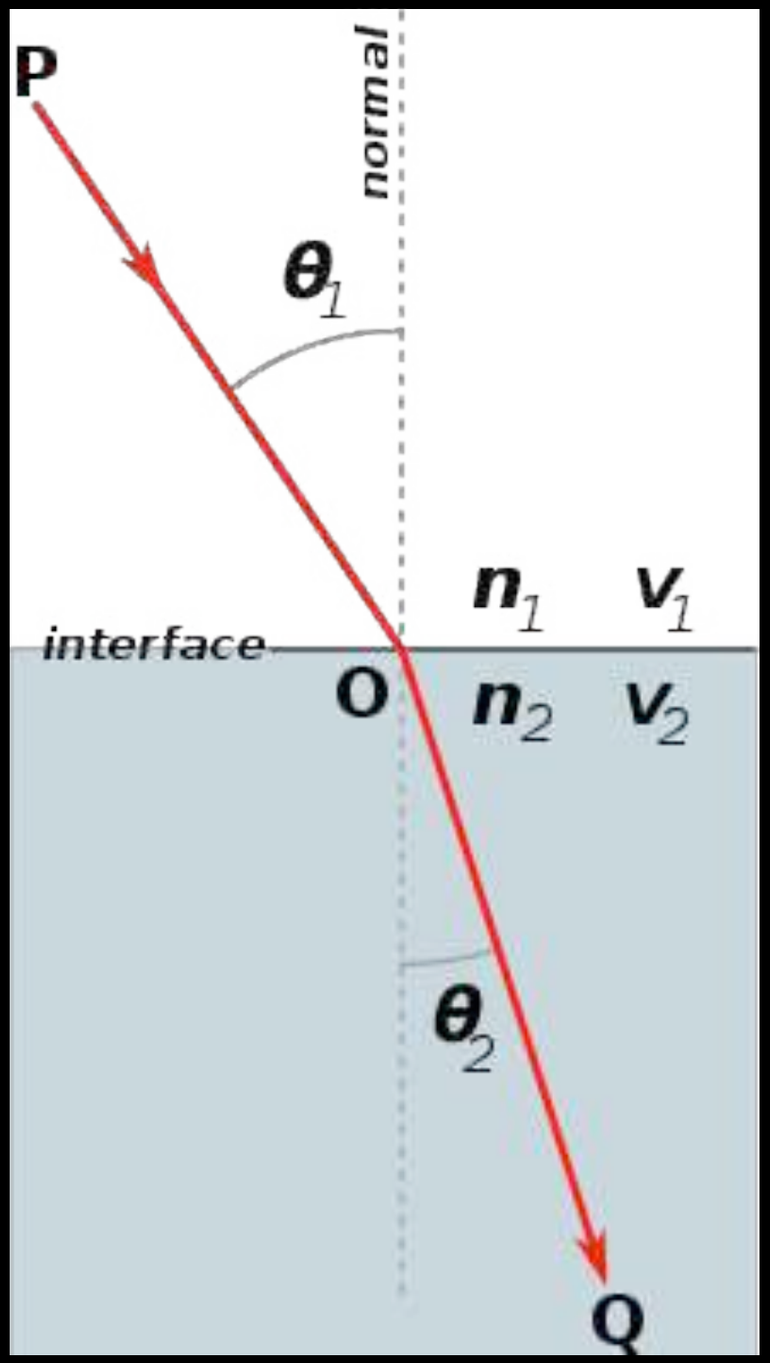


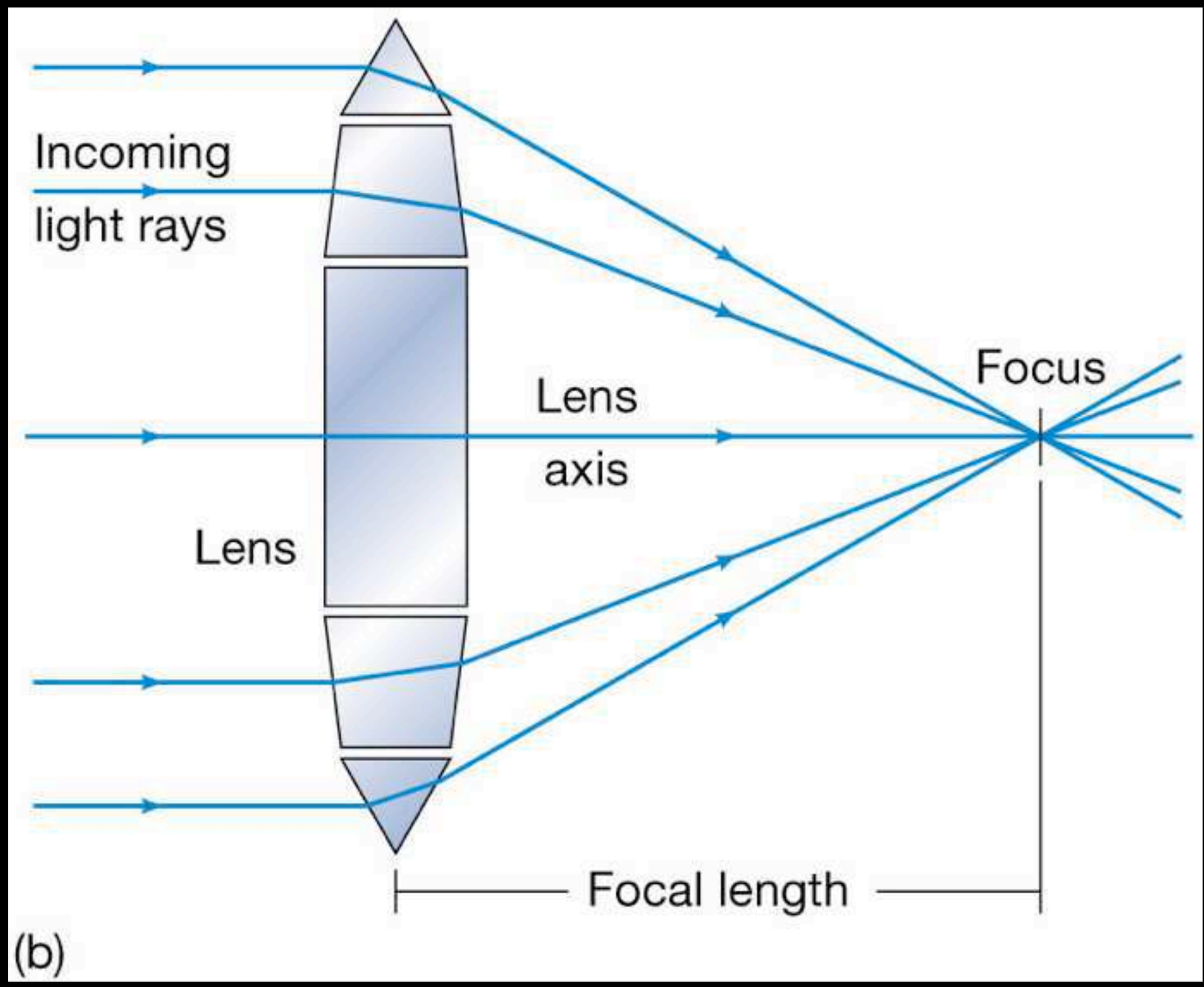
(how far the light travels in the optical system) →

Two Main Types of Optical Telescopes

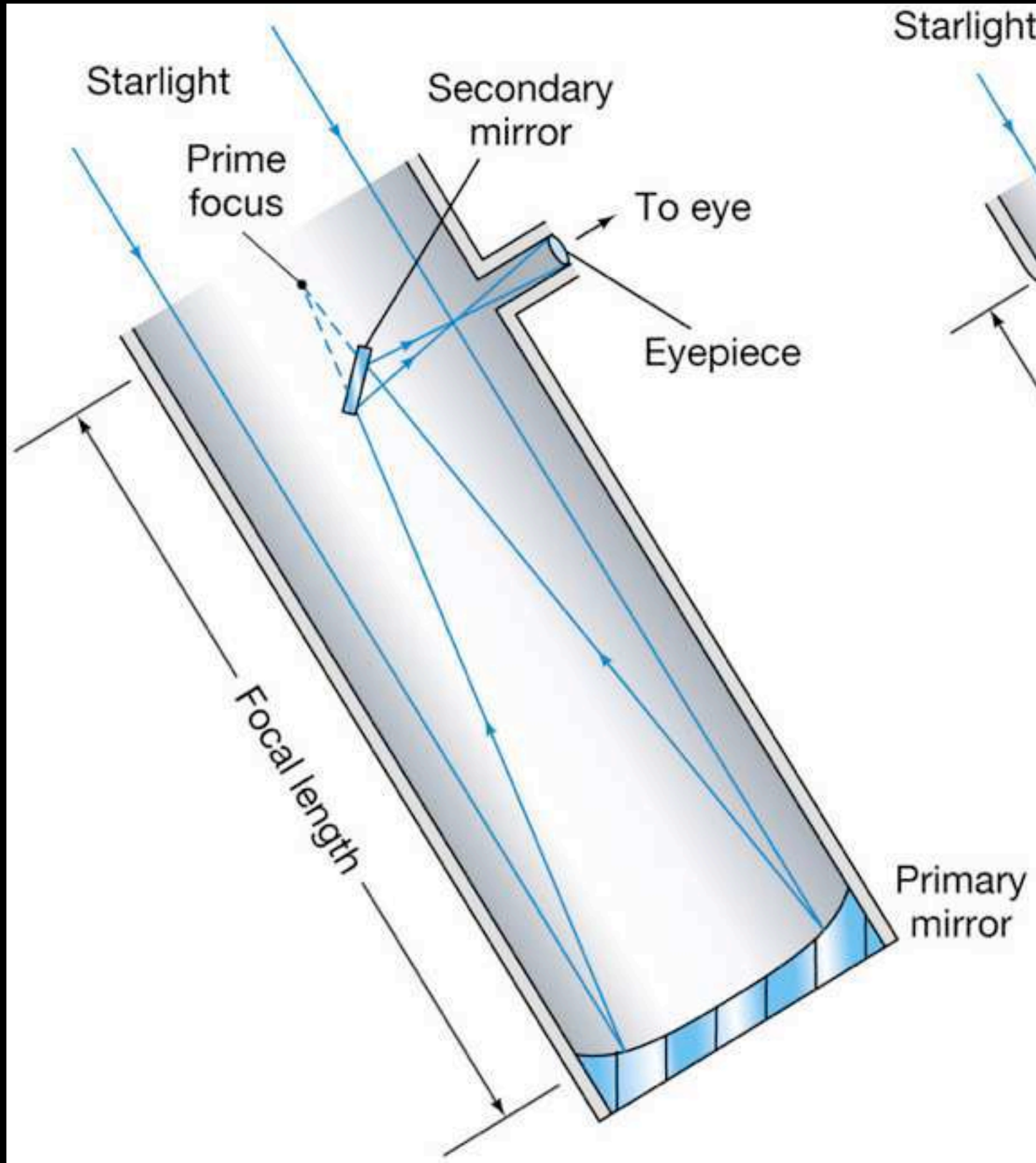
Refractors — Lenses

Law of Refraction (Snell's Law)

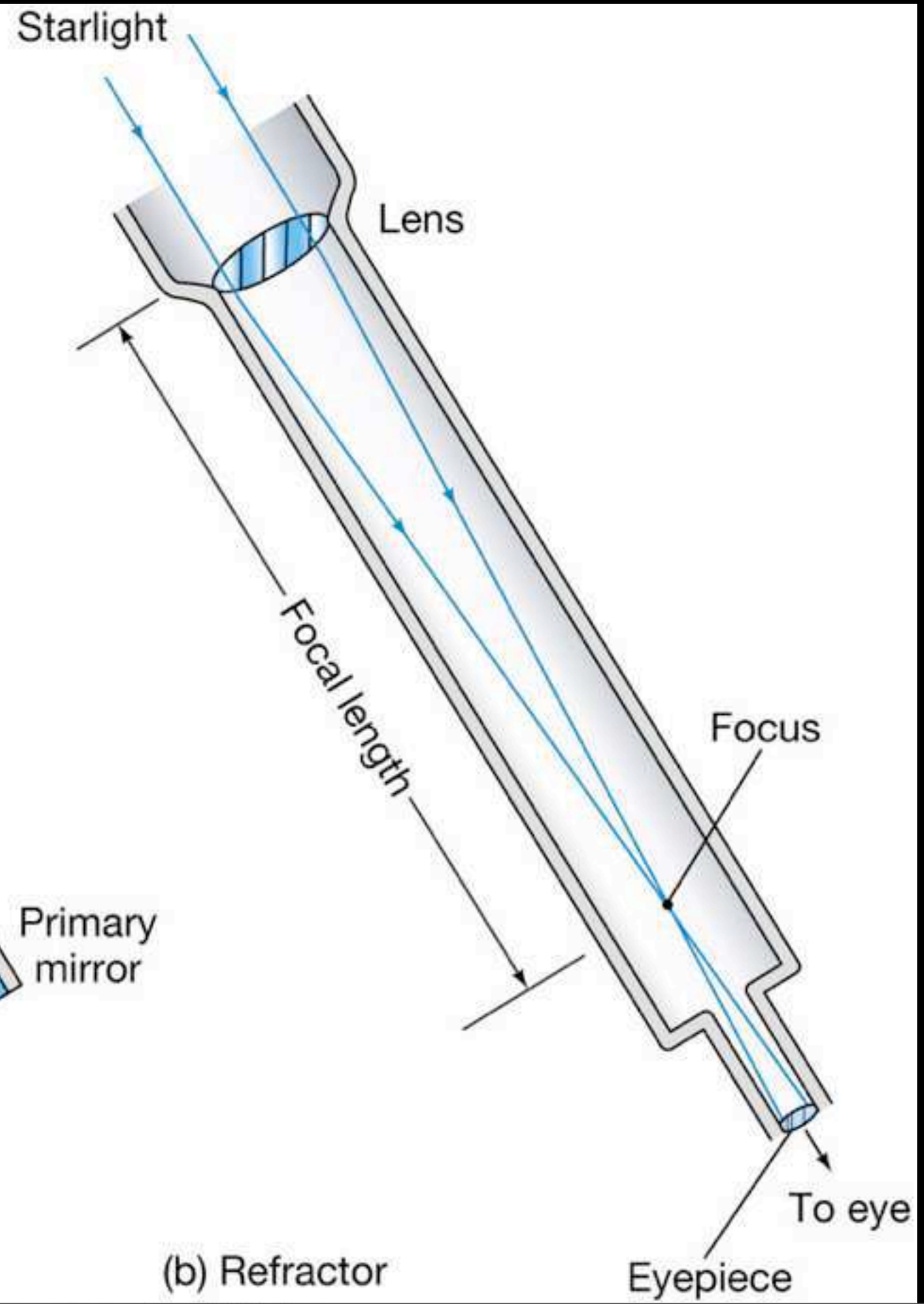




General Optical Telescope Design

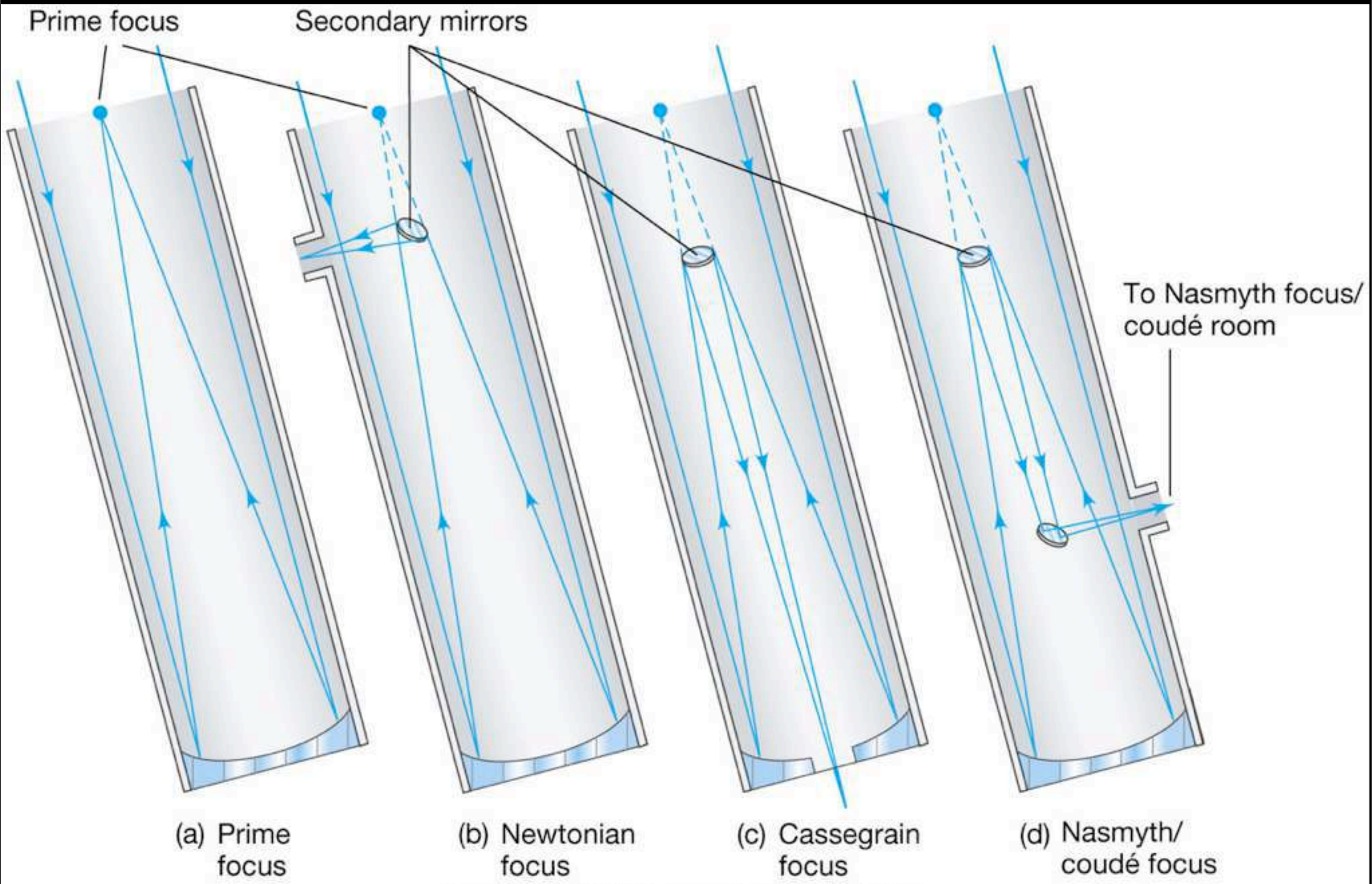


(a) Reflector



(b) Refractor

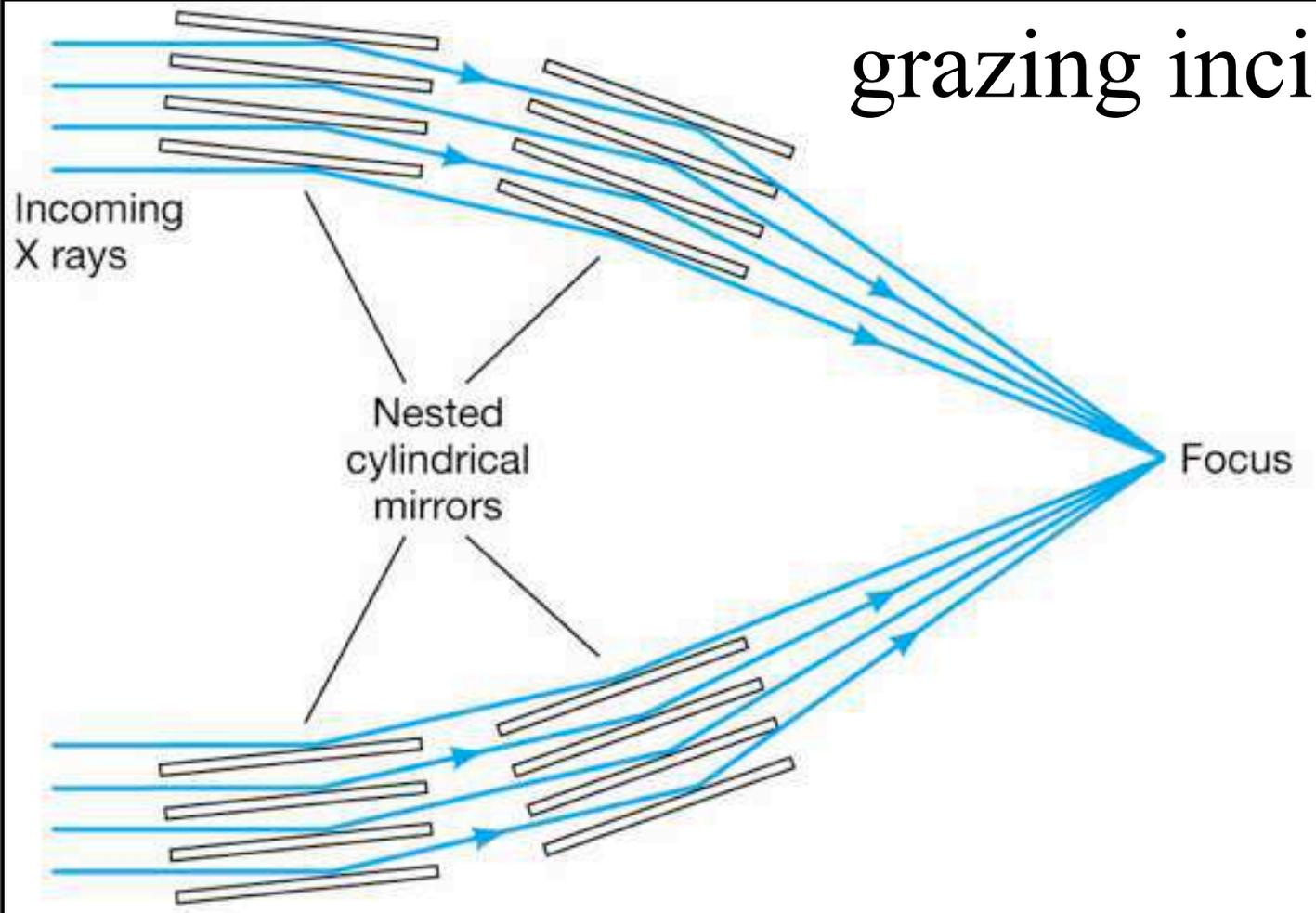
General Optical Telescope Design

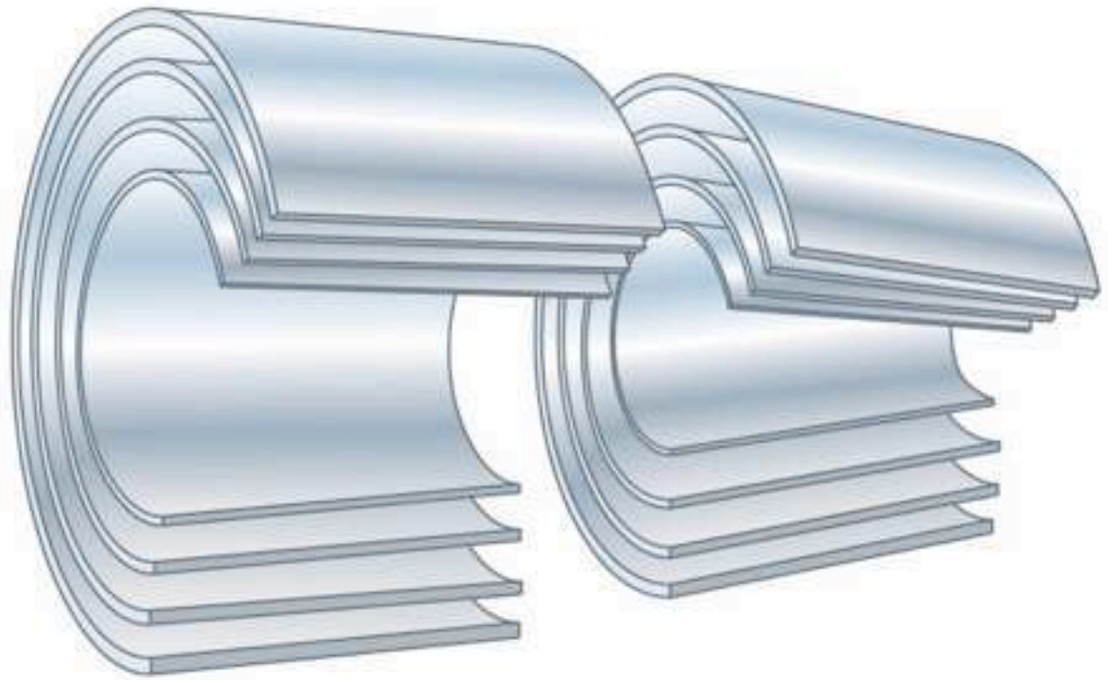


General X-ray Telescope Design

Example: The Chandra X-ray Telescope

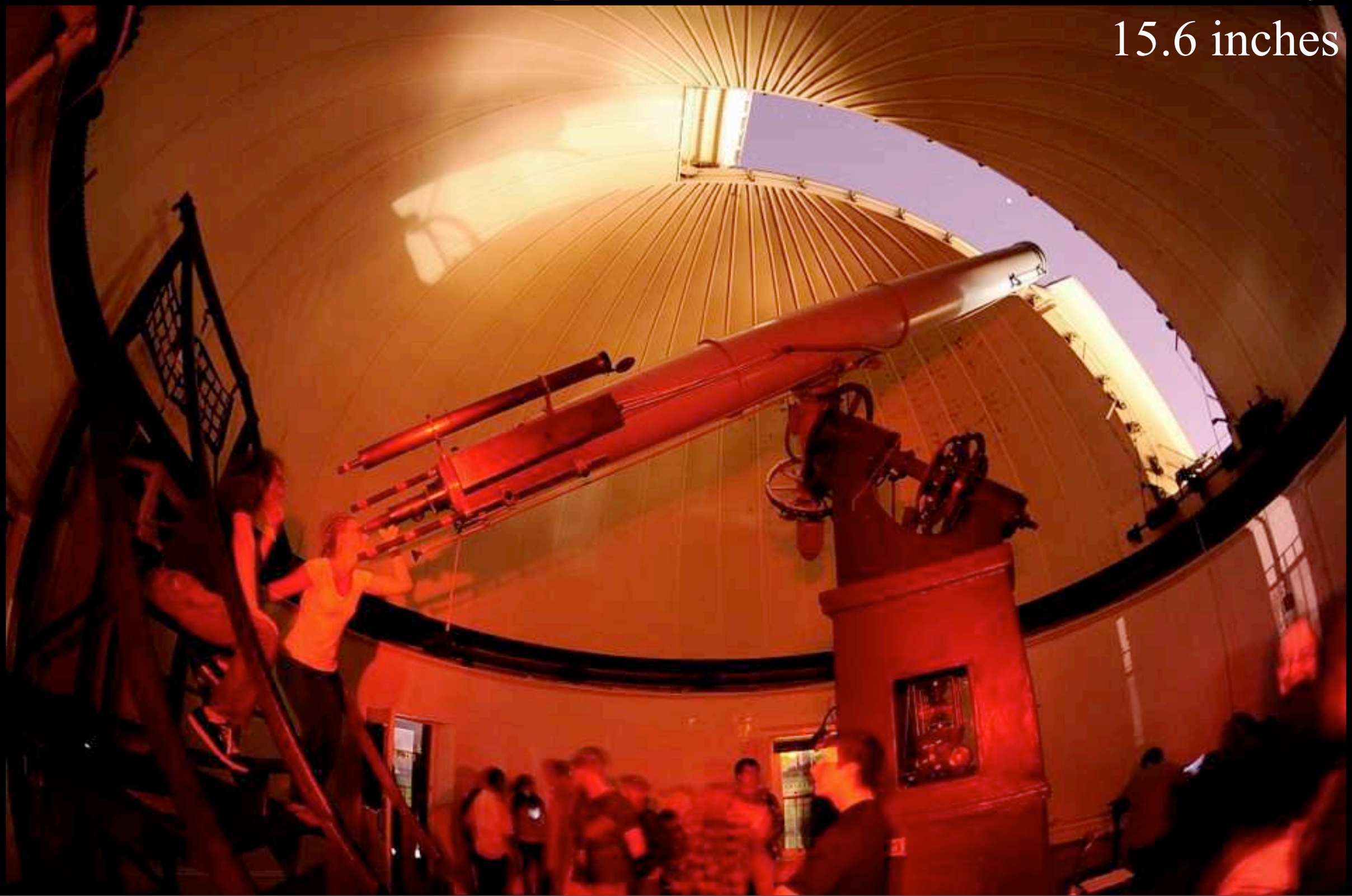
grazing incidence





Two Main Types of Optical Telescopes

Refractors — Examples: Washburn Observatory



Two Main Types of Optical Telescopes

Refractors — Examples: Washburn Observatory

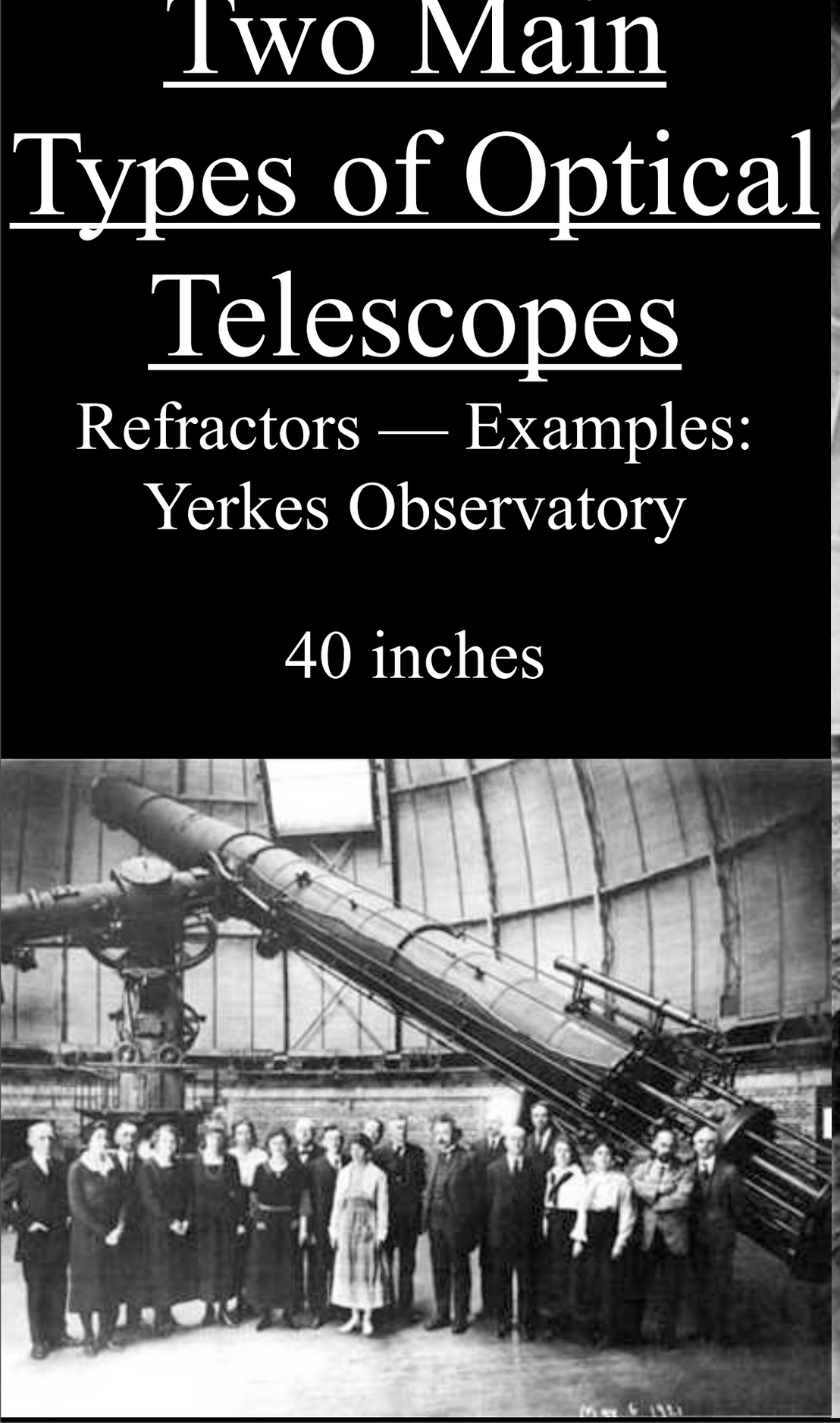
15.6 inches

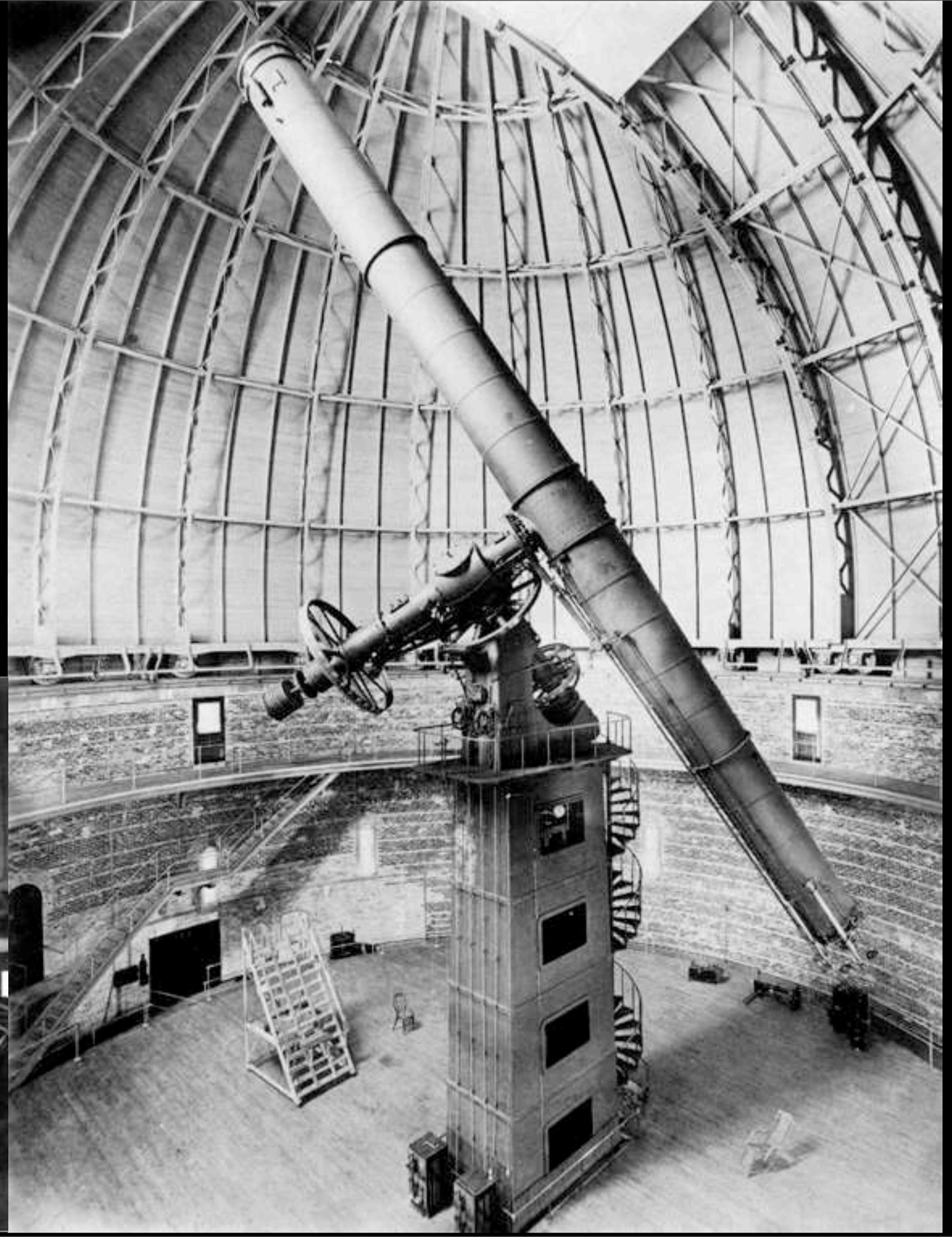
Free Public Observing 1st and 3rd Wednesday nights of each month during the school year (weather permitting): http://www.astro.wisc.edu/the-public/public-observing-at-washburn/

Two Main Types of Optical Telescopes

Refractors — Examples:
Yerkes Observatory

40 inches





Two Main Types of Optical Telescopes

Reflectors — Examples

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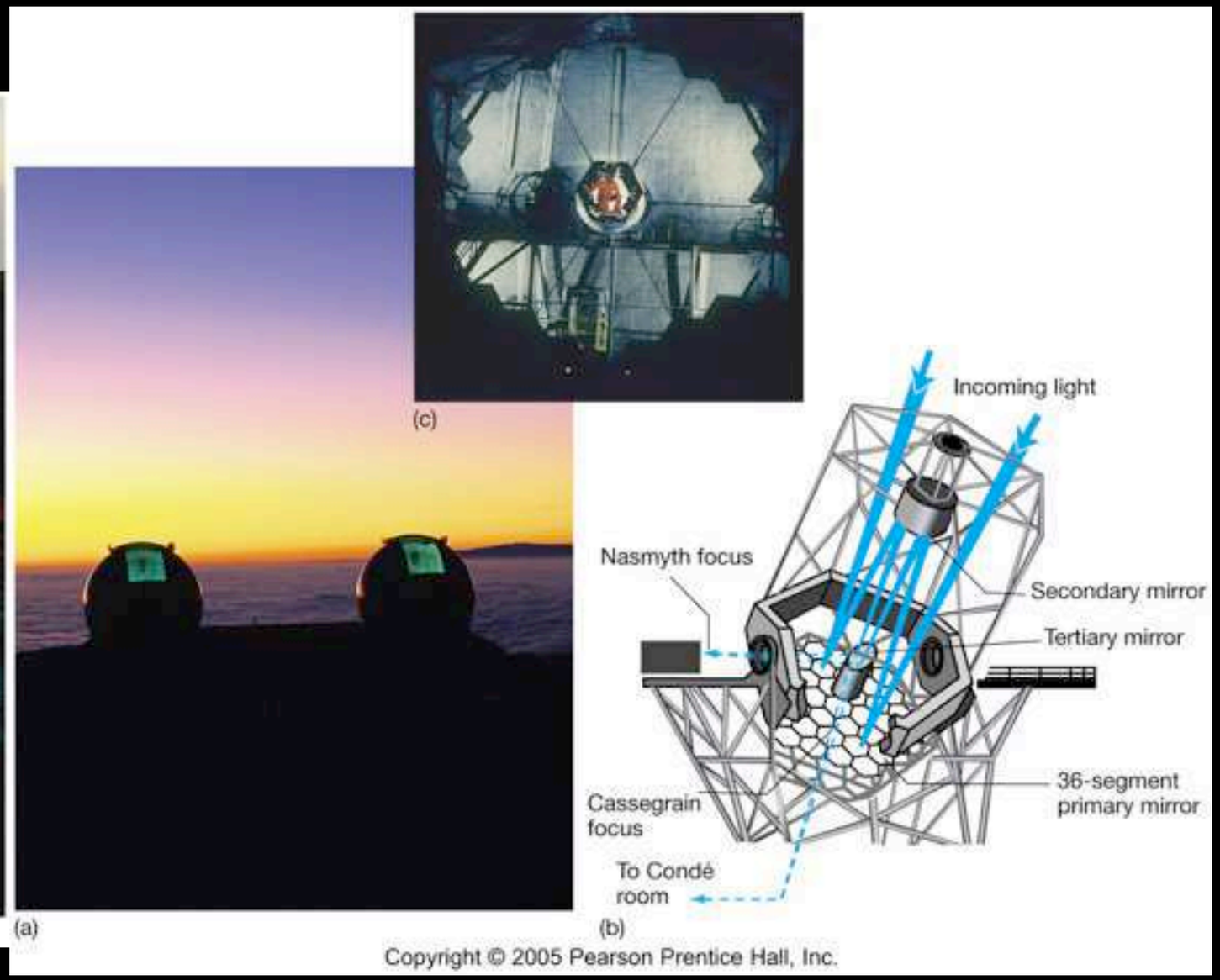
Very Large Telescopes (VLT)
8 meters each



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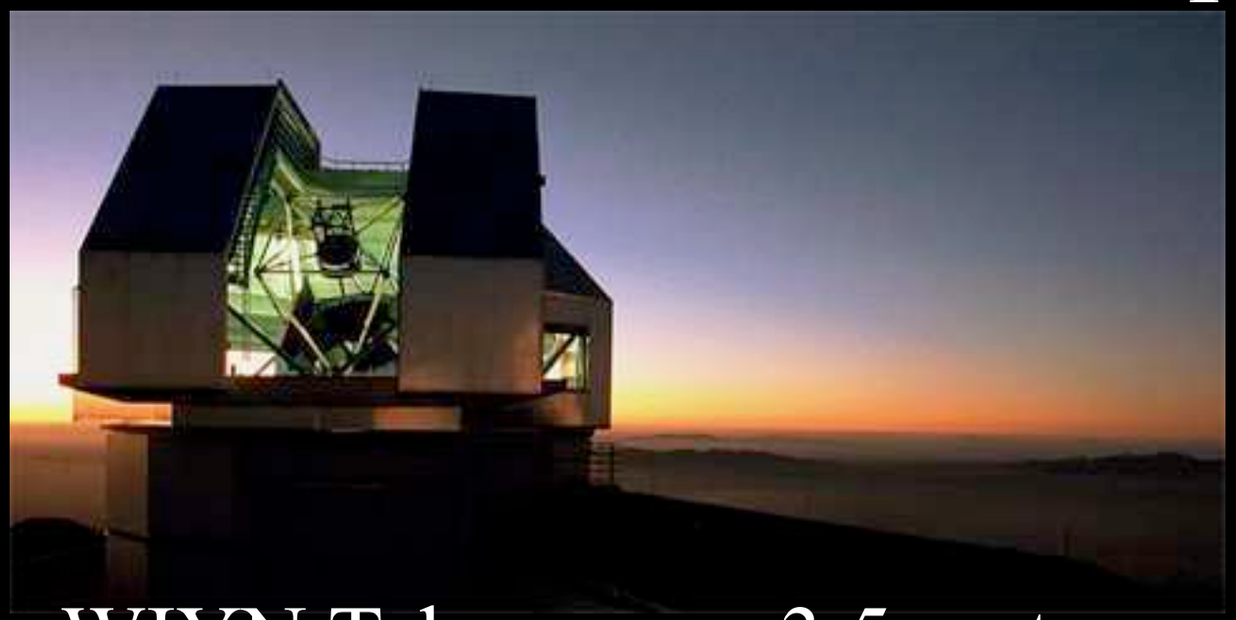
Keck Telescopes
10 meters each

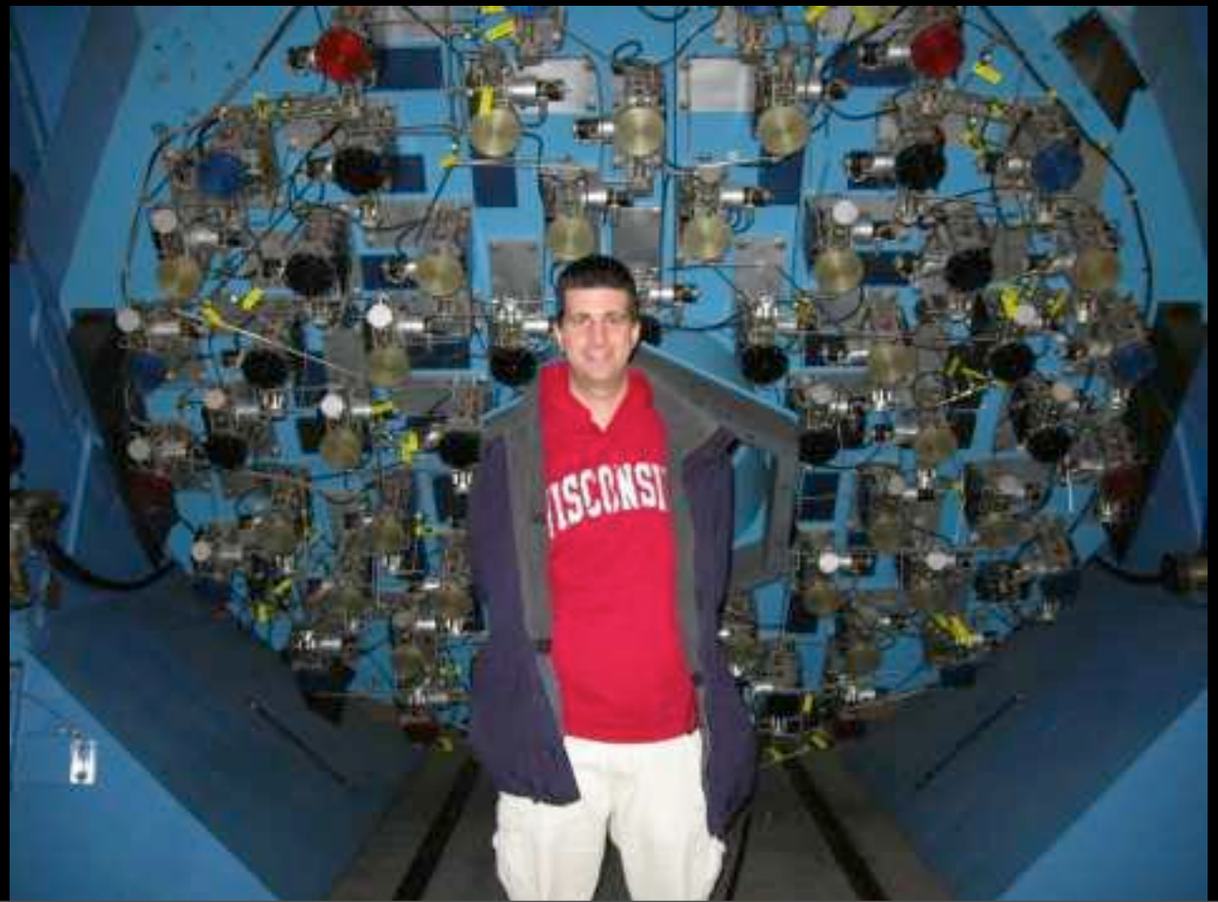
Two Main Types of Optical Telescopes

Reflectors — Examples with UW-Madison



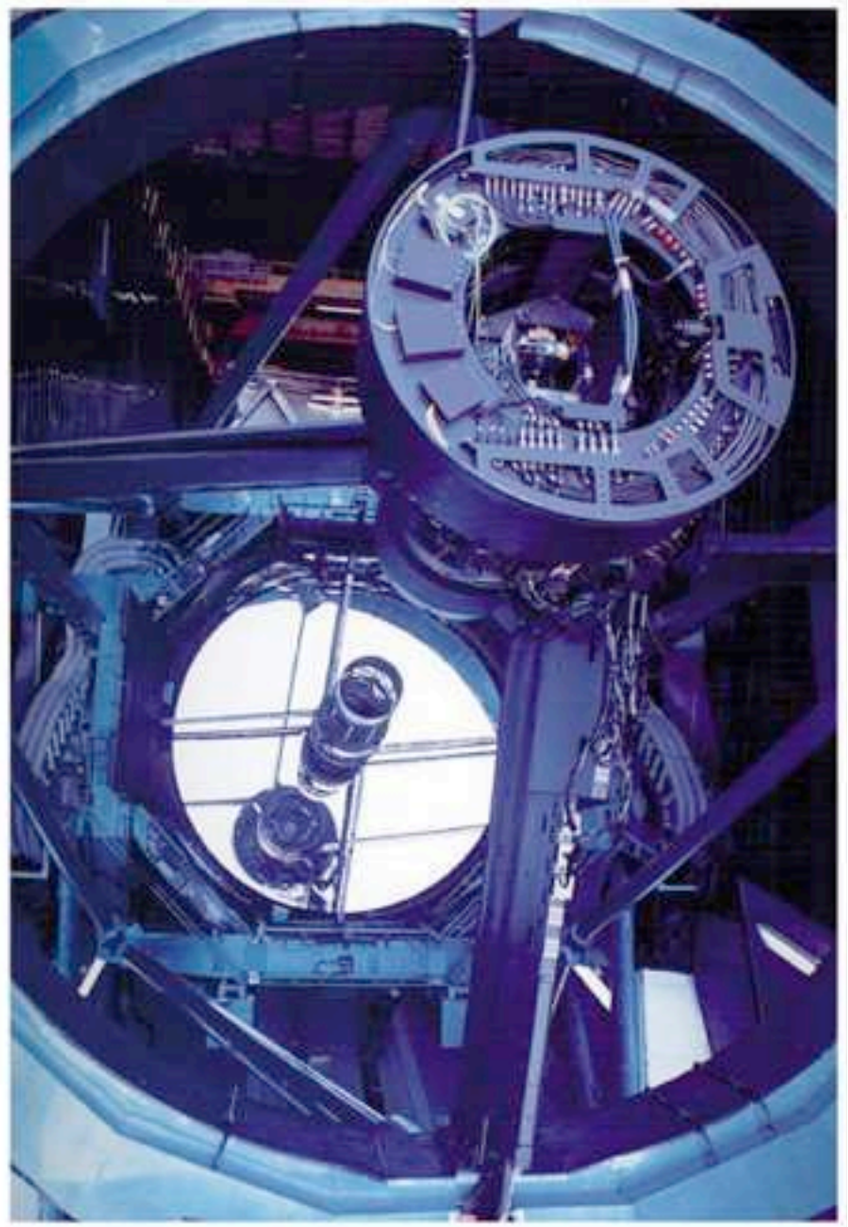
WIYN Telescope 3.5 meters

South African Large Telescope (SALT)
11 meters



Telescopes on Mauna Kea, Hawaii

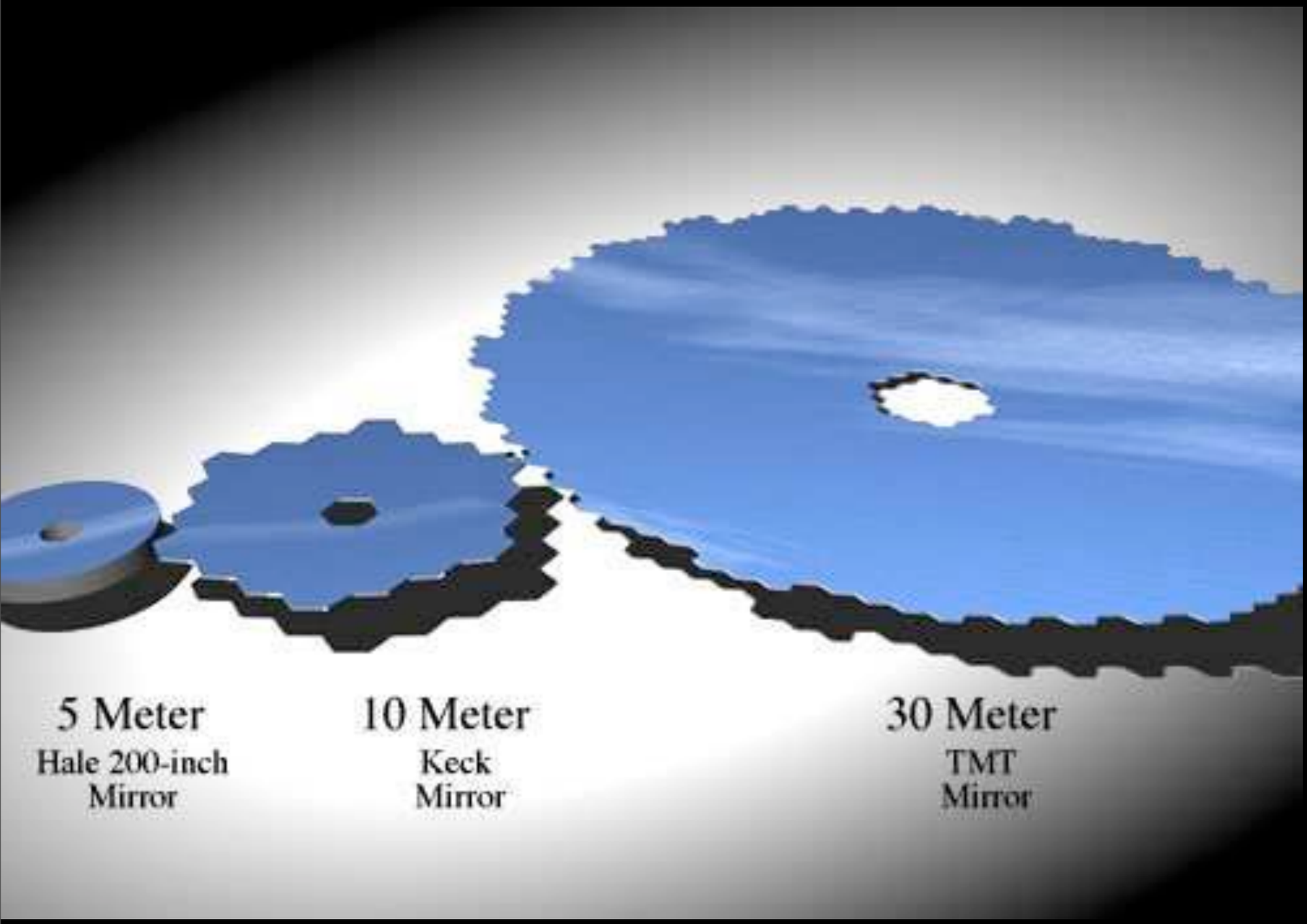
(a)



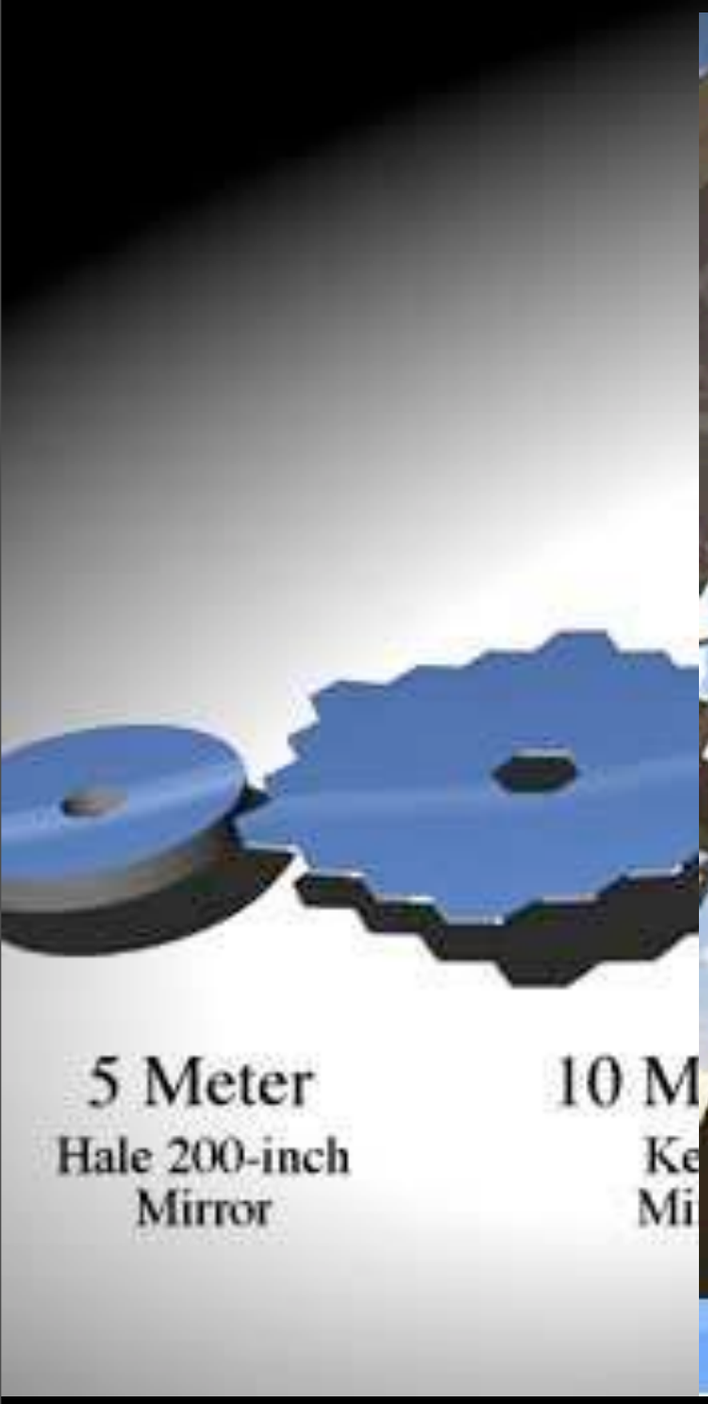
(b)

Why are all of these telescopes on mountains?

Future LargeTelescopes



Future LargeTelescopes

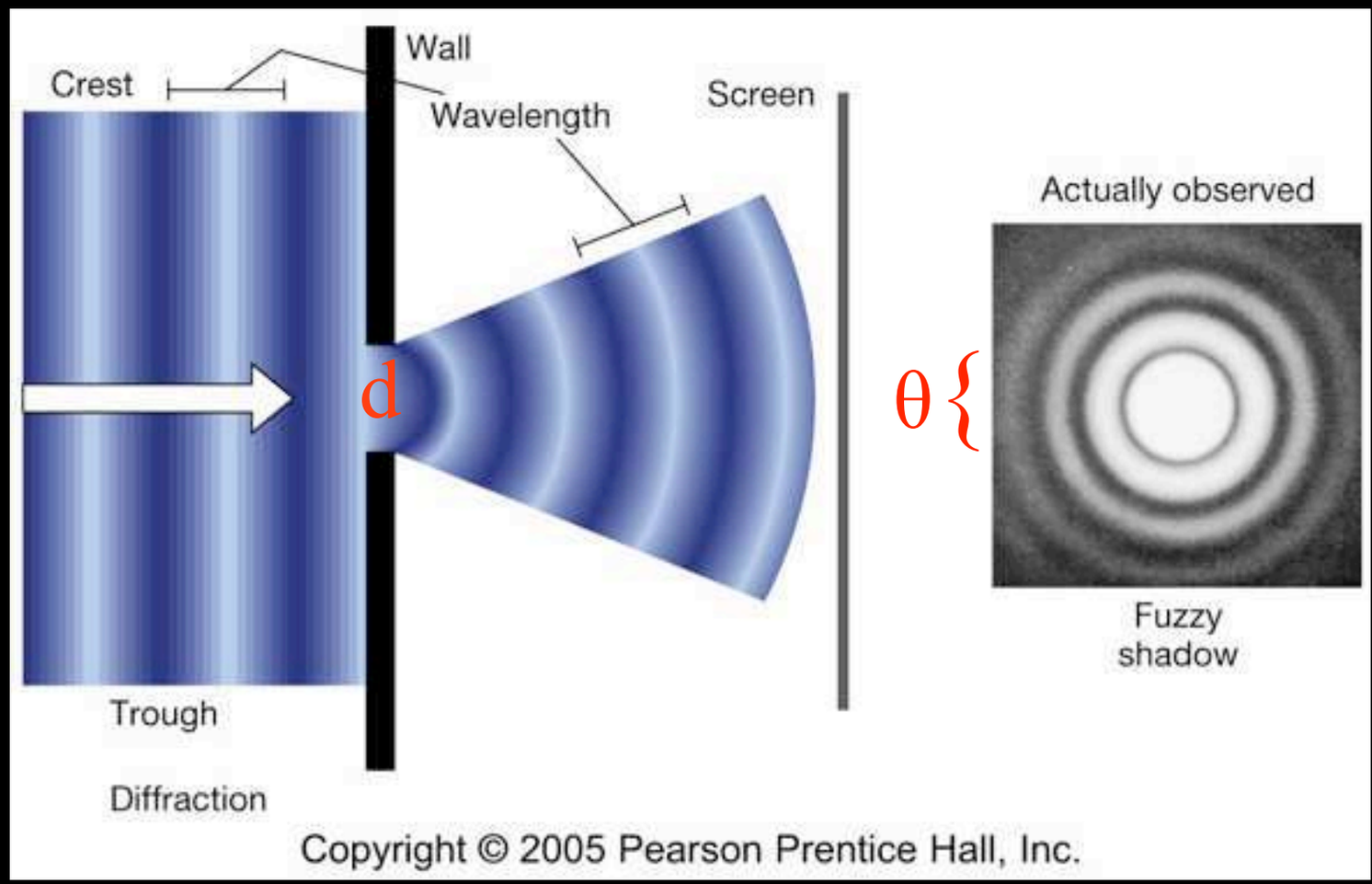


Why are all of the largest telescopes reflectors?

Why Build Large Telescopes?

Collecting Area

Diffraction Limit



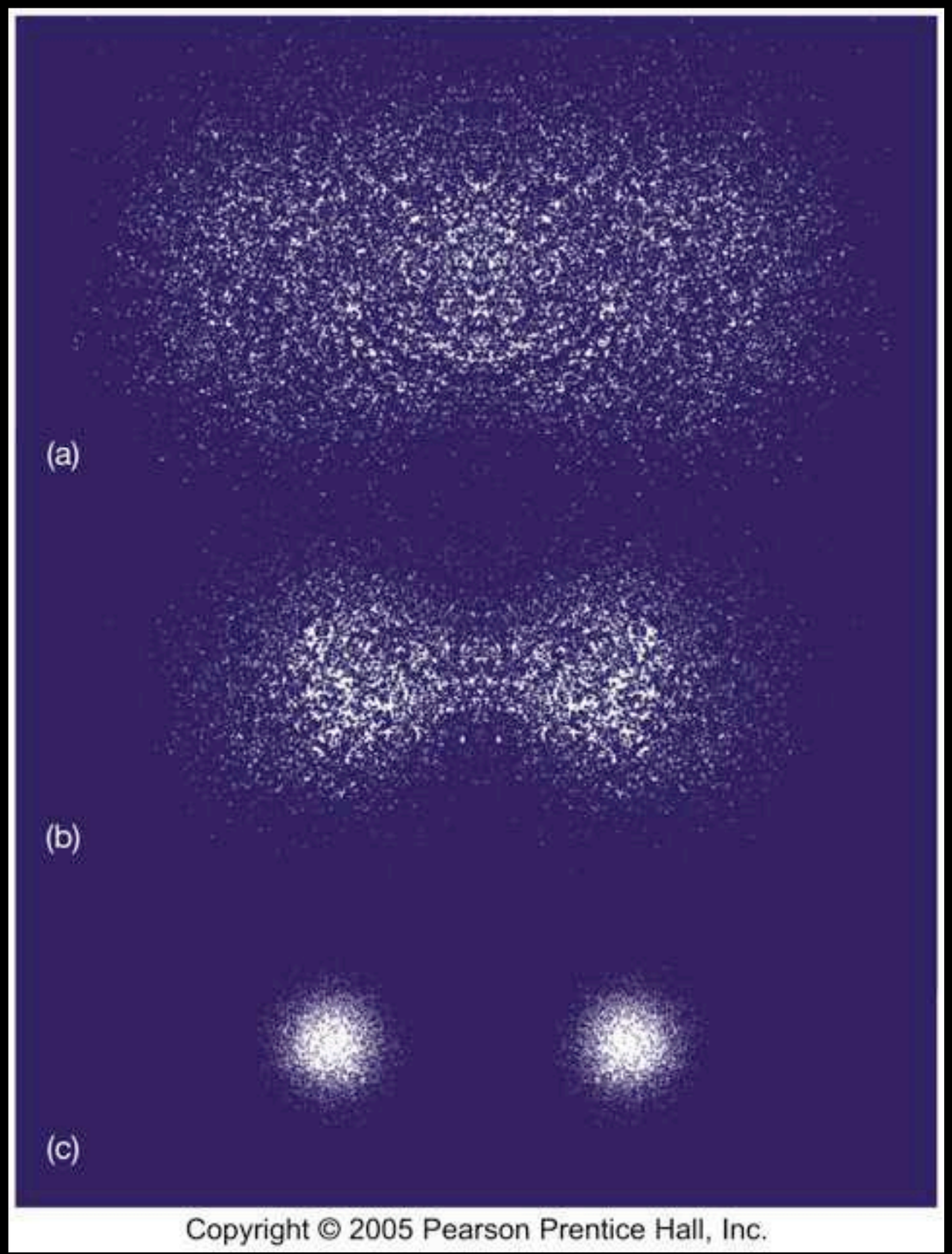
Why? The Uncertainty Principle Again

$$\text{resolution limit} = \theta = 1.22\,\lambda / d$$

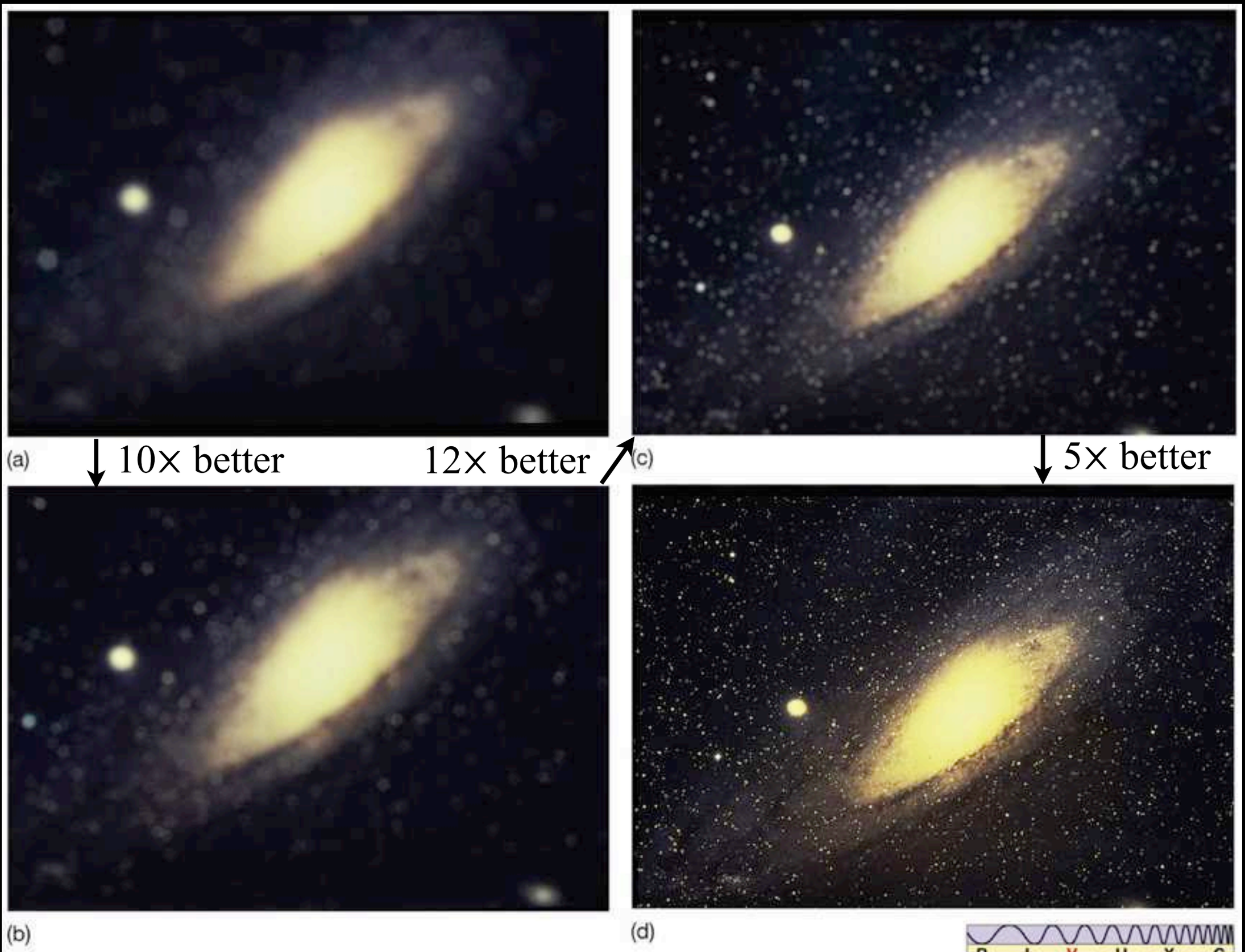
minimum size of the object you can resolve

diameter of collector (telescope)

Varying Resolution Images

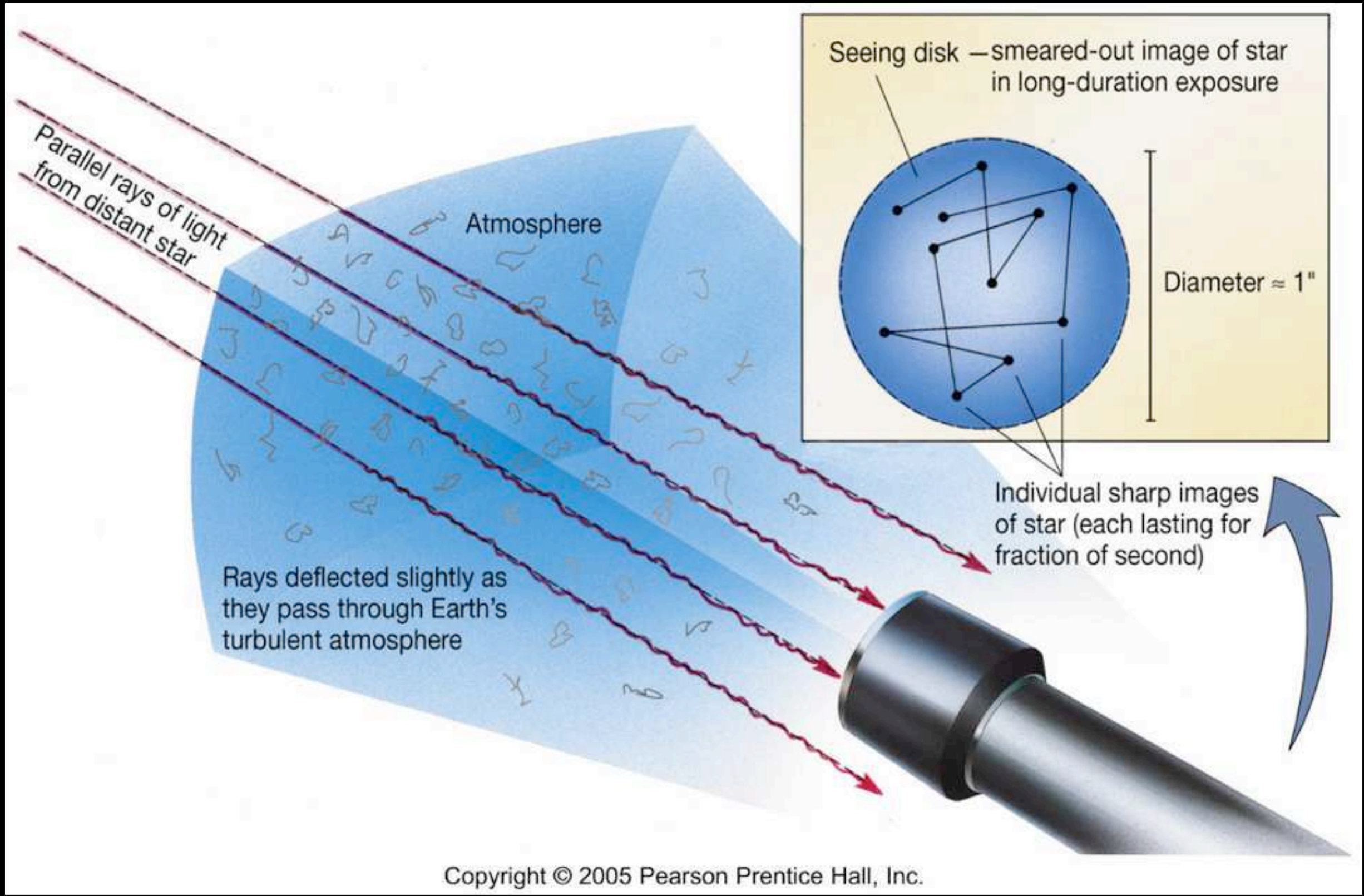


Varying Resolution Images



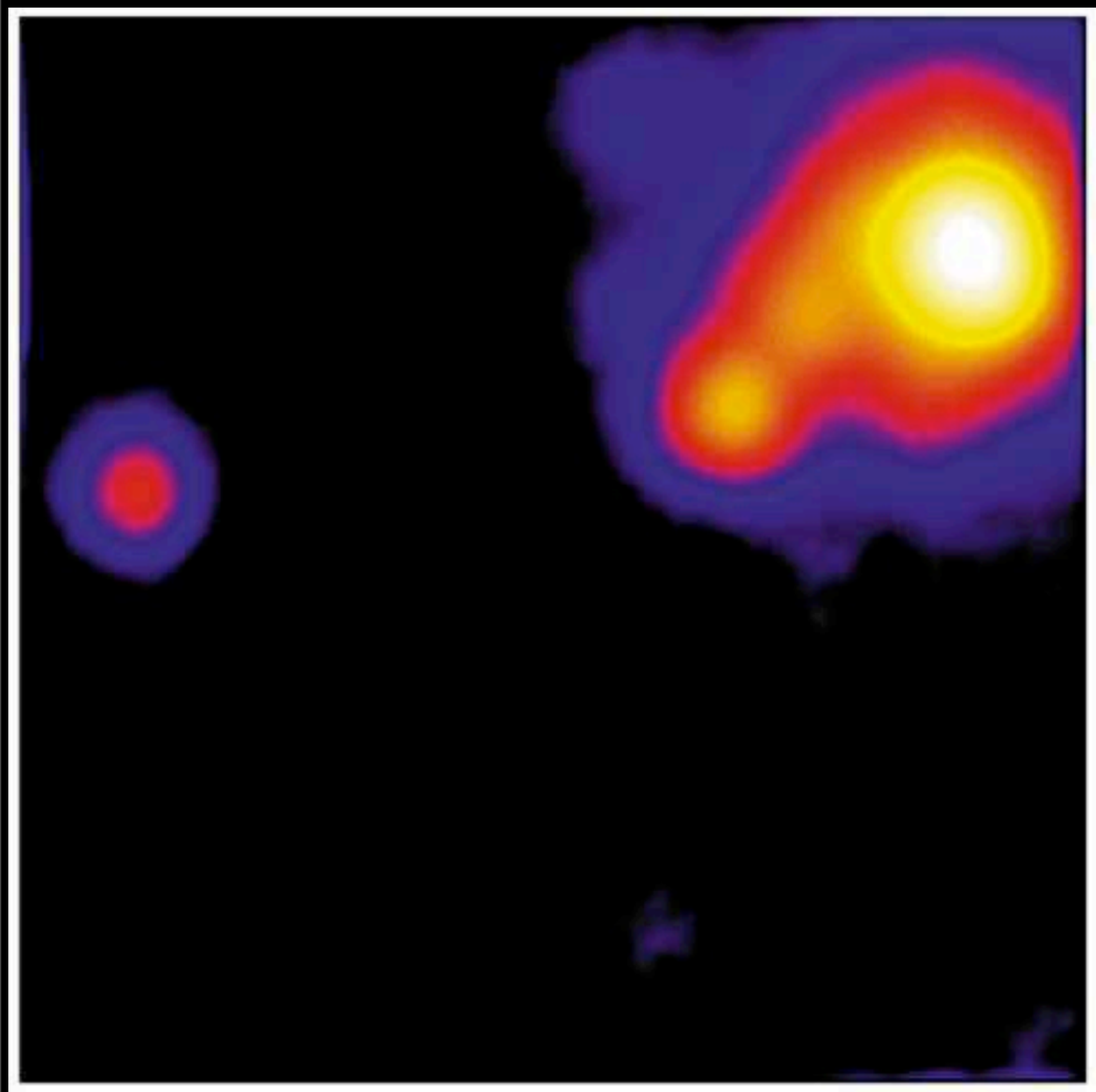
The Atmosphere: A Love/Hate Relationship

Seeing

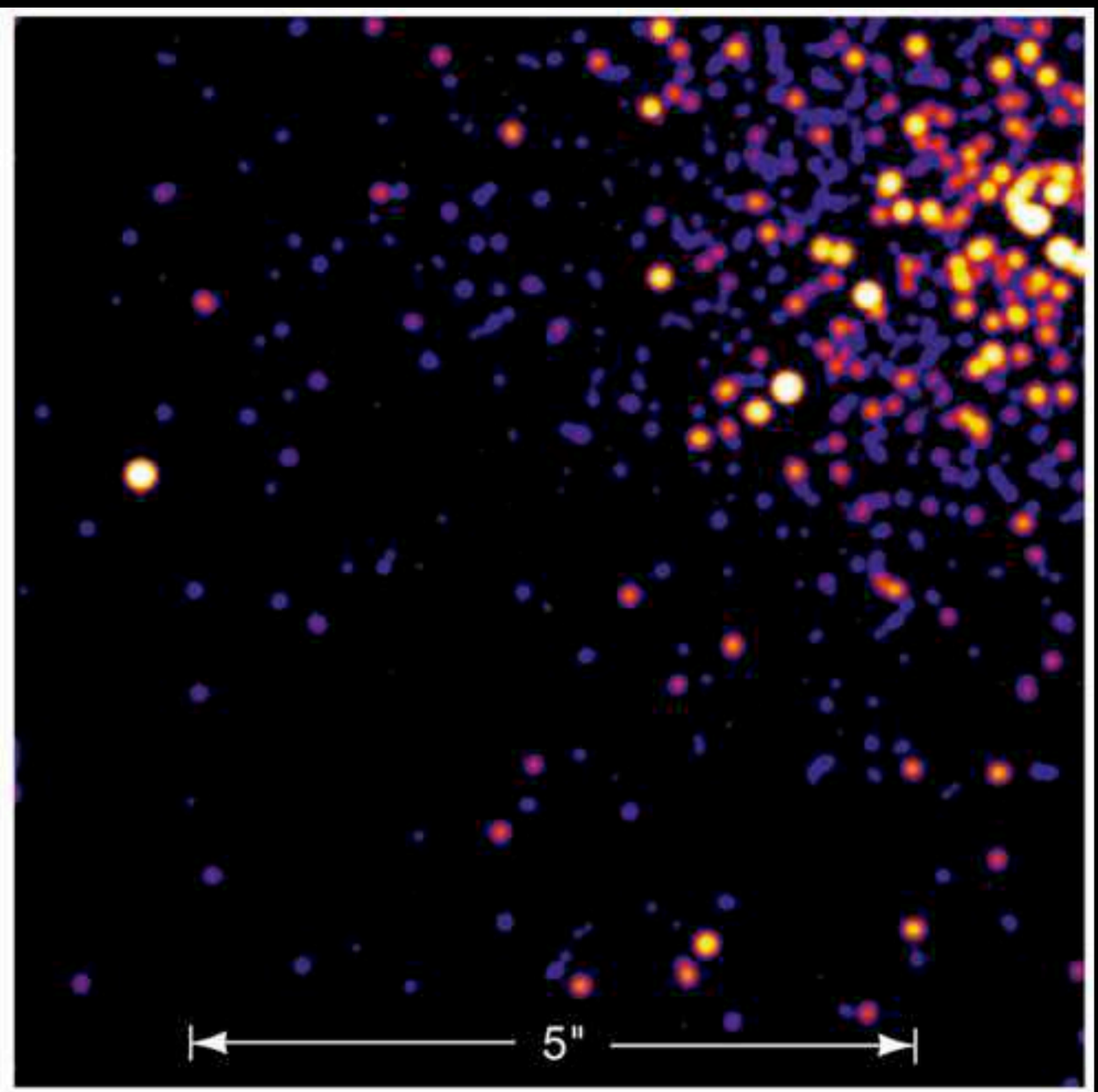


Compensating for Seeing

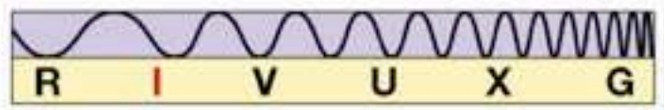
Compensating for Seeing



(a)



(b)



Getting Around Seeing

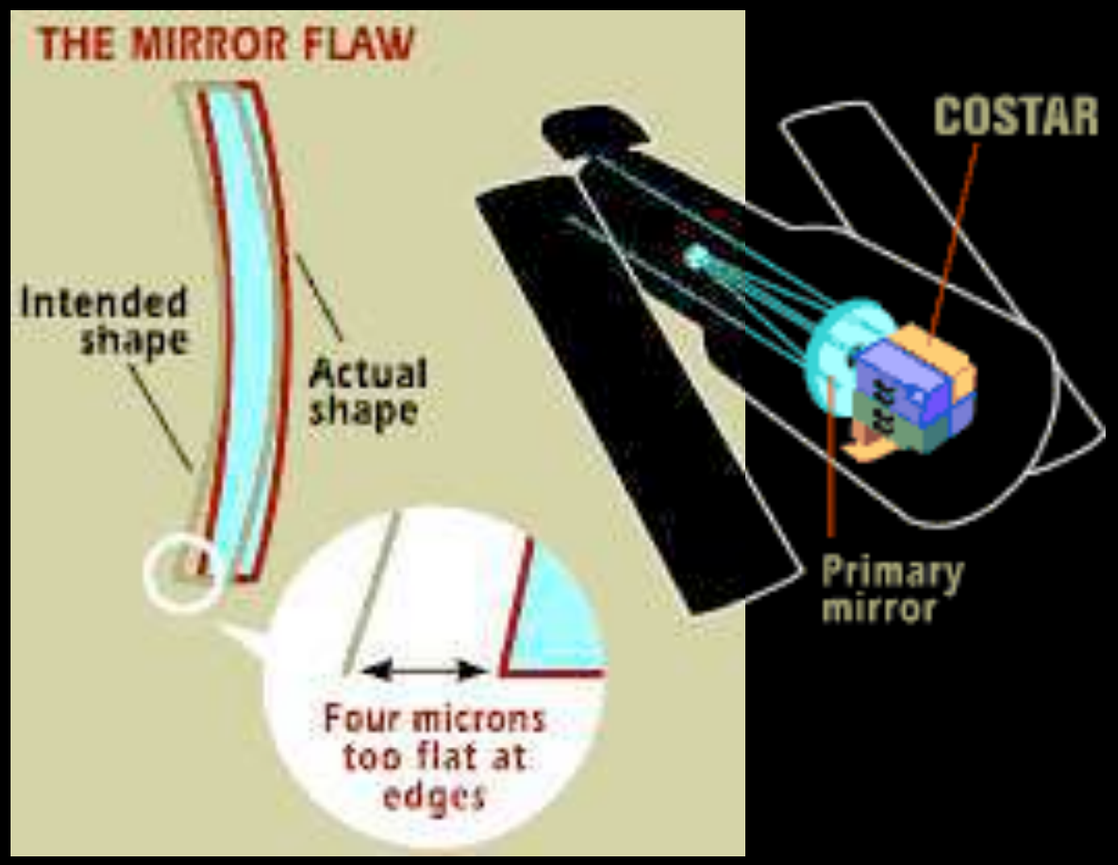
Go Into Space

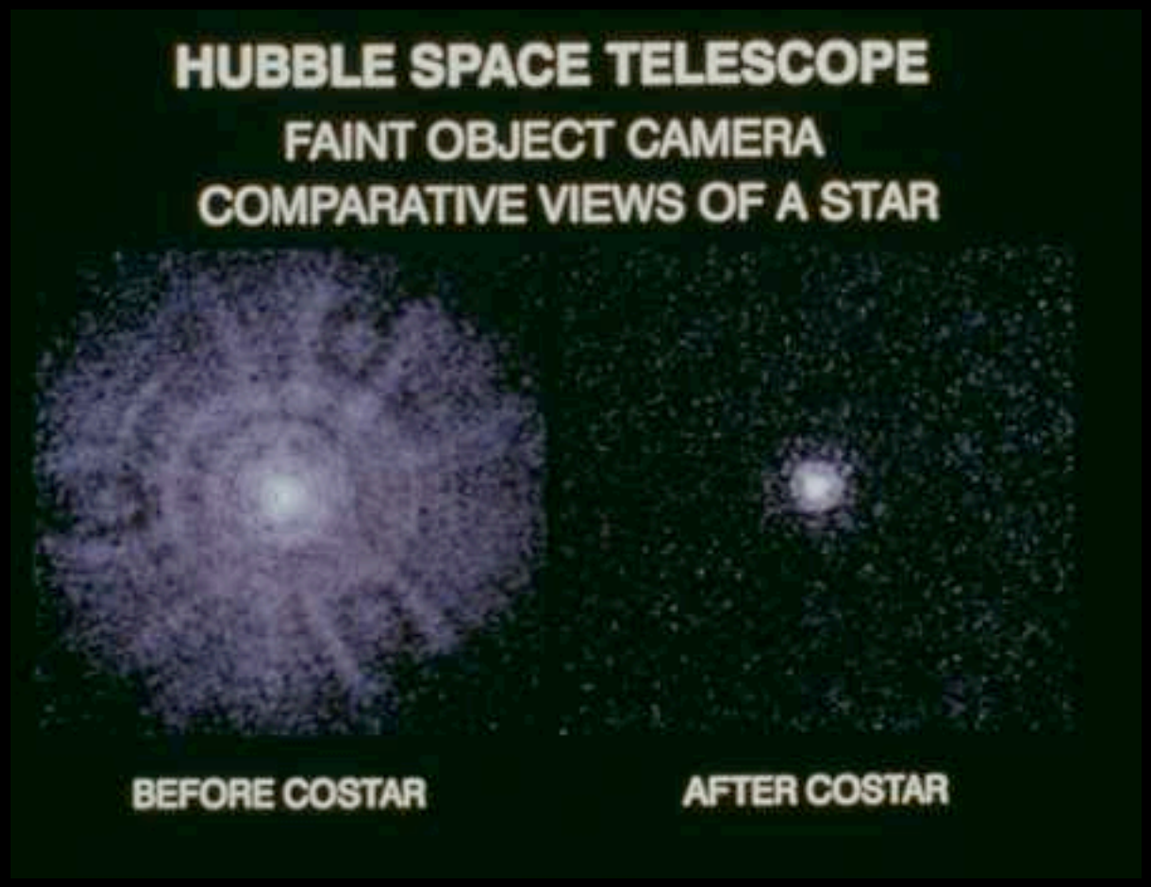
(NASA)

The Hubble Space Telescope

The Hubble Space Telescope

Oops!

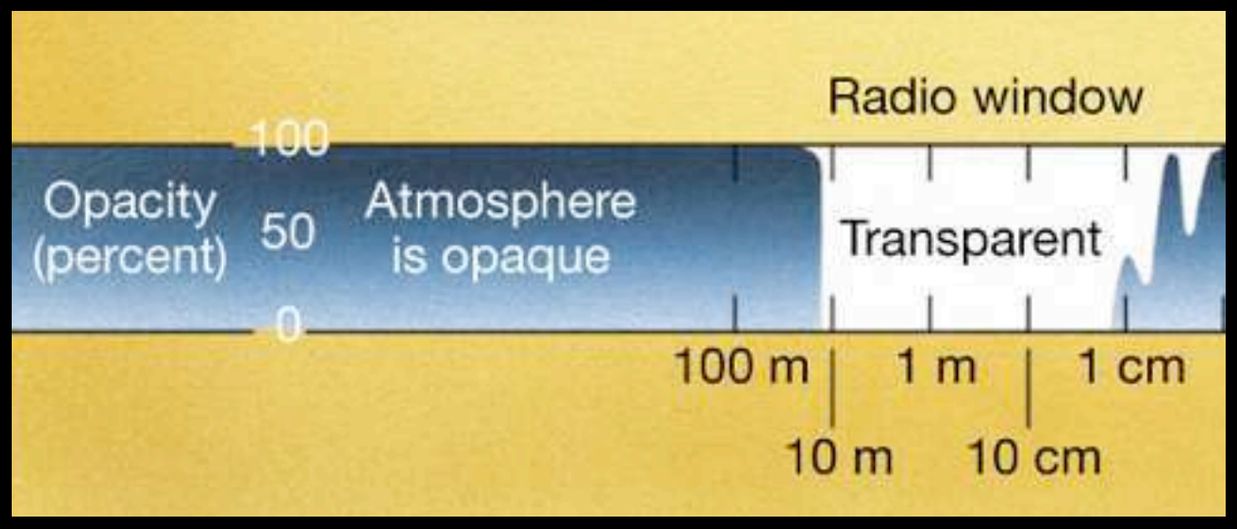


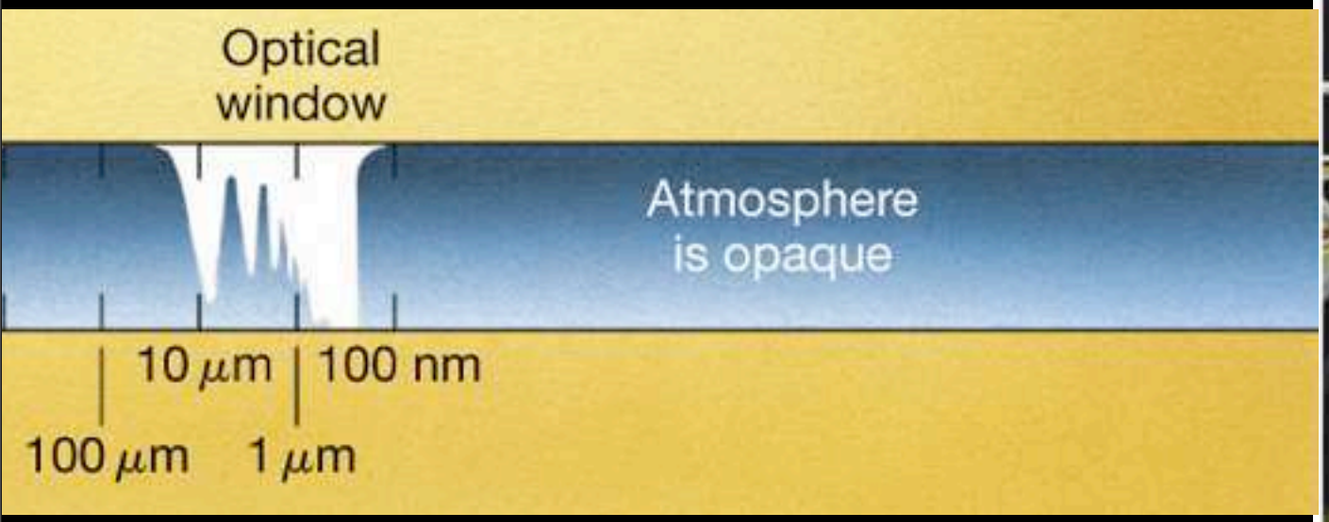


About 10x smaller than the width of a human hair!

Another Space Telescope

Chandra X-ray Telescope

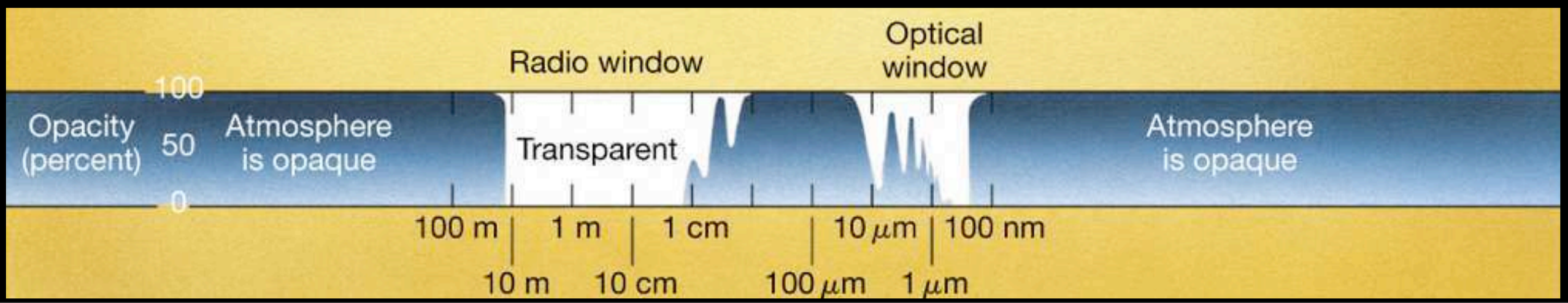




When Do We Have to Go to Space?

At what wavelengths can you observe from the ground?

- gamma ray (not directly, but can be observed through air showers)
- ~~X-ray~~
- UV (some near the optical; ≳ 320 nm)
- Optical (all)
- IR (some near the optical, ≲ 1 micron)
- radio (only 1 cm to 10 m)



Multiple Choice Question

The primary mirror on the Hubble Space Telescope (HST) has a diameter of about 2 meters, which still provides better resolution than just about any other telescope (because it is in space). NASA is constructing the next generation space telescope, the James Webb Space Telescope (JWST), which will have a primary mirror diameter of about 6 meters from pieced together hexagonal segments. An astronomer has used HST to observe an objects at a wavelength of about 500 nm, while he/she plans to use JWST to observe the same object at a wavelength of about 4.5 microns. How will JWST's resolution compare to HST's for these two observations of this object?

a) JWST will resolve this object about 9 times better than HST.
b) JWST will resolve this object about 3 times better than HST.
c) JWST will resolve this object about just as well as HST.
d) HST will still resolve this object about 3 times better than JWST.
e) HST will still resolve this object about 9 times better than JWST.

Multiple Choice Question

The prima… …a diameter
of about 2 … …about any
other teles… …g the next
generation … …(JWST),
which will … …om pieced
together he… …bserve an
objects at … …use JWST
to observe … …ns. How
will JWST … …vations of
this object?

$$\theta = 1.22\,\lambda / d \propto \lambda / d$$

$$\frac{\theta_{HST} \propto 500\text{ nm} / 2\text{ m}}{\theta_{JWST} \propto 4500\text{ nm} / 6\text{ m}}$$

$$\frac{\theta_{HST}}{\theta_{JWST}} = \frac{500\text{ nm}}{2\text{ m}} \times \frac{6\text{ m}}{4500\text{ nm}}$$

$$\frac{\theta_{HST}}{\theta_{JWST}} = \frac{1}{3}$$

a) JWST …
b) JWST …
c) JWST …

θ_{HST} (0.05 arcsec) is 3 times smaller than θ_{JWST}

What does this imply about the resolution of radio telescopes?

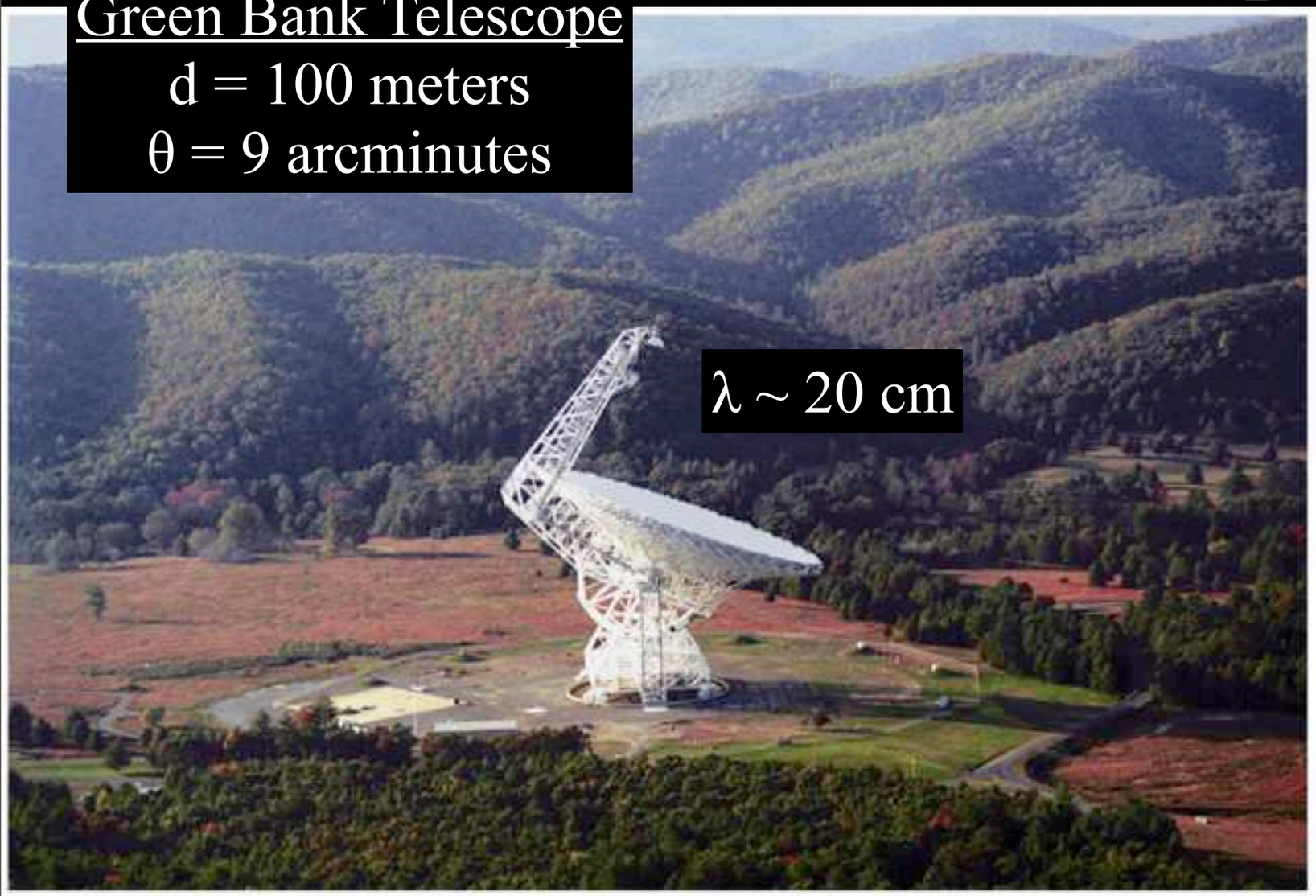
Other Examples of Telescopes

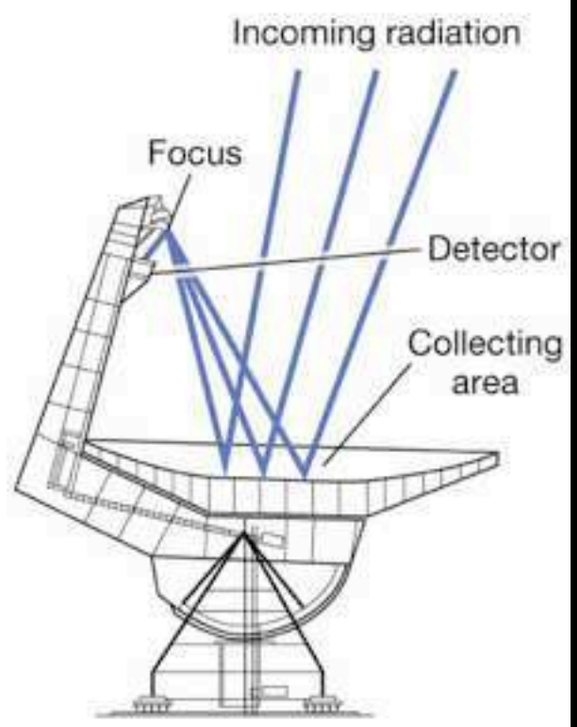
Radio Telescopes

Green Bank Telescope

d = 100 meters

θ = 9 arcminutes





Other Examples of Telescopes

Radio Telescopes

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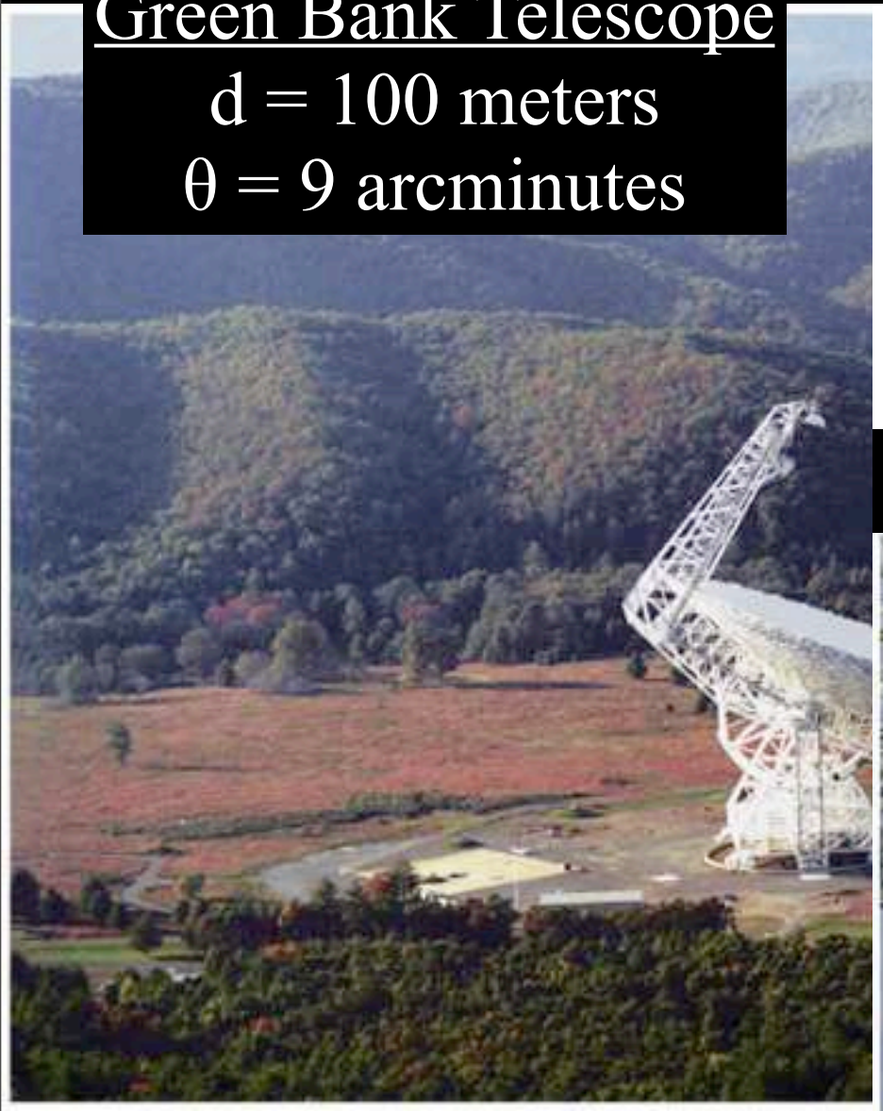
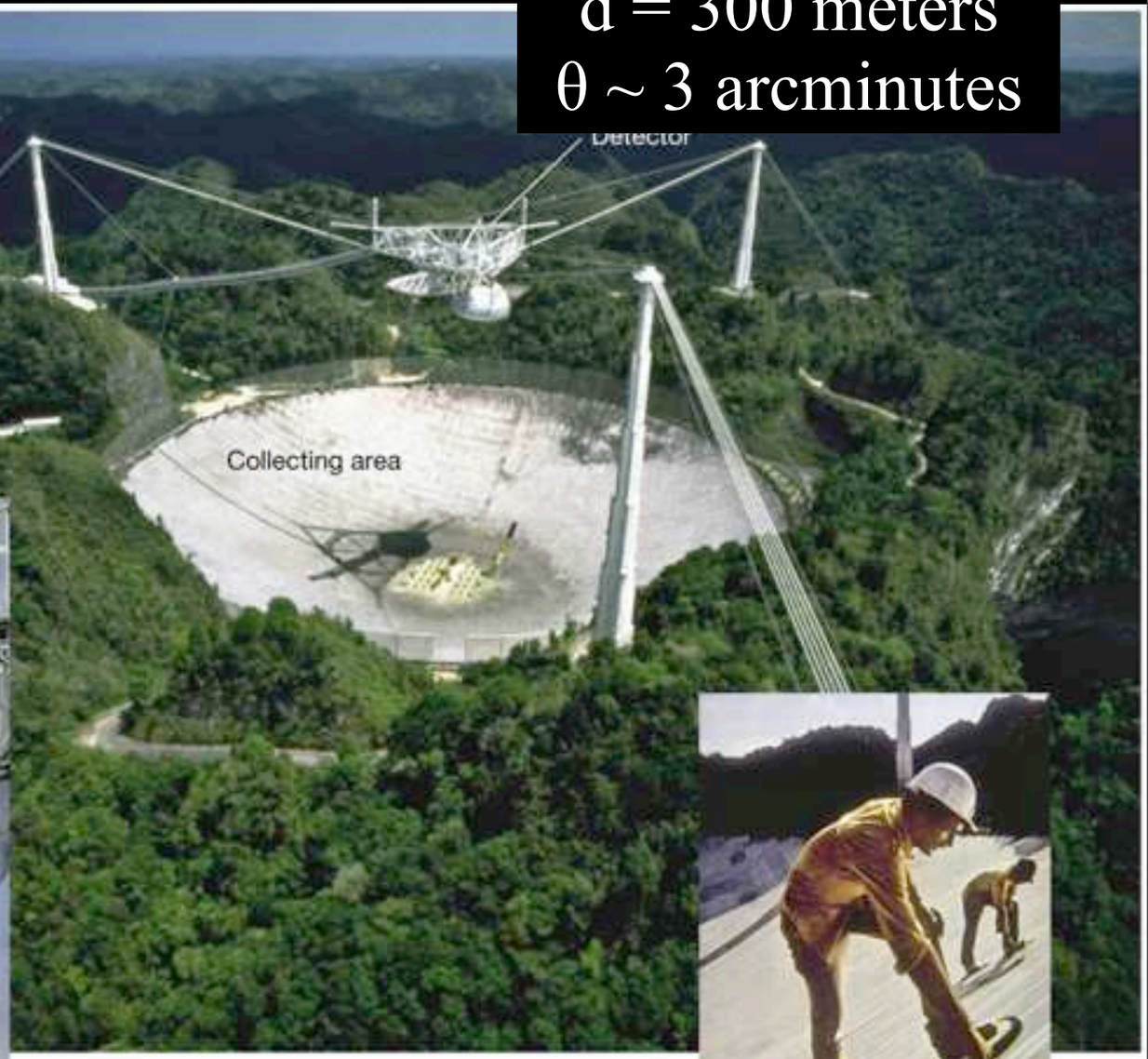


Copyrigh

λ ~ 20 cm

Arecibo Telescope
d = 300 meters
θ ~ 3 arcminutes



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Other Examples of Telescopes

Radio Telescopes

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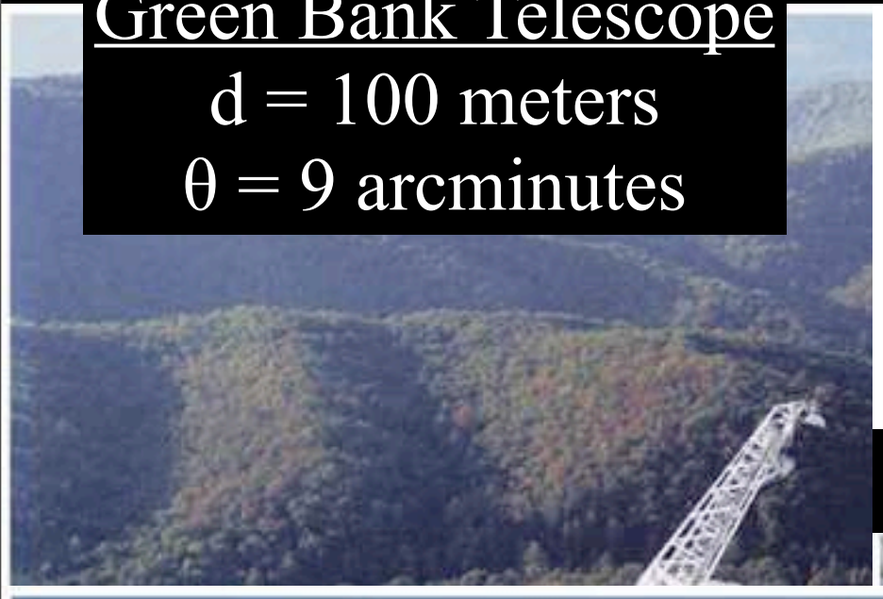

Arecibo Telescope
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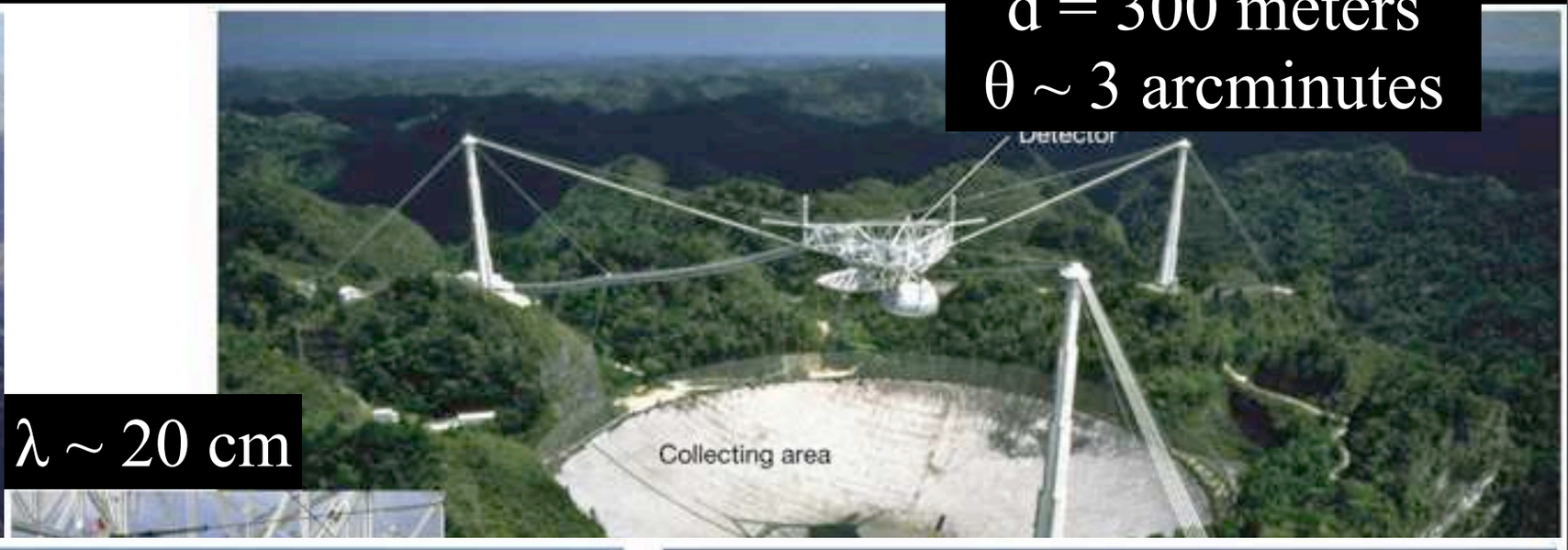
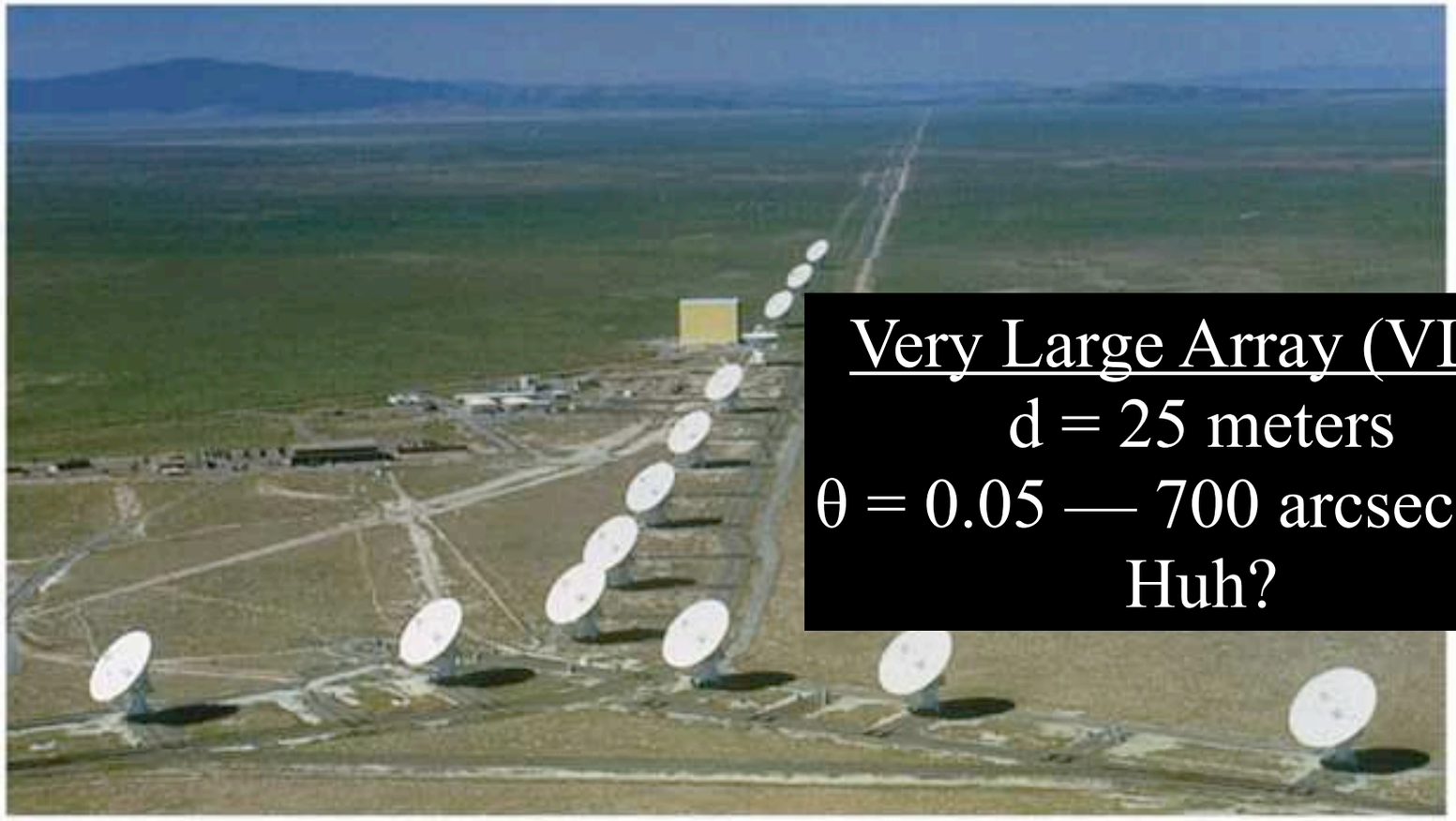


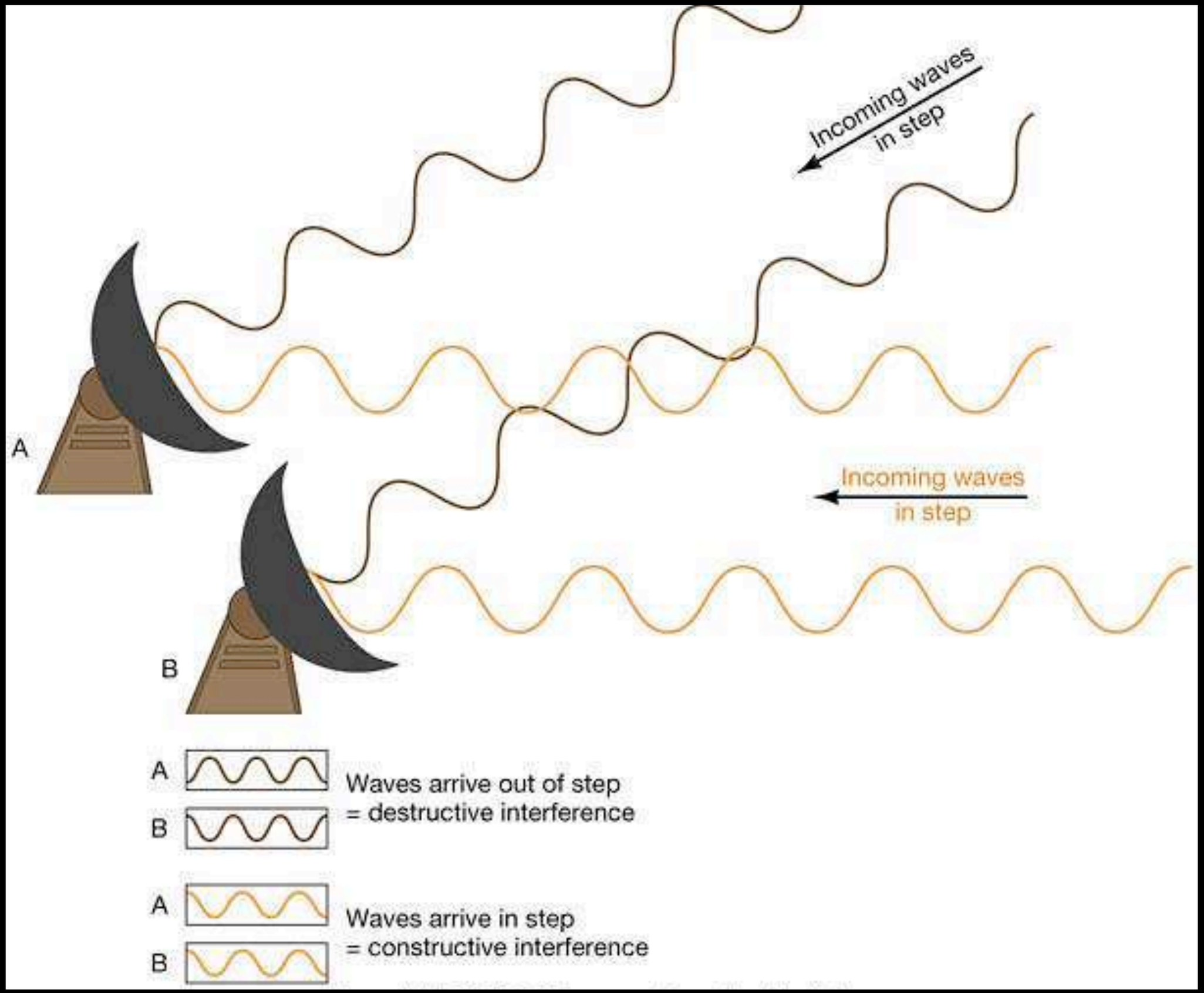
λ ~ 20 cm



Very Large Array (VLA)
d = 25 meters
θ = 0.05 — 700 arcseconds
Huh?

(a) (b)

Interferometry



Multiple Choice Question

Why would it be useful to build a radio telescope on the far side of the moon (as opposed to building one here on Earth)?

a) Because it is always dark there, the Moon would always block radio waves from the Sun
b) Because the Moon would always block radio waves from the Earth
c) Because it would be cheaper and easier than here on Earth
d) Because the Moon has no atmosphere
e) Because aliens would be more likely to contact us there

Multiple Choice Question

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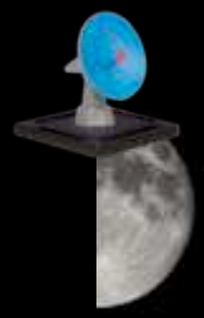
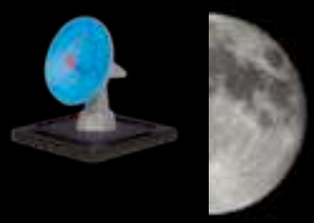
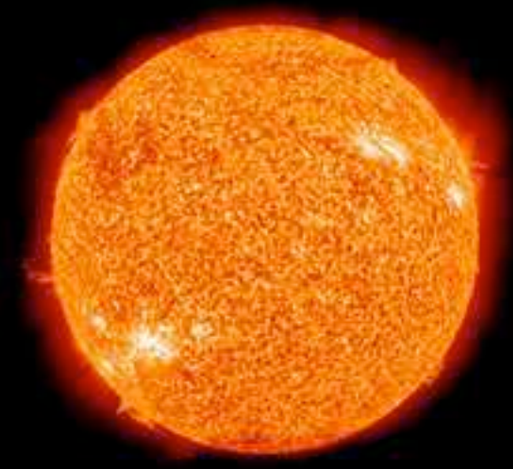
Earth, Moon, Sun Geometry

(not to scale!)



The Moon rotates as fast as it revolves, so the Moon always shows us the same face. We never see the far side of the Moon.





Radio Astronomers can observe while the Sun is up as long as they don't look right at it